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CONTENTS

[Cover Photo] A phased array weather radar: We are researching and developing phased array weather radar as a means of predicting sudden localized extreme weather events and reducing the damage they cause. This phased array radar can measure three-dimensional structures of localized heavy rain, torrential rain, tornadoes and the like with a spatial resolution of 100 m within 10 seconds (Onna Village, Okinawa).

INTERVIEW

Supporting the Cutting Edge of Evolving Remote Sensing

Katsuhiro NAKAGAWA
Director of Remote Sensing Laboratory, Applied Electromagnetic Research Institute
Joined the Communications Research Laboratory (currently NICT) in 1998 after completing a doctoral course at university. He has been engaged in the research of microwave remote sensing. Ph.D. (Engineering).

Remote sensing refers to the use of optical and radio waves from remote locations to conduct wide-ranging examinations of the state of the ground surface and atmosphere. For example, it can be used to study extreme weather events like localized heavy rain and tornadoes that occur suddenly and change from one moment to the next, volcanic activity that is difficult to investigate up close, and the state of vegetation and land use over a wide range. We talked to Katsuhiro Nakagawa, director of the Remote Sensing Laboratory at the Applied Electromagnetic Research Institute, about his laboratory's involvement in the evolution of remote sensing equipment and systems.

Research and development advancing in eight projects across three fields

— To start with, perhaps you could tell us what the Remote Sensing Laboratory's current mission is?

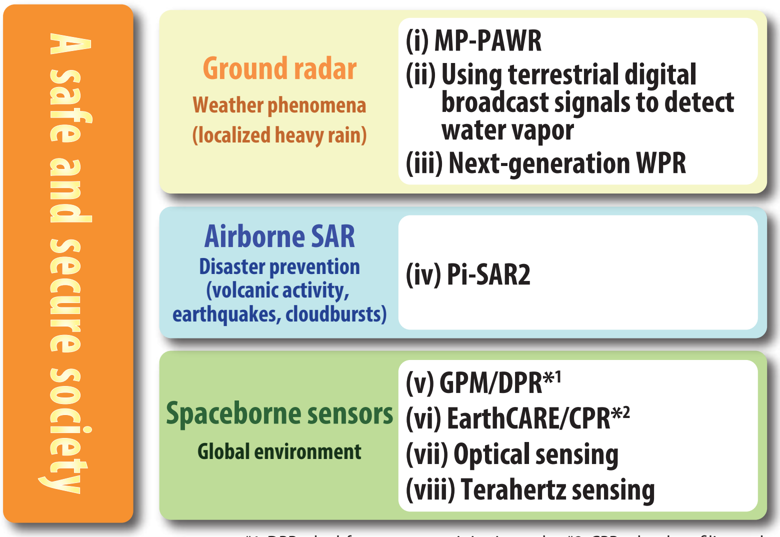
Nakagawa: Our research activities can be broadly divided into three fields: the study of weather phenomena such as localized heavy rain, natural disaster prevention such as volcanic activities and earthquakes, and observations of the global environment from space.

In these three fields, we are currently working on eight R&D projects. In the observation of weather phenomena, we are studying (i) a phased array weather radar (PAWR) for observing rainfall in the horizontal polarized wave, and a multi-parameter phased array weather radar (MP-PAWR) that uses dual polarization to perform observations in both the horizontal and vertical polarized waves, (ii) a method for using terrestrial digital broadcast waves to estimate the amount of water vapor in the air, and (iii) a next-generation wind profiler (WPR).

In the disaster prevention field, we are using radar to observe the ground surface, and specifically, (iv) we are studying airborne polarimetric and interferometric synthetic aperture radar (Pi-SAR).

And regarding the observation of the global environment from space, we are interested in phenomena such as precipitation, clouds, and wind (atmospheric states). Consequently, our R&D projects include (v) using the Global Precipitation Measurement Mission (GPM) to study rain, (vi) using EarthCARE to study clouds and, for atmospheric observations, (vii) lidar (laser radar) and (viii) sensors that operate at terahertz frequencies.

When you list these projects like this, it might seem that our research covers a very wide range of fields, but one thing they all have in common is the aim of creating safe and secure society.



*1: DPR=dual-frequency precipitation radar, *2: CPR=cloud profiling radar

Figure The Remote Sensing Laboratory's 8 projects in 3 research fields

Putting MP-PAWR to practical use at the Tokyo 2020 Olympics and Paralympic Games

— We noticed that MP-PAWR was mentioned in several recent media reports, including one on the development of the world's first practical implementation of the technology.

Nakagawa: There have been some terrible incidents. In 2008, flash flooding in the Toga River in Kobe swept away 16 people, including children. Five people died. In the same year, five workers drowned in the sewers below Toshima Ward, Tokyo due to a sudden increase in water levels caused by a localized heavy rain. Our research and development of PAWR and MP-

PAWR came about as a direct response to these tragedies.

In particular, MP-PAWR is aimed at the implementation of systems that can provide information by accurately capturing the signs and trends of capricious weather phenomena such as localized heavy rain and tornadoes. Our development efforts are being funded as part of the cross-ministerial Strategic Innovation Promotion (SIP) Program, which is promoting measures to implement resilient disaster prevention and mitigation measures including the sharing and use of real-time disaster information.

NICT is currently operating PAWR at three locations: Osaka University's Suita campus, NICT's Advanced ICT Research Institute (in Kobe), and NICT's Okinawa Electromagnetic Technology Center (in Onna Village, Okinawa), and we recently released a "3D Rain Watcher" app that provides this data to the public (http://pawr.life-ranger.jp/).

Unlike a radar with a parabolic antenna that has to be mechanically oriented to different elevation angles and azimuth angles, a phased array radar can perform high-speed stereoscopic observations by electronic scanning. We have developed a PAWR that takes about 30 seconds to obtain a stereoscopic view that would have taken at least 5 minutes to obtain using conventional radar. MP-PAWR can also capture incipient localized heavy rain. If localized heavy rain can be detected 20 or 30 minutes before it happens, it will be possible to respond more appropriately.

We set up a MP-PAWR system at Saitama University in November 2017 based on the cross-ministerial SIP program. We aim to have this system fully operational in time for the Tokyo Olympics and Paralympic Games in 2020, where it could provide the Organizing Committee, the Tokyo Metropolitan Government, and the Cabinet Office with useful information. For example, it could be used in the management of not only outdoor events but also indoor events where a sudden downpour is liable to cause congestion at the entrance to the venue.

From simple data provision to the extraction of information with added value

— Airborne synthetic aperture radar (Pi-SAR) seems to be another area in which you are benefiting society by, for example, publishing data on the acquisition of disaster information.

Nakagawa: We're using Pi-SAR to obtain radar images with a large simulated aperture (radar dish diameter) by mounting it on a moving body. At the microwave frequencies we're using, clouds and smoke are transparent. This means our system can examine the craters of active volcanoes without having to wait for clear weather. NICT developed a Pi-SAR system with a resolution of 1.5 m, which went into operation in 1998. And since 2008, we have been operating a Pi-SAR2 system with an improved resolution of 30 cm.

As I mentioned earlier, since this technology allows us to observe wide areas of terrain without being affected by the weather, it is also suitable for seeing how the terrain changes at particular points in time. We are also operating a system that can retrieve and distribute observation data obtained from areas affected by events including the 2011 Great East Japan earthquake, the 2014 eruption of Mount Ontake, and the Kumamoto earthquakes of 2016.

In FY 2018, we hope to complete our Pi-SAR X3 system, with an even better resolution of just 15 cm. At the same time, we are advancing the research and development of methods for extracting information from observation data, such as the condition and elevation of terrain. We are also looking at how to extract information with added value. For example, in the event of a landslide, we don't just want to be able to confirm where a landslide has happened, but we also hope to be able to estimate the amount of soil that moved.

— This seems like the sort of research that will have direct benefits in terms of the safety and security of ordinary people.

Nakagawa: Well, yes. You could say that is our ultimate goal. I think we've already partly reached our goal of researching and developing new equipment, and in the future, I'm hoping we can concentrate more on making available the data we obtain through our research and development and finding ways for the data to be used more effectively.

Of course, since these eight projects are still at different R&D phases, I don't think they're directly benefiting society just yet. But having said that, we have already produced systems with a certain degree of functionality, and I'm hoping we will be able to guide them to the point where they can be made available to specialist users.

In fact, unlike most people at NICT, my background is in civil engineering. So I've already spent time working with data relating to disaster prevention and the like. From this point of view, I hope to actively promote links with external organizations in the future.

