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Ice surface anomalies, hydraulic potential and subglacial lake chains in East Antarctica

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Summary The most recent subglacial lake inventories and classification methods further demonstrate the strong correlation between subglacial lakes and flat anomalies on the ice surface. A reanalysis of older radar sounding data shows that several subglacial basins previously identified as “lake less” may actually contain multiple lakes along with other important subglacial hydraulic features. The combined use of radar sounding and satellite surface mapping is allowing unprecedented detail in the mapping of subglacial hydraulic systems in East Antarctica.

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Introduction

Observations of ice surface geometry are the oldest method of subglacial lake identification (Kapitsa 1965), and are still used to locate subglacial lakes where radar echo sounding data is sparse or absent (Ridley et al., 1993; Siegert and Ridley 1998; Remy et al., 2003; Remy et al., 2004; Bell et al., 2006; Bell et al., 2007). It is observed however that many of these surface anomalies are not the result of basal floatation associated with a subglacial lake, but associated with simple sliding on saturated sediments or related to high relief in the subglacial topography. The most recent lakes inventory in the Dome C – Wilkes Basin region of East Antarctica came from three airborne radar data sets: The SPRI / NSF / TUD missions of the 1970’s, the UTIG SOAR data Archive, and the Italian Antarctic program. Tabacco et al., (2006) has compared the Italian lakes with the SPRI / NSF / TUD lakes, developing a morphological classification scheme for subglacial lakes in the process. The SOAR UTIG lakes are classified according to the properties of the basal reflection. Here we compare the SPRI lakes and SPRI ice thickness data against the Carter et al., (2007) classification system to infer hydraulic properties associated with known hydraulic basins through the Byrd, Totten, and David Glacier catchments, comparing inferred hydrology to features on the ice surface with the aim of inferring more detailed hydrology where ice thickness data is absent.

Methods

In locating surface anomalies, we use RAMP ice surface elevation DEM (Liu et al., 2001), creating a fine 5 km resolution grid, and a regional 50 km grid. The surface elevation gradient on the fine grid is then compared to the surface elevation gradient on the coarse grid using the methods of Smith et al., (2006). Surface anomalies are then classified as any area where the local ratio of local slope to regional slope is negative. These locations of these slope anomalies is then compared with the locations of inferred hydraulic features. In the southern part of the Byrd catchment ERS-1 altimetry is absent; there we used the MODIS Mosaic of Antarctica (Haran et al., 2005). We justify this substitution by pointing out that the illumination direction is parallel to the approximate regional slope in this region, and thus negative slope anomalies will appear exceptionally bright.

We obtain profiles of hydraulic head using the ice thickness from SPRI / NSF / TUD flight lines in the BEDMAP data archive (Drewy et al., 1983; Lythe et al., 2001) and surface elevation from the RAMP DEM (Liu et al., 2001). From these data we can obtain the bed elevation, and the overburden pressure, the sum of which is equal to the hydraulic potential. Lake candidates in the SPRI ice thickness lines were defined as any continuous local minimum of line across which the hydraulic head changed 1 m per kilometer of distance. The locations of these lake candidates are then compared against the locations of known lakes from all three surveys.

The hydraulic potential at more prominent minima is also used to determine the likely flow route of any likely subglacial channels. These are all then plotted on a map of surface anomalies. Additional comparison was done against a balance velocity map generated by (Le Broca et al., 2006).

Locations of SPRI bedmap lake candidates are checked against locations of surface anomalies and lakes from the Carter et al., (2007) classification (Figure 1). Additional analysis is performed on both the SOAR / UTIG data and SPRI data to identify likely hydraulic drainages in areas where lakes and lake candidates are clustered. Form this work we can identify flow paths and predict the behavior of water between the interior subglacial lakes and the eventual outlet glacier. By comparing the bedrock gradient to the pressure gradient we can identify whether subglacial water flow is likely to melt the base of the ice or freeze on due to supercooling (Nye, 1976; Alley et al., 1998).

