Division for Meteorological and Atmospheric Research

- Precipitation measurements by advanced polarimetric radars and hydrometeor videosondes
- Development of new instrumental technology
- Clouds and precipitation observed by multiple satellites
- Millimeter-wave/infrared spectroscopy of green house gases and ozone-depleting substances
- Measurements and analyses of properties and behaviors of aerosols using advanced techniques

Ongoing global warming caused by increasing concentrations of carbon dioxide and other greenhouse gases will result in both gradual climate change and intensification of weather extremes and ecological catastrophes. Among the most urgent tasks for confronting global environmental problems more effectively is a close monitoring of the atmosphere using different observation methods and a better understanding of the atmosphere through theoretical insights and numerical modeling. To address these problems, the Division for Meteorological and Atmospheric Research is dedicated to several research projects for exploring the atmosphere from various angles.

Main Activities in FY2018

Characteristics of particle size distributions of a stratocumulus cloud undetected by a Ka-band radar

A Ka-band radar can observe smaller cloud particles by shorter wavelength than microwave-band radars. However, a Ka-band radar cannot sometimes detect stratocumulus and shallow cumulus clouds that we can clearly see with naked eyes. This study aims to confirm the characteristics of particle size distributions (PSDs) of a stratocumulus cloud undetected by a Ka-band radar by simultaneous observations using a cloud particle sounding: Hydrometeor Videosonde (HYVIS). A Ka-band radar was installed at Sesoko Research Facility, University of the Ryukyus. Stratocumulus and cumulus clouds frequently develop over Mt. Yae, whose height is 453 m above sea level and is located 6 km from the radar within the observation range. A balloon-borne sounding was launched from around the top of Mt. Yae into a stratocumulus cloud with thickness between 400 and 700 m at 1916 LST on June 10, 2017. Analyses of the soundings showed that the volume average and maximum diameters of PSDs in the lower two third of the cloud were 17.5 and 30.6 μm, respectively. In addition, the number concentration of particles was ~100 cm^{-3}. At that time, the Ka-band radar could not detect any echo related to the stratocumulus cloud. The equivalent reflectivity estimated by PSDs obtained by HYVIS was less than approximately -20 dBZ. This value is below the lowermost limit (-16.6 dBZ) obtained by the Ka-band radar in that situation. Assuming that the PSD shape does not change, the Ka-band radar should detect an echo in which the volume average particle size is greater than 23.8 μm.

Estimated PSD of an echo using the super droplet method

The Ka-band radar enables us to detect earlier the first echo, which shows the generation of cumulonimbus clouds. However, it is very difficult to observe PSDs of the first echo. For this purpose, we apply a sophisticated microphysical parameterization, i.e., a super droplet method with a cloud-resolving model (CReSS-SDM), which can track a particle development process from aerosols to cloud and precipitation particles by using the Lagrangian method. In the simulation result, a stratocumulus-like cloud is developed initially; however, an average particle size of less than 10 µm is too small in comparison with the sounding observation in Okinawa. After the development of active cumulus clouds, raindrops whose diameter is greater than 100 µm are formed by collision and coalescence processes and an equivalent first echo obtained by the Ka-band radar is detected when the maximum diameter of the particle is greater than 200 µm.

New rainfall observation tool: MP-PAWR

In the "Enhancement of societal resiliency against natural disasters" of the Cross-ministeral Strategic Innovation Promotion (SIP) program, the dual polarization multi-parameter phased array weather radar (MP-PAWR) was developed. As MP-PAWR can provide data about 10 times faster and a higher vertical resolution than conventional weather radars, it is suitable for observing severe weather, such as torrential heavy rainfall or tornado. Observation using MP-PAWR began in March 2018 and has succeeded in revealing new aspects of various precipitation phenomena. An example of the MP-PAWR observation on September 6 revealed the 3D structure of precipitation clouds that exist only 5 km or above and the MP-PAWR data enable the analysis of the characteristics precipitation particles as well as the kinematic characteristics of the cloud, such as quantitative estimation of not only the wind speed but also the vertical profiles of the divergence and deformation by using considerable elevation angle Doppler velocity data of MP-PAWR.

