Comparison and evaluation of publicly available bathymetry grids in the Arctic

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Introduction

In this study we compare and evaluate the quality of six bathymetry grids in different regions of the Arctic. This study assesses differences between the grids, and provide guidance on the choice of grid. The analyzed grids include IBCAO ver. 2.23 [1], GEBCO 1 minute grid [2], GEBCO 30 arc second gird [3], ETOPO 1 [4], Smith and Sandwell v. 13.[5] and SRTM30 PLUS [6].

The datasets analyzed are separated into two major types: Type A, datasets based solely on sources derived from sounding data, and Type B, datasets based on soundings and gravity data. Assessment is done in terms of regional depth accuracy by comparison to Strakhov multibeam (MB) gridded data, internal consistency based on proximity to depth soundings, and interpolation reliability based on distance from source depth soundings. These three criteria are considered to be the primary quality criteria of any bathymetry dataset. Additionally all datasets are compared in terms of resolution of the coastline, registration issues and global depth distribution.

We find that Type A bathymetry datasets have higher accuracy over the shelf area compared to Type B datasets based on comparison with high resolution multibeam grid; also Type A bathymetry datasets have better internal consistency compared to Type B datasets with large number of artifacts. At the same time, Type B datasets provide information on seafloor features such as seamounts and ridges that are not reflected in Type A datasets in the areas of no source soundings. Finally, we propose qualitative metrics that are important when choosing a bathymetry grid. These results are preliminary.

Materials:

•Bathymetry grids

The main differences between analyzed grids are summarized in Table 1.

Based on differences in data sources and interpolation method used, datasets are separated into two types:

•Type A (grey line in Table 1) - based solely on IBCAO dataset and therefore based on acoustic sounding data sources and interpolated on contours in the areas with lack of data.

•Type B datasets (red line in Table 1)– based on acoustic sounding data sources (singlebeam and multibeam) and interpolated with satellite-derived gravity data.

Table 1.

	GRID	Date released	Coverage	Spacing	Format	Projection	Node	Based on
Type A datasets	IBCAO ver. 2.23	2001, updated 2008	64°-90° N	2 km/ 1 min	netCDF, Arc ascii, pdf map	Polarstereographic, true scale at 75 N WGS 1984 / Geographic WGS 1984	grid/ pixel	soundings from hydro charts, ice camps, single and multibeam surveys and sumbarines interpolated on contours in the areas with no data [1]
	GEBCO 1 min ver. 2.00	2003, updated 2008	global	1 min	netCDF	Geographic WGS 1984	grid	IBCAO ver. 2.23
	GEBCO_08 ver. 20091120	Feb. 2009	global	30 arc sec	netCDF	Geographic WGS 1984	pixel	IBCAO ver. 2.23
	ETOPO 1	2009	global	1 min	netCDF, GRD98, binary, xyz,	Geographic WGS 1984	grid / pixel	IBCAO ver. 2.23
Type B datasets	Smith and Sandwell ver.13.1	Aug. 2010	80.738° S- 80.738° N	1 min longitude	binary, gif image	Mercator on GMT Sphere	pixel	high resolution marine gravity model ver. 18.1 combined with depth soundings [5]
	SRTM30_Plus ver.6.0	Nov. 2009	global	30 arc sec	netCDF, xyz	Geographic WGS 1984	pixel	high resolution marine gravity model ver. 18.1 combined with depth soundings, IBCAO database for lat. north of 80° N [6]

