Antarctica sea-ice thickness distributions derived from surface elevation compared to measured thickness values

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Introduction:

Submarines, utilizing sonar, were originally used to find ice thickness in the Arctic and have shown the recent decline in sea ice thickness in the Arctic attributed to global warming. For the Antarctic, sea ice thickness, without submarine traverses, is unavailable on the regional or circumpolar scales. The ICEsat satellite was launched by NASA in 2002 in order to help measure sea ice thickness in the polar regions,. Satellite altimetry however measures only the above sea level portion of the ice cover (elevation) which is less than 10% of the thickness. Snow cover can also mask ice elevation changes that are related to ice thickness. Using data on snow cover and ice thickness collected from the Antarctic we wish to improve ICEsat methods for estimating ice thickness from surface elevation and develop algorithms for the accurate conversion of elevation into ice thickness. Estimating the accuracy of predicted ice thickness from satellite altimetry is important to know for validation of numerical models and whether or not ice thickness in the Antarctic is changing for future assessment.

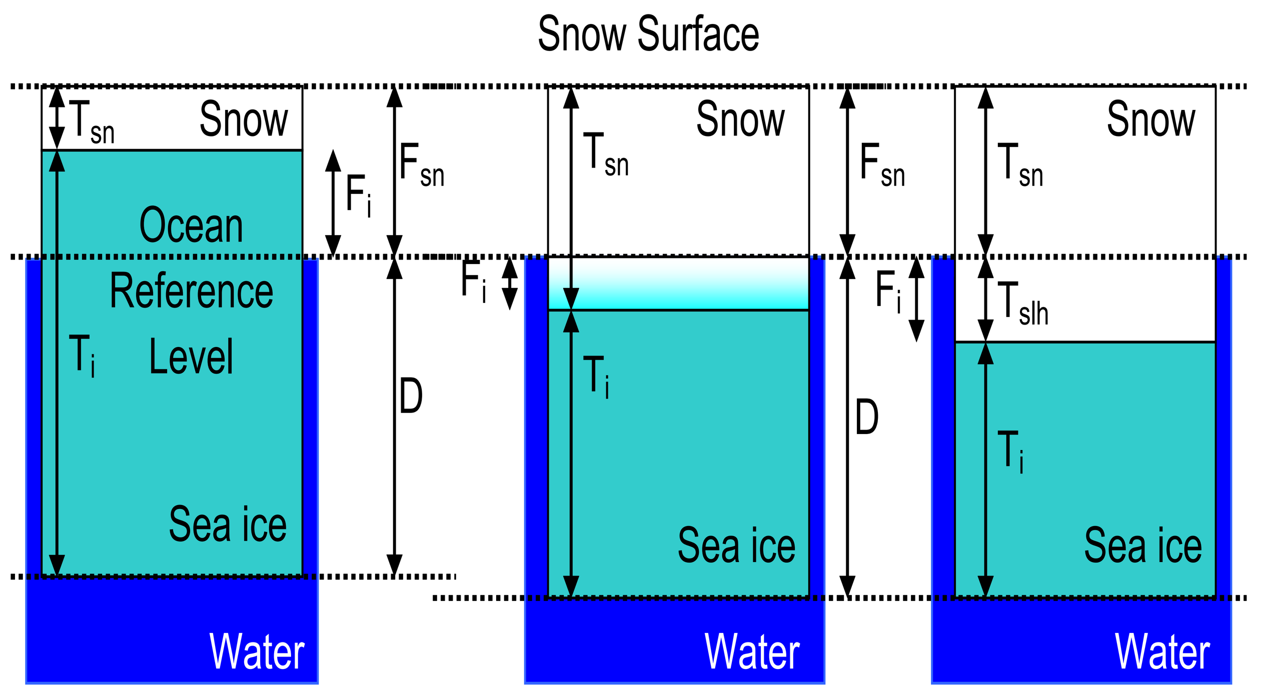

Figure 1 Antarctic sea ice can have the ice surface above sea level (left), below sea level (center) or below sea level with flooded snow (slush).

