

Supplementary info

Intercomparison and validation of SAR-based ice velocity measurement techniques within the Greenland Ice Sheet CCI project

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Table S1. GPS data overview

Id	Region	Acquisition interval	Lat	Lon	ve^a	vn^b	vu^c
			(°)	(°)	(m/y)	(m/y)	(m/y)
3 ^d	Storstrømmen	02.08.1993 - 27.06.1995	77.170341	-22.029282	8 ± 1	-2 ± 0.1	0.7 ± 0.1
6 ^d	Storstrømmen	10.07.1992 - 29.06.1995	77.295785	-22.509360	68 ± 9	-91 ± 12	3.7 ± 2.3
7 ^d	Storstrømmen	10.07.1992 - 28.06.1995	77.334029	-22.922625	183 ± 11	-88 ± 5	0.6 ± 1.9
25 ^d	Storstrømmen	10.07.1992 - 29.06.1995	77.224419	-22.497379	39 ± 7	-73 ± 14	3.6 ± 0.6
26 ^d	Storstrømmen	11.07.1992 - 29.06.1995	77.157949	-22.298982	9 ± 3	-30 ± 19	4.3 ± 2.2
27 ^d	Storstrømmen	11.07.1992 - 29.06.1995	77.084980	-22.426339	-3 ± 2	-12 ± 15	1.2 ± 0.7
28 ^d	Storstrømmen	11.07.1992 - 29.06.1995	76.966862	-22.666034	1 ± 1	0 ± 4	-1 ± 1.0
29 ^d	Storstrømmen	11.07.1992 - 27.06.1995	76.867312	-22.773332	0 ± 1	-1 ± 0.5	-0.4 ± 0.6
32 ^d	Storstrømmen	04.08.1993 - 27.06.1995	76.832968	-22.676708	0 ± 0.1	-1 ± 0.1	-0.2 ± 0.8
34 ^d	Storstrømmen	04.08.1993 - 30.06.1995	76.758095	-22.700271	1 ± 1	-1 ± 3	-0.7 ± 2.5
UPE 2 ^e	Upernavik	14.07.2010 - 19.08.2010	72.818144	-53.758695	-971 ± 0.04	146 ± 0.03	-71 ± 4.6
UPE 3 ^e	Upernavik	14.07.2010 - 19.08.2010	72.806948	-53.482982	-573 ± 0.03	62 ± 0.03	-23 ± 4.3
UPE 4 ^e	Upernavik	14.07.2010 - 19.08.2010	72.792934	-53.202300	-301 ± 0.03	75 ± 0.03	-20 ± 4.3
UPE_U ^f	Upernavik	14.07.2010 - 19.08.2010	72.890945	-53.540858	-216 ± 0.06	-72 ± 0.07	-29 ± 10
UPE_L ^f	Upernavik	14.07.2010 - 19.08.2010	72.893211	-54.295123	-2.4 ± 0.05	-1.4 ± 0.07	1.4 ± 8.4
UPF1 ^g	Upernavik	28.08.2010 - 29.08.2010	73.021031	-54.319543	-5783 ± 0.15	-4606 ± 0.05	6 ± 0.1
UPF2 ^g	Upernavik	28.08.2010 - 29.08.2010	72.995701	-54.311239	-263 ± 0.15	93 ± 0.05	-42 ± 0.09
UPF3 ^g	Upernavik	28.08.2010 - 29.08.2010	72.851473	-54.310751	-2481 ± 0.22	10 ± 0.08	-26 ± 0.14
UPM1 ^g	Upernavik	28.08.2010 - 29.08.2010	73.037651	-54.265447	-4682 ± 0.22	-4305 ± 0.08	-756 ± 0.14
UPM2 ^g	Upernavik	28.08.2010 - 29.08.2010	72.949319	-54.110098	-2163 ± 0.15	-110 ± 0.05	-125 ± 0.1
UPM3 ^g	Upernavik	28.08.2010 - 29.08.2010	72.838857	-53.979683	-1150 ± 0.19	226 ± 0.07	-18 ± 0.12
AVA1 ^e	West margin	20.11.2009 - 05.01.2010	70.128509	-50.171517	-243 ± 0.01	-425 ± 0.01	26 ± 1.7
RNK2 ^e	West margin	20.11.2009 - 05.01.2010	71.774787	-51.154374	-1449 ± 0.02	363 ± 0.02	-28 ± 2.1
STO4 ^e	West margin	20.11.2009 - 05.01.2010	70.521853	-50.065972	-530 ± 0.02	-863 ± 0.02	-44 ± 2.1

