NICT NEWS

National Institute of Information and Communications Technology

No.2 2022

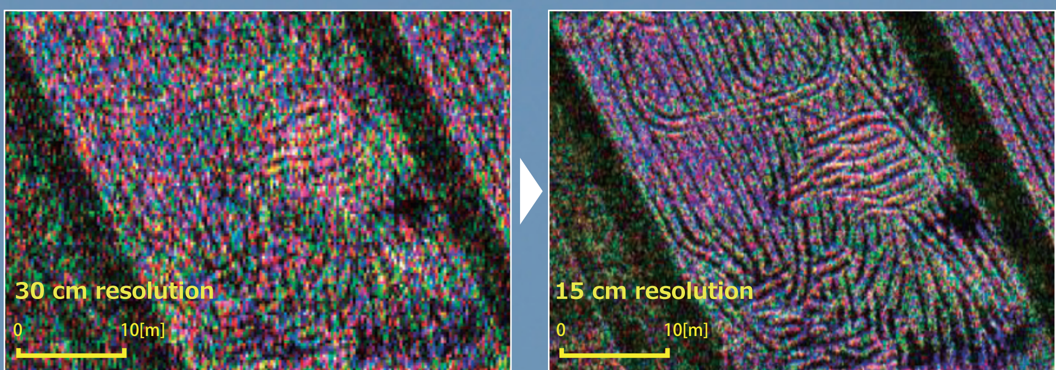
Vol.492

FEATURE

Special Issue on Remote Sensing Technologies

Interview

High-precision Environmental Observation using Remote Sensing Technology



CONTENTS

National Institute of Information and Communications Technology

NICT NEWS 2022 No.2 Vol.492

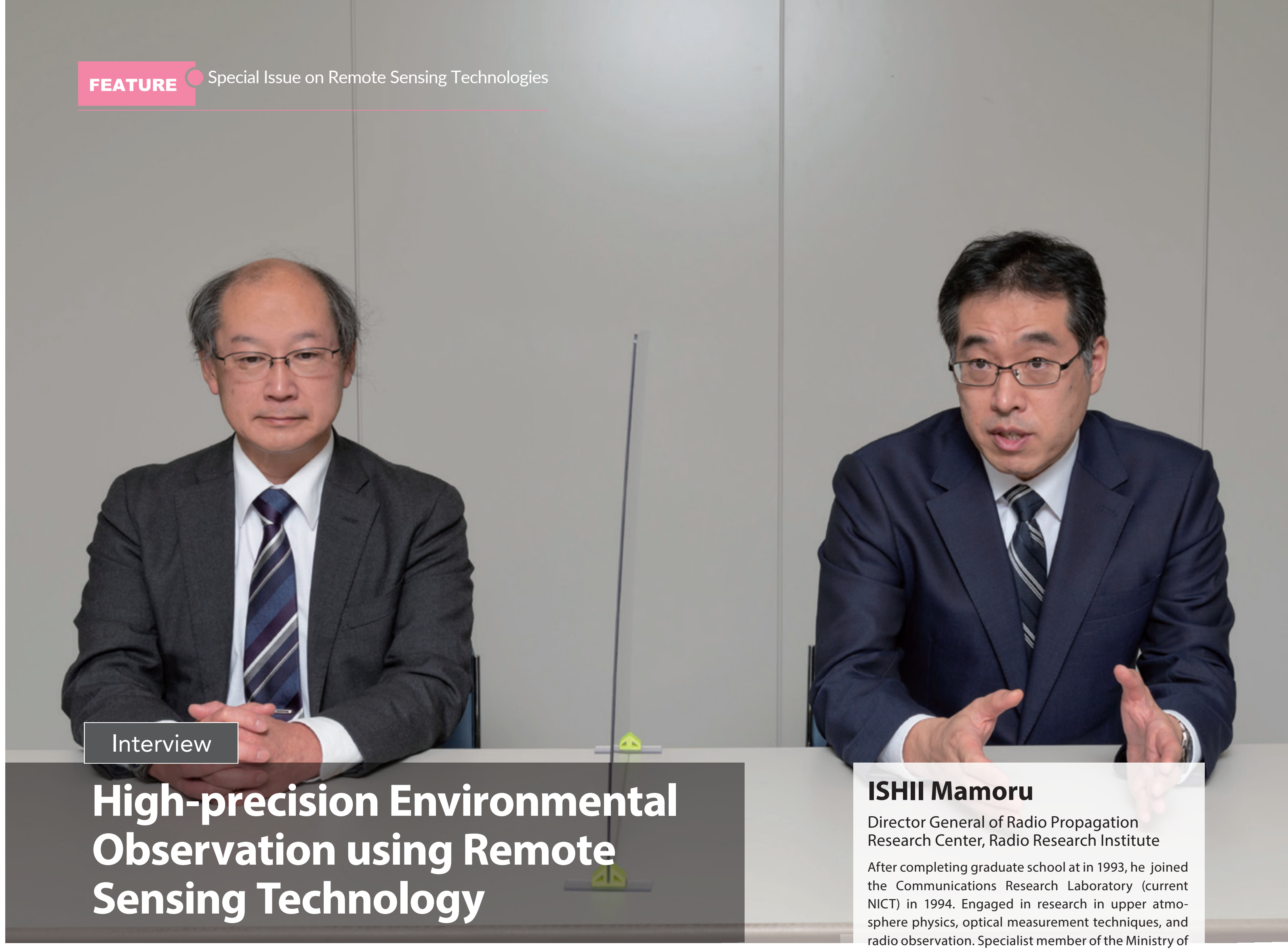
FEATURE

Special Issue on Remote Sensing Technologies

Interview

Cover Photo:
Aircraft equipped with a high-precision airborne synthetic aperture radar (Pi-SAR X3) with a spatial resolution of 15 cm—among the highest SAR resolutions in the world. The antenna housing radome is mounted on the lower anterior surface of the aircraft's body. Pi-SAR X3 is capable of performing environmental and natural disaster monitoring on land regardless of the time of day or weather.
(Image on the front cover's lower left corner) A rice field area near Wajima City imaged by Pi-SAR X3. Farm tractor tracks are only vaguely discernible at the conventional resolution of 30 cm (left), while they are clearly visible at a resolution of 15 cm (right).

Photo Upper Left:
Seed laser capable of emitting single-wavelength laser light in the 2 μm range developed by NICT. Several seed lasers are used in a multi-parameter lidar to precisely control the wavelength of the pulsed laser light it emits. This seed laser is approximately an order of magnitude cheaper than conventional seed lasers. This cost reduction is a major step forward in developing practical multi-parameter lidar.



Interview

High-precision Environmental Observation using Remote Sensing Technology

ISHII Mamoru
Director General of Radio Propagation Research Center, Radio Research Institute

After completing graduate school at in 1993, he joined the Communications Research Laboratory (current NICT) in 1994. Engaged in research in upper atmosphere physics, optical measurement techniques, and radio observation. Specialist member of the Ministry of Internal Affairs and Communications, Vice Chairman of ISES, Specialist member of UN/COPUOS, ICAO, WDS-SC. SCOSTEP, URSI, and ITU-R, Councilor, Society of Geomagnetism and Earth, Planetary and Space Sciences. Ph.D. (Science).

KAWAMURA Seiji
Director of Remote Sensing Laboratory, Radio Propagation Research Center, Radio Research Institute

After completing his doctorate, he served at Communications Research Laboratory (currently NICT) as a postdoctoral fellow for the Japan Society for the Promotion of Science(JSPS), and then joined NICT in 2006. He is engaged in the research of radar remote sensing. Ph.D. (Informatics).

Meteorological disasters, including flooding and landslides caused by torrential downpours, have become more frequent in recent years. These extreme weather events are now considered by some to be the "new normal."

Remote sensing technology has been used to measure and analyze the global environment from the ground and the sky, and expectations for it are continuing to grow. We asked Mamoru Ishii (Director General of the Radio Propagation Research Center) and Seiji Kawamura (Director of the Remote Sensing Laboratory) about remote sensing research at NICT and its future prospects.

NICT's remote sensing research function

——First, what is the significance for NICT of remote sensing research? Could you also talk about the NICT division dedicated to remote sensing research?

ISHII NICT has been engaged in a wide range of research related to information and communications technology (ICT), such as speech translation and cyber security. The Radio Research Institute—NICT's oldest ICT research function—has been carrying out R&D related to radio propagation, which continues to be of great importance to today's society.

The ways in which radio waves propagate are greatly influenced by the surrounding environment. These influences are usually undesirable in radio communications. However, they could offer useful information on the environment using remote sensing technology. This is why the Radio Research Institute has been conducting remote sensing research.

The Radio Research Institute currently consists of three centers: the Electromagnetic Standards Research Center, the Applied Electromagnetic Research Center, and the Radio Propagation Research Center. The Radio Propagation Research Center—to which both of us belong—has been researching the effects of various environmental conditions on the ways in which radio waves propagate. This Center oversees two labs: the Remote Sensing Laboratory directed by Dr. Kawamura and the Space Environment Laboratory. The former has mainly been developing technologies to take meteorological and land surface measurements, while the latter has been conducting space weather research, including the impact of solar activity.

