Mapping the low-tide coastline of Iceland using Sentinel-1 amplitude images

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Abstract

Having a precise map of the low-tide coastline of Iceland is important. Specific icelandic laws refer to this line. It is also a valuable information for marine and environment institutions. Mapping the low-tide coastline is challenging because of its extent. Fields surveys and aerial surveys would take a long time to cover the entire coastline and would therefore be very expensive. Here, we explore the possibility of using the remote sensing dataset provided by the Sentinel-1 Copernicus SAR mission. Its offers two main advantages compared to previous SAR satellite missions: repeat acquisitions (every 6 or 12 days) and free and open data. The concept is that as images are acquired at the exact same time every 6/12 days and the tides are shifting with time, there should be images acquired during low tide. This study confirms this and shows it is possible to map the low-tide coastline this way. However, spring tides were not observed with this method, meaning the mapped low-tide coastline is not the absolute low-tide coastline. Also, the coastline is not well resolved on sand or mud flats.

1 SAR images

For this study, Sentinel-1A and Sentinel-1B SAR images were used because of data availability. Sentinel-1 images are automatically acquired every 12 days since early 2015 and 6 days since early 2017 and they are freely accessible for everyone. The main mode of acquisition "Interferometric Wide" (IW) provides coverage over a 250-km wide swath. The swath is divided in three subswaths, each covering about 80 km. The level-1 Single Look Complex (SLC) images provided by Copernicus are used in order to obtain the highest resolution possible. For IW SLC images, a pixel is about 4 in range (approximately EW) and 14 meter in azimuth (approximately NS).

SLC SAR images contains two information: the amplitude of the reflected signal and its phase. Only the amplitude is used in this study. The SAR signal is always sent with an angle from vertical. This means that a smooth surface (like water) will tend to reflect all the signal away from the satellite while rough surfaces (like ground) will tend to reflect part of the signal back to the satellite. This property is therefore used to distinguish the water areas from the ground areas and map the coastline.

2 Tides

Tides were calculated using the global tide model FES2014 and a modified C program. The program calculates tide for a given location, date, and time. It was therefore possible to calculate the tides at the exact acquisition time of each SAR image, allowing to select images acquired during the lowest tides. Tides were also calculated every 30 min to find the lowest and highest tides during the period of acquisition of Sentinel-1 images (early 2015 - august 2019). These information are indicated in the tables for each area in the Areas section. The location for tide calculation was arbitrarily chosen within the area as long as it is relatively close to the coast.

3 Processing

Tides do not have the same amplitude or timing around Iceland. Therefore, each SAR image was cropped by subswath and along the North-South direction into areas considered to have similar tides.

3.1 For each areas

Sentinel-1 SLC IW images were processed using the InSAR Scientific Computing Environment (ISCE) software and the topsStack contribution program. It takes a series of SLC images and put them in the exact same geometry. Next, the following procedure was used: i) Amplitude images are extracted for each SLC within the stack. ii) A median stacking of these amplitudes images is done using the Ames Stereo Pipeline (ASP) software. iii) The resulting amplitude image is filtered using a 7 pixels by 7 pixels median filter to reduce noise. iv) A threshold value is determined to separate land from water and then used to create a binary mask (land=1, water=0)

3.2 Final mosaicking

ASP was used to merge the binary masks from all areas into one binary mask covering the whole Iceland. Because shadows caused by topography look like inland water, pixels within current high-tide coastline mapped by Landmælingar Íslands were set to 1. The mask was converted with Quantum GIS to a vector file showing the low-tide coastline.

4 Results quality assessment

Landmælingar Íslands have high-resolution aerial images acquired during low-tide over Breiðarfjörður. Figure 1 shows the comparison between these aerial images and the low-tide coastline. There is a very good agreement between the two datasets, the low-tide coastline covers most of the exposed rock seen on the aerial images. Areas not covered by the low-tide coastline were likely only exposed during spring tides, which the SAR acquisitions missed. Also, small isolated rocks are missing because of the limited resolution of the SAR images and the median filtering that was applied to them.

Another issue the low-tide coastline is shown on Figure 2. It appears that if the topography is very large at the coast (e.g. cliffs), the SAR amplitude of the topography is projected onto the sea during geocoding. This issue appear mostly in the East fjörds and need to be manually corrected.

Figure 1: **(Left)** Aerial IR images acquired at low tide in 2008 in Breiðarfjörður, superimposed with the IS50v high-tide coastline (orange area). Coordinate system: ISN93. **(Right)** Same as the Left panel but with the low-tide coastline added (green area).

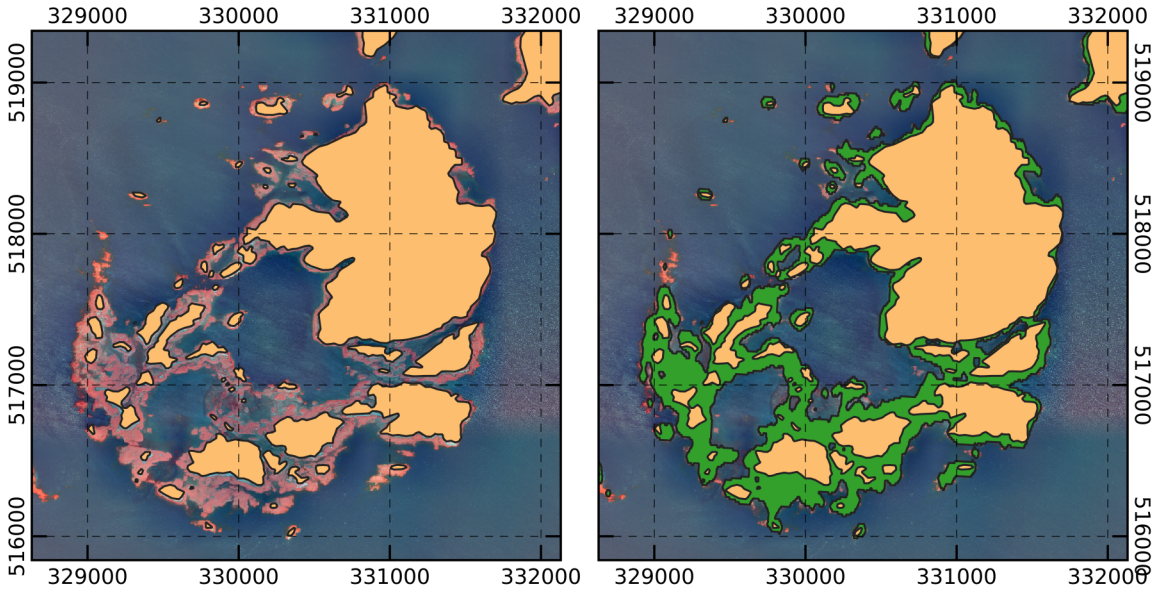
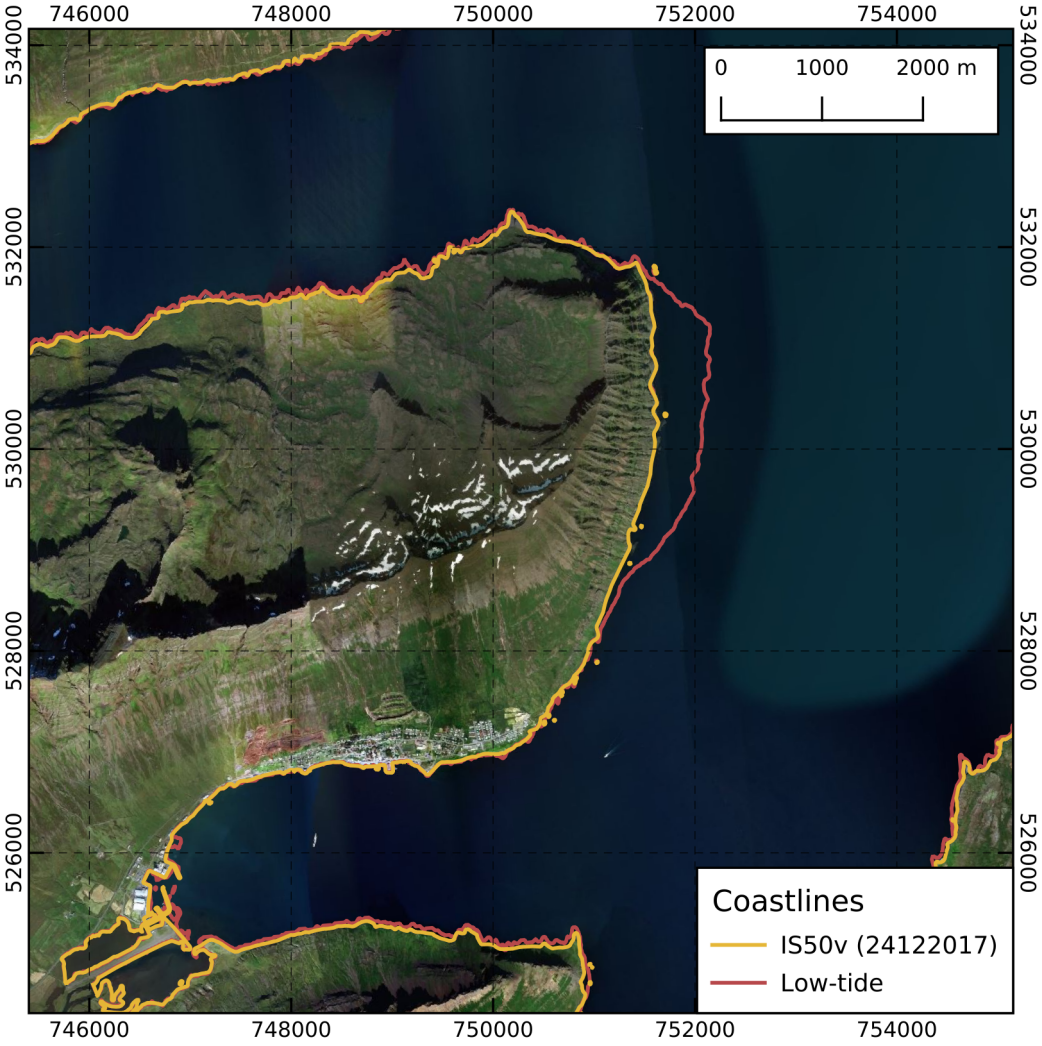


Figure 2: Example of low-tide coastline miscalculation caused by strong topography, near Neskaupstaður. Background shows Bing maps©.



5 Areas

(see following pages)

T111 IW1 Mid

Figure 3: Coverage of T111 IW1 Mid. The red circle indicates the point at which tides were calculated.

