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DebDaB: a database of supraglacial debris thickness and physical properties

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Abstract. Rocky debris covers around 7.3 % of the global glacier area, influencing ice melt rates and the surface mass balance of glaciers, making the dynamics and hydrology of debris-covered glaciers distinct from those of clean-ice glaciers. Accurate representation of debris in models is challenging, as measurements of the physical properties and thickness of the supraglacial debris layer are scarce. Here, we compile a database of measured and reported bulk physical properties and layer thicknesses of supraglacial debris that we call the supraglacial Debris Database (DebDaB) and that is open to community submissions. The majority of the database (90 %) is compiled from 172 sources in the literature, and the remaining 10 % was previously unpublished. DebDaB contains 8741 data entries for supraglacial debris layer thickness, of which 1770 entries also include sub-debris ablation rates, 179 thermal conductivity of debris, 160 aerodynamic surface roughness length, 79 debris albedo, 59 debris emissivity, and 37 debris porosity. The data are distributed over 84 glaciers in 13 regions in the Global Terrestrial Network for Glaciers. We show regional differences in the distribution of debris thickness measurements in DebDaB and fit simplified Østrem curves to 19 glaciers with sufficient debris thickness and ablation data. The data in DebDaB can be used for energy balance, melt, and surface mass balance studies by incorporating site-specific debris properties or for evaluation of remote sensing estimates of debris thickness and surface roughness. They can also help future field campaigns on debris-covered glaciers by identifying observation gaps. DebDaB's uneven spatial coverage points to sampling biases in community efforts to observe debris-covered glaciers, with some regions (e.g. central Europe and South Asia) well-sampled but others having gaps with prevalent debris (e.g. the Andes and Alaska). Debris thickness measurements are mostly concentrated at lower elevations, leaving higher-elevation debris-covered areas undersampled and suggesting that our knowledge of debris properties might not be representative of all elevations. The aims of DebDaB, as an openly available dataset, are to evolve over time, to be updated, and to add to community submissions as new data on supraglacial properties become available. The data described in this paper can be accessed from Zenodo at https://doi.org/10.5281/zenodo.14224835 (Groeneveld et al., 2025).

1 Introduction

Debris-covered glaciers are characterised by a layer of rock debris on part of their surfaces. Debris covers approximately 7.3 % of the global glacier area, and about 20 % of Earth's glaciers have a substantial debris cover of at least 7 % or 10 km^2 (Herreid and Pellicciotti, 2020; Scherler et al., 2018). Crucially, this debris influences ice melt rates and therefore surface mass balance, depending on its thickness and physical properties, with thin debris (less than a few centimetres) enhancing melt through energy absorption, while thicker debris reduces melt by insulating the glacier ice (Østrem, 1959; Nicholson and Benn, 2006). The thickness-dependent melt can lead to an inverted mass balance profile and elongated low-gradient glacier tongues that extend to lower elevations than expected for clean-ice glaciers in the same locations (Benn and Lehmkuhl, 2000; Quincey et al., 2009; Benn et al., 2012). Due to the different melt and geometric characteristics of debris-covered glaciers, their dynamics and hydrology are also distinct compared to clean-ice glaciers (Scherler et al., 2011; Anderson and Anderson, 2016; Fyffe et al., 2019; Miles et al., 2020). As such, debris cover has been recognised as an essential mountain climate variable (Thornton et al., 2021). Understanding debris-covered glaciers (in the current study excluding the Antarctic and Greenland ice sheets) is essential for predicting water availability in regions with substantial debris cover such as Alaska, South-East Asia, and New Zealand in order to understand regional and global patterns of glacier response to climate (Scherler et al., 2011; Kääb et al., 2021) and for long-term reconstruction of glacier dynamics (Anderson and Anderson, 2016).

Improved understanding of the response of debris-covered glaciers to climate change (Rounce et al., 2023; Postnikova et al., 2023) is currently hampered by insufficient data on key debris parameters (Rounce et al., 2021; Miles et al., 2022) as well as limited understanding of debris thickness patterns (Anderson and Anderson, 2018; Nicholson et al., 2018) and sub-debris melt rates (Rounce et al., 2021). Direct measurements of debris thickness and sub-debris ice melt are essential for evaluating sub-debris melt models (Nicholson and Benn, 2006; Reid and Brock, 2010; Evatt et al., 2015; Rounce et al., 2015). Furthermore, gaining insights into the surface mass balance of debris-covered glaciers through energy balance modelling requires a detailed understanding of the physical properties of the debris layer, such as thermal conductivity, aerodynamic surface roughness length, emissivity, porosity, and albedo (Nicholson and Benn, 2006; Rounce et al., 2015). Accurate representation of debris thickness and debris properties in energy balance models is necessary for predicting the melt rates of debris-covered glaciers and their contribution to water resources (Lejeune et al., 2013; Brock et al., 2010). However, estimating these physical properties for a particular glacier usually presents several challenges, as collecting such measurements can be labour-intensive and economically expensive or have a large degree of uncertainty in time and space. These measurements are often a combination of field measurements, laboratory experiments, remote sensing techniques, or model optimisations. Although the development of remote sensing methods to estimate debris properties is promising (Racoviteanu et al., 2022), these methods require in situ measurements for evaluation. Unfortunately, supraglacial debris layer thicknesses and physical properties have been measured for relatively few glaciers. Many studies therefore optimise debris properties for the purpose of ice melt modelling or rely on literature values (Rounce et al., 2015; Fugger et al., 2022). In addition, some measured debris properties and thicknesses have not been published openly, and, to date, there is no central repository with debris property data which could facilitate individual glacier studies as well as large-scale model studies.

Here we aim to compile existing and new measurements of debris thickness and physical properties into one database, together with reported literature values and optimised debris properties from modelling efforts, for as many glaciers as possible. Our goal is to create an open central repository for use by the scientific community to support and enhance numerical modelling at the glacier, regional, and global scales when debris-covered glaciers are involved. We call this the supraglacial Debris Database (DebDaB). Below we briefly describe each of the supraglacial debris layer properties considered in DebDaB. Thereafter, we describe the data compilation and curation process and show key features of the dataset as well as the spatial distribution and variability of the measurements and reported values. Finally, we discuss potential applications of the dataset as well as limitations and priorities for future measurements.

2 Debris properties

Debris thickness is a key control on melt enhancement or reduction in the bulk debris layer (Østrem, 1959) and is typically measured in situ by manual excavations from the debris surface to the ice surface. However, these measurements are labour-intensive, and remote sensing estimates of debris are becoming more widely available. For example, debris thickness can be inferred from its relation to debris surface temperatures using thermal-band satellite images, either empirically (Mihalcea et al., 2008a; Kraaijenbrink et al., 2017) or with a physically based approach (Foster et al., 2012; Rounce and McKinney, 2014; Stewart et al., 2021). At the glacier scale, ground-penetrating radar (GPR) (McCarthy et al., 2017; Giese et al., 2020) and ground-based thermal infrared radiometry (Aubry-Wake et al., 2023) have also been used to estimate debris thickness. Sub-debris melt modelling has provided fully distributed estimates of debris thickness at regional and global scales (Rounce et al., 2021; McCarthy et al., 2022), sometimes also making use of satellite thermal data (Rounce et al., 2021). L-band synthetic aperture radar also shows promise in retrieving debris thickness through its internal volume scattering (Huang et al., 2017). Despite the advancements in remote sensing and modelling techniques, all of these methods require direct in situ measurements to validate the estimates.