Interview

High-precision Environmental Observation using Remote Sensing Technology

KAWAMURA The Remote Sensing Laboratory's current main research focus is meteorological and environmental measurements using remote sensing technology.

We use radio waves and light to accurately measure various meteorological elements, including rain, wind, clouds, and water vapor. The repeated occurrence of rainstorms in specific locations (i.e., training rainstorms) has been the subject of frequent news media coverage in recent years. Our lab has been working to develop technology capable of more accurately and rapidly forecasting sporadic weather changes, such as sudden heavy rain.

We are also researching the use of airborne synthetic aperture radar (SAR) to measure land surface changes caused by volcanic activities, landslides, earthquakes, and other causes.

These sensing technologies are useful in detecting both daily changes and abrupt changes caused by natural disasters and other events. We're working constantly to develop cutting-edge, versatile remote sensing technologies capable of detecting both ordinary and extraordinary events and phenomena.

New technologies to observe land surface and atmospheric behavior

——What major research projects are ongoing at the Remote Sensing Laboratory?

KAWAMURA First, we've been researching the use of airborne SAR to measure land surfaces. For example, we've used it to observe the areas surrounding a volcanic crater before and after an eruption and to measure landform changes caused by earthquakes. Our airborne SAR has just upgraded from its second generation (Pi-SAR2) to the third generation (Pi-SAR X3). In fact, we just flew our Pi-SAR X3 for the first time over the Noto Peninsula on December 15 and 16, 2021 and tested its performance.

The spatial resolution of our airborne SAR will increase from 30 cm with Pi-SAR2 to 15 cm with Pi-SAR X3. In addition, Pi-SAR X3 has various new features enabling improved vertical measurement precision. Although the current 30 cm resolution is already high, this upgrade will significantly increase it. I'm very excited to see what kinds of data we will be able to collect using Pi-SAR X3.

Meteorological research is another major research focus of ours. We have developed a phased array weather radar (PAWR) capable of very rapidly scanning a three-dimensional space. We are currently operating four PAWRs across Japan. Among these, the one installed at Saitama University is the most advanced. In fact, it is the world's first multi-parameter phased array weather radar (MP-PAWR) in practical use. This MP-PAWR is equipped with high-precision precipitation measurement capabilities in addition to the high-speed three-dimensional measurement capabilities it inherits from existing PAWRs.

We're also participating in the EarthCARE (Earth Clouds, Aerosols and Radiation Explorer) mission. The EarthCARE satellite is scheduled to be launched in 2023. In this mission, our lab and the Japan Aerospace Exploration Agency (JAXA) will be responsible for developing the world's first cloud radar with Doppler capabilities. We're participating in the GPM (Global Precipitation Measurement) mission as well, for which the GPM satellite is currently in operation. In addition, we're researching and developing new technology for the space mission that will succeed the GPM mission.

Another major ongoing project at our lab is the development of technology to measure atmospheric water vapor using digital terrestrial television broadcasting (DTTB) waves before it develops into rain-producing clouds. In principle, radar can measure atmospheric water content only after it forms water droplets. If water vapor can be measured before it grows into droplets, this data could be used to accelerate weather forecasting. For this reason, water vapor measurement is currently a hot meteorological research topic, and many research teams are attempting to achieve it using different approaches. Our very unique approach of using DTTB waves is capable of measuring propagation delay time to a precision of a picosecond and of determining the cumulative amount of water vapor across the horizontal direction immediately above the ground.

In collaboration with other organizations, we're currently testing the usability of our water vapor measurement technique using DTTB waves in an area of Kyushu where training rainstorms frequently occur. We're monitoring the amount of water vapor that potentially contributes to the formation of these training rainstorms. This project is supported by the Cabinet Office's Cross-ministerial Strategic Innovation Program (SIP).

Yet another project in progress at our lab is the development of lidar (light detection and ranging) capable of measuring various meteorological factors (e.g., wind, water vapor and CO2) using laser light. Laser light, which can travel in a perfectly straight line, is very useful in making high-precision measurements in a desired direction. Our current major research focus is to create lidar with the capability to measure multiple parameters. We are also working to reduce the cost of the lidar, since it is currently very expensive.

The Japan Meteorological Agency operates a network of wind profiler radars named WINDAS (the wind profiler network and data acquisition system) which measure upper-air wind speed and direction at 33 observation sites across Japan. We've been developing next-generation wind profiler technology.

We're working to enable this technology to reduce noise in the wind profile data it collects by minimizing the effect of ground clutter—unwanted reflections from non-target objects. We installed a sub-antenna dedicated to receiving clutter signals on the wind profiler in proximity to the main antenna that receives signals from the wind and are attempting to eliminate clutter by processing these two signals.

Finally, NICT has been playing an active role in coordinating discussions by the ISO (International Organization for Standardization) aiming to set standards for wind profiler technology.

NICT's commitment to advanced ICT technology R&D

——What are your future R&D goals?

KAWAMURA "Beyond 5G" and "quantum ICT" have recently become popular buzzwords among ICT researchers. I believe that we need to pay attention to the latest ICT trends and take on new challenges rather than merely hewing to tradition. For example, we have begun studying the use of lidar in quantum sensing because of its significant relevance to quantum mechanics.

Another example is a digital twin—a virtual representation that serves as a digital counterpart to the real world—a focus of active research. The sensing technology we have been researching and developing could be used to collect the real-world data needed to create a digital twin. This way of thinking may help us make a breakthrough in our R&D related to beyond 5G technology.

The amount of data we deal with in our remote sensing, Pi-SAR and PAWR projects has increased by orders of magnitude over the years. It is therefore important that we create a system that will enable us to quickly deliver this data to those who need it. We plan to launch a full-scale project to research and develop a new data system in FY2022. Our R&D efforts are in synch with global trends in ICT technology.

ISHII I was also a remote sensing researcher when I joined NICT's predecessor, the Communications Research Laboratory. I then transferred to a NICT division unrelated to remote sensing a long time ago. I assumed my current position at the Radio Propagation Research Center that oversees the Remote Sensing Laboratory in FY2021. I've been excited by the Center's many enthusiastic researchers, including Dr. Kawamura. I'd like to widely publicize the excellent R&D results produced by these researchers—a role somewhat similar to the sales, marketing and advertising division of a private company.

As lab director Kawamura said earlier, sensing technology can serve as a bridge between the real and cyber worlds. I also anticipate that unmanned technology, such as drones and automated driving, will become increasingly important, and sensing technology will play a vital role in this area.

——Thanks very much to both of you.

