Monitoring the light absorbing aerosols and the impact on radiation budget of atmosphere and snow ice
（**Abstract of the Interim Report**）

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1. Introduction

The cryosphere is one of the regions most vulnerable to climate change. The Arctic has witnessed approximately a twofold increase in surface air temperature than the global average in the recent warming period. In addition, the reductions of snow cover duration and sea ice extent and mass loss of ice sheets and glaciers are proceeding rapidly. One of the leading causes of the cryosphere’s vulnerability is a mechanism called ice-albedo feedback, strong positive feedback peculiar to the cryosphere. The decrease in albedo is not caused only by the reduction in the area of snow and ice. Snow impurities originating from Light Absorbing Aerosols (LAAs) such as black carbon (BC) and mineral dust are also contributors; they reduce the visible albedo on the snow surface. Furthermore, an increase in snow grain size causes a decrease in albedo in the near-infrared region. However, quantitative understandings regarding the contributions and effects of LAAs and snow grain size on global warming are still insufficient, and their dynamics have not been modeled sufficiently yet.

2. Research Objectives

This research project aims to monitor LAAs and their impact on radiation budget in the atmosphere-snow/ice system and the climate system by (1) ground-based observations and (2) satellite remote sensing with special focuses on East Asia, one of the major sources of LAAs, and the Arctic region that is recently affected by LAAs from East Asia. We also make (3) evaluations on the impacts of LAAs on both systems using numerical models that incorporate the atmospheric dynamics, the snow physical process and the chemical process.

3. Reseaech Method

In order to achieve our research objectives, we will conduct research on LAAs and snow impurity by dividing the research into the following three sub-themes. (1) Monitoring by ground-based observations; Field observations will be conducted in Japan and overseas to obtain observation data on ground meteorology, radiation, LAAs, snow impurity, snow particle size, etc., and to monitor LAAs in the atmosphere and snow cover in Japan at the same time. (2) Monitoring by satellite remote sensing; Based on the detailed data obtained from ground-based observations, snow particle and LAA particle shape models will be developed and validated. This snow particle and LAA particle shape model will be applied to satellite remote sensing to improve the algorithm, and satellite data will be used for highly accurate and spatially and temporally extensive monitoring. (3) Evaluations by numerical models; We will validate and improve the numerical models that incorporate the necessary processes using observation data, and evaluate the effects of LAAs on the radiation budget of the atmosphere and snow/ice system using the numerical models.

4. Results and Discussions

(1) Monitoring by ground-based observations

In Japan, in situ observations of near-surface meteorology, radiation, and snow properties were carried out in Sapporo, Kitami, and Nagaoka and the interannual variation of LAA concentrations in surface snow cover in Sapporo were compiled (Fig. 1). Snow pit measurements were also carried out periodically in winter to monitor snow accumulation, including snow particle size and impurity concentration, and detailed observation data were obtained. The meteorology, radiation, snow/ice observation data in Sapporo contributed to the further promotion of the international snow model intercomparison project, ESM-SnowMIP.

Outside Japan, we continued observations with automatic weather stations at the SIGMA-A and SIGMA-B sites in Northwest Greenland. Meteorological, radiological, and snow/ice observation data from Sapporo and some snow/ice observation data acquired in the past on the Greenland ice sheet were made available to the research community.

In addition, many results were obtained on the composition, mixing state, generation, removal, and effects on snow and ice crystals of aerosol particles including LAA particles in the atmosphere. The details of each of these are reported in detail in the respective papers. The results obtained have been published in many international scientific journals, including internationally recognized journals (Nature Geoscience, PNAS, Nature Communications, etc.).

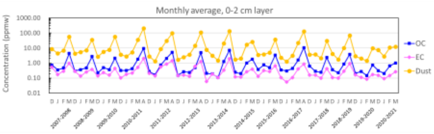

Figure 1 Variation of monthly mean LAA

(2) Monitoring by satellite remote sensing

The comparison of the results of scattering property calculations using detailed snow particle shapes obtained by X-ray micro-CT showed the validity of Voronoi particles in the scattering properties of snow particles. The validity of Voronoi particles in snow particle scattering properties was demonstrated by comparing the results of scattering property calculations using detailed snow particle geometries obtained by X-ray micro-CT.

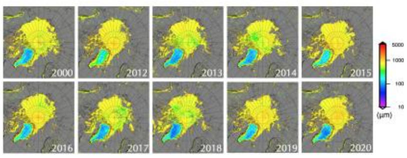

Figure 2 One-month composite images of

The algorithm for observing the atmosphere and snow cover by geostationary meteorological satellite Himawari-8 was developed and improved, and observations of snow cover distribution in East Asia, sea ice extent in the Sea of Okhotsk, and yellow sand were carried out. We also developed snow cover products using high frequency observations by Himawari-8.

The long-term data set of the Northern Hemisphere since 2000 was compiled by MODIS in order to clarify the spatio-temporal variation of the physical snow cover by polar-orbiting satellites (Fig. 2).

(3) Evaluations by numerical models

The newly developed Meteorological Research Institute Earth System Model (MRI-ESM2.0) enables us to estimate the radiative effects of light-absorbing aerosols more reliably than before by comparison with observational data, and has greatly improved the reproducibility of radiation and clouds. Using MRI-ESM2.0, the effective radiative forcing by anthropogenic gases and aerosols was estimated on a global scale and in the Arctic region at the present time with respect to the pre-industrial era. In the Arctic, black carbon, a light-absorbing aerosol, is found to have the second largest positive radiative forcing after carbon dioxide (Oshima et al. (2020), Fig. 3).

The NHM-SMAP, a coupled domain meteorological model and snow cover transformation model, revealed for the first time in the world that although the area of snow and ice surface melting expands as cloud cover increases, snow and ice mass loss is accelerated by a decrease in cloud cover. The results also suggest that light-absorbing impurities on the snow/ice surface (including snow/ice microorganisms) may suppress the radiative effect of clouds on snow/ice surface melting (Niwano et al., 2019). The NHM-SMAP participated in the Greenland Ice Sheet Surface Mass Balance Model Intercomparison Project, GrSMBMIP, which also contributed to IPCC AR6 directly.

In addition, we developed NHM-Chem-SMAP, a regional atmospheric model that incorporated chemical and snow physical processes, in this project. In the model, we succeeded in reproducing BC and dust concentrations in the snowpack in Sapporo.

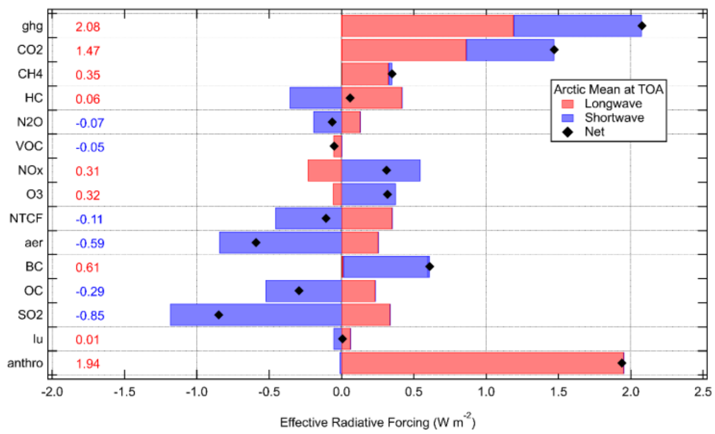

Figure 3.　Effective radiative forcing of the

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