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GEOPHYSICAL TECHNIQUES AND ANALYSIS IN ANTARCTIC SCIENCE

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A magnetic data correction workflow for sparse, four dimensional data (MDCWS-4D)

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High-quality magnetic data are important in guiding new knowledge of the solid earth in frontier regions, such as Antarctica, where these data are often among the first data collected. The difficulties of data collection in remote regions often lead to less than ideal data collection, leading to data that are sparse and four-dimensional in nature. Standard aeromagnetic data collection procedures are optimised for the (nearly) 2D data that are collected in industry-standard surveys. In this work we define and apply a robust magnetic data correction approach that is optimised to these four dimensional data. Data are corrected in three phases, first with operations operating on point data, correcting for spatio-temporal geomagnetic conditions, then operations operating on line data, adjusting for elevation differences along and between lines and finally a line-based levelling approach to bring lines into agreement while preserving data integrity. Comparison with more traditional processing approaches demonstrates superiority, however gains are variable, being relatively marginal for phase 1 (3-5%) and more substantial for phase 2 (10-35%). For the full implementation median cross-tie error reduction is 89%, reaching a final error of 8-9 nT. Residual errors are attributed to limitations in the models used for in predicting the 4D geomagnetic conditions and also some limitations of the inversion process used in phase 2. Nevertheless, data have improved utility for tectonic and glacio-tectonic interpretation and modelling, in particular quantitative approaches, which are enabled with less bias and more confidence compared to conventional processing.

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Working towards an improved bathymetry model for the Ross Ice Shelf, Antarctica

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The bathymetry beneath the Ross Ice Shelf is insufficiently known to provide useful input into ocean circulation models; yet it is the key parameter controlling the ice shelf's evolution in a warming world.

Our long-term objective is to derive an accurate and high-resolution model of the seafloor under the entire Ross Ice Shelf that blends seamlessly with regional models. To this aim we are developing a 3-D inversion algorithm capable of combining data from multiple sources. As inputs to our inversion, we currently combine ROSETTA airborne gravity data and ice surface elevation, guided by known depth points. This gives us our first generation of bathymetry models. Over time the inversion process will be further constrained by developing a shelf-wide geological model derived from improved digital processing and quantitative modelling of existing seismic and magnetic data and new aerogeophysical data (gravity, magnetic, radar).

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UAV tecnological tools for the assessment of the glacier volume retreat in Antarctic

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The use of UAV technology coupled with the zenithal photogrammetric flight methodology with geodetic adjustment, processed and analyzed in the Geographic Information System environment, allowed the quantification of the Znosko glacier tongue volume loss, relying on the geospatial products (orthophotos and digital terrain models) obtained during the austral summers of 2018, 2019 and 2020. This methodology provided high-resolution geospatial information, facilitating systemic and remote monitoring, in order to replicate the same parameters annually. Based on the quantified glacier tongue volume achieved during the study period, we propose the use of geotechnologies for glacier research.

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Using GPR to estimate the SMB at the scale of a few kilometers over Princess Ragnhild Coast, East Antarctica, and determine the representativeness of ice core data

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Simulated and measured SMB over the last centuries generally do not match well when comparing ice core and regional model data (Agosta et al. 2019). This could arise from misrepresentation of physical processes in models that affect simulated SMB (blowing snow processes are particularly difficult). Ice cores provide a detailed annual record of SMB but the signal is often reworked by post-depositional processes (Casado et al., 2019) and may be strongly influenced by local processes. The discrepancy in modeled and ice core SMB rates over the past centuries is most likely a combination of these two uncertainties. We use ground-penetrating radar (GPR) data, collected over the high accumulation Princess Ragnhild Coast (East Antarctica), to obtain an annual resolution record over several ice rises, representing conditions at a scale of a few km2. An ice core was collected on each surveyed ice rise, which allows us to place age constraints on the radar stratigraphy. By comparing this GPR-based SMB estimate with the ice core data, we calculate an error of representativity for each ice core's SMB record, estimated as the difference between the average GPR SMB over a few km2 and the ice core SMB. We then compare our corrected ice core SMB records to regional climate model SMB simulations to quantify the impact of ice core uncertainties on the modeled-observed SMB discrepancy.

The GPR system uses a 400 MHz center frequency with a maximum depth of ~60m, a vertical resolution ~30 cm in snow and a horizontal spacing ~20 cm.

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Ocean tide induced icequake swarms at the grounded margin of the Ross Ice Shelf, Antarctica

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Persistent swarms of icequakes were recorded by a broadband seismic array deployed on the Ross Ice Shelf (RIS), Antarctica from late 2014 to early 2017. These occur diurnally and appear to be driven by flexure of the shelf in response to coupling with ocean tides. The phenomenon is recorded only at stations near the grounded margin indicating that sources are local and low-magnitude. Two populations of swarms exist and are differentiated by their timing in the tidal cycle. The primary population is in phase with falling tides and the smaller secondary population appears at high tide only during spring tides. A single swarm typically consists of several 1000's of individual events occurring over several hours and usually follows a pattern of steadily increasing activity before stopping abruptly. Swarms are recorded at all times of year with varying character that can be explained by changes in tidal and environmental factors that affect the true intensity of the seismicity and our ability to accurately observe it. Event signals are dominated by Rayleigh wave energy in ~4-10 Hz band but weaker body wave arrivals in the ~20-30 Hz band are also present. A catalog of events and their locations is created using STA/LTA triggers, polarization analysis, and assumptions of RIS near-surface seismic velocities. The catalog provides information on how these swarms evolve over time and respond to environmental conditions. We anticipate these results should contribute to our understanding of dynamic processes and brittle properties of the RIS at it grounded margins.