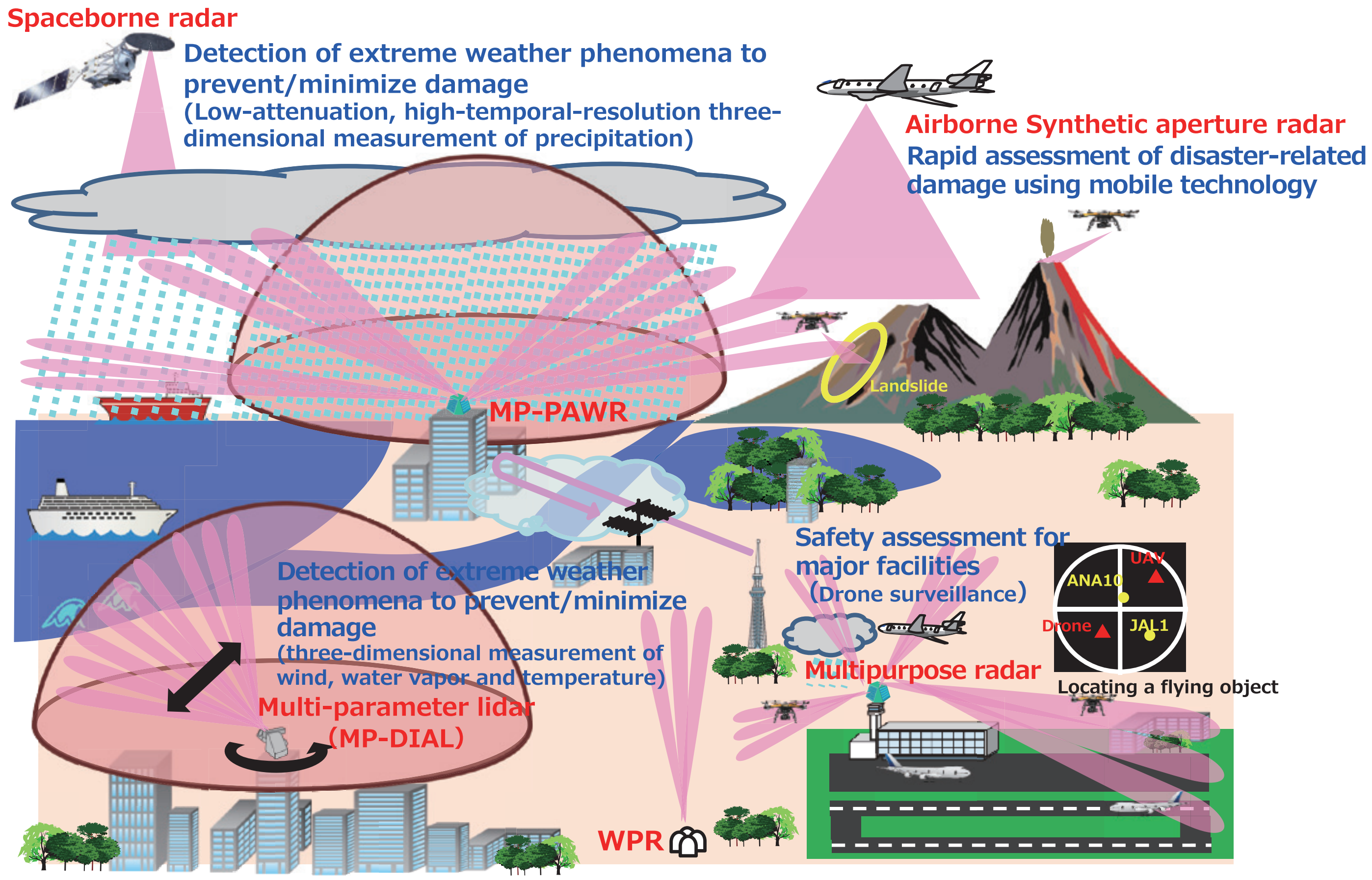


Figure Promoting more comfortable, higher quality life in a safer society using remote sensing technology

Development and Demonstration of a High-precision Airborne Synthetic Aperture Radar (Pi-SAR X3)

Next-generation imaging radar capable of imaging the earth's surface at the world's highest resolution of 15 cm

KOJIMA Shoichiro,
Research Manager,
Remote Sensing Laboratory

After earning his Ph.D. in engineering, Kojima joined the Port and Harbour Research Institute under the former Ministry of Transport (currently the Port and Airport Research Institute) as a research fellow. He transferred to the Communications Research Laboratory (currently NICT) in 2002, where he has researched marine radar and airborne synthetic aperture radar (Pi-SAR X2), among other technologies. Kojima is currently focused mainly on the research and development of Pi-SAR X3, the successor to Pi-SAR X2. Ph.D(Engineering).

Airborne synthetic aperture radar (SAR) is a type of the earth's surface imaging radar. It emits a swath of radio waves directed at the ground perpendicular to the direction of its flight path. It then receives and analyzes radio waves backscattered from the earth's surface and converts them into an image. Airborne SAR is able to image land surfaces regardless of the time of day and weather. We have developed a new high-precision airborne SAR, Pi-SAR X3, with the world's highest spatial resolution of 15 cm. This was achieved by enhancing the functions and performance of Pi-SAR X2—an airborne SAR NICT previously developed. Pi-SAR X3 is expected to be useful in environmental and natural disaster monitoring on the earth's surface (Figure 1). In future studies, we plan to research and develop observation and analytical technologies compatible with Pi-SAR X3, thereby promoting its practical use.

Development of high-precision airborne SAR

SAR performs synthetic aperture processing and pulse compression processing on received signals to achieve higher spatial resolution. Synthetic aperture processing improves radar resolution in the direction parallel to the radar's flight path (i.e., azimuth resolution), while pulse compression improves it in the direction perpendicular to the flight path (i.e., range resolution).

Synthetic aperture processing is a technology that images the earth's surface with the same high resolution possible with a large, highly directional antenna by flying an SAR-equipped aircraft in a straight line, forming a large, virtual array antenna in the sky. In pulse compression processing, radio waves are transmitted with linear modulation. The system then analyzes and processes the received radio waves to visualize the earth's surface with the same high resolution possible with a single, high-powered pulse wave. The improvement in range resolution made possible by pulse compression processing is proportional to the bandwidth of the transmitted and received radio waves. In other words, the larger the bandwidth of the transmitted and received radio waves, the higher the range resolution of the radar. Accordingly, Pi-SAR X3 was designed to use the 1 GHz radio frequency band (9.2 - 10.2 GHz). This bandwidth is double that of Pi-SAR X2. Developing an antenna and transmitter/receiver compatible with this large radio frequency band was a great technical challenge. It was also a great technical challenge to develop the higher speed, higher capacity observation data recorder needed to store the significantly increased amount of data associated with the increased radio bandwidth.

Development of Pi-SAR X3

To develop Pi-SAR X3, we developed a new transmitter/receiver and antenna compatible with the 1 GHz band. We also developed a new high-speed, high-capacity observation data recorder (write speed: 4 GB/s, storage capacity: 128 TB) capable of storing huge amounts of data without delay. Pi-SAR X3 instruments, including a transmitter/receiver and an antenna, were mounted on an aircraft (Figure 1). In addition, we developed a signal processing device capable of converting the huge amounts of observation data collected into images in the flying aircraft in quasi-real time. This device enables the staff in the aircraft to collect observation data while examining the captured radar images. It also enables the transmission of captured images to ground stations via communication satellites or other means.

Pi-SAR X3 demonstration

We tested the performance of Pi-SAR X3 in December 2021 and confirmed its ability to measure the earth's surface at a resolution of 15 cm. Figure 2 shows an image of a 1 km by 1 km area captured by Pi-SAR X3 near Wajima City, Ishikawa Prefecture and two enlarged views of the same rectangular rice field area outlined in white (left: 30 cm resolution, which is equivalent to the Pi-SAR X2's resolution; right: 15 cm resolution). The 30 cm resolution image was taken by Pi-SAR X3 using its 30 cm resolution mode. The time difference between the 30cm resolution image and the 15cm resolution image is about 23 minutes. Pi-SAR X3 was able to clearly resolve farm tractor tracks, which was difficult with Pi-SAR X2. Pi-SAR X3 may be used in more detailed observation of land surface changes caused by earthquakes, volcanic eruptions and other events. It also may be used to assess natural disaster damage in greater detail, potentially facilitating smoother and more effective rescue operations and recovery efforts.

Future Prospects

In FY2022, we plan to start testing the performance of new Pi-SAR X3 functions while observing different types of the earth's surfaces. We will then develop more advanced techniques to analyze the observation data. These analytical techniques will be designed to enable high-precision natural disaster monitoring (e.g., earthquakes, tsunamis, flooding and active volcanos in a resting state), environmental monitoring (e.g., land use patterns, forest destruction, marine oil pollution and ocean waves) and marine monitoring (e.g., ships and drifting objects). Through these efforts, we will promote practical use of Pi-SAR X3.

