MAPPING SNOW ACCUMULATION OF ANTARCTICA

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Abstract

Many regional studies have focused on snow accumulation in Antarctica but only a few have attempted to collate this data (Bromwich, 1988, Bromwich et al, 2004, Arthern 2006, Eisen et al 2008). In situ measurements of previous local studies within Antarctica are collated and interpolated onto a map with some comparison to Arthern's 2006 mapping of snow accumulation base on ground-based and satellite measurements and passive microwave emission. Analysis of snow accumulation rates highlight the atmospheric, topographic, elevation, precipitation, wind distribution and sublimation are interacting and responsible for the results showing on a regional scale, focussing on Oates Land, Dronning Maud Land and the Filcher-Ronne Ice Shelf.

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INTRODUCTION

In this section we describe the topic and the questions that are addressed in this report

Topic

The reduction in snow extent of snow cover, earlier blooming of plants reduction in sea ice and rising sea levels are all methods of calculating global temperature change. Data collection performed in Antarctica undertakes many logistical challenges however much research has gone into the local and regional studies of snow mass budget of various areas in Antarctica and the dynamics of the polar ice sheets observed in the 1980's, 90's and 2000's.

This report attempts to collate data gained from previous studies to provide a map of snow accumulation across Antarctic further regional analysis. Arthern et al 2006 is one of few studies that have attempted to do this on a continental scale by estimating snow accumulation within gridded cell based format through polarisation derived from satellite, ground –based measurements.

Ground-based Penetrating Radar (GPR) data combined with quality ice-cores will allow for spatial and temporal calculations and variations within their region. A substantial dataset within these parameters will be required if we wish to increase our understanding of Antarctica's snow mass budget continent wide, (Eisen et al, 2008).

The Antarctic continent reaches 14.2 square kilometres but over winter this extends to 20 square kilometres due to the addition of sea ice around its coast. It is twice the size of Australia and the highest continent at 2,300m above sea level. Its environmental uniqueness means that processes are very different that occur here than anywhere else in the world. Scientific data that has been acquired in situ is crucial to the future understanding due to the logistical and financial challenges taken to acquire it and the reliability it brings to computer modelling.

This report attempts to map data from previous studies and interpret the environmental processes occurring over a spatial reference while making regional comparisons. It compares against Arthern et al 2007 data to observe whether there is correlation.

SIGNIFICANCE OF SNOW

Snow has several properties which modulate the energy exchange between the surface and atmosphere. The surface reflectance – albedo, thermal insulating properties of snow, ability to exchange heat – latent heat and other physical properties such as crystal structure, density and liquid content which contribute to the mechanical state for example relevant to transport.

Snow is also important to tourism for commercial skiing, as well as a source of water during the Spring melt. Snow provides a hazard in which avalanches can demolish people and towns. However they also moderate the soil and surface organisms by insulating them from the diurnal winter season temperature, Armstrong, R.L & Brown, R (2008). All of which allow it to be a suitable regulator of the earth's climate, Hansen & Nazarenko (2004)

SIGNIFICANCE OF MAPPING SNOW ACCUMULATION

Bromwich 1988 estimated accumulation over Antarctica in line contours of 100kgm-2a-1 and Arthern, Winebrenner and Vaughan 2006 mapped snow accumulation using polarization of 4.3-cm wavelength microwave emission.

The immediate threat to the Antarctic environment is through anthropogenic impacts and mapping will provide a common approach for governing bodies and national programmes. It is necessary to catalogue and collaborate data because once the snow and ice melt it may not retun.

National Programmes that operate under the Antarctic Treaty system within Antarctica are to follow best practice guidelines produced by the Council of Managers of National Antarctic Programmes (COMNAP) when carrying out environmental monitoring to ensure their human impact on the unique environment is minimised. A routinely mapped collation of snow accumulation of Antarctica as well as regional information on a spatial and temporal scale would provide national programmes with scientific understanding of the area in which they operate. Mapping the scientific monitoring is crucial to environmental management and conservation as well as providing easy access to otherwise technical information for public. The mapping of snow accumulation can give a current indicator of the health of Antarctica as attention is more focused towards Antarctica as a global indicator of climate change for Earth.

With the current attention towards sea ice, land ice should still be studied as both give evidence of climate change. The different process in which both land and sea ice are accumulated and/or ablated proved evidence of atmospheric and oceanic variances. Land ice is formed by the increase in precipitation, low temperatures and low ablation rates, whereas sea ice is formed by cold temperatures of both atmosphere and sea. The colder and drier atmospheric temperatures will contribute to forming sea ice however decrease the amount of precipitation available to form land ice, thus when one is increasing the other is decreasing.

GEOGRAPHICAL DESCRIPTION OF ANTARCTICA

The Antarctic continent is a land mass covered in ice surrounded by ocean. A circular dome forms the East Antarctic Ice Sheet or inland ice sheet plateau making up two thirds of the continent. An arm out to the West side (Antarctic Peninsula) makes up the West Antarctic Ice sheet and the formation of the Ross and Filcher-Ronne Ice shelves. The two are divided by the TransAntarctic Mountains.

The Antarctic continental plate broke away from Gondwana land to where it currently resides today. It's final separation from South America and opened up the Drake Passage which then formed the Circumpolar Ocean current that circulates around Antarctica, isolating it further. The Antarctic differs from the Arctic in that is land surrounded by ocean. This land is covered by 98% ice is known as a dessert for it's cold, windy and high altitude climate creating the driness of a dessert. This can be observed in its dry valleys where it is so dry that snow accumulation does not occur due to submilation. The TransAntarctic Mountains and Ellsworth mountiains extend through the continent as well as a rift volcano system which still remains active today observed through Mt Erebus and Mt Terror. Scientists have recognised over 70 subglacial lakes which are thought to be spawning life and all interconnected through subglacial drainage systems.

The cold temperatures of Antarctica can be attributed to the high latitudes and angle of sun to the polar regions. The high pressure systems within the middle of the continent cause the descending motion of air and limits precipitation giving clear skies and causing heat loss. The high albedo of the ice contributes to reduction in the ability to retain heat causing a surface chilling. The low pressure systems surround the continents coasts including cloud, precipitation and storms.

