INTENSIVE OBSERVATIONS OF METEOROLOGICAL AND SNOW-PHYSICAL PARAMETERS AT SITE SIGMA-A IN NORTHWESTERN GREENLAND IN SUMMER 2012

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To clarify the contributions of light absorbing snow impurities and glacial microbes to recent abrupt melting of snow/ice in Greenland, intensive observations of meteorological and snow-physical parameters have carried out at the site SIGMA-A (78°03'N, 67°38'W, 1,490 m a.s.l.) on northwestern Greenland ice sheet during the period June 26 – July 16, 2012. We installed automatic weather station (AWS) to measure the basic meteorological elements, radiation budget for shortwave, near-infrared, and longwave spectra, snow temperatures, and snow depth relative to the level of thick ice layer estimated to be formed in the previous summer. We have also performed snow pit work, near-infrared photometry measurement for snow grain size, snow samplings for water-soluble ions and light absorbing insoluble impurities, snow core drilling with a hand auger, and detailed spectral radiation measurements with a spectrometer. It was reported that a melting event of surface snow/ice over 97% of Greenland ice sheet happened between July 8 and 12 including our observation period. At SIGMA-A a large amount of rainfall was observed from July 10 to 13 and the snow surface level decreased by 25 cm (Fig. 1). After the rainfall event we found high concentration of insoluble particles on nuclepore filter with the pore size of 5 micrometers from surface snow samples. This indicates a possible transport of even large particles such as mineral dust to ice sheet surface at the height of 1,500 m. This is important for nutrient supply to glacial microbes.

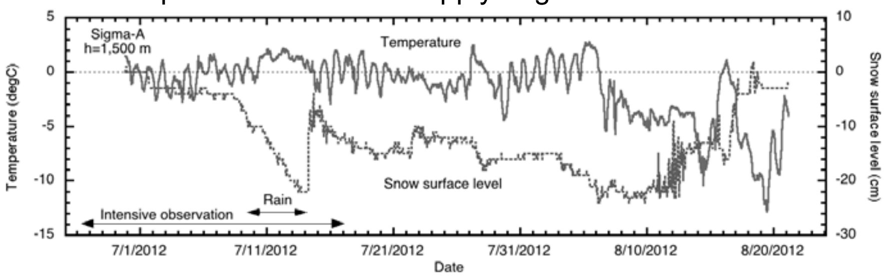

Fig. 1 Temperature and snow level measured with AWS at SIGMA-A. Snow surface level is the value relative to the measurement on 29 June 2012 when AWS was installed. An abrupt raise on 14 June was artificially made to keep the AWS mast.

S3–P2

MELTING RECORD IN NORTHWESTERN GREENLAND ICE SHEET

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To evaluate melting rate of snow/ice on Greenland Ice Sheet, we carried out meteorological and glaciological expedition at the site SIGMA-A (78°03'N, 67°38'W, 1490m a.s.l.) on the northwestern Greenland ice sheet from June 26 to July 16, 2012 (Fig. 1). During the expedition, we obtained a 19m ice cores using a hand auger, and observed bulk density and visible stratigraphy of the ice cores, and prepared samples for chemical analysis from the ice cores. Profiles of ice layer percentage and density showed that the ice cores from surface to 3m depth were influenced by melt water owing to recent warming (Fig. 2). In this contribution, we discuss melting features of the observation site shown by ice core analysis and satellite data analysis.

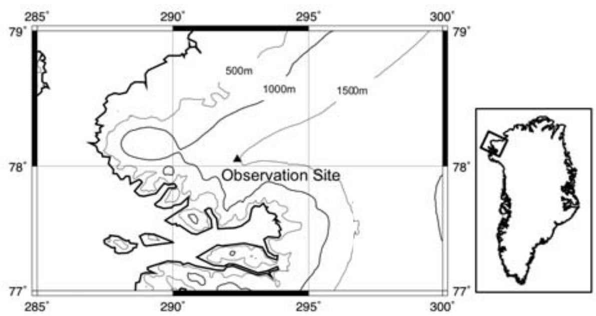

Fig1. Location of observation site

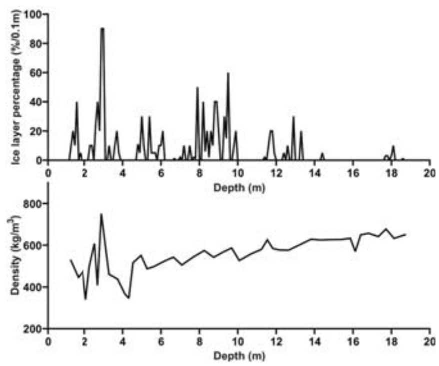

Fig2. Profiles of ice layer percentage in 0.1m long ice core and density.

