Attribution of inhomogeneous glacial fluctuation in High-Mountain Asia

*Akiko Sakai[1], Koji Fujita[1]

1.Graduate School of Environmental Studies, Nagoya University

Glacier shrinkage under global warming have significant contribution to global sea level rise. Particularly in Asia, water demand exceeds supply due to rapid population growth, with glacier meltwater being a crucial water resource in some river basins. Recent studies of Asian glaciers elucidated that Karakoram glaciers were slightly gaining mass while nearby Himalayan glaciers were rapidly losing mass. These different glacial behaviors have been attributed to one of two possible causes: inhomogeneity in recent climate change9-11 or differing glacial responses to climate change. We examined both the climate forcing and the response causes, specifically, we calculate the mass-balance sensitivity to temperature change in high-mountain Asia. Then, in support of the response cause, we find a strong correlation between observed glacier-surface-elevation changes and glacial mass-balance sensitivity. It suggests that spatial heterogeneity of climate change could not be the main cause of that in glacier mass change.

Keywords: High Mountain Asia, glacier fluctuation, climate change, mass balance

Exploration of basal condition in winter by numerical glacier hydrological model -Preliminary results-

*Takahiro Abe[1], Mauro Werder[2], Martin Funk[2], Takatoshi Yasuda[3], Masato Furuya[3]

1.Department of Natural History Sciences, Hokkaido University, 2.VAW, ETH-Zurich, Switzerland, 3.Department of Earth and Planetary Sciences, Hokkaido University

Ice surface speed is a combination of ice deformation and basal sliding (including sediment deformation under the glacier). Well-known spring/summer speed-up cannot be explained by ice deformation and can only be induced by basal sliding. Faster basal sliding is attributed to higher basal water pressure, which reduces the effective pressure (ice-overburden pressure minus basal water pressure) and lubricates the interface between ice and bed. Many observations and modeling have been performed so far, and basal condition plays a key role in driving seasonal changes in ice speed.

Applying offset tracking method to satellite radar images, we found winter speed-up signals of surge-type glaciers at two distinct setting, Yukon Territory in Canada (Abe and Furuya, 2015) and West Kunlun Shan, in Northwestern Tibet (Yasuda and Furuya, 2015). In Yukon, the winter speed-up from fall to winter was seen at many surge-type glaciers during their quiescent phases. In West Kunlun Shan, seasonal modulations were identified at two active surging glaciers, which are faster from fall to winter and slower from spring to summer. These findings tell us that we have to consider some mechanisms that can increase basal water pressure even at low water flux in winter.

Werder et al (2013) developed the 2D subglacial drainage system model (GlaDS), which consists of R-channel conduit and distributed cavity system. Using this model, we have examined how the drainage system evolves from spring to summer, and how it does in the following winter, as well as effective pressure changes. We could show that the effective pressure drops at the same time as the onset of meltwater input. After that, the subglacial drainage system evolves and reaches a steady state. Immediately after the onset of the melting season, spring/summer speed-up event occurs. At the end of the season, when meltwater input ceases, the effective pressure remains a high value in winter. This is because there is no water input and the channels close due to creep closure.

In our presentation, we will show the time evolution of the drainage system during melting season, and discuss how it does in winter with some assumptions.

Keywords: Glacial hydrology, Numerical modeling, Basal condition, Winter

A study on the glacial dynamics in central Karakorum

*Muhammad Usman[1], Masato FURUYA[1]

1.Space Geodesy Research Section,Division of Earth and Planetary Dynamics, Department of Natural History Science, School of Science, Hokkaido University

The regions of high-mountains are frequently called ‘‘water towers’’ for the lowlands and a precise knowledge of the characteristics is required for their proper management. The glaciers provide water by melt down not only to the people living close to the mountains but also contribute runoff to the lowlands and recharge the river fed aquifers and finally effect the global sea level change. After Alaska and Arctic regions, the Karakorum-Himalaya (K-H) area constitutes the second largest glacial cover of the Earth. The Karakoram glaciers are fed by precipitation and avalanche. Based on previous studies, surges and slight gain in the mass of central Karakorum glaciers has been reported. The surges of individual glaciers are generally out of phase, indicating a limited climatic control on their dynamics. In the present research, the focus is to observe the effect of seasons and earthquake events on the glacial dynamics, in this region.