Results

A survey different lake classes from the Carter et al., (2007) lake classification paper revealed that 16 out of 17 definite lakes, 10 out of 19 dim lakes, and 20 out of 46 fuzzy lakes coincided with prominent negative slope anomalies. The majority of lakes not lining up with surface anomalies were less than 5 km in diameter. This result is consistent with the findings of Siegert and Ridley (1998) in a study of lakes near Dome C.

An analysis of the SPRI ice thickness revealed approximately 100 local minima capable of either carrying or trapping water. Approximately 15-20 of these prominent basins are associated with known subglacial lakes from this data set. About 9 – 10 of the lakes apparently identified in these surveys do not coincide with any prominent subglacial hydraulic basin. An additional 9 – 10 overlie lakes identified in other survey campaigns. When these locations are compared against the Carter et al., (2007) classification system it reveals that dim and fuzzy lakes were more likely to be overlooked than definite lakes. Some of this discrepancy is no doubt associated with size of the feature relative to the navigational imprecision of the SPRI data however some are not recovered in the initial inspection of the SPRI radargram. There were no instances of SPRI survey lines crossing subglacial lakes determined by other methods and not producing at least a prominent hydraulic basin.

Discussion

We focus our analysis on the Wilkes Basin (figure 1) where older and more recent data overlie one another, a known lake system is present and radar coverage is sufficiently dense for drainage network delineation. From this region associated with a subglacial basin underneath a ice divide it is apparent that regional water flow is Northeast and southeast away from the divide. Several of the largest subglacial lakes appear to be directly on top of the water divide. It is not readily apparent as to which direction water flows out of these lakes. Or how such an apparently unstable situation is maintained. Given the proximity of these lakes to the ice divide it is apparent that all water flowing into them must be derived from basal melting of local ice rather than collection from a broad catchment. Several valleys contain multiple lakes. It is not clear at this time how these various lakes communicate. There appears to be a loose connection between the flow paths and surface anomalies as suggested by Remy et al., (2004), though more analysis is necessary to determine the full nature of the association.

Conclusions

Ice surface slope anomalies are useful in locating possible subglacial lakes, and water systems, but are not unique to such situations (Siegert and Ridley, 1998). This surface data when supplemented with even sparse ice thickness data can be used to determine how water would likely flow at the base and possibly even rule out certain types of hydraulic systems such as a Rothlisberger channel in supercooling conditions (Alley et al., 1998). All warm subglacial basins have the potential to store and /or carry subglacial water, especially when associated with even a minor ice divide. Existing radar sounding data covering these regions may contain previously undiscovered subglacial lakes.

The question of if and how water moves from the ice sheet center subglacial lakes to the ice streams at the margins is an ongoing work of importance, that no one data set can answer. The combined surface topography and the ice velocity and ice thickness when used together will yield insight into this question unavailable from any single source of data.