Thermodynamic mechanism for the maintenance of sharp tropical margins

The deep tropics characterized by moist air and deep convection are often separated from the dry, quiescent subtropics by a sharp horizontal gradient of moisture. Existing observations show that this margin of the moist tropics is a true PDF minimum along the column water vapor contour of ~48 mm in instantaneous data. Quasi-meridional statistical composites of observations across the poleward-most excursion of this sinuous contour retain the sharpness of the margin. In this paper, the 48-mm margin is first defined with Aqua AMSR-E observations. Observations from the CloudSat cloud radar and CALIPSO lidar are then analyzed to reconstruct the cloud and radiative heating profiles on both sides of the margin. Aqua AIRS temperature and humidity soundings are ingested into a water and energy budget analysis to find a remarkable contrast in the meridional structure of the thermodynamic state across the margin. These observed features are interpreted in terms of a simple conceptual theory from the moisture and heat budget perspectives. The findings offer a novel, "dynamic" view to characterize the tropical margin, urging an update of the conventional picture of the "static" tropical climate.

Continuous measurements of stratospheric ozone in the Patagonia region, South America

ISEE and the National Institute for Environmental Studies have implemented the "SAVER-Net project," a joint research project with Argentina and Chile as part of the SATREPS program, for 5 years since 2013. Although the project ended in March 2018, a cooperative research has continued using a facility for the ozone layer measurements in Rio Gallegos, Argentina, and an aerosol lidar network comprising nine lidars, developed by the SAVER-Net project, spread over the two countries. We advanced the retrieval analysis of vertical distribution of O_3 from the spectrum observed with a millimeter-wave spectral radiometer at Rio Gallegos from 2015 to 2017. Using the O_3 data, as well as the MERRA-2 dataset, in September and October, when the ozone hole often passes over the facility, we found a good correlation between potential vorticity and O_3 mixing ratio below the potential temperature of ~1000 K, corresponding to an altitude of 35 km. We also found temperature decrease and increase at altitudes of ~25 and ~35 km, respectively, when the ozone hole passed over the facility. These are due to the transport of polar airmass, suggesting that the potential vorticity and temperature are a good proxy of arrival of the ozone hole.

Observations of chemical composition change in the polar mesosphere

In the polar region, energetic particle precipitation (EPP) causes chemical composition changes in the atmosphere due to ionization and dissociation of nitrogen and oxygen molecules in the mesosphere. To understand these processes in detail, ISEE and NIPR conducted continuous monitoring of NO concentrations in the mesosphere and lower thermosphere using a ground-based millimeter-wave spectral radiometer installed at Syowa station, Antarctica, from January 2012 onward. In addition, the millimeter-wave measurements of NO at Tromsø, Norway, in collaboration with the University of Tromsø resumed after we fixed the issue of the FFT spectrometer in January 2019. Using the Syowa dataset, we found that the amplitude of the annual variation in NO in 2014 was significantly smaller than that in other years, and the flux of the energetic electron whose energy was larger than 1 MeV, measured with Van Allen Probes, was also significantly less than that in the other years, indicating that the flux of the energetic electron affects the seasonal and inter-annual changes in chemical composition in the mesosphere. Moreover, statistical analysis of O_3 depletion caused by precipitating protons has been performed using the O_3 dataset with AURA/MLS and the proton fluxes with GOES and POES since 2004, and a good correlation between O_3 depletion rate at 0.1 hPa (~60 km) and maximum flux of proton at solar proton events has been found.

Measurements of tropospheric and stratospheric minor constituents using infrared spectrometers

The measurements of atmospheric trace gases in the troposphere and stratosphere with a ground-based high-resolution Fourier Transform Infrared Spectroscopy (FTIR) instrument operated at Rikubetsu have been continued. Total column amounts and vertical profiles of 11 species, including O_3, CH_4, and CO, are retrieved from the observed solar absorption spectrum. Moreover, we analyze the vertical distribution of HCHO, which is associated with forest fires and biogenic volatile organic compounds, and find that the column amount of HCHO over Rikubetsu becomes a maximum in summer, and is close to the value in a remote area of the northern mid-latitude region throughout the season. We have also developed and evaluated an observation system using an optical spectrum analyzer (OSA). The observed values of the OSA system are highly correlated with those of the large FTIR whose accuracy has been validated, showing that the seasonal variation of the daytime column-averaged mixing ratios of atmospheric CO_2 (XCO_2) can be observed using it. We measured XCO_2 with it in the central area of Tokyo for 2 years, and found that the observed XCO_2 increased during south and southwest winds, suggesting that it was caused by large anthropogenic emissions of CO_2 from thermal power stations and traffic around the Tokyo central area.

