Takeda Award 2002 Achievement Facts Sheet

Techno-Entrepreneurial Achievements
for World Environmental Well-Being

Technical Achievement: The Development of Spaceborne Microwave Radar for Monitoring the Global Environment

Awardees:
Charles Elachi (Jet Propulsion Laboratory and California Institute of Technology) is honored for pioneering the development of remote environmental monitoring technology by spaceborne microwave radar

Nobuyoshi Fugono (Advanced Telecommunications Research Institute International) and **Ken'ichi Okamoto** (Osaka Prefecture University) is honored for the development of spaceborne microwave precipitation radar

One half of the prize is awarded to Charles Elachi, and the other half is awarded jointly to Nobuyoshi Fugono and Ken'ichi Okamoto.

(Awardees are listed in alphabetical order.)

Executive Summary

The development of spaceborne microwave sensors, known as spaceborne "radars," enables the measurement of the spatial distribution of physical, chemical, and biological parameters of the Earth's surface, atmosphere, and oceans. Moreover, spaceborne microwave radars are able to do this with accuracy and homogeneity, independent of cloud coverage or the angle of the sun.

Charles Elachi, Nobuyoshi Fugono, and Ken'ichi Okamoto contributed to the development of technologies for obtaining essential data, such as plant distribution, ocean winds, and precipitation, on a global scale, and validating the capability of spaceborne radar for remote sensing purposes. These technologies enable the continual measurement of precipitation, wind, water content of soil, and structural or topographic features of the Earth's surface in tropical or

polar areas, which are frequently covered by clouds. Obtaining data on various parameters in such areas is not possible with visible or thermal infrared waves, however the collection of such data is considered to be essential for studying environmental problems and global climate change.

They foresaw the importance of environmental problems and water resource issues in the late 1970s, and developed spaceborne microwave radars for monitoring the global environment to resolve such issues. Their foresight and pioneering achievements should be highly evaluated.

In 1978, Elachi played a major role in getting high-resolution global environmental measurements using three kinds of radars (Synthetic Aperture Radar, Ocean Scatterometer, and Altimeter) onboard the satellite “SEASAT,” while working for the Jet Propulsion Laboratory. Between 1981 and 1994, he played the leading role in the definition and development of a series of shuttle space borne imaging radars that established observation techniques for collecting various kinds of environmental data after extensive research on the interaction between microwaves and objects on the Earth.

Furthermore, he played a leading role in both designing spaceborne radars and planning and promoting the remote sensing project, establishing the basic and fundamental science and technologies on earth environment monitoring radars.

Fugono and Okamoto commenced research on remote measurement of rainfall, getting a hint from the attenuation of radio waves by rainfall on satellite communication, because rainfall is an important energy source in atmospheric circulation as well as a significant water resource. In 1980, working at the Communications Research Laboratory in Japan, Fugono and Okamoto succeeded in measuring rainfall with an airborne dual-frequency rain-scatterometer/radiometer for the first time in the world. This success triggered the start of collaborative remote sensing rainfall project between the U.S. and Japan, known as the Tropical Rainfall Measuring Mission (TRMM), in 1986.

Fugono and Okamoto developed the precipitation radar, which was a core device on the TRMM satellite, and, in 1997, the TRMM satellite was launched. Since its launch, the TRMM satellite has been providing accurate and homogeneous data on rainfall in the tropical zone, where previously rainfall data was lacking. It has also succeeded in sending accurate and detailed three-dimensional precipitation data on typhoons and unusual rainfall associated with the El Niño phenomena.

The spaceborne global environment measuring radars, Elachi, Fugono and Okamoto contributed to through their technical creativity and excellent leadership, have provided very accurate and homogeneous data on various parameters of the global environment. This data enables humankind to proceed in taking a great step towards assuring the quality of life into the future. The Takeda Foundation honors this achievement and bestows upon this achievement the

Takeda Award.

Achievement and Creativity

1. Introduction

Observation and prediction of global environmental changes brings significant benefit to people, such as precise and detailed weather forecasting. It is also important for acting against environmental changes to understand the global mechanisms of environmental changes that are complicated each other through circulation of atmosphere or water.