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Seafloor depth of George VI Sound, Antarctic Peninsula, from inversion of Operation IceBridge aerogravity

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The George VI Sound (GVIS) is a long curvilinear channel on the west coast of the southern Antarctic Peninsula and separates Alexander Island from Palmer Land. The sound is a geologically complex region, presently covered by an ice shelf. One of the requirements for to understanding the ocean-ice interactions and to predict ice changes on the Antarctic Peninsula is the knowledge of the seabed beneath George VI Ice shelf (GVIIS). Here we model the bathymetry using gravity and ice thickness data from Operation IceBridge (OIB) and the International Thwaites Glacier Collaboration (ITGC) along 29 profiles over the sound. Our model is constrained with all available bathymetric information from seismic measurements and depths from CTD stations are used for comparison. Our results show that GVIIS presents depths up to 1425 m, with two deep basins (~1100 m) in the southern section separated by a 500 m high ridge. Localized areas of deeper bathymetry (450 m to 550 m) occur where there is high ice flow from glaciers grounded more than 300 m below sea level. This geometry can influence the pathways for Circumpolar Deep Water and the ice at those points might be exposed to higher oceanic heat. The water column thins significantly between the two deep basins, which could be crucial for ocean circulation models. We present a crustal density model for GVIIS and define the extent of a dense body of 2.95 gm/cm3 on the Palmer Land side.

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Filling the voids: Airborne gravity, radar and lidar surveys in Antarctica

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The gravity coverage of Antarctica has improved significantly in recent years, with airborne and satellite measurements now giving a reliable representation of the gravity field, useful for both geophysical studies and the geodetic infrastructure (improved geoid). Recent DTU Space-initiated survey activities 2013-18, in cooperation with BAS and NPI, has mapped major data voids in East Antarctica and the South Pole region, and has together with radar and magnetic data highlighted hitherto unknown structures under the ice sheet. The talk summarizes the results of the various campaigns, including a recent ESA satellite validation campaign, and also illustrates by cross-over results how older campaigns can have large gravity errors. Ongoing developments in light-weight gravity sensors allow for easier integration in small aircraft and drones. An ultimate near term goal for "piggy back" gravity applications in Antarctica could be an internationally coordinated flight campaign, filling the gaps around the perimeter of Antarctica, to allow - together with radar and lidar –the mapping of outlet glacier sub-ice topography, and thus improve overall accuracy of fluxgate "input-output" measurements of icesheet mass loss ("the Antarctic Rings", an initiative being discussed informally with LDEO, BAS, NPI and other partners).

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Geophysical Evidences for Crustal Structures and Dynamic Settings of the Ross Sea Continental Shelf

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Because tectonic divisions and geodynamic settings of the Ross Sea are still unclear, we systematically analyzed geopotential data of RS to answer some questions.
Reduction to the pole (RTP) magnetic anomalies and pseudo-gravity anomalies clearly reflect the fluctuation trends of the Curie point. Our model of depths to the Curie point shows an uplifting zone between the Transantarctic Mountains and the Terra Rift in the Victoria Land Basin. The belt of high heat-flow anomalies given by the Curie point corresponds to the Cenozoic volcano zone, which is consistent with the surface wave low-velocity zone and its derived high heat-flow zone. It may indicate the residual weakened branch of the triple junction, which would play an important role in the Ross Sea Rift System.
After gravity effects of bedrock topography, ice cover and water body are removed from free-air gravity anomalies, complete Bouguer anomalies are corrected for variable density sedimentary strata and heat-flow given geothermal field, and then 3-D density structure with depths to the Moho are inverted. The stretching factors (β) of the whole, upper and lower crust are calculated to show that crustal thinning increases with depth. Based on Bouguer anomalies and topographical loads, the effective elastic thickness of lithosphere (Te) is also calculated, and Te varies oppositely corresponding to heat-flow anomalies. β and Te N-S zonal distribution of high and low alternating in the E-W direction may reflect that the residual branch of the triple junction controls the development pattern of the Ross Sea Rift System.

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Using an Antarctic Dataset to Expand Ultra-low Velocity Zone Investigations in the Southern Hemisphere

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Less than one-fifth of the core-mantle boundary (CMB) has been surveyed for the presence of ultra-low velocity zones (ULVZs); therefore, investigations that sample the CMB with new geometries are important to further our understanding of ULVZ origins. Using ScP waves recorded by the Transantarctic Mountains Northern Network in Antarctica, our study expands ULVZ investigations in the southern hemisphere. Our dataset samples the CMB in the vicinity of New Zealand, providing coverage between an area where ULVZ structure has been previously identified and another where prior ULVZ evidence was inconclusive. This area is of particular interest because the data sample across the boundary of the Pacific Large Low Shear Velocity Province (LLSVP). The Weddell Sea region is also well sampled, providing new information on a region that has not been previously studied. A correlative scheme between 1-D synthetic seismograms and the observed ScP data demonstrates that ULVZs are required in both regions. Modeling uncertainties limit our ability to definitively define ULVZ characteristics but also likely indicate more complex 3-D structure. Given that ULVZs are detected within, along the edge of, and far from the LLSVP, our results support the hypothesis that ULVZs are compositionally distinct from the surrounding mantle and are not solely related to partial melt. ULVZs may be ubiquitous along the CMB; however, they may be thinner in many regions than can be resolved by current methods. Mantle convection currents may sweep the ULVZs into thicker piles in some areas, pushing these anomalies toward LLSVP boundaries.