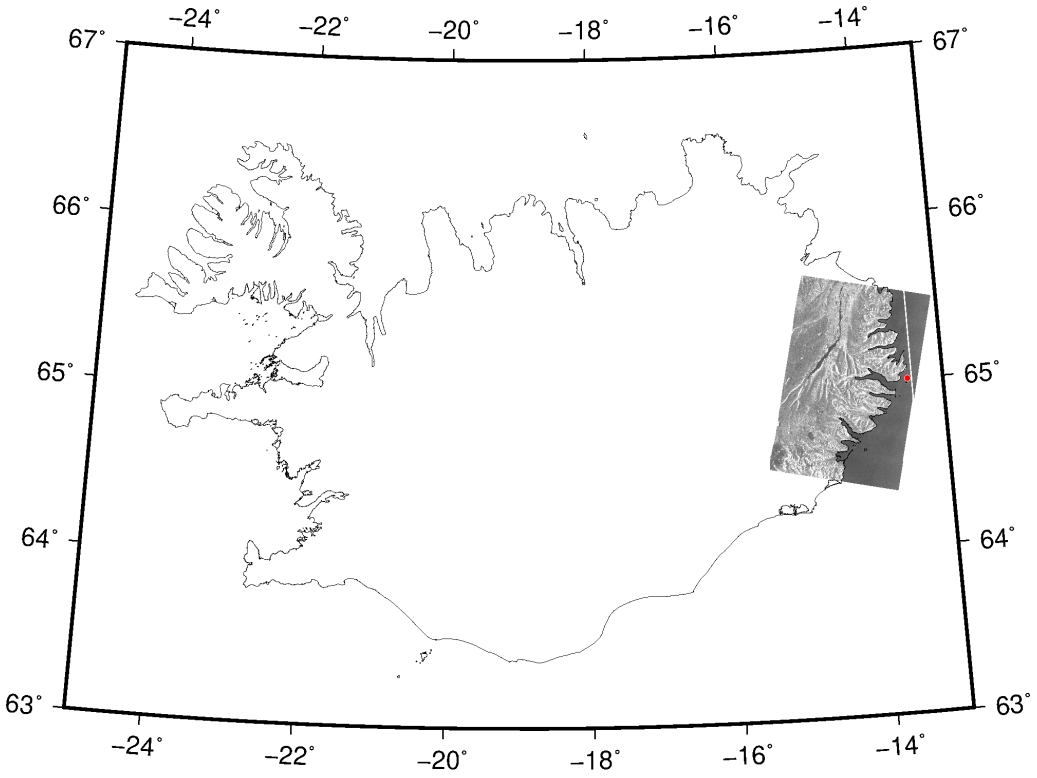


Table 1: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 3. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-103	94
At acquisition time	-82	55

Date	Tide [cm]	Used
2018-09-10	-82	x
2018-08-11	-82	x
2017-07-23	-80	x
2016-06-04	-77	x
2015-11-25	-77	x
2017-06-23	-75	x
2017-08-22	-75	x
2016-12-13	-73	x
2018-07-12	-71	x
2017-12-02	-68	x
2016-08-03	-68	x
2015-09-26	-68	x
average(used)	-75	

T111 IW1 North

Figure 4: Coverage of T111 IW1 North. The red circle indicates the point at which tides were calculated.

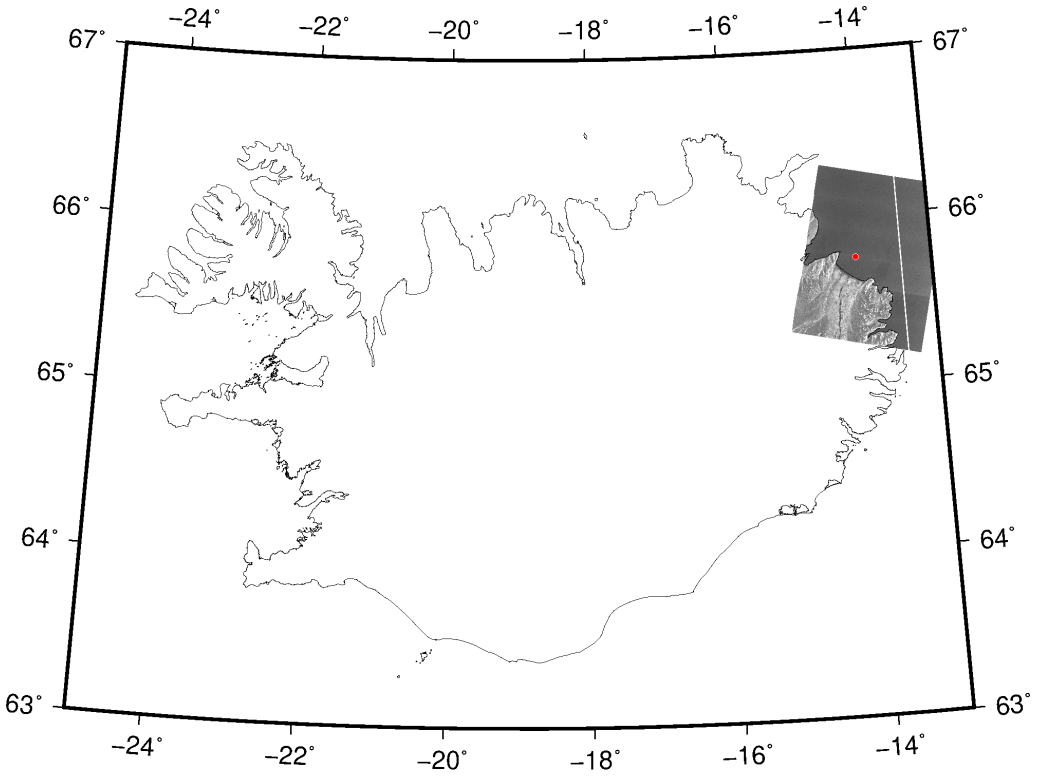


Table 2: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 4. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-89	77
At acquisition time	-78	35

Date	Tide [cm]	Used
2018-09-10	-78	x
2018-10-10	-75	x
2017-08-22	-73	x
2015-07-04	-72	x
2019-04-20	-72	x
2017-09-21	-72	x
2019-05-20	-71	x
2016-07-22	-68	x
2018-04-01	-66	x
2018-05-01	-66	x
2017-09-09	-66	x
2017-03-31	-66	x
average(used)	-70	

T111 IW1 South

Figure 5: Coverage of T111 IW1 South. The red circle indicates the point at which tides were calculated.

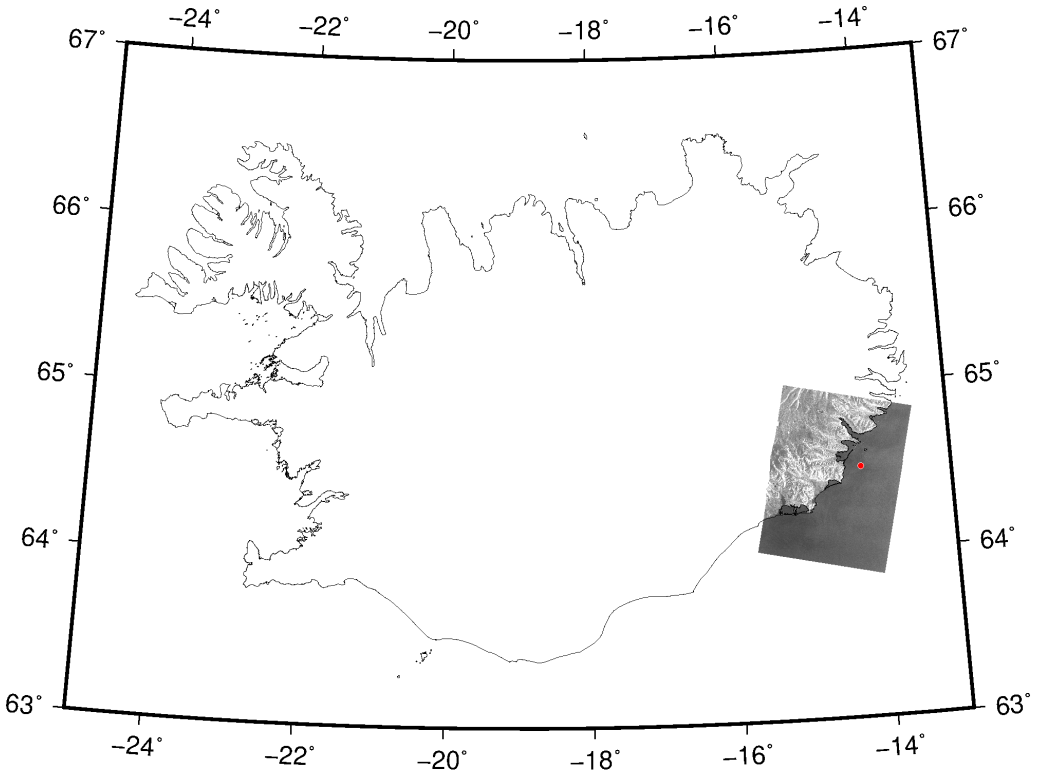


Table 3: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 5. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-126	122
At acquisition time	-82	97

Date	Tide [cm]	Used
2015-09-26	-82	x
2016-10-14	-78	x
2016-06-04	-71	x
2017-06-23	-71	x
2018-06-12	-70	x
2017-11-02	-70	x
2016-04-05	-69	x
2017-04-24	-68	
2017-12-02	-68	x
2018-07-12	-66	x
2018-05-13	-64	x
2017-10-03	-62	x
average(used)	-70	

T111 IW2 North

Figure 6: Coverage of T111 IW2 North. The red circle indicates the point at which tides were calculated.