Keywords: SAR, Pixel Offset, Glacial Dynamics

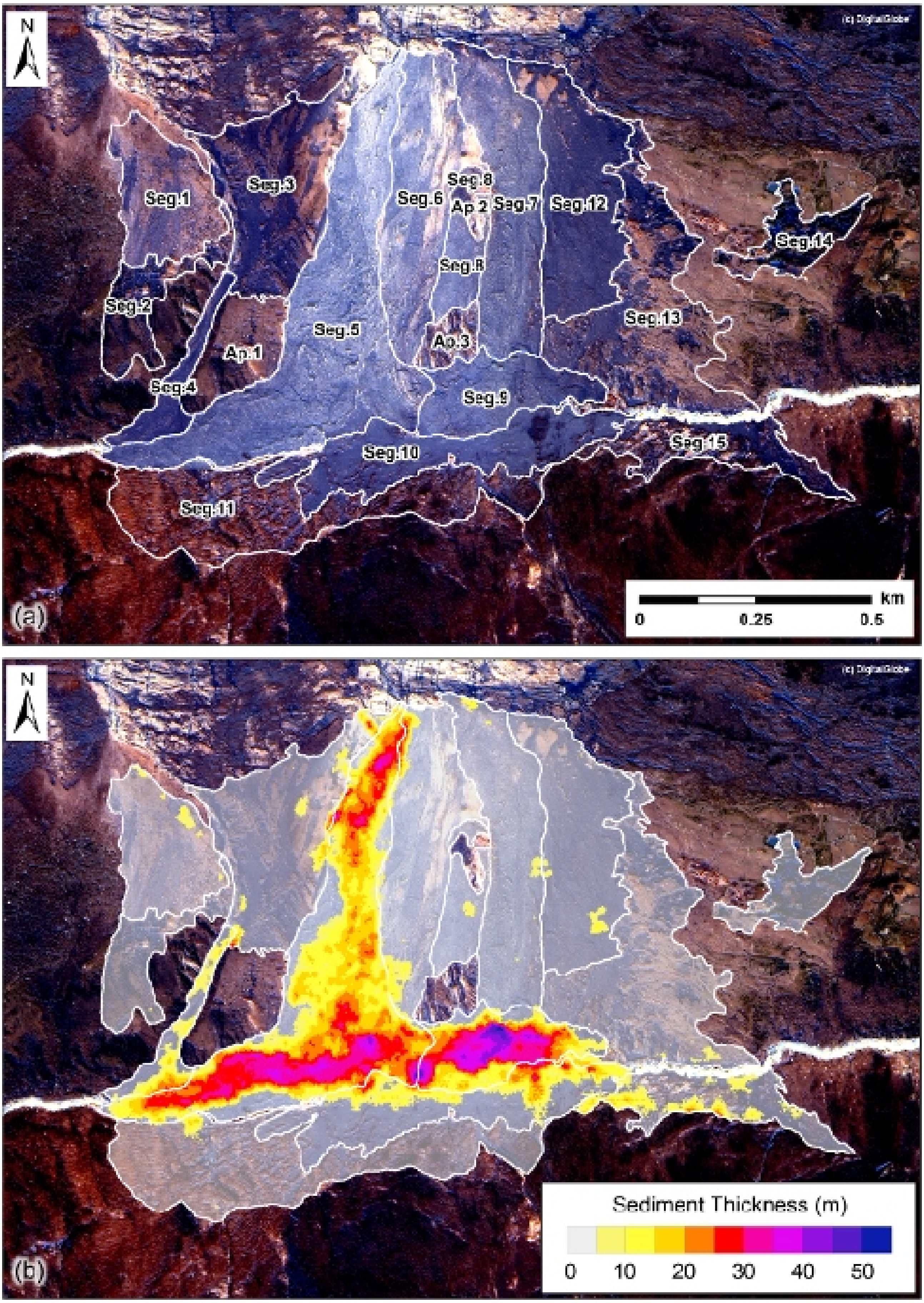
Remote sensing observations for a catastrophic avalanche collapse in Langtang induced by the Gorkha, Nepal earthquake

