InitMIP-Antarctica experiments with the ice sheet model SICOPOLIS

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The Ice Sheet Model Intercomparison Project for CMIP6 (ISMIP6) brings together a consortium of international ice sheet and climate models to explore the contribution from the Greenland and Antarctic ice sheets to future sea level rise. For such projections, initialisations are required that provide initial states of the respective ice sheet. InitMIP-Antarctica is an early initiative within ISMIP6 in order to explore this issue for the Antarctic ice sheet across a variety of models and initialisation techniques. We contribute to InitMIP-Antarctica with the ice sheet model SICOPOLIS and a spin-up-type initialisation, that is, a paleoclimatic simulation over 135 ka until the present. A major new component of the model is a physically-based parameterisation of ice shelf basal melting. In this parameterisation, basal melting of ice shelves is computed as a function of both the depth of ice below mean sea level and far-field ocean temperatures. The parameterisation is tuned differently for eight Antarctic sectors in order to achieve reasonable agreement with the modern spatial distribution of ice shelf basal melting. InitMIP-Antarctica also comprises three future climate scenarios, all to be run over 100 a: ctrl (present-day climate), asmb (prescribed schematic surface mass balance anomaly) and abmb (prescribed schematic basal melting anomaly under ice shelves). We present and discuss the performance of the spin-up in terms of agreement between simulated and observed present-day geometry and flow. Further, we investigate the response of the Antarctic ice sheet to the three future climate scenarios.

Keywords: Antarctica, Ice sheet, Ice shelf, Basal melting, Climate change, Modelling

Climate dependent contrast in surface mass balance in East Antarctica over the past 216 ka

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Documenting past changes in the East Antarctic surface mass balance is important to improve ice core chronologies and to constrain the ice-sheet contribution to global mean sea-level change. Here we reconstruct past changes in the ratio of surface mass balance (SMB ratio) between the EPICA Dome C (EDC) and Dome Fuji (DF) East Antarctica ice core sites, based on a precise volcanic synchronization of the two ice cores and on corrections for the vertical thinning of layers. During the past 216 000 a, this SMB ratio, denoted SMB_{EDC}/SMB_{DF}, varied between 0.7 and 1.1, being small during cold periods and large during warm periods. Our results therefore reveal larger amplitudes of changes in SMB at EDC compared with DF, consistent with previous results showing larger amplitudes of changes in water stable isotopes and estimated surface temperature at EDC compared with DF. Within the last glacial inception (Marine Isotope Stages, MIS-5c and MIS-5d), the SMB ratio deviates by up to 0.2 from what is expected based on differences in water stable isotope records. Moreover, the SMB ratio is constant throughout the late parts of the current and last interglacial periods, despite contrasting isotopic trends.

Keywords: Antarctica, precipitation, ice core

Improvement in dating of the Dome Fuji ice core using O_2/N_2 (80-165 ka)

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The Dome Fuji ice core preserves valuable information on the climatic changes over the last 720 kyr, which enables to investigate forcings and mechanisms in the Earth's system. Precise ice core chronology is essential to determine sequences and durations of climate events, and to examine the phasing with forcings and other paleoclimatic records. Orbital scale variations in O_2/N_2 ratio of occluded air in the Vostok ice core are similar to those in local summer solstice insolation[1)]. By using this similarity, Kawamura et al. (2007) synchronized the O_2/N_2 variations in the Dome Fuji and Vostok ice cores with local summer insolation, and established chronology for the ice cores with accuracy generally better than ±2000 years (DFO-2006). However, it was recently pointed out by using detailed age matching between Dome Fuji, EDC and Chinese speleothem records that the DFO-2006 chronology around 90 kyr BP is too old by ~3 kyr[3)]. Possible cause of this error is dislocation of O_2/N_2 peaks because of large noise in the O_2/N_2 record. Recently, O_2/N_2 variations between 300 and 800 kyr has been reconstructed from EPICA Dome C ice core[4),5)], however, their records do not always show similar variation with local summer insolation. Thus, their O_2/N_2 record was not used for orbital tuning. These recent studies motivate us to examine the reliability of age markers based on the O_2/N_2 ratio of Dome Fuji ice core. In this study, we reanalyzed O_2/N_2 ratio in the first Dome Fuji ice core for 1200 –1974 m, which covers 80 –165 kyr BP.