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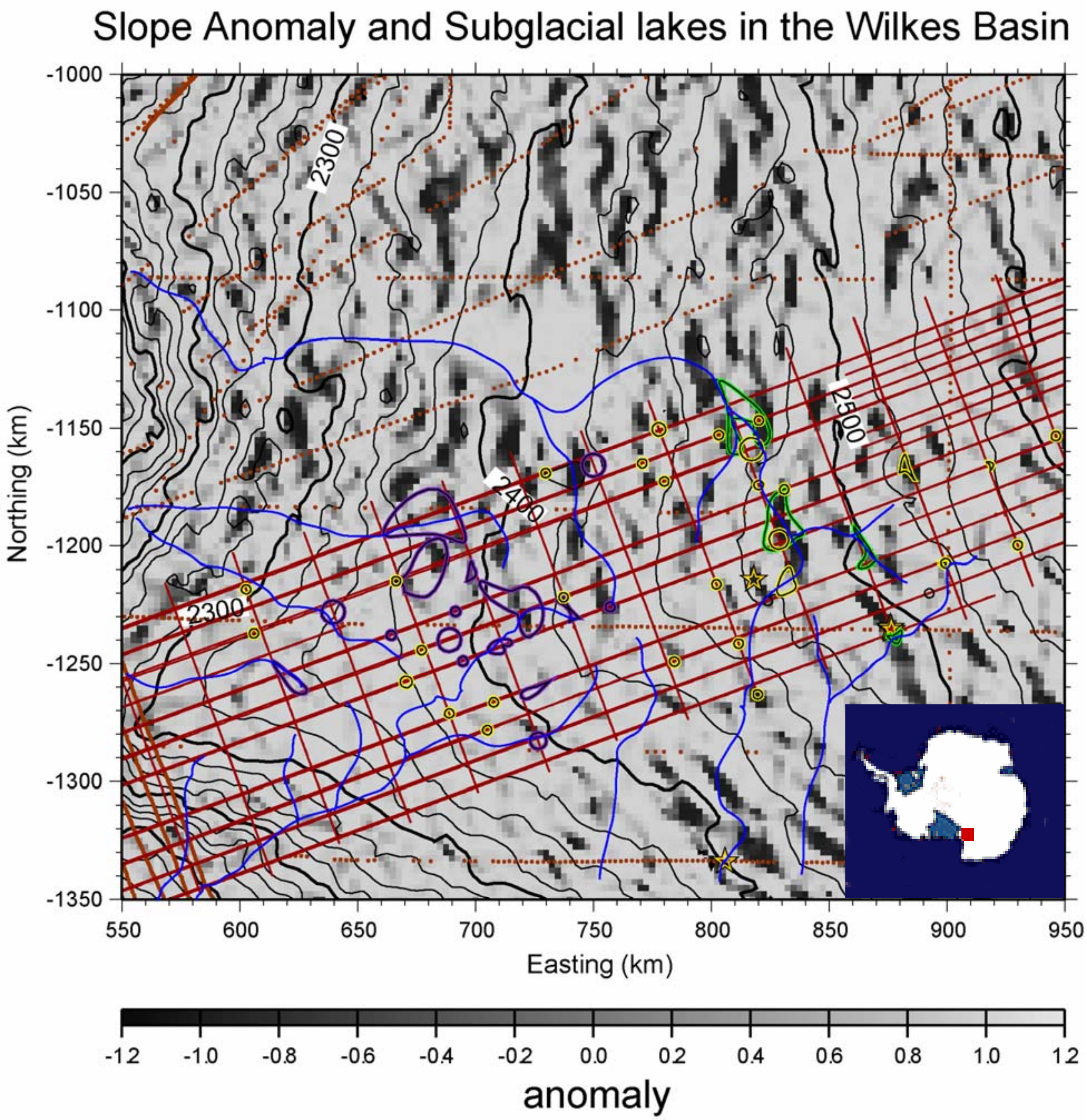

Figure 1: Map of ice surface anomalies and subglacial lakes in the Wilkes basin. Solid lines denote 1999 UTIG SOAR RTZ9 radar sounding coverage. Dotted lines denote 1972 - 1974 SPRI / NSF / TUD radar sounding coverage. By the classification system of Carter et al., (2007) the various lake colors are: green for “Definite Lake”; Purple for “Dim Lake”; and yellow for “Fuzzy lake”. Stars depict subglacial lakes from the Siegert et al., (2005) inventory. All of the larger lakes are correlated with negative slope parallel anomalies as found using the methods of Smith et al., (2006). Several SPRI lines intersect lakes found by more recent efforts suggesting that some lakes within “lake less” basins identified using SPRI data may in fact contain lakes. Blue lines denote pathways inferred from the hydropotential. Surface elevation contour interval is 25m. Projection is polar stereographic 71.

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