Katabatic winds drain from the centre of temperatures from -30 to -70 degrees across the plateau out to the coast reaching speeds of up to 40mph.

GENERAL CHARACTERISTICS OF SNOW ACCUMULATION AND PROCESSES

Snow accumulation requires environmental processes for accumulation to occur. Accumulation requires precipitation and cold temperatures for snowfall and cold temperatures combined with no wind for the snowfall to remain and compact. A lower ablation rate than the rate of accumulation will also help to accumulate snow. Accumulation and ablation fluxes will vary depending on snow conditions, environmental, topographical, vegetative and surface conditions. Vaughan et al, (1999) recognises snowfall from clouds and clear skies, formation of hoarfrost at the surface within the snow pack, sublimation melting and runoff, wind scouring and snowdrift deposition as contributors to solid, liquid and gaseous water transfer across the surface of the Antarctic Ice sheet.

The complex interaction of these processes on a micro-scale make it difficult to measure the snow accumulation in Antarctica (King & Turner 1997) Individually these are impossible to measure (Turner et al, 1999) however glaciological techniques help in allowing us to measure these processes as an aggregate. They are spatially & temporally highly variable.

Identifying how to attribute accumulation rates to a particular area proves difficult and assumptions are made that the uniformity of the East Antarctic Ice sheet plateau allows measurements to be inferred for a larger area than the point in which it was taken.

When conditions are cold enough, such as those in Antarctica, precipitation in the form of snow crystals from humid air fall to the surface observed as diamond dust without the presence of clouds (Jordon et al, 2008).

Sublimation accounts for 70% removal of precipitation from Dronning Maud land, Victoria Land and the southern part of the Ross ice Shelf (Van der Broeke 1997).

Blowing Snow requires exposure to wind and erodible snow. Variances occur on different scales, with the potential for steady state conditions on relatively large uniform surfaces such as ice sheets. Small scale features act by increasing the surface roughness and impeding erosion and creating areas of deposition of wind blown snow, for example sastrugi and nanutaks. Large scale features such as valleys and mountains cause flow separation in the wind reducing the shear stress on downwind surfaces (King et al, 2008) resulting in the formation of large snowdrift.

The moderation of latent heat is transferred to the surface through snow melt acting as a latent heat sink due to the large amounts of heat required to melt snow where it provides communities with their seasonal water supply. And the transfer of latent heat to atmosphere by blowing snow via sublimation can influence the mass balance of non-melting snow cover in open areas. (King et al, 2008).

Relationships between atmospheric variability and accumulation in the West Antarctic Ice Sheet divide area is also complex with the local accumulation record and Antarctic oscillation (also known as the Southern Annular Mode, SAM) switching several times in the last decade to prove problematic when interpreting geophysical processes on a temporal scale (Banta et al, 2008).

DATA FRAMEWORK

Data was collected from publicly available information of previous papers that have collected snow accumulation data in the past either for the purpose of their research or as a by-product for other calculations. Beginning with a search for research on the whole continent little was found, it seems most of the research is regional, with a few people recognising the need for collation of all regional Antarctic data (Bromwich, 1988, Bromwich et al, 2004, Arthern 2006, Eisen et al 2008).

Data is from regional studies spanning across thirty-eight years from 1971 to 2008 from snowpit, ice core and firn analysis combined with Arthern's data from both satellite and ground –based measurements and mapped using polarisation of 4.3-cm wavelength microwave emission.

Sampling was random with access to compatible datasets being a significant parameter. This required collecting X and Y coordinates for positioning and their accumulation rate.

METHODS

This section explains order of operation in data collating.

Data was collated into an excel spreadsheet obtaining xy coordinates and accumulation rates, author, year of drilling and publication for reference. Across 26 papers 184 values were obtained, Arthern's data presented 22,000 points of data on a grid model.

Due to the various authors different methods, measurements and units were utilised. X and Y coordinates were given by either geographic degrees or polar stereographic coordinate system with decimal degrees and accumulation rates presented as both kilograms per metre squared, per annum (kg/m-2a-1) or metres (or centremetres) per water equivalent (m/weq-1.)

Two sets of conversions were performed. X and Y coordinates were formatted to decimal degrees for a polar stereographic projection and accumulation rates were altered to kg/m-2a-1 from m/weq-1.

Two different excel spreadsheets were created within excel. One for Arthern's polarised mapping and another for the ice-core and in situ measurements.

Arthern's data is now referred to 'satellite' data as a difference from the 'point measurements' of the in situ ice core and firn data.

Both excel spreadsheets are added to ArcGIS10 as separate data layers. A digital elevation model is also added for viewing.

Data is represented by proportionate symbols. This means the quantity of kg/m2a-1 of each data layer is represented by the size of the symbol, in this case a circle. This enables a continental wide comparison within one layers dataset as well as being comparable to another dataset. Graduated colour was also used.

For the purpose of analysis it is assumed that a high level of accuracy is achieved with in situ point measurements and is only compared to the passive interpolation of Arthern's snow accumulation.

Data collection by stratigraphy has been avoided due to the subjectivity of individual interpretation and records are irregularly sampled over space and time.

RESULTS

This section will present the findings which includes the map of data collated and DEM images representing data of specific regional locations. A large map of Antarctica is located in the Appendices for easier understanding than the small image of figure 6c.

The Antarctic continent reaches a scale of 14.2 kilometres squared and in the winter reaches 20 kilometres squared with the increase in ice extent around the coast. The point measurements or in situ measurements as it were cover little of the continent (Fig 1), the mapping of Arthern's polarisation is a gridded cell model based on both satellite and ground based measuring. This gives an indication of snow accumulation across the whole continent. The larger the symbol is the higher the accumulation rate is (Fig 1). Majority of the larger red dots occur around the coastal edge in comparison to smaller red dots which are measuring at accumulation rates of 16.0-104kg/m-2a-1. An anomaly is found with two red dots inside Arthern's map. This is compared to the mosaic inset image (Fig 1) of Antarctica which we can see is also on the coast of the land however due to snow and ice cover being accounted for in Arthern's map the image is deceiving to somebody unaware of the ice extent of Antarctica.

