Division for Meteorological and Atmospheric Research

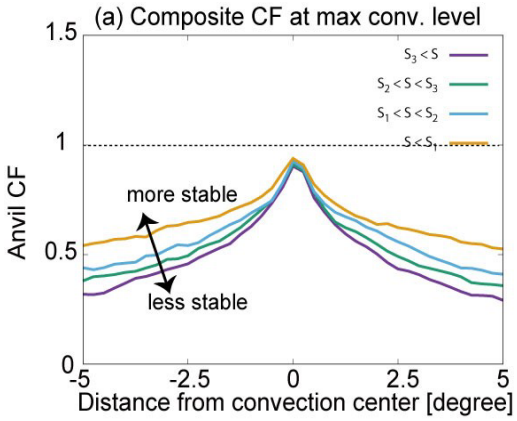
- Precipitation measurements by advanced polarimetric radars and hydrometeor videosondes
- Development of new instrumental technology
- Clouds and precipitation observed by multiple satellites
- Millimeter-wave/infrared spectroscopy of green house gases and ozone-depleting substances
- Measurements and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

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

Main Activities in FY2021

Process-level assessment of the Iris effect over tropical oceans

The iris hypothesis suggests a cloud feedback mechanism in which a reduction in the tropical anvil cloud fraction (CF) in a warmer climate may act to mitigate warming by enhanced outgoing longwave radiation. Two different physical processes, one involving precipitation efficiency and the other focusing on upper-tropospheric stability, have been argued to be responsible for the iris effect. In this study, A-Train observations and reanalysis data were analyzed to assess these two processes. The major findings were as follows: (1) the anvil CF changes evidently with upper-tropospheric stability, as expected from the stability iris theory (see Figure); (2) precipitation efficiency is unlikely to have control of the anvil CF but is related to mid- and low-level CFs; and (3) the day and nighttime cloud radiative effects are expected to largely cancel out when integrated over a diurnal cycle, suggesting a neutral cloud feedback.

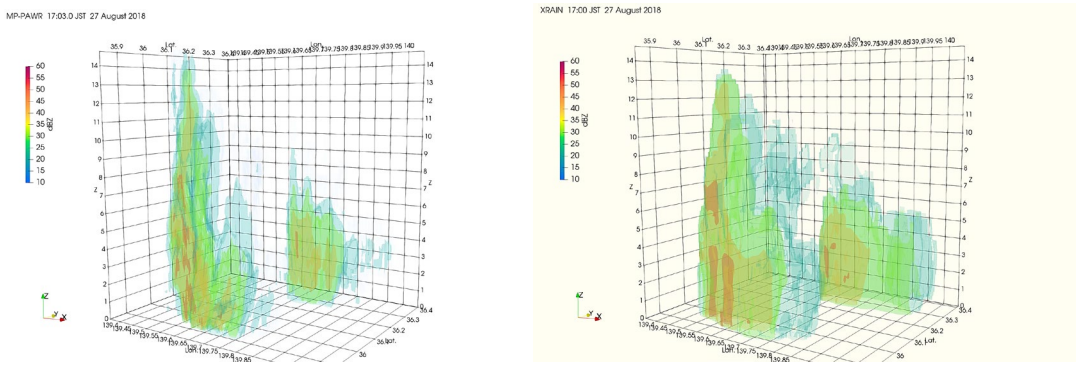


Composite anvil CF for different quartiles of 200-hPa stability.

Calibration of MP-PAWR

The state-of-the-art radar technology, multi-parameter phased array weather radar (MP-PAWR), transmits with a fan beam and receives with a pencil beam; therefore, its calibration must be performed at all elevation angles. This is different from the conventional radar, which can be calibrated at a single elevation angle. The relationship between the ratio of the specific phase shift between the two polarizations (KDP) to the radar reflectivity factor (Z) and differential reflectivity (ZDR) was used because of its small dependence on the raindrop particle size distribution. The ZDR was calibrated by