An advanced way of measuring changes in the global environment is through spaceborne remote sensing technologies using radars (active microwave sensors). These can be used for observing phenomena or making measurements in cases where the phenomena are large scale or occurring in areas that are far offshore or in remote locations where it is difficult to obtain measurements by other means. Spaceborne radar measurement technologies have the ability to cover wide ranges in a short time as well as to make measurements that are highly accurate. Moreover, they are not affected by cloud cover or sun angle [1)]. There are four kinds of spaceborne radars monitoring the Earth environment changes currently.

These are: Synthetic Aperture Radar (SAR), Ocean Scatterometer (SCAT), Altimeter (ALT) and Precipitation Radar (PR).

Mainly, Elachi contributed to the development of the first to the third ones [2)], which were developed largely by the Jet Propulsion Laboratory, and Fugono and Okamoto, leading research at the Communications Research Laboratory, developed the last one, the precipitation radar.

2. Elachi's pioneering achievement in remote environmental monitoring by space borne microwave radar

Elachi has been a pioneer in the field of precise observation technologies to monitor the global environment using spaceborne radars onboard space craft, including satellites, space shuttles, and other spacecraft. His important achievement is in optimizing the design of spaceborne radar systems for global environmental observation and using the data obtained to contribute to advances in scientific fields, such as geology, environmental science, oceanography, and archeology.

Since he was familiar with both elemental radar techniques and the earth sciences, he could lead the detailed design of the first spaceborne imaging radars for environmental monitoring, as well as a series of increasingly advanced successors onboard subsequent space missions.

It is necessary to apply short pulse waves and use a long antenna to obtain high-resolution images using radars. In the case of using a 9.5 GHz electric wave from an altitude of 12,000 meters, for example, it is necessary to use an antenna of over 250m in length to recognize subjects that are 1.5 m in size on the ground. Because of the difficulty in making such a long spaceborne antenna, a sophisticated new idea was considered. The Synthetic Aperture Radar (SAR) achieves high spatial resolution by recording backscatter signals from a target as its platform (aircraft or satellite) moves along the track in conjunction with the use of advanced signal processing technologies.

Using these sophisticated technologies, even a small antenna boarded on planes or satellites can get the same grade of high-resolution images as using the large size one in principle[1)].

Elachi understood well the role of microwave lengths and injection angles, the principles of polarimetory that use different reflection phenomena obtained from vertical polarization or horizontal polarization, and the methods to get vertical images using interferences of mutual waves. Appling this understanding, he developed spaceborne radar instruments to collect data on the Earth environment with excellent precision and accuracy.

In June 1978, the Synthetic Aperture Radar onboard the satellite SEASAT successfully presented radar imaging data on the Earth for the first time[2)]. This satellite only obtained data on oceanographic phenomena for 100 days, but they were equal in quantity to those obtained in the past 100-years of observations on boats[3)].

SEASAT's SAR discovered the remains of an ancient irrigation system, which would have been impossible to discover using conventional optical sensors. Three kinds of radar systems (SAR, SCAT and ALT) were loaded on SEASAT and they provided information on wind rates and directions, currents or swirls and seabed structures in oceans globally. These successes based on spaceborne radar systems were a great advance in global environmental observation.

The Shuttle Imaging Radar-A（SIR-A）, which was a synthetic aperture radar with HH polarization and 50° incidence angle at the surface, was launched on the Space Shuttle Columbia in November 1981[4)] . This experiment demonstrated the radar's ability to penetrate extremely dry surfaces, which resulted in the discovery of ancient river channels buried beneath the Sahara desert.

Shuttle Imaging Radar-B (SIR-B) was placed onboard the Space Shuttle Challenger in October 1984. This time, the incidence angle of the microwave was designed to be mechanically tilted. This modification resulted in clear 3-D images[5)].