Development of a Next-generation Wind Profiler Radar (WPR) for Resolving Fine-scale Turbulence Structure and Wind Perturbations

Masayuki YAMAMOTO
Senior Researcher, Remote Sensing Laboratory, Applied Electromagnetic 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).

Seiji KAWAMURA
Senior Researcher, Remote Sensing Laboratory, Applied Electromagnetic 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).

Fine-scale monitoring and prediction of weather condition is indispensable for the prevention and reduction of natural disasters. It also contributes to the operation of social infrastructure such as electric power, river management, and transportation. In this project, we have been developing a next-generation 1.3 GHz wind profiler radar (WPR) that is capable of resolving fine-scale turbulence and wind perturbations. Measurement capability required for next-generation WPR is attained by using range imaging (RIM) and adaptive clutter suppression (ACS). RIM and ACS are techniques used for improving height resolution and the quality of measurement data, respectively. By implementing RIM and ACS capabilities in existing WPRs, the installation cost of next-generation WPR can be reduced. This cost reduction increases the likelihood that next-generation WPRs will be widely used as a means of measuring fine-scale turbulence and wind profiles.

Background

By receiving echoes scattered by radio refractive index irregularities (clear-air echo), a wind profiler radar (WPR) measures the height profile of vertical and horizontal wind velocities in the clear air. For fine-scale monitoring and prediction of weather condition, wind profiles must be measured with high resolution and accuracy. However, the height resolution of conventional WPRs is insufficient for resolving fine-scale turbulence and wind perturbations. Furthermore, the quality of wind products obtained by WPR often degrades owing to contamination by undesired echoes from scatterers such as trees, vehicles, aircraft, birds, and so on. Such undesired echoes are referred to as clutter.

New technology in next-generation WPR

In order to attain the measurement capability required for next-generation WPR, we have been developing RIM and ACS. Figure 1 shows an overview of RIM and ACS. In RIM, received signals from multiple frequencies are collected by varying the transmitted frequency from pulse to pulse. In the signal processing, range subgates are set with an interval smaller than that of range gates in conventional WPRs. At each height (subgate), the weighted sum of the received signals is computed so that the power of the synthesized signal is minimized with the constraint of constant gain at the target subgate. This computation method, which is referred to as direction-constrained minimization of power (DCMP), enhances the range resolution because it can suppress echoes at undesired heights.

In ACS, received signals from multiple antennas (subarrays) are collected. In the signal processing, the weighted sum of received signals at each range gate is computed so that

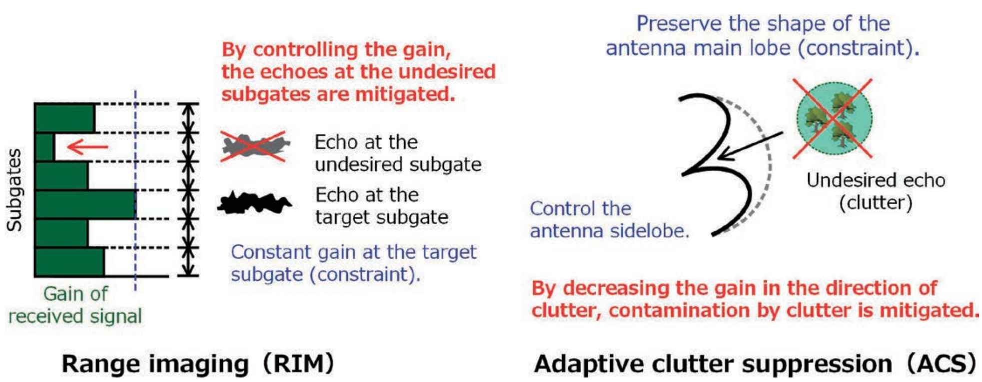


Figure 1　Overview of range imaging (RIM) and adaptive clutter suppression (ACS)

the power of the synthesized signal is minimized with the constraint that the shape of the antenna main lobe is preserved. This computation method, which is referred to as norm-constrained DCMP, reduces clutter contamination because clutter from antenna sidelobes can be suppressed.

In the signal processing of RIM and ACS, the weighting of input signals is adaptively computed according to their characteristics. Such signal processing is referred to as adaptive signal processing.

Multi-channel receiver system using software-defined radio technique

Reducing the installation cost of next-generation WPR increases the likelihood that next-generation WPRs will be widely used as a means of measuring fine-scale turbulence and wind profiles. We therefore aim to implement RIM and ACS capabilities in existing WPRs. LQ-13, a WPR operated by NICT, has been utilized as a platform for developing techniques of next-generation WPR.

The original receiver and signal processing unit of LQ-13 does not have functions for oversampling (OS) and multi-channel reception. OS enhances the measurement performance of RIM. Multi-channel reception using subarrays is indispensable for ACS. Figure 2 shows an overview of a multi-channel receiver system developed by NICT. The receiver system was developed for implementing OS and multi-channel reception capabilities in LQ-13. Digital signal processing is performed by signal samplers for software-defined radio and a general-purpose workstation. By utilizing software-defined radio techniques, the functions of the multi-channel receiver system can easily be changed and improved.

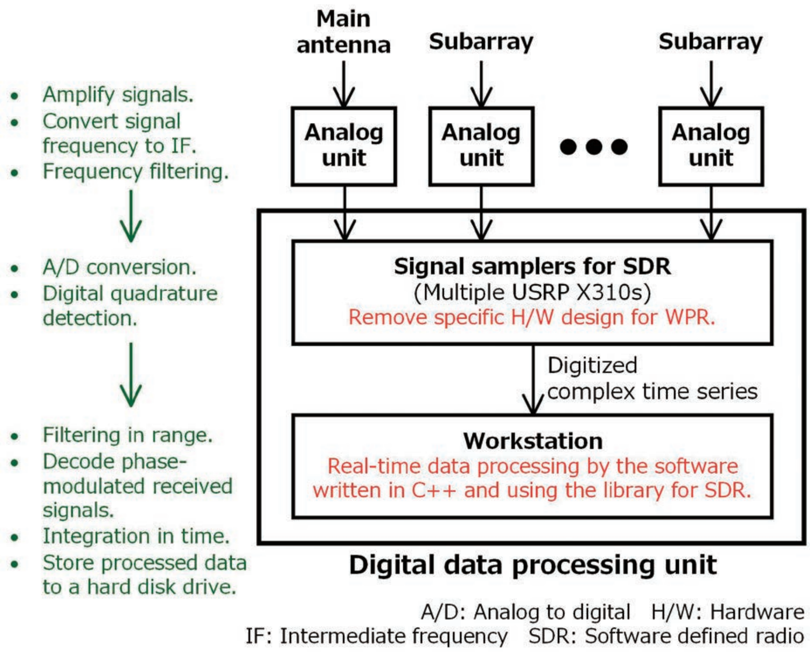


Figure 2 Overview of a multi-channel receiver system developed by NICT

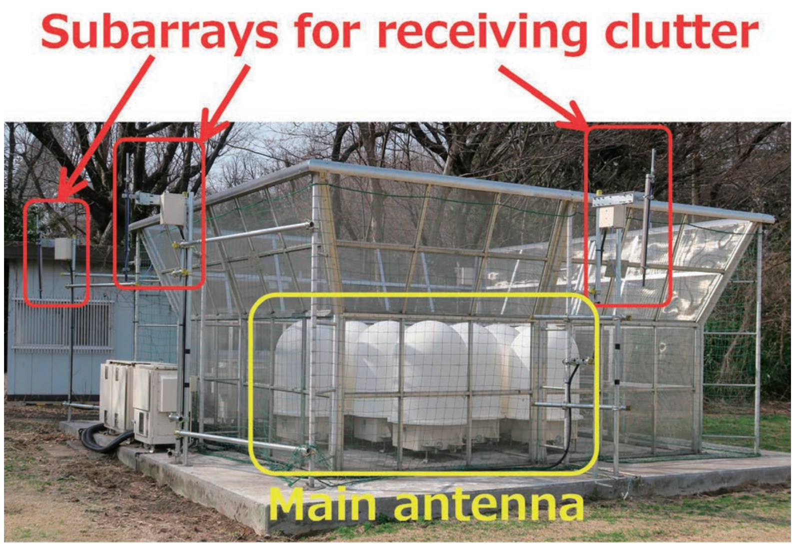


Figure 3 The ACS system installed at LQ-13

Future prospects

Owing to developments made so far, we have implemented RIM and OS capabilities in LQ-13. We have also developed an ACS system, which works as an additional subsystem of an existing WPR. The system implements ACS capability in an existing WPR by installing auxiliary subarrays around the main antenna (see Figure 3). The auxiliary subarrays are used for receiving clutter.