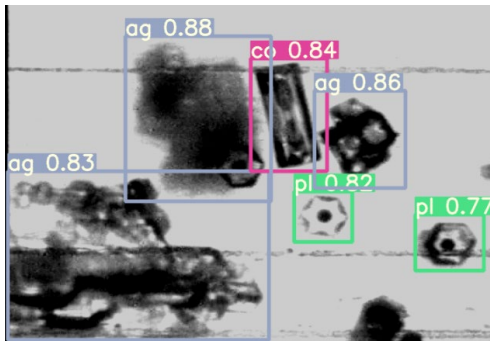
assuming a Marshall-Palmer type raindrop size distribution and, at the same time, by determining the Z bias that satisfies the relationship between KDP/Z and ZDR. The results showed that ZDR bias jumps appeared at the elevation angle of transmitter fan beam switching. This calibration was evaluated by comparison with a well-calibrated radar system.



3D structure of Z from MP-PAWR (left) and XRAIN (right) on August 27, 2018, at 17:00 JST. The 3D structure of XRAIN is broadened by integrating 4 different radars for 5 minutes.

Objective classification of solid hydrometeor images using deep learning

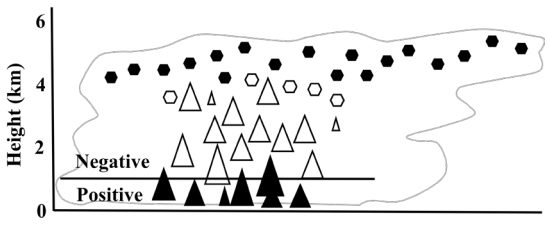
A balloon-borne "hydrometeor videosonde (HYVIS)" equipped with a microscope camera was used to observe the cloud particles in various clouds. As HYVIS observations can obtain a large number of particle images, it is very difficult for an analyzer to conduct quantitative and statistical analyses, that is, to objectively identify their categories, such as plate-, column-, and dendric-type ice crystals. Thus, we developed an image analysis method using deep learning. The figure shows an example of the particles identified by this method. Solid particles in actual clouds are not six-fold symmetric dendritic- and column-type crystals but are dominated by diverse, complex, and asymmetric crystals. As the classification method can objectively identify particle categories in a very short time, statistical analyses of cloud particles should be performed. This method is highly novel because the engineering method can be applied to meteorological research. It is expected to contribute not only to advancing our knowledge of cloud microphysics but also to improving parameterizations of cloud-resolving models.



An example of deep-learning objective classification of solid hydrometeors observed by an HYVIS in a cloud. The particles surrounded by a square are identified particles, where "ag", "co", and "pl" show identified categories as "aggregate", "column", and "plate" particles.

Hypothesis on the mechanism of gamma-ray glow events inferred from a meteorological perspective

Recently, gamma-ray glows from active convective clouds have been observed on the ground in the Hokuriku region during the winter season. Gamma-ray glows typically last a few seconds to several minutes and are considered to originate from relativistic runaway electron avalanches (RREAs) in strong electric fields owing to charged hydrometeor particles. This study aimed to confirm that the inner structure of precipitation clouds brought about gamma-ray glows using an X-band

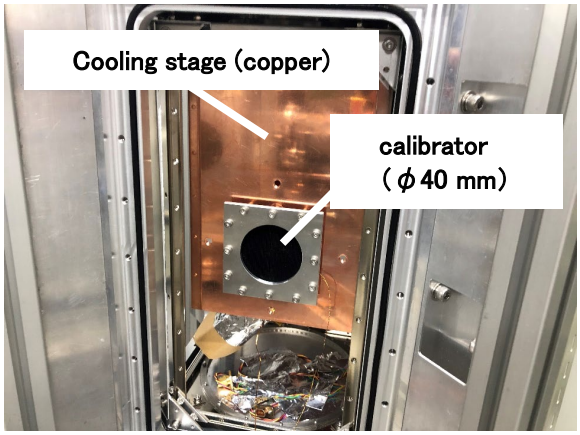


Conceptual model of precipitation particles and their charge distributions during the gamma-ray glow event. Black (white) triangles (hexagons) indicate the presence of positively (negatively) charged graupel particles (ice crystals).