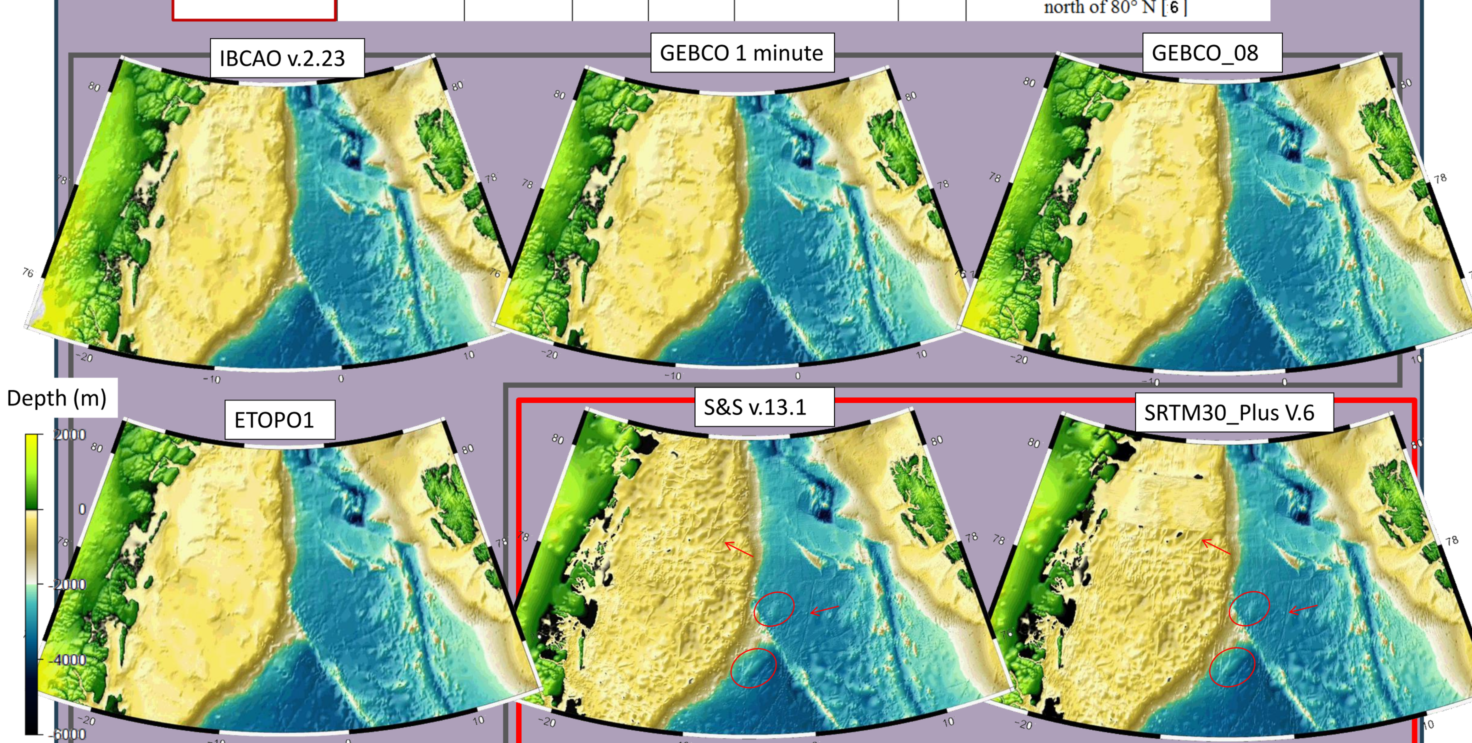

Figure 1. Visual differences between the datasets in the area of Norwegian-Greenland Sea. Note very few differences within Type A datasets based on IBCAO (grey ouline). Also note similarity between Type B grids (red outline). Also note Type A has visually more smooth appearance rather than Type B datasets with more rugged appearance and with presence of artifacts such as "traces" of tracklines in the bathymetry (shown by ↗). At the same time, seamounts which are resolved by satellite altimetry grids are absent on the grids based on contours (shown by ○).

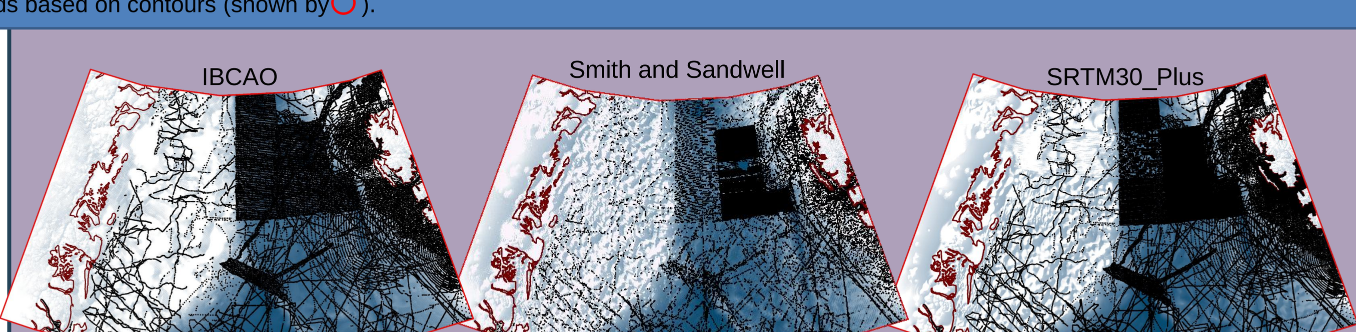

Figure 2. Comparison between ship trackline coverage used in the construction of grids in the study subarea. Tracklines are overlaid on shaded relief bathymetry of corresponding grid. Note very few differences in the source data coverage. Differences might be due to data thinning over different cell size. IBCAO and SRTM30_Plus tracks are derived from D.Sandwell.

•Strakhov multibeam bathymetry grids (ground truth)

In the current study, sonar multibeam (MB) gridded bathymetry not incorporated into any of the evaluated datasets is used as a ground truth. High resolution and accuracy gridded bathymetry datasets were provided by the Geological Institute Russian Academy of Sciences (GIN RAS). The bathymetry grids are based on the sonar multibeam data acquired during cruises 24, 25 and 26 of RV "Akademik Nikolai Strakhov" in 2006-2008 [7]. Table 3 gives results of cross-over comparison with independent MB datasets and Figure 4 gives overall uncertainty of Strakhov MB according to W.D