From now on, we will continue to develop technology for next-generation WPR to enhance its measurement performance. We will also study how next-generation WPR can be used in practical applications. High-resolution wind and turbulence measurements made using RIM and OS can contribute to aviation safety by detecting the onset of turbulence. They also contribute to the detection of deep cumulus convection from an early development stage. Since clutter can originate from a wide variety of sources, its characteristics vary widely depending on the WPR location and weather conditions. We will continue to work towards realizing an ACS system that can mitigate clutter effectively under various environments.

A Study on Processing Algorithm for Satellite-borne Cloud Profiling Radar

Development of ground-based electronic scanning cloud profiling radar for the validation of EarthCARE/CPR

Hiroaki HORIE
Senior Researcher, Remote Sensing Laboratory, Applied Electromagnetic Research Institute

Joined the Communications Research Laboratory (currently NICT) in 1990 after completing a master's course at university. He is engaged in the research of radar remote sensing for environmental measurements.

Extreme weather events caused by global warming have been observed recently, and a major uncertainty in global warming predictions is impact estimation of interaction between clouds and aerosols. For accurate predictions, we need information from satellite observations of clouds and aerosols on a global scale. For this purpose, NICT is collaborating with the Japan Aerospace Exploration Agency (JAXA) to develop a CPR (Cloud Profiling Radar) for the EarthCARE (Earth Clouds, Aerosols and Radiation Explorer) satellite. The EarthCARE is joint mission between Europe and Japan, and its satellite will mount three other sensors. It will be launched by the European Space Agency (ESA) in FY2019.

Background

EarthCARE/CPR is four times as sensitive as the CPR mounted on the NASA's CloudSat satellite, which was launched in 2006. It will be able to observe 98% of the cirrus ice clouds, which affect the global radiation budget (i.e., the difference between the radiation that Earth receives from the sun and the heat it radiates back out into space), and will also be able to observe stratocumulus water clouds. It is also the first satellite-borne weather radar with a Doppler velocity measurement function in order to obtain the vertical velocity of cloud particles (Figure 1). This vertical velocity information allows it to distinguish between clouds and drizzle, so it is expected to improve the processing algorithms used to obtain physical quantities such as the liquid water content of clouds.

To improve the measurement accuracy of a satellite-borne radar, it is important to perform validation with a ground-based radar. This involves not only making a direct comparison of observations of the same areas by satellite-borne and ground-based radar systems after the satellite has been launched, but also acquiring observation data to confirm the validity of the processing algorithms before the satellite is launched. This article introduces an electronic scanning cloud profiling radar for ground-based validation called ES-SPIDER (Electronic Scanning SPIDER <Super Polarimetric Ice-crystal Detection and Explication Radar>) that we are developing in order to observe the horizontal non-uniformity of clouds within the antenna illumination area of EarthCARE/CPR .

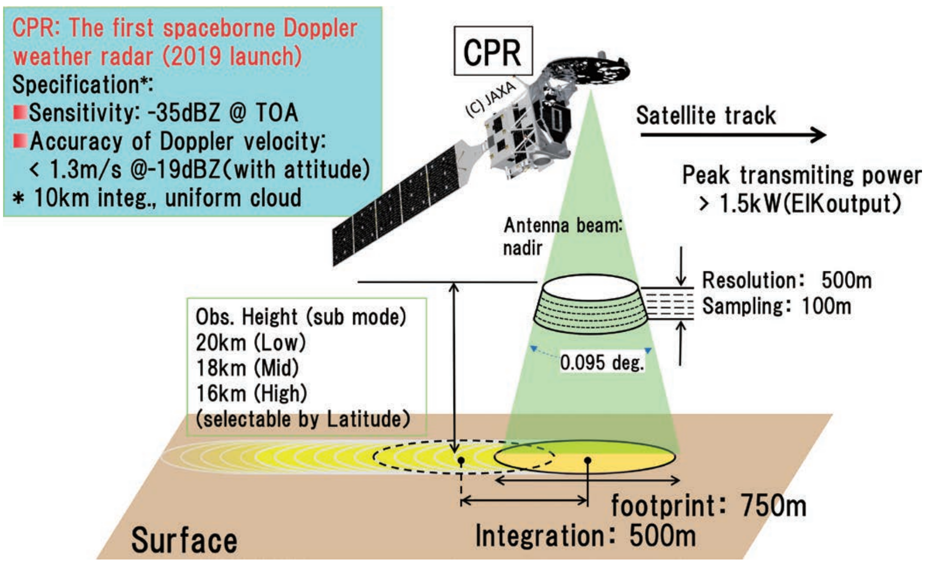


Figure 1 Concept of EarthCARE/CPR

Figure 2 High Sensitivity Ground based Cloud Profiling Radar (HG-SPIDER) Antenna and transmitter
Sensitivity: -40dBZ(@ Integ. 1 second, height 15km)

Figure 3 Electronical Scanning Cloud Profiling Radar (ES-SPIDER)
far: horn antenna array and receiving system
near: transmitting fan beam antenna
below: signal combiner
Scanning angle: +/-4.5 degrees.
Sensitivity: -27dBZ (@Integ. 1 second, center of scanning angle)

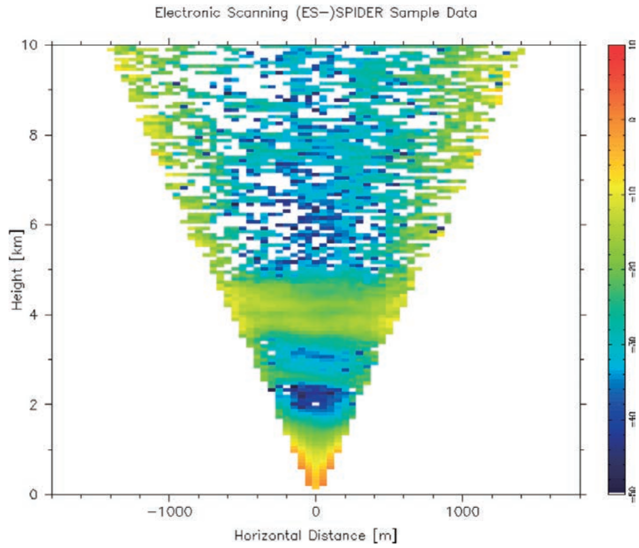


Figure 4 Test results for electronical scanning cloud profiling radar
Sequential scanning method using phase shifter. Data acquisition time : about 7 seconds (Integ. 0.1 second by 64 angle bins), Horizontal: range ±1500m, Vertical: range 0 to 10km Color: Blue to Red (higher reflectivity), Currently, Digital beam foaming method to obtain various antenna beam by calculation is under development. After completed, it will take only 0.1 second for the above figure.

About cloud profiling radar

In general, the purpose of a precipitation radar (commonly known as a weather radar) is to determine the amount of rainfall. However, a CPR derives physical quantities such as the liquid water content and ice content of clouds, and directly measures the radar scattering cross section of cloud particles per unit volume (1 m^3). These measurements are converted into a parameter called the Z factor (or radar scattering coefficient), which is proportional to the sixth power of the diameter of raindrops and cloud particles. Since this parameter has a large dynamic range (the ratio of the largest and smallest values), it is normally expressed using decibel notation (dBZ). For example, suppose one raindrop with a diameter of 1 mm per unit volume corresponds to a Z factor of 1 (0 dBZ). The Z factor of the same unit volume containing a thousand cloud particles with a diameter of 0.1 mm would be 0.001 (−30 dBZ), so the sensitivity has to be improved by using short-wavelength radio waves called millimeter waves. It is also necessary to use a processing algorithm in which the Z factor is converted into a quantity proportional to the third power of the diameter of particles such as the liquid water content of clouds.

NICT started cloud observations with CPR (SPIDER) in 1998 and it was Japan's first radar to use millimeter waves in the 94 GHz band, which is 10–20 times higher than the frequencies used by ordinary weather radars. Thus, based on our experience of CPR, we developed a ground-based CPR called HG-SPIDER (High-sensitivity Ground based SPIDER), which has enough sensitivity for the validation of EarthCARE/CPR (Figure 2).

Electronic scanning cloud radar (ES-SPIDER)

As mentioned above, EarthCARE/CPR is the first satellite-borne radar to include a Doppler velocity measurement function. One of the reasons why it has been difficult to introduce this technology for satellites in the past is because the contributions of the satellite's orbital velocity are non-negligible compared with the vertical velocity of the particles, even if the antenna beam width is narrow. It has also been pointed out that horizontal non-uniformity of clouds along the track direction of the satellite causes measurement errors that are weighted by strong scattering. To develop a processing algorithm that reduces this error, we need to perform ground-based CPR measurements of the horizontal non-uniformity of clouds. Also, considering the length of the integration time, it is more effective to use a phased array antenna with electronic scanning (where the beam can be switched instantaneously) instead of mechanical antenna scanning.