The Spaceborne Imaging Radar C/X band Synthetic Aperture Radar (SIR C/X SAR) was launched via space shuttle twice, once in April 1984 and once in October 1994, and was one of. Elachi's most important contributions. This system consisted of three individual frequency antennas. Polarimetory and phased array systems were applied for two of them. The multi-frequency, multi-polarization capability created a new and more powerful tool for observing the global environment. This mission provided a wide range of information on the

Earth's surface structures including those on the ground, ocean surface and polar regions[6, 7, 8] (Fig 1)[9].

The effectiveness of the technologies developed by Elachi encouraged others to use spaceborne radar in other missions. The satellite "RADARSAT" was launched in November 1995 and uses SAR to collect data on global environmental changes and natural resources. It has obtained data on various phenomena, such as snow fall, crop growth, oil spill dispersion, forestry, flooding, ice melt, glacier movement, and so on.

Another radar, NSCAT, loaded on the satellite "ADEOS," was launched in August 1996 by H-2 rocket. This radar was specially designed to measure wind speed and direction. The system could take data covering over 90% of ocean surfaces with 50 km in range resolution every two days. This capacity is equal to nearly 100 times the information obtained by conventional observation from boats. The data collected has made substantial contributions to improving climate models and investigating the causes of the El Niño phenomenon.

The Shuttle Radar Topography Mission was launched by NASA in February 2000 via space shuttle and has resulted in a high-resolution, 3-D map of approximately 80% of the Earth's land mass — the most complete map ever assembled.

Recent state-of-the-art spaceborne imaging radar systems, which were led by Elachi, presented new tools for observing the global environment for researchers in various fields. Researchers have used these tools to collect ecological data on land including plant distribution, crop cultivation, the estimation of biomass, and the monitoring of seaside areas or swamp regions. Other kinds of environmental data are also collected regardless of cloud condition and with day-night imaging over wide ranges of the Earth. Examples of such data include the water content in soil and snow, characteristics of ocean waves and currents, the distribution and classification of sea ice, changes in and movement of glaciers, crystal changes caused by earthquakes, volcanic activity, degradation of the Earth's crust, geographical information, hazard monitoring and the discovery of ancient geographical patterns.

Elachi has technical expertise in the design of radar instruments, as well in the earth sciences and their applications. These talents allow him to present the importance of spaceborne imaging radar technologies to scientists as well as to decision makers. His skills have also led him to be a leader of project teams, in charge of projects that include many scientists and or engineers.

3. Development of spaceborne precipitation radar by Fugono and Okamoto

Rain circulates sunshine energy and greatly affects the global climate. Each year, two-thirds of the world's rainfalls occur in tropical areas. Since oceans or jungles largely cover tropical areas, it is difficult to get accurate data on precipitation. However, correct and detailed data is essential to predict weather or investigate the causes of climate changes.

Meteorological satellites cannot observe rainfall data directly, because visible and infrared sensors provide only the surface features of clouds. A passive microwave sensor, SSM/I (Special Sensor Microwave Imager), can provide rough rain data only on the sea surface and not on land, and cannot observe the three-dimensional structure of precipitation[10)].

In the mid-1970s, Fugono and Okamoto conducted research on satellite communication that increased interest in research on the attenuation of radio waves by rain and other phenomena. Since then, they have shifted their emphasis to research on more accurately measuring rainfall, which drives atmospheric circulation and water cycles. In 1979, they succeeded in measuring rainfall using airborne radar for the first time. Immediately after they publicized the experimental results, they received a proposal from NASA for a joint flight experiment at the end of 1980. After two joint flight experiments from 1983, the U.S.-Japan collaborative rainfall measurement project, the Tropical Rainfall Measuring Mission (TRMM), began 1986. The precipitation radar was the key sensor of the TRMM satellite. Fugono promoted the project, and Okamoto led the technology development. Although there were some difficulties, such as project discontinuation, after the Paris Summit in 1989 at which global environment subjects were discussed, the development of the TRMM went ahead. In 1997, TRMM was launched by H2 rocket at Tanegashima in Japan[11)].

