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——Regular Articles——

Inconsistent relationships between major ions and water stable isotopes in Antarctic snow under different accumulation environments

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Major ions, stable oxygen isotopes ($\delta^{18}O$), and accumulation rates are analyzed using high temporal resolution data from shallow ice cores and snow pits from East and West Antarctica. Seasonal cycles of major ions and $\delta^{18}O$ are well preserved at sites with an accumulation rate threshold of >100 kg m^{-2} a^{-1} and calm wind conditions. The seasonal cycle is unclear at sites with high wind speeds, even if the accumulation rate is greater than the threshold. To eliminate the influences of different source regions on major ion and $\delta^{18}O$ signals in ice cores, we calculate correlation coefficients between annually averaged major ion concentrations and $\delta^{18}O$, and then compare these with accumulation rates and other geographical variables such as latitude, elevation, and distance from the coast. We find that accumulation rates are highly correlated with elevation and the 10-m snow temperature, and that major ions and $\delta^{18}O$ are negatively correlated at low accumulation sites in inland Antarctica. Negative correlations could reflect inconsistent accumulation due to a large inter-annual variability in the accumulation rate. The results show that the relationships between major ions and $\delta^{18}O$ may not reflect climatic signatures, and could be a result of the unique characteristics of this arid environment.

Comparison of thermodynamics solvers in the polythermal ice sheet model SICOPOLIS

Ralf Greve, Heinz Blatter

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. 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). The comparison uses scenarios of the EISMINT Phase 2 Simplified Geometry Experiments (Payne et al., 2000, J. Glaciol. 46, 227-238). The POLY scheme is 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, which is explicitly enforced by the ENTM scheme. ENTM 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.

Stable isotopic evidence for anaerobic maintained sulphate discharge in a polythermal glacier

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To understand the sources and sinks of sulphate and associated biogeochemical processes in a High Arctic environment, late winter snowpacks, the summer melt-waters and rock samples were collected and analysed for major ions and stable isotope tracers ($\delta^{18}O$, $\delta^{34}S$). The SO_4^{2-}/Cl^-, ratio reveal that more than 87% of sulphate (frequently > 95%) of total sulphate carried by the subglacial runoff and proglacial streams was derived from non-snowpack sources. The proximity of non-snowpack sulphate $\delta^{34}S$ (~8-19‰) to the $\delta^{34}S$ of the major rocks in the vicinity (~−6 to +18‰) suggest that the non-snowpack sulphate was principally derived from rock weathering. Furthermore, $Ca^{2+} + Mg^{2+}/SO_4^{2-}$ molar shows that sulphate acquisition in the meltwaters was controlled by two major processes: 1) coupled-sulphide carbonate weathering (molar ratio ~ 2) and, 2) re-dissolution of secondary salts (molar ratio ~ 1). The $\delta^{34}S\text{-}SO_4$ = +19.4‰ > $\delta^{34}S$-S of rock, accompanied by increased sulphate concentration also indicates an input from re-dissolution of secondary salts. Overall, $\delta^{18}O$ composition of these non-snowpack sulphate (−11.9 to −2.2‰) mostly stayed below the threshold $\delta^{18}O$value (−6.7 to −3.3‰) for minimum O_2 condition, suggesting that certain proportion of sulphate was regularly supplied from anaerobic sulphide oxidation.

Seasonal variations in the major chemical species of snow at the South East Dome in Greenland

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We analyze snow-pit samples collected in May 2015 at the South East Dome (SE Dome) on the Greenland ice sheet. The analysis includes high-resolution records of δD and $\delta^{18}O$, as well as the major ions, $CH_3SO_3^-$, Cl^-, NO_3^-, SO_4^{2-}, Na^+, NH_4^+, K^+, Ma^{2+} and Ca^{2+}. We find that the 3.55-m snow pit recorded temperature and aerosol proxies back to summer or autumn of 2014. This indicates a higher accumulation

rate than those at other major drilling sites in Greenland. Due to this high accumulation rate, ion concentrations except Na^+ are lower than those typical of the central Greenland ice sheet. Concerning seasonal variability, the Na^+, Cl^-, Ca^{2+}, Ma^{2+}, and NO_3^- vary similarly to other sites in Greenland, with the Na^+ and Cl^- peaking in winter to early spring,Ca^{2+} peaking in spring, Ma^{2+} peaking in winter to spring, and NO_3^- towards a peak in summer while showing smaller peaks in winter to spring. The NH_4^+ increased in spring, and SO_4^{2-} increased in autumn to winter at SE Dome. On the other hand, the seasonal trend in the Cl^-/Na^+ ratio differs from those in the inland region. As we did not fully recover one seasonal cycle, some seasonal peaks may have been missed.