Fractionation of O_2/N_2 ratio occurs from ice surface during storage[6)]. Because the first Dome Fuji core has been stored for about 20 years, we expect fractionated O_2/N_2 near the surface of ice. We thus tested different thickness of surface shaving, and found that shaving-off of about 1 cm of surface (and only using the inner part of the ice) is required for precise measurements for the ice samples below 1200 m depth. Because of this careful examination and improvement in methodology, our new O_2/N_2 data set on average do not indicate preferential loss of O_2. Reproducibility of O_2/N_2 ratio are ±0.425‰ for 1200 –1440 m, ± 0.263‰ for 1440 –1640 m and ±0.088‰ for 1640 –1974 m, respectively.

We find large scatter in the new O_2/N_2 data between 1200 and 1440m (typical amplitude: ~6 –10 ‰). This depth range is just below bubble-clathrate transition zone where both air bubbles and clathrate hydrates were observed by microscopes. To investigate the cause of this scatter, we conducted a high-resolution continuous analysis at 2.5-cm resolution for 1399.030 –1399.484 m. The O_2/N_2 shows unexpected wave-like variation from -17 to -9 ‰with a wavelength of ~18 cm. The amplitude is comparable to the typical scatter in the O_2/N_2 data set from the discrete 11-cm samples. If we take 11 cm average of the high-resolution data, the average ratio only varies by ±~1‰, which is insufficient to explain the scatter in the discrete data. Our current speculation is that the wavelength and/or amplitude of the O_2/N_2 variations in other depths may be larger than those in the investigated section, and that O_2/N_2 of 11 cm samples can also vary by up to 10 ‰.

Our new Dome Fuji O_2/N_2 record confirms strong correlation with local summer insolation. Assuming no phasing between O_2/N_2 and insolation variations, O_2/N_2 data was smoothed by a low-pass filter with the cut-off period of 16.7 –10.0 kyr, and then tuned with local summer solstice insolation by peak-to-peak matching[2)]. Because the scatter in 1200 –1440 m does not reflect insolation signal, we rejected data

points as outliers if they deviate from fitting curve by more than 3.3‰.

Compared with the DFO-2006 chronology, the new age scale (DF-2016) is younger around 90 and 130 kyr BP, while it is older around 150 kyr BP. There were sharp steps in annual layer thickness (calculated from depth –age relationship) at 94.2 and 150.3 kyr BP from DFO-2006[3)], but these unnatural steps disappeared in that from DF-2016. The DF-2016 and speleothem (U-Th) age scales agree within 1000 yrs. These results indicate that the revised chronology greatly improved from the DFO-2006 chronology.

To summarize, even though large O_2/N_2 fractionation occurs near the surface of the ice core over two decades of storage, the original O_2/N_2 ratio is preserved in the inner part of ice if it is stored at -50˚C, and it can be precisely measured by sufficiently removing the ice surface. Accurate chronology can be constructed by orbital tuning of the high quality O_2/N_2 ratio from the Dome Fuji ice core with local summer insolation.

1) Bender, M. L., EPSL, 2002. 2) Kawamura et al., Nature, 2007. 3) Fujita et al., CP, 2015. 4) Landais et al., CP, 2012. 5) Bazin et al., CP, 2016. 6) Ikeda-Fukazawa et al., EPSL, 2005.