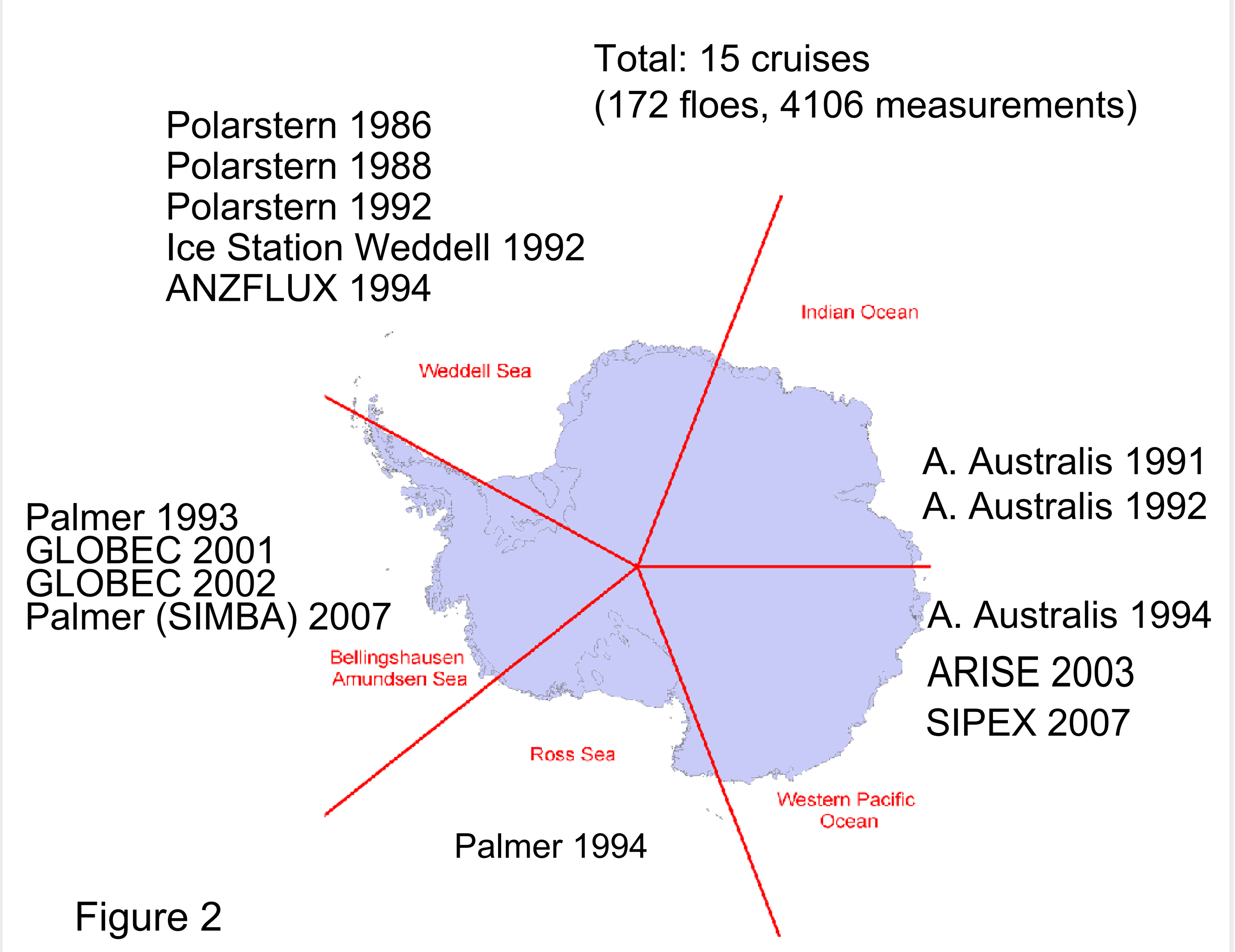

Figure 2

Data Source:

Data was obtained from 15 cruises to the Antarctic (fFigure 2) and all data was analyzed for each of four sectors, Ross, Bellingshausen-Amundsen, Weddell and Indian Pacific. Each data set contained ice thickness, ice freeboard, and snow thickness from drilling and traditional surveying techniques in line transects (~100m) at typically 1m spacing. Figure 3 shows the average data for snow elevation, ice freeboard, and ice thickness for four typical cruises. Each profile was averaged for these parameters over its full length. As can be seen here the ice freeboard is typically negative or small positive as a general feature. In Fig 4a, the data from every measurement on one cruise was taken and the Snow Freeboard is plotted against Snow Depth. Linear regressions, corresponding to negative freeboard (red), positive freeboard (blue) and all data (black), all showed R2 values >0.91. This means that Snow depth can be directly inferred from an elevation measurement alone. Since the isostatic balance equation is linear (assuming constant densities) a means of predicting ice thickness is possible from linear regression of snow elevation and ice thickness, shown in Fig Fig 4b. Since it is difficult to know if an area is flooded from space, the prediction line for all data, with an R2 ~.7, is the predictor of choice.