The thermal conductivity of the debris influences the rate at which heat is transferred through the debris layer, affecting the melt rate of the underlying ice, and it depends on factors such as composition, moisture content, and grain size, which can vary widely in space (Juen et al., 2013) and time (Nicholson and Benn, 2013). Thermal conductivity can be determined through laboratory analysis of debris samples or in the field by placing thermistors within the debris layer and analysing the vertical temperature profiles (Nakawo and Young, 1982; Conway and Rasmussen, 2000). Importantly, however, discrepancies between methods to derive thermal conductivity can be substantial and significantly affect modelled melt in energy balance simulations (Laha et al., 2023; Melo-Velasco et al., 2025).

The aerodynamic surface roughness length of the debris layer, which is the height above the debris surface at which the mean horizontal wind speed theoretically becomes zero, affects the turbulent heat fluxes at the glacier surface. It can be derived from wind profile data and microtopographic or eddy covariance methods (Chambers et al., 2020; Rounce et al., 2015; Nicholson and Stiperski, 2020) and can vary significantly with surface conditions and debris distribution (Miles et al., 2017; Quincey et al., 2017; Sicart et al., 2014). Methods to derive surface roughness can be financially expensive but remain independent of melt modelling choices and are therefore preferable to approaches that might optimise surface roughness through a model routine (Melo-Velasco et al., 2025).

The emissivity of the debris, which is the efficiency with which the debris surface emits thermal radiation, influences the longwave radiation balance. Emissivity is mostly assumed constant in time and is usually taken from published literature values for the specific type of rock (Brock et al., 2007, 2010), although it can also be estimated from thermal imagery and site-specific measurements (Herreid, 2021) or satellite datasets (Casey and Kääb, 2012).

The porosity of the debris layer, defined as the void space within the debris material, influences the thermal properties and water retention capabilities of the debris layer (Juen et al., 2013). Porosity can be measured by filling the air spaces in a known volume of surface debris with water and has been found to range from ~ 20 % to ~ 60 % (Brock et al., 2006). Porosity has been assumed to linearly decrease with depth in the debris layer, decreasing from ~ 40 % at the surface to ~ 20 % at the debris–ice interface (Collier et al., 2014), but often a bulk porosity of 30 % is adopted (Nicholson and Benn, 2013). Ultimately it is difficult to measure or estimate porosity while keeping the original structure of the debris layer untouched, and measurements are therefore scarce.

Albedo, the reflectivity of the debris surface, depends on properties such as the colour and moisture of the debris. It determines the amount of solar radiation absorbed by the glacier surface, such that a lower albedo promotes higher melt rates and a higher albedo lower melt rates. It can be measured using ground-based albedometers or pyranometers (Brock et al., 2000) or estimated from multi-temporal satellite imagery (Fujita and Sakai, 2014). The albedo of a debris-covered glacier decreases as the proportion of the debris-covered glacier surface increases (Brock et al., 2010; Azzoni et al., 2016), and it is therefore important for melt modelling.

3 Data compilation

DebDaB targets the supraglacial debris layer properties described above. The dataset compiles measurements, literature values, and optimised or calculated debris properties from modelling exercises.

3.1 Published data

The majority (90 %) of the data entries in DebDaB are published data from 172 different sources. These data are obtained from tables, digitised figures, text and supplementary files in research articles or scientific reports, and publications in data repositories and personal communications from data collectors. DebDaB is therefore a central database of supraglacial debris thickness and bulk properties to which the scientific community can refer instead of searching through hundreds of research articles. The dataset acknowledges the data source and provides a citation for each data entry that has previously been published elsewhere (see Table A1 in the Appendix). For the current version of DebDaB, there was no public call for gathering data except for advertising it at scientific conferences.

3.2 Unpublished data

The remaining 10 % of the data in DebDaB have not been published previously and correspond almost exclusively to debris thickness measurements. These are from 10 different field campaigns undertaken by the authors and colleagues at 10 different glaciers between 2013 and 2023. They are briefly described below:

- Baghirath Kharak, Satopanth, and Raj Bank (Marin Kneib et al., unpublished data) – 162 debris thickness measurements were taken on Satopanth, Baghirath Kharak, and Raj Bank glaciers in September 2022. Debris thickness ranged between a few centimetres and several metres.

- Clariden Glacier, Switzerland (Michael McCarthy et al., unpublished data) – 19 debris thickness measurements were taken by manual excavation on Clariden

Glacier, Switzerland, in September 2020. Debris thickness ranged between 1 and 29 cm.

- Ghanna Glacier, Nepal (McCarthy et al., 2019, unpublished data) – seven debris thickness measurements were taken by manual excavation on Ghanna Glacier, Nepal, in May 2019. Debris thickness ranged between 21 cm and more than 53 cm.

- Kyzylsu Glacier, Tajikistan (Evan Miles et al., unpublished data; Melo Velasco et al., 2023, unpublished data) – ongoing field campaigns in the western Pamir, Tajikistan, have provided debris thickness measurements through excavation or, at the time of ablation, stake installation on the debris-covered terminus of Kyzylsu Glacier. In 2021, a total of 249 measurements of debris thickness were collected by manual excavation. Additionally, in August 2023, 123 debris thickness measurements were taken on the glacier. In both field campaigns, debris thicknesses ranged between less than 1 cm and a maximum digging depth of 1 m.

- Lirung Glacier, Nepal (Lene Petersen et al., unpublished data; Buri et al., 2014, unpublished data) – this gives a short description of field measurements. Between 2012 and 2014, 227 measurements of debris thickness were collected on the Lirung Glacier, along with corresponding debris classification descriptions. Debris thickness ranged between 6 and 70 cm.

- Oberaletsch Glacier, Switzerland (Vicente Melo Velasco et al., unpublished data) – between June and August 2023, 196 measurements of debris thickness were taken on the glacier to investigate the spatiotemporal evolution of the debris layer. Debris thicknesses ranged between 1 and 87.5 cm.

- Piramide Glacier, Chile (Vicente Melo Velasco et al., unpublished data) – in March 2023, 103 distributed measurements of debris thickness were taken on this glacier as part of a dedicated survey to understand debris thickness variability (Melo-Velasco et al., 2024). Debris thickness ranged between less than 1 cm and 1.1 m.

- Gangotri Glacier, India (Aditya Mishra et al., unpublished data) – in June 2023, 12 measurements of debris thickness were taken on this glacier, ranging between 14 cm and 1.05 m.

3.3 Data curation

The data from different sources were collected, organised, and structured in a logical, consistent, and standardised manner. Errors and inconsistencies in the source data were identified and corrected, in some cases by contacting the authors, and the units of the data were standardised to metric values: debris thickness values and surface roughness length are provided (m) together with thermal conductivity ($\mathrm{W\,m^{-1}\,K^{-1}}$). Albedo, emissivity, and porosity are dimensionless values ranging between 0 and 1. The data descriptions provided in the database are as detailed as possible, integrating the information from tables, figures, text, and metadata from the original source data. The origin of the data is denoted by a data and/or paper citation and the corresponding DOI. At present, a glacier name and a glacier ID based on the Randolph Glacier Inventory (RGI) 6.0 (RGI Consortium, 2017) are given for each data entry. Dates on which measurements were collected are also included and are usually sourced from the methods sections of research articles or table and figure captions. In some cases an exact date was not stated or clear, and thus a quality flag for the date entry is included. The coordinates of the measurement location, where available, were all standardised and are provided in decimal degrees, along with the elevation in metres above sea level at the time of the measurement. Other location data such as the specific site name in a study are also included, as well as any relevant notes (e.g. the type or size of the debris, the average of the measurements, or the moisture conditions). The methods used to obtain each debris property value are also shown in the database, together with any relevant notes. Where available, measurements are provided with uncertainty estimates or with a range if multiple debris thickness measurements are provided without a precise location.