The proportionate symbols of Arthern's map also provides a comparison with the in situ, ice-core data (comparing blue map with red dots, Fig 1). The proportionate symbols of the blue map also have bigger circles around the coastline than the interior. What looks like white lines also appear in the mapping of these symbols. These are areas which have a higher accumulation rate than its surroundings. This is addressed in the anaylsis in more detail.

Areas of mention with significantly larger blue dots includes the right hand side where the Amery ice shelf exists and another on the lower right hand corner where Whilkes Land to Terrie Adelie exists.

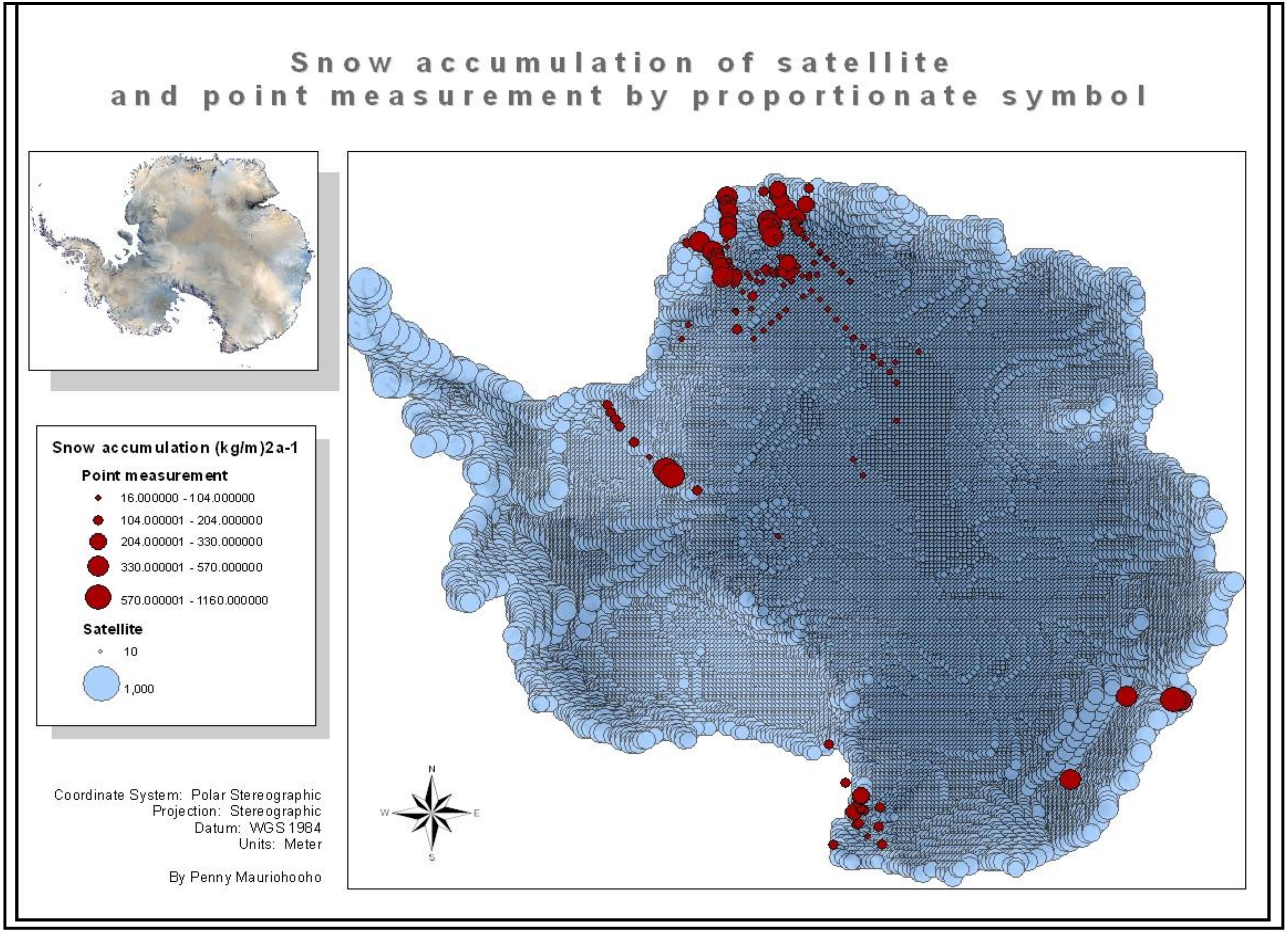


Fig 1: A map presenting snow accumulation by proportionate symbol. The red dots are in situ ice-core data and the blue dots represent polarisation of microwave emission based

Dronning Maud Land

The graduated colours (Fig 2) indicate the increase in snow accumulation. The darker the colouring the higher the rate of snow accumulation. This is most visible on the coastline areas with the darkest colouring observed at the Antarctic Peninsula. Lightest colouring is on the plateau atop the East Antarctic Ice sheet and the drainage basin of the Ross Ice Shelf. The red dots in this image represent the in situ ice-core data and highlights the scale of data collection required to complete a map of ground based data to be compared against Arthern's polarisation map.

The DEM model closeup of Dronning Maud Land emphasises again the scale of the point data in relation to the size of the continent. They are very small and much more data is required to accurately record for large spatial areas. The red dots here show an increase in size as they decrease in elevation and as they move higher into the plateau they grow smaller. A few measurements are observed atop the crest as being large in comparison to those surrounding them and further analysis focuses on why this might be.

It is obvious that some data has been taken together as a project focussing on transects here towards the interior. It is also of note that the DEM itself has a very light coloured crest where snow may have accumulated and hardened.

Fig 2: An image from a Digital elevation model of the mapped data across Antarctica. Graduated colour indicates the increasing rate of snow accumulation.