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A parametric method for snow density estimation based on ultrasonic waves

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In this paper a method for snow density estimation based on non contact ultrasound examination is described. This ground based method involves a constant frequency, air coupled ultrasound waves and incorporates a parametric method for reflected energy estimation. The paper issues theoretical considerations as well as the technological details of the addressed problem. Due to the fact that the amount of the reflected sound energy is related to the snow density the acoustic data processing scheme is presented. The theoretical model was applied to the data collected during field experiments in the vicinity of the Polish Antarctic Station Arctowski, South Shetlands, Antarctic. The results obtained permit to develop a new autonomous sensor for measurements of the snow ablation and density.

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The use of magnetotellurics in the Antarctic Interior: Examples from the Central Transantarctic Mountains and Mount Erebus – Ross Island

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Thick snow and ice cover present over the majority of the Antarctic continent necessitates geophysics to investigate both processes within the ice sheets as well as the underlying solid earth. The wide bandwidth, minimal ground disturbance coupled with the manageable logistical support associated with magnetotelluric studies, makes them attractive for Antarctic studies. The unique geography and climatic conditions of the Antarctic combined with collecting magnetotelluric data at high latitudes presents challenges not typically encountered. (1) The very-high contact resistance between electrodes and the surficial snow and ice cover can interfere with the electric field measurement. (2) Proximity to the geomagnetic poles requires verification that the magnetic source field is a vertically-propagating, horizontally polarised plane-wave. (3) The generation of 'blizstatic', localised random electric fields caused by the spin drift of moving charged snow and ice particles, produces significant noise in the electric fields during periods of strong winds. At wind speeds above ~10m/s the effect of the distortion is broad-band. Early application of magnetotellurics in the Antarctic interior was on a reduced scale to similar investigations in low latitude settings. However, our recent studies of the Central Transantarctic Mountains, and Mount Erebus – Ross Island to investigate large scale tectonic and volcanic processes are of the same scale. A ~550 km transect across the Central Transantarctic Mountains revealed that the high topography is the result of non-thermal flexural uplift. At Mount Erebus the first true 3D survey of the Antarctic Interior identifies a 'fault-valve' structural control on the magmatic system.

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Physical properties of the firn layer without coring: the possibilities and limitations of seismic refraction

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Most of the Antarctic continent is covered by a firn layer. An accurate understanding of the firn evolution is of growing importance for ice sheet modelling and remote sensing techniques. Direct measurements of the key firn properties originate from firn cores, which are sparse and labour intensive to collect. An alternate and more feasible approach is to infer firn properties from diving waves via seismic refraction. This is commonly done in a two-step process: (i) determine seismic velocity and thickness using the 1D velocity-depth inversion proposed by Wiechert-Herglotz (WH), and subsequently (ii) determine firn density using an empirical relationship proposed by Kohnen. Its application is today restricted by a limited understanding of the method's accuracy and its performance under varying climatological conditions. Here, we investigate the performance of this approach by analysing 15 sites around Antarctica that provide both direct firn density measurements and seismic surveys in close proximity. The analysis is complemented by a P-wave model which is used to systematically analyse the performance of WH for varying firn thicknesses and survey arrangements. We find that the WH method holds true for favourable measurement conditions which depend mainly on offset length, receiver spacing and the presence of summer melt. Density estimates are reasonable if WH produces good results. Our results highlight the potential of seismic refraction to retrieve information of the firn layer for carefully arranged instrumentation. We provide recommendations such that future seismic surveys can optimise field data collection for the subsequent analysis of the firn layer.

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Seismic harmonic tremors determined by local arrays and their relation to cryosphere dynamics in Lützow-Holm Bay, Antarctica

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Characteristics of seismic tremors occurring during April 2015 were investigated by seismographs at Syowa Station, in the Lutzow-Holm Bay (LHB), East Antarctica. To examine a relationship between surface environment in cryosphere variation, MODIS satellite images were utilized for comparison with detected tremor events. Since a large volume of sea-ice was discharged during April 2015, along with a few numbers of large icebergs passed through the northern edge of the fast sea-ice of LHB, it was supposed to detect characteristic seismic tremors involving cryospehre dynamics at local region. During the month, a total number of 49 tremor events including short duration ice shocks were identified. Majority of the events had their duration times more than 15 minutes, which were divided into both tremors and ice shocks. Cryospheric sources recorded by seismic tremors were classified by their origins; “crevassing events” along the large cracks inside the fast sea-ice, “discharge events” of fast sea-ice from the bay, “collision events” between iceberg and the edge of fast sea-ice, “crashing movement” between fragmentation of fast sea-ice and packed sea-ice. Particularly, strong amplitude tremors with harmonic overtones were assumed to be occurred independently from meteorological condition, along with episodic events in the cryosphere. The most plausible candidate of the source origins are collision events between bottom of drifting icebergs with the top of sea-bedding sediments/crystalline rocks at the places where the northern edges of continental shelf of LHB in which the depths of the ocean-floor could be less than 300 m from mean sea level.