polarimetric radar. Eleven gamma-ray glow events were analyzed during the five winter seasons. The time series of reflectivity shows that both heights of maximum reflectivity and 35-dBZ echo-top, which is a proxy for the existence of graupel particles, clearly decreased before and after the time when the gamma-ray glows were observed. This indicates that the convective cell is in the dissipating stage of its life cycle. As a result, updraft and riming electrification should hardly exist at this stage. Thus, dense graupel particles and the boundary between a positively charged region formed by graupel particles below a height of −10 °C and a negatively charged region above the height move downward and approach the ground surface. If the boundary between the positive and negative charge regions has sufficient intensity for the RREAs and reaches close to the surface, gamma-ray glows should be observed at the surface.

Development of a new calibrator for the millimeter-wave atmospheric radiometer

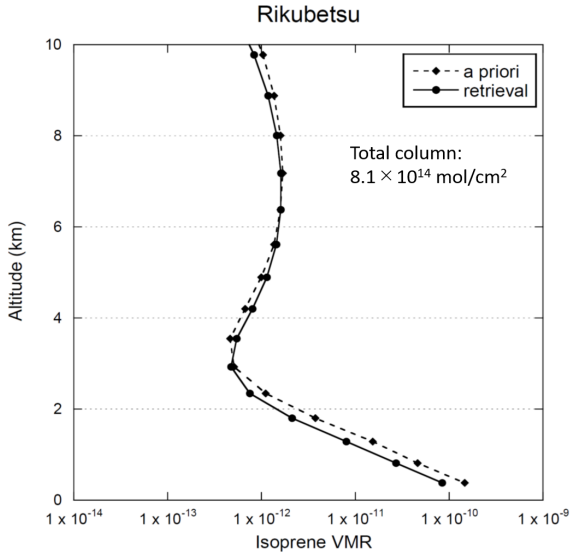
A calibrator composed of blackbody radiation sources was used for calibrating the signal intensity of a millimeter-wave atmospheric radiometer. The existing calibrator is cooled by liquid nitrogen but must always generate, supply, and store it during observation, which is not suitable for long-term unmanned observation at remote sites. In this year, we developed a new mechanical cooled calibrator using a cryogenic refrigerator which is primarily used for cooling the superconducting detector in an observation system, in collaboration with Kyoto University. We designed a calibrator with the characteristics of reflection coefficient, observation frequency, and size of the receiver, and carried out cooling tests. It was found that the temperature was stably controlled at approximately 76 K, which is almost the same as the temperature of liquid nitrogen. This suggests that this new cooling method can be adopted in our radiometer system



New calibrator installed on the cooling stage of the receiver cryostat.

Monitoring atmospheric minor constituents with a high-resolution infrared spectrometer

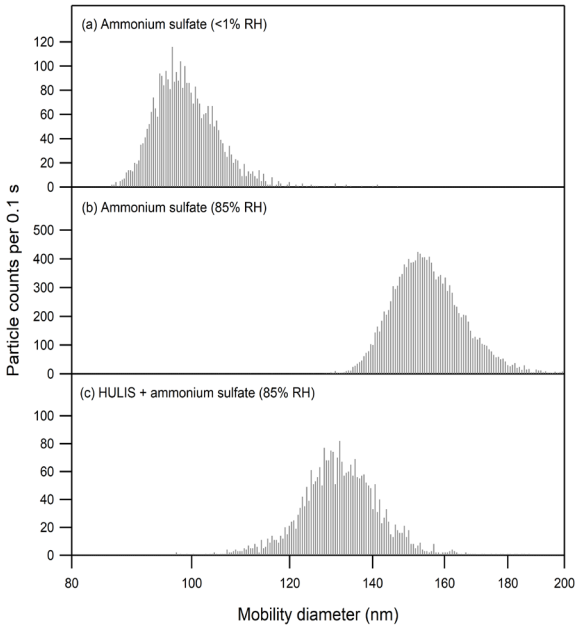
Monitoring observations of solar absorption spectra using high-resolution Fourier transform infrared spectroscopy (FTIR) at Rikubetsu Observatory have continued in cooperation with the National Institute for Environmental Studies (NIES). The total column amounts and vertical profiles of the 17 molecular species, including O_3, CH_4, and CO, were retrieved from the spectrum. In this year, we newly attempted to derive the column amount of isoprene, the major biogenic volatile organic compound. After a preliminary analysis of the vertical distribution of CO_2 and H_2O from the observed spectra, the column amount of isoprene was determined simultaneously with CFC-12, HCFC-142b, NH_3, and HNO_3. The isoprene column amount observed in 2020 was estimated to be (2–8)$\times 10^{14}$ mol/cm^2, which was significantly lower in winter.



