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Supporting Information for

Sea Surface Height Anomalies of the Arctic Ocean From ICESat-2: A First Examination and Comparisons with CryoSat-2

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Introduction

This supplement contains text, figures and tables in support of the main document.

Text S1 describes an adjustment needed to correct a discrepancy in the permanent tide system between geophysical corrections applied to ICESat-2 release 003 ATL10 data.

Figure S1 shows a map of the Arctic Ocean with the names of the main seas and the extent of the NSIDC Sea Ice Index Arctic regional mask used to define the area of interest.

Figure S2 is complementary to Figure 1 and shows the differences between SSHA estimates from ICESat-2 and CryoSat-2 for four *CRYO2ICE* overlaps. This figure also highlights the importance of geophysical corrections when comparing non-synchronous

SSHA measurements by showing the differences introduced by the ~3-hour time lag between the passes of the two satellites.

Figure S3 shows the variability (standard deviation) and number of data points (segment/interval count) associated with each dataset used to produce the multi-year (2018-2020) SSHA composite maps shown in Figure 3b – ICESat-2 – and Figure 3c – CryoSat-2.

Figure S4 shows SSHA differences between ICESat-2 and CryoSat-2 in three-month composites for the duration of the mission overlap. The figure is complementary to Figure 4 and used to assess the ability of ICESat-2 in tracking seasonal and inter-annual changes in SSHA.

Table S1 lists all the geophysical corrections that are applied to obtain SSHA estimates from ICESat-2 and CryoSat-2 and provides information on the tidal and atmospheric models used for each sensor.

Table S2 provides the statistics for monthly SSHA estimates for ICESat-2 and CryoSat-2 used to generate the time-series plot presented in Figure 3a. The table also provides the count of the total number of segments/intervals used to generate each monthly estimate, and the number of valid grid cell in each monthly SSHA composite.

Text S1: Permanent tide adjustment for ICESat-2

The ICESat-2 release 003 (r003) ATL03 photon heights used for the production of r003 ATL07/10 data products are corrected for the solid earth tide (SET) and include both the time-dependent (periodic) and the time-independent (permanent) components, so that ellipsoidal heights are in a tide-free system. However, the mean sea surface (MSS) grid used to estimate sea surface height anomalies (SSHA) in ATL07/10 (see Section 2.3) is in the mean-tide system (i.e., it includes the distortion of the geoid due to the permanent tide). While this inconsistency will be rectified in future ICESat-2 data releases (starting from r004 all data will be in a tide-free system), in this study we adjust the SET correction for ICESat-2 by reintroducing the time-independent component as follows:

$$SSHA_{mean-tide} = SSHA_{r003} + 0.060292 - 0.180873 \, sin^2\varphi$$

where the degree-2 Love number, *h2*=0.609 is implicit in the equation (IERS2010 Conventions) and φ is the latitude in radians.

The approach described above makes sure that SSHA estimates from both ICESat-2 and CryoSat-2 are in the same permanent tide system (mean tide system), enabling SSHA comparative analyses.

Figure S1. Map of the Arctic Ocean showing the extent of the area of interest in blue.