Normally, the distance between antenna elements should be less than one wavelength, but the wavelength is about 3 mm in this frequency band. Arranging the elements of the phased array antenna with a separation of less than one wavelength over the antenna aperture of approximately 30 cm would make it difficult in terms of both realistic cost and physical implementation, and to achieve a sufficient antenna gain, in addition. We therefore selected one-dimensional scanning and limited the scanning range to ±4.5°, which can be covered with an antenna beam diameter of approximately 750 m at an altitude of 5 km for the EarthCARE/CPR, and instead of a large number of antenna elements, we selected a more practical horn antenna array with 8×32 elements. To resolve technical problems, a receiver module is located directly under each antenna to convert the millimeter-wave band to an intermediate frequency band before performing received signal synthesis. Electronic scanning is only applied to the receiver, and the transmmiter has a fixed wide fan beam anttena in the scanning direction.

Although our prototype system uses a phase shifter to perform sequential scanning of the antenna beam, it is the first electronic scanning cloud profiling radar operating in the 94 GHz band (Figures 3, 4).

We are currently developing a digital receiver to perform digital beam forming (DBF), which obtains multiple antenna beams simultaneously by performing calculations based on the received signal from each antenna. After the digital beam forming (DBF) system has been introduced, it should have enough sensitivity for Doppler velocity measurements in EarthCARE/CPR.

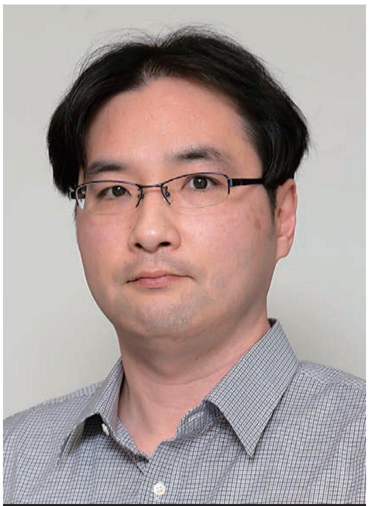
Future prospects

The CPR for ground-based validation introduced in this article is considered to obtain useful observation data for the research and development of processing algorithms prior to the launch of the satellite as well as for satellite validation.

Plans have been proposed for the next generation of satellite observations, including NASA's mission that will measure rain and clouds by mounted precipitation radar and CPR. For ground-based radar, it is expected that excessive precipitation can be predicted from the state of clouds before it has started raining. We are also focusing on the development of the next generation of CPR for such applications.

Measuring Elevation Height with a Synthetic Aperture Radar

From relative to absolute measurements



Jyunpei UEMOTO
Senior Researcher, Remote Sensing Laboratory, Applied Electromagnetic Research Institute

Joined NICT in 2008 after completing a doctoral course at university. He is engaged in researches on aeronomy and remote sensing data analysis. Ph.D. (Science).

NICT has developed the Pi-SAR (Polarimetric and Interferometric Synthetic Aperture Radar) series of the airborne SAR instrument and new techniques to analyze data. An airborne SAR can measure various quantities such as the polarimetry characteristics of the target, texture information, height, and movement. This article introduces a method for measuring one of these quantities (height) and presents some results obtained in an actual analysis.

Measuring height with SAR Interferometric SAR:

Airborne SAR is a type of radar that observes the earth's surface by transmitting radio waves and processing returned signals. Unlike aerial photography, SAR can perform observations at any time of day or night due to its transmitting ability. Furthermore, by using radio signals at frequencies that have high atmospheric transmissivity, it is possible to observe the ground even when targets are veiled by clouds or smoke. Owing to these features, the Pi-SAR series have contributed for the rapid assessment of damage caused by natural disasters such as volcanic eruptions, earthquakes, tsunamis, and landslides.

Since SAR identifies the position of a target based on measurements of the round-trip time of the transmitted signal, the quantities obtained by a single antenna are basically only polarimetry characteristics and texture information. However, when two receiving antennas are used, it is possible to measure the difference of distance from the target to each antenna and thereby calculate its height (Figure 1). Figure 2 shows a schematic illustration of how the difference of distance appears in the received signal. The position of a wave (peaks and valleys) is represented by its phase, which differs in the signals received by the two antennas due to the difference of their positions. In this figure, there is a phase difference of 3.5 peaks and valleys. The phase difference is extracted by combining the signal data from the two antennas. This processing is called the interferometric SAR (InSAR).

Relative and absolute heights

As an actual observation example, Figure 3 shows the texture image (left) and the result of InSAR processing (right) performed for the Sakurajima volcano in Kagoshima Prefecture. The phase differences represented by rainbow colors look like contour lines. We can see that they clearly relate to the height of targets, however, we need further processing to extract the absolute height of targets.

The phase difference in the received signals shown in Figure 2 corresponds to 3.5 valleys and troughs, but in practice the phase difference

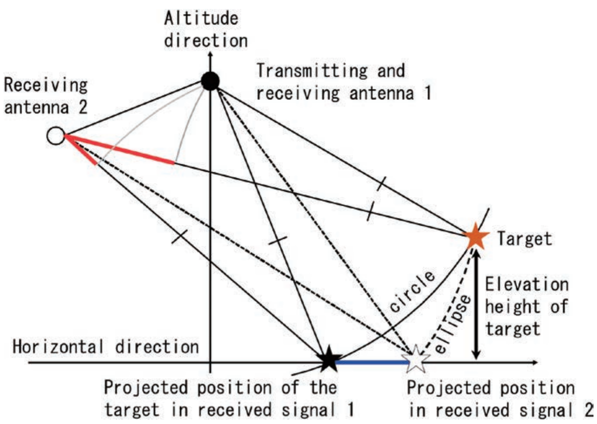


Figure 1 Schematic image of SAR observation using two antennas. If we have only one antenna, we cannot distinguish the target positions of ★ and ★ because the roundtrip times are same. By adding one more antenna, we observe the difference of paths (red lines) for each target. Therefore, the elevation height of target can be measured utilizing the path difference. The blue line corresponds to the disparity utilized in the stereo radargrammetry.

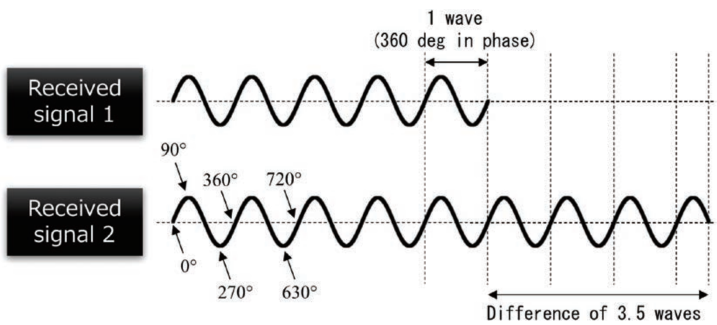


Figure 2 Schematic image of the effect of path difference in received signals. Degrees in the figure correspond to the phase.

that can be extracted by the InSAR processing is only a fractional part, which means we cannot extract the absolute number of multiple peaks and valleys. Therefore, same phase differences (same colors) can correspond to different heights in Figure 3. For example, the position indicated by the upper arrow in Figure 3 is nearer to the top of mountain than that indicated by the lower arrow. The upper arrow position is higher, but these two positions have the same phase difference (the same color). To measure the height of target, we must derive the absolute number of peaks and valleys hidden in the interferometric phase differences. Furthermore, we still don't know the relationship between height and phase difference (i.e., what height in meters corresponds to what color). In other words, we can measure the shape of the mountain, but not its absolute height in meters. The interferometric phase differences only provide information about relative height differences, but not absolute heights. Normally, this problem is solved by tying the phase difference to the absolute height at one or more reference points whose height has been given by other means.

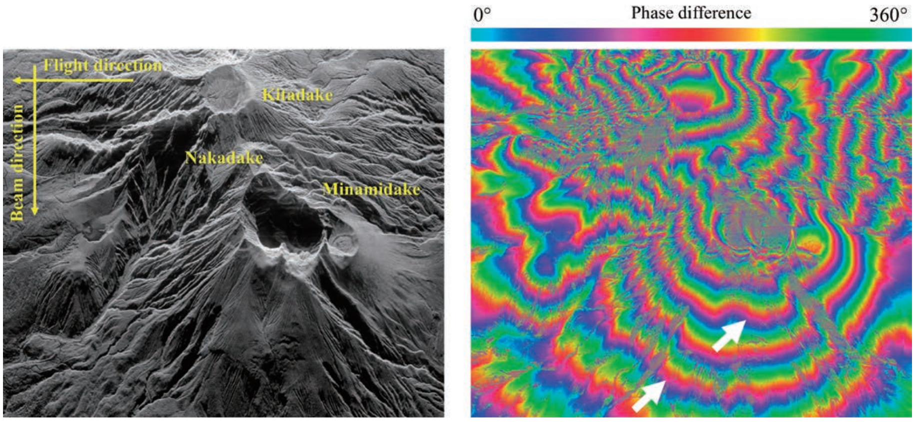


Figure 3 Texture (left) and interferometric SAR (right) images of Mt. Sakurajima. Phase differences are drawn with the rainbow color in the right image.