^{a,b,c}West-east, South-north and vertical velocity components respectively

^dThe reported velocities were linearly extrapolated to Feb. 1st, 1996 (see section 2.3). The given positions are at the end of the acquisition interval.

^eDeployed within the Ice2sea project. The given positions are at the start of the acquisition interval.

^fAutomatic Weather Station (AWS) deployed within the PROMICE project

^gDTU campaign measurements

Table S2. Task 1 validation results

Station	Component	GPS ^a	SAR – GPS ^b					
			G1 ^c	G2 ^d	G3 ^c	G4 ^c	G5 ^c	G6 ^c
3	LoS	-1.95 (0.38)	36.30 (8.78)	-0.65 (0.92)	1.70 (1.33)	0.91 (0.65)	1.40 (0.84)	1.81 (0.64)
6	LoS	-3.94 (4.54)	28.21 (9.43)	0.05 (0.82)	1.69 (1.45)	0.82 (0.76)	1.90 (1.00)	1.47 (0.76)
7	LoS	-48.03 (4.41)	24.51 (10.7)	-2.18 (0.72)	0.22 (1.54)	1.51 (0.84)	-0.06 (1.1)	0.01 (0.83)
25	LoS	3.11 (3.73)	31.21 (9.31)	-0.04 (0.92)	1.82 (1.41)	0.74 (0.74)	1.85 (0.94)	1.64 (0.73)
26	LoS	6.36 (4.28)	32.03 (9.00)	-1.50 (0.89)	0.07 (1.37)	-1.22 (0.71)	0.13 (0.88)	-0.17 (0.70)
27	LoS	4.43 (2.98)	44.66 (9.3)	-0.77 (0.93)	1.07 (1.38)	0.33 (0.71)	0.97 (0.88)	1.25 (0.71)
28	LoS	-1.27 (1.23)	58.31 (10.6)	-0.41 (0.92)	1.19 (1.39)	0.51 (0.69)	1.16 (0.85)	1.67 (0.68)
29	LoS	0.19 (0.65)	60.05 (12.5)	-1.00 (0.93)	0.55 (1.41)	-0.38 (0.65)	0.63 (0.84)	-0.40 (0.65)
32	LoS	-0.00 (0.74)	62.14 (13.1)	-0.99 (0.93)	0.78 (1.40)	-0.29 (0.64)	0.79 (0.84)	-0.28 (0.64)
34	LoS	-0.80 (2.4)	62.13 (15.3)	0.16 (0.93)	2.09 (1.44)	0.59 (0.66)	1.91 (0.90)	0.61 (0.65)

^aGPS velocity component(s) and estimated 1 σ uncertainties (in brackets) in m/y.

^bDifference between SAR and GPS velocity component(s) in m/y and SAR quality parameters (in brackets).

^cQuality parameter is per-pixel error standard deviation in m/y.

^dQuality parameter is interferometric SAR coherence.