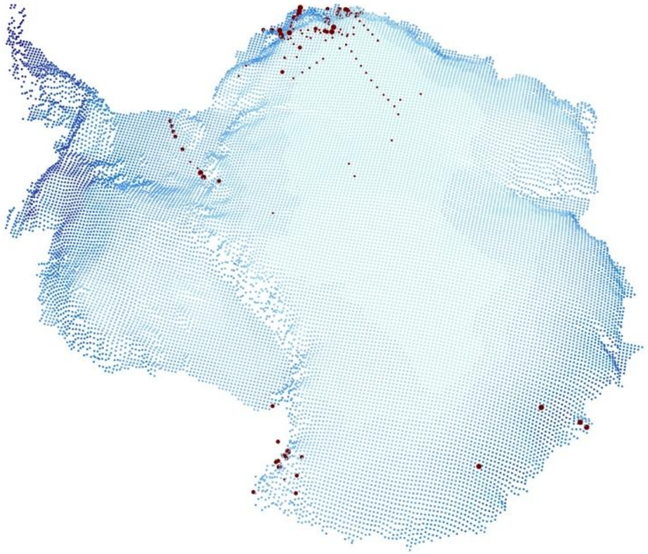
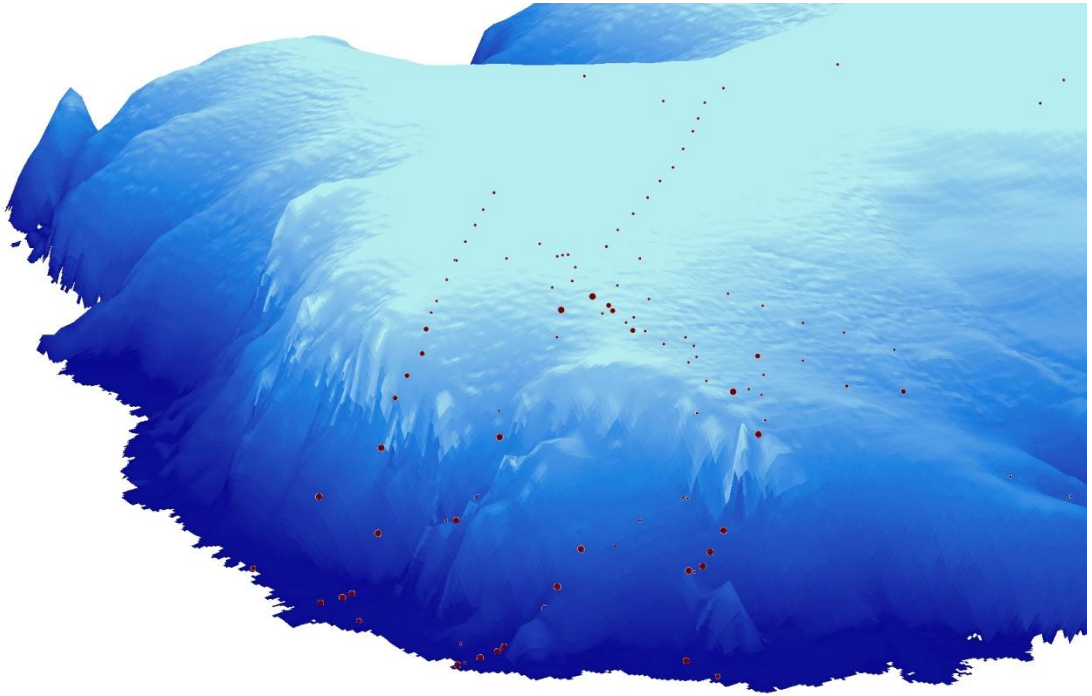


Fig 3: A digital elevation model of Antarctica with location of in situ measurements.

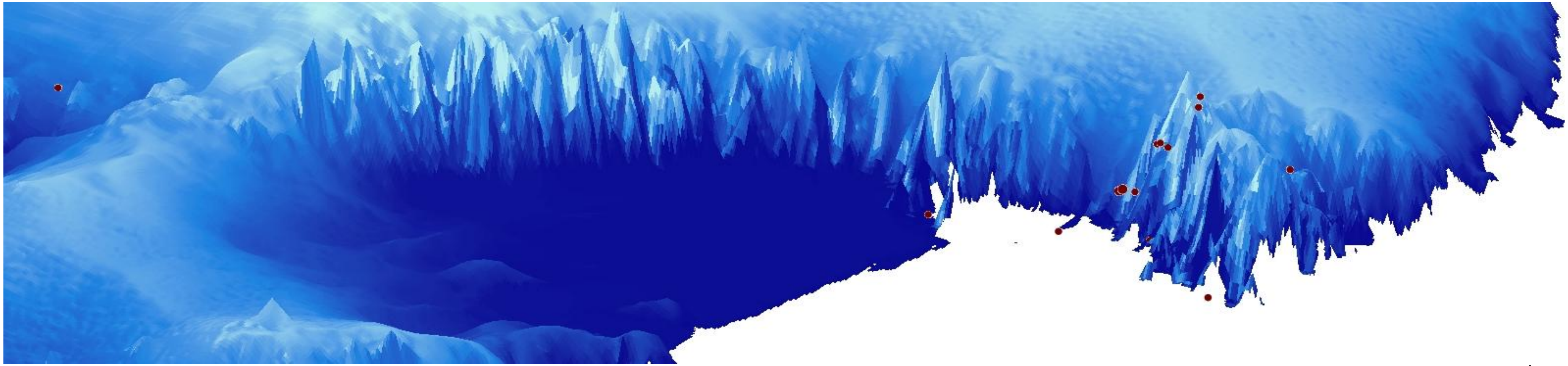


▲ **Fig 4: North to South DEM view of Filcher-Ronne Ice Shelf and in situ ice-core measurements with proportionate symbol**

▼ **Fig 5: West to East DEM of Oates Land with in situ ice-core measurements of proportionate symbols and the Ross Ice shelf with the TransAntarctic Mountains.**

Filcher-Ronne Ice Shelf Figure 4 is a North to South facing view of Filcher-Ronne Iceshelf which is 900 ms thick. The island central in the image is called Berkner Island. The red dots here curve parallel to Berkner island and it is noticed that the dots appear to be larger beside the island than when on the iceshelf independant. As the line continues to curve inland the dots get bigger again and a steep mountain is nearby.

Oates Land in figure 5 sees the beginning of the TransAntarctic mountains from a south to north direction. This image is West to East facing and highlights the change in snow accumulation with elevation at Oates Land with bigger dots than those on the plateau, yet smaller than those below on the coastal edge.