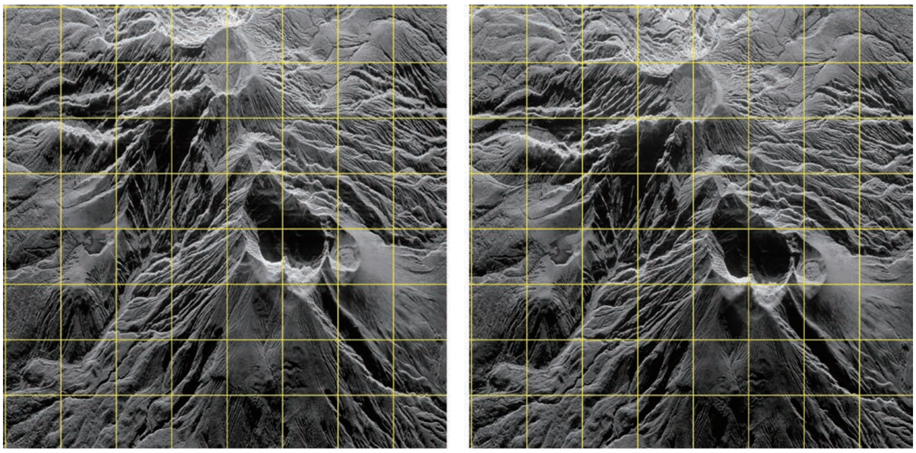


Figure 4 Two texture images obtained at the different flight paths whose distance in the cross-track direction is approximately 1.5 km. It can be recognized that disparities in the vertical direction between two images are related to the target elevation height.

Another height measurement method Stereo radargrammetry:

As mentioned above, we can use reference points to obtain the absolute height. However, the reference data are not always available. Is it impossible to measure the absolute height without using any external reference data? The answer is no. There is another way of measuring absolute heights by processing SAR data. This is a method called the stereo radargrammetry. In Figure 1, we saw how InSAR converts the difference of distance between two antennas shown as the red lines to the phase difference. Actually, there is another difference between the data obtained by the two antennas. This is shown by the blue line. The SAR observation results are displayed as 2D image data whose vertical and horizontal axes correspond to the signal transmission direction and the flight direction, respectively. The vertical position in the image is determined by the round-trip time of the signal. However, the round-trip times at each antenna can differ even for the same target position since the two antennas are located at different positions. This gives rise to a height-dependent disparity in the images received by the two antennas. In the stereo radargrammetry, the height of target is measured based on the disparity from the two antennas. Unlike the InSAR processing, this disparity has no ambiguities such as the number of peaks and valleys in the phase difference and therefore the stereo radargrammetry can measure absolute heights.

Figure 4 is a texture image of Sakurajima which was obtained by two adjacent flight trajectories. The distance between trajectories is approximately 1.5 km. As you can see, there is a greater disparity at higher regions around the rim of the crater than at lower regions around the base of the volcano. That is, the degree of disparity is related to height.

Future prospects

For accurate height measurements by the stereo radargrammetry, we must measure accurately the amount of disparity between the images received by the two antennas. This is a subject we have worked on for several years together with the Aoki Laboratory at the Graduate School of Information Science of Tohoku University. We have already verified that the algorithm we have developed can extract the absolute height of targets from disparities in Pi-SAR2 data. We have submitted a patent application for a part of this algorithm (Kokai number (2016) 57092). If we can perform absolute measurements, we will be able to use SAR data to obtain three-dimensional data on building developments and disaster-affected areas even when, for example, the topology changes over a wide area so that it is not possible to use external sources of reference data.

As mentioned above, the stereo radargrammetry can measure absolute height. However, accurate disparity measurements result in poorer spatial resolution than the InSAR processing. In the future, we plan to develop a height measurement algorithm that exploits the benefits of both methods.

Earth Observation with Terahertz Waves

Technology for satellite observation of temperatures and winds in the middle and upper atmosphere

Satoshi OCHIAI
Chief Senior Researcher, Remote Sensing Laboratory, Applied Electromagnetic Research Institute
Joined the Radio Research Laboratory (currently NICT) in 1988 after completing a master's course at university. He is engaged in the research of millimeter and submillimeter remote sensing technology. Ph.D. (Engineering).

Yoshihisa IRIMAJIRI
Senior Researcher, Remote Sensing Laboratory, Applied Electromagnetic Research Institute
After finishing at graduate school, he carried out research for the Nobeyama Solar Radio Observatory at the National Astronomical Observatory of Japan before joining the Communications Research Laboratory (currently NICT) in 1993. His research interests include terahertz wave receiver systems. Ph.D. (Science).

Unlike visible light, the appearance of the Earth from outer space as seen with terahertz waves shows little contrast between day and night. Terahertz waves, which lie at the lower-frequency end of the far infrared spectral region, are emitted from the Earth at a rate corresponding to the atmospheric temperature. When imaged at these frequencies, the Earth looks misty and its appearance bears little relation to the direction of sunlight. Terahertz waves are strongly absorbed in the atmosphere, especially by water vapor, and cannot penetrate the troposphere (the layer of the Earth's atmosphere between the ground and the stratosphere). Therefore, they cannot reach the Earth's surface from space except in a few atmospheric frequency windows. Although they are unsuitable for ground observations, they can be used to observe cirrus clouds which exist in the upper troposphere. In the terahertz spectrum, it is possible to see details in the middle and upper atmospheres that are inaccessible by other methods.

Appearance of the atmosphere at terahertz wavelengths

If the limb of the earth is viewed using a terahertz telescope with sufficient resolution, it is possible to observe various features outside of the troposphere. Oxygen and ozone have many emission lines (unique electromagnetic radiation frequencies corresponding to molecular structure) in the terahertz band. At atmospheric temperatures, the emissions of these molecules can be distinctly detected against the cold background radiation of space. Strong emission lines from ozone can be seen in the limb layer corresponding to stratospheric altitudes, and in layers situated even further out, it is still possible to detect emission lines from oxygen. At an altitude of about 100 km from the Earth's surface, the concentration of oxygen molecules decreases while the proportion of dissociated atomic oxygen increases, resulting in increased intensity of the 2.06 THz emission line from atomic oxygen. By measuring the radiation of terahertz waves, we can not only find out the concentration of these substances, but also their temperatures. Furthermore, by examining Doppler shifts in the frequencies of these emission lines, we can also find out how fast these substances are moving. In other words, it is possible to measure wind speeds.

Observations with terahertz waves are useful because by selecting the right frequency, it is possible to find some atmospheric constituents that emit radiation at any altitude ranging from the tropopause (approx. 15 km) to over 150 km, and because these observations can be performed with roughly the same precision at any time of day or night. If measurements can be made over the whole atmosphere above the tropopause, they will bring new insights into the vertical coupling of atmospheric layers including the ionosphere and can be expected to contribute to improving the accuracy of medium-term weather forecasts and climate change

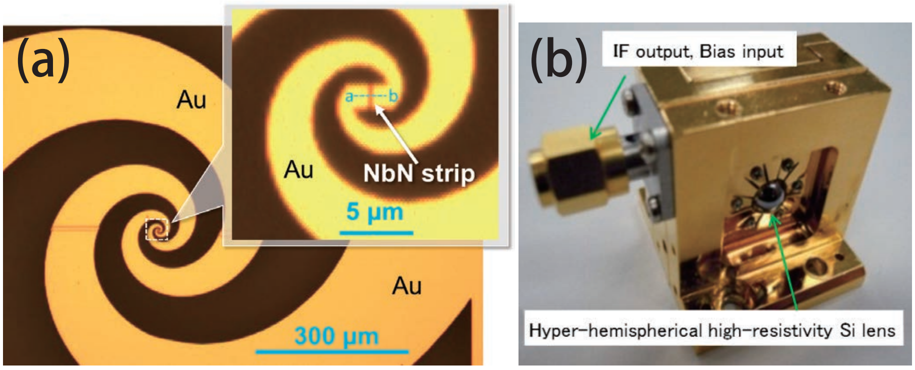


Figure 1 (a) Superconducting device and (b) Quasi-optical mixer mount for an HEB mixer