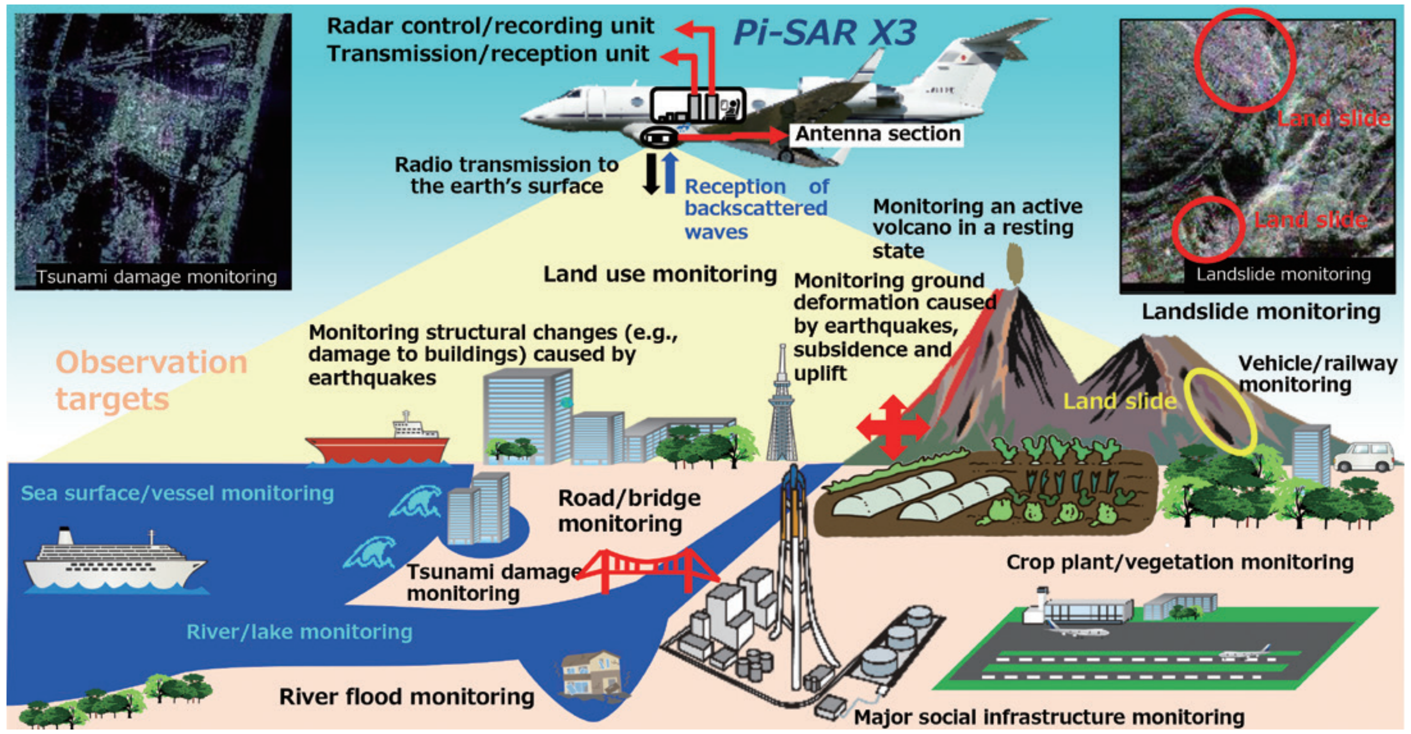


Figure 1　Pi-SAR X3's observation targets

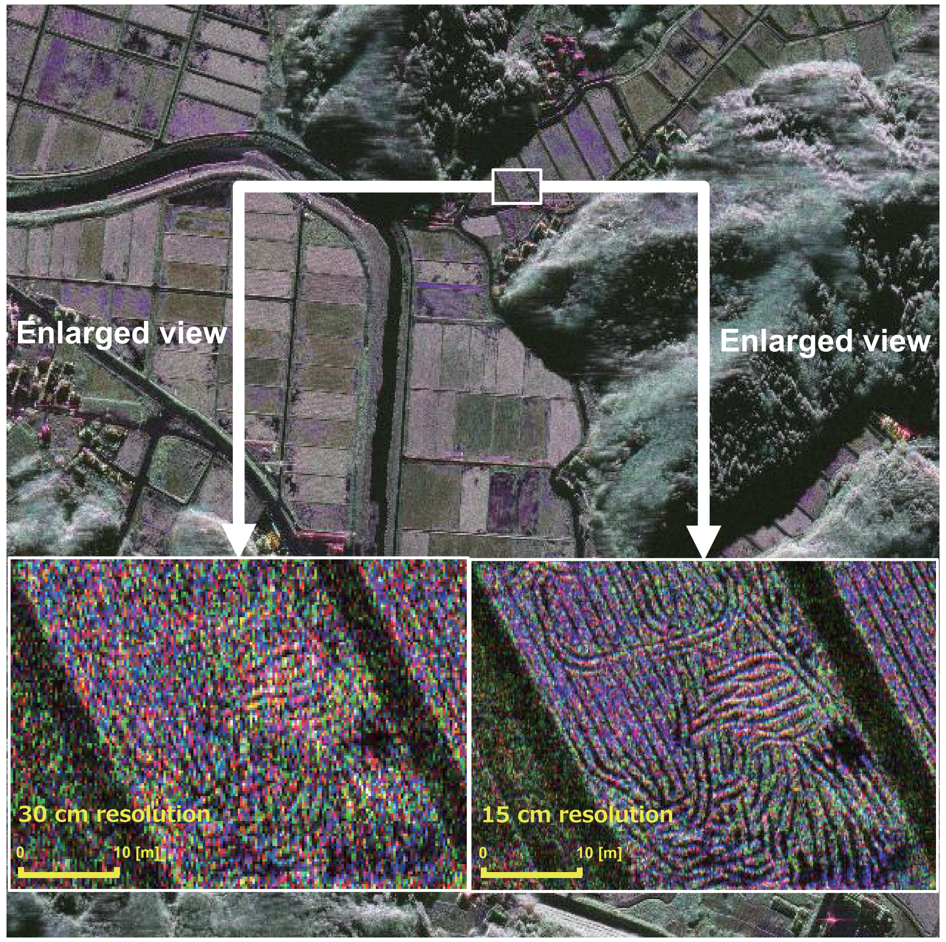
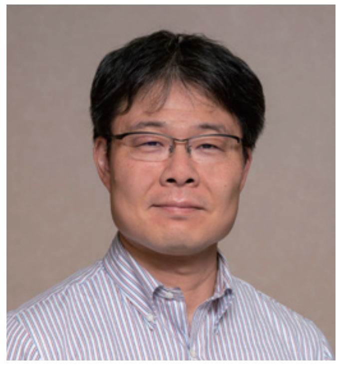


Figure 2　SAR image taken at two spatial resolutions

Laser Remote Sensing of Atmospheric Wind and Water Vapor

Development of multi-parameter differential absorption lidar



IWAI Hironori

Senior Researcher,
Remote Sensing Laboratory,
Radio Propagation Research Center,
Radio Research Institute

He joined the Communications Research Laboratory (currently NICT) in 2001 after completing a master's course. He has engaged in the research of radar and laser remote sensing technologies for environmental measurements. Doctor of Science.

AOKI Makoto

Researcher,
Remote Sensing Laboratory,
Radio Propagation Research Center,
Radio Research Institute

After completing his doctoral degree, he worked as postdoctoral researcher of Shizuoka University and joined NICT in 2014. He is engaged in research of solid-state laser and laser remote sensing technology. Doctor of Engineering.

Water vapor is currently a hot meteorological research topic. In recent years, Japan has regularly experienced unexpected localized atmospheric phenomena (e.g., torrential rain and tornados) and quasi-stationary band-shaped precipitation systems (Senjo-Kousuitai), that have caused severe damage. Reliable forecasting of these events is currently very difficult due partly to a lack of data on wind and water vapor that would be needed to accurately measure the amount and flow of atmospheric water vapor. To address this issue, we have been developing an H_2O differential absorption lidar (H_2O DIAL) capable of measuring atmospheric water vapor and wind.

Background

Advances in meteorological technology (e.g., weather satellites and radar) and numerical forecasting models have significantly improved the forecasting accuracy of meso-scale weather events and phenomena (e.g., typhoons and fronts). As a result, the number of casualties inflicted by these events has declined. On the other hand, reliable forecasting of localized extreme weather events remains difficult. These events are known to be associated with the development of one or more cumulonimbus clouds. The series of events from the development of cumulonimbus clouds to the occurrence of heavy rainfall is schematically illustrated in Figure 1. First, wet air masses containing water vapor gather in wind and are lifted to higher altitudes by updrafts where they transform into clouds. When these air masses containing cloud particles are lifted to much higher altitudes by strong updrafts, large amounts of raindrops are produced. These raindrops start to fall when the updrafts can no longer support their weight, resulting in torrential rain. This figure indicates that torrential rain can be forecasted by measuring and analyzing the amount and flow of atmospheric water vapor before it develops into clouds.

The main water vapor measurement method currently available is the use of sensors installed at specific weather stations. However, these sensors can measure water vapor only at these observation points and are unsuitable for measuring its spatial distribution. A new technology is required that can measure the spatial distribution and flow of water vapor. To meet this demand, we have been researching and developing differential absorption lidar (DIAL), a remote laser sensing technology able to measure the spatial distribution of water vapor and wind.

Measuring wind and water vapor using a 2 µm laser

The principle applied in the DIAL to measure wind and water vapor is illustrated in Figure 2. We have chosen infrared lasers in the 2 µm wavelength range because they are relatively safe for human eyes and are suitable for measuring water vapor. The DIAL emits laser pulses at H_2O-absorbing and non-H_2O-absorbing wavelengths, referred to as online and offline, respectively. The emitted laser pulse is backscattered by aerosol particles in the atmosphere. The DIAL determines the distance to the aerosols using time-of-flight principles. The device is also able to determine wind velocity along its line of sight by measuring frequency shifts caused by the Doppler effect. Moreover, the DIAL can measure the amount of atmospheric water vapor using differential absorption in the backscattered signal intensities of the two different wavelengths. The intensity of the backscattered signal varies between the two wavelengths as they are absorbed by water vapor differently.

The main components of the DIAL are illustrated in Figure 3. In 2019, we began developing a coherent H_2O DIAL using the results of our previous research into coherent Doppler lidar and CO_2 DIAL technologies using 2 µm lasers. The H_2O DIAL is composed of 1) seed lasers with continuous-wave and single-longitudinal-mode (SLM) operation in the 2 µm wavelength range, 2) a wavelength controller which tunes the wavelengths of the seed lasers and 3) a high-power pulse laser injection-seeded by the wavelength-controlled seed lasers.