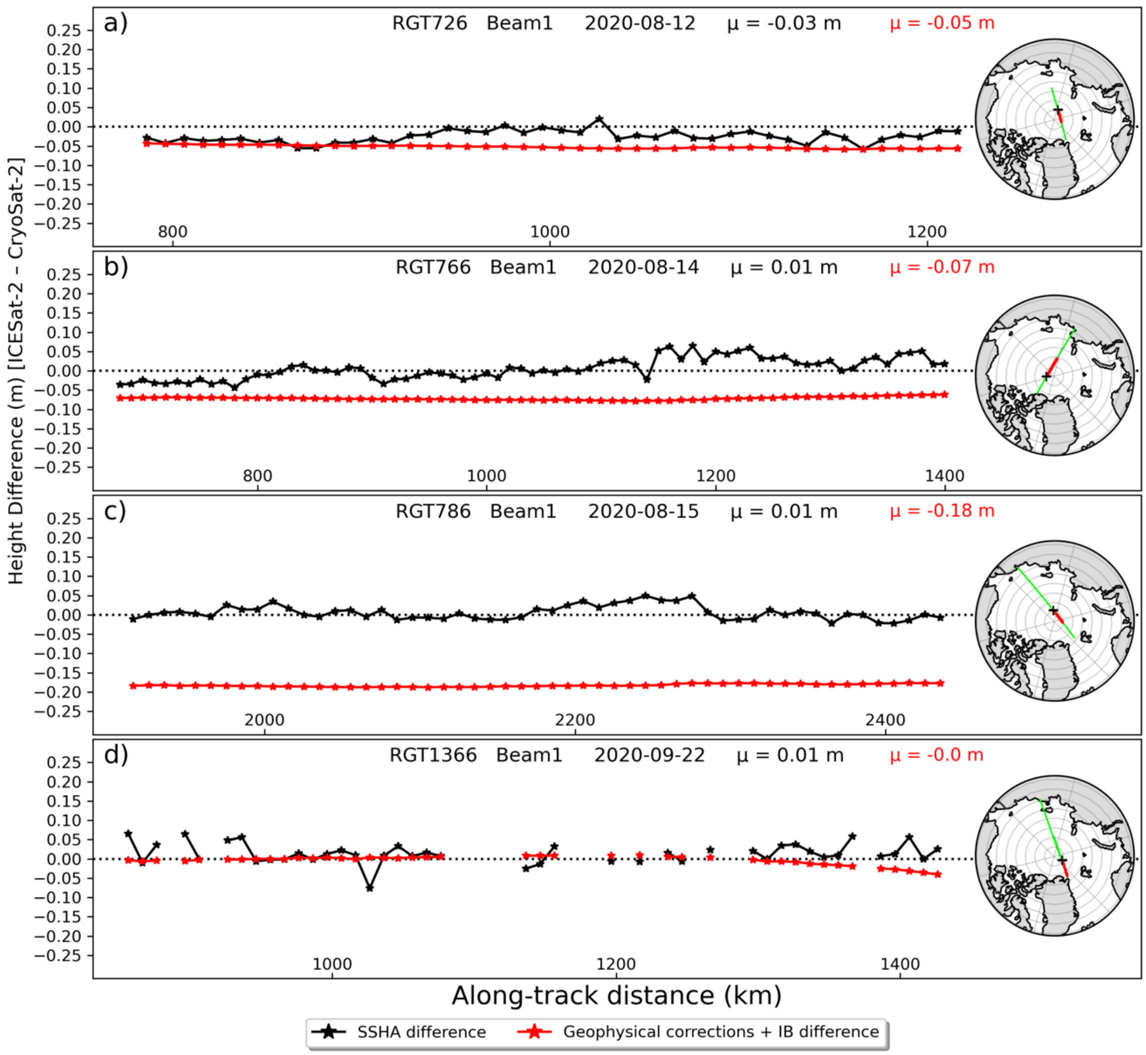

Figure S2: *CRYO2ICE* differences between ICESat-2 and CryoSat-2. Black stars show the SSHA difference (ICESat-2 – CryoSat-2) calculated for 10-km sections presented in Figure 1. Red stars show differences in geophysical corrections (ocean tide, ocean long period tide, pole tide, solid earth tide, ocean loading, and inverted barometer) for the same 10-km segments. These differences are mainly due to the time difference between acquisitions (~3 hours), and to a minor extent to the different tidal/IB models, and do not include other sensor-specific corrections for instrumental and atmospheric effects (e.g., wet and dry troposphere) that are applied to SSHA estimates. The RGT number identifies the ICESat-2 reference ground track number. For each overlap we report the SSHA (in black) and geophysical corrections (in red) mean difference ($\boldsymbol{\mu}$). Map insets show the CryoSat-2 ground track in green and the extent of the overlap with ICESat-2 in red. The black + symbol marks the beginning of the overlap (left side of main panel).