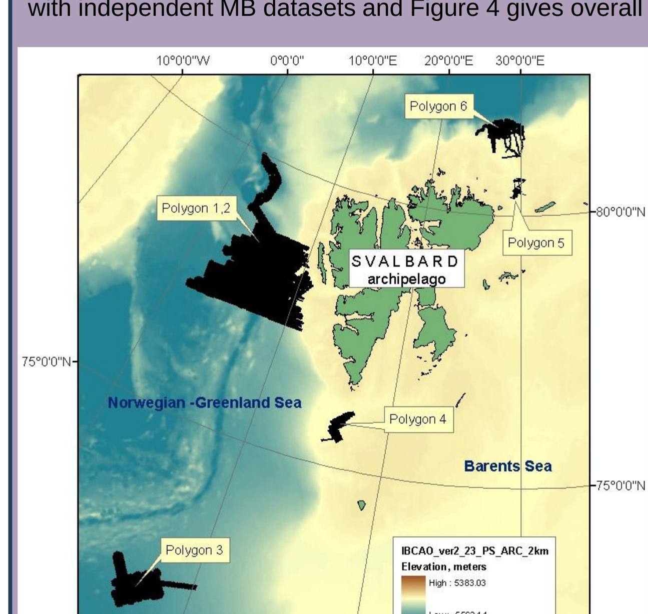

Figure 3. Overview map of the location of sonar MB grids

polygon No / name	depth range meters	morphologic province	roughness of seafloor	resolution of Mb grid	data source type used to construct bathymetry grids*
1 Molloy	1200-5400	mid-oceanic ridge	very rough	100 m	Mb
2 Knipovich	110-3600	mid-oceanic ridge	very rough	100 m	Sb + Hy
3 Mohns	1700-3000	abyssal plain	smooth	100 m	Mb + Sb
4 Barents Trough	150-400	shelf (trough)	smooth	50 m	Hy
5 Trough Orli	50-500	shelf (trough)	rough/smooth	10 m	Hi +Mb
6 Arctic Slope	60-2900	continental slope	smooth sloped	50 m	Hi +Mb

Mb = multibeam, Sb = singlebeam, Hy = hydrographic soundings, Hi = historical soundings

Table 2.

Multibeam data uncertainty and accuracy (rough estimates)

Research vessel	cruise index	diff stats mean	diff stats std	difference grid cell size	original grid coordinate system*	acquisition dates	aquistion system	depth range
Oden	SAT0809	6.14	18.07	29.4	geographic	Sept 2008	EM 122	-2500 to -5300
Oden	SAT0809	8.24	68.83	30.4	geographic	Sept 2008	EM 122	-1100 to -2600
Oden	LOMROG2007	-0.19	14.85	100	PS 75N	Sept 2007	EM 120	-300 to -900
Healy	HLY0503	-3.71	36.43	20	UTM32N	Sept 2005	SeaBeam 2112	-2000 to -3400

Table 3. Results of depth difference between Strakhov MB grid and gridded multibeam data from surveys of US RV "Healy" (HLY0503) [ref] and Swedish RV "Oden" (LOMROG 2009 and SAT0809)[ref]. MB grids were subtracted from Strakhov MB. Differences between these multibeam grids are within the uncertainty of Stralkov multibeam data, which is approximately 1.7% of water depth according to CARIS uncertainty model (Fig. 4) .

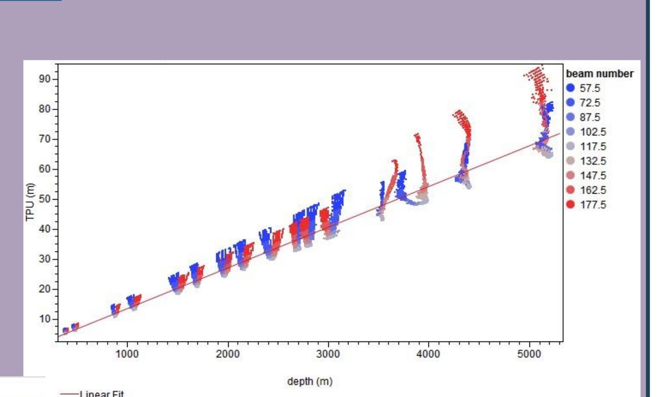

Figure 4. The total propagated uncertainty* of Strakhov MB soundings, 16 subsets of 15 along profiles were used (beams 60 to 190). Several raw MB lines were provided by GIN RAS to get rough estimates of Strakhov MB uncertainty. The worst case estimates for average TPU (linear fit) of MB according to CARIS uncertainty model comprise around 1.7% of water depth (at 95 % confidence level). *Total propagated uncertainty was computed from hzTPU and dpTPU extracted from CARIS: √(average vertical uncertainty² +average horizontal uncertainty²).

Methods & results

Six quality criteria were chosen as important in the choice of bathymetry grid. These include:

1. Depth accuracy of the modeled surface and of source data, measured by how well the bathymetric model fits values from an independent source of higher accuracy (Strakhov MB grid)

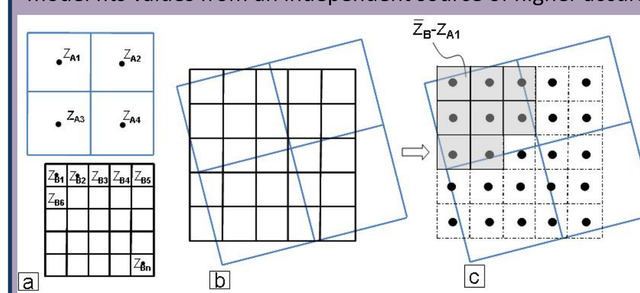

Figure 5. Method used for depth difference computation between high resolution MB grids and analyzed grids: a) Two grids A and B of different projections and resolutions; b) overlaid grids in some projected space, mismatch between cells makes it impossible to calculate the difference;
c) representing grid B as point depth values and reprojecting into the projection of grid A; multibeam data poins B are averaged over the resolution of dataset A.