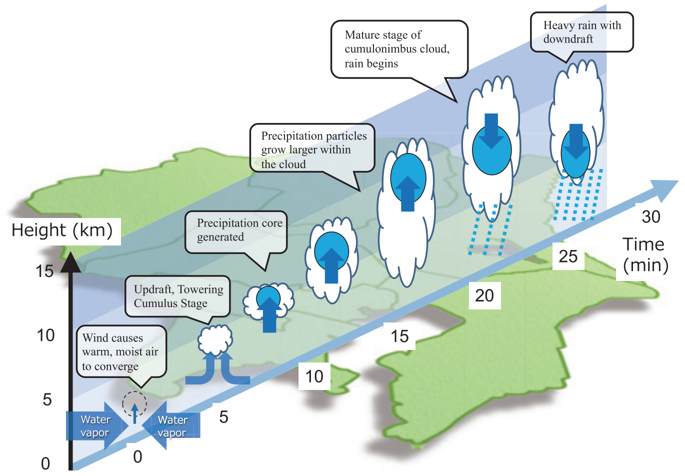


Figure 1 Schematic diagram illustrating the series of events from the onset of cumulonimbus formation to a burst of heavy rainfall

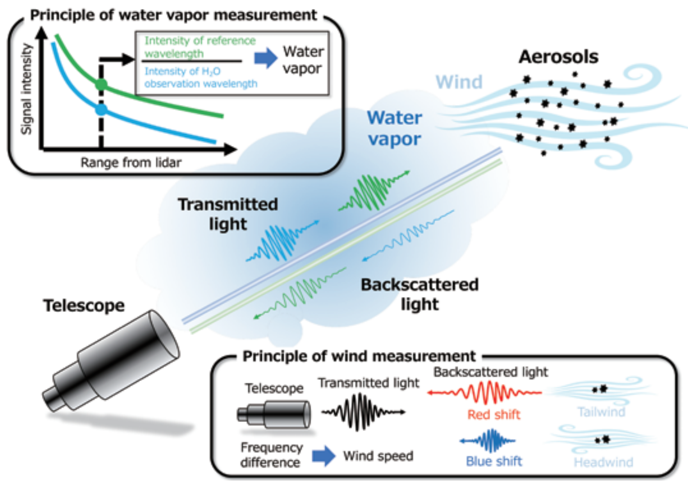


Figure 2 Principle behind the measurement of wind and water vapor using differential absorption lidar (DIAL)

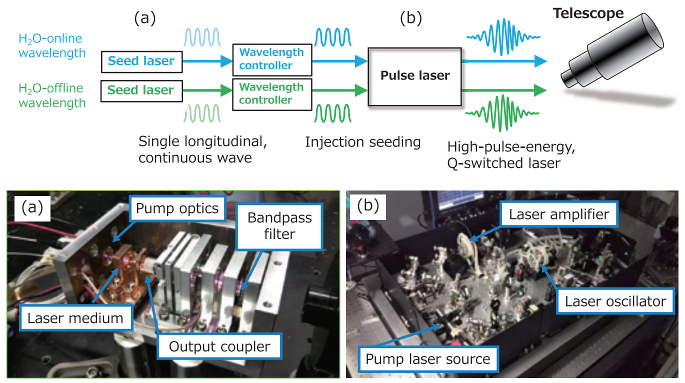


Figure 3 (Top) Composition of the differential absorption lidar (DIAL). (a) Prototype seed laser. (b) Prototype pulse laser.

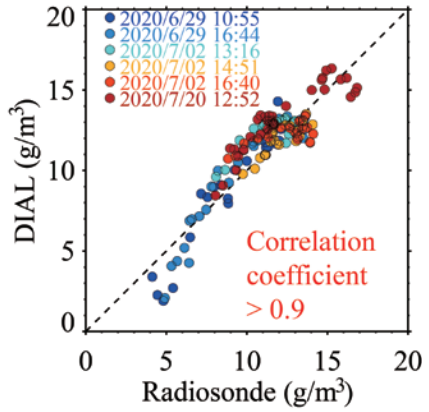


Figure 4 Correlation between water vapor content measured using a differential absorption lidar (DIAL) and a radiosonde

Accurate water vapor measurement requires the use of seed lasers with online and offline wavelengths. In addition, measuring water vapor with an accuracy of ±10% requires the use of a wavelength controller capable of stably tuning the wavelength of the lasers to a precision of 1 pm (= one trillionth of a meter) over long periods of time. In 2020, we developed a novel wavelength controller able to simply and easily tune laser wavelengths. This controller exhibited the ability to tune the wavelengths of the lasers to a precision of 0.5 pm over long periods of time. We compared the observed results of water vapor measured by radiosondes and by our H_2O DIAL (Figure 4). The measurements were in good agreement with a correlation coefficient of over 0.9.

Achieving practical use

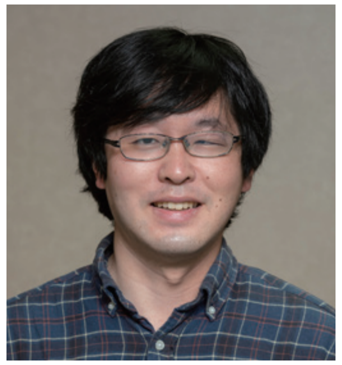
To achieve widespread use of our DIALs, their performance must be improved while their production cost is reduced. We are working to achieve more stable operation by the components of the DIAL (Figure 3) at lower cost. We began developing a prototype seed laser and pulse laser in 2020. Despite its simple design, the wavelength of the seed laser (Figure 3 (a)) can be tuned very accurately with long-term stability. We are currently evaluating its performance. The high-power Ho:YLF pulse laser (Figure 3 (b)) produced by a readily available and very reliable thulium fiber laser is used as the transmitter for the DIAL.

Future prospects

We plan to develop multi-parameter differential absorption lidar (MP-DIAL) capable of measuring atmospheric temperature—another factor contributing to the development of heavy rainfall. An advanced multi-wavelength control technique will be needed for the MP-DIAL. We believe that using MP-DIAL to measure the spatial distribution and temporal changes in wind, water vapor and temperature will significantly improve the accuracy of torrential rain forecasting.

Development of Global Cloud and Precipitation Measurement from Space

Past and future of spaceborne cloud and precipitation radar



KANEMARU Kaya

Researcher,
Remote Sensing Laboratory,
Radio Propagation Research Center,
Radio Research Institute

After received Ph.D. degrees from Nagoya University and worked in JAXA and the University of Tokyo, he joined NICT since 2019. His research interests include algorithm development and calibration for spaceborne precipitation radar.
Ph.D. (Science).

Did you know that rainfall can be measured from space? Spaceborne precipitation radar (a.k.a., flying rain gauges) has enabled accurate measurement of regional characteristics of precipitation systems and global precipitation distribution. Moreover, measurement of vertical motion in clouds with spaceborne radar will soon be possible thanks to years of research and development. In this article, we briefly describe the history of spaceborne cloud and precipitation radar research and development at NICT and report recent trends in the development of future spaceborne precipitation radar.

Why do measurements need to be made from space?

Extreme weather events, such as heavy rainfall and drought, are becoming increasingly frequent around the world. In Japan, heavy rainfall and heat waves previously experienced once every few decades now occur almost every year. A recent study indicated that the probability of heavy rainfall events is linked to global warming. While heavy rainfall is in part associated with global-scale phenomena (i.e., global warming), precipitation (i.e., rainfall and snowfall combined) is essentially a local phenomenon: atmospheric water vapor condenses into cloud droplets, raindrops or snowflakes and falls to the ground. Therefore, monitoring precipitation is required at both the local and global scales.

Some issues have been identified around the world in measuring and sharing precipitation information. Dense networks of rain gauges and weather radar to measure precipitation are available only in developed countries. In addition, in the case of rivers that pass through several countries, downstream countries need to obtain rainfall information from neighboring upstream countries in order to prepare for potential flooding. This can be difficult for several reasons, including environmental issues and regional conflicts. Repeated, uniform measurement of global precipitation from space would help resolve these issues.

Spaceborne cloud/precipitation radar R&D at NICT

Since the 1970s, NICT and its predecessors—the Radio Research Laboratory and the Communications Research Laboratory—have been developing technologies to measure rainfall. In addition, since the 1990s, they have been developing spaceborne cloud radar to measure cloud droplets before they grow into raindrops. The precipitation radar (PR) onboard the satellite of the Tropical Rainfall Measuring Mission (TRMM, a US-Japan joint mission) was a product of these R&D efforts. The PR measured global rainfall from space for many years (1997–2015). In addition, NICT and the Japan Aerospace Exploration Agency (JAXA) jointly developed dual-frequency precipitation radar (DPR), which is mounted on the Core Observatory of the ongoing Global Precipitation Measurement mission (GPM, a US-Japan-led international mission). The DPR has been measuring global precipitation since becoming operational in 2014.

Both PR and DPR can measure three-dimensional precipitation structures all over the globe and accurately estimate surface precipitation intensity. The global distributions of surface precipitation measured by PR and DPR are shown in Figures 1 and 2. The PR measured precipitation across the Earth's surface between the latitudes of approximately 35° south and 35° north for approximately 17 years. In comparison, the DPR has been measuring it between the latitudes of approximately 65° south and 65° north. The DPR's improved performance enables it to detect light rainfall and snowfall which occurs more frequently at higher latitudes. In addition, the DPR can measure precipitation intensity more accurately using radio waves with two different frequencies in the Ku- (13.6 GHz) and Ka- (35.5 GHz) bands.