S3–P3

MEASUREMENT OF SPECIFIC SURFACE AREA OF SNOW COVER IN GREENLAND

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Specific Surface Area (SSA) is considered an essential physical parameter for the characterization of snow. We measured time series change in SSA of snow cover in Greenland (SIGMA-A: 78°03' N; 67°38' W; 1,490 m a.s.l.) using the "near-infrared photography (NIR) method" and we compared our measured data with snow pit data. The SSA fluctuated with variations in snow properties (such as grain type and grain size). Although the distribution pattern of the SSA did not vary with time, its value reduced (Fig.1). This decrease in the SSA is probably due to an increase in grain size. Data from our SSA measurements will become a valuable part of validating numerical snowpack metamorphism.

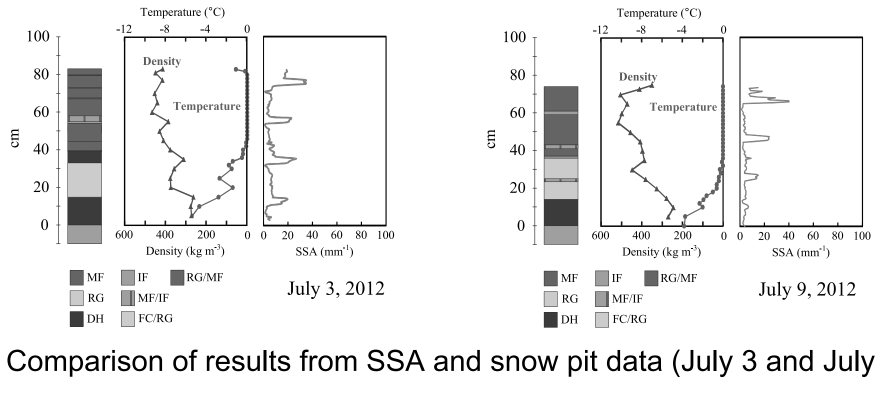

Fig.1 Comparison of results from SSA and snow pit data (July 3 and July 9, 2012).

NUMERICAL SIMULATION OF SUMMER SNOWMELT AT SITE SIGMA-A NORTHWESTERN GREENLAND DURING 2012 INTENSIVE OBSERVATIONS

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It is widely recognized that snow and ice on the Greenland ice sheet (GrIS) are melting abruptly in recent years, although its robust mechanisms have not been fully understood yet. In order to clarify such mechanisms we employ the one-dimensional physical snowpack model SMAP [*Niwano et al*., 2012], which was originally developed and validated against seasonal snowpack. With SMAP we calculate physical states of the latest annual snow layer during the 2012 intensive field observations (30 June to 10 July, 2012) conducted in the site SIGMA-A, which locates on northwest part of GrIS (78°03'N, 67°38'W, 1,490 m a.s.l.). During the period we observed rapid surface-level lowering caused mainly by snowmelt. The initial physical states of snowpack are given from those obtained by snow-pit observations carried out on 30 June. From the initial state we perform numerical simulation of physical states of snowpack by forcing measured meteorological data, mass concentrations of snow impurities, and snow temperature at the depth of bottom ice formation in the latest annual layer. The simulated snow temperature profiles are compared against *in-situ* measurements. As shown in an example of the comparisons (Figure 1) SMAP tends to underestimate snow temperature. The result suggests that it is necessary to adapt several snow physical processes, especially liquid water displacement, to the polar snow condition.

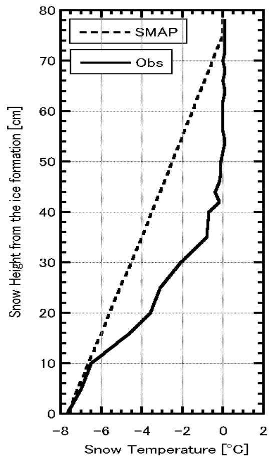

Figure 1. Snow temperature profile at 0930 LT on 8 July.