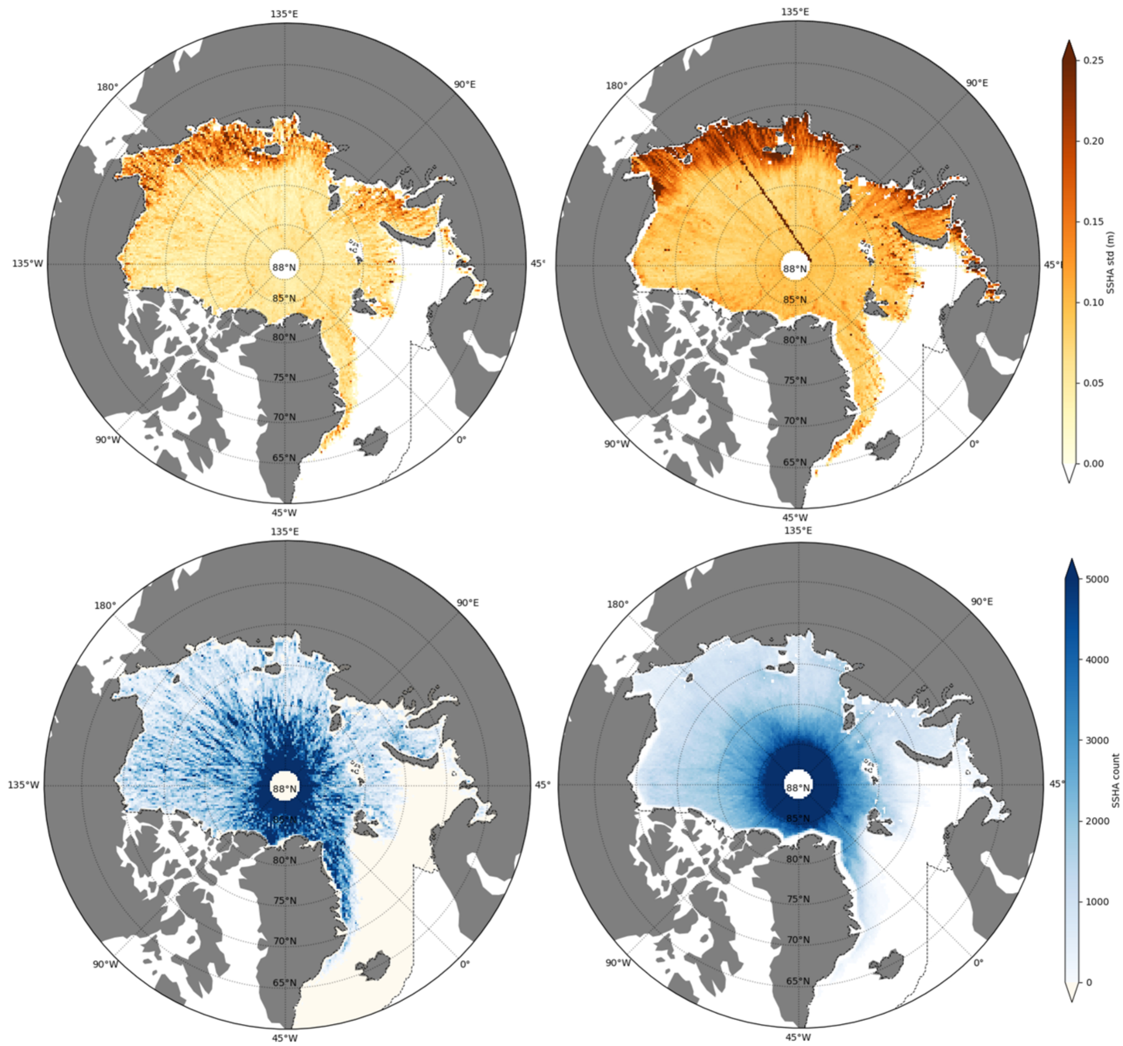

Figure S3. Maps showing (top) the standard deviation of SSHA measurements and (bottom) the number of data segments/intervals in each grid cell for the entire mission overlap (November 2018 – October 2020). (left) ICESat-2 and (right) CryoSat-2.

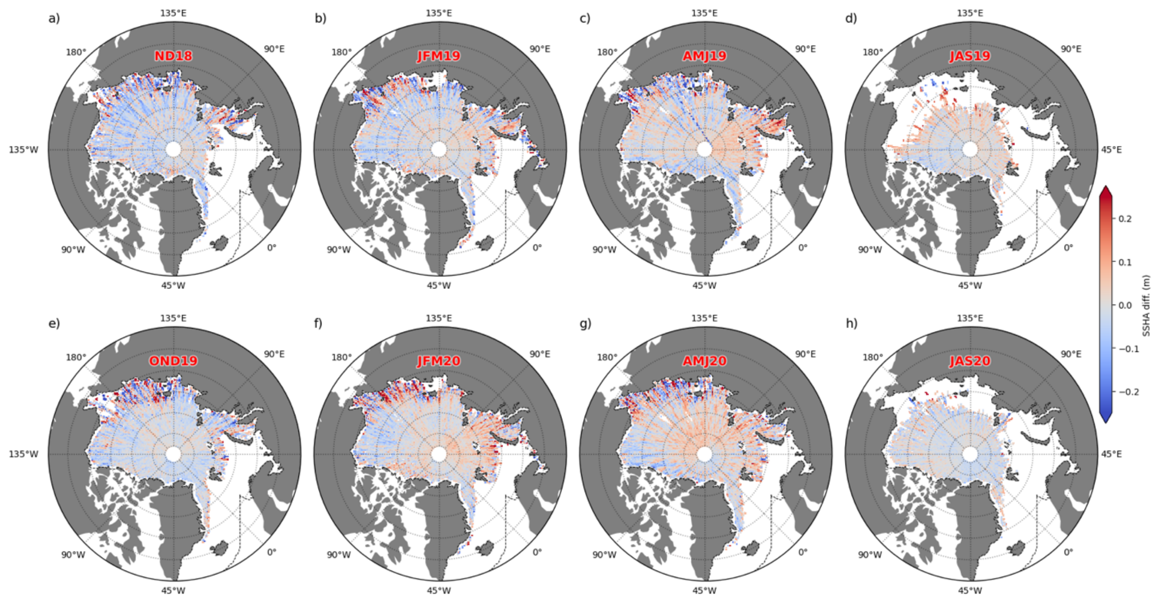

Figure S4: Seasonal mean SSHA difference maps (ICESat-2 – CryoSat-2). OND = October, November, December; JFM = January, February, March; AMJ = April, May, June; JAS = July, August, September. The black dashed line marks the extent of the area of interest (data outside this line are masked out).