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The structural and stratigraphic evolution of the Central Basin, northwestern Ross Sea (Antarctica): preliminary results

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The Central Basin is located in the northwestern Ross Sea outer continental margin and is presumably formed during the early Cenozoic (ca. 61–53 Ma) in the development of the West Antarctic Rift System. The structural and stratigraphic evolution of the Central Basin is lesser known than other marginal basins in the Ross Sea due to lack of extensive geophysical data. Here we present the newly acquired multichannel seismic profile, which crosses the middle of Central Basin, to describe the general sedimentary and basement structures. The east-west basin cross section shows up to 3 km deep (> 3 sec in TWT) basement in the middle of the basin and normal faults with tilted fault blocks or half grabens in both sides of the basin. These basement features could indicate that the Central Basin was formed by extensional tectonic events, and it is consistent with previous gravity modeling results. The sedimentary successions above the middle Miocene unit boundary show that the thickest parts of lens-shaped sediment bodies, which have discontinuos internal reflections, shifted from the middle to eastern side of the basin during the middle to late Miocene. Since the early-mid Pliocene, sheeted or mounded sediment drifts with subcontinuous internal reflections developed on the slopes and crests of bounding bathymetric highs and a lens-shaped sediment body deposited close to the Hallett Ridge. These seismic stratigraphic characteristics possibly reflect the variation of sediment supply and sedimentary processes controlled by the ice sheet dynamics and bottom current activity in the northwestern Ross Sea.

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Can integrated magnetotelluric and seismic geophysical measurements reveal subglacial groundwater and geothermal heat exchanges with the Institute Ice Stream, West Antarctica?

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The Institute Ice Stream (IIS) in the central Weddell Sea sector of the West Antarctic Ice Sheet (WAIS) is vulnerable to dynamic change and one of the largest sources of uncertainty in predictions of sea-level change from Antarctica. Fast streaming of the IIS, like that of all WAIS ice streams, relies on the presence of a substrate of basal till that dilates because it is lubricated well by water. Such till is commonly supplied by erodible sedimentary rocks emplaced in underlying crustal basins. The water is usually assumed to originate from, and flow within, a hydrological system at the ice-till interface. The underlying sedimentary rocks are therefore, in effect, assumed to be impermeable. Evidence is now growing that this assumption is wrong. Such rocks may host reservoirs of mobile groundwater that interacts hydrologically with the interfacial water system. Indeed, according to recent numerical modelling, up to half of all water available for basal lubrication may have been overlooked in models of ice flow. This situation may be typified by the IIS and its vulnerability to change therefore be controlled by a subglacial groundwater – heat flux - till system that is poorly understood. Other ice streams may experience similar hydrological controls. Here, we discuss a large forthcoming geophysical field project on the IIS that aims to understand this system by acquiring extensive magnetotelluric (MT) and seismic geophysical measurements and integrating them to constrain a next-generation numerical ice sheet model.

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Shear-wave Velocity Structure of the Crust and Upper Mantle beneath East Antarctica from Full-Waveform Ambient Noise Tomography

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The origin and tectonic evolution of various features in East Antarctica, such as the Wilkes Subglacial Basin (WSB), Aurora Subglacial Basin (ASB), Transantarctic Mountains (TAMs), and Gamburtsev Subglacial Mountains (GSM), are unconstrained due to thick ice coverage and a lack of direct geologic samples. We are modeling the crustal and upper mantle structure beneath these areas using a full-waveform tomography method to further our understanding the tectonic evolution of the continent as well as the behavior of the overlying ice sheet. A frequency-time normalization approach is employed to extract empirical Green's functions (EGFs) from ambient seismic noise, between periods of 15-340 seconds. EGF ray path coverage is dense throughout East Antarctica, indicating that our study will provide new, high resolution imaging of this area. Synthetic waveforms are simulated through a three-dimensional heterogeneous Earth model using a finite-difference wave propagation method with a grid spacing of 0.025º, which accurately reproduces Rayleigh waves at 15+ seconds. Following this, phase delays are measured between the synthetics and the data, sensitivity kernels are constructed using the scattering integral approach, and we invert using a sparse, least-squares method. Preliminary results show that slow velocities are present beneath both the WSB and ASB, possibly indicating old rift systems or other inherited tectonic structures. The transition from slow to fast velocities beneath the Northern Victoria Land section of the TAMs is consistent with thermal loading beneath the mountain range. The presence of slow velocities near the GSM may be associated with rifting along the Lambert Rift System.