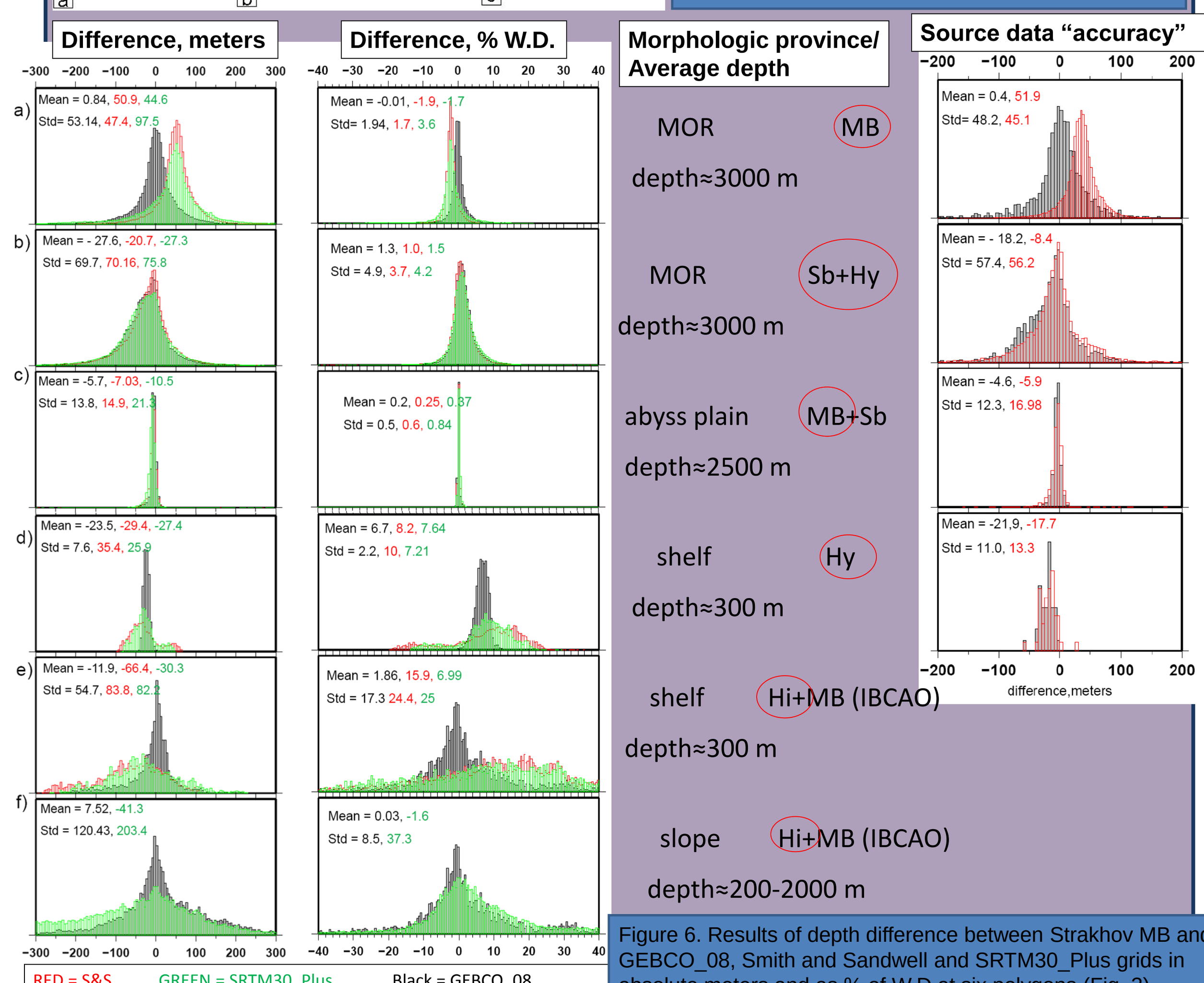

Figure 6. Results of depth difference between Strakhov MB and GEBCO_08, Smith and Sandwell and SRTM30_Plus grids in absolute meters and as % of W.D at six polygons (Fig. 3)

The grids are subtracted from Strakhov MB values. Standard deviation of differences for GEBCO_08 is considerably smaller over the shelf compared to S&S. SRTM30_Plus performs similar to S&S. All datasets have bias over 20 m at the polygons 2,4 where grids are based on hydrographic soundings. Considerate bias is observed in S&S and SRTM30_Plus at the polygon 1. "Accuracy" of source data for each of the polygons is assessed by taking the difference between the source values of GEBCO_08 and S&S and Strakhov MB at corresponding locations. Note that S&S has better accuracy them GEBCO_08 at polygons 2 and 4. Also note considerate bias at the polygon 1.

2. Internal consistency of the modeled surface, measured by the presence of artifacts and smoothness of the surface (consistency with neighborhood values).

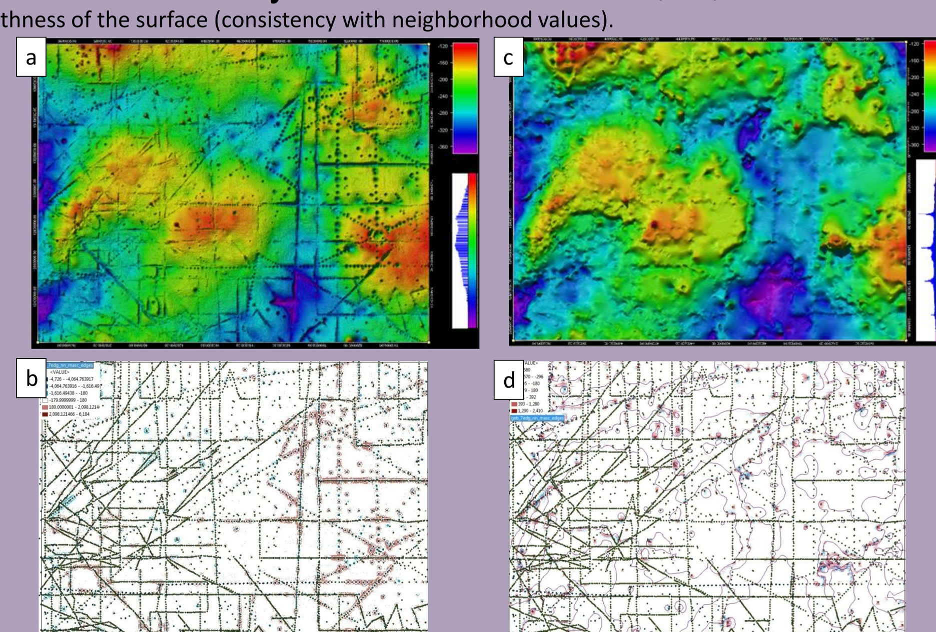

Figure 7. Bathymetry in S&S (a) and GEBCO_08 (c) at the shelf area. (b), (d): edge detection map for corresponding grids produced by running 7x7 edge detection filter on the bathymetry values. The map is overlaid by source tracks (green dots)(b) and source tracks and contours (d). Note the correlation between location of input data and high edge detection values.