Table S3. Task 2 validation results

Station	Component	GPS ^a	SAR – GPS ^b			
			G1 ^c	G2 ^c	G3 ^c	G4
3	Azimuth	-5.5 (0.47)	22.37	33.53 (5.4)	33.25 (3.8)	6.08 (9.9)
6	Azimuth	-112.2 (11.4)	-	-6.92 (5.4)	4.38 (3.6)	9.18 (8.2)
7	Azimuth	-164.1 (6.8)	4.39	17.48 (6.1)	2.40 (3.9)	5.55 (15.8)
25	Azimuth	-82.8 (12.8)	-10.88	-24.85 (5.4)	-26.86 (3.4)	-20.87 (7.6)
26	Azimuth	-30.8 (16.9)	8.16	30.62 (4.4)	19.37 (3.2)	12.61 (12.0)
27	Azimuth	-9.2 (13.3)	19.46	41.71 (5.0)	33.14 (3.2)	10.45 (6.8)
28	Azimuth	-0.47 (3.56)	-15.76	-13.18 (4.00)	-8.79 (2.7)	-1.44 (6.2)
29	Azimuth	-0.88 (0.65)	-3.96	-7.83 (4.8)	-7.06 (3.0)	0.82 (7.1)
32	Azimuth	-0.88 (0.1)	4.97	9.23 (3.9)	5.18 (2.8)	1.61 (5.1)
34	Azimuth	-1.35 (2.7)	16.82	13.97 (5.0)	6.99 (3.3)	-4.23 (7.2)

^aGPS velocity component(s) and estimated 1 σ uncertainties (in brackets) in m/y.

^bDifference between SAR and GPS velocity component(s) in m/y and SAR quality parameters (in brackets).

^cQuality parameter is per-pixel error standard deviation in m/y.

Table S4. Task 3 validation results

Station	Component	GPS ^a		SAR – GPS ^b				
			G1 ^c	G2	G3 ^d	G4 ^e	G5 ^d	G6 ^e
UPE 2	LoS	254 (4.3)	-85 (102)	-32	-	-	-9.9 (0.19)	-3.2 (13.4)
	Azimuth	501 (0.03)	-191 (191)	88.5	-	-	7.9 (0.19)	-6.7 (35.7)
UPE 3	LoS	176 (4.0)	-	-	-	-144 (5.1)	-37 (0.20)	-
	Azimuth	271 (0.03)	-	-	-	229.4 (5.1)	16.9 (0.20)	-
UPE 4	LoS	82 (3.9)	-	-	-	-	254 (0.07)	-
	Azimuth	180 (0.03)	-	-	-	-	48.4 (0.07)	-
UPE_U	LoS	77 (9.3)	-9.15 (11)	-	-	-	-	-
	Azimuth	19 (0.07)	13.6 (12.4)	-	-	-	-	-
UPE_L	LoS	-9.9 (9.2)	-12.3 (13.2)	-	-5.5 (0.18)	-	-	5.2 (37.2)
	Azimuth	-6.5 (0.07)	7.6 (97.2)	-	-67 (0.18)	-	67.4 (0.1)	102.6 (90.5)
UPF1	LoS	2629 (0.1)	-	-	-	-	-5445 (0.2)	-
	Azimuth	-2025 (0.07)	-	-	-	-	1757 (0.2)	-
UPF2	LoS	37.1 (0.1)	-37.7 (15)	-	-47.3 (0.62)	-20.3 (10.5)	-	-37.2 (37.6)
	Azimuth	187 (0.07)	-34.9 (108)	-	-203.5 (0.62)	34.5 (10.5)	-192.4 (0.6)	-31.9 (175.1)
UPF3	LoS	801 (0.15)	42.7 (37.6)	27.4	-	-	66.6 (0.13)	60.2 (34.9)
	Azimuth	965 (0.11)	37.2 (68.2)	-16.8	-	-	-22.4 (0.13)	38.0 (58.7)
UPM1	LoS	1519 (0.15)	-	-	-	-	-2201 (0.07)	-
	Azimuth	-2177 (0.11)	-	-	-	-	3035 (0.07)	-
UPM2	LoS	645 (0.11)	3 (25.6)	0.0	5.8 (0.15)	4 (14.5)	9.4 (0.16)	8.8 (23.8)
	Azimuth	724 (0.07)	-49.2 (17.3)	-125	-25.2 (0.15)	-48.2 (14.5)	-49 (0.16)	-41.9 (30.0)
UPM3	LoS	347 (0.13)	-27.9 (48.8)	-34.7	-	-11.2 (7.6)	-21.3 (0.2)	-12.8 (37.7)
	Azimuth	646 (0.1)	-62.6 (137)	-6	-	-25 (7.6)	-16.8 (0.2)	-21.5 (105.2)

^aGPS velocity component(s) and estimated 1 σ uncertainties (in brackets) in m/y.