References
Niwano, M., T. Aoki, K. Kuchiki, M. Hosaka, and Y. Kodama (2012), Snow Metamorphism and Albedo Process (SMAP) model for climate studies: Model validation using meteorological and snow impurity data measured at Sapporo, Japan, J. Geophys. Res., 117, F03008, doi:10.1029/2011JF002239.

MONITORING OF THE DARK REGION ON GREENLAND BY AQUA/MODIS DURING THE MELTING SEASON 2002 - 2012

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We monitor the dark region in the western and northern bare ice areas of Greenland ice sheet by using MODIS images during the melting season. The areas of dark region and their albedo variations make a large contribution to the total melt energy, which is important to control temporarily and spatially melt water generation. We built monthly composite MODIS images by collecting clear day (cloud-free) pixels, and then examined the recent trend of temporal and spatial variations of the dark region. Figure 1 shows true color images over the Greenland ice sheet. The dark region in the western area and the surrounding blue-ice expanded during eleven years, and the north/northwest coastal area also was confirmed to be dark. Figure 2 shows radiance profiles for different years as observed by the MODIS visible channel (470 nm) in the western (Fig.2a) and northern bare ice areas (Fig.2b). The radiance profiles of the dark region drastically decreased in 2007, and lower radiance areas extended toward the inner area including the dark region especially during recent three years. This means there was an expansion of the blue ice or large snow-grain-size area. And, this phenomenon is caused by the snow impurities such as dust and glacial microbes together with recent surface temperature increasing.

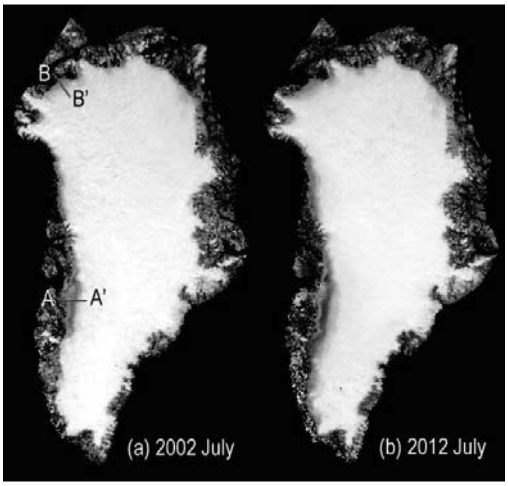

Fig1: MODIS true color image.

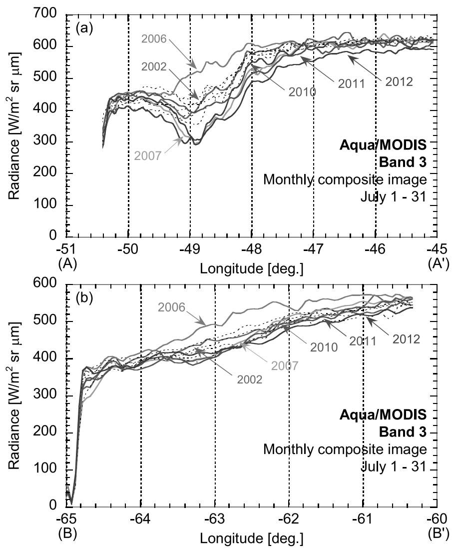

Fig2: Radiance profiles at different years for (a) A-A' and (b) B-B' profile of Fig.1.

MASS CONCENTRATION OF SNOW IMPURITIES AND SNOW GRAIN SIZE ON NORTHWESTERN GREENLAND ICE SHEET: COMPARISON BETWEEN RETRIEVAL FROM MODIS AND IN-SITU MEASUREMENT

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Light absorbing impurities in snow and snow grain size are important parameters controlling snow albedo. Changes of these snow physical parameters could be one of the possible causes of the recent snow/ice melting in the Arctic. The snow physical parameters retrieved from the Terra/Aqua MODIS were validated using the intensive observations which were carried out at the SIGMA-A site (78°03'N, 67°38'W, 1,490 m a.s.l.) on northwestern Greenland ice sheet during June 26 – July 16, 2012.