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Active Glacier Processes From Machine Learning Applied to Seismic Records

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The large outlet glaciers of Antarctica, which buttress the great ice sheets from the influence of the warming ocean, evolve through a diverse set of active processes. Many of these deformation, or hydrological, processes are hidden from the view of satellite observations but give rise to seismic signals. Seismology therefore provides a viable means of further understanding and/or monitoring remote outlet glaciers if the challenge of working with the diverse range of signals can be addressed. Machine learning provides an innovative approach which complements conventional seismology techniques.
We compare unsupervised learning methods for identifying and characterizing deformation events in glacier seismic data. We use continuous data from seismic networks deployed on the Whillans Ice Stream, West Antarctica from the austral summers of 2010 and 2011. We first apply a tailored algorithm for STA/LTA event detection to build a database of glacier seismic events of various time scales and magnitudes. Then, we cluster the diverse range of signals by waveform, spectral, and polarity attributes using the k-means and self-organizing maps algorithms. Working in a high-dimensional feature space, we explore the feature groups which emerge from pattern detection. The various groups can be related to glacial seismic event types like stick-slip events, long period tremors, and crevassing. Further, data like ITS LIVE and Sentinel-I can be used to inform the other physical mechanisms that may be at play, like draining lakes or surges. Our techniques form the basis for future seismic monitoring of remote glaciers and the early identification of major change.

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Mapping subglacial sedimentary basin distribution in Antarctica using Random Forest

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The subglacial sedimentary basin distribution is key for understanding ice sheet dynamics and tectonic evolution, yet it is poorly known in Antarctica. Continental scale geophysical and remote-sensing data have the ability to reveal subglacial geology. However, cautions should be made by directly using these datasets due to the irregular data distributions and their respective ambiguities. Here, based on these continental scale datasets, we use supervised random forest method to classify the bedrock type (sedimentary rock or crystalline basement rock) in the interior of Antarctica continental shelf break. In this study, we generate training points in a regular grid to deal with heterogeneous data distribution. We present a series of studies to understand the effect to the classification result of the training point generation and distribution. We find that using only outcrop data produces a result that is likely to underestimate sedimentary basin distribution. By adding inferred result from regional geophysical studies, we improve the classification result. The uncertainty of classification and bedrock type complexity are evaluated by the information entropy. Additionally, we demonstrate the robustness of workflow by shifting the training point in 4 different directions. We conclude this method can be an effective tool to deal with heterogeneous data with limited ground truth information. In addition, this model can be easily updated with future Antarctic geophysical data compilations.

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Active source borehole seismology in the Ross Ice Shelf: applications of vertical seismic profile and cross-hole shooting techniques to study ice shelf anisotropy and temperature

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The Aotearoa Ross Ice Shelf Drilling Program visited the central Ross Ice Shelf in late 2017, drilling two hot water drill boreholes through ~370 m of ice. This rare opportunity to control the depth of both seismic receivers and sources was used to design a seismic survey targeted at the vertical distribution of anisotropic ice fabrics and temperature inside an ice shelf.

In the first borehole eight 3-component, 15 Hz seismometers were frozen into the ice at 35 m spacing between depths of 80 m and 325 m. Surface shots from a shear wave seismic source recorded on the borehole sensors show observations of shear wave splitting from multiple azimuths and offsets. A potential explanation of the observed seismic anisotropy from a synthetic crystallographic preferred orientation forward model in the ice with its implications for ice shelf deformation history is discussed.

The second borehole, located at a distance of ~560 m along the ice flow direction was used to operate a sparker borehole seismic source that was fired in 10 m spacing between depths of 70 m and 270 m. Recording of these seismic signals on the borehole seismometers allows to study the vertical variation of seismic velocities and attenuation in the ice shelf and how these are affected by ice temperature. Finite-element modelling of the effects of different anisotropic ice fabrics on synthetic traveltimes provides another constraint on character of ice anisotropy at the study site.

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First observation of an optical anisotropy in the deep glacial ice at the geographic South Pole using a laser dust logger

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We report on the observation of a directional anisotropy in the recorded intensity of back-scattered light as measured using an oriented laser dust logger. The measurement has been performed in a drill hole at the geographic South Pole, about a kilometer away from the IceCube Neutrino Observatory. The drill hole was preserved for logging access, after the SPICEcore collaboration had retrieved a 1751 meter ice core. We find the measured, optical anisotropy axis of 126° to be compatible with the local flow direction. The observation is discussed in comparison to a similar anisotropy observed by the nearby IceCube Neutrino Observatory. The measurement principle, when combined with a full-chain simulation, may in the future be used to provide a continuous record of fabric properties along the entire depth of a drill hole.

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Well-posed Use of Colour in Visualisations for Data Inference in Antarctic Sciences

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Session 17: Geophysical Techniques and Analysis In Antarctic Science

Antarctic sciences are progressing through the increasing use of remote sensing data, data compilations, and geophysical models that rely on visualisations, for example coloured contour maps, as the key medium of knowledge discovery. Such data-driven approaches benefit from careful attention to 'visual literacy' in parallel with good written or spoken communication. Antarctic research has a more frequent need for good management of resolution changes, data gaps and uncertainty than is common for other continents.
Using a recently published software suite that enables researchers to make well-posed colour choices, we present a set of colour maps that are suited to the display of Antarctic geophysics data and models. These colour maps consider human perception, and hence maximise the chance of feature discovery within a given datasets, and also minimise the possibility of a mistaken inference due to artefacts of the display process. We also show some workflows that provide an exemplar of the use enhanced graphics capability such as opacity that enable the better management of patchy coverage. We also provide exemplars of visualisation techniques and colour optimisation for rapid display and exploration of volumetric data.
We hope that our colourmaps will find wide usage within Antarctic Sciences, and related disciplines. We also anticipate that wider use of enhanced capability with opacity will help researchers to progress knowledge discovery, finding insights from their data, in the case of resolution challenges and analysis of multiple datasets that are commonly encountered in Antarctic research.