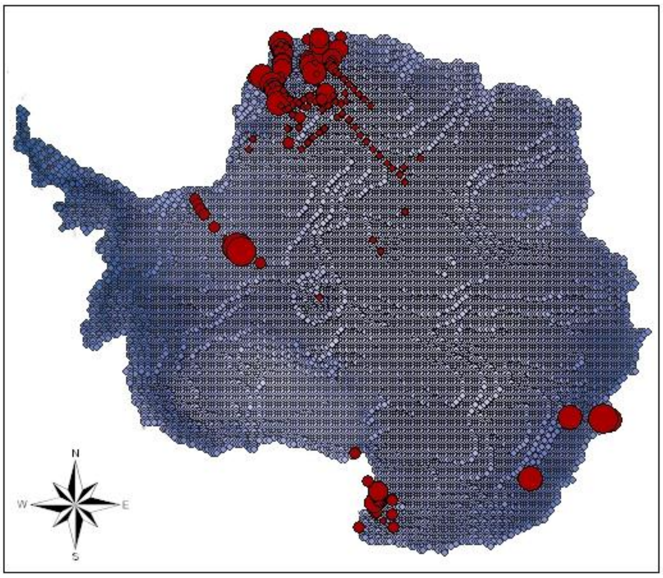


Fig 6a

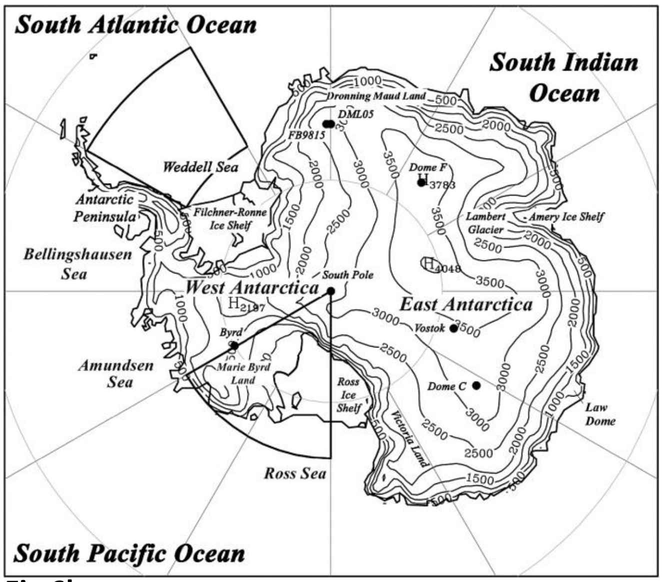


Fig 6b

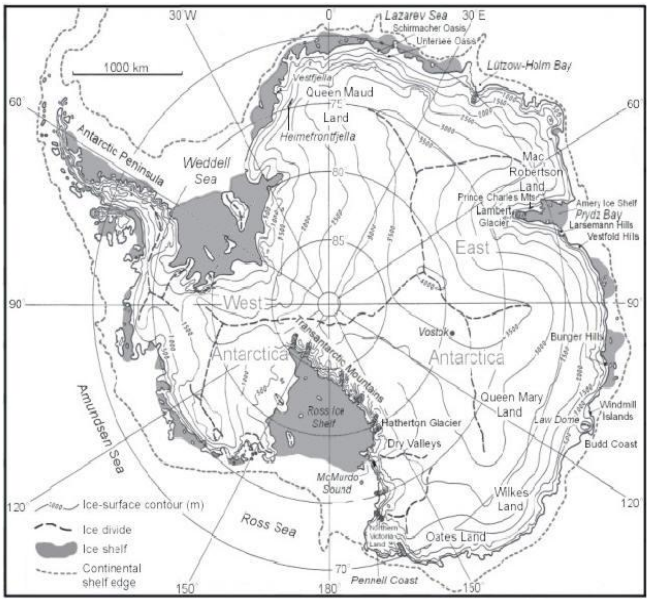


Fig 6c

ANALYSIS

This section focuses on the analysis of environmental processes to interpret the snow accumulation results comparing at a regional scale.

<u>Elevation and topography</u>

The proportionate size of the circle symbols of snow accumulation (Fig 6a) mirror the elevation contours of elevation (Fig 6b). This suggests a direct relationship between snow accumulation and elevation, decreasing in both snow accumulation and elevation moving from the interior to the coastline. The results show that the lowest accumulation rate is in the interior which exists at 3500 m's high. This reins true for topographic influences where troughs will have 30-50% more accumulation than exposed crests, (Kaspari 2004). Nanutaks at Dronning Maud Land increase the terrain and give topographic interruption to the winds forcing the humid air from shore to rise which results in accumulation extremes.

Fig 6a: Map of snow accumulation rates by both point measurements and satellite.

Fig 6b: Map of elevation contours at 500m intervals with points indicating station locations. *Ingolfsson, O. (2004)*

Fig 6c: Map of Antarctica with reference to names of important locations. *Ingolfsson, O. (2004)*

Elevtion and Topography continued

- Low level blocking of onshore winds by the cliffs increase the difference between surface and midtropospheric layers, this convection is important for coastal precipitation and thus accumulation (Bromwich 1988). This is evident in the larger accumulation rates around the coastline (Fig 1). Blocking is also observed in the Ross drainage system where the graduated colour (Fig 2) shows similar accumulation rates in comparison to the interior of the continent. This is due to the partial blocking of moisture transport further inland by the Ross drainage system resulting in lower accumulation rates (Kaspari, 2004).

- Vertical descending motion of offshore cyclones combined with topographic lifting and blocking of airflow near surface layers accounts for snow deposited 1000m below elevation with a minimum base height of 1000m over Durmont d'urville (Bromwich 1988).

- The formation of sastrugi on the plains contributes to small scale snow accumulation over large areas, this alters the topography of the surface contributing to accumulation at the top of an ice column or core. This provides some margin of error when measuring results.

- Slope and aspect influence wind speed and direction with snow accumulating in concave depressions (Fressotti 2002) convex rises in contrast have the opposite effect. This can be observed within the Amery Ice shelf where the concave land contour has a higher accumulation rate (Fig 1).

- Changes in topography alter the wind field in a feedback system between the cryosphere and the atmosphere and thus affecting precipitation. The ice drainage systems are also affected by topography (Fig 7) and thus result in ablation affecting snow accumulation.