Vertical distribution of isoprene, with a solid line representing observed values and a broken line representing an initial guess.

Analyses of the hygroscopicity and light-absorption property of atmospheric aerosol

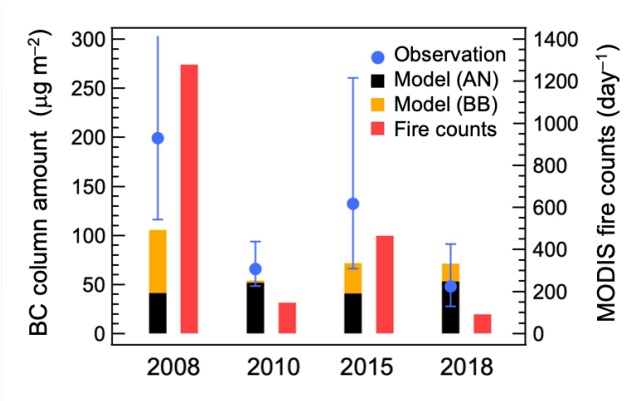
Atmospheric aerosols affect the radiative balance of Earth, and the properties regulating this effect include hygroscopicity and light-absorption properties. The hygroscopicity of aerosols is generally represented by the assumption of additivity of the hygroscopicity parameter of the chemical components. However, its appropriateness has not been tentatively assessed. In this study, particles composed of humic-like substances (HULIS) extracted from atmospheric aerosol samples and ammonium sulfate were generated and the relationship between the proportions of the two components and hygroscopic growth was investigated. The relationship of κ values with chemical composition (proportions of organics and inorganics) was then determined. Regarding the light-absorption property of atmospheric aerosol, the contribution of light-absorptive organics is not well understood. The light absorption properties were analyzed for organic fractions from atmospheric aerosol samples collected in urban and forest environments. For future analysis of aerosol hygroscopicity, aerosol sampling was performed at the Hyytiälä Forestry Field Station in Finland, under the support of the University of Helsinki.



Examples of data from the hygroscopic growth measurements of particles using an HTDMA. (a,b) Particle counts versus diameter for ammonium sulfate particles under (a) dry and (b) humidified conditions. (c) Particle counts versus diameter for particles composed of the mixture of HULIS and ammonium sulfate under the humidified condition. The relative humidity of the humidified condition was 85%. The horizontal axis uses a logarithmic scale.

Evaluation of the methods to measure water-insoluble aerosols and observations

Water-insoluble aerosols, such as black carbon (BC) and mineral dust, can influence the climate through their light-absorption and ice-nucleating properties. However, their atmospheric behavior is poorly understood owing to the limited number of observations and the lack of established measurement methods. In this study, data obtained from aircraft-based observations conducted in the Arctic region from March–April 2018 were analyzed. We showed that the year-to-year variations in BC column amounts in the Arctic spring were strongly correlated with magnitudes of biomass burning in the mid-latitudes and that current numerical models significantly underestimated the contribution of BC from biomass burning. Moreover, we evaluated a new method for measuring the number concentrations of water-insoluble particles collected on filters, where the particles were dispersed in water and optically detected. For analysis using this method, intensive aerosol sampling was conducted in Nagoya and Ny-Ålesund in the Arctic.



Spring BC column amounts for different years in the Arctic. Observations and numerical model simulations for anthropogenic BC and biomass burning BC are shown. MODIS-derived average fire counts at latitudes north of 50°N are also shown.