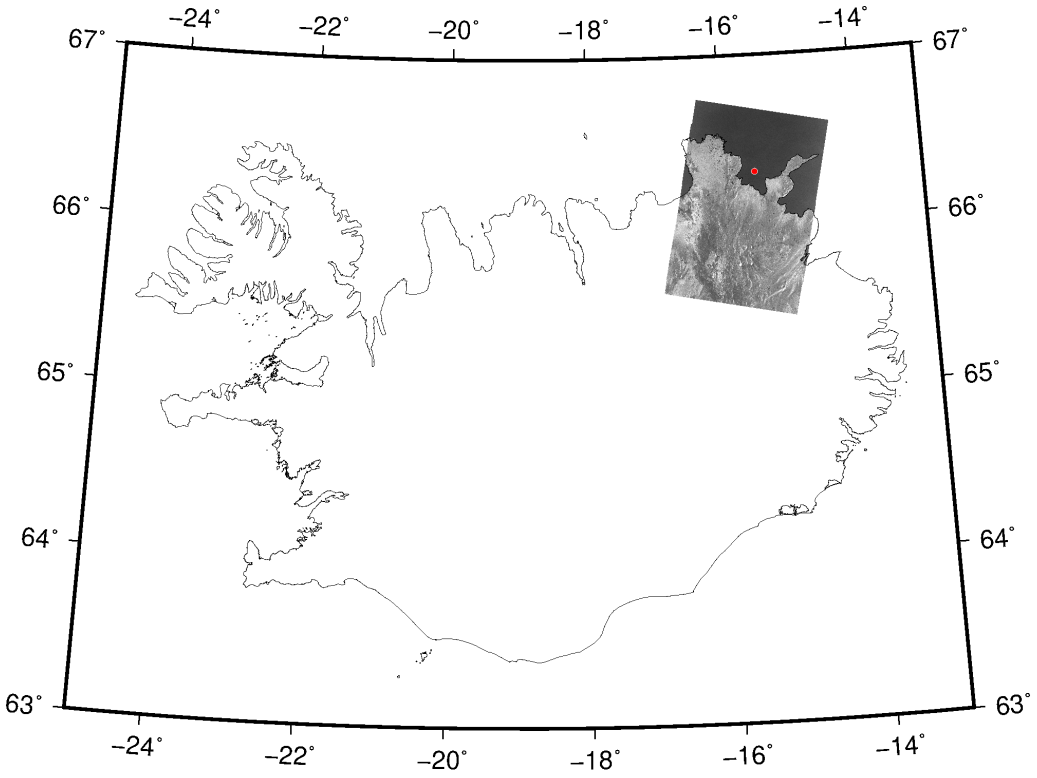


Table 4: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 6. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-92	78
At acquisition time	-81	40

Date	Tide [cm]	Used
2015-09-02	-81	x
2016-03-12	-80	x
2017-03-31	-79	x
2016-09-20	-77	x
2018-04-19	-74	x
2017-09-09	-74	x
2015-07-04	-73	x
2018-05-19	-71	x
2016-07-22	-70	x
2017-10-09	-69	
2018-03-20	-67	x
2017-08-10	-67	x
average(used)	-74	

T111 IW2 South

Figure 7: Coverage of T111 IW2 South. The red circle indicates the point at which tides were calculated.

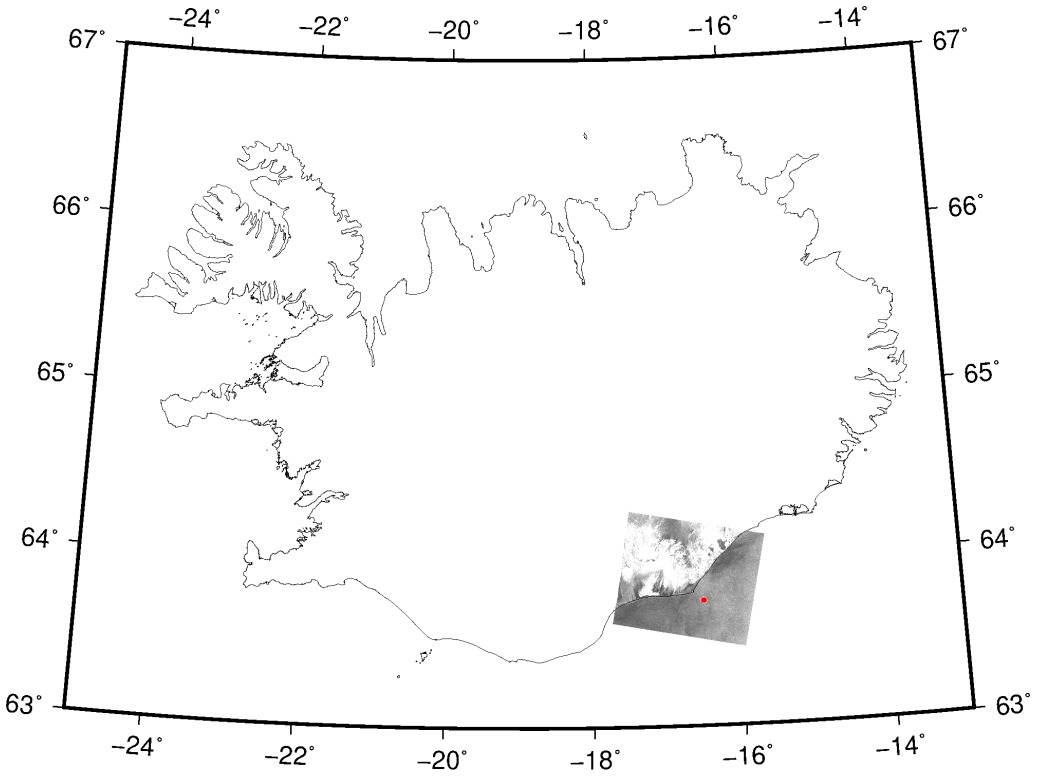


Table 5: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 7. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-144	143
At acquisition time	-78	124

Date	Tide [cm]	Used
2019-06-13	-78	x
2019-05-14	-71	x
2018-05-25	-70	
2018-11-03	-65	x
2019-07-13	-64	x
2018-04-25	-64	
2018-12-03	-63	x
2017-10-15	-62	
2018-06-24	-62	x
2017-05-06	-60	
2017-11-14	-60	
2015-08-09	-57	
average(used)	-67	

T155 IW1 Hvalfjörður

Figure 8: Coverage of T155 IW1 Hvalfjörður. The red circle indicates the point at which tides were calculated.

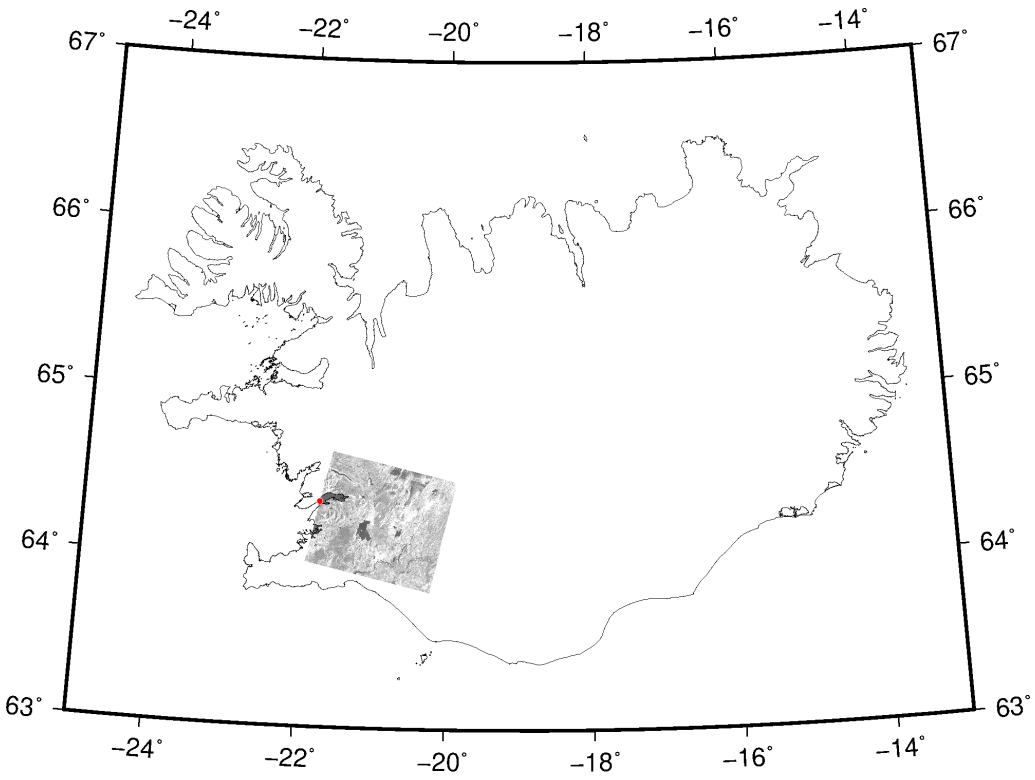


Table 6: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 8. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-244	231
At acquisition time	-113	224

Date	Tide [cm]	Used
2017-06-20	-113	x
2018-06-21	-107	x
2019-07-10	-105	x
2018-07-21	-102	x
2016-05-02	-101	
2015-04-14	-100	
2018-07-09	-100	x
2019-08-09	-99	x
2017-05-21	-98	x
2017-06-02	-98	x
2017-07-02	-97	x
2015-10-23	-94	x
average(used)	-101	

T155 IW1 North

Figure 9: Coverage of T155 IW1 North. The red circle indicates the point at which tides were calculated.

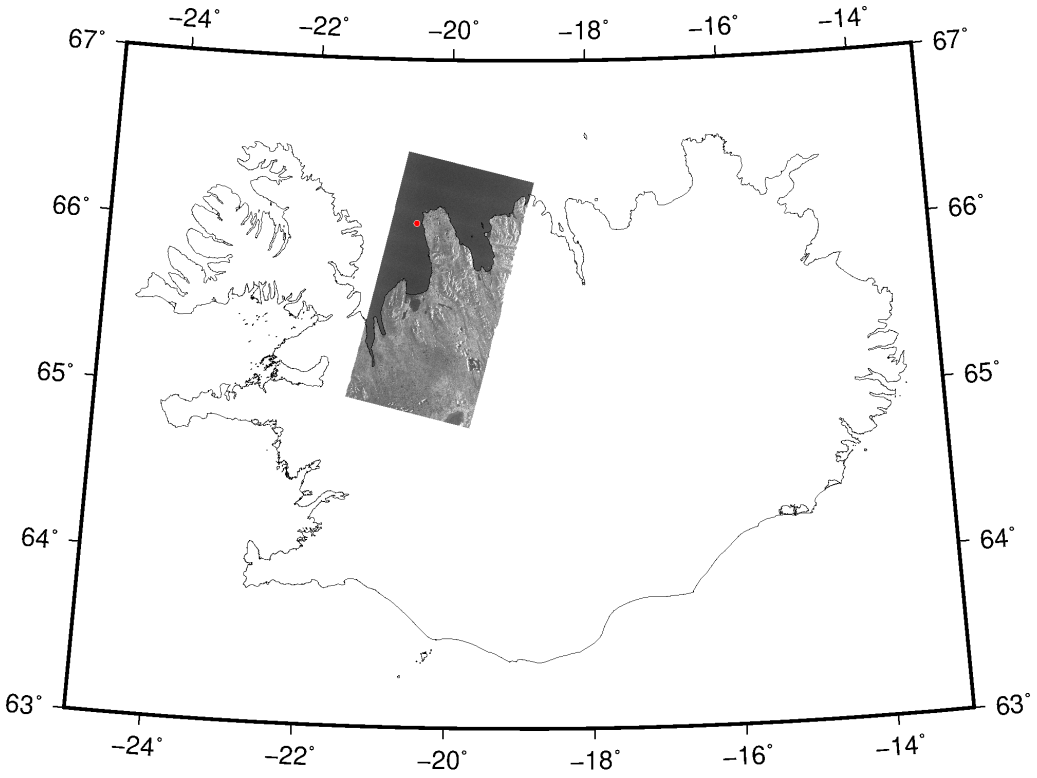


Table 7: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 9. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-94	83
At acquisition time	-74	56

Date	Tide [cm]	Used
2015-07-07	-74	x
2016-07-25	-72	x
2017-08-13	-66	x
2018-03-23	-61	x
2017-07-14	-59	x
2017-02-02	-59	
2016-01-15	-59	
2018-08-14	-59	x
2017-09-12	-58	x
2018-02-21	-58	
2018-09-01	-58	
2018-08-02	-57	
average(used)	-64	

T155 IW1 South

Figure 10: Coverage of T155 IW1 South. The red circle indicates the point at which tides were calculated.