Interannual variability in sea-ice thickness in the pack-ice zone off Lützow-Holm Bay, East Antarctica

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Under the Japanese Antarctic Research Expedition (JARE) program, sea-ice thickness has been routinely monitored off Lützow-Holm Bay (East Antarctica) during the summer (mid-December to early January) since 2000/01, using an electromagnetic induction (EM) instrument onboard the icebreaker Shirase. Analysis of these data over a 10-year period, combined with visual observations using a simplified form of the ASPeCt (Antarctic Sea ice Processes and Climate) protocol, suggests a strong interannual variability in sea-ice thickness in this region. For the repeat pack-ice observation area, where the sea-ice thickness averaged over the nine seasons is ～1.9 m, mean thicknesses of observed sea-ice in 2010/11 and 2011/12 are exceptionally large, at ～3.3 and ～5.8 m, respectively. This result is strongly related to regional patterns of sea ice dynamics. Ice convergence caused by anomalous northerly winds was particularly high in 2011/12, suggesting that the extremely thick ice observed in that season resulted largely from sea-ice deformation processes (including pressure ridging). Longer-term analysis of data from the past 34 years confirms that sea-ice conditions and thickness off Lützow-Holm Bay in summer are determined mainly by the large-scale pattern of atmospheric pressure in December.

Resilience in polar ecosystems: From drivers to impacts and changes

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The theory of resilience is increasing in applied ecosystem research and has become a valuable concept for analyzing relationships between natural environments and various stressors, e.g., global warming or direct human impacts. This concept offers opportunities to apply management strategies to different system levels and can provide insights into future ecosystem change. Polar systems are known to be ecologically sensitive to global and local impacts. Records of changes in polar

environments, used as alarm signals by governmental and non-governmental institutions, are well documented in various reports. However, it remains difficult to define specific disturbance thresholds, only few methods allow an evaluation of the actual natural state of polar systems, its degree of modification they can accommodate before trophic systems change with severe damages. Some of the main drivers of system changes have been analyzed with respect to possible effects on system changes over different time scales. This paper reviews studies of polar ecosystems and their ability to cope with changes by assessing their resilience in response to human disturbances. Furthermore, we suggest that a customized framework (drivers, pressures, states, impacts, and responses (DPSIR)) should be applied to obtain an improved understanding of the interactions between the state of, and changes in, natural systems.

Aerosol black carbon over Svalbard regions of Arctic

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In view of the climate impact of aerosol Black Carbon (BC) over snow covered regions (through enhanced absorption of radiation as well as snow-albedo forcing), and in view of the increasing anthropogenic presence and influence in the northern polar regions, continuous long term measurements of airborne BC have been undertaken from the Svalbard region of Norwegian Arctic (Ny-Ålesund, 79° N, 12° E, 8 m a.s.l.). This study, employing data over a period of 4-years (2010-2013) have shown a consistent spring-time enhancement in BC concentrations, having a (climatological) seasonal mean value of ~50.3 ± 19.5 ng m^{-3}, nearly 3-times higher than the lowest BC concentrations in summer (~19.5 ± 6.5 ng m^{-3}). Spectral variation of absorbance indicates that long-range transported biomass burning aerosols contribute as high as 25% to the high BC concentrations in the Arctic atmosphere in spring. Concurrent estimates of BC concentrations in the Arctic snow (for an ensemble of snow samples collected over a period of time during spring) showed values ranging from 0.6 ppb to 4.1 ppb. These values have been used to estimate the BC scavenging ratio (SR). Our studies revealed a mean value of SR ~98 ± 46, which varied over wide range from 40 to 184 for individual samples. In a broader perspective, the seasonal variations of atmospheric BC concentrations at the Arctic are similar to those seen at the high altitude Himalayas; even though the concentrations are much lower at Arctic. It is found that synoptic conditions mainly influence the high altitude Himalayas, while the influences of local anthropogenic influences are not negligible at the Arctic in modulating the seasonal variations of absorbing aerosols.

Atmospheric bioaerosols originating from Adélie penguins (*Pygoscelis adeliae*): Ecological observations of airborne bacteria at Hukuro Cove, Langhovde, Antarctica

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The relationship between atmospheric bioaerosols and ecosystems is currently of global importance. Antarctica has an extreme climate, meaning that ecosystem behavior in this region is relatively simple. Direct sampling of atmospheric bioaerosols was performed at an Adélie penguin (*Pygoscelis adeliae)* colony at Hukuro Cove, Langhovde, Antarctica on 22 January 2013. The aim of the sampling was to reveal the effect of the penguins on the Antarctic ecosystem within the atmospheric bioaerosols. Samples were bio-analyzed using a next-generation sequencing method. Biomass concentrations of Bacilli-class bacteria were 19.4 times higher when sampled leeward of the penguin colony compared with windward sampling. The source of these bacteria was the feces of the penguins. Predicted atmospheric trajectories indicate that the bacteria disperse towards the Southern Ocean. The largest biomass concentration in the windward bacteria was of the Gammaproteobacteria class, which decreased markedly with distance through the penguin colony, being deposited on soil, surface water, and ocean. It is concluded that bioaerosols and ecosystems near the penguin colony strongly influence each other.