*Hiroto Nagai[1], Manabu Watanabe[1], Naoya Tomii[1], Takeo Tadono[1], Shinichi Suzuki[1]

1.Japan Aerospace Exploration Agency

We demonstrated an assessment of the sediments caused by a catastrophic avalanche, induced by the main shock of the 2015 Gorkha Earthquake in Nepal. Calculation of decreasing coherence and visual interpretation of amplitude images by means of the Phased Array-type L-band Synthetic Aperture Radar-2 (PALSAR-2) have a high potential for delineating the hazardous zone. These delineated outlines area highly consistent with that from a high-resolution optical image of WorldView-3 (WV-3). The delineated sediment collapse areas were estimated as 0.63 km^2 (PALSAR-2 coherence calculation), 0.73 km^2 (PALSAR-2 visual interpretation), and 1.09 km^2 (WV-3), respectively. In the WV-3 image, surface features were classified into 15 segments, with the flowing, scattering, and other characteristics implying different physical properties; the different features suggest sequential collapse from multiple sources. Differences in the surface elevations of the collapse events estimated the total volume of the sediments as 5244.5 $\times10^3$ m^3, with a error possibility between 3652.4$\times10^3$ to 10687.4$\times10^3$ m^3, most of which are distributed along the river bed and the water stream. Further elevation measurements after ice/snow melting would reveal a contained volume of melting ice and snow, which will contribute to numerical avalanche simulation and source considerations.

Keywords: the Gorkha, Nepal earthquake, avalanche, PALSAR-2, ALOS, WorldView-3, remote sensing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(a)
Sediment Thickness (m)
0
10
20
30
40
50
(b)

Characteristics of cryoconite on the Lewis Glacier in Mt.Kenya Africa

*Kenshiro Miyauchi[1], Jun Uetake[2], Nozomu Takeuchi[1]

1.Graduate school of Science, Chiba University, 2.National Institute of Polar Reaserch

There are glaciers in the high mountains around the equator of East Africa because of low temperature throughout the year and heavy snowfall in wet season. As glaciers and ice sheets worldwide have shrunk recently, the tropical glaciers in Africa has also been reported to shrink significantly. Although melting of glaciers is usually believed to be caused by temperature rise with global warming, it is also caused by decrease of the surface albedo of glaciers. The albedo reduction is cause by impurities in snow and ice, such as cryoconite. Cryoconite is dark-colored materials consisting of mineral particles and organic matter on glacier surface. These mineral particles and organic matter often form spherical aggregates called cryoconite granules. The dark coloration of cryoconite is due to humic substances produced by bacterial activity. As cryoconite decreases surface albedo of glacier and accelerates melting of the glacier, it is important to know their physical, chemical, and biological characteristics. However, there is little information of cryoconite on African glaciers. This study aims to describe characteristic of cryoconite on Lewis glacier in Mt.kenya, Africa.
Microscopy of the cryoconite revealed that its characteristics were distinctive between the lower and upper areas of the glacier. Cryoconite consisted of mineral particles and filamentous cyanobacteria, but cryoconite granules were formed only in the lower site. The amounts of organic matter in cryoconite were more abundant in the lower site than in the upper site. Optical analyses of cryoconite showed that spectral reflectance of cryoconite in the lower site was low and constant in the visible and near-infrared wavelength range while that in the upper site was relatively higher. The difference is probably due to effect of organic matter, which can darken cryoconite. The reflectance of mineral particles in cryoconite was similar to that of cryoconite in the upper part, indicating less effect of organic matter on the reflectance. The factors causing the different characteristics of cryoconite between upper and lower sites are uncertain, but they may affect surface albedo and melting of the glacier surface.