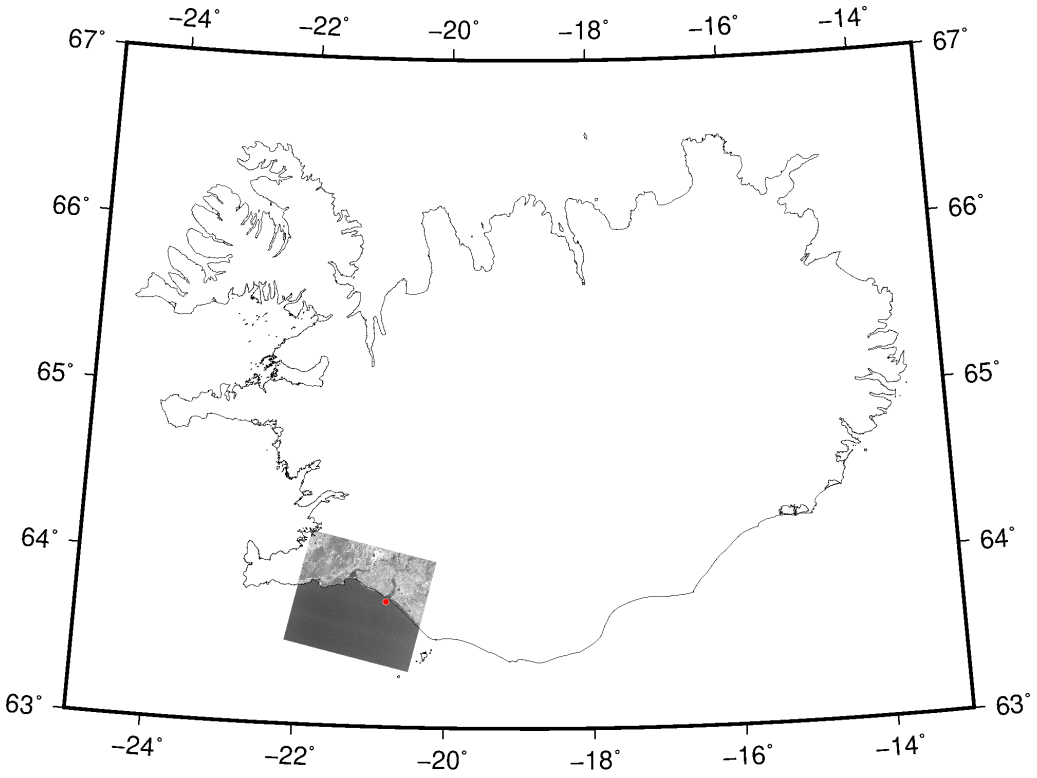


Table 8: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 10. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-182	181
At acquisition time	-99	175

Date	Tide [cm]	Used
2017-06-20	-99	x
2016-07-01	-97	x
2017-07-20	-95	x
2015-06-13	-94	x
2018-07-09	-90	x
2018-08-08	-86	x
2016-05-02	-83	
2017-05-21	-83	x
2015-04-14	-82	
2018-06-09	-80	x
2015-12-22	-80	
2015-10-23	-80	x
average(used)	-89	

T155 IW2 Breiðafjörður

Figure 11: Coverage of T155 IW2 Breiðafjörður. The red circle indicates the point at which tides were calculated.

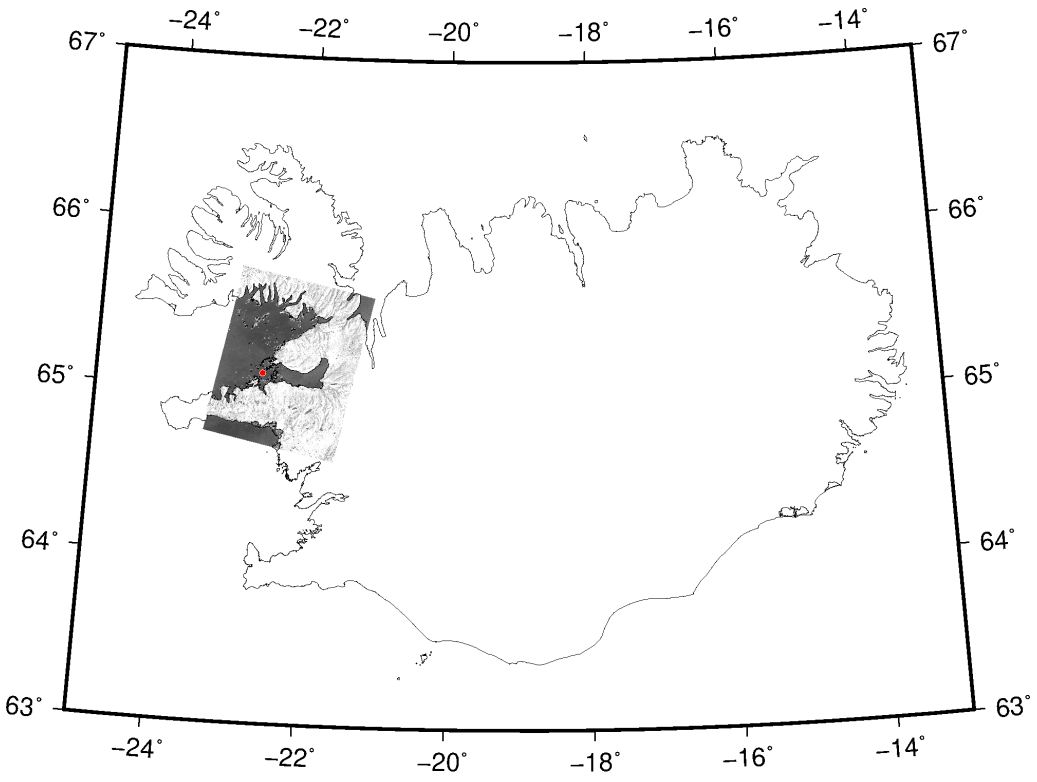


Table 9: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 11. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-297	250
At acquisition time	-128	240

Date	Tide [cm]	Used
2019-07-10	-128	x
2018-06-21	-125	x
2017-06-20	-113	x
2017-06-02	-112	x
2018-07-21	-107	x
2016-05-02	-106	
2019-08-09	-105	x
2017-05-21	-104	x
2018-07-09	-104	x
2015-04-14	-101	
2017-07-02	-101	x
2019-06-10	-100	x
average(used)	-110	

T155 IW2 Faxaflói

Figure 12: Coverage of T155 IW2 Faxaflói. The red circle indicates the point at which tides were calculated.

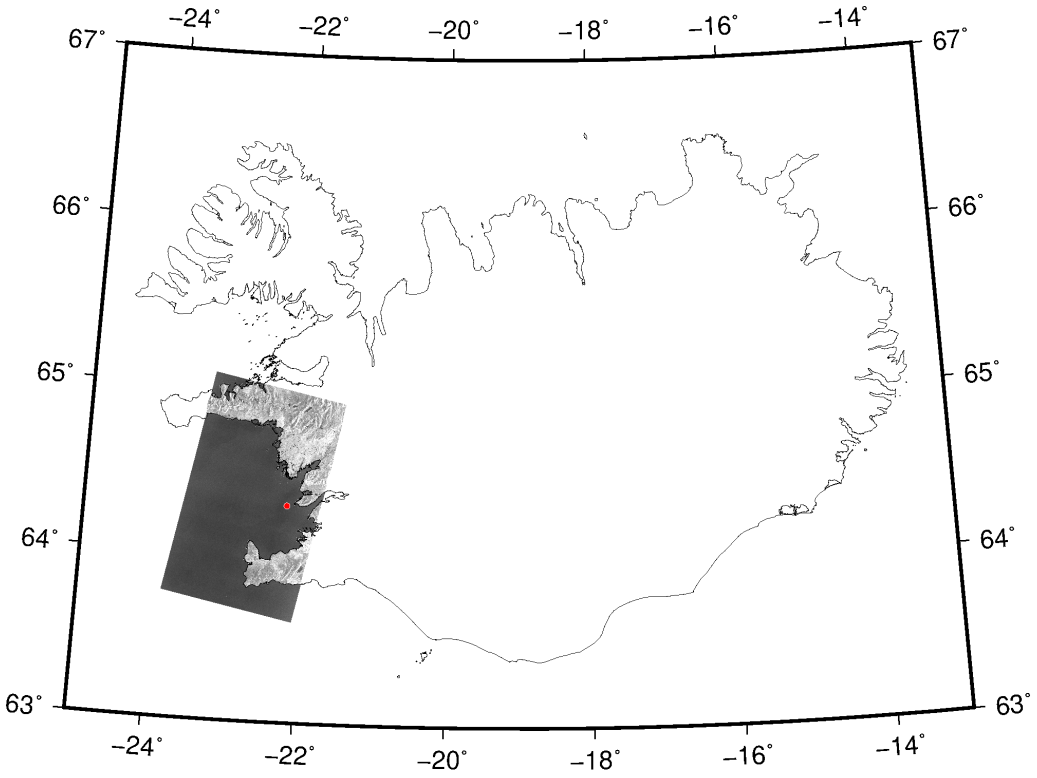


Table 10: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 12. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-238	227
At acquisition time	-111	221

Date	Tide [cm]	Used
2017-06-20	-111	x
2018-06-21	-105	x
2019-07-10	-103	x
2016-05-02	-100	
2018-07-21	-100	x
2018-07-09	-99	x
2015-04-14	-99	
2017-05-21	-97	x
2019-08-09	-96	x
2017-06-02	-96	x
2017-07-02	-95	x
2015-10-23	-93	x
average(used)	-100	

T155 IW2 North

Figure 13: Coverage of T155 IW2 North. The red circle indicates the point at which tides were calculated.