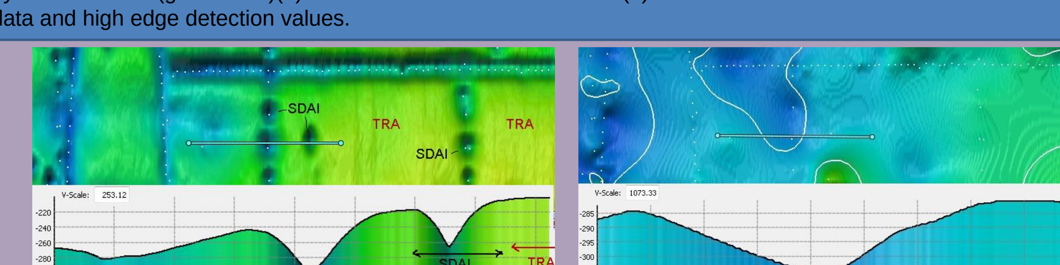

Figure 8. Fragment of GEBCO_08 and S&S bathymetry overlaid by source soundings (white dots) and contours (white lines). Profile is taken across the bathymetry in the area of source soundings. GEBCO_08 fits smoothly input soundings, while S&S has "holes" in the bathymetry surface at the locations of source data points. The values of the source soundings are also influencing values in the surrounding area, which we refer to as a *source data area of influence (SDAI)*. The area outside of SDAI in S&S bathymetry is referred to ***the "true" variability area*** (TVA). The assumption is made that the gravity-predicted bathymetry surface reflects the true behavior of the bathymetry surface

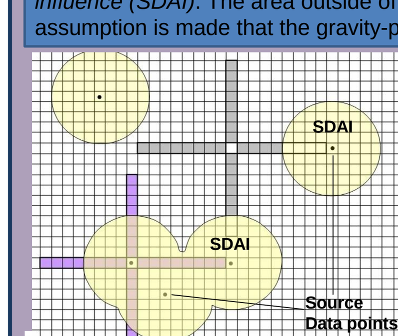

Figure 9. Illustrates method of assessing variability at the location of source data points and outside, where the "true" variability is assumed. Cells outside the yellow buffer (SDAI) are those used to estimate the "true" variability. The variability is computed by comparing the center cell value to the median value in the narrow window in the X direction and then comparing to the same value in the narrow window in the Y direction. The highest difference value in the two directions is taken. Purple cells illustrate values used within the window for variability computation at the locations of source data points. Grey cells illustrate values used within the window for "true" variability computation. Note that SDAI cells are not used in assessing "true" variability.

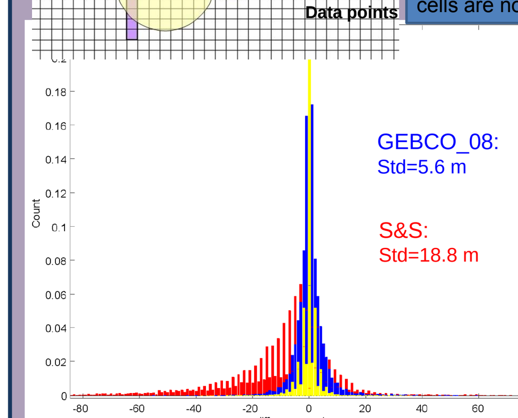

Figure 10. Variance of variability values for GEBCO_08 (blue) versus S&S (red) and the "true" variablity (yellow). Note that GEBCO_08 has much closer distribution to the "true" variability, compared to S&S with large standard deviation and negatively biased differences.