Keywords: Cryoconite, East Africa

The cell morphology and pigment composition of red snow algae in Japanese and Alaskan mountain ranges

*Tomomi Nakashima[1], Nozomu Takeuchi[1], Yukiko Tanabe[2], Masaharu Tsuji[2], Jun Uetake[2], Kenshiro Miyauchi[1], Chika Okamoto[1]

1.Graduate School of Science, Chiba University, 2.National Institute of Polar Research

Snow algae are photosynthetic microbes that adapt to low temperature environment and grow on snow and ice surface. When they bloom, they can change color of snow from white to red or green. This phenomenon is known as “red snow” or “green snow”. The coloring snow is caused by various pigments in algal cells. The algal pigments mainly consist of chlorophylls and carotenoids and have physiologic functions in their cells. Variation in snow color may be associated with environmental conditions and/or taxa of the algae. Red snow can be seen at snowfield or glaciers all over the world. However, there has been still limited information of their pigment composition and relationship with the environmental condition. In this study, we analyzed microscopic cell morphology and pigment compositions of red algal snow collected in the melting season of Japanese and Alaskan mountain regions. We aim to understand the relationship between environmental conditions and pigments of algae in each region.

Red snow sample collections were carried out in Mt. Tateyama, Toyama prefecture, Japan in June and July 2015, and on Gulkana Glacier in Alaska Range in August 2015. Algae in the samples were observed with an optical microscope. To analyze pigment composition, another samples of snow algae were filtered through a grass-fiber filter and pigments were extracted with N, N-dimethylformamide as a solvent, and then absorption spectra were measured. Pigment compositions were also analyzed using high-pressure liquid chromatography (HPLC).

Microscopy of the red snow revealed that there were various morphologies of algal cells. Red sphere, orange sphere and green sphere cells accounted for a high proportion. Green oval and orange oval cells were also present but had low abundance. Small amounts of red sphere cells, which crust shaped like petals, and red oval cells were only observed in the samples of Gulkana Glacier. Absorption spectra of pigment extracted from red snow were different among the samples and can be classified into 4 types (Type A~D) based on the absorption features. The HPLC pigment analysis showed that there were at least three major pigments (Chlorophyll *b,* Astaxanthin and Lutein) in all spectral types, and no difference in their composition among the types. The HPLC analysis revealed that the astaxanthin had two chemically distinct structures: free and ester bodies. In addition, the content of astaxanthin differed among the spectral type: a high proportion of ester body were present in Types A and C, free body and ester body were present in Type B, a high proportion of free body were present in Type D.

There was no difference in cell morphologies, but significantly different in pigment composition between Japanese and Alaskan red snow. Four spectral types (Type A~D) were present in Japanese red snow, while Type A was only present in Alaskan snow. The results indicate that red snow contains more diverse algal cells in Japan compared with in Alaska in terms of pigment compositions, probably due to different species and environmental conditions.

Keywords: snow algae, red snow, pigment composition, Astaxanthin

Can snow impurities be detected on Greenland ice sheet by satellite remote sensing?

Teruo Aoki[1], Tomonori Tanikawa[1], Masashi Niwano[1], Hiroshi Ishimoto[1], Masahiro Hori[2], *Rigen Shimada[3]

1.Meteorological Research Institute, 2.Japan Aerospace Exploration Agency, 3.Chiba University