4 DebDaB

4.1 Spatial distribution of data

DebDaB includes data from 84 glaciers across various regions (Fig. 1). The majority of the glaciers with data are located in High Mountain Asia (45) and the European Alps (18), showing that these regions have been a major focus of study and field campaigns for debris-covered glaciers, while other regions such as the Andes (4), North America (9), Svalbard (3), and New Zealand (3) contain fewer data (Fig. 1). The majority of the glaciers (76) have debris thickness measurements, with a total of 8741 measurements in the dataset to date, of which 1770 contain data on sub-debris ablation as well (Table 1), although 965 of those are from Satopanth Glacier (Banerjee, 2022). There are also 188 sub-debris ablation measurements in clean-ice areas of debris-covered glaciers. The number of data entries of other debris properties is considerably lower, with 179 for thermal conductivity and as few as 37 for porosity (Table 1), although every property has values for at least 30 glaciers. Most data entries for debris thickness contain spatial information with latitude, longitude, and elevation provided, but this is rarely the case for the other debris properties, which are usually only assigned to a glacier but not a specific location on the glacier.

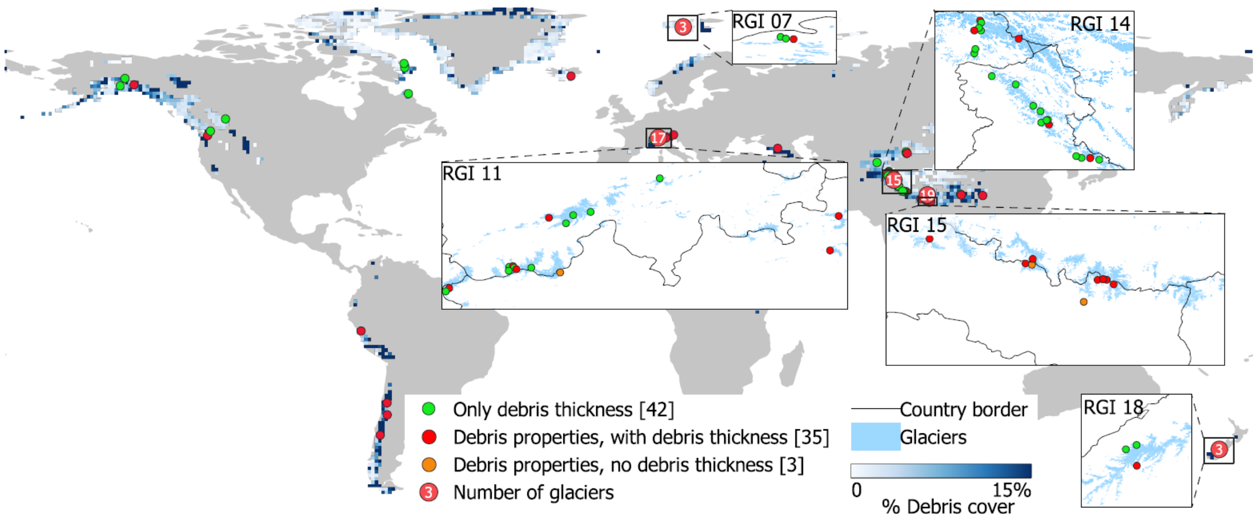

Figure 1. Spatial distribution of the data in DebDaB. Points show the locations of all glaciers with at least one data entry for a debris property. The underlying pixel colours show the percentage of debris cover on glaciers in that pixel area, based on Scherler et al. (2018).

Table 1. Summary of the data entries in DebDaB.

DebDaB data entry	Total number	With coordinates	With elevation only	Number of glaciers
Debris thickness	8741	4369	1675	76
Sub-debris ablation	1770	546	1088	41
Thermal conductivity	179	33	44	31
Surface roughness	160	26	4	28
Albedo	79	2	9	25
Emissivity	59	10	0	27
Porosity	37	11	0	19

4.2 Observed variability of the physical properties

Figure 2 highlights the variability in the distribution of debris thickness measurements, thermal conductivity, and surface roughness values. Debris thicknesses range from dirty ice or patchy debris (< 1 cm, Fyffe et al., 2014) to thick debris (> 1 m). The interquartile range of measurements is also highly variable across glaciers and regions, with some glaciers having the majority of their measured debris thicknesses below 10 cm, some measuring predominantly above 10 cm, and some which span the whole range of thicknesses. The measured glaciers are from 13 RGI regions, with some apparent regional differences in debris thickness (Fig. A1 in the Appendix). The three regions with the highest median debris thickness (with a minimum of measurements on three different glaciers) are Region 2 (western Canada and the USA, 40 cm), Region 15 (South-East Asia, 40 cm), and Region 17 (southern Andes, 30 cm). The regions with the lowest median debris thicknesses are Region 1 (Alaska, 4 cm) and Region 11 (central Europe, 8 cm). However, the regional observed differences could also simply be due to sampling biases (see Sect. 5.2 on the limitations). The number of data entries per glacier varies greatly: 49 glaciers have fewer than 50, only 21 glaciers exceed 100, and just 2 glaciers (Ngozumpa and Satopanth) have over 1000.

Along with debris thickness measurements, many glaciers have measurements of sub-debris ablation rates, enabling the fitting of simplified Østrem curves (Østrem, 1959) in the form of a rational curve that only depicts the declining limb of melt with debris thickness (see the equation in Fig. 3). Note that application of this curve to derive melt rates based on debris thickness can lead to unrealistically high melt rates for very thin debris. These are typically derived from modelling exercises or are based on measurements from a single glacier. To the best of our knowledge, this paper provides the most detailed scatterplot of debris thickness and ablation rates yet, with simplified Østrem curves fitted for 19 glaciers based entirely on observational data (Fig. 3). The alignment of data points along the characteristic negative exponential Østrem curve strongly supports the well-documented reduction in melt rates after the initial few centimetres of debris and the subsequent minimal reduction in melt rates for thicker debris. Only one glacier (Venerocolo) displays nearly no reduction in ablation for increasing debris thickness, in-

Figure 2. The distribution of debris thickness measurements **(a)**, thermal conductivity **(b)**, and surface roughness length **(c)** for each glacier in DebDaB. The glaciers are sorted by RGI region (RGI6.0, https://www.glims.org/rgi_user_guide/regions/overview.html, last access: 20 November 2024). The number of measurements or data values are shown on the left. Literature values are not shown. Note the logarithmic x-axis scale for debris thickness and surface roughness length.

stead of the expected exponential reduction, and a poor R^2 (Table A1).

The observed variability of thermal conductivity and surface roughness per glacier is shown in Fig. 2b and c, the variability of all other debris properties in DebDaB is shown in Fig. 4, and regional differences are shown in Fig. A1. The median of all data entries for thermal conductivities across the dataset is $0.98\,\mathrm{W\,m^{-1}\,K^{-1}}$, which is near the $0.96\,\mathrm{W\,m^{-1}\,K^{-1}}$ value that Brock et al. (2010) calculated and is widely used in the literature. However, the range of thermal conductivities is large, from $0.3\,\mathrm{W\,m^{-1}\,K^{-1}}$ at Villarrica Glacier (Brock et al., 2007) to $2.8\,\mathrm{W\,m^{-1}\,K^{-1}}$ at Satopanth Glacier (Laha et al., 2023). There is also regional variability in thermal conductivity values, which is apparent despite the fewer data available. The highest median thermal conductivity is observed in Central Asia and South-East Asia, while the lowest one is observed in the southern Andes (Fig. A1).