^bDifference between SAR and GPS velocity component(s) in m/y and SAR quality parameters (in brackets).

^cQuality parameter is per-pixel error standard deviation in m/y.

^dQuality parameter is normalized cross-correlation (common for LoS and azimuth).

^eQuality parameter is cross-correlation peak Signal to Noise Ratio (common for LoS and azimuth).

Table S5. Task 4 validation results

Station	Component	GPS ^a	SAR – GPS ^b							
			G1 ^c	G2	G3	G4 ^d	G5 ^e	G6 ^c	G7 ^c	G8 ^c
AVA1	LoS	228 (1.3)	-	-1.9	-16.1	-	-14.1 (0.28)	-	34.4	-
	Azimuth	-358 (0.01)	-	42.1	-23.7	-	24.0 (0.28)	-	2.6	-
RNK2	LoS	809 (1.6)	33.1 (51.7)	14.4	7.0	-9.8 (8.2)	29.2 (0.31)	27.8 (66.7)	50.7	24.6 (20.3)
	Azimuth	698 (0.02)	22.7 (17.3)	-15.1	12.1	-10.6 (8.2)	13.6 (0.31)	20.2 (22.6)	17.9	32.8 (7.8)
STO4	LoS	418 (1.6)	-39.6 (11.8)	-32.1	-21.8	-	-32.8 (0.16)	-	-7.1	-19.8 (7.1)
	Azimuth	-720 (0.02)	-65.0 (22.5)	-5.37	-38.5	-	-32.3 (0.16)	-	-29.3	-49.6 (24.5)

^aGPS velocity component(s) and estimated 1 σ uncertainties (in brackets) in m/y.

^bDifference between SAR and GPS velocity component(s) in m/y and SAR quality parameters (in brackets).

^cQuality parameter is per-pixel error standard deviation in m/y.

^dQuality parameter is cross-correlation peak Signal-to-Noise-Ratio (common for LoS and azimuth).

^eQuality parameter is normalized cross-correlation (common for LoS and azimuth).