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The field of linear velocities and movements of the Earth's crust in the Penola Strait - Lemaire Channel fault area (West Antarctica)

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Based on the results of 5 cycles of periodic static GNSS campaigns conducted on geodynamic monitoring polygon of the Penola Strait- Lemaire Channel fault area recent local geodynamic processes during 2003-2019 were identified. The vectors of horizontal and vertical movements of the geodynamic polygon are determined in the work and their scheme is constructed. Based on the determined average linear velocities of vertical movements, the field of their spatial distribution in the fault area was constructed. As a result of the analysis of velocity distribution of the vertical movements, the area of subsidence was identified. Based on the determined average linear velocities of the horizontal movements, the values of the dilatation velocity, which characterizes the relative expansion or compression of the territory, as well as the value of total shear, which characterizes the horizontal heterogeneity of the deformed area, were calculated, and the field of their spatial distribution in the area of Penola Strait - Lemaire Channel fault area was constructed. As a result of the distribution analysis of the territory's dilatation velocities, the zones of extreme compression and expansion values were revealed, indicating increased geodynamic activity of the region. As a result of the analysis of the distribution of values of the total shear, it is confirmed that the studied region is horizontally heterogeneous. Based on the analysis, a new kinematic fault area model was developed. The assumption was made that the specified fault transgressive characterized by a combination of strike-slip and thrust.

1227

Improved regional and global gravity field modelling to provide a consistent grid of terrestrial gravity anomalies in Antarctica for further application in geosciences

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To infer both precise satellite-only as well as high-resolution combined Earth gravity field models (EGM) terrestrial gravity data are needed globally and, especially, in the polar regions. For Antarctica, a first consistently compiled gravity anomaly grid was published by Scheinert et al. 2016, which, however, did not cover the entire Antarctic continent. Since then, new data have been acquired, especially over the GOCE polar gap region (Forsberg et al. 2017). Now, in a joint project funded by the German Research Foundation, we aim to re-process all available ground-based and airborne gravity data in Antarctica in order to come up both with an improved grid compilation and an enhanced global model. We will discuss the different steps of processing, including the cross-validation of individual surveys with a combined high-resolution EGM based on satellite and topographic data (Zingerle et al. 2019), and the least-squares collocation for the combination of the different datasets. The improved Antarctica gravity anomaly grid will have a resolution of 5x5 km^2. It will be used for further studies in Antarctic geosciences, e.g. to infer by inverse methods bedrock topography and depth of the Mohorovicic discontinuity. We will discuss how such analyses will benefit from the improved gravity field solution.

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Geomorphological comparison of the seafloor volcanism in the Bransfield Basin volcanoes in other Back-Arc Basin settings

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The Bransfield Strait is a seismically active back-arc basin between the Antarctic Peninsula and the South Shetland Islands. Subduction slowed in the region around four million years ago; however, back-arc volcanism and extension continued throughout the basin. The extensional rifting and local volcanism are believed to mark the transition to seafloor spreading within the Bransfield Basin. BRAVOSEIS (BRAnsfield VOlcano SEISmology) is an international effort focused on the understanding of the submarine volcanoes and complex tectonic regime in the Bransfield Strait. During research cruises conducted by the BRAVOSEIS Project in 2019 and 2020, aboard the R/V Sarmiento de Gamboa and BIO Hespérides, we collected multibeam soundings, gravity and magnetic measurements, and multi-channel seismic data around two central locations: Orca Volcano, located near King George Island, and Humpback (Edifice A), located near Livingston Island. Over Orca Volcano, we collected data along 21 profiles with lengths of 20 to 30 km, and over Edifice A data, we collected 16 profiles. Interpretation of the bathymetry shows significant differences between the morphology of these two volcanic features. Our study will use high-resolution publicly-available bathymetry data along with data collected during the BRAVOSEIS expeditions to compare the volcanic features in the Bransfield Basin with each other, and with volcanic edifices along the rift axis of similar marine basins undergoing active back-arc volcanism and extension. Our comparison between the seafloor geomorphology observed in areas with similar tectonic settings will inform our interpretations of the complex tectonics in the Bransfield Basin.

1162

Crustal composition and its thermal and geological implications of continental Antarctica: progress from receiver functions

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The chemical composition of the Antarctic crust has been difficult to assess since over 98% of the continent is covered by ice-sheets, yet it is necessary for investigating the geological history and sub-ice geotherms. Seismological tools provide in-direct measurements to the physical attributes (e.g., seismic properties) of the crust and uppermost mantle. In this presentation, we report the result from a systematic investigation to the crustal Poisson's ratios across the continent using the receiver function technique. We show that an improved 2-layer H-k stacking to the receiver functions can provide more accurate estimates of the Poisson's ratio for the crystalline crust. After its application to all seismic stations deployed in Antarctica, a general trend emerges in which lower Poisson's ratios are found beneath the tectonically active West Antarctica, while the central and East Antarctic show higher Poisson's ratios. More importantly, we show that comprehensive seismic properties (Vs from surface waves and Poisson's ratio) together with petrologic databases can determine the chemical composition (i.e., the silica content) of the crust beneath each station, quantitatively with error estimates. The measured crustal composition has important thermal and geological implications. For instance, a more granitic crust is found beneath the Polar Sub-glacial Basins, indicative of either a more chemically evolved crust or an Archean crust with Tonalite-trondhjemite-granodiorite composition. The high SiO_2 near the S. Pole also provides insights to the anomalously high geothermal heat flux, which is indicated by the thermal profile and the existence of sub-ice melting.