The variability of the values reported for surface roughness length is also large, i.e. at a logarithmic scale between 0.008 m at Svinafellsjokull Glacier (Nield et al., 2013) and 0.06 m at Khumbu Glacier (Lejeune et al., 2013), with most literature values using 0.016 m from Brock et al. (2010). Albedo ranges from 0.03 at Larsbreen Glacier

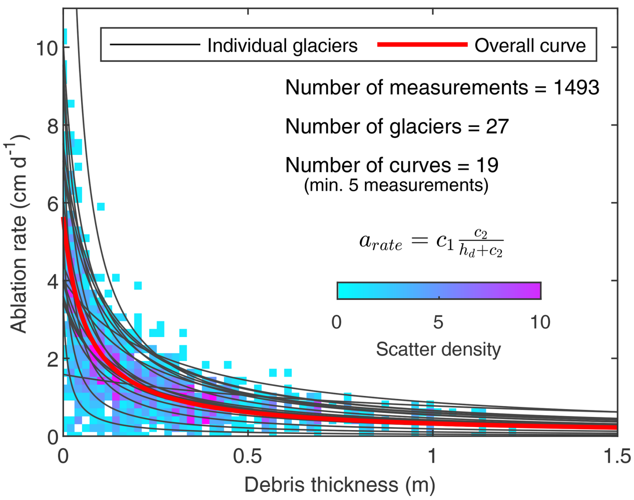

Figure 3. Simplified Østrem curves (Østrem, 1959) based on observations of debris thickness and observations of sub-debris ablation rates. All measurements are plotted in the scatter, but simplified Østrem curves (rational curves) are only fitted for the 19 glaciers that have at least five measurements. The equation shows the form of the curve, as in Anderson and Anderson (2016). The fitted parameters and R^2 for each curve are shown in Table A1 in Appendix A.

(Nicholson and Benn, 2006) to 0.35 at Venerecolo Glacier (Bocchiola et al., 2015), but the most common reported values are around 0.1.

Regarding emissivity, no actual measurements are reported, only literature values and assumed values ranging from 0.9 to 1, making it the apparently least important variable of all the debris properties in the database. Measurements of porosity are also scarce and are most common between 0.2 and 0.45, with most of the literature using values around 0.3 (Fig. 4e). Optimised values from modelling exercises for all debris properties fall within the overall range (not site-specific) of reported field measurements in DebDaB, except for the highest reported value of surface roughness, which is an assumption by Fujita and Sakai (2014) and is above any surface roughness measurement reported in DebDaB. The number of measurements is too low to observe any regional differences for surface roughness, albedo, porosity, and emissivity (Fig. A1).

4.3 Variability of the methods

The debris layer properties in DebDaB are measured, derived, and calculated with a variety of methods, which can result in large differences in estimates (Melo-Velasco et al., 2025). Debris thickness is primarily measured by excavating the debris until the ice surface is reached. In the case of thick debris, manual excavations may not reach the ice surface, usually stopping at 0.5 m. The debris thickness data in DebDaB contain a column indicating whether or not the ice surface was reached by manual excavation. Manual excavations are also performed when installing ablation stakes, and the debris is restored to its original configuration as much as possible afterwards. Other manual measurement methods include experimentally adjusting the debris cover (Muhammad et al., 2020; Winter-Billington et al., 2022) or placing metal rods in between the debris stones down to the ice surface (Popovnin and Rozova, 2002). Debris thickness is also measured directly at exposed ice cliffs or using a laser theodolite and reflector positioned on the upper debris surface in case it is dangerous to access the edge of the cliff (Nicholson and Benn, 2013). Close-range remote sensing measurements from photogrammetric terrain models and GPR (McCarthy et al., 2017; Nicholson and Mertes, 2017) are also present in DebDaB.

Debris thermal conductivity is calculated using the one-dimensional heat conduction equation and measurements of vertical temperature profiles within the debris (Conway and Rasmussen, 2000; Nicholson and Benn, 2006) or is based on the Fourier heat conduction equation with different combinations of meteorological and glaciological data (Brock et al., 2010; Reid et al., 2012). Some studies use optimising equations of energy balance to match measurements of ice ablation (Bocchiola et al., 2015; Fugger et al., 2022). Laha et al. (2023) use a Bayesian inversion approach, and Kirkbride and Warren (1999) use a weighted average of the present parent rock type and interstitial media.

Surface roughness values in DebDaB are estimated using four methods: the profile aerodynamic method, the microtopographic method, the optimisation method, and eddy covariance systems. The profile aerodynamic method determines aerodynamic surface roughness length using Monin–Obukhov similarity theory (Miles et al., 2017; Quincey et al., 2017). Microtopographic approaches estimate roughness through (i) mechanistic methods, which identify surface obstacles from elevation profiles, and (ii) empirical techniques, which calculate the standard deviation of elevations from a detrended digital elevation model (DEM) of equal height and width (Miles et al., 2017). Alternatively, optimisation methods used in energy balance modelling adjust surface roughness to best reproduce observed surface temperature, ice melt, or mass loss (Steiner et al., 2021; Fugger et al., 2022). Finally, point-scale estimates can be obtained from turbulent fluxes measured with eddy covariance systems (Steiner et al., 2018).

The rest of the properties have fewer measurements and therefore fewer methods. Albedo is measured with albedometers (Brock et al., 2007; Nicholson and Benn, 2006), handheld luxmeters (Steiner et al., 2015), or the ratio of incoming and reflected shortwave radiation (Steiner et al., 2021). Porosity measurements are taken by placing a known amount of debris in a graduated bucket and measuring the volume of water required to fill the interstitial pore spaces (Collier et al., 2014; Giese et al., 2020). Porosity can also be estimated from the matrix particle size determined by laser diffraction (Nicholson and Benn, 2006) or using a soil corer

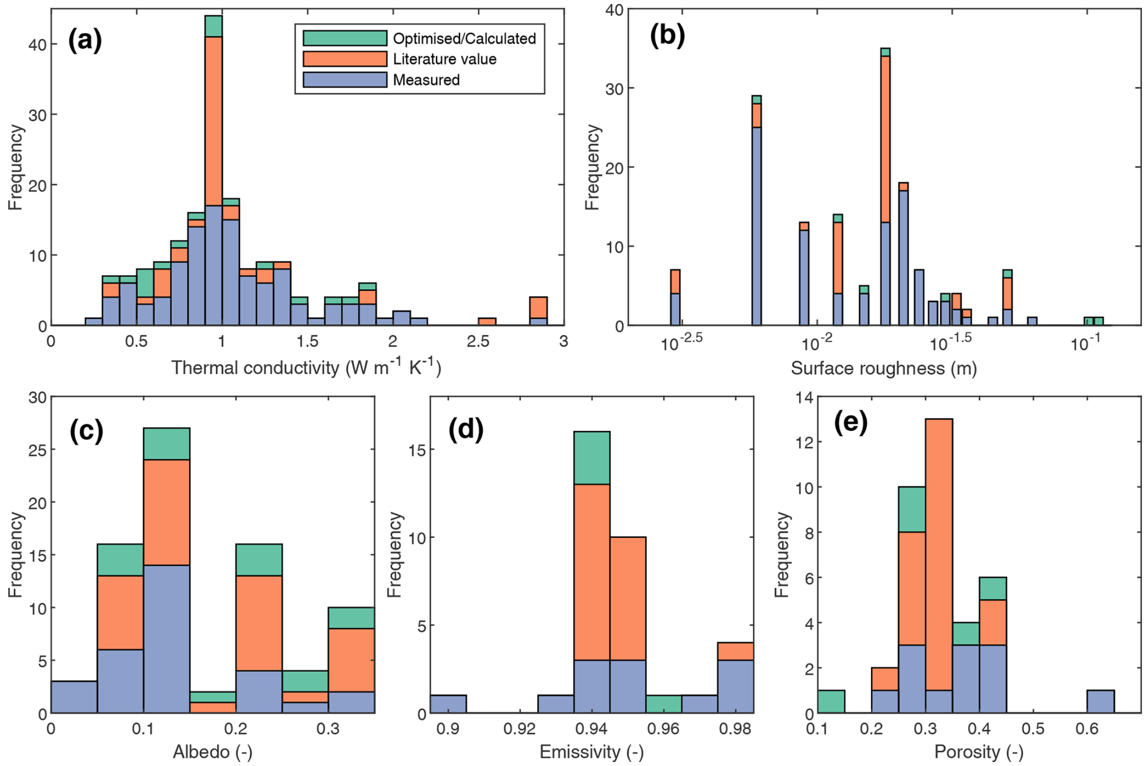

Figure 4. Frequency distributions of the physical properties of debris in DebDaB, except for debris thickness. The histogram bars are stacked.

and drying, weighing, and sieving the debris in the laboratory (Steiner et al., 2021). Emissivity, however, lacks direct measurements in DebDaB, relying only on literature and assumed values.