Stability of permafrost dominated coastal cliffs in the Arctic

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Block failure is considered to be an important component of coastal retreat in permafrost regions. A comprehensive model is developed to study the effects of thermoerosional niche and ice wedge morphology on the stability of permafrost dominated coastal cliff against block failure. The model is formulated by coupling slope stability analysis with a time dependent progression of thermoerosional niches and the morphology of the nearby ice wedges. Model computations are initially performed for failure conditions for a given cliff height, frozen soil strength, ice content, water pressure in the active layer, thermoerosional niche depth and ice wedge morphology. Under these conditions block failures are found to be predominantly overturning failures and are governed by the tensile strength of frozen soil, thermoerosional niche depth and ice wedge location and depth. The effects of ice wedges are then examined by analyzing failure conditions for ice wedges of different locations and depths. For a given cliff height, strength and thermoerosional niche, block failure may occur at a range of different combinations of ice wedge locations and depths. Two stability nomograms are developed through repeated model calculations for range of cliff heights and frozen soil tensile strength. These nomograms can be used to determine the critical combinations of thermoerosional niche depth, ice wedge distance and ice wedge depth that lead to block collapse of a cliff of known height and soil strength. Some analytical expressions are also derived to determine potential block failure criteria along Arctic coasts.

Sediment grain size and surface textural observations of quartz grains in late quaternary lacustrine sediments from Schirmacher Oasis, East Antarctica: Paleoenvironmental significance

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In this study we report the sediment grain size parameters and surface textural observations (using scanning electron microscopy (SEM)) of quartz grains from sediments of Sandy Lake, Schirmacher Oasis, East Antarctica. The sediment core spans the last 43 cal ka B.P. The statistical parameters of grain size data (sorting, skewness, kurtosis, mean grain size, D_{10}, D_{50}, D_{90} and SPAN index) indicate that the sediments are primarily transported by melt-water streams and glaciers. However, during the last glacial period, sediments seem to be transported due to wind activity as evident by the good correlation between rounded quartz data and dust flux data from EPICA ice-core data. The mean grain size values are low during the last glacial period indicating colder climatic conditions and the values increase after the last glacial maximum suggesting an increase in the energy of the transporting medium, i.e., melt-water streams. The sediments are poorly sorted and finely skewed and show different modes of grain size distribution throughout the last 43 cal ka B.P. SEM studies of selected quartz grains and analyses of various surface textures indicate that glacigenic conditions must have prevailed at the time of their transport. Semi-quantitative analyses of mineral (quartz, feldspar, mica, garnet and rock fragments & other minerals) counts suggest a mixed population of minerals with quartz being the dominant mineral. Higher concentration of quartz grains over other minerals indicates that the sediments are compositionally mature. The study reveals the different types of physical weathering, erosive signatures, and chemical precipitation most of them characteristic of glacial environment which affected these quartz grains before final deposition as lake sediments. The palaeoclimatic signals obtained from this study show similarities with ice-core and lake sediment records from Schirmacher Oasis and other ice-free regions in East Antarctica.

Precise gravity-field modeling in the area of the Japanese Antarctic station Syowa and evaluation of recent EGMs

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By combining a Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) Earth Gravity Model (EGM) and in situ gravity data obtained from the Japanese Antarctic Research Expedition (JARE) surveys, we estimated the regional gravity field in the area of Syowa Station, a Japanese research station located in Lützow-Holm Bay, East Antarctica. In situ data sets that were used consisted of land gravity data collected since 1967, shipborne data collected since 1985 and airborne gravity data collected in 2006. The GOCE direct (DIR) solution release 5 (R5) model was used as the long-wavelength reference of the gravity field. Using these data sets, we calculated gravity nomalies and geoid heights at 1-by-1’ grid by means of least-

squares collocation. The resulting geoid height at Syowa Station was compared with a local height based on GPS, spirit leveling and tide gauge data. The result suggests that the sea surface height at Syowa Station is −1.57 m, which is consistent with a dynamic ocean topography model. During this investigation, we also evaluated GOCE EGMs and other recent EGMs by comparing them with the airborne gravity data. The results indicate that the GOCE DIR R5 produced the smallest RMS (Root Mean Square) differences and that the newer models performed nearly as well. These comparisons demonstrate the importance of using reliable in situ data when evaluating satellite-only EGMs.