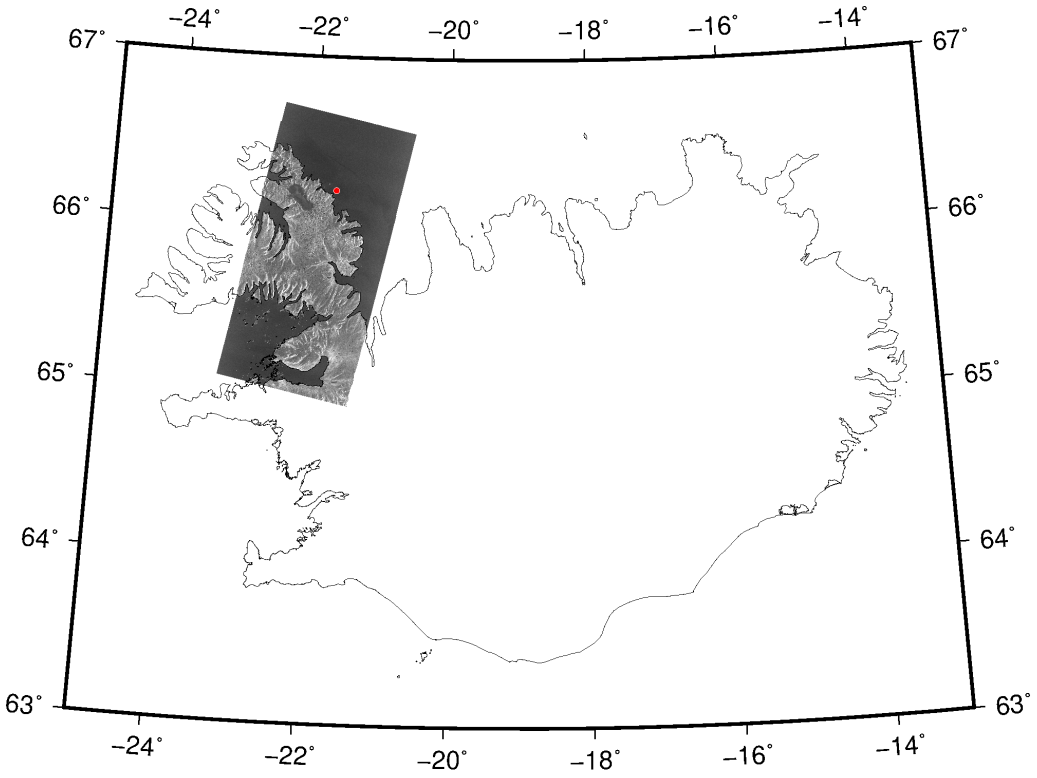


Table 11: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 13. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-97	86
At acquisition time	-75	59

Date	Tide [cm]	Used
2015-07-07	-75	x
2016-07-25	-71	x
2017-08-13	-65	x
2018-03-23	-62	x
2016-01-15	-59	
2017-09-12	-59	x
2017-02-02	-59	
2017-07-14	-58	x
2018-02-21	-57	x
2018-09-01	-57	
2017-04-03	-56	x
2019-04-11	-56	x
average(used)	-62	

T155 IW3 Snæfellsnes

Figure 14: Coverage of T155 IW3 Snæfellsnes. The red circle indicates the point at which tides were calculated.

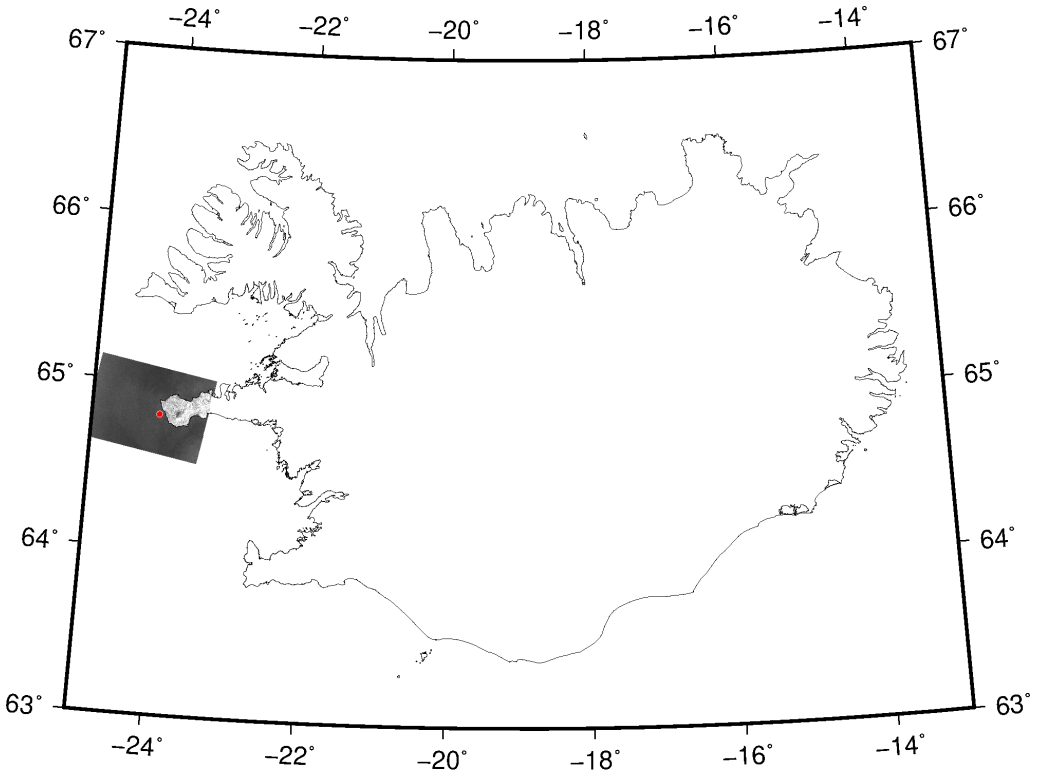


Table 12: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 14. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-224	213
At acquisition time	-107	205

Date	Tide [cm]	Used
2019-07-10	-107	x
2018-06-21	-106	x
2017-06-20	-98	
2017-06-02	-96	x
2018-07-21	-96	x
2019-08-09	-93	x
2017-07-02	-92	
2016-05-02	-89	
2018-07-09	-88	x
2017-05-21	-88	x
2015-04-14	-86	
2019-06-10	-85	x
average(used)	-95	

T155 IW3 Vestfirðir

Figure 15: Coverage of T155 IW3 Vestfirðir. The red circle indicates the point at which tides were calculated.

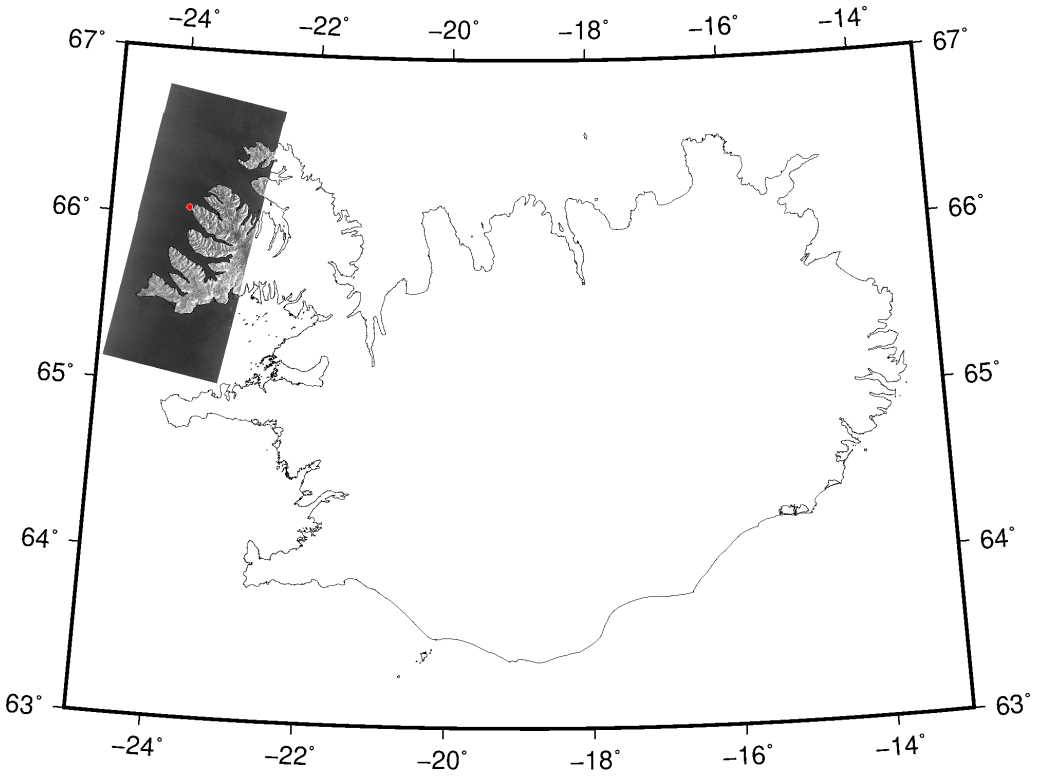


Table 13: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 15. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-163	154
At acquisition time	-88	135

Date	Tide [cm]	Used
2019-06-10	-88	x
2019-07-10	-88	x
2018-05-22	-83	x
2018-06-21	-80	x
2015-09-05	-76	
2017-04-03	-72	x
2016-03-15	-72	
2016-09-23	-71	x
2017-06-02	-70	x
2018-04-22	-69	x
2015-02-25	-68	
2015-07-07	-67	x
average(used)	-76	

T16 IW1 Breiðafjörður

Figure 16: Coverage of T16 IW1 Breiðafjörður. The red circle indicates the point at which tides were calculated.