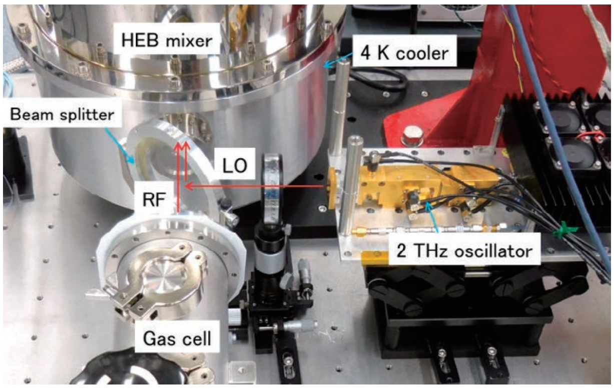


Figure 2 Measurement setup of molecular spectrum using a gas cell and a heterodyne receiver in the 2 THz band

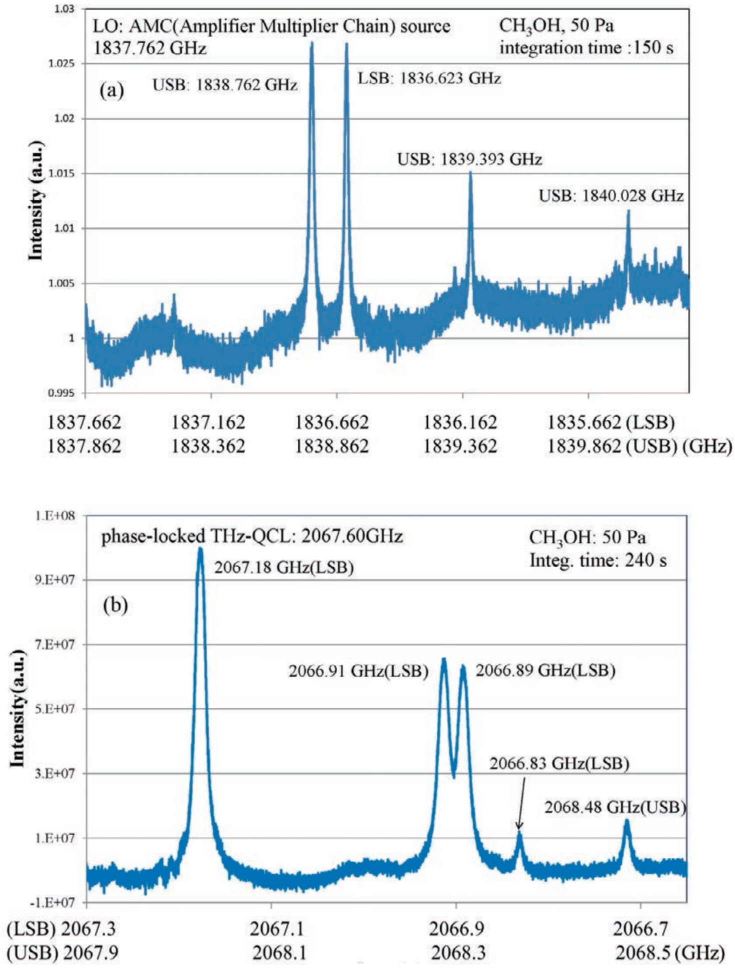


Figure 3 Detected emission line spectra of methanol in the (a) 1.83 THz and (b) 2.06 THz bands

predictions.

In collaboration with researchers from universities and other research institutes, NICT is studying the concept of a satellite to observe the Earth's atmosphere with terahertz waves, such as the 640 GHz band where dense ozone emission lines are observed, and at the 2.06 THz emission line of atomic oxygen. In 2009, in cooperation with JAXA, we performed observations of the ozone layer and other atmospheric layers in the 640 GHz band from the International Space Station. We are now working on technology that operates in the 2 THz band in order to perform observations of the whole atmosphere including the ozone layer and the upper atmosphere.

Detecting the spectra of weak terahertz waves radiated from molecules in Earth's atmosphere

We developed a heterodyne receiver to detect weak terahertz waves radiated from molecules in Earth's atmosphere. This receiver works by using a frequency mixer to combine the RF signals received from atmospheric molecules with a terahertz signal of roughly the same frequency generated by a local oscillator (LO). This converts the signal to an intermediate frequency (IF) signal in the gigahertz band, which can be amplified and used to detect the spectrum. Although this is an ordinary and widely used method, it is seldom used in the THz band. The keys to this technique are the low-noise mixer and high-power local oscillator.

Using superconductivity to build a highly sensitive receiver from the level of discrete devices

A receiver with higher sensitivity can obtain signals of better quality in a shorter time. We are developing a superconducting high-sensitivity receiver from the device level up. A hot electron bolometer (HEB) mixer is the most sensitive form of spectral detector for the terahertz band (especially above 1.5 THz). Figure 1(a) shows a photograph of a device fabricated in the clean room at the Advanced ICT Research Institute (Kobe), and Figure 1(b) shows a quasi-optical mixer mount incorporating this device that was made at the Remote Sensing Laboratory. At the center of the device there is a superconducting thin film of NbN (niobium nitride) (size about 2 µm × 0.2 µm, thickness about 3 nm). This device has a response speed of the order of gigahertz and is thus able to detect the phase and amplitude of the IF signal. The device has a logarithmic spiral antenna with a wide bandwidth, which is attached to a super-hemispherical high-resistance silicon lens with an antireflective coating to form a quasi-optical mixer.

Successful detection of molecular radio spectra in the 2 THz band

We used this mixer to build a heterodyne receiver, which we used to detect the spectra of electromagnetic waves emitted from molecules in the 2 THz band (Figure 2).

The mixer is mounted inside a cryostat that cools it to 4 K so that it can operate in a superconducting state. For the local oscillator, we used a device that multiplies the frequency of a microwave signal by 144 to produce an output frequency of 2 THz. This signal is introduced to the mixer by a beam splitter, and in experiments using a gas cell, we were able to detect terahertz waves from methanol molecules (Figure 3).

Future prospects

In the future, we hope to make further improvements to the performance of the receiver. Also, since we have successfully tested the receiver at frequency bands above 2 THz (3–4 THz), we aim to make this technology available for new forms of earth observation in the future.

Optical Remote Sensing Technology for the Observation of Tiny Invisible Particles

Shoken ISHII

Senior Researcher, Remote Sensing Laboratory, Applied Electromagnetic Research Institute

Joined NEC in 1994, then entered the Communication Research Laboratory (currently NICT) as a chief researcher in 2000. In 2014, he worked as a visiting researcher at NASA. He is engaged in the research and development of optical remote sensing technology and fundamental optical technology. Ph.D. (Science).

The air around us contains tiny particles that are too small to be seen with the naked eye. These particles are called "aerosols," and are produced by the oceans, soil, and human activities. They are so light that they can be carried from place to place by the wind. This article introduces remote sensing technology that makes it possible to view these tiny particles.

Background

Aerosols are known to affect climate systems through the Earth's radiation budget. They can scatter or absorb sunlight and can therefore have warming or cooling effects. These effects are called direct effects. Aerosols can also act as seeds for cloud formation. They are deeply involved in the formation and life cycle of clouds, and through the microphysical processes of evaporation and condensation, they affect the Earth's radiation budget by changing the radiation characteristics of clouds. These effects are called indirect effects. Also, since chemical changes can take place when aerosol particles interact with one another or with the atmosphere, their chemical composition is also important. To qualitatively and quantitatively evaluate the impact of aerosols on climate change, it is necessary to gather information about their optical properties (complex refractive index, hygroscopicity), chemical properties (composition, state of mixing), and microphysical properties (particle shape, particle size distribution, number density).

Recently, so-called "PM2.5" aerosols have received a lot of media attention. These are particulate substances with a size of 2.5 µm or less, including dust particles and soot particles created by human activity, as well as naturally occurring dust clouds. Since these particles are so small, they are easily inhaled into the trachea and lungs, where they can cause health problems. In early spring and autumn when Japan is found to lie in the path of a desert dust cloud from the Asian continent, it has been reported that the risk of hospital admissions due to cases of childhood asthma increases within a week, and that the risk of admissions still increases even when the concentration of dust particles is below the environmental reference value. The observation of aerosols as continuous spatio-temporal data has thus become very important at many levels ranging from the health of individuals to the health of the global environment. The observation of wind patterns is one of the keys to predicting when aerosols will arrive, where they will come from, and where they will go next (Figure 1).