3.Interpolation accuracy

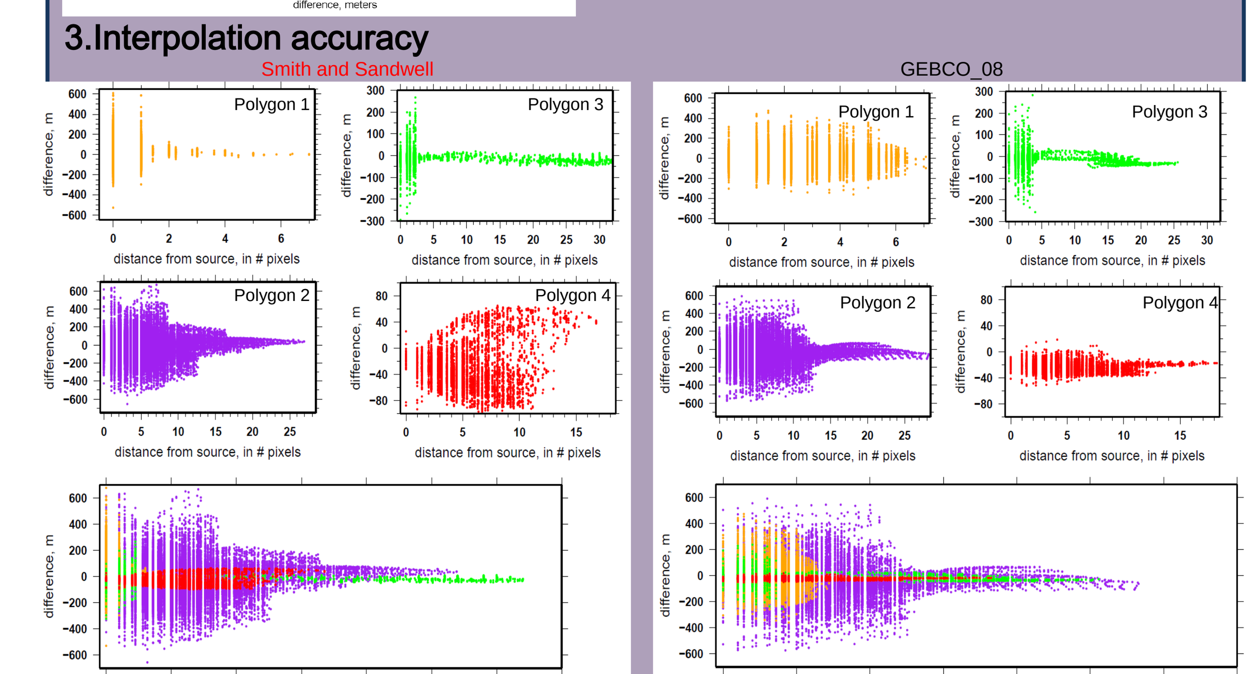

Figure 11. Interpolation accuracy is tested by plotting differences between Strakhov MB and analyzed grids versus the distance to the closest source data point The distance to the nearest source point grid is created for the two datasets within each polygon of interest. The distance grids are created with the same resolution as the original analyzed datasets. Distance is measured on projected space in pixels to the nearest source point. Preliminary analyses of interpolation accuracy reveal that both types of datasets perform similarly: closer to the source data points errors are higher then further away from the source data points. These results might imply that further then particular distance (defined by tension in spline) both methods of predicting values or by gravity or by contours - perform similarly. The interpretation is preliminary.

4. Resolution of the coastline

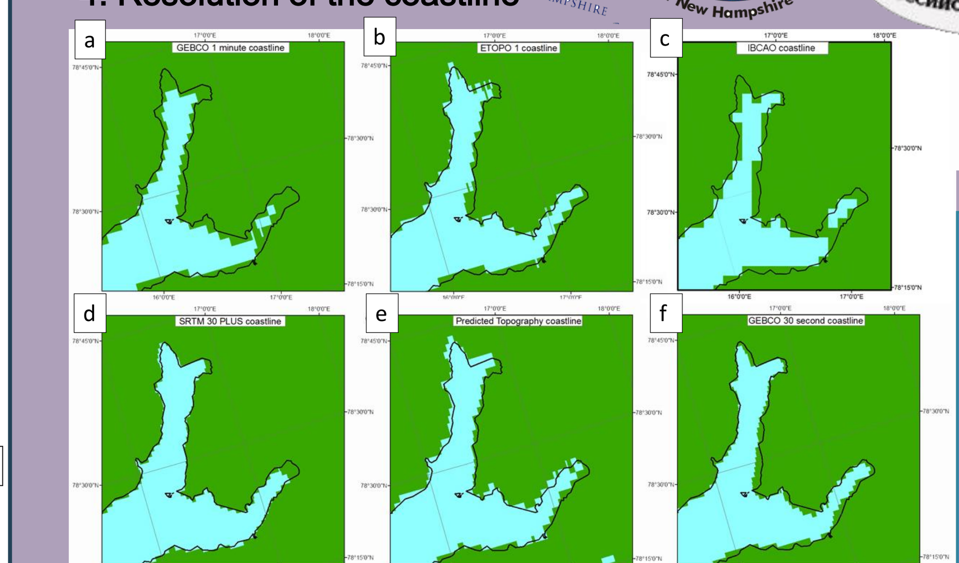

Figure 12. Comparison of how well grids resolve coastline in the Svalbard region. All analyzed grids constrain interpolation in coastal zone to fit or GSHHS database [11] or GEBCO shoreline database [12] which are identical in the region. The bathymetry of six grids is overlain by the GEBCO shoreline.

Figure 5 (continue). At large scales GEBCO 1 minute (a) and IBCAO (c) do not resolve shoreline mainly due to the resolution of the grid, while the rest of the grids reveal shift between shoreline and gridded values: in S&S grid (northern shift) (e), in ETOPO 1 grid (northern shift)(b), in GEBCO_08 (north-western shift)(f) as well as in SRTM 30 Plus grid (southern shift)(d).