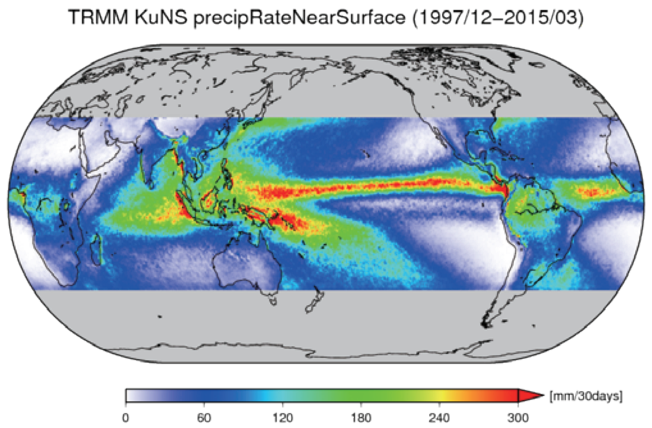


Figure 1 Global map of surface precipitation (in millimeters / 30 days) measured by precipitation radar (PR) onboard the TRMM satellite. The PR data was obtained over 17 years from December 1997 to March 2015.

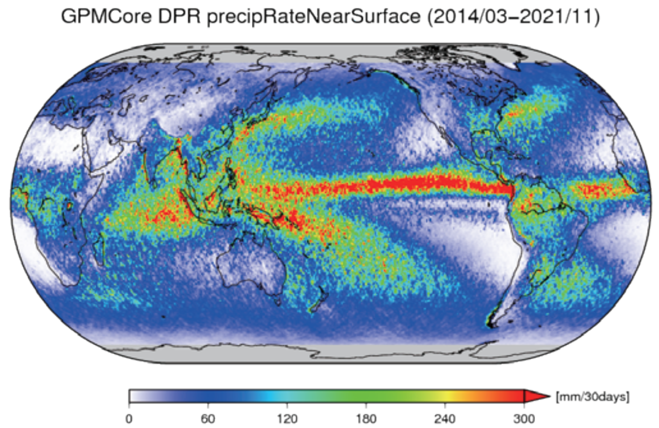


Figure 2 Global map of surface precipitation (in millimeters / 30 days) measured by the dual-frequency precipitation radar (DPR) onboard the GPM core satellite. The DPR data was obtained over 7 years from March 2014 to November 2021.

The difference in radar echoes between these two frequencies is used to distinguish rainfall from snowfall and to determine raindrop size and concentration.

NICT and JAXA have also been developing a cloud profiling radar (CPR) which will be mounted on the satellite for the EarthCARE (Earth Clouds, Aerosols and Radiation Explorer) mission to be conducted jointly by Europe and Japan. The EarthCARE satellite is now in the final stages of development and is planned to be launched in FY2023. Millimeter waves (frequency of W-band (94 GHz)) have been adopted by the CPR to measure cloud droplets, light rainfall and snowfall, which are hard to detect using the DPR. In addition, the CPR can observe the vertical velocity of clouds and precipitation with its Doppler measurement capability. Doppler information is useful in improving the classification and estimation of cloud droplet sizes and precipitation amounts. We anticipate that simultaneous observation by the CPR and other sensors onboard the EarthCARE satellite will help reduce uncertainties in current global warming prediction models.

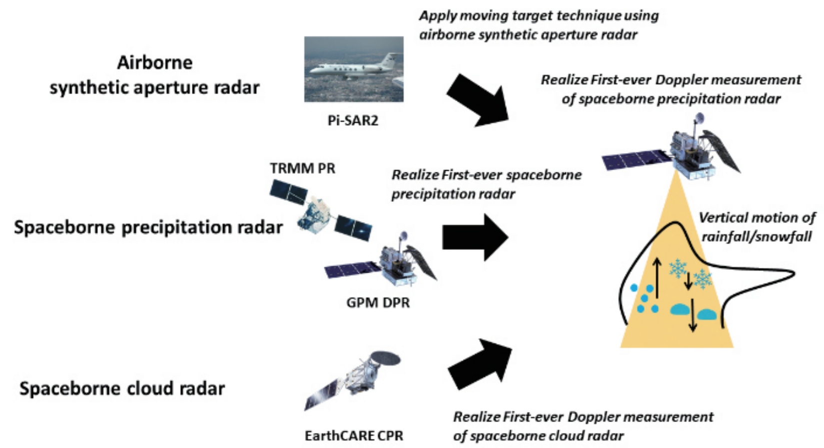


Figure 3 Next-generation spaceborne precipitation radar being developed at NICT. The satellite photos were obtained from the JAXA digital archives. Pi-SAR2 is the airborne SAR developed and operated by NICT.

Airborne SAR technology: a potential key to enhancing spaceborne precipitation radar

To improve the ability to forecast disaster-causing rainfall events for short-term weather forecasts and projections of future changes in precipitation characteristics, it is important to better understand the growth process from cloud droplets to precipitation in heavy precipitating clouds. Observation of motion in precipitating clouds is useful in interpreting cloud-precipitation processes. To achieve this, Doppler measurement capability is being discussed in Japan for use in the next generation of spaceborne precipitation radar. This radar could be used to investigate vertical motion by observing various precipitating clouds all over the globe and build an understanding of cloud-precipitation processes. The Doppler capability of future spaceborne precipitation radar will adopt the moving target detection technique used in airborne synthetic aperture radar (SAR). This is exciting because since the 1990s, NICT has been researching and developing airborne SAR systems for surface observation with very fine spatial resolution. Since the moving target detection technique has never been used in Doppler measurement of precipitation from space, NICT researchers of both spaceborne radar and airborne SAR are currently studying how it can be achieved. The various radar technologies developed by NICT over the years are enabling the design of the next-generation of spaceborne precipitation radar (Figure 3).

Future prospects

NICT is committed to making the world more resilient to natural disasters by observing clouds and precipitation globally with remote sensing technologies. To achieve this, we must accelerate collaboration with external research organizations, including JAXA.

This article does not describe the overall objectives of the satellite missions mentioned above (i.e., TRMM, GPM and EarthCARE) or of airborne SAR. It also does not describe the results achieved (or expected to be achieved) by these missions/technologies. If you find these topics interesting, please seek out other articles that explain them in detail. Please also share any thoughts you may have on ways in which spaceborne cloud/precipitation measurement systems could be improved.

In preparing this article, I referred to JAXA's report on the Precipitation Measurement Mission (PMM) (in Japanese only). The satellite photos were obtained from the JAXA digital archives (https://jda.jaxa.jp/?lang=e). PR and DPR precipitation data have been downloaded from the JAXA's Global Portal System (https://gportal.jaxa.jp/gpr/?lang=en).

Rapid Prediction by AI using MP-PAWR data

Philippe Baron

Researcher,
Remote Sensing Laboratory,
Radio Propagation Research Center,
Radio Research Institute

Born in France in 1970. After finished Doctorial course in 1999, he worked for Stockholm University (Sweden) as a researcher and for Noveltis Co. (Toulouse) as research engineer. He joined NICT in 2007. He has engaged in research in electro-magnetic sensing of the atmosphere. Ph.D. (Physics)

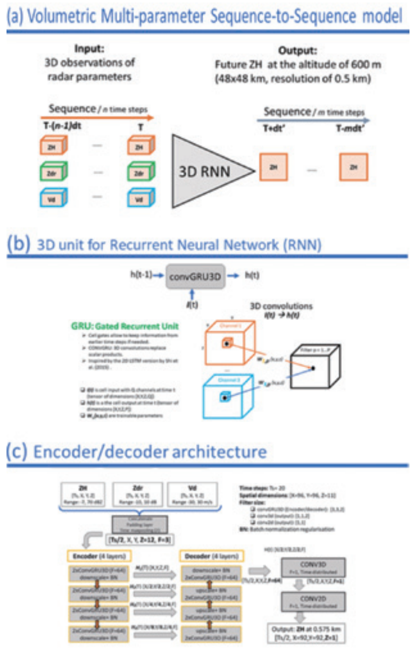


Figure 1 Overview of (a) model interfaces, (b) time recurrent units and (c) the encoder-decoder architecture.

The prediction in real time of localized torrential rains is an important issue for the development of a safer society. Storm nowcasting, i.e. forecasting tens of minutes in advance with a spatial resolution of a few hundred meters, based on conventional observation and prediction methods has a predictive horizon that does not exceed 10 min. Under the Japanese Cross Strategic Innovation Promotion Program (SIP), NICT has contributed to the development of the Multi-Parameter Phased-Array Weather Radar (MP-PAWR) to provide precipitation observations with unprecedented spatio-temporal resolution. Methods using Artificial Intelligence (AI) are being studied to exploit these new data and to push the nowcast limits.

Background

Localized torrential rains are sudden convective thunderstorms developing over a small area of about 5x5 km in few tens of minutes. They are responsible of serious flooding causing infrastructure damages, often with fatalities and their frequency is expected to increase because of climate change. Therefore, their prediction at least few tens of minutes in advance with a high spatial resolution is mandatory to develop efficient alert systems. Such a very short-term prediction is called nowcast. The short lifetime and narrowness of these storms make their nowcast extremely difficult with conventional observation and nowcast methods. Typically, the best nowcasts do not exceed 10 minutes.