Warren (2013) pointed out that attempts to use satellite remote sensing to estimate the black carbon (BC) content of snow are unlikely to be successful, except in highly polluted industrial regions, with the reasons as follows. The possible albedo reductions for the shortwave and visible wavelengths due to the typical concentration of BC (3–30 ppbw) in remote areas of the Northern Hemisphere are 0-1 % and 0-2 %, respectively for cold fine-grained snow, and 0–3% and 1–6%, respectively for melting snow. Compareing to these small albedo reductions typical errors in surface albedo inferred from satellite measurements are comparable (a few percent), which are attributed to uncertainties of undetected thin clouds, atmospheric aerosols, vertical profile of snow grain size, surface roughness, and subpixel heterogeneity of the thin and patchy snow cover as well as satellite sensor calibaration and bidirectional reflectance distribution function (BRDF) model of snow surface used in the retrieval algorithm.
We are challenging to develop the satellite remote sensing algorithm to retrieve snow impurities on Greenland ice sheet (GrIS) to estimate the possible contribution to the recent albedo reduction. The algorithm is based on look-up table method in which BRDFs are tabled as functions of solar and satellite zenith angles and relative azimuth angle, snow impurity concentration and snow grain size. Our algorithm employed a two-snow layer model by which the effect of vertical inhomogeneity of the snow parameters is taken into account. To examin the possibility of satellite remote sensing of snow impurities with our algorithm on GrIS, we estimated the albedo reduction due to BC on GrIS with physically based snow albedo model (Aoki et al., 2011). The albedo reduction for melting snow for the BC concentration range previously measured (0.55-20 ppbw) on GrIS is 0.02-2.6% and 0.03-4.8% for the shortwave and visible wavelengths, respectively. On GrIS there are no uncertainties of subpixel heterogeneity of the thin and patchy snow cover. The surface roughness is also very small in summer season over acculuration area on the ice sheet. The atmospheric aerosols effect are generally small. Hence, the major uncertainties are satellite sensor calibaration, thin cloud effect, and BRDF model used in the algorithm. These issues were improved by employing the latest MODIS C6 data set, new cloud detection algorithm (Chen et al., 2014), and Voronoi snow shape model for BRDF calculation in our algorithm. The retrieval results of monthly mean BC-equivalent concentration of snow impurities from 2000 to 2015 on GrIS in summer season were 8-34 ppbw which are same or somewhat higher than the previous in-situ measurements (0.55-20 ppbw). However, those in spring reason were too high (29-383 ppbw) compared to the in-situ measurements. The inter-annual trend of the concentration in summer was small increase of 10-30%/decade. From this result, there is a possibility to detect snow impurity on GrIS in summer season by satellite remote sensing.

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Keywords: snow impurities, black carbon, albedo, satellite remote sensing, Greenland ice sheet

Metamorphism of layered firn at Dome Fuji, Antarctica: Evolution of relations between Near-infrared reflectivity and the other textural/chemical properties

*Shuji Fujita[1,2], Kumiko Goto-Azuma[1,2], Hiroyuki Enomoto[1,2,3], Kotaro FUKUI[1,7], Motohiro Hirabayashi[1], Akira Hori[3], Yu Hoshina[4,8], Yoshinori Iizuka[5], Yuko MOTIZUKI[6], Hideaki Motoyama[1,2], Fumio Nakazawa[1], Shin Sugiyama[5], Sylviane Surdyk[1], Kazuya Takahashi[6]

1.National Institute of Polar Research, Research Organization of Information and Systems(ROIS), 2.Department of Polar Science, The Graduate University for Advanced Studies (SOKENDAI), 3.Kitami Institute of Technology, 4.Nagoya University, 5.Institute of Low Temperature Science, Hokkaido University, 6.RIKEN, 7.Now at: Takteyama Caldera Sabo Museum, 8.Now at: National Institute for Environmental Studies Center for Global Environmental Research