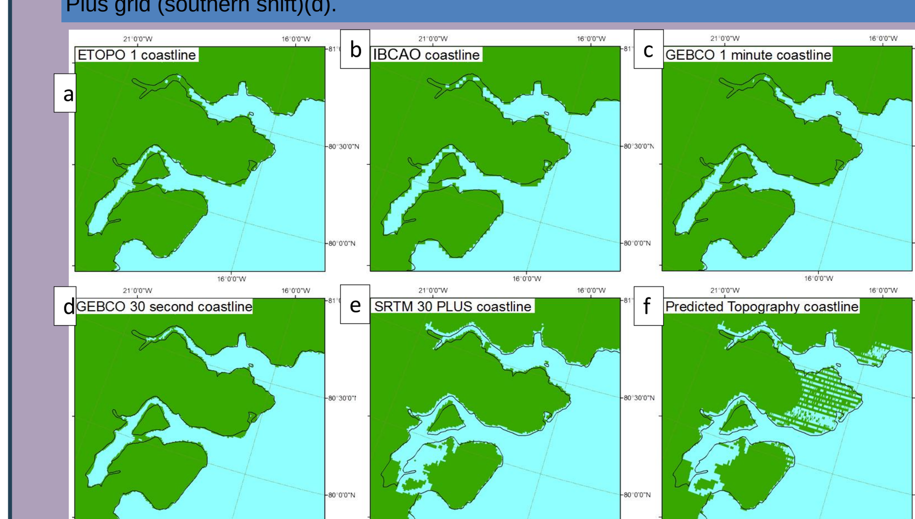

Figure 13. Comparison of how well grids resolve coastline in the Greenland region. Type A datasets are based on GEBCO coastline, while Type B datasets were based on GSHHS coastline which had projection shift in the Greenland area. Note negative depths in S&S and SRTM30_Plus (e,f) on land.

5. Registration issues

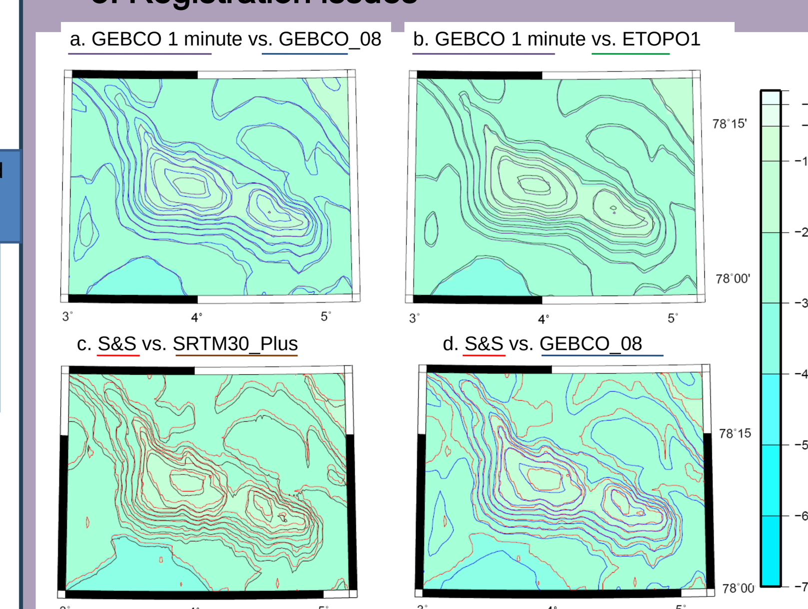

Figure 14. Contours generated on bathymetry (200 m interval):
GEBCO 1 minute contours overlain by
a) GEBCO _08 contours an
b) ETOPO 1 contours;
S&S contours overlain by
c) SRTM30_Plus contours and
d) GEBCO_08 contours.
Comparison between contours reveal consistency between IBCAO, GEBCO 1 minute contours, GEBCO_08 and S&S contours. Consistent offset between ETOPO 1 and GEBCO 1 minute grid is observed (b). Same problem is observed in registration of SRTM 30 PLUS (c), where systematic south offset of contours occurs with respect to S&S contours.

6. Global depth distribution

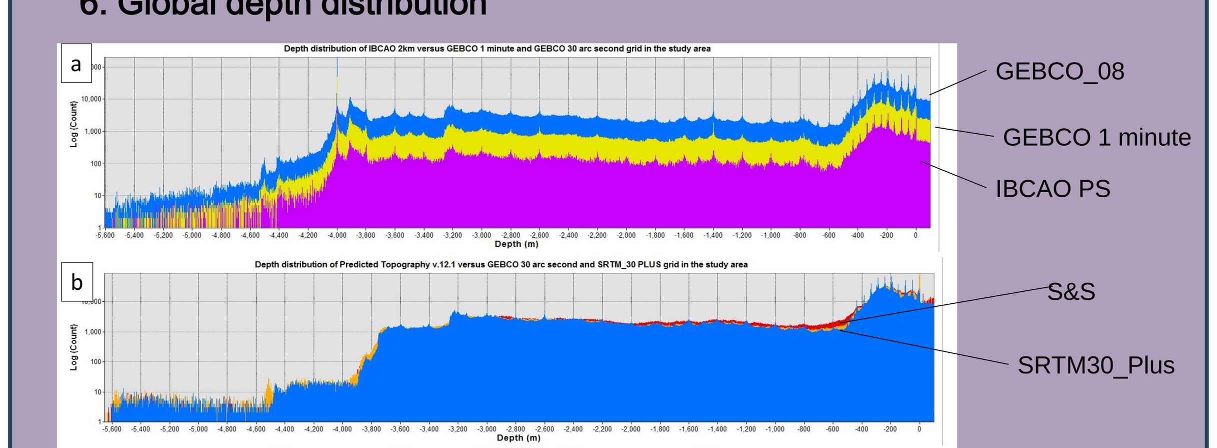

Figure 15. Comparison of depth distribution between analyzed datasets: (a) between IBCAO 2 km PS grid, GEBCO 1 minute and GEBCO_08 for the region 30 E - 52 W 64 N - 85 N, (b) between Predicted Topography v 13.1, GEBCO 30 arc second and SRTM_30 PLUS for the region 30 E - 52 W 64 N - 80 N. Similarity of distribution between datasets in (a) is caused by that GEBCO datasets are based on IBCAO by regridding it to finer resolution. Grids based on satellite altimetry reveal smoother distribution compared to datasets based on contours with spikes at contour values (b). At the same time GEBCO 30 sec grid has very similar distribution to SRTM30_Plus and Predicted Topography, that raises the question: does interpolation on contours globally performs as good as on satellite altimetry?