Correction	*ICESat-2*		*CryoSat-2*	
Solid Earth Tide	IERS 2010 conventions	Y	Cartwright model	Y
Ocean Loading	GOT 4.8 ocean tide model	Y	FES 2004 model	Y
Ocean Tides	GOT 4.8 ocean tide model	Y	FES 2004 model	Y
Long Period Equilib. Tide	GOT 4.8 ocean tide model	Y	FES 2004 model	Y
Solid Earth Pole Tide	IERS 2010 conventions	Y	SSALTO	Y
Ocean Pole Tide	N/A	N		?
Inverted Barometer	From sea level pressure (ATL09)	Y	CNES SSALTO (ECMWF)	Y
Total column atm. delay	Luthcke & Petrov, ATBD ATL03a	Y	N/A	N
Dry troposphere	N/A	N	CNES SSALTO (ECMWF)	Y
Wet troposphere	N/A	N	CNES SSALTO (ECMWF)	Y
Ionosphere	N/A	N	GIM/Bent model	Y

Table S1. Geophysical and atmospheric corrections applied to each dataset. Y= yes, N=no, ?=unknown.

DATE	IS-2 SSHA MEAN	CS-2 SSHA MEAN	IS-2 SSHA GRID COUNT	CS-2 SSHA GRID COUNT	ICESAT-2 N. SEGMENTS	CRYOSAT-2 N. INTERVALS	MEAN (SD) OF **DIFFERENCES IS-2 – CS-2**
201811	-0.133	-0.128	3,084	4,291	651,527	870,650	-0.010 (0.061)
201812	-0.183	-0.173	3,218	4,356	484,112	883,514	-0.012 (0.065)
201901	-0.189	-0.173	3,170	4,402	546,014	808,559	-0.020 (0.066)
201902	-0.169	-0.190	2,756	4,408	520,729	686,661	0.015 (0.075)
201903	-0.165	-0.202	2,581	4,370	678,093	672,523	0.029 (0.054)
201904	-0.120	-0.159	3,131	4,312	964,540	707,937	0.033 (0.061)
201905	-0.148	-0.180	3,891	4,433	819,505	1,111,238	0.032 (0.049)
201906	-0.128	-0.128	3,748	4,421	1,476,440	2,352,078	0.008 (0.077)
201907	-0.072	-0.083	3,226	4,404	2,079,310	3,131,588	0.012 (0.049)
201908	-0.105	-0.119	3,859	4,403	2,830,539	2,607,746	0.016 (0.045)
201909	-0.129	-0.121	3,932	4,290	1,180,395	1,280,231	-0.007 (0.059)
201910	-0.090	-0.078	3,767	4,397	859,163	797,832	-0.011 (0.047)
201911	-0.113	-0.113	3,600	4,415	733,714	944,903	0.001 (0.050)
201912	-0.126	-0.132	3,798	4,416	646,454	959,979	0.005 (0.059)
202001	-0.110	-0.119	3,374	4,395	648,188	819,654	0.007 (0.062)
202002	-0.158	-0.176	2,998	4,377	573,857	680,526	0.016 (0.058)
202003	-0.144	-0.182	3,192	4,397	620,692	748,099	0.036 (0.056)
202004	-0.156	-0.204	3,583	4,388	982,488	897,103	0.047 (0.058)
202005	-0.110	-0.167	3,726	4,399	955,037	1,363,667	0.057 (0.066)
202006	-0.109	-0.135	4,071	4,443	2,200,551	2,602,271	0.026 (0.070)
202007	-0.138	-0.098	4,224	4,415	7,609,865	3,117,697	-0.039 (0.038)
202008	-0.102	-0.100	3,718	4,191	4,466,378	2,652,584	-0.001 (0.047)
202009	-0.140	-0.153	3,002	3,640	898,732	1,193,840	0.011 (0.056)
202010	-0.106	-0.137	3,411	4,130	563,092	1,940,856	0.031 (0.072)

Table S2. Monthly mean SSHA for the Central Arctic (see Figure 3a) from ICESat-2 and CryoSat-2. YYYYMM = year and month. Mean values are in meters. Grid cell counts are calculated as the total number of 25-km grid cells within the area of interest containing at least one data point.