The MODIS-derived snow physical parameters are mass concentrations of snow impurities optically equivalent to soot and snow grain sizes in top and bottom snow layers. The in-situ measured mass concentrations of elemental carbon (EC) in the surface to 2 cm snow layer at the SIGMA-A site were several ppbw, which were gradually increased during the observation period. The soot concentrations retrieved from Aqua MODIS were generally consistent with the EC concentrations. In contrast, those from Terra MODIS were significantly overestimated, which might be due to the interannual change in the sensitivity of the Terra MODIS. The snow types were melt forms or ice layer in the top 5 cm layer. The snow grain radii measured with snow pit work were 100–800 μm. The top layer snow grain radii retrieved from the Terra/Aqua MODIS agreed with the in-situ measurement in the 0–2 cm layer. They were increased more than 1000 μm after the rainfall event from July 10 to 13. The bottom layer grain radii retrieved from Terra/Aqua MODIS were somewhat larger than the in-situ measured grain radii in the 2–5 cm layer. The ice layers in near snow surface would reduce the snow reflectance, causing the overestimation in the bottom layer snow grain size retrieval.

S3–P7

ICE FRONT VARIATIONS AND VELOCITY OF OUTLET GLACIERS TERMINATING IN INGLEFIELD FJORD, THE NORTHWEST GREENLAND

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Recent studies on Greenland Ice Sheet have revealed widespread retreat, thinning, and acceleration of marine terminating outlet glaciers within the past decade. As a result of the observed changes, contribution of the ice sheet mass loss to the sea level rise is increasing. It is likely that the changes in outlet glaciers are triggered by thinning and retreat of ice front which subsequently reduce back resistance force acting on inland ice. Thus, monitoring ice front variations is important to predict future changes of calving glaciers. Such studies have been carried out mostly at large glaciers in the southern part of Greenland. Because the influence of warming trend is expected to spread to higher latitude, it is urgently needed to collect data in the northern Greenland. Here, we report changes of glacier front positions and ice velocity of 19 outlet glaciers terminating in Inglefield Fjord in the Northwest Greenland.

We measured glacier front positions and ice velocity using Landsat imagery form 1988 to 2012. Our analysis revealed that all of the studied glaciers have retreated over the last decade at a mean rate of -51 ± 44 m a^{-1}. The front positions of some of the glaciers were relatively stable before 2000s (-2 ± 21 m a^{-1}). Tracy Glacier, the second largest glacier terminating in the fjord, retreated by 2200 m from 2002 to 2010 Coincided with the terminus retreat, surface velocity near the terminus increased by 20%. These observations at Tracy Glacier suggest that the ice velocity change was the result of terminus retreat. Terminus retreat trend is similar in the other glaciers, but clear acceleration was observed only for Tracy Glacier. The synchronous retreat of calving glaciers implies that the glaciers in the studied region are changing under the influence of climate and/or ocean forcing.

S3–P8

THINNING OF AN ICE CAP AT THE COASTAL MARGIN OF NORTHWESTERN GREENLAND

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Recent satellite observations have shown that Greenland ice sheet is losing ice mass. About a half of the mass loss is attributed to warming climate conditions, which produce greater amount of snow and ice melt. Because the influence of temperature rise on melting is more significant in the lower elevation range, Greenland peripheral ice caps and glaciers, which are physically separated from the ice sheet, are rapidly losing ice as well. However, mass balance of the ice caps and glaciers has not yet studied in detail. To better understand recent volume change in these ice caps and glaciers in Greenland, we carried satellite and field measurements on an ice cap near Qaanaaq in the northwestern Greenland.

Our study site was an ice cap located north of Qaanaaq, a village located at N 77°28’ and E 69°13’. Ice is covering an elevation rage of 250–1000 m a.s.l. over an area of 320 km^2. We measured ice surface elevation by analyzing a satellite data obtained by Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) of Advanced Land Observing Satellite (ALOS). The PRISM data were analyzed with a stereoscopic monitor and digital photogrammetric software. From this analysis, we obtained digital elevation models (DEM) in 2007 and 2009. In the summer 2012, we performed ground based kinematic GPS survey on the ice cap to measure surface elevation along an 8 km long survey route, which connects the ice cap summit and the terminus of an outlet glacier flowing down to the south. The DEMs and the field data were compared to calculate the changes in the ice thickness between these years. A comparison of DEMs in 2007 and 2009 showed that the ice thinned at a rate of 1.8 m a^{-1} as an average along the kinematic GPS survey route.