Preliminary conclusions

1. Comparison between Type A versus Type B datasets revealed that Type A visually reveal more smooth appearance and are more consistent compared to the grids of Type B with large number of artifacts in the bathymetry. At the same time grids based on satellite altimetry resolve seamounts unresolved by grids based solely on acoustic sounding data sources. Meanwhile, global distribution of depths in Type B datasets is smoother then in Type A, where depth values are biased towards the contour values.
2. Comparison between datasets within Type A (based on IBCAO) revealed very few differences between the datasets, since they are all resampled versions of IBCAO PS. Slight shift was found in ETOPO1 relative to the others which should be due to misregistration while reprojecting to geographic coordinate system. GEBCO_08 could be preferred over the others in terms of higher resolution, and fitness to the vector shoreline (also fitness to input IBCAO source data, which is not covered here)
3. Comparison between datasets within Type B (satellite gravity based) revealed overall similarity between SRTM30_Plus and S&S dataset. Regional differences directly correlate with differences in source trackline coverage and finer resolution of SRTM30_Plus compared to Smith and Sandwell. Overall SRTM30_Plus has higher resolution and is represented in more convenient geographic coordinate system (vs. S&S in Spherical Mercator), has global coverage (vs. S&S covers till 80° N) and, due to higher resolution, resolves shoreline better. SRTM30_plus has higher accuracy over one of the shelf areas and has very similar accuracy with S&S in all other polygons. Meanwhile should be noted that SRTM30_Plus has slight shift relative to S&S.
4. Preliminary proposed metrics important in choice of bathymetry grid include the following:

	IBCAO	GEBCO_08	ETOPO1	GEBCO 1 minute	Smith and Sandwell	SRTM30_Plus
projection issues	none	none	shift	none	not common projection	shift
trackline coverage map	none	based on IBCAO	based on IBCAO	based on IBCAO	good	good
shoreline resolution	poor due to resolution	good	poor due to resolution	poor due to resolution	shift/ negative values on land (Greenland)	shift/ negative values on land (Greenland)
global coverage	no	yes	yes	yes	no	yes
interntal consistency	good				bad	
source data accuracy	regional difference*	based on IBCAO	based on IBCAO	based on IBCAO	regional difference*	not evaluated
depth accuracy	not evaluated	good where based on MB, shallow biased where based on hydrographic data	not evaluated	not evaluated	final surface accuracy is worse then the source data accuracy, global fit of satellite altimetry is adding bias, bad on shelf	bad on shelf, at one polygon better then S&S
interpolation accuracy	good?				good?	
						* see section 1

References

[1] Jakobsson, et al, 2008, An improved bathymetric portrayal of the Arctic Ocean: Implications for ocean modeling and geological, geophysical and oceanographic analyses, *Geophys. Res. Let.*, 35: pp. 1-5

[2] British Oceanographic Data Centre (BODC), 2003, GEBCO 1 minute grid, Cententary Edition of the GEBCO Digital Atlas [CD]

[3] British Oceanographic Data Centre (BODC), 2008, The GEBCO_08 Grid, version 20091120, General Bathymetric Chart of the Oceans (GEBCO)

[4] Amante, C. and B. W. Eakins, ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. NOAA Technical Memorandum NESDIS NGDC-24, 19 pp, March 2009

[5] Smith, W.H.F., Sandwell, D.T., 1997, Global sea floor topography from satellite altimetry and ship depth soundings, *Science*, Vol. 277 (5334), pp.1956-1962

[6] Becker, J.J., et al., 2009, Global Bathymetry and Elevation Data at 30 Arc Seconds Resolution: SRTM30_PLUS, *Marine Geodesy*, 32 (4): pp. 355-371

[7] Zayonchek, A.V., et al., 2010, results of 24-26 cruises of RV "Akademic Nikolaj Strakhov', 2006-2009, Original Russian Text, in *Results of expeditions in the framework of the International Polar Year*, Vol. 4

[8]Jakobsson, M., Marcussen, C., LOMROG, S.P., 2008, Lomonosov Ridge Off Greenland 2007 (LOMROG) - Cruise Report, *Special Publication Geological Survey of Denmark and Greenland*. Geological Survey of Denmark and Greenland, Copenhagen, p. 122.

[9] NGDC online delivery multibeam data from HLY0503

[10] Marks, K.M., Smith, W.H.F., 2010, Evolution of errors in the altimetric bathymetry models used by Google Earth and GEBCO, *Mar. Gephys. Res*., Vol. 31 (3), pp. 223-238

[11] Wessel, P., and W. H. F. Smith, A Global Self-consistent, Hierarchical, High-resolution Shoreline Database, *J. Geoph. Res., 101, B4, pp. 8741-8743*

[12] British Oceanographic Data Centre (BODC), 2003, Cententary Edition of the GEBCO Digital Atlas [CD]

Acknowledgements

I would like to thank CCOM for providing funding for this research and Geological Institute Russian Academy of Sciences for providing multibeam data for this study. Special thanks to D. Sandwell, B. Calder, T. Lippmann, G. Masetti, P. Weatherall, M. Jackobsson, S. Peeri, K. Marks and A. Jaggarwal for their constructive input, patience and helping this work happen.

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