The outstanding breakthroughs in this mission are the followings[12)]:

(i) The echoes of rainfall are much weaker than those from land or sea surfaces. To observe weak echoes from an altitude of 350km, very low antenna side lobe level was established and the high 14.5 GHz operating frequency microwave was adopted.

(ii) The TRMM satellite is traveling at a very high velocity of 7km/sec. To observe rainfall data in a 215km swath width with contiguous coverage, a 128-element active phased array antenna was adopted. The precipitation radar is only one example that succeeded to develop active phased array of the frequency as high as 14GHz. Two-channel frequency agility technique of 13.796 and 13.802 GHz was used to increase S/N ratio.

(iii) Active array implies that each antenna array element has its own active devices, which includes transmit and receive amplifiers. The active array has advantages over its conventional passive array counterpart, such as a low system loss that is achieved by an almost direct connection between each antenna element and a transmitter/receiver unit. Moreover, for the distributed configuration, there is no need to use a high-voltage power transmit tube.

The PR on this mission has provided a detailed 3-D precipitation structure of many instances of concentrated rainfall and typhoons, and the data gained by the PR is superior in quality than what was expected by many researchers in the world. This data is freely accessible to researchers all over the world and have been promoting scientific research.

The most important accomplishment of this mission is to measure precipitation with equal accuracy both on land and sea. It makes reliable records of data on tropical and subtropical regions on daily, monthly, and yearly time scales. The monthly summary of rainfall in tropical and subtropical zones between January 1998 and December 2001 clearly showed differences in the zone distribution of precipitation in May 1998 when El Niño was occurring compared to those of non El Niño periods[13)] (Fig.3). The PR data has also provided some information on diurnal cycles of precipitation from long term statistics[14)]. Recently, TRMM observations are being combined with ground based observations by the Japan Meteorological Agency to help refine the precision of weather predictions[15)].

The PR radar collects precipitation data only about 10% of its total working hours, with the remaining hours spent collecting data on the Earth's surface. Oki, a professor at Tokyo University in Japan, has developed an algorithm to analyze data on water content in soil and land surface conditions globally derived from such extra data[16, 17)]. He had reported in his research paper presenting the analytical results on the flooding damages in Mozambique and on the preceding increase of water contents along the river basin when Yangtze River in China had flooded.

Rosenfeld has also reported new ideas on changes of precipitation effected by the amounts of Suspended Particulate Materials (SPM) in the air. His idea, which is that if the amount of SPM increases precipitation decreases, is contrary to the accepted theory. His new theory is derived and supported by the data of PR[18, 19)]. These findings will provide new and useful treatment against ought.

Recently, the system resolution limit of the Earth Simulator that create a "virtual earth" on a supercomputer to show what the world will look like in the future by means of advanced numerical simulation technology is 5 km square and it is nearly equal to that of PR in resolution level. Now, the precise and homogeneous precipitation data are being assimilated on the Earth Simulator, and the PR data have made great contributions to the improvements of simulation models on global warming or climate changes[20)].

Since the TRMM program has achieved great progress and the key technology is the PR, a innovative Global Precipitation Measurement（GPM） program is now planned by Japan, the United States and Europe, with the GPM mission satellites scheduled to launch in 2007. The aim of the program is to collect precipitation data with improved accuracy every 3 hours over the entire globe. The core satellite will use two frequencies of PR, which are being developed by Fugono and Okamoto, in collaboration with 8 other satellites carrying microwave radiometers[21)].

4. Enhancement of the value of human life

The truly great contributions of Elachi, Fugono and Okamoto have helped make it possible to record precise Earth environment data with good accuracy and homogeneities on land, over oceans and polar regions, together with tropical rainfall that is considered to greatly affect global climate. Their work has enabled a practical earth environment observation system using radars. This system has improved the quantitative and logical understanding of the present state of the Earth's environment and the changing trends.

The data obtained from this radar system have good synergetic effects with other data from conventional systems, such as optical sensors or passive microwave sensors. Data gathered from these systems have been important and essential datasets that are available freely to be accessed on Internet web sites by peoples all over the world.