MICROBIAL COMPOSITION CHANGES IN CRYOCONITE FORMATION PROCESS IN NORTHWESTERN GREENLAND

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On the glacier surface, psychrophilic microorganisms forms brown-black color small (1mm diameter) granule called cryoconite. From microscopic observation, main structures of cryoconite are formed by filamentous cyanobacteria aggregation and these keep organic material, other microorganisms and mineral particles. Cryoconite are widely distributed on the ablation area of glacier and ice sheet in various parts of the world, and reduce the albedo and accelerate the melting of ice surface. Despite of importance of cryoconite for glacial melting effect, microbiological formation process of cryoconite is not well understand. Therefore, in order to understand microbial diversity changes during formation process, we compared microbial diversities in 8 different size of cryoconite.

In July 2011, on the middle of Qaanaaq Glacier located in Northeastern parts of Greenland, we collected the cryoconite distributed on the surface of glacier. We sorted cryoconite by each sizes (Size 1: 30-100 μm, Size 2: 100-250 μm, Size 3: 250-500 μm, Size 4: 500-750 μm, Size 5: 750-1000 μm, Size 6: over 1000 μm) using niron mesh filter and by tweezers (approximately diameter 1000 μm and 2000 μm). By stereoscopic microscopic observation, all larger diameter cryoconite (Size 3-6) are coated by black organic materials, otherwise half of size 2 and most of size 1 is non-organic attached mineral particles. Therefore, size 1 could be recognized as primary stage of microorganisms growth. Clones of eukaryotic 18S rRNA are classified into algae, cercozoa, fungi, tardingrade. Through all sizes, *Raphidonema nivale* which snow living green algae and ameba belonging into family: *Vampyrellidae* are detected. Diversity index increase with cryoconite size increase show that diversified eukaryote live in large sized and mature cryoconite. In lager cryoconite than size 3, many types of ameba and fungi are detected. Usually ameba eat the bacteria and other small microorganisms, and fungi decompose organic materials, therefore larger sized cryoconite become much hetertrophic. Result of bacterial 16S rRNA show that cyanobacteria related to *Phormidium pristleyi* known as filamentous species are detected in all sizes. Because main structure of cryoconite is composed by filamentous cyanobacteria, this species would be essential for thickening growth around the surface. Otherwise, in lager than size 3, no other bacteria can not be detected due to large amount of cyanobacterial DNA included in samples. In size 1, more than half of total clones are retrieved from glacier environment. Dominant clone is *Acidobacterium* which reported in Gulkana Glacier in Alaska, however this uncultured clone is genetically far from isolated species and we can not characterize these. Otherwise, one OTU (4 clones) is closely related to genus *Deinococcus*. *Deinococcus* is well-known species have tolerance of UV, radioactive ray and desiccation. Because cryoconite are exposed under strong UV and freeze-chew effect, *Deinococcus* can survive these harsh environment.

S3–P10

EFFECT OF MICROORGANISM ON GREENLAND ICE SHEET SURFACE TEMPERATURE CHANGE

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Greenland ice sheet holds approximately 10% of the fresh water on earth. If it melts all, sea level rises about 7.2meter. It is reported that mass of Greenland ice sheet is decreasing with temperature rising of climate change. However many climate models aren't able to simulate the recent melting of snow and ice in the Arctic including Greenland. One of the possible causes is albedo reduction of snow and ice surface by light absorbing snow impurities such as black carbon and dust and by glacial microorganisms. But there are few researches for effect of glacial microorganism in wide area. So it is important to clarify the impact of glacial microorganisms in wide area.

The purpose of this study is to clarify the effect of microorganism on Greenland ice sheet surface temperature change using satellite images and observation carried out in northwestern Greenland.

We use MODIS LST Product as ice sheet surface temperature. It estimates land surface temperature using thermal infrared bands. MODIS data is calculated the ratio of the temperature change per year. Analysis period is from December 2002 to November 2010.

Results of calculating Greenland ice sheet surface temperature change using the MODIS data, our analysis shows that it is upward trend in the whole region. We find a striking upward trend in northern and western part of Greenland. The rate is 0.33±0.03 degree Celsius per a year from 47.5° W to 49° W. While in the coastal area from 49° W to 50.7° W, the rate is 0.26±0.06 degree Celsius per a year. This large upward trend area is the same area as dark region (Wientjes and Oerleman., 2010). It is considered that the cause of the dark region is Cryoconite on the glacier. So, upward trends have relation to glacial microorganism including cryoconite. In the future, in order to clarify the relationship between temperature change and glacial microorganism, we will develop product to determine the quantity of glacial microorganism by satellite images.