- The orientation of topography with respect to wind and accumulation sources has a lot of influence over snow accumulation (Morse et al, 1999). This is reiterated with Berkner Island above as an example of the accumulation by point measurement on the leeward side being higher than the points on the open sheet with a wind flow between Berkner Island and the Antarctic coastline potentially eroding the ice sheet at that location and decreasing snow accumulation at that location relative to Berkner Island (Fig 4). Observed here is the high accumulation rate at the coastal edge of the Filcher-Ronne Ice shelf, this is due to the change in elevation and the increase in precipitation with the change in pressure and albedo feedback system.

Atmosphere

- Southern Oscillation index (SOI)

  The El Nino Southern Oscillation (ENSO) is the circle of climate variability that encompasses the southern hemisphere and moves latitudinal up or down with the change of season (Bromwich 2000), net precipitation was positively correlated with ENSO in 1988-1990 (Kaspari, 2004). Here the ice divide and South Pole a SOI accumulation indicates a climate boundary (Kaspari, 2004).

- Coastal snowfall is inassociation with synoptic features such as cyclones and fronts. Strong cyclonic activity for coastal regions is a significant factor contributing to increase in in accumulation rate (Morgan et al 1991), (Fig 1). Lettau 1969 mentioned a 3 day cyclone as the cause of a 20% increase in precipitation. Cyclonic activity around 60-70 degrees latitude results in descending motion and cooling air (Bromwich 1988, Streten 1990), this results in much colder temperatures than that of the Artic. This also ensure a lack of humidity on the plateau resulting in low precipitation and therefore low accumulation rates (Fig 1). Most of the interior snowfalls occur in the winter due to this dominace of atmospheric circulation over the moisture holding capacity of the air, (Bromwich 1988).

- Anticyclone events in the South Tasman sea convey warm moist air masses to the interior of the continent contributing to the snow accumulation of the East Antarctic Ice sheet (Massom et al, 2004) this then undergoes radiative cooling, this is the dominant process over the highest parts of the sheet.

- Bromwich & Parish 1988 mention the cold air drainage across the edge of the East Antarctic Ice sheet is foccussed around several areas this is observed by the drainage systems highlighted (Fig 1) and ice flows (Fig 7) with a similar correlation between the two.

- The affect of cool air from descending motion also results in crevasse and surface hoar frost which forms in cool air space and adds to small amounts of snow accumulation. This can affect the vertical ice-column in measurements.

Precipitation

- Precipitation is a key process in snow accumulation and in Antarctica this is related to the intensity of cyclonic activity. It is highest in winter (Bromwich 1988, Loewe 1957). The moisture holding capacity of air increases with increasing temperatures and on cooling sublimation of the vapour takes over and ice crystasl fall thinly from cloudless skies during the night. This is common over the plateau. Ice particles from cirrus clouds fall to the surface or reform in the inversion layer of the atmospheric column.

Wind deposition and Sublimation

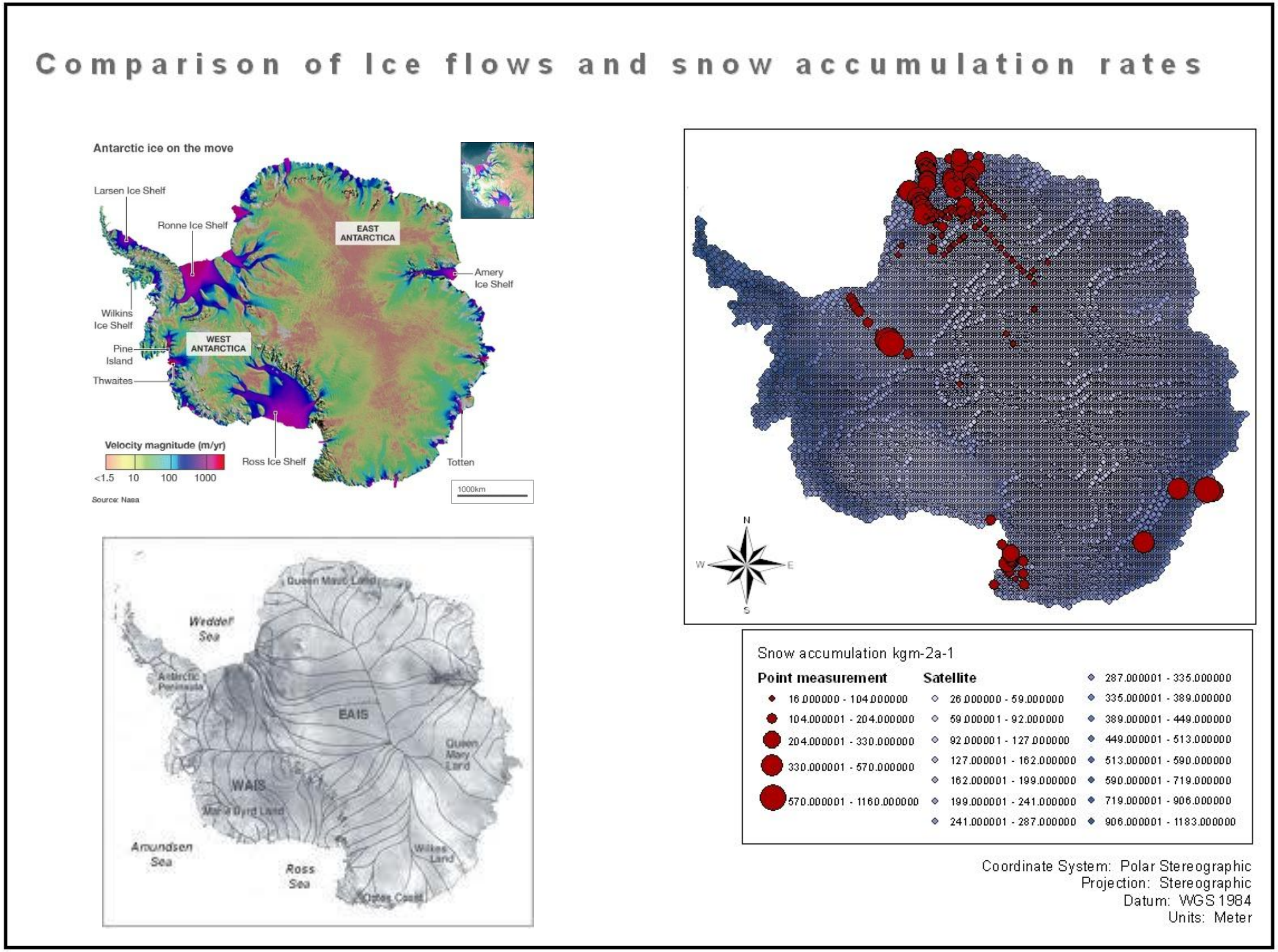
- Gravity winds funnel cold interior air through the valleys of the TransAntarctic mountains.and transport snow from a southwest orientationand eroding the surface
- Horizontally transported snow by the upwind presence of recently deposited snow contributes to sastrugi formation and accumulation at higher elevation. Strong and violent katabatic winds sweep across the plateau negatively affecting the accumulation process and causing ablation by erosion. Hence the lower accumulation rates in the interior of the continent. Blowing snow increases the latent heat transfer to atmosphere which can control the mass balance of non-melting snow cover in open areas
- Winds move from a East to northeast direction, figure 1 highlights this in the contour of snow accumulation rates in correspondence against drainage systems and ice flows.
- Katabatic processes and elevation affect accumulation at Oates Land in comparison to the lower accumulation rates relative to other coastal areas such as Dronning Maud Land and the Filcher-Ronne Ice Shelf (Fig 1)