NICT's observation technology: Lidar (light detection and ranging)

Remote sensing technology is used to mea-

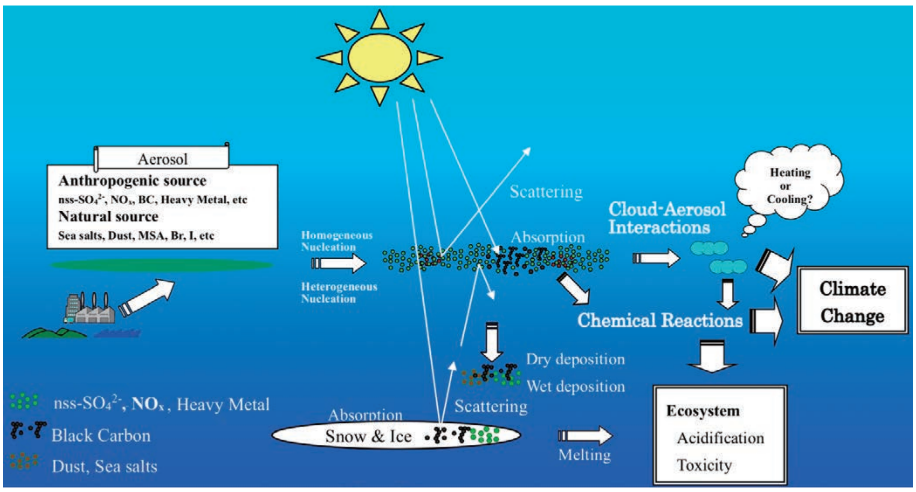


Figure 1 Schematic of roles of aerosol

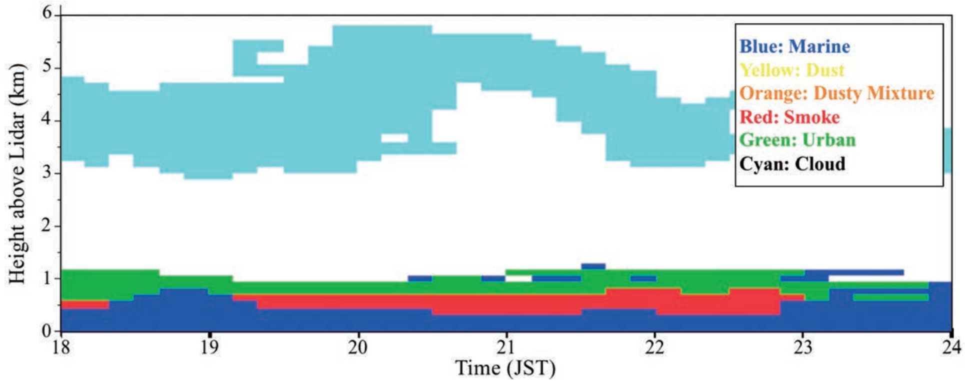


Figure 2 Aerosol typing observed by a multi-wavelength Lidar installed at Fukuoka University on December 2, 2017: marine (blue), dust (yellow), dusty mixture (orange), urban (green), and cloud (cyan)

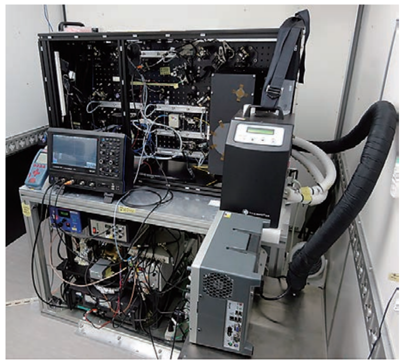


Figure 3 Newly-developed 2-μm Doppler Wind Lidar (DWL) for ground-based and airborne wind measurements

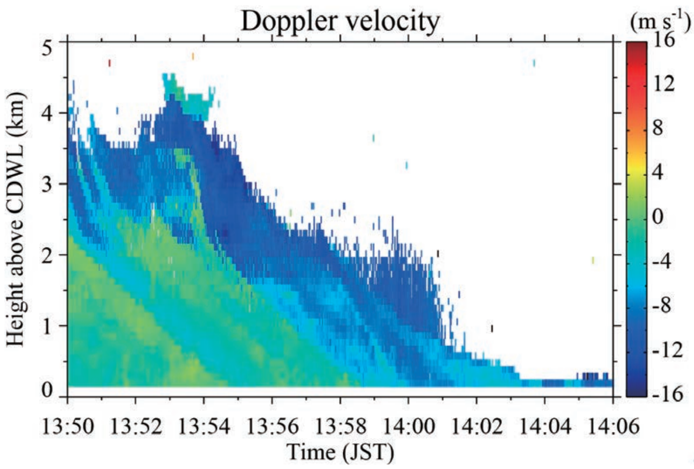


Figure 4 Falling speed of hail observed by a newly-developed 2-μm DWL at NICT Headquarters on July 18, 2017

sure information remotely in order to gather information about a target object without coming into direct contact with it. It can be broadly classified into active techniques that use a source of electromagnetic waves, and passive techniques that rely on external sources. NICT is developing a Lidar, which is a form of active sensor that uses laser light as its source of electromagnetic waves.

・**Aerosol Lidar**

The properties of the laser light used for Lidars include excellent temporal and spatial coherence, good monochromaticity, and sharp directivity. Continuous wave lasers are sometimes used, but most Lidars use pulsed lasers. The use of a pulse laser makes it possible to measure distances with very high precision, and Lidar is able to observe the distribution of aerosols with high range resolution. When laser light encounters molecules or aerosols in the air, it interacts with them (e.g., Mie scattering, anisotropic scattering) and is reflected. This reflected light yields information about physical quantities such as the optical and microphysical properties of aerosols. At NICT, we have also found a way to retrieve chemical compositions based on the optical properties obtained in this way, which is useful for atmospheric research (Figure 2).

・**Doppler Wind Lidar**

One of the interactions mentioned above is the Doppler effect. The frequency of laser light emitted from a Lidar is changed due to the Doppler effect when the light is reflected by atmospheric molecules or aerosols. By measuring the change in frequency, it is possible to determine the velocity of the interacting particles. The World Meteorological Organization has stressed the importance of sensors that can obtain global information on the vertical distribution of winds for numerical forecasting. NICT has independently developed a wind Lidar that can be used not only for numerical forecasting research but also for predicting local weather phenomena with greater precision and for meso-scale (2–2,000 km) climate studies (Figure 3).

To avoid the risk of damaging people's eyesight, our wind Lidar uses a laser with a wavelength of 2 μm, and we are developing the following two types of laser:

Low pulse energy:

This type has a slightly faster repetition frequency.

High pulse energy:

Has a lower repetition frequency.

The former is mainly used for observations on the ground, while the latter can be used for observations from the ground, from aircraft, and from satellites.

Lidars for ground-based measurements have a two-axis scanning system and can observe winds in three dimensions by changing their azimuth and elevation. Figure 4 shows the results of observations made during a hailstorm at NICT's headquarters in Koganei, Tokyo. Blue colors represent motion towards the ground. It is possible to see that hailstones were falling at speeds of 10–15 m/s from altitudes of 2–4 km above the region of background winds (shown in a neutral color).

Future prospects

NICT is developing a wind Lidar that can be used not only for ground-based observations but can also be mounted on aircraft. By mounting this Lidar on an aircraft and observing air flows around typhoons and the motion of weather fronts accompanied by rainfall, we hope it will be useful for forecasting heavy rainfall, cloudbursts, and typhoons with greater precision, and for meso-scale climate studies. We also plan to launch a Lidar into space on board a satellite to observe the distribution of winds and aerosols around the world, which should improve the accuracy of numerical forecasting and predictions of climate change due to global warming.

A Lidar is an active sensor that is able to perform measurements with excellent range and temporal resolutions. However, it lacks the ability of passive sensors to acquire data over a wide area. To address this shortcoming, we are working on the development of new Lidar technology including multi-element photodetectors and phased array detectors.

Recently, other technologies such as artificial intelligence (AI) and IoT have also been used in the remote sensing field. We will work on using Lidar to improve the accuracy of altitude information (vertical direction) and data obtained from satellites and multiple ground-based sensors (horizontal direction), and to improve the accuracy of air quality forecasts and data assimilation technology that combines IoT data and techniques.

An atomic clock to fit inside a smartphone
– Toward a microchip atomic clock –

Motoaki HARA
Space-Time Standards Laboratory,
Applied Electromagnetic Research Institute

A precise clock is indispensable when exploring unknown territory territory. When visiting an unfamiliar city, we can always keep a map to hand, but in places that do not appear on any maps, we must resort to making careful measurements of how fast we are traveling and for how long in order to calculate and record our route.