Development of a wide-frequency-range and dynamic-range detector for a new radiometer system

Recently, millimeter–terahertz band technologies for application to information, telecommunication, and radio astronomy research have been developed rapidly. Based on these new technologies, we are developing a new receiver system for an atmospheric radiometer that is wide-band, highly sensitive, and highly accurate. We have also been developing a new millimeter-wave radiometer system to monitor multi-molecular lines such as O_3, NO_x, and HO_x. This year, we designed a frequency-independent optics, which covers a wide observation frequency range from 179 to 254 GHz. A new corrugated feed horn and some mirrors were fabricated and their propagation characteristics were measured. As a result, we confirmed good consistency between the design and experiment. Furthermore, we fabricated a new superconducting device for a millimeter-wave detector under collaborative research with the Advanced Technology Center at the National Astronomical Observatory of Japan (NAOJ). The measured noise temperature of this device is ~40 K, which is roughly two times the quantum noise limit, from 160 to 180 GHz. However, this resonance frequency is 60–80 GHz lower than that of the design, and we are attempting to investigate the reason behind this using simulators.

Development of a method for aerosol reaction experiments utilizing a gas-exchange technique

Aerosols in the atmosphere are considered to age through reactions with gas-phase oxidants. However, how the processes affect aerosol properties such as chemical structure and cloud condensation nucleus activity have not been clarified. For the atmospheric aerosol reaction experiments conducted to reveal this, we developed a reaction experiment system composed of a flow tube reactor with a double-tube structure and a gas-exchange device commercialized for use with ICP-MS. We calculated the gas flow in the flow tube reactor by computational fluid analysis and obtained the results regarding the diffusion of a reactive gas (ozone) and the residence time of aerosol particles, both of which are necessary for the analysis of data obtained from the reaction experiments. Furthermore, we performed an experiment in which atmospheric aerosol was passed through the gas-exchange device, followed by the conversion of the gas to argon and the introduction of aerosol to an aerosol mass spectrometer. The result shows that the argon conversion method has an advantage in the separation of ion signals from aerosol particles and those from gases. We will further evaluate the experimental system and perform reaction experiments for atmospheric aerosols.

Analysis of the relationship between size-resolved hygroscopicity distributions of atmospheric aerosols and their respiratory deposition

Aerosol is an atmospheric pollutant that has an adverse effect on human health through its deposition within the human body through respiration. Various aerosol particles with different sizes and compositions are present in the atmosphere, and the extent of their deposition in the human body is considered an important factor for clarifying the health effect of atmospheric aerosol quantitatively. We analyzed the relationship between dry-diameter/hygroscopicity distributions of aerosols and their deposition in the respiratory system based on the deposition fractions obtained from a respiratory deposition model, using data from the measurement of size-resolved hygroscopicity distributions of aerosols in the urban air of Nagoya in the past. We analyzed the data collected in June and August 2010 before this fiscal year, and this year, we performed an analysis using data obtained from an atmospheric observation in September 2009, when size-resolved hygroscopicity distributions were measured more frequently. We obtained the characteristics of the deposition of atmospheric aerosols in the respiratory system when a human inhaled them during the observation period. The variation in the deposition amount during the observation period should have been affected by the variations in the meteorologically controlled transport and aging of aerosols, besides the variation in the emission of aerosols and their precursors in the city. We will further study the deposition of aerosols in the respiratory system, to understand the connection of the deposition amount with these regulating factors.

Data analysis of black carbon aerosols observed in the Arctic

The Arctic is warming more rapidly than the rest of the globe. Besides contributions from greenhouse gases, forcing and feedback mechanisms associated with light-absorbing aerosols, such as black carbon (BC), also need to be elucidated. In this study, we analyzed the data of vertical profiles and microphysical properties (size distributions and mixing states) of BC particles in the Arctic. These data were obtained during an international aircraft observation campaign in March–April 2018, using an onboard instrument that is based on the laser-induced incandescence technique developed by the University of Tokyo group. A series of aircraft measurements were conducted from the northern tip of Greenland. From the data analysis, we found atmospheric pollution layers at altitudes of ~3.5 and 5 km, where BC mass concentrations were distinctly high. We also found that most BC particles were thickly coated with non-BC materials at all altitudes below 5 km. Furthermore, we analyzed long-term data of the surface BC mass concentrations at multiple sites in the Arctic to reveal their temporal and spatial variations. Currently, we are analyzing the emission sources and transport process of BC particles observed by these aircraft- and ground-based measurements.