Drainage systems and ice flows

- Figure 7 illustrates the relationship between ice flows, drainage systems and accumulation rates. Topography influences this showing high accumulation rates in areas of convergence either due to change in elevation from ice shelf to ice sheet in coastal areas and a general decrease in elevation across the EAIS.

▶ Fig 7: Map of snow accumulation by point and satellite data in comparison to two separate maps one indicating ice flow and the bottom image representing ice drainage paths.

Images from Rignot. E., et al & Ingolfsson (2004)



DISCUSSION

In this section validity of methods, data is considered when mapping snow accumulation. Temporal issues are also mentioned for further consideration into extending this study.

Variations over the years from different studies have proven that the discrepancies highlight the approximate nature of the precipitation calculation (Kotlayakov & Sharova 1969, Barkov, 1974 & UNESCO, 1978) proving some margin of error when estimating snow accumulation and evaluating the reliability, accuracy, calibration and validation data when interpolating snow accumulation maps, (Magand et al 2006).

Snowfall amounts on the small scale such as falling ice crystals, over a large spatial area still prove difficult to measure the contribution to snow accumulation. Calculating wind that is redeposited against recently deposited snow still proves to be problematic.

Discrepancies in spatial variability due to method of data collection (Fig 8) have not been considered in this study. Increase in accuracy would ensure that data methods and depths of snowpits and ice cores are compared.

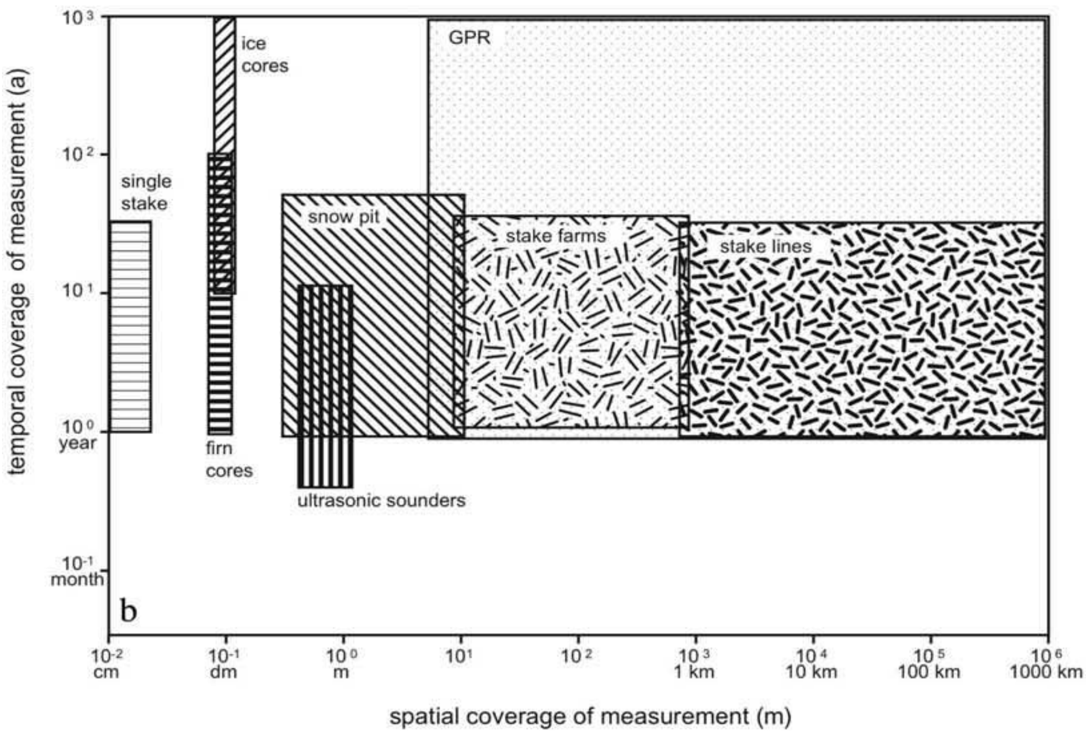


Fig 8: Spatial coverage of measurement (m) from Eisen et al 2008. Illustrating difference in data acquired by various methods

Data conversion to kg/m2a-1 is the result of measuring a solid substance in the Antarcic in comparison to the measurement of centremetres or metres per water equivalent in areas of valley glaciers where subglacial and proglacial water drainage systems are used for data calculation.

Rotschky et al 2007 suggest that variances between Vaughan & others 1999, Hubrechts & others 2000, Arthern & others 2006 and Rotschky & others 2007 are due to interpolations techniques and approaches this influences the accuracy of data that has been interpolated for this study.