The variability of the approaches described above should be carefully considered when assessing the variability in debris properties across sites and climates.

5 Discussion

5.1 Potential applications

The DebDaB dataset presents a large collection of reported supraglacial debris layer property values and can be a valuable resource for numerous scientific applications, some of which we outline here.

The debris property values within DebDaB may be used to constrain energy balance, melt, and surface mass balance models, potentially improving the performance of these models by incorporating site-specific physical properties of debris. DebDaB serves as a central public repository of physical properties of supraglacial debris layers that modellers can refer to in case they need a property value for their modelling efforts. When data for a specific glacier are not available, modellers have sometimes chosen values from other similar glaciers, and DebDaB makes relevant values accessible. However, regional differences between debris properties were not apparent in DebDaB, except for debris thickness, with glaciers in High Mountain Asia consistently having thicker debris than in central Europe, although this could also be due to an observational bias. Future research could explore whether using the most common literature values for debris properties or the average of DebDaB values is better than using a value from a nearby glacier. Furthermore, evaluation of energy balance models is usually limited by the number of measurements available. The data provided by DebDaB could be used to re-evaluate remote sensing efforts (Miles et al., 2017; Chambers et al., 2020; Rounce et al., 2021) more broadly and understand their wider applicability and expected uncertainties.

DebDaB can be used to assess the sensitivity of glacier melt modelling to varying debris properties. Previous studies have assessed melt model sensitivity using assumed ranges for debris properties, varying values by up to $\pm 10\,\%$ (Reid and Brock, 2010). The variability of debris properties from actual measurements and reported values available in DebDaB allows future research to use more realistic ranges of debris property values in model sensitivity tests (Miles et al., 2022).

Researchers planning field campaigns on debris-covered glaciers can use DebDaB to identify gaps in current datasets and prioritise regions or glaciers that have not been thoroughly studied. By leveraging existing debris property data, field campaigns can be more efficiently designed, focusing on collecting missing or complementary data to fill the gaps identified from DebDaB. Moreover, campaigns on previously monitored glaciers could be repeated and compared to existing data to understand broad temporal changes and trends in properties such as debris thickness and surface roughness, which can have implications for the non-linear response of glacier evolution to ongoing climate change.

Recent efforts have estimated spatially distributed debris thickness from remote sensing data by inverting sub-debris melt models or surface temperature data (Rounce et al., 2021). Distributed surface roughness estimates have also been obtained from digital elevation models (Miles et al., 2017; Chambers et al., 2020). For both, evaluation is usually limited by the number of measurements available. The data available in DebDaB could be used to re-evaluate remote sensing efforts more broadly and understand their wider applicability and expected uncertainties.

DebDaB's coverage across multiple glaciers in various regions allows for comparative studies of debris properties on regional and global scales. The dataset could be used to explore regional differences in debris characteristics and their influence on glacier melt as more data become available. When more fully populated, the database could form the basis for investigating links between different debris parameters. Such analyses can provide insights into how different environmental conditions, as well as geology and glacier morphology, can shape debris properties on glaciers.

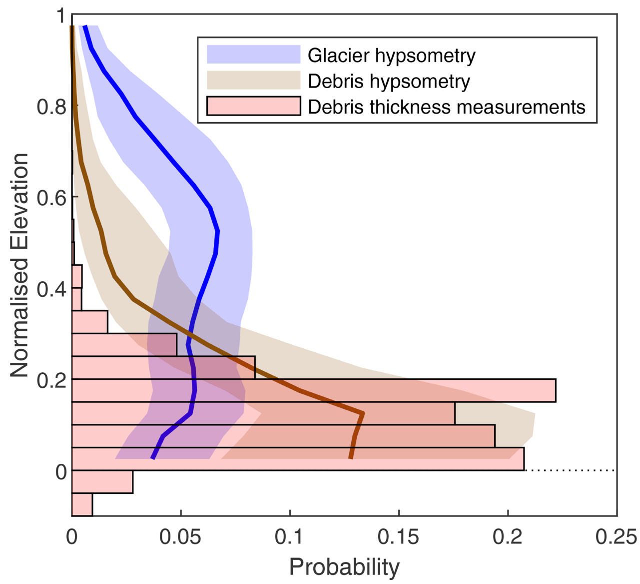

Figure 5. Glacier hypsometry and elevation of the debris thickness measurements in DebDaB. The hypsometry is based on RGI6.0 (RGI Consortium, 2017). The shaded areas show interquartile ranges and the solid lines the medians of the normalised hypsometries of all glaciers with debris thickness measurements. Note that negative values in normalised elevation for debris thickness measurements may be due to inaccuracies in the delineation of the debris cover outlines used (see the text). The debris thickness measurement histogram is based on 5756 measurements.

5.2 Limitations

The main limitations of DebDaB come from potential sampling biases and an unbalanced spatial coverage. Some regions, such as central Europe and South Asia, are well-sampled with data from at least 10 different glaciers, while other highly glacierised regions such as the Andes or Alaska only have data from 4 and 3 glaciers, respectively. There are also many RGI regions for which no data are available (3, 5, 8, 9, 10, 19, and 20) and some glaciers or regions for which only one data entry is available (Caucasus and the Middle East). It is therefore difficult to assess whether measurements on those sampled glaciers are representative of their wider regions or not. Furthermore, the initial effort to compile DebDaB did not include a community-wide call for data submissions, biasing data inclusion towards open-data sources as well as submissions by the authors and their immediate networks.

Debris thickness is the property with the most spatial and temporal representation in DebDaB. Some regional differences are apparent, e.g. between South Asia, showing consistently thicker debris, and central Europe, showing consistently thinner debris. However, it could also be that thinner debris areas in South Asia are more inaccessible due to their high elevation compared to central Europe. Figure 5 shows the overall representativeness of debris thickness measurements considering the hypsometry of the debris and the glaciers in DebDaB. Using a 30 m resolution DEM, the glacier outlines from RGI6.0, and the debris outlines from Scherler et al. (2018), Fig. 5 compares debris hypsometry, glacier hypsometry, and the altitudinal distribution of debris thickness measurements. It shows that debris may already be present in the upper 50 % of glacier elevations (> 0.5 of normalised elevations in Fig. 5), is most prominent in the lower 40 % of glacier elevation ranges, and peaks in the lowest 20 % of the elevation ranges. The debris thickness measurements from DebDaB, however, are mostly located in the lower 20 % of the glacier elevations, and almost no debris thickness measurements are collected above the lower 30 % of glaciers. Consequently, these results highlight the fact that there is a lack of data available for the middle segments of glaciers. The middle glacier areas are usually more inaccessible areas where elevation, surface topography, or crevassing might pose problems, but they may also present a large sampling bias, as these higher areas closer to the debris-free glacier usually have thinner debris where ablation of ice may be enhanced (e.g. Fig. 3). Meanwhile, in the lower portion of the glacier, the upper quantiles of actual debris thickness may also be underestimated given the inability to manually excavate debris due to large clast sizes or infilling of excavation pits beyond a given depth (McCarthy, 2018). Similar conclusions can be drawn from the elevation distribution of thermal conductivity and surface roughness measurements (Figs. A3 and A4), although the number of measurements is much lower.