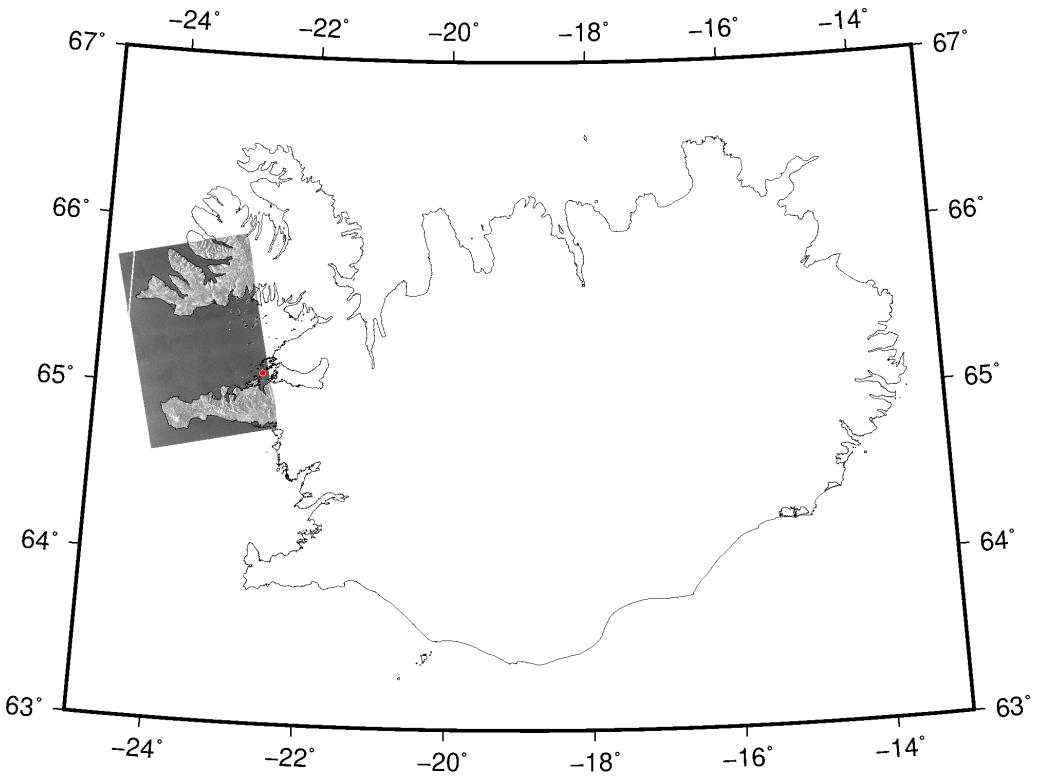


Table 14: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 16. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-296	250
At acquisition time	-141	228

Date	Tide [cm]	Used
2016-01-17	-141	x
2017-02-04	-136	x
2015-07-09	-125	x
2016-07-27	-124	x
2018-02-23	-121	x
2017-08-15	-115	x
2018-01-24	-113	x
2017-03-06	-104	x
2017-07-16	-102	x
2018-03-25	-100	x
2018-09-03	-99	x
2019-03-14	-99	x
average(used)	-115	

T16 IW1 Faxaflói

Figure 17: Coverage of T16 IW1 Faxaflói. The red circle indicates the point at which tides were calculated.

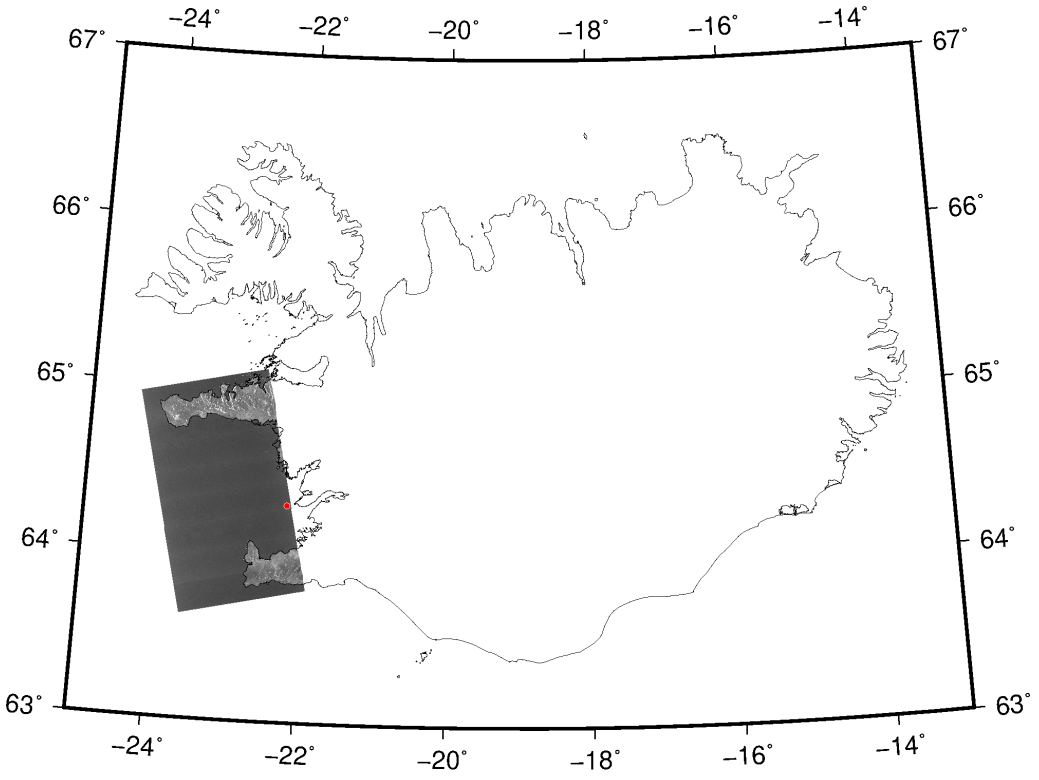


Table 15: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 17. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-237	227
At acquisition time	-117	204

Date	Tide [cm]	Used
2016-01-17	-117	
2015-07-09	-111	
2017-02-04	-106	
2016-07-27	-104	
2017-03-06	-92	
2017-08-15	-92	
2018-02-23	-89	
2017-09-14	-86	
2018-03-25	-85	
2018-01-24	-83	
2018-10-03	-81	
2019-05-13	-79	
average(used)		

T16 IW2 Breiðafjörður

Figure 18: Coverage of T16 IW2 Breiðafjörður. The red circle indicates the point at which tides were calculated.

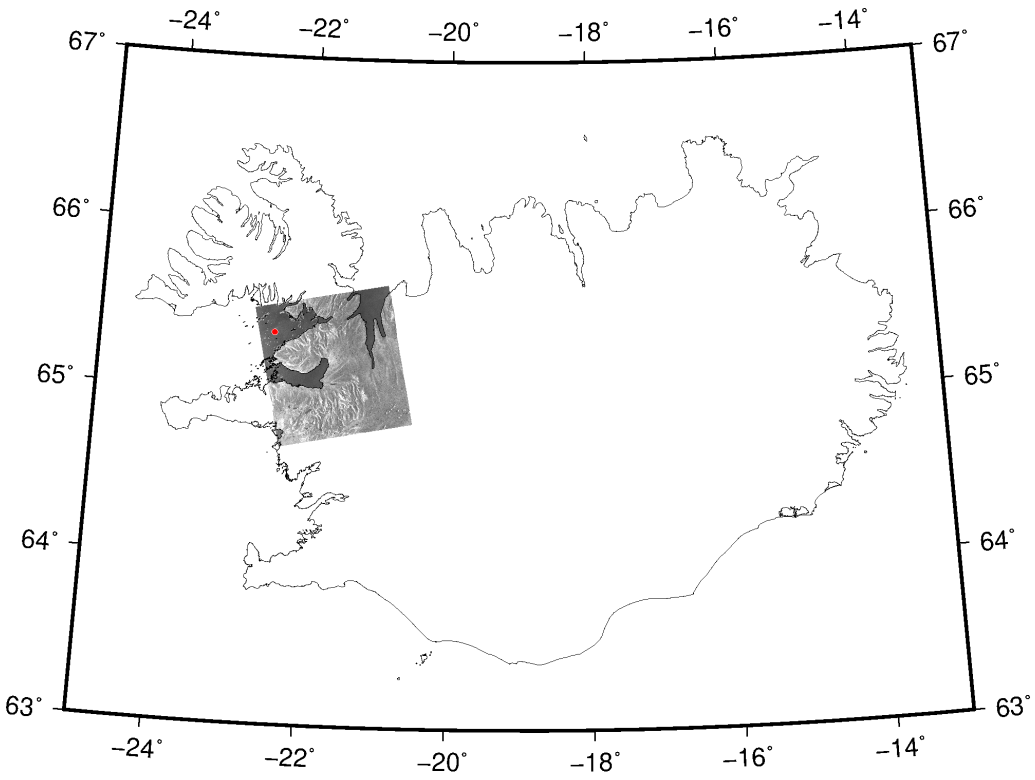


Table 16: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 18. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-303	255
At acquisition time	-147	233

Date	Tide [cm]	Used
2016-01-17	-147	x
2017-02-04	-144	x
2016-07-27	-131	x
2015-07-09	-130	x
2018-02-23	-130	x
2017-08-15	-123	x
2018-01-24	-123	x
2017-07-16	-113	x
2019-03-14	-108	x
2018-09-03	-107	x
2017-03-06	-107	x
2019-02-12	-104	x
average(used)	-122	

T16 IW2 Faxaflói

Figure 19: Coverage of T16 IW2 Faxaflói. The red circle indicates the point at which tides were calculated.