Many scientists and engineers are analyzing the complicated changes in the global environment, and they are steadily clarifying the causes of global environmental issues. These huge amounts of data are also contributing to the developments of simulation technologies such as the Earth Simulator that predict changes of climate, water circulation, ecological systems and other environmental systems. Major advances in scientific knowledge and progress in simulation have the potential to contribute concretely to our life by helping preserve the Earth's environment, manage water resources, and contribute to diverse applications in agriculture, forestry, fishery, and industry. This achievement has taken a great step toward improving the quality of life for humanity.

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The Takeda Award 2002
World Environmental Well-Being
Profiles

Charles Elachi

1968 B.Sc., Physics, University of Grenoble
1968 Diploma, Engineering, Polytechnic Institute, Grenoble
1969 M.S., Electrical Science, California Institute of Technology
1971 Ph.D., Electrical Sciences, California Institute of Technology
1978 M.B.A., University of Southern California
1983 M.S., Geology, University of California, Los Angeles
1971 Joined Jet Propulsion Laboratory
1994-2001 Director for Space and Earth Science Programs at Jet Propulsion Laboratory
2001-Present Director of Jet Propulsion Laboratory

Honors:
1968 Prix de la "Houille Blanche", Institute Polytechnics de Grenoble
1995 Honorary Professor, Chinese Academy of Science
1995 Nevada Medal
1996 COSPAR Nordberg Medal
2000 Dryden Lectureship in Research Award
2002 Wernher Von Braun Award
He is honored with many other awards, including various medals/awards of NASA, and of IEEE.

Nobuyoshi Fugono

1959 B. S., Microwave Electronics, Kyoto University
1961 M.S., Microwave Electronics, Kyoto University
1971 D.S., Upper Atmospheric Physics, Kyoto University
1961 Radio Research Laboratory of Ministry of Posts and Telecommunications (currently) Communications Research Laboratory)
1989-1993 Director General of Communications Research Laboratory
1993-present Professor of Research Institute of Science and Technology of Tokai University
Professor of Tokai University
1993-1995 Visiting Senior Research Scientist of Texas A&M University and Visiting Senior Researcher of GSFC/NASA
1994-1996 Visiting Professor of University of Maryland

1995-1996 Visiting Professor of University of Tokyo

1997-2001 President of Support Center for Advanced Telecommunication Technology Research Foundation (SCAT)

2001 Vice President of Advanced Telecommunications Research Institute International (ATR)

2001-pressent President of Advanced Telecommunications Research Institute International (ATR)

Honors:

1983 Exceptional Research Award of the Minister of Science and Technology of Japan

1990 Group Achievement Award of NASA

1998 Distinguished Public Service Medal of NASA

2000 Medal with Purple Ribbon, Government of Japan

Ken'ichi Okamoto

1968 B. Sc., Pure and Applied Science, Tokyo University

1973 D. Sc., Pure and Applied Science, Tokyo University

1973 Radio Research Laboratory of Ministry of Posts and Telecommunications (currently Communications Research Laboratory)

1993 Director, Global Environment Division of Communications Research Laboratory

1997 Director, Standard Measurement Division of Communications Research Laboratory

1999 Associate Director General of Communication Research Laboratory

2000-pressent Professor, Osaka Prefecture University

Honors:

1991 Paper Award of the Remote Sensing Society of Japan

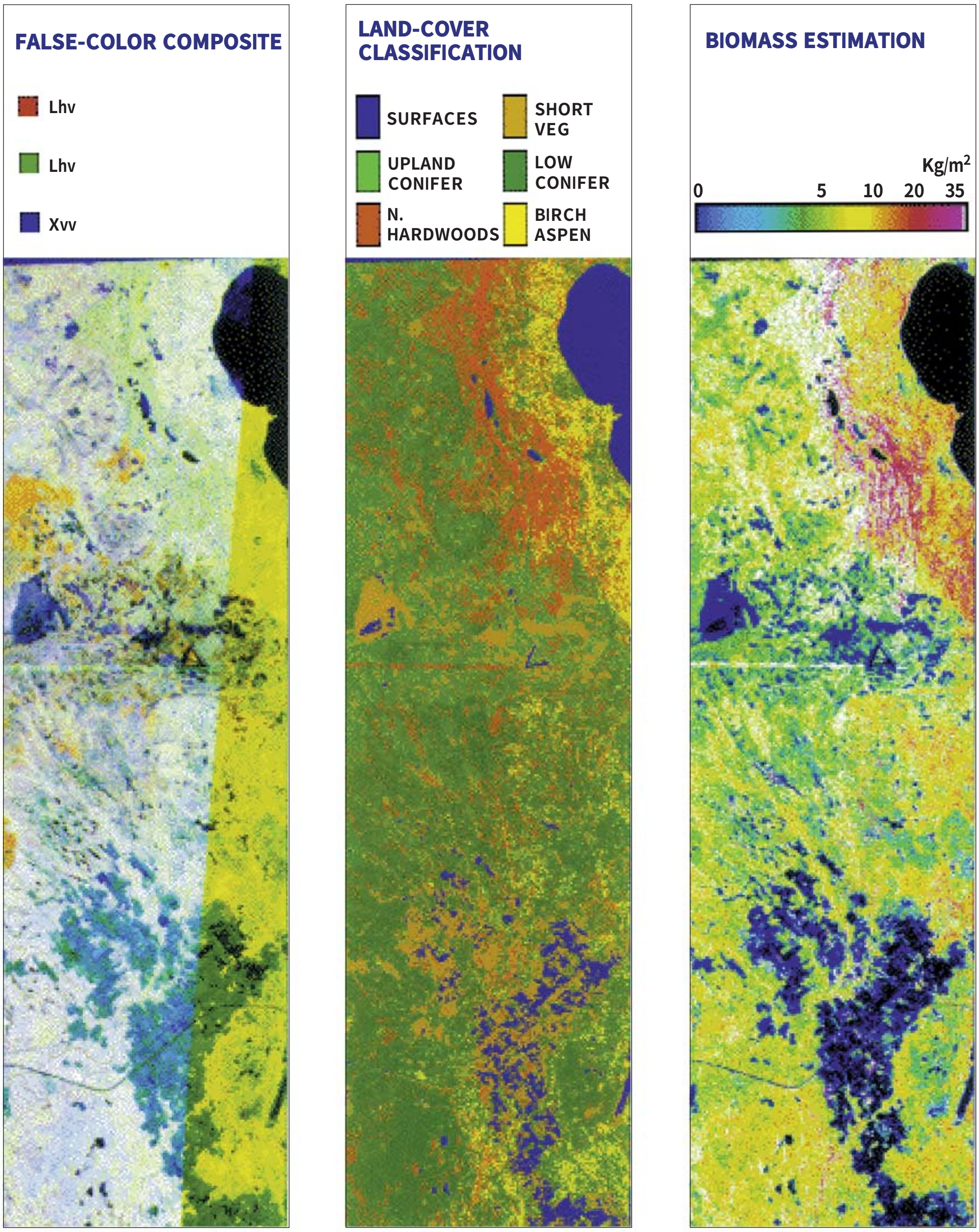
1993 Horiuchi Foundation Encouraging Award of the Meteorological Society of Japan