Under SIP, a new MP-PAWR has been developed by NICT, Toshiba Co., and Osaka University. The instrument is exploited in Saitama University (35.86N, 139.60E) since 2018. Combining mechanical horizontal scanning with electronic vertical one, the instrument is able to scan the whole surrounding atmosphere up to of 60 km from the instrument every 30 sec with high spatial resolution. Hence the evolution of the thunderstorms can be described in details from the early phase that appears above the altitude of 3 km. This information is essential to properly initiate nowcast models.

Supervised deep neural network (DNN), one of the tools of Artificial Intelligence, is a promising method to realize nowcasts. A DNN is a computer program capable of recognizing features in data. It can map the model inputs and outputs even for problems with high dimensions and a nonlinear relationship. Nowcasting can be done in real-time with relatively small computers. The training is realized offline using a large dataset of observations, and requires heavy calculations. It consists of finding the optimal values of model parameters in order to reduce the differences between the model output and the observations.

Development plan

We have chosen to carry out deterministic nowcasts, that is to say to predict the intensity of the precipitation at a given location. This study aims at the realization of a first version of the nowcasts with the objective to obtain performance comparable to other models and to define ways of improvement. The study was divided in three tasks.

The first task of this study was to build independent databases for training and validating the model. Only MP-PAWR observations are used. Although the primary target is heavy rains, our model is trained with all rain types to produce a robust model that can recognize heavy rain precursor from all the possible cases.

The second task was to define and implement the model. We consider a recent technique that merges well-established techniques used in recurrent neural networks (RNN) and in convolutional neural networks (CNN) to analyze time series and images, respectively. The technique CRNN was proposed by Shi et al. (2015) for nowcasting precipitations from 2D radar observations on larger spatial scales than those considered here. Our model is implemented using the google open-source library TensorFlow.

The final task was the validation of the model and the comparison with works carried out in Osaka University to assess its performance.

Challenges to be solved

The model needs to recognize and extrapolate temporal and spatial features in a large number of observations. The 3 spatial dimensions must be used unlike most studies where only the horizontal plane is considered. Furthermore, the model should be able to leverage all the information provided by the instrument, i.e., the Doppler velocity and the radar reflectivity for both polarizations.

The large amount of information to be stored in the model and the number of computations inherent in 3D convolutions lead to a model with more than 10^7 parameters which is trained over several weeks with large GPUs.

Outcomes at present

Figure 1 shows the Multi-parameter Volumetric Sequence-to-Sequence model that has been implemented. Here “multi-parameter” refers to the use of 3 radar parameters: the radar reflectivity of the horizontal polarization (ZH), the reflectivity ratio between both polarizations (Zdr) and the Doppler velocity (Vd). These parameters inform on the rainfall intensity (ZH), the type of rains (Zdr) and the raindrops motion with respect to the instrument (Vd). Typically ZH = 10 dBZ indicates a light rain intensity of about 0.05 mm 9mm/h while the value of 37 dBZ represents heavy rain of 9 mm 9mm/h.

The core of the model is a 4-layers encoder-decoder module based on ConvGRU3D units which is adapted from the 2D CRNN mentioned above. Each layer processes features with a given spatial size and resolution. The encoder extracts the spatio-temporal features from the input sequence while the decoder realizes their extrapolation. The model is trained with all the rainfall events observed between August and October 2018.

Figure 2 shows a set of 10-minutes lead-time nowcasts at the altitude of 600 m with a resolution of 500 m from observations of July 2018. The predictions are consistent with the observations though they appear blurred. The performance of the models is comparable to that of models developed in other teams. As in other studies, the nowcast skills strongly decrease beyond 10 minutes (not shown here).

Future prospects

Further work is needed to improve nowcasting beyond 10 minutes and for heavy rainfalls. The latter are under-represented in the database but are the most important events to predict. Figure 3 summarizes different ways to improve the nowcast. Improving the model architecture and training using recent techniques such as adversarial training or attention mechanism are planned, as well as to increase the representativeness of heavy rain cases in the training database. However, the close performance of models with different architectures and training strategies may reveal that significant improvements could only be obtained with additional information such as relative humidity or cloudiness that cannot be provided by the radar. To carry out all these tasks effectively, it will be necessary to strengthen the exchanges with other teams such as those at Osaka University or RIKEN.

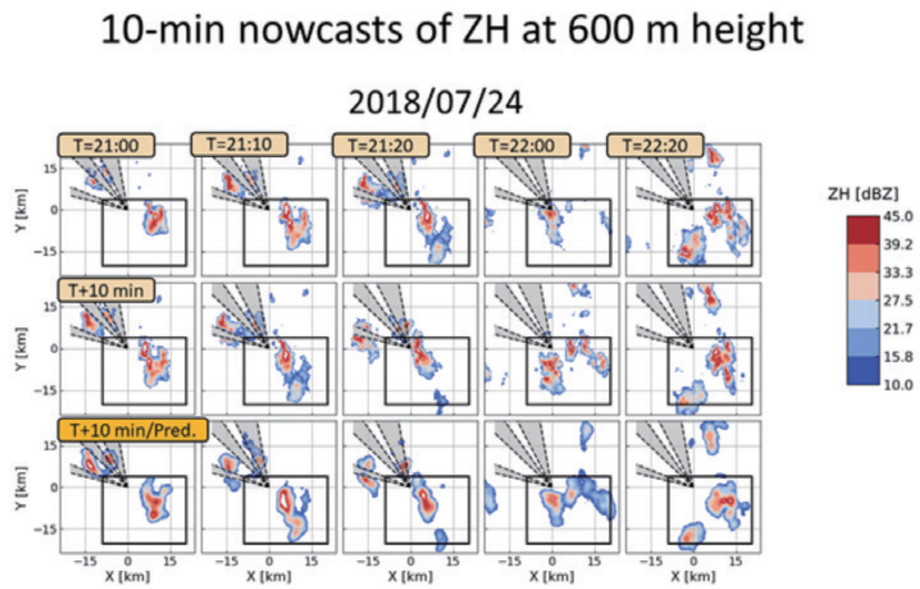


Figure 2 Examples of ZH predicted with 10 min lead-time. From top to bottom: observations at the height of 600 m at time T (see caption in panels), observations and nowcasts at T+10 min.

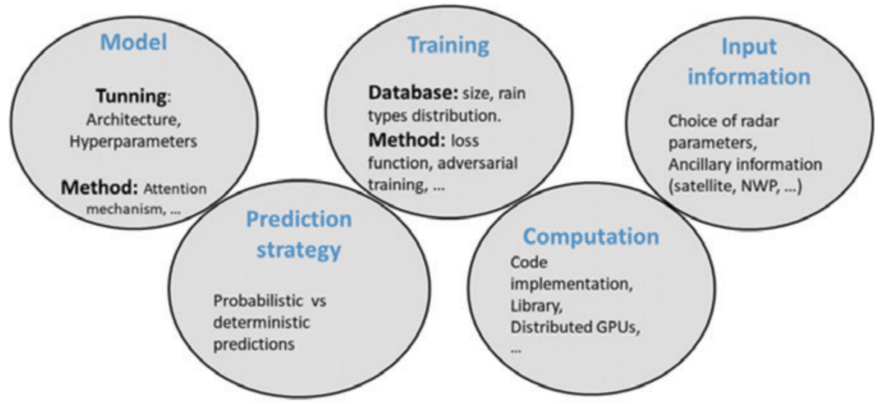


Figure 3 Example of issues to be investigated to improve the model performance.

Development of an ISO Standard for Wind Profiler Radars

YAMAMOTO Masayuki
Planning Manager, Evaluation Office, Strategic Planning Department

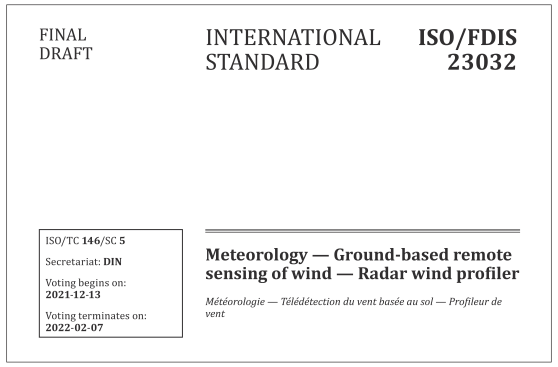
KAWAMURA Seiji
Director of Remote Sensing Laboratory, Radio Propagation Research Center, Radio Research Institute

Observed meteorological data are widely used in the weather services of national meteorological agencies, agriculture, industry, commerce, and so on. To ensure the accuracy of observed meteorological data, international standards for meteorological instruments have been formulated. An International Organization for Standardization (ISO) standard for wind profiler radar (WPR), an instrument for measuring height profiles of wind velocity in the clear air, is being developed.