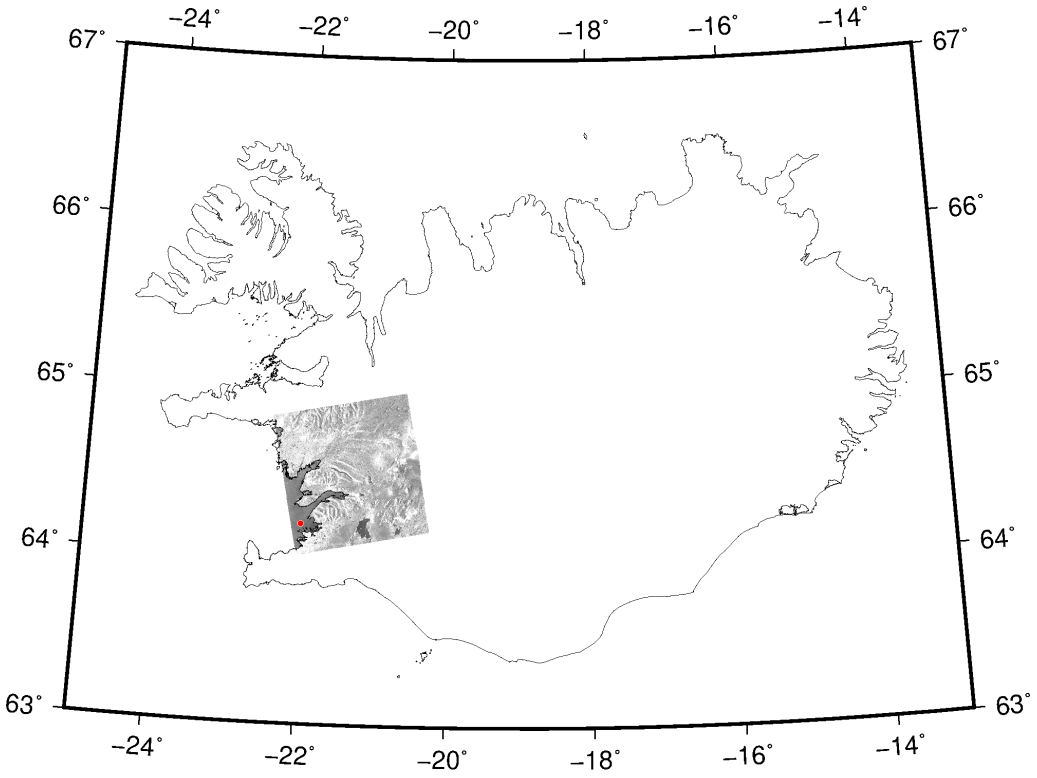


Table 17: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 19. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-239	228
At acquisition time	-118	206

Date	Tide [cm]	Used
2016-01-17	-118	x
2015-07-09	-112	x
2017-02-04	-106	x
2016-07-27	-105	x
2017-03-06	-93	x
2017-08-15	-92	x
2018-02-23	-89	x
2017-09-14	-87	x
2018-03-25	-85	x
2018-01-24	-82	x
2018-10-03	-82	x
2019-05-13	-80	x
average(used)	-94	

T9 IW1 North

Figure 20: Coverage of T9 IW1 North. The red circle indicates the point at which tides were calculated.

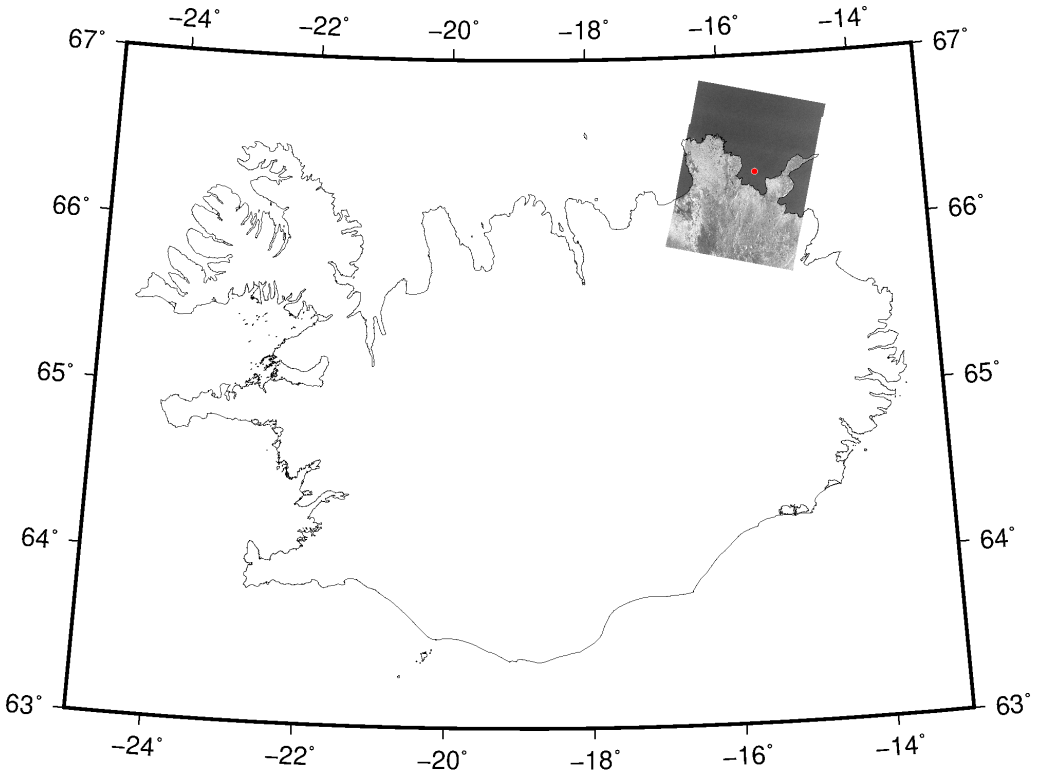


Table 18: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 20. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-92	78
At acquisition time	-86	41

Date	Tide [cm]	Used
2016-04-10	-86	
2017-04-29	-83	x
2017-05-29	-79	x
2018-06-17	-78	x
2018-05-18	-78	x
2015-10-01	-77	x
2015-08-02	-77	x
2019-07-06	-76	x
2017-03-30	-75	x
2016-08-20	-73	x
2016-10-19	-72	x
2019-08-05	-71	x
average(used)	-76	

T9 IW1 South

Figure 21: Coverage of T9 IW1 South. The red circle indicates the point at which tides were calculated.

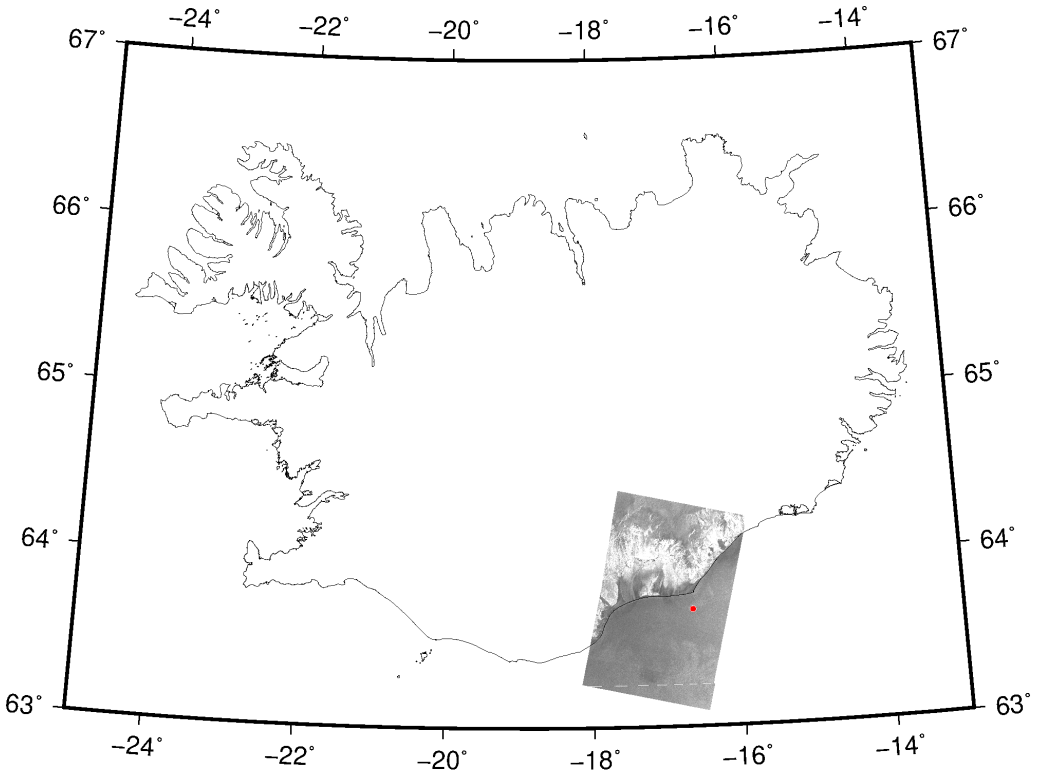


Table 19: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 21. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-144	143
At acquisition time	-73	131

Date	Tide [cm]	Used
2019-06-12	-73	x
2019-07-12	-71	x
2018-06-23	-69	x
2018-05-24	-69	x
2017-05-23	-65	x
2016-05-04	-65	x
2017-06-04	-64	x
2015-10-25	-63	x
2018-12-02	-61	x
2017-05-05	-60	x
2018-06-11	-60	x
2015-08-26	-60	x
average(used)	-65	

T9 IW2 North

Figure 22: Coverage of T9 IW2 North. The red circle indicates the point at which tides were calculated.

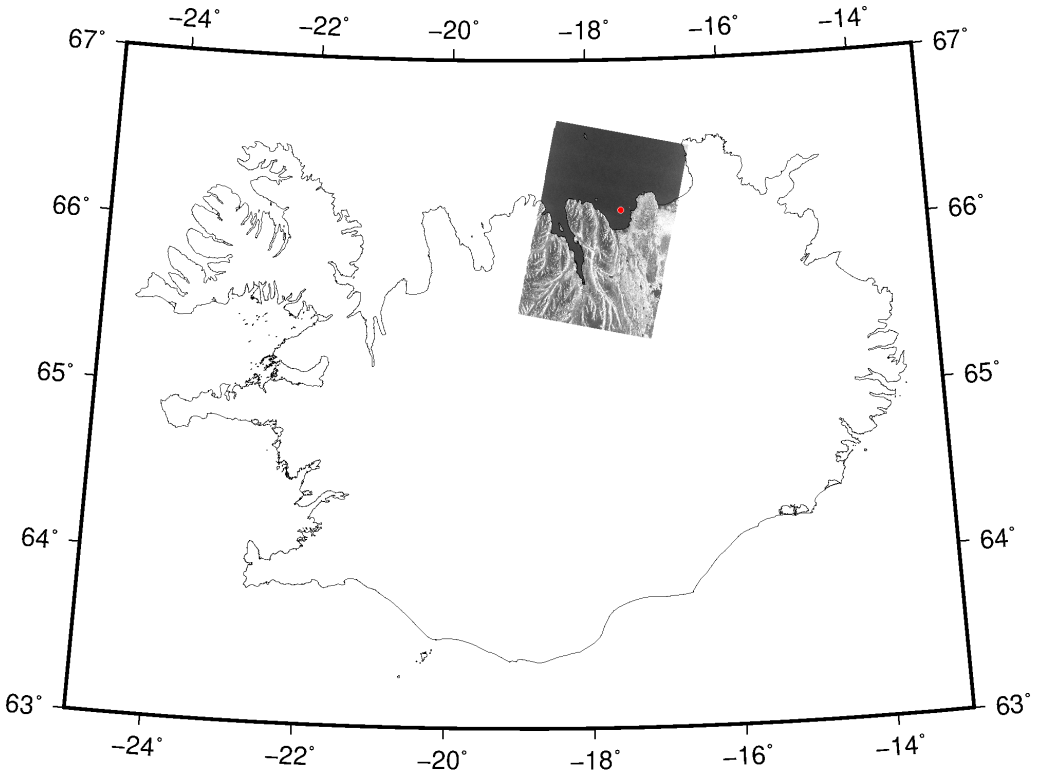


Table 20: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 22. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-87	74
At acquisition time	-77	40

Date	Tide [cm]	Used
2019-08-05	-77	x
2017-05-29	-76	x
2018-06-17	-76	x
2018-07-17	-75	x
2019-07-06	-75	x
2016-04-10	-74	
2017-04-29	-72	x
2017-06-28	-71	x
2018-05-18	-67	x
2016-06-09	-66	x
2015-10-01	-64	x
2019-06-06	-61	x
average(used)	-71	

T9 IW2 South

Figure 23: Coverage of T9 IW2 South. The red circle indicates the point at which tides were calculated.