Keywords: ice core, Dome Fuji, chronology, O2/N2

Seafloor topography surveys around the East Antarctic continental margin

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Seafloor topography is fundamental information for marine research. However, the detailed topography in the Southern Ocean has not generally been understood yet. Especially, seafloor topography around the Antarctica margin covered by sea ices has been unknown. The Antarctic continental margin is the boundary area between ice sheet and ocean and the bathymetry around this region is essential element to understand the interaction between ice sheet and ocean as well as the tectonic evolutions. Single beam echo soundings have been conducted by old icebreaker Shirase, and multi beam echo-sounder has been installed on new icebreaker Shirase and the swath bathymetry data have been obtained since the 51 st Japanese Antarctic Research Expedition (2009-2010). Moreover, sub-bottom profiler has also been equipped on the new icebreaker. Unknown seafloor topography and sub-bottom profiles under sea ices around the Antarctic margin such as continental shelf and sloop are becoming clear, and those data are used as basic data for the Antarctic bottom water channels as well as paleoenvironment studies. Those data combined with magnetic and gravity anomalies have also contributed to the study related to the continental breakup. But there is a limit to observations by the icebreaker. The surveys under sea ices using ROV and/or AUV should be considered. We introduce the present status of multi beam echo-sounder and sub-bottom profiler obtained around the East Antarctic continental margin by icebreaker Shirase and future development of research using ROV and/or AUV are discussed.

Keywords: seafloor topography, East Antarctica, continental margin

Sea ice expansion in Antarctic warming events in the glacial Southern Ocean

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The Southern Ocean has played an important role in the evolution of the global climate system. Area of sea ice shows a large seasonal variation in the Southern Ocean. Sea ice coverage on sea surface strongly affects the climate of the Southern Hemisphere through its impacts on the energy and gas budget, on the atmospheric circulation, on the hydrological cycle, and on the biological productivity. However, millennial-scale sea ice coverage and its impacts are not well understood. Here we show high-resolution records of sea ice-rafted debris (SIRD) and diatom assemblage to reveal a rapid change of sea ice distribution in the glacial Southern Ocean. The depositions of rock-fragment SIRD excluding volcanic glass and pumice were associated with increasing of sea-ice diatoms, suggesting that the millennial-scale events of cooling and sea-ice expansion were occurred in the glacial South Indian Ocean. The extent of sea ice in the Southern Ocean is occurred during the Antarctic isotope maximum (AIM) events, which is partly linked with the Heinrich Events in the Northern Hemisphere.

Keywords: Southern Ocean, sea-ice, Antarctic warming events, Heinrich Event

Radiolarian changes since the last glacial period in the Conrad Rise and their relation to the oceanic environments

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It is well known that the oceanic circulation in the Southern Ocean plays an important role in the global climate changes. For reconstruction of the past ocean circulation in the Southern Ocean, siliceous microfossils such as diatoms and radiolarians preserved abundantly in deep-sea sediments are widely used as paleoceanographic proxies. Fossil assemblages of diatoms (phytoplankton) indicate usually surface water environments, while radiolarians (zooplankton) can be used as indicator for not only surface but also intermediate and deep water conditions because of their discrete habitat depths for each species. In this study, quantitative analysis of radiolarians was conducted for core COR-1bPC (54°S) from Conrad Rise in the Indian Ocean sector of the Southern Ocean.

Keywords: paleoceanography, biogenic productivity, intermediate water

Toward understanding the cause and mechanism of catastrophic collapse of Antarctic ice sheets during the last interglacial