Evolution of polar firn was investigated at sites at Dome Fuji, to better understand signals of deep ice cores. Using samples from a 4-m-deep pit and a 122-m-deep core, relations between major textural and chemical properties, such as Near-infrared light reflectivity R, density ρ, microwave dielectric anisotropy $\Delta\varepsilon$, and concentration of major ions, were investigated at a depth range of 0 –122 m, with high spatial resolutions. At the near-surface depths, we found: (i) Fluctuations of R , ρ, and $\Delta\varepsilon$are positively correlated; (ii) $\Delta\varepsilon$ranges 0.03 –0.07 at depths immediately below the snow surface at ~0.1 m; (iii) These properties of R, ρ, and $\Delta\varepsilon$are not correlated to major ions. With increasing depths during reported phenomena of density crossover, the positive corrlation of R to $\Delta\varepsilon$persistently remains with a slight decrease. Besides, R becomes weakly negatively correlated to concentration of Na^+ which is the sea salt marker. These facts suggest that textural features of the near-surface depths are preserved in both R and $\Delta\varepsilon$at a depth range immediately below bubble-close-off, being weakly affected by reported softening of ice by Cl- ions. We therefore suggest that optically layerd features in ice cores are directly linked to the metamorphism.

Keywords: Antarctica, snow, firn, metamorphism, ice sheet

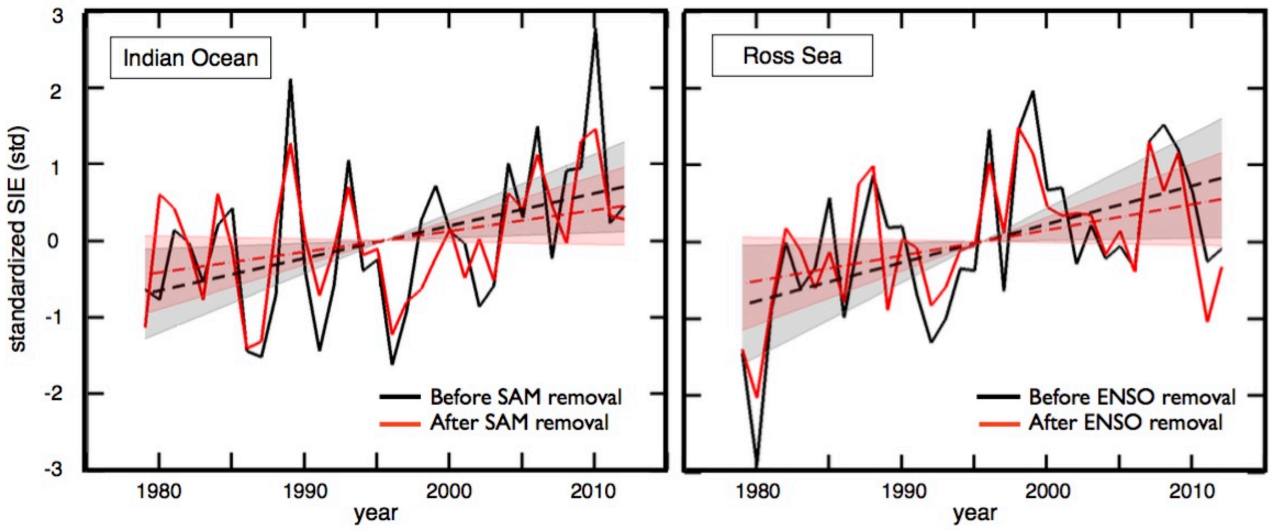
The relationship between natural climate modes of variability and Antarctic sea ice interannual variability/trends

*Tsubasa Kohyama[1], Dennis L. Hartmann[1]

1.Department of Atmospheric Sciences, University of Washington

The relationship between climate modes and Antarctic sea ice is explored for interannual variability and trends. On the interannual time scale, El Niño Southern Oscillation (ENSO) and Southern Annular Mode (SAM) are important, but a large fraction of sea ice variance can also be explained by Rossby wave-like structures in the Drake Passage region. After regressing out the sea ice extent variability associated with ENSO, the observed positive sea ice trends in Ross Sea and Indian Ocean during the satellite era become statistically insignificant. Regressing out SAM makes the sea ice trend in the Indian Ocean insignificant. Thus, the positive trends in sea ice in the Ross Sea and the Indian Ocean sectors may be explained by the variability and decadal trends of known interannual climate modes.