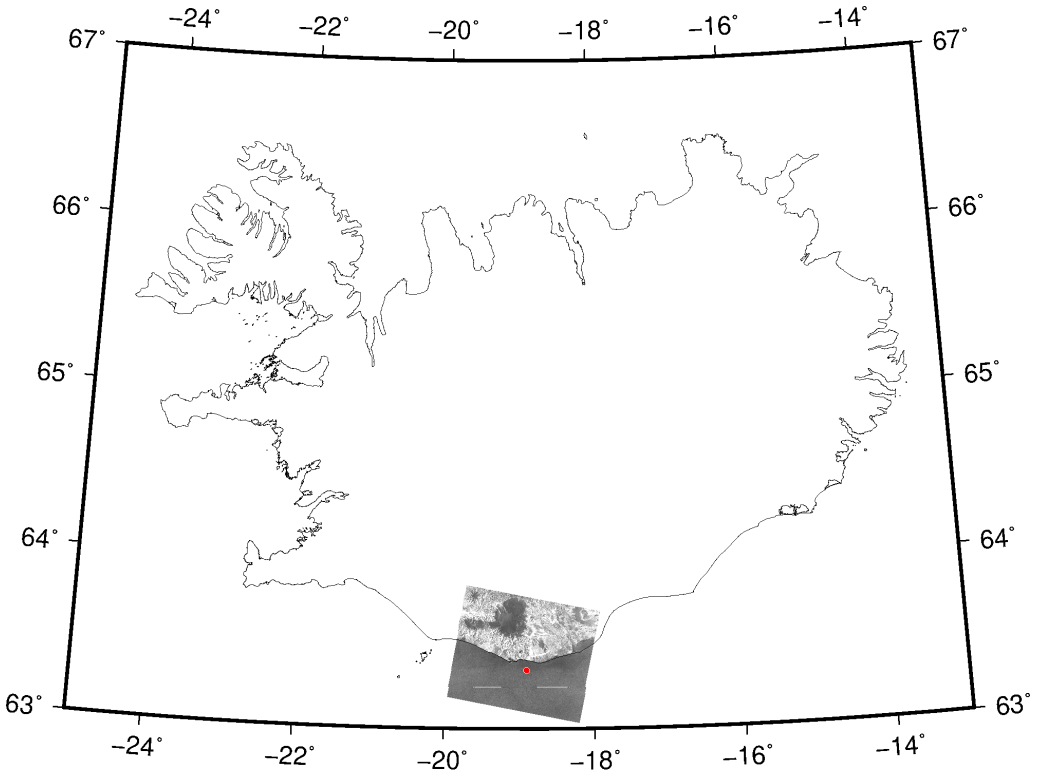


Table 21: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 23. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-155	159
At acquisition time	-82	142

Date	Tide [cm]	Used
2019-06-12	-82	x
2018-05-24	-77	x
2019-07-12	-75	x
2018-06-23	-73	x
2018-12-02	-70	x
2017-05-05	-67	x
2017-06-04	-67	x
2017-11-13	-67	
2019-05-13	-64	x
2019-01-01	-62	x
2018-04-24	-61	x
2015-08-26	-60	x
average(used)	-69	

T9 IW3 North

Figure 24: Coverage of T9 IW3 North. The red circle indicates the point at which tides were calculated.

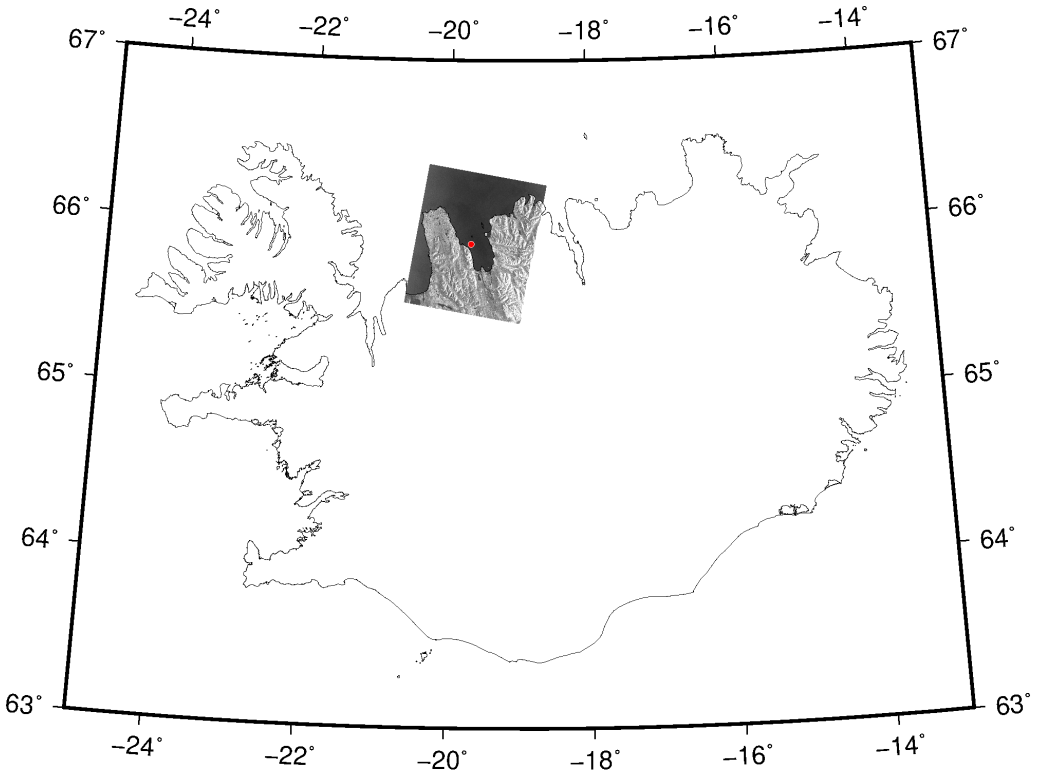


Table 22: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 24. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-90	78
At acquisition time	-80	50

Date	Tide [cm]	Used
2019-08-05	-80	x
2018-07-17	-78	x
2018-06-17	-74	x
2017-05-29	-73	x
2017-06-28	-73	x
2019-07-06	-72	x
2018-08-16	-67	x
2016-06-09	-67	x
2019-02-24	-65	x
2016-04-10	-65	x
2017-07-28	-64	x
2017-04-29	-63	x
average(used)	-70	

T9 IW3 South

Figure 25: Coverage of T9 IW3 South. The red circle indicates the point at which tides were calculated.

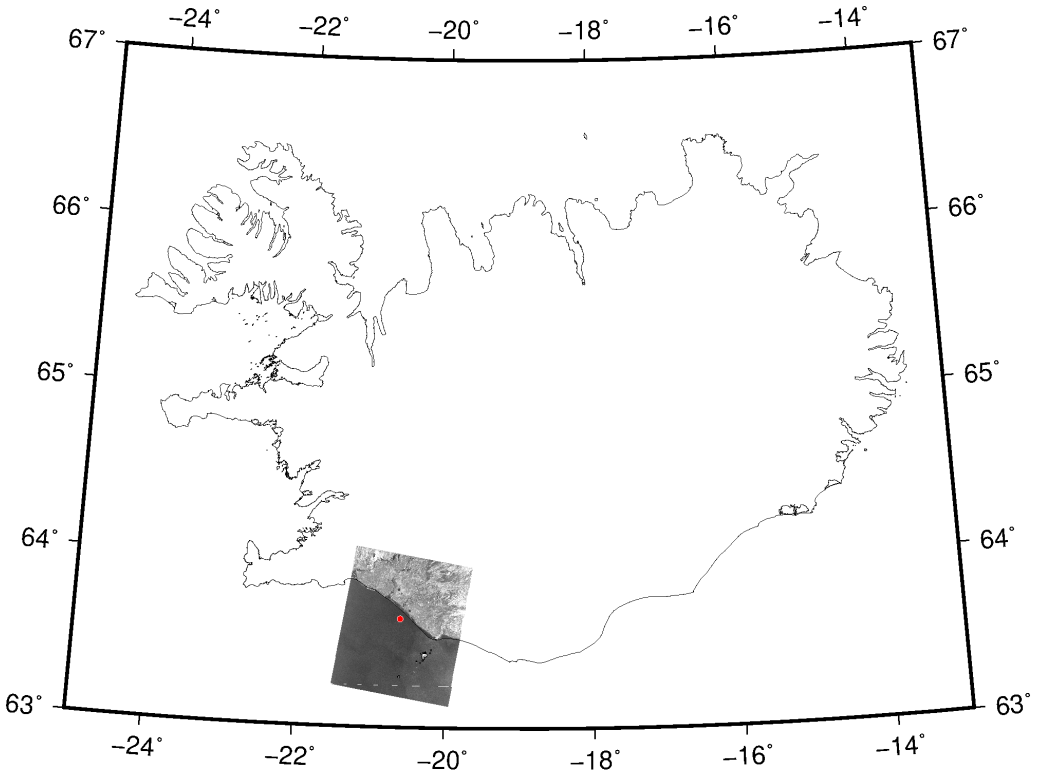


Table 23: **(Left)** Tide estimates derived from the FES2014 model between early 2015 and August 2019 at the location indicated on figure 25. **(Right)** Lowest tides at acquisitions time. The images are used to form the stack from which the land binary mask is derived. Some images are unused because of missing data. The average indicates the average tide of used images.

Tide [cm]	Lowest	Highest