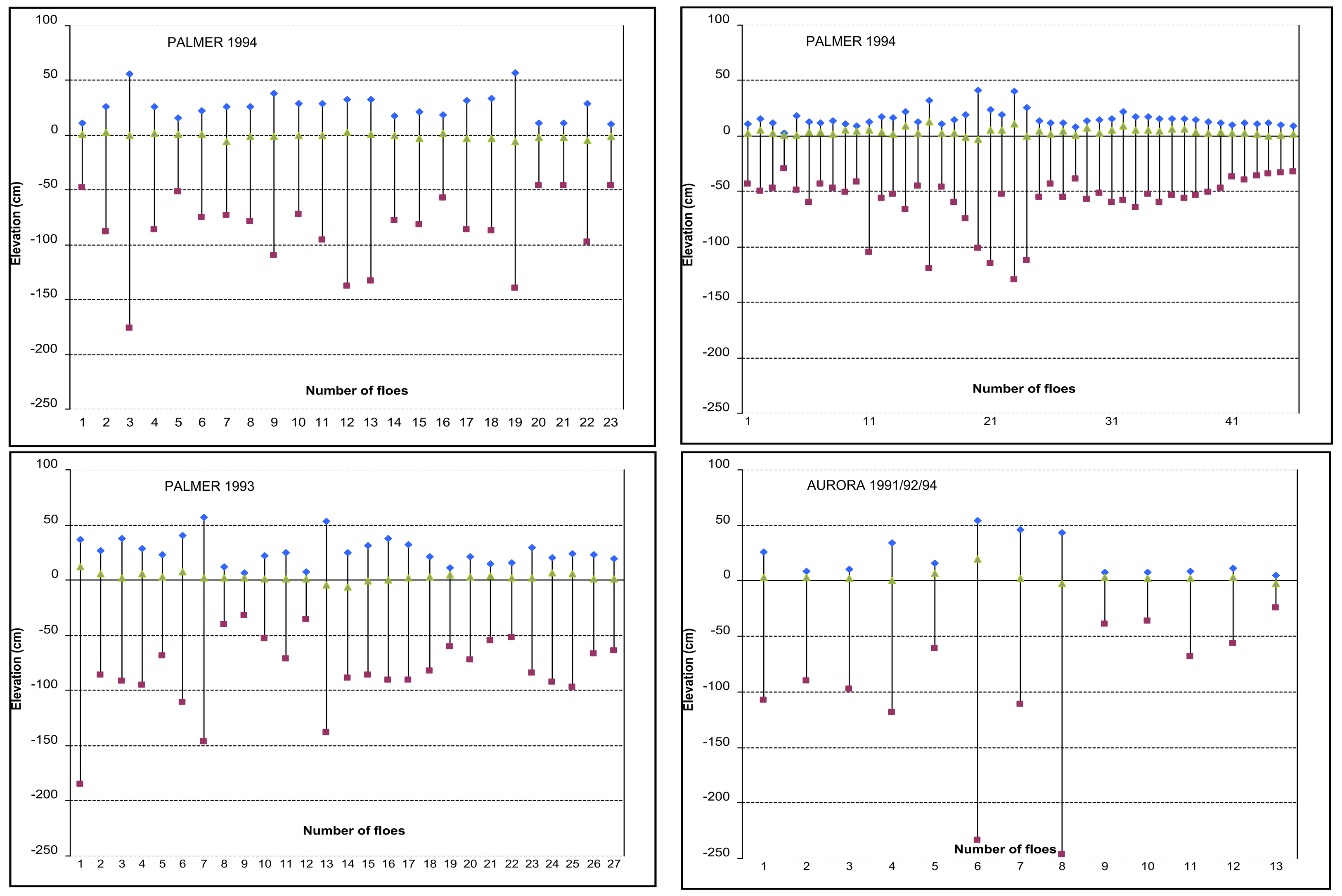

Figure 3

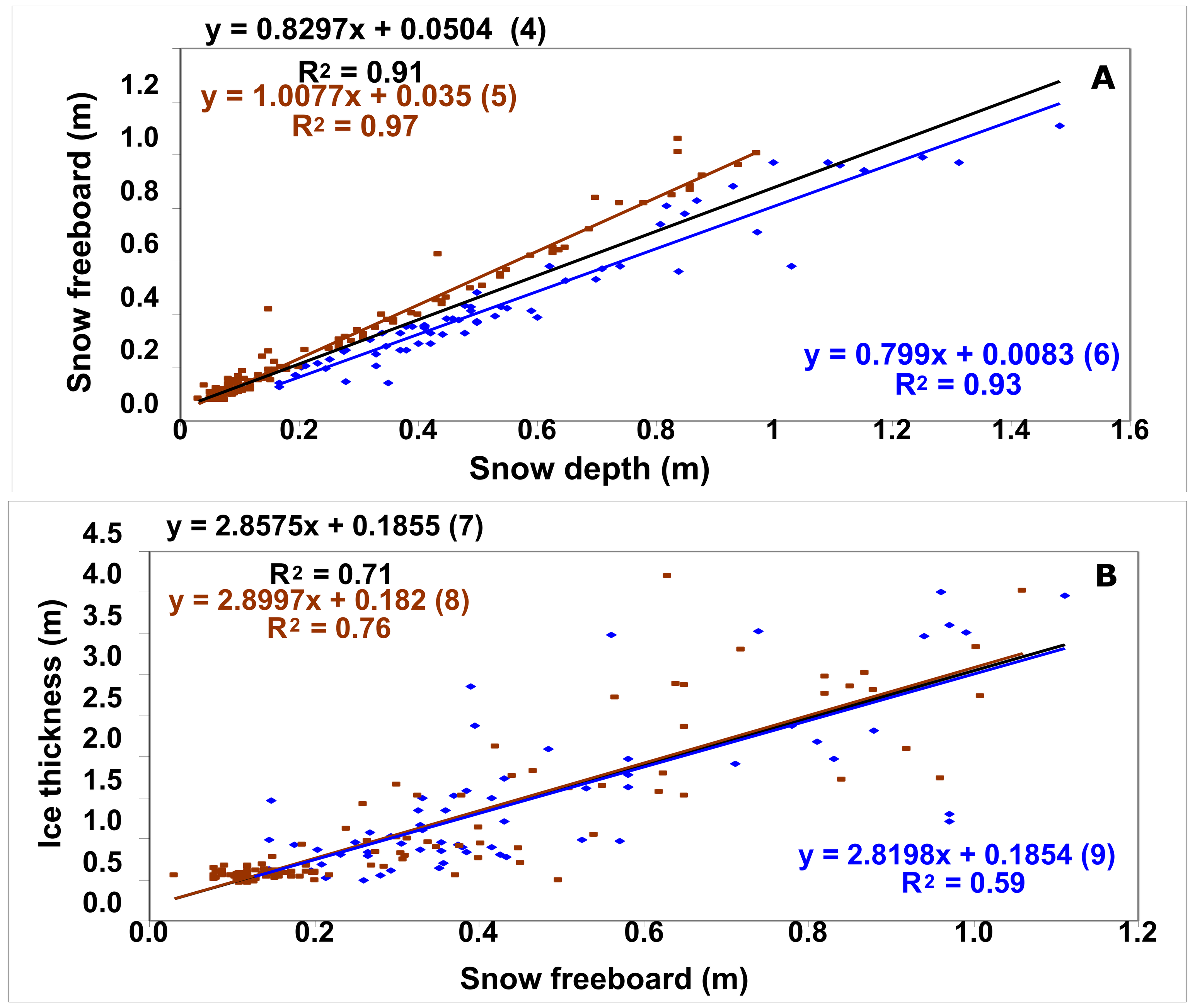

Figure 4

In FIgure 5, the linear regressions of Snow Freeboard and Ice Thickness are shown for the four regions with R2 values for each line shown below. The Indian-Pacific region is characterized by thicker ice for thinner snow than the other three regions and has a line of a different slope for prediction. This characteristic is related to the ice growth characteristics and relatively younger ice found there, In Table 1 are shown the R2 values for the various correlations and the RMS differences between Snow Freeboard and Snow Depth and between Ice Thickness predicted from the linear regression and measured Ice thickness. As seen here, the greatest difference in predicted and measured thickness is of 18 cm seen for the Indian-Pacific region.