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The HiPSMI project: High Precision Supercooling Measurement Instrument for supercooling measurements under ice shelves

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The oceans beneath Antarctic ice shelves are the least measured waters on Earth. Beneath the Antarctic sea ice and ice shelves, sea water is often colder than its freezing point temperature, yet still liquid. Such water is called “supercooled” sea water. Snap-freezing of supercooled sea water and small free-floating ice crystals known as “frazil” are fundamental obstacles to obtaining high-precision measurements of key ocean parameters needed for climate research. In the project “Supercooling measurements under ice shelves”, we are working to overcome this obstacle by working as an international collaborative team (New Zealand, USA and Norway) to design and construct a new novel instrument; the High Precision Supercooling Measurement Instrument (“HiPSMI”). HiPSMI has been designed and built over the last year, and is optimised for harsh Antarctic ocean conditions and installed into an innovative, modular underwater robot, “Icefin”. HiPSMI includes high precision temperature and pressure sensors and a pumped electrical conductivity sensor, configured for supercooling measurements with a frazil melting unit. In addition, Icefin will have on-board un-pumped electrical conductivity sensors, possibly including nanotechnology sensors, to allow comparisons with HiPSMI. Observations will be made beneath the sea ice and McMurdo Ice Shelf, Antarctica in October and November 2020. We will determine the influence of frazil crystals on measurements of in situ supercooling. The measurements, in conjunction with numerical modelling and laboratory work, will revolutionise our understanding of supercooled waters by providing a high-precision, observational-based indicator for future climate observations beneath the vast cold cavity ice shelves of Antarctica.

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Gravity and Magnetics Results from a Marine Geophysics Survey of Orca Volcano in the Bransfield Strait, Antarctica

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The Bransfield Strait, a seismically active extensional rift between the Antarctic Peninsula and the South Shetland Islands. The region is characterized by subaerial volcanism at several locations, most recently the eruptions at Deception Island in 1967-1970, and multiple prior marine surveys provide extensive morphological and petrological evidence for submarine volcanism. As part of the BRAVOSEIS project, an international effort focused on the seismological research of submarine volcanoes and rift dynamics in the Bransfield Strait, we used the R/V Sarmiento de Gamboa during January-February 2019 to collected multibeam soundings, gravity and magnetic measurements, and multi-channel seismic data along 21 profiles with lengths of 20 to 30 km spaced 500 m apart over Orca volcano and 11 profiles with lengths of 20 to 30 km spaced 1 km apart over Humpback Volcano. Analysis includes a geomorphological interpretation of the bathymetry, the construction of maps of gravity and magnetic anomalies, and the processing of seismic sections across the caldera. The bathymetry data from Orca Volcano are consistent with recent motions on both inward and outward dipping ring faults within the caldera. We will present intersecting 2D model profiles comparing the distribution of crustal densities, magnetic structure and underlying mantle densities for Orca and Humpback Volcanoes. This work is supported with funding from NSF Office of Polar Programs and the Spanish Polar Committee.

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Aeromagnetic data reveal broad basement structures under the Ross Ice Shelf, Antarctica

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Deconvolution of aeromagnetic data from ROSETTA-Ice and Operation Ice Bridge was used to estimate the top of the magnetic sources in the crust beneath the Ross Ice Shelf (RIS). The resulting solutions were filtered to match points of known basement depth from seismic surveys on the RIS and in the Ross Sea, then interpolated to produce the first view of the sub-RIS basement surface. The basement surface reveals large scale features that we interpret as sediment filled structural troughs and basement highs formed during opening of the West Antarctica Rift System. The southward continuation of the Central High, a basement feature identified from marine seismic surveys and DSDP drilling in the Ross Sea, is evident. It spatially coincides with the tectonic boundary between West Antarctica and East Antarctica and separates two sectors that have contrasting densities and seabed depths (Tinto et al. 2019). The gravity-derived bathymetry model for the eastern RIS region shows areas of shallow seabed that may inhibit ocean circulation to critical grounding zones of the RIS along the Siple Coast. In aid of accurate modeling of ocean circulation, the basement surface can be used to refine the bathymetry model further by introducing crustal density variations across the sediment-basement interface. Future work will investigate the resulting differences in the bathymetry model with the inclusion of the basement surface.

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L-band sounding of the Greenland and Antarctic ice sheets

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An L-band radar system has been built to measure ice thickness, basal conditions and melt rates of ice shelves in Greenland and Antarctica. The Remote Sensing Center at the University of Alabama has successfully mapped deep layers of ice sheets in Greenland and Antarctica using VHF and UHF radar systems. A new system, operating from 1.2-1.4 GHz across eight channels, has been built and operated in Greenland and again in Antarctica during the 2019-2020 Austral summer near Dome Concordia. As a part of a multi-radar deployment, this L-band radar sounder system was installed in a PistenBully vehicle with an eight-element antenna array being pulled behind the system on a makeshift sled. After having successfully sounded the bed in Greenland, initial quick-look data suggests that the bed has been sounded in Antarctica using L-band for the first time. This paper will discuss the overall design of the system as well as the signal processing considerations for the associated data. It will also present preliminary results showing the successful sounding of the bed near the Dome Concordia research station.