Keywords: Antarctic sea ice, El Niño Southern Oscillation, Southern Annular Mode



Comparison of thermodynamics solvers in the polythermal ice sheet model SICOPOLIS

*Ralf Greve[1], Heinz Blatter[1,2]

1.Institute of Low Temperature Science, Hokkaido University, 2.Institute for Atmospheric and Climate Science, ETH Zurich, Switzerland

In order to model the thermal structure of polythermal ice sheets accurately, energy-conserving schemes and correct tracking of the cold-temperate transition surface (CTS) are necessary. We compare four different thermodynamics solvers in the ice sheet model SICOPOLIS (www.sicopolis.net). Two exist already, namely a two-layer polythermal scheme (POLY) and a single-phase cold-ice scheme (COLD), while the other two are newly-implemented, one-layer enthalpy schemes, namely a conventional scheme (ENTC) and a melting-CTS scheme (ENTM) (Blatter and Greve, 2015, Polar Sci. 9, 196-207). The comparison uses two scenarios of the EISMINT Phase 2 Simplified Geometry Experiments (Payne and others, 2000, J. Glaciol. 46, 227-238), one with no-slip conditions at the base and one with basal sliding. In terms of temperate ice layer thickness, CTS positioning and smoothness of temperature profiles across the CTS (a requirement for the assumed case of melting conditions), the POLY scheme performs best, and thus its results are used as a reference against which the performance of the other schemes is tested. Both the COLD scheme and the ENTC scheme fail to produce a continuous temperature gradient across the CTS, and both overpredict temperate ice layer thicknesses to some extent (the COLD scheme more). In the ENTM scheme, a continuous temperature gradient is explicitly enforced. This scheme is more precise than ENTC for determining the position of the CTS, while the performance of both schemes is good for the temperature/water-content profiles in the entire ice column. Therefore, the one-layer enthalpy schemes ENTC and ENTM are viable, easier implementable alternatives to the POLY scheme with its need to handle two different numerical domains for cold and temperate ice.

Keywords: Ice sheet, Thermodynamics, Polythermal ice, Enthalpy method, Modeling

Accuracy of the SMAP model-simulated snow density, temperature, and grain shapes at Sapporo, Japan

*Masashi Niwano[1], Teruo Aoki[1], Katsuyuki Kuchiki[1], Sumito Matoba[2], Yuji Kodama[3], Tanikawa Tomonori[1]

1.Meteorological Research Institute, 2.Institute of Low Temperature Science, Hokkaido University, 3.National Institute of Polar Research

A multi-layered physical snowpack model has a special feature that it can calculate temporal evolution of detailed snow internal stratigraphy. This characteristic is a considerable advantage of such a model, because it is impossible for a typical land surface model to simulate realistic layer structure of the snowpack. In the present study, we evaluated a 1-D multilayered physical snowpack model SMAP (Snow Metamorphism and Albedo Process) in terms of snow density, temperature and grain shapes using in-situ data obtained at Sapporo (43°05'N, 141°21'E, 15 m a.s.l.), Japan from the 2005 to 2015 winters (November to April). The model was driven by quality controlled 30-min averaged data for air temperature, relative humidity, wind speed, surface pressure, snow depth, liquid precipitation, downward and upward shortwave radiant flux, downward longwave radiant flux, and ground surface soil heat flux measured with an AWS installed at Sapporo.