Our research team is looking into the applications of such clocks and aim to develop an ultra-precise atomic clock in microchip scale by using microfabrication technology. Such a device would greatly widen the possibilities for exploration in uncharted places including the deep sea and outer space.

Atomic clocks are also of key importance in the IoT era. Smartphones and drone aircraft are equipped with large numbers of sensors. These sensor groups rely on radio waves from GPS satellites for their map functions. However, the quality of radio waves depends on the environment, and they cannot always be received. This is often not a problem for humans; even when your GPS equipment goes offline, you would not lose your position using two eyes and the map in your hand. But for miniature sensor components, the loss of a GPS signal is equivalent to being blindfolded. The creation of a microchip atomic clock would make it possible to compensate for this instability of GPS so that sensor components can be constantly provided with time and position information. This would result in huge numbers of sensors sharing time and coordinates information, making it easy to assimilate big data over a range of times and places from measurements that would hitherto have been disconnected. If this technology can be incorporated into drone imaging, it will be easy to acquire 3D/4D images of places that are impassable.

Atomic clock is a technique to stabilize the frequency of microwave oscillator by using an extremely narrow resonance line obtained by interference between alkali metal atoms and a laser (Figure 1). The development of miniaturized atomic clocks has mostly taken place in Europe and the United States, and major advances have been made in the miniaturization of devices used to obtain resonance lines. However, work is still under way to develop miniaturized microwave oscillators and control circuits for stabilizing these oscillators. By focusing on this issue, our team has proposed a new atomic clock system that uses a microwave oscillator based on the vibrations induced in a piezoelectric thin film (Figures 2, 3). The piezoelectric thin film resonates strongly in the same frequency band as the frequency of atomic resonance. This makes it easier to perform synchronization control and allows the oscillator and control circuit to be made much simpler and more compact. As a result, we have achieved great reductions in power consumption and chip area compared with commercially available atomic clocks.

Smartphones include many advanced technologies that have been adopted in satellites, and the addition of an atomic clock would make it possible for you to carry the same functions as a satellite in your pocket. We predict this will lead to a bright future for the creation of new industries and services.

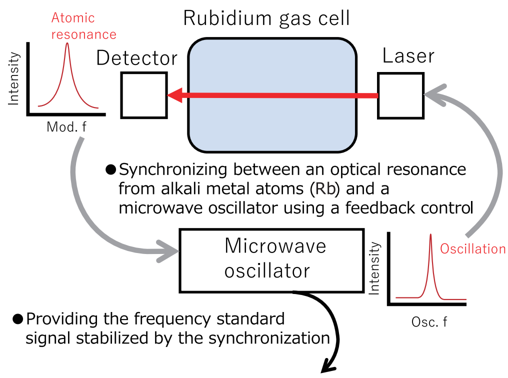


Figure 1 The principle of atomic clocks

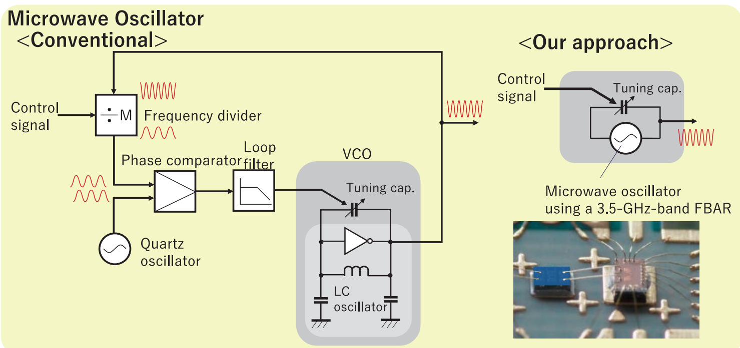


Figure 2 Microwave oscillator: Comparison of conventional method and proposed method

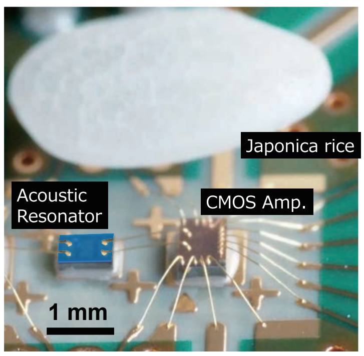


Figure 3 Photograph of the oscillator we developed

■Press release and related articles (January 23, 2018)
http://www.nict.go.jp/press/2018/01/23-1.html

Motoaki HARA
Senior Researcher, Space-Time Standards Laboratory, Applied Electromagnetic Research Institute
After completing a doctoral course at university, he joined Fujitsu Laboratories and then worked as an Associate Professor at Tohoku University graduate school of engineering before joining NICT in 2016. He is engaged in the study of microfabrication technologies and their applications to micro devices. Ph.D. (Engineering).

Calendar of NICT FY2018 Events

Wireless Technology Park (WTP) 2018

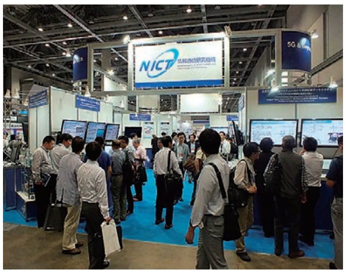
https://www.wt-park.com/2018/en

Date: 23rd–25th May 2018

Venue: Tokyo Big Sight

Japan's largest event specializing in wireless communication technology. Through exhibitions, seminars, and academia programs, the 2018 event will introduce the latest state-of-the-art technologies centered on 5th generation (5G) mobile communication systems. NICT will demonstrate and deliver lectures on our latest achievements including wireless technology (main exhibition section: Wireless Network Research Center, Advanced ICT Research Institute, Strategic Program Office, Network Testbed Research and Development Promotion Center).

* Jointly organized by NICT, the YRP R&D Promotion Committee, and the YRP Academic Exchange Network




Photos from the 2017 event

Interop Tokyo 2018

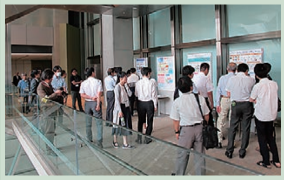
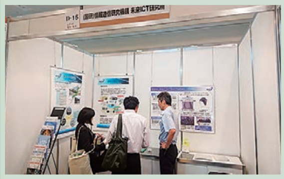
https://www.interop.jp/2018/en/

Date: 13th–15th June 2018

Venue: Makuhari Messe

In addition to the Cybersecurity Laboratory's annual demonstrative presentation, we also plan to exhibit the results of the program carried out by the National Cyber Training Center.


Photos from the 2017 event

Exhibition Event Name	Date/Venue	Exhibit Details (Exhibitors)	Photos from 2017
14th International Conference on IP + Optical Network (iPOP2018) https://www.pilab.jp/ipop2018/	Date: 31st May and 1st June, 2018 Venue: NICT headquarters	Exhibition on network infrastructure technology: Dynamic Construction and Control of Virtual Network Platform Utilizing OpenStack. (Network System Research Institute)	
The 8th CiNet Symposium https://www.cinet.jp/nict180627/ (Japanese only)	Date: 27th June 2018 Venue: Knowledge Capital Congrès Convention Center	The Symposium will introduce CiNet's research outcomes. Scientists incl. Hiroshi Ishiguro, known for Humanoid robots, will speak. (CiNet)	
Frequency Resource Development Symposium 2018 http://www2.nict.go.jp/wireless/event.html (Japanese only)	Date: 6th July 2018 Venue: Meiji Memorial Hall	Experts in the field will introduce the latest topics on government policy, market trends, and trends of wireless technologies that are essential for the efficient use of radio frequency in the 2030s. (Wireless Networks Research Center) *A joint event by NICT and the Association of Radio Industries and Businesses.	
International Industrial Fair 2018 Kobe https://www.kobemesse.com/en/	Date: September 6th and 7th 2018 Venue: Kobe International Exhibition Hall	We will present an introduction to the Advanced ICT Research Institute (Kobe) and its research achievements. (Advanced ICT Research Institute)	
International Home Care & Rehabilitation Exhibition (HCR 2018) http://www.hcrjapan.org/english/	Date: 10th–12th October 2018 Venue: Tokyo Big Sight	We will exhibit the results of our work on Conducting Business Without Information Barriers (supported by a subsidy for the development of broadcasting services and communication technology for challenged persons), together with other technologies including Wi-SUN and Koetora. (Deployment Promotion Department)	
nano tech 2019 http://www.nanotechexpo.jp/	Date: 30th January–1st February 2019 Venue: Tokyo Big Sight	With the main focus on the Advanced ICT Research Institute, we will exhibit the results of our applied research and technology transfer efforts. (Advanced ICT Research Institute)	

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

E-mail: publicity@nict.go.jp
URL: http://www.nict.go.jp/en/
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