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Ongoing global warming could cause various influences to our lives. One of the most serious concerns caused by the global warming is sea level rise due to large scale collapse and melting of polar ice sheets. Recent observation revealed that the fastest melting rate of polar ice sheets ever observed is ongoing and there is growing concern of greatly rise of sea level in the future. Knowledge of sea level fluctuations in the past warm period provides useful information to better understand future sea level changes. Geological records have shown that sudden and abrupt rises in sea level (6 m rise within hundreds of years) were happened during the last interglacial (13,000-11,500 years ago) when global mean sea surface temperature (SST) was slightly higher (0.5 degree C) than the preindustrial level. If this were really happening, there is a critical ice sheet stability threshold resulting in the catastrophic collapse of polar ice sheets and substantial rapid sea-level rise in the interglacial climate condition. Since the Greenland ice core record showed a 2 m eustatic component from the Greenland ice sheet during the last interglacial, the Antarctic ice sheet greatly contributed to eustatic rise of sea level at that time. Given that the current global mean SST already reached the last interglacial level, it is urgent issue to evaluate whether massive collapse of the Antarctic ice sheets could occur in the future. For that purpose, it is necessary to investigate whether a massive collapse of the Antarctic ice sheet actually happened during the last interglacial or not. However, variability of the Antarctic ice sheets during the period has not been investigated. In this presentation, I will talk about an importance of research on the variability of the Antarctic ice sheets during past warm period such as the last interglacial to better understand the presence of “tipping point” into the new and irreversible melt regime of Antarctic ice sheets.

Keywords: Antarctic ice sheet, last interglacial, sea level rise

Amundsen Sea simulation with optimized ocean, sea ice, and thermodynamic ice shelf model parameters

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The ice shelves and glaciers of the West Antarctic Ice Sheet (WAIS) are melting and thinning rapidly in the Amundsen Sea (AS) and Bellingshausen Sea (BS), with consequences for global sea level rise and ocean circulation. First, approximately 10% of the observed sea level rise has been attributed to the thinning of WAIS between 2005 and 2010. Second, the melting of ice shelves in the AS and BS will freshen the shelf water locally as well as downstream in the Ross Sea (RS), which may lead to a change in the characteristics of Antarctic Bottom Water formed in the RS and thus influence the global thermohaline circulation.

Agreement between model results and observations are crucial for understanding and projecting these impacts on the current and future climate. Thus, we aim to conduct model optimization for a regional Amundsen and Bellingshausen Seas configuration of the MITgcm. Currently, we have adjusted a small number of model parameters to better fit the available observations during the 2007-2010 period using trial-and-error adjustment and a Green’ s function approach. As a result of adjustments, our model shows significantly better match with observations than previous modeling studies, especially for Winter Water (WW). Since density of sea water depends largely on salinity at low temperature, this is important for assessing the impact of WW on Pine Island Glacier melt rate. We also conduct several sensitivity studies, showing the impact of surface heat loss on the thickness and properties of WW.

Our work is a first step toward improved representation of ice-shelf ocean interactions in the ECCO (Estimating the Circulation and Climate of the Ocean) global ocean retrospective analysis. In this presentation, we briefly explain our overall project and present some preliminary results pertaining to sensitivity simulations using high resolution (2 km) configuration and adjoint sensitivity simulations.

Keywords: Amundsen/Bellingshausen Sea, Ice shelf-ocean interaction, Circumpolar Deep Water

Observations of ice tongue-ocean interaction at Shirase Glacier

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Shirase Glacier Tongue (SGT) is a thick floating slab of ice that forms where the glacier flows down onto the ocean surface at the southern closed-section of Lutzow-Holm Bay (LHB) off Enderby Land, East Antarctica. Compared with other major ice shelves/tongues around Antarctica, SGT is smaller in area but its basal melt rate was estimated to be relatively high at a rate of ~7 m per year (Rignot et al., 2013) based on presence of warm deep water. Although comprehensive hydrographic observations in LHB is indispensable for understanding the SGT-ocean interaction, they are extremely limited, with exception of those conducted by wintering party of the 31st Japanese Antarctic Research Expedition (JARE) in 1990/92. Detailed analysis of the JARE-31 winter hydrographic observations suggests a 3-dimenstional circulation, associated with the SGT-ocean interaction, that comprises: (1) warm modified CDW (Circumpolar Deep Water) flows southward at the deep layer of submarine canyon that leads into the region beneath SGT, (2) mCDW meets to melt the base of SGT, and (3) mixture of mCDW and basal melt water exports northward at subsurface layer.
To explore in detail the SGT-ocean interaction, summer comprehensive hydrographic observations in LHB are now in progress during JARE-58 in 2016/17 under the project called ROBOTICA. In this talk, preliminary results from the JARE-58 hydrographic observations are also presented.