Before investigating accuracy of the model-simulated snow internal physical properties, the SMAP model was evaluated in terms of column-integrated snow water equivalent (SWE) and snow surface temperature in order to check the mass and surface energy balances are calculated adequately. At Sapporo, SWE data was obtained by snow pit measurements, while snow surface temperature was observed with the AWS. Comparison of observed and simulated column-integrated SWE revealed that the model tended to underestimate SWE (mean error; ME was −19 mm); however, root mean square error (RMSE) was 34 mm, and these scores are better than those for simulations driven by not snow depth but precipitation (ME was less than −25 mm and RMSE was more than 40 mm). It suggests that the correction technique for precipitation measurements considering catch efficiency of a rain gauge is still insufficient. As for snow surface temperature simulated by the SMAP model, systematic overestimation nor underestimation was not found (ME = 0.4 ºC), and obtained RMSE was also in a sufficiently low (1.6 ºC). Overall, these results assure that the mass and surface energy balances of the snowpack at Sapporo were modeled and calculated reasonable enough by the SMAP model.

In the model validation in terms of snow internal physical properties, accuracy of the model-simulated snow density and temperature were investigated first using the in-situ measured data from snow pit works. Validation results indicated that the model tended to underestimate snow density (ME = −51 kg m^{-3}) and overestimate snow temperature (ME = 0.4 ºC); however, RMSE for both properties were sufficiently small (88 kg m^{-3} and 1.6 ºC, respectively). In order to permit higher precision of the model, it would be necessary to develop physically based schemes for new snow density and effective thermal conductivity of the snowpack. Next, snow grain shapes simulated by the SMAP model was evaluated using the manually measured data obtained from snow pit works. During accumulation period (November to February), precipitation particles, decomposing and fragmented precipitation particles, rounded grains, and melt forms were mainly observed at Sapporo. Generally, they were stratified from the surface to the bottom of the snowpack. On the other hand, during ablation period (March and April), melt forms were principally observed in the snowpack every winter period. Basically, these above mentioned features could be reproduced by the model; however, faceted crystals and depth hoar, which are generally developed through the temperature gradient metamorphisms, were not simulated by the model at all. It suggests that improving physical processes under the temperature gradient metamorphism, and reconsidering the method to diagnose snow grain shape from snow physical properties such as geometric grain size and water content are

quite necessary.

Keywords: the SMAP model, snow metamorphism, snow internal physical properties

Measurements of the coefficient of dynamic friction for Cross-country skiing

*Tomomi Teraoka[1], Hirokazu Fujiwara[1], Natsumi Kamada[1], Yuka Ogino[1], Yoko Hasegawa[1], Emi Akashi[1], Nobuyasu Naruse[1,2], Yukihiro Takahashi[1,3]

1.Global Science Campus, Hokkaido University, 2.Institute for the Advancement of Higher Education, Hokkaido University, 3.Graduate School of Science, Hokkaido University

In cross-country skiing, the result of competition depends on the preparation whether we can prepare the skiing equipment having an appropriate friction between the ski and the snow surface. The previous researches on the friction reported that coefficient of dynamic friction (μ) is associated with the material and the shape of ski. The selection of the shape and materials is possible to prepare in advance. On the other hand, the wax also related to the μ, has been selected empirically by the weather conditions. According to the previous report, μdepends on temperature and snow temperature; μis under (over) 0.05 (0.10) when the temperature is one (seven) degrees and snow temperature is minus four (zero) degrees, respectively. The selection of optimum wax should be judged form the physical results of quantitative measurements. It would be desirable to measure the μat the site of the venue. Although there have been reports of the μmeasurements in the laboratory, the difficulty arises when we use in the venues because the instruments are too large (6m length). Our study aims 1) to develop a compact instrument to measure the coefficient of dynamic friction between ski and snow surface, and 2) multi-point meteorological observations on the venue for cross-country skiing. This study focused on 1).
The ski carrying on the weight of 5Kg is connected to the force gauge. To develop a compact instrument, it has become the 90 degrees bending structure by pulley. The weight was moved 1m at a constant speed using an electric reel. The tension measured by force gauge was recorded by intervals of one tenth second. The average tensile force as F, we deduced the coefficient of dynamic friction μ, using the equation of $\mu = F / 5\ (Kg) \times 9.8$.

Keywords: cross-country skiing, coefficient of dynamic friction