Interestingly, Fig. 5 shows that the hypsometry of debris thickness measurements may be below the minimum glacier elevation according to the debris cover outlines from Scherler et al. (2018). This makes the elevation of those measurements when normalised to the glacier elevation negative (i.e. below the glacier minimum). The minimum and maximum glacier elevations extracted from the DEM used here correlate almost perfectly with those in the metadata of RGI6.0 (Fig. A2), which suggests that the DEM used is not the cause of the negative normalised elevations. Instead, these may be due to inaccuracies in the delineation of the debris cover outlines, showing that some glaciers may extend beyond the published outlines in RGI6.0. Indeed, the delineation of debris-covered glaciers remains a major challenge for the remote sensing community (Racoviteanu et al., 2022). For some older debris thickness measurements, it could also be that the elevation at which the debris thickness measurement was taken in the past is now glacier-free due to glacier retreat.

As discussed in Sect. 4.3, DebDaB contains values of debris properties measured, derived, and estimated using a number of approaches, which should be considered when comparing values. It is increasingly apparent that different approaches can lead to largely varying estimates of thermal conductivity and surface roughness even when applied to the same sites (Melo-Velasco et al., 2025). Even simple measurements such as manual excavation to determine debris thickness might differ for distinct data collectors. More systematic intercomparisons of methods for deriving debris properties thus seem important, and DebDaB can offer the baseline data for such intercomparisons.

Finally, despite the effort to collate as many detailed data as possible, some metadata, notes, and details on sampling and measurements were not available for inclusion in DebDaB. Despite the data curation and quality control, some data may still have inaccuracies or incomplete information or notes on the data collection procedure.

5.3 Future development of DebDaB

The aim of DebDaB is for it to keep evolving and keep being updated as more data on supraglacial debris properties become available, making it an up-to-date central repository for research on debris-covered glaciers and the potential applications outlined above. We suggest the scientific community submit new data entries to DebDaB, using standard templates for each type of supraglacial debris data, which are already included in the repository. These data can then be included in future updated versions of DebDaB. In addition to continuing to maintain DebDaB and ensuring its availability to the community, we envision the following efforts to update and improve DebDaB in the coming years:

- We will undertake a community call for data submissions to the database. This will include specific data requests from some known data sources as well as a Cryolist call and broad advertising at relevant conferences.
- We will migrate the database from RGI6.0 to RGI7.0 glacier identifications for consistency with the current standards.
- We will consider the inclusion of other debris parameters, as requested by the community. This could include other physical parameters for which few measurements currently exist, such as water content, predominant lithology, grain size distribution, internal debris layer temperatures, or possibly empirical parameters (e.g. critical thickness or effective thickness) that may be useful for other models.
- We will consider the inclusion of data from debris-covered glaciers in Greenland and Antarctica, if available.
- We will seek to connect with efforts by the Debris-Covered Glaciers Working Group (DCGWG) of the International Association of Cryospheric Sciences (IACS) to host raw datasets (e.g. meteorological data, thermistor data, and UAV data) and to reprocess those data according to new methods, for inclusion in DebDaB.
- We will support efforts to homogenise debris parameter measurement methods, enabling improved annotation and categorisation of data entries within DebDaB.

5.4 Priorities for future measurements

DebDaB shows that, despite the tremendous progress with data collection on debris-covered glaciers, considerably more measurements are needed to complement the existing dataset and to improve the aforementioned sampling biases and representativity of measurements. Nearly 10 000 debris thickness measurements are included in DebDaB, but these are still limited to relatively few (< 100) glaciers and are not representative of the global distribution of supraglacial debris. As seen in Fig. 1, areas with prominent debris cover, such as North America and South America, are highly undersampled. Future debris thickness measurement efforts must include, if possible, measurements from the middle and upper reaches of the debris-covered areas of glaciers, aiming to cover the full elevation range of debris on glaciers that have not been sampled before, or at locations similar to previous measurements in order to focus on the temporal evolution of debris thickness. Mitigation of the undersampling of very thick debris areas might be achieved through ground-penetrating radar and ice cliff exposure surveys (Nicholson et al., 2018).

DebDaB contains about 150 entries each for debris thermal conductivity and aerodynamic surface roughness length.

Our literature review highlighted that most modelling studies have used literature values from one study (Brock et al., 2010). Interestingly, the value of thermal conductivity of Brock et al. (2010) is similar to the central value of measurement entries in DebDaB. This highlights the need for more in situ measurements of these properties, although the variability of the methods used to derive these properties undermines the comparability of values between sites and even studies. Using the same measured data with different methods can lead to substantial differences in the derived property values, and the established methods may be difficult to implement successfully at some sites (Melo-Velasco et al., 2025). For energy balance modelling, the choice of method for thermal conductivity has proven to be more critical than for aerodynamic surface roughness length (Rounce et al., 2015; Miles et al., 2022; Melo-Velasco et al., 2025).

The other debris properties within DebDaB have even fewer measurements, so any additional measurements are useful for understanding how variable these properties may be. In some cases, these values can be supported by remote sensing efforts (Racoviteanu et al., 2022). One parameter of particular note is broadband surface albedo, for which DebDaB only includes effective values reported by automatic weather stations and the literature. Albedo can also be inferred from satellite remote sensing given the appropriate bihemispheric reflectance distribution function. However, for this physical property, as for thermal conductivity and surface roughness, it is important to recall that the value can vary temporally. As such, future measurements are needed to assess the temporal (not only spatial) variability of physical properties (Quincey et al., 2017).

6 Data availability

DebDaB is publicly available on Zenodo at https://doi.org/10.5281/zenodo.14224835 (Groeneveld et al., 2025). The dataset is organised in a spreadsheet with a separate tab for each debris property (debris thickness and sub-debris ablation, thermal conductivity, surface roughness, albedo, emissivity, and porosity). Each tab has one row per data entry. All of the data entries provide (where possible) a citation, a DOI, a glacier name and RGI identifier, a date, the coordinates and elevation of the measurement, the debris property value, an uncertainty range, the measurement method, measurement notes, and quality control flags for the dates and locations of the measurements. More detailed information can be found in the metadata file in the repository.

DebDaB data users should cite this data descriptor paper, the DebDaB Zenodo repository (Groeneveld et al., 2025), and the original data sources when using the database, given that DebDaB is mostly a compilation of previously published data. To facilitate the citation of the original data sources, each of the data entries in DebDaB contains the corresponding original reference and the corresponding DOI.