Keywords: Shirase Glacier Tongue, basal melt, Circumpolar Deep Water

Breakup of land-fast sea ice in Lutzow-Holm Bay, East Antarctica and its teleconnection to tropical Pacific

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A large land-fast sea ice breakup occurred in 2016 in Lutzow-Holm Bay, East Antarctica. The breakup caused calving from the Shirase Glacier Tongue (SGT), which is otherwise held back by the ice. Although similar breakups and calving have been observed in the past, the timing and magnitudes are not well-constrained. We analyzed the ice's breakup latitude during 1997-2016 to investigate the variables controlling breakup and examine correlation with local calving for a longer period. The breakup latitude had a persistently high correlation with sea-surface temperature (SST) in the tropical Pacific, which exceeds correlations with local atmospheric variables. The multi-decadal variability of the tropical SST can explain the multi-decadal variation of the calving front of SGT from the 1950s through the breakup of fast ice. The SST-regressed breakup latitude can potentially explain 5 out of 6 SGT calving events from the mid-20th century, including its frontal retreat in the 1980s. Our proposed teleconnection between tropical SST and Antarctic sea ice could lead to better predictions of breakup and might impact the glacier flux for a wider region.

Standing meanders of the Antarctic Circumpolar Current as observed by Argo floats

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Eddies in the Southern Ocean have been quantified by such measures as eddy kinetic energy and vertical eddy momentum transfer. Recent studies suggest length of streamlines can be used to characterise the eddy activity. The Antarctic Circumpolar Current, the greatest ocean current in the world, is known to have steady transport under increasing westerly wind stress in interdecadal time scales. From eddy resolving simulations, it has been hypothesised that some adjustment to the wind occurs on and around standing meanders of the ACC. One manifestation of the adjustment is the lengthening of streamlines.
I used trajectory and hydrography data from Argo floats to study this behaviour in observed data. Seven major meanders were identified along the ACC. Eddies around the meanders have an effect to increase the radius of curvature, or stretch the streamlines. This effect was found generally on the eastern flanks of meridional ridges, where poleward eddy transport was found. The poleward eddy transport plays important roles in the meridional overturning cirulation and momentum budget. Another important role in shaping the streamlines was highlighted.

Keywords: Antarctic Circumpolar Current, Interdecadal variability, Eddy transport, Curvature

Research prospects on variations and interactions of Antarctic ice sheet and climate

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We introduce our research plan over the next five years on variations and ineractions of Antarctic ice sheet and climate. The research aims at better documenting and understanding of the Antarctic ice sheet and climate: their status, variability and interactions in the present and past. We particularly emphasizse (1) analyses and proxy developments for reconstructing past, long-term temperature, accumulation rate, sea ice and carbon cycle, and (2) modern observations of the ice sheet margin and ocean by direct observationa and remote sensing.

Keywords: Antarctic ice sheet, Climate change, Ice cores, Ice sheet melting

Current climate-ice sheet studies related to Antarctica and Souther ocean ocean using Earth system modells

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Climate-Antarctica ice sheet and Southern ocean interaction not only affects the local climate but also affect the global climate and ocean. We present some of our current modelling studies and plan using coupled atmophere and ocean model and ice sheet model. In one of our studies, Eocene experiments were carried out to test the model’ s ability to reproduce proxy data and to investigate the climate system under high CO_2 concentration. Furthermore, in order to investigate to what extent topographical changes are responsible for the difference between the Eocene and present day climates, we created Eocene-like geometries from the present day topography. We present the individual effects of the Drake Passage, Tasman Gateway, Antarctica Ice Sheet on the climate.

Keywords: paleoclimate, Climate modeling, Antarctica ice sheet