The values of the data acquired during snow accumulation and the interation of processes that occur after data has been collected alters the value of the data. This implies that data is more significant over a large spatial scale to aggregate all of the environmental processes occurring. With this in mind this occurs on a temporal scale also with coring sites needing several decades to travel from low accumulation surface crest to a high accumulation rate depending on ice flow velocity and surface undulations in a kilometre magnitude. This temporal lag of changing accumulation is due to response to climatic changes and requires understanding when selecting coring sites for analysis.

Spatial representation of point measurements are still under debate. This is concerned with how representative a point can be for its surroundings. Large areas of the continent have not been mapped with in situ measurements a lack of data will be a combination of it not existing for an area or cost in acquiring extensive datasets (Vaughan et al 1997).

FURTHER THOUGHTS

An interactive map which could see scientists upload their datasets and calibrate it to a common approach in methods and units could be useful when considering environmental monitoring of the Antarctic on a continental scale and global scale. This will ensure the recording of spatial, temporal and cumulative information that will otherwise be lost with melting of snow and ice. To have this free to public would be a significant achievement and to be able to cross reference different data layers and calculate datasets for various purposes would prove beneficial.

In collaboration with research in sea ice this will help to monitor feedbacks to environmental changes of basal melting as a result of thermal expansion and

CONCLUSION

The relationship between poleward moisture transport and mid-latitude blocking highs is significant to understanding the response of the Antarctic Ice Sheet in predicting global warming.

Slope aspect as a part of topography and the high elevation of ice sheets to sea level affect the atmospheric in the form of mid-latitude blocking and winds that penetrate to the interior of the East Antarctic Ice Sheet results in the sublimation of moisture holding air masses to account for ice crystals and their contribution to snow accumulation.

Cyclonic activity that encompasses the continent creates the cold descending motion of air and thus low humity in the interior affecting low precipitation and thus low accumulation. The albedo effect and pressure changes from sea to snow around the coastline results in the higher precipitation levels around the coastline.

Here we have explained the map of snow accumulation in comparison and alongside Arthern's map as well as provide environmental reasonings for both in-situ point measurements.

The scale of this data's study requires additional information to add to the value of this study and continental analysis. Here specific observations have been made between the regional locations of Oates Land, Dronning Maud Land, and the Filcher-Ronne Ice shelf with mention of the Amery Ice shelf. Contrast between the interior and coastlines have also been addressed.

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APPENDICES

Appendix 1

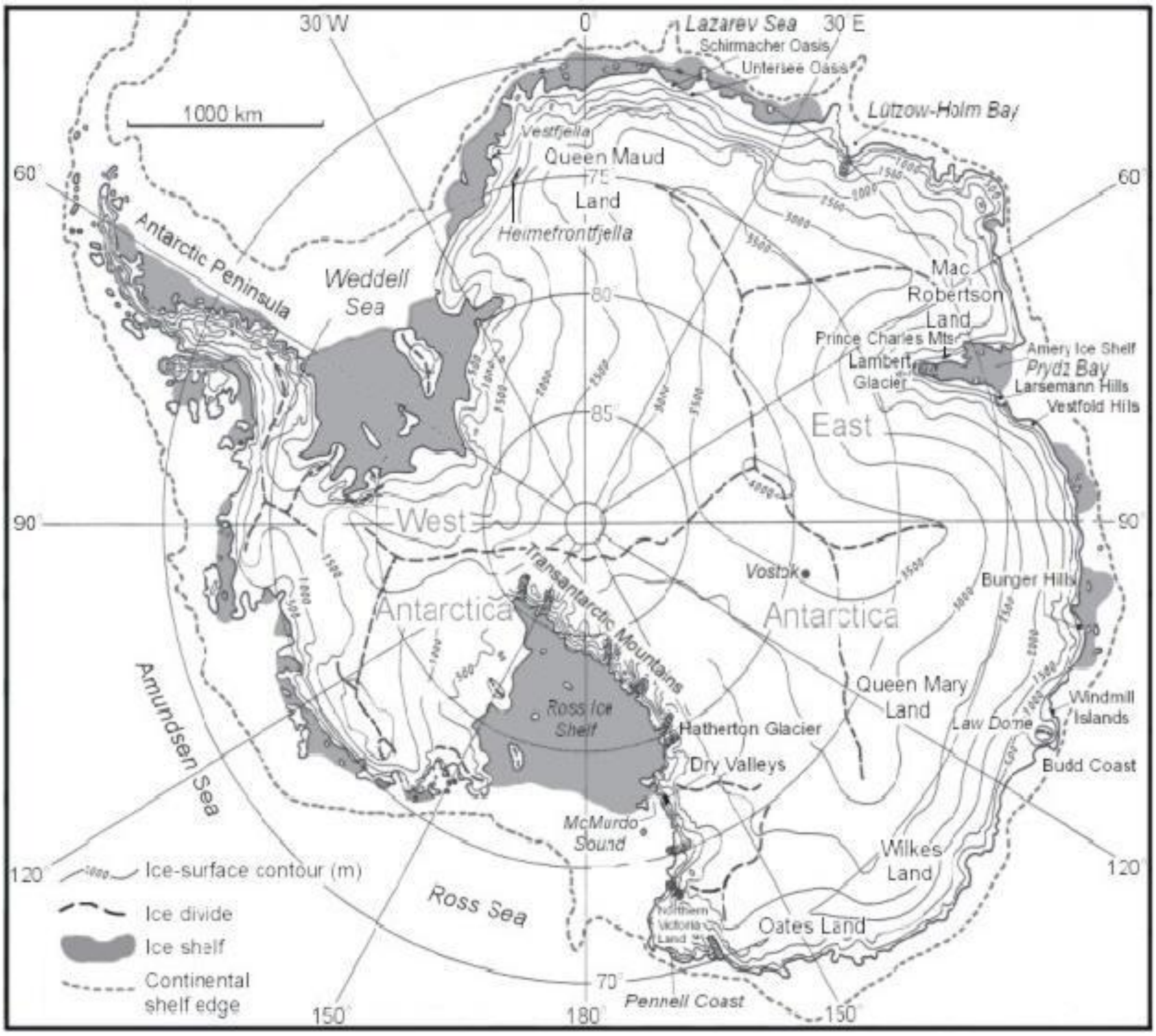

Fig. 1. Map of Antarctica and its continental shelf

Quaternary glacial and climate history of Antarctica

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Insert table of in situ data