1136

An adaptive sampling approach for optimizing radar sounder flight paths for use in mass conservation models of bed topography

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Mass conservation is a highly effective technique for interpolating sparse radar sounder measurements over fast-flowing areas. In areas with multiple radar sounder flight lines, fitting an approximately mass-conserving bed profile to fixed measurement points can be framed as an optimization problem. Ideally, mass conservation and measured bed elevation constraints can be simultaneously satisfied, however this is not generally the case due to measurement errors and simplified models of unobserved ice dynamics. By comparing model-data misfit to known uncertainties in the input measurements, the probable impact of model error can be assessed. When the error exceeds that plausibly attributed to measurement uncertainty, that suggests a need for more data to reduce the measurement uncertainty and either resolve the potential model misfit or provide hard evidence for the origin of the model error.

A simple algorithm is developed using real-time mass conservation modelling to dynamically update a flight path for an airborne radar sounding system to achieve a specified level of uncertainty in ice thickness by continuously collecting new flight lines in optimized locations until the threshold is met. This algorithm could be applied to future autonomous data collection platforms to assess when the collected measurements are sufficient and to avoid large variations in the resulting model uncertainty. Applying this dynamic sampling strategy can minimize the need to repeat field campaigns when the data collected is found later to be insufficient.

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Assessing satellite and helicopter-borne radar for observing crevasses in Antarctica

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Crevasses can provide valuable information about the glacial system, current and past, but they also pose significant risks to operating safely and effectively in glaciated areas. Radar has a long legacy of application to ice and snow environments, including the identification of buried crevasses. Over 2019-20 Austral summer we conducted operational trials of a helicopter-mounted GPR system for detecting and mapping crevasses out of Davis Station, Antarctica. In conjunction with each GPR survey performed, a number of supporting ground-based snow measurements were made, collecting data on snow moisture, snow density and pH and EC of melted snow samples. At crevassed sites we also measured the snow bridge thickness and crevasse width to ground truth spatial information derived from the GPR data.

Data from these test flights is also being used in conjunction with high resolution X-band satellite radar images to test their capacity to identify crevassed regions. These satellite images, acquired by the German Space Agency's TerraSAR-X instrument, in combination with the radar data, have the potential to significantly enhance the future identification of safe field sites, and this validation will be a world-leading test of their use in this context. The combined data sets allow us to investigate the potential and limitations of each radar method over a range of glacial site characteristics and provide significantly improved dimensional and locational accuracy.

429

Characterising the ice sheet - bedrock interface zone using seismic waveform modelling: challenges and technique development.

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The character of the ice sheet - bedrock interface zone potentially yields insight into the tectonic evolution of regions such as East Antarctica, and also has significant impact on the response of the overlying ice sheet to global change. While seismic techniques are well established in understanding hidden structure, relatively thin layers at depth present a challenge for techniques based on arrival time.

In this presentation we explore the potential of waveform modelling techniques to infer the character of structure at the base of ice sheets. Parameters of interest include sediment thickness, saturation, composition, grain size, the composition of the bedrock beneath, and whether any water present is in a frozen or liquid state. With light-logistic data acquisition in remote areas of East Antarctica in mind, we simulate seismic waveforms recorded using a small number of stations over plausible sub-ice structures such as flat layers, channels and eskers. We use either small active sources, or ambient seismic wavefield configurations.

Using pre-existing and newly-written numerical codes for waveform simulation, running on GPU-accelerated architecture, we explore the advantages and disadvantages of available techniques. We find that new implementations of a spectral (Fourier) method and a finite difference method have practical advantages for the characterisation of ice sheet basal structures. In particular, the new methods are suitable for rapidly scanning over a range of interfacial parameter values, allowing determination of the sensitivity of the system to small variations in these parameters.

1569

Integrating englacial reflectors between the the Amundsen Sea and Ross Sea Embayment of West Antarctica.

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The Antarchitecture project is a multinational initiative to construct a cohesive englacial stratigraphy for the Antarctic Ice Sheet, using ice penetrating radar. This compilation will require integrating data from radar systems with differing center frequencies, bandwidths and processing approaches, from multiple institutions and surveys with different science goals. Early work on such inter-comparisons has focused on Dome C in East Antarctica. Here we discuss progress on performing these inter-comparisons in West Antarctica, in the vicinity of Thwaites Glacier, the Siple Coast Ice Streams, and Pine Island Glacier. Using oil industry seismic packages, UTIG and the University of Edinburgh have performed extensive mapping of key glacial horizons through the catchments of Thwaites Glacier (with HiCARS), the Ross Sea Embayment (with the SOAR incoherent system) and Pine Island Glacier (PASIN). UTIG has mapped out six key horizons and connected them to the WAIS and Byrd ice cores, and performed a Bayesian analysis on the uncertainty in the age of four of these horizons. In Marie Byrd Land, we find evidence of complex englacial structures related to subaerial volcanism. Through flight lines that were shared between the surveys, we assess the correspondence between the three stratigraphies.

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