1995 Award of Minister of Posts and Telecommunications

1995 Presentation Award of the Remote Sensing Society of Japan

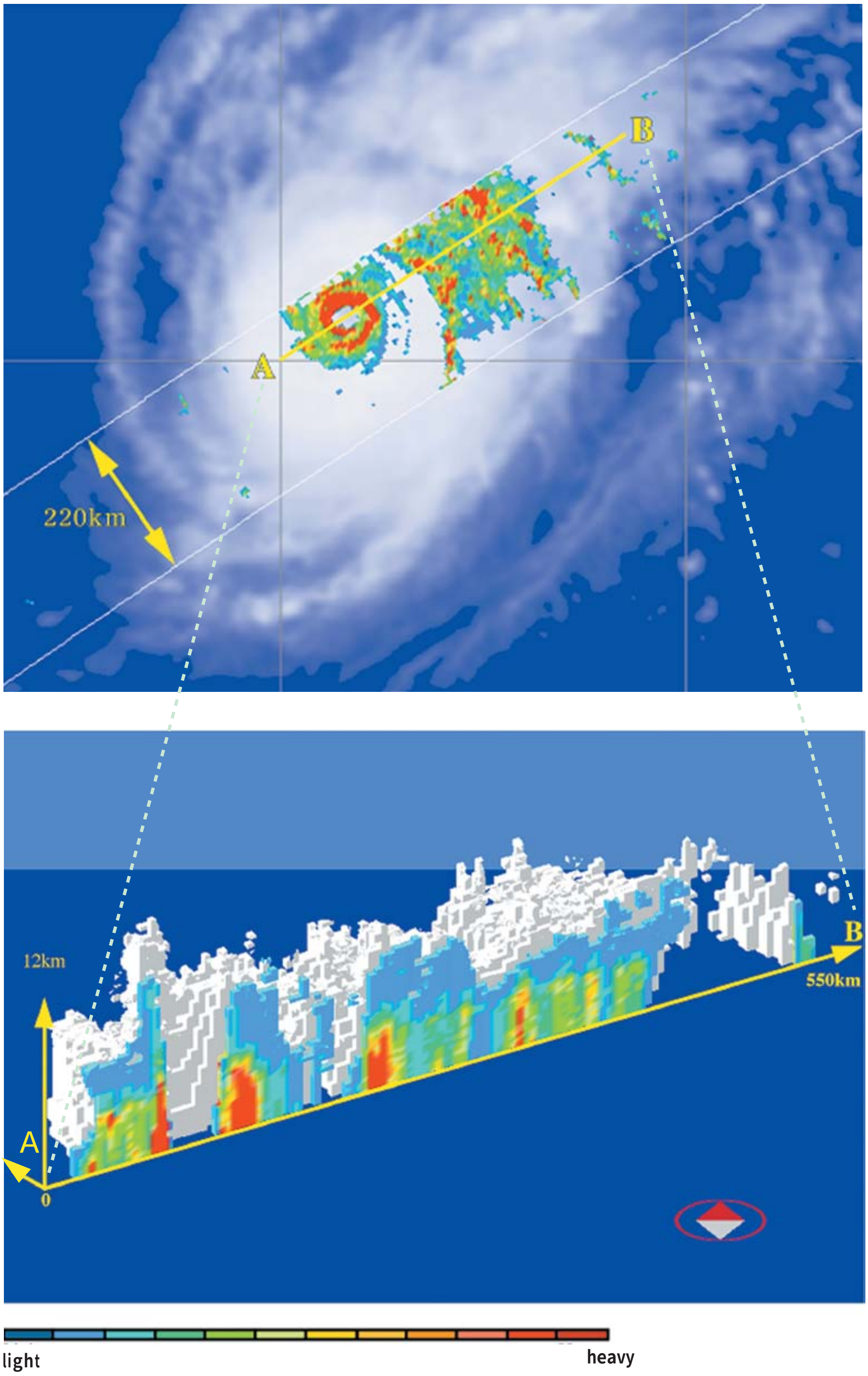
1998 Maejima Prize

Fig.1 Images showing classification of natural vegetation/ land cover and biomass estimation of Northern Michigan forests