7 DebDaB data sources

7.1 Published literature

DebDaB (Groeneveld et al., 2025) includes data from the following 172 published literature sources: Adhikary et al. (2000), Anderson and Anderson (2016, 2018), Anderson et al. (2020, 2021), Aubry-Wake (2022), Aubry-Wake et al. (2023), Ayala et al. (2016), Azzoni et al. (2016), Banerjee (2022), Banerjee and Wani (2018), Benn and Lehmkuhl (2000), Benn et al. (2012), Bishop et al. (1998), Bisset et al. (2023), Bocchiola et al. (2015), Bozhinskiy et al. (1986), Brock (1996), Brock et al. (2000), Brock et al. (2006), Brock et al. (2007), Brock et al. (2010), Brock (2019), Brook and Paine (2012), Brook et al. (2013), Buri et al. (2022), Carenzo et al. (2016), Casey and Kääb (2012), CEAZA (2015), CEAZA (2021), Chambers et al. (2020), Chand and Kayastha (2018), Chand and Kayastha (2021), Collier et al. (2014), Collier et al. (2015), Comitato Ev-K2-CNR (2012), Conway and Rasmussen (2000), Crump et al. (2017), Das et al. (2022), del Gobbo (2017), Dobhal et al. (2013), Drewry (1972), Evatt et al. (2015), Evatt et al. (2017), Foster et al. (2012), Fujita and Sakai (2014), Fyffe et al. (2014), Fyffe et al. (2019), Fyffe et al. (2020), Fugger et al. (2022), Garg et al. (2022), Gibson et al. (2017), Giese (2019), Giese et al. (2020), Giese et al. (2021), Gök et al. (2022), Gök et al. (2023), Groos et al. (2017), Hagg et al. (2008), Haidong et al. (2006), Han et al. (2015), He et al. (2023), Heimsath and McGlynn (2008), Herreid (2021), Herreid and Pellicciotti (2020), Huang et al. (2017), Huang et al. (2018), Huo et al. (2021), Inoue and Yoshida (1980), Juen et al. (2013), Kääb et al. (2021), Kellerer-Pirklbauer (2008), Khan (1989), Kneib et al. (2022), Kirkbride and Warren (1999), Kirkbride and Deline (2013), Kraaijenbrink et al. (2017), Laha et al. (2023), Lejeune et al. (2013), Lukas et al. (2005), MacPhee et al. (2019), Mattson et al. (1993), Mayer et al. (2010), Mayer and Licciulli (2021), McCarthy (2018), McCarthy et al. (2017), McCarthy et al. (2022), McPhee et al. (2019), Melo-Velasco et al. (2025), Mihalcea et al. (2006), Mihalcea et al. (2008a), Mihalcea et al. (2008b), Miles et al. (2017), Miles et al. (2020), Miles et al. (2022), Minora et al. (2015), Mölg et al. (2019), Moore et al. (2019), Muhammad et al. (2020), Nakawo and Young (1982), Nicholson and Benn (2006), Nicholson and Benn (2013), Nicholson and Stiperski (2020), Nicholson (2018), Nicholson (2019), Nicholson et al. (2018), Nicholson and Boxall (2020), Nicholson and Mertes (2017), Nield et al. (2013), Østrem (1959), Patel et al. (2016), Patel et al. (2021), Pellicciotti et al. (2019), Pellicciotti and Fontrodona-Bach (2019), Pelto (2000), Petersen et al. (2022), Popovnin and Rozova (2002), Popovnin et al. (2015), Postnikova et al. (2023), Pratap et al. (2015), Pratap et al. (2023), Purdie and Fitzharris (1999), Purdie (2005), Purdie (2019), Purdie et al. (2018), Puyu et al. (2013), Quincey et al. (2009), Quincey et al. (2017), Racoviteanu et al. (2022), Rana et al. (1997), Reid and Brock (2010), Reid and Brock (2014), Reid et al. (2012), Rets et al. (2019), Robertson (1988), Rogerson et al. (1986), Röhl (2008), Romshoo et al. (2022), Romshoo et al. (2024), Rounce and McKinney (2014), Rounce et al. (2015), Rounce et al. (2021), Rounce et al. (2023), Rowan and Gibson (2020), Rowan et al. (2020), Rowan et al. (2021), Schauwecker (2012), Schauwecker et al. (2015), Scherler et al. (2011), Scherler et al. (2018), Shah et al. (2019), Sharma et al. (2016), Shaw et al. (2016), Shroder et al. (2000), Shukla and Garg (2019), Sicart et al. (2014), Soncini et al. (2016), Steiner et al. (2015), Steiner et al. (2018), Steiner et al. (2021), Stewart et al. (2021), Takeuchi et al. (2000), Vincent et al. (2016), Wagnon (2019), Wang et al. (2017), Wei et al. (2010), Westoby et al. (2020), Winter-Billington et al. (2022), Yang et al. (2017), Zhang et al. (2011), and Zhao et al. (2023).

According to the authors' understanding of FAIR (findability, accessibility, interoperability, and reusability) principles, authors of published literature and data who (1) correct existing data within DebDaB in case of errors, (2) send the raw data from digitised figures, and (3) submit additional data that were previously unavailable (e.g. accurate coordinates or additional data or metadata which are not already available) will have the right to be added as co-authors of the database in Zenodo. The authors are working to re-evaluate their policies to conform with changes or unusual circumstances in authorship contributions and are happy to involve eager people in the core team.

7.2 Previously unpublished data

DebDaB (Groeneveld et al., 2025) includes previously unpublished data from Pascal Buri et al., Marin Kneib et al., Michael McCarthy et al., Evan Miles et al., Vicente Melo Velasco et al., Lene Petersen et al., Aditya Mishra et al., and Sandro Schmid et al. See the database entries for full details.

DebDaB is open for new data submissions, and therefore future data submissions of previously unpublished data to DebDaB will entail co-authorship of the DebDaB database on Zenodo. Data submissions to DebDaB should be sent to debriscoveredglaciers@ista.ac.at.

8 Conclusions

DebDaB is an open-access central repository database that compiles supraglacial debris layer properties from various sources. These will be updated as more data become available. It is a database for the scientific community to refer to for a variety of applications related to debris-covered glaciers.

There is considerable variability in the number of measurements per debris property as well as their range of values, regionally and per glacier. Some regions, such as South-East and South-West Asia, show consistently thicker debris than other regions such as central Europe or Alaska, although this could be due to sampling biases. DebDaB also enables the production of an updated multi-glacier simplified Østrem curve in the form of a rational curve depicting the declining limb of melt with debris thickness based on observations from many glaciers (currently 19), supporting the general understanding of melt reduction under thicker debris layers.

Despite the comprehensive nature of the dataset, there are gaps in regional coverage and in the measurement of certain debris properties, especially at higher glacier elevations where thinner debris layers are likely present. Sampling biases are present in DebDaB and should be taken into account when using the dataset and prioritising future measurements of debris properties.

Appendix A

Table A1. Coefficients, number of measurements, and R^2 of the fitted simplified Østrem curves (rational curves) in Fig. 3.

Glacier	c_1	c_2	Number of measurements	R^2
Baltoro	4.414	0.16	54	0.55
Barpu	9.368	0.036	104	0.76
Emmons	4.024	0.275	16	0.46
Fox	7.074	0.102	16	0.88
Franz Josef	9.515	0.051	10	0.98
Ghulkin	3.599	0.114	6	0.98
Hinarchi	6.892	0.095	21	0.54
Hoper	3.985	0.089	6	0.97
Kennicott	6.099	0.066	66	0.73
Lirung	3.36	0.015	22	0.38
Miage	4.046	0.115	66	0.49
Rakhiot	10.118	0.056	13	0.79
Satopanth	3.43	0.128	965	0.45
Snow Creek	7.834	0.025	10	0.91
Spire	3.589	0.086	9	0.48
Tasman	38.019	0.015	28	0.79
Tsijiore-Nouve	5.29	0.021	13	0.53
Venerocolo	1.586	0.965	8	0.05
Zmuttgletscher	7.511	0.097	6	0.95
Overall curve	5.621	0.061	1493	0.59