Both the weather varying from day to day and the climate changing with a time scale longer than several decades significantly affect the human society. To investigate atmospheric phenomena in the past, to know current weather conditions, and to predict the weather and climate change, it is imperative to collect high-quality, publicly-available meteorological data. ISO/Technical Committee (TC) 146/Subcommittee (SC) 5 has been developing ISO standards for meteorological instruments. TC 146 addresses air quality, and SC 5 is dedicated to meteorology. The Commission for Observation, Infrastructure and Information Systems (INFCOM) of the World Meteorological Organization (WMO) investigates atmospheric measurement methods and standards for meteorological instruments. SC 5 develops ISO standards as technical guidelines for meteorological instruments, and it communicates closely with INFCOM in their developments. Working Groups (WGs) of SC 5 have formulated the ISO standards for anemometers, thermometers, laser radars (lidars), and weather radars. The Japanese Industrial Standards Committee (JISC), the ISO representative of Japan, has organized domestic committees on the ISO standards.

WPR measures height profiles of wind velocity in the clear air with high time resolution (typically from 10 minutes to an hour). It detects echoes from irregularities of the radio refractive index generated by turbulence (clear-air echoes) and retrieves the wind vector using the Doppler shifts of the clear-air echoes. ISO/TC 146/SC 5/WG 8, established in November 2017, is developing the ISO standard for WPR. WG 8 includes experts from France, Germany, Japan, the United States of America, and other countries. The convenor of WG 8 is Dr. Volker Lehmann of the Deutscher Wetterdienst. WG 8 has issued the Working Draft (WD), Committee Draft (CD), and Draft International Standard (DIS). Now the development of the ISO standard for WPR is in the stage of Final Draft International Standard (FDIS).

The domestic committee in Japan includes representatives of the Japan Meteorological Agency which operates the WPR network named WINDAS, manufacturers that have experiences of WPR development and production, and research institutes that have been carrying out research and development of WPR measurement techniques and studying atmospheric science using WPRs. The Japan committee has contributed greatly to the development of the ISO standard by submitting proposals that meet international requirements for the design, production, installation, operation, and maintenance of WPRs. NICT, participating in WG 8 as an expert from Japan, has facilitated international agreements through discussion and coordination of proposals from Japan and other countries. The third international conference in May 2019 was held at the NICT's open space for research in Osaka, Japan. Adaptive clutter suppression (ACS) is a technique to mitigate undesired echoes (clutter) by using adaptive antenna arrays, and range imaging (RIM) is a technique to enhance vertical (range) resolution by using frequency diversity. NICT has contributed to demonstrating their usefulness. In the ISO standard for WPR, ACS and RIM are recommended as a technique to mitigate clutter and that to enhance vertical (range) resolution, respectively.


FINAL DRAFT

INTERNATIONAL STANDARD

ISO/FDIS 23032

ISO/TC **146**/SC **5**

Secretariat: **DIN**

Voting begins on: **2021-12-13**

Voting terminates on: **2022-02-07**

Meteorology — Ground-based remote sensing of wind — Radar wind profiler

Météorologie — Télédétection du vent basée au sol — Profileur de vent

Cover of FDIS.

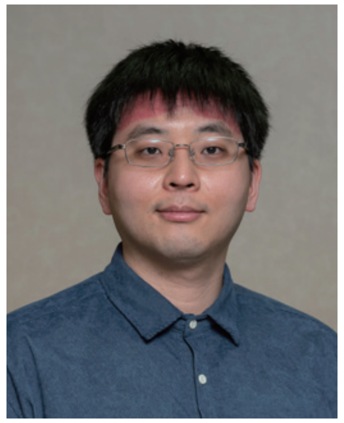
YAMAMOTO Masayuki
Planning Manager, Evaluation Office, Strategic Planning Department (Until Dec. 31, 2021) Senior Researcher, Remote Sensing Laboratory, Radio Propagation Research Center, Radio Research Institute

After completing a master's course at graduate school, he worked in industry as an engineer and then at university as an assistant professor before joining NICT in 2015. He is engaged in the research of atmospheric remote sensing. Ph.D. (Informatics).

KAWAMURA Seiji
Director of Remote Sensing Laboratory, Radio Propagation Research Center, Radio Research Institute

After completing his doctorate, he served at Communications Research Laboratory (currently NICT) as a postdoctoral fellow for the Japan Society for the Promotion of Science (JSPS), and then joined NICT in 2006. He is engaged in the research of radar remote sensing. Ph.D. (Informatics).

Land Surface Observation using Airborne Synthetic Aperture Radar (SAR) and Information Extraction from SAR data



GOCHO Masanori
Fixed Term Researcher, Remote Sensing Laboratory, Radio Propagation Research Center, Radio Research Institute Ph.D. (Engineering)

Biography

1993: Born in Niigata Prefecture.
2016: Graduated from Niigata University with a BS in engineering.
2019: Joined NICT while pursuing a Ph.D. at Niigata University's Graduate School of Science and Technology.
2021: Earned a Ph.D. in engineering from Niigata University's Graduate School of Science and Technology.

Awards, etc.

Won the Best Paper Award for FY2018/2019 from the Technical Committee on Antennas and Propagation, the Institute of Electronics, Information and Communication Engineers and the 2020 Student Award from the IEEE Antennas and Propagation Society's Japan Chapter

Q&As

Q When did you want to be a Researcher?

I recently ran into an elementary school classmate who told me that I had said as a child that I wanted to become a research scientist. I didn't believe him, but when I looked up my elementary school graduation essay, I found that I had actually said this in my own words. I made my dreams come true without even knowing it!

Q What is the biggest failure in you life so sar?

A This may not be my biggest mistake ever, but when I was in my doctoral program, I was receiving a loan-based scholarship. Because I failed to submit a waiver request, I'm still paying it back.

Q What are you interested in other than research?

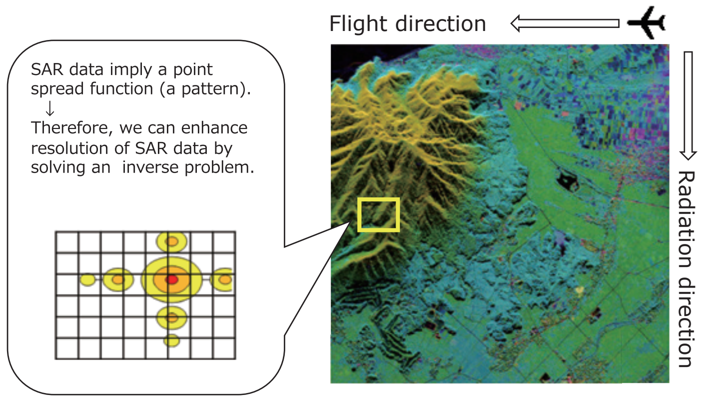
A Making coffee is a pastime of mine. I used an electric coffee grinder for a long time, but I recently switched to a manual grinder. I find that grinding coffee beans clears my mind.

Geographical survey products, including maps, are commonly used in daily life. While small-scale surveys can be achieved manually by geographic surveyors, global-scale surveys require the use of remote sensing technologies.

Radar—a remote sensing technology—is able to determine the distance of objects by transmitting radio waves, receiving their reflections and measuring the time elapsed between transmission and reception. In essence, a radar device produces an echo effect using radio waves. Through combined use of airborne SAR and sophisticated signal processing, two-dimensional images of land surfaces can be generated. Remote sensing from aircraft flying at high altitudes allows large areas to be surveyed quickly. NICT has been developing airborne SARs and making land surface observations using them since the 2000s.

I have been developing signal processing techniques to extract information from data collected by airborne SARs. My current main research focus is to develop signal processing techniques capable of enhancing the resolution of SAR images. The higher the SAR resolution (i.e., the smaller the area the SAR can resolve), the more detailed the land surface images the SAR can capture. However, SAR resolution is difficult to enhance due to certain limitations, including the radar frequency band. I have developed a signal processing technique to enhance the resolution of SAR images by removing the blurring caused by the point spread function of the SAR imaging system. This technique more than doubles SAR image resolution. This was achieved using a virtual frequency bandwidth two to three times wider than the actual radar frequency bandwidth SAR uses to collect data.

In future research, I will conduct in-depth testing to verify the performance of this technique. I will also further improve the technique with the aim of achieving its practical use.



The resolution of an SAR image (left) is determined by the pixel size of the imaging sensor and a consistent blur pattern created by the point spread function of the SAR imaging system. This blurring can be corrected by inversely solving the point spread function, thereby enhancing SAR resolution virtually.

NICT NEWS 2022 No.2 Vol.492
Published by **Public Relations Department, National Institute of Information and Communications Technology**
Issue date: Mar. 2022 (bimonthly)

4-2-1 Nukui-Kitamachi, Koganei, Tokyo
184-8795, Japan
TEL: +81-42-327-5392 FAX: +81-42-327-7587

URL: https://www.nict.go.jp/en/
@NICT_Publicity
#NICT

ISSN 2187-4050 (Online)