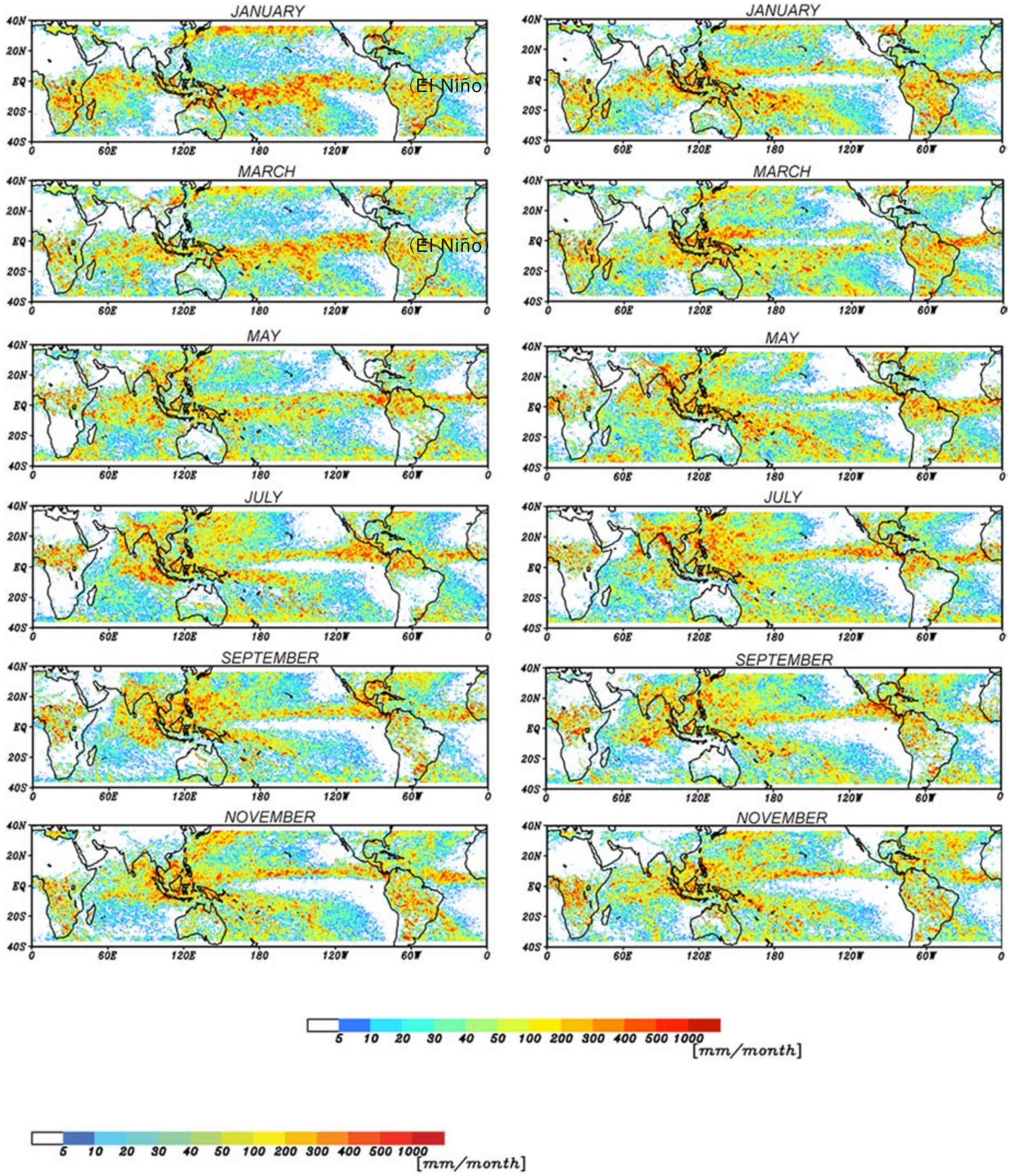
Source: Evans,D.L.,"Spaceborne Synthetic Aperture Radar: Current Status and Future Directions," *NASA Technical Memorandum* 4679(NASA.1995)
"Courtesy of NASA/JPL"

Fig.2 The horizontal rainfall structure of Typhoon No.28 in 1997 on its mature stage at an altitude of two kilometers superimposed on a GMS image of clouds (Top), and the three-dimensional structure(Bottom)



"Courtesy of NASDA" The dotted lines are added by the Takeda Foundation.

Fig.3 Two-year Global Rainfall Distribution Measurements Using the TRMM Precipitation Radar



"Courtesy of NASDA"