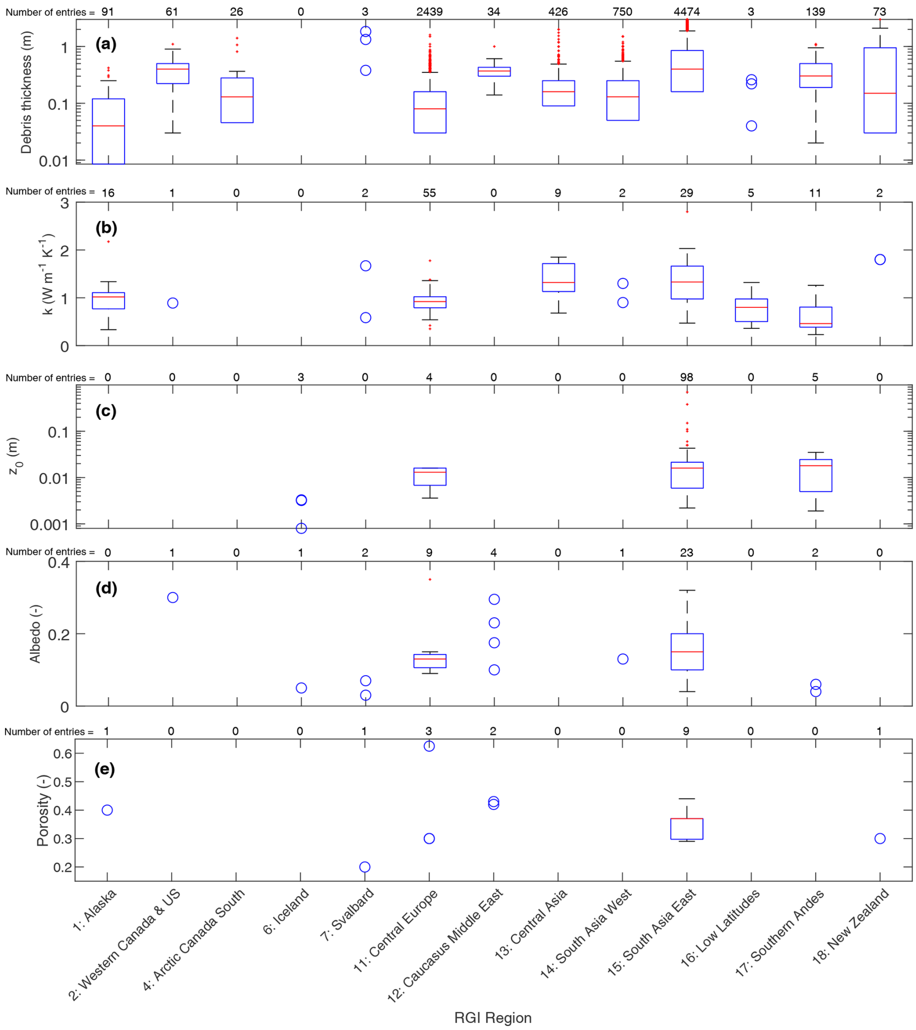

Figure A1. Debris properties in DebDaB averaged per RGI region. A boxplot is shown if there are at least five data entries for a property in a region. Otherwise, individual points are shown. The literature values are not included in this figure.

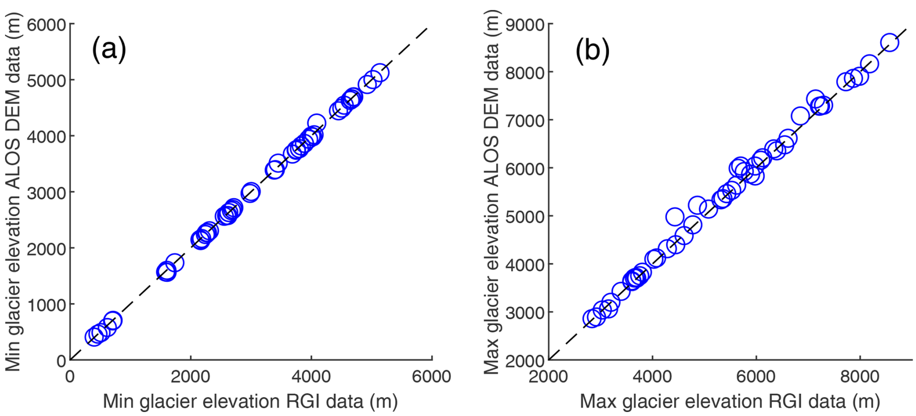

Figure A2. Minimum **(a)** and maximum **(b)** glacier elevations in the Advanced Land Observing Satellite (ALOS) (DEM) and RGI metadata, per glacier.

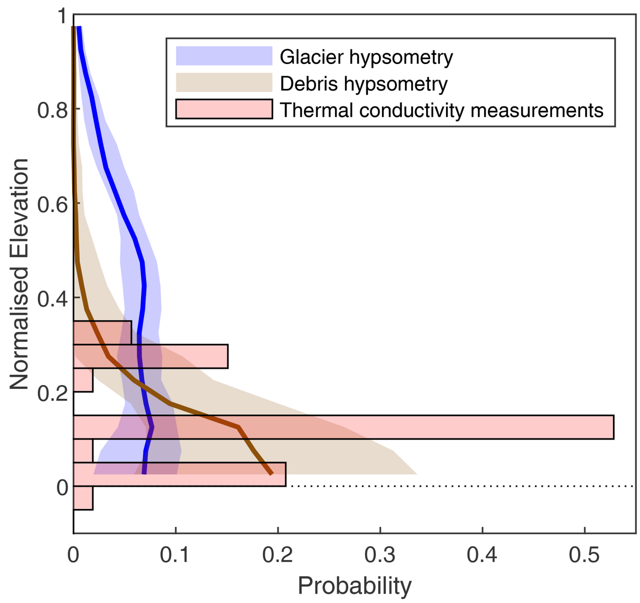

Figure A3. Glacier hypsometry and elevation of thermal conductivity measurements in DebDaB. The hypsometry is based on RGI6.0 (RGI Consortium, 2017). The shaded areas show interquartile ranges and the solid lines the medians of the normalised hypsometry. Note that there are only 51 thermal conductivity measurements.

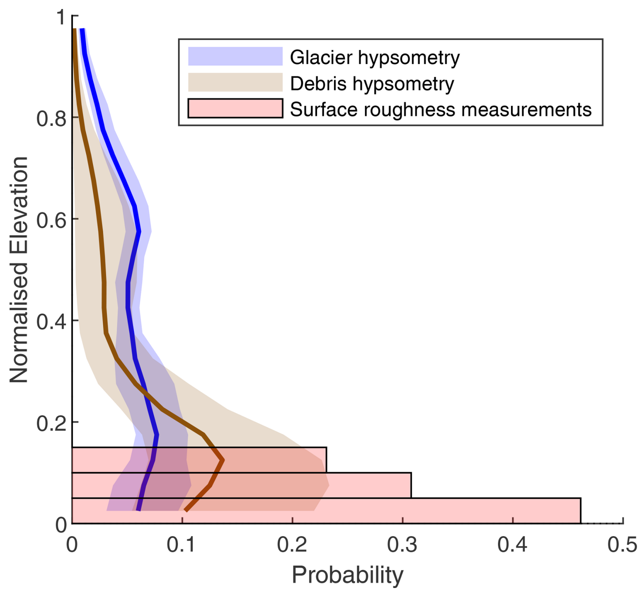

Figure A4. Glacier hypsometry and elevation of surface roughness length measurements in DebDaB. The hypsometry is based on RGI6.0 (RGI Consortium, 2017). The shaded areas show interquartile ranges and the solid lines the medians of the normalised hypsometry. Note that there are only nine surface roughness measurements.

Author contributions. AFB and LG contributed equally to this work. EM, MM, and FP together conceived of the database. LG created and compiled the dataset under the guidance of EM, MM, and FP and contributed to the final stages of the manuscript. AFB curated the data, wrote the manuscript, and created most of the figures. EM, MM, TS, VM, and FP provided unpublished data for the dataset and contributed to the manuscript preparation and figures.

Competing interests. The contact author has declared that none of the authors has any competing interests.

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