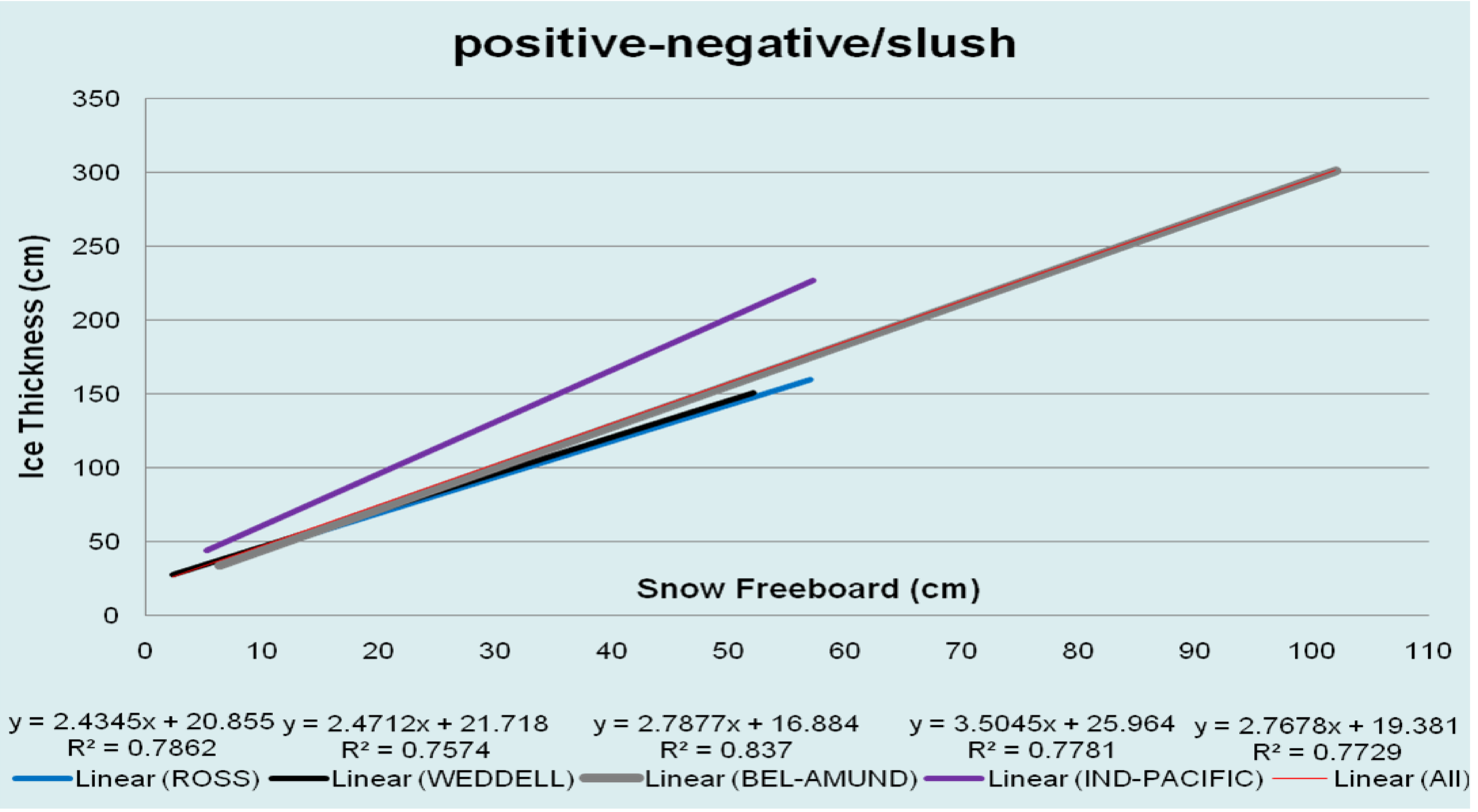

Figure 5

Sectors	R^2 (T_i vs T_{sn})	R^2 (T_i vs F_{sn})	R^2 (F_{sn} vs T_{sn})	R^2 ($[T_i]$ vs $[T_i]$)	RMSD (T_{sn} and T_{sn})	RMSD (T_i and T_i)	# of profiles
Ross	0.67	0.79	0.96	0.83	0.024	0.120	23
Weddell	0.61	0.76	0.90	0.60	0.035	0.140	79
Bel- Amun	0.69	0.84	0.93	0.81	0.045	0.150	55
Indian-Pacific	0.61	0.78	0.91	0.73	0.040	0.180	26

Table 1

Conclusion:

Previous attempts to analyze IceSAT elevation data for Anttarctic sea ice thickness have had to rely on a separate, lower resolution satellite estimate of snow depth. Our technique, relying on the unique and high correlation of Snow Elevation and Snow Depth over the large proportion of the Antarctic sea ice cover, means instead that the IceSAT elevation measurement alone can be converted into Ice Thickness with potentially much lower errors than using other assumptions about snow depth. Because of the correlation, the elevation is also a strong predictor of the snow depth, making computations of snow depth distributions over Antarctic sea ice also possible. RMS error values in this method are small and can also be quantified based on the comparison to field data available from the cruise profiles analyzed here.

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