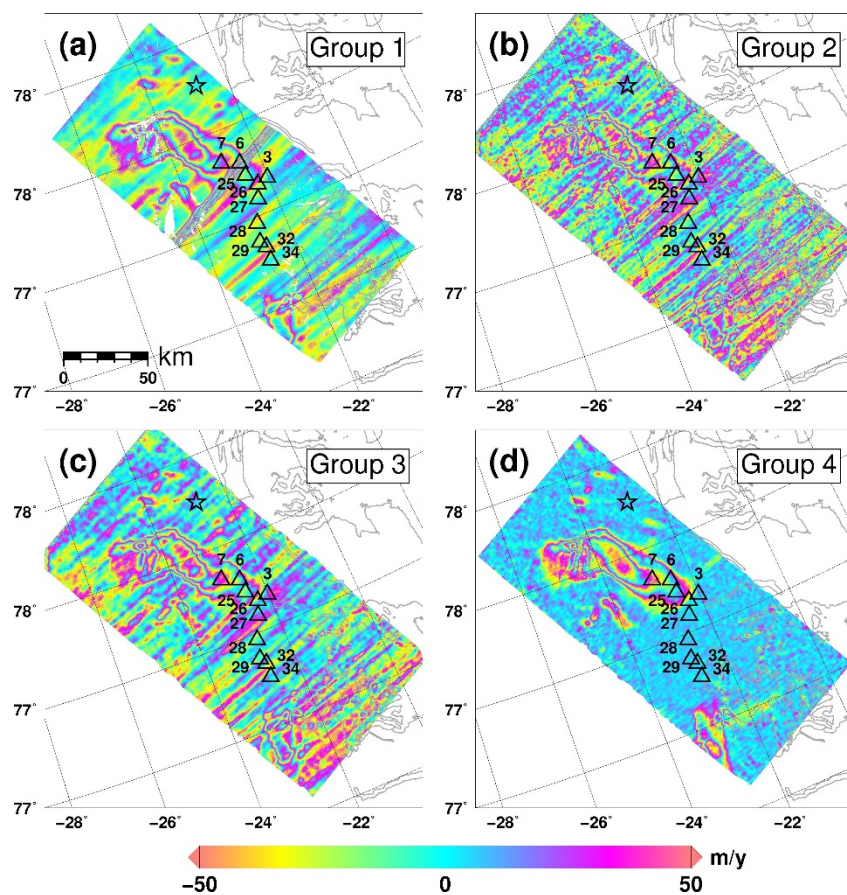


Figure S1. Task 2 wrapped azimuth velocity maps provided by groups 1 to 4. Each color cycle represents a 100 m/y variation. Velocities are referred to the star (zero velocity).

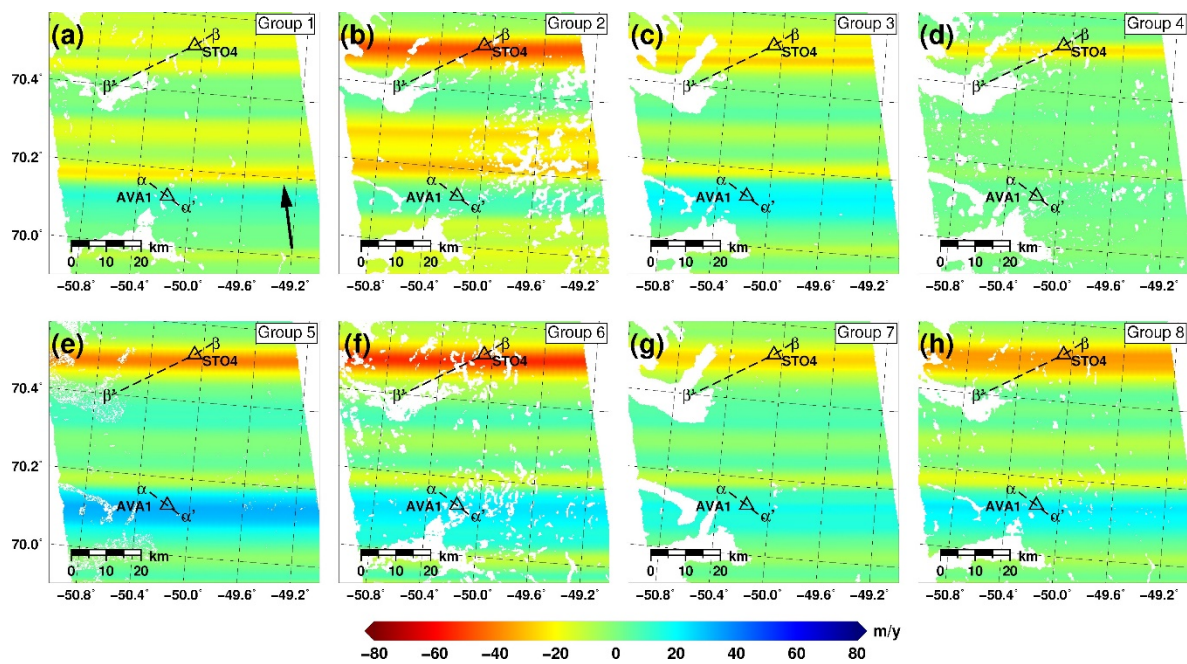


Figure S2. Task 4 estimated azimuth velocity ionospheric propagation errors for groups 1 to 8.

Table S6. Task 4 estimated azimuth ionospheric errors at GPS locations (m/y)

Station	Group							
	G1	G2	G3	G4	G5	G6	G7	G8
AVA1	-	7.7	19.9	-	30.7	-	16.4	-
RNK2	4.9	-3.8	4.1	-0.03	4.4	3.9	2.0	2.8
STO4	-17.7	-43.4	-23.1	-	-30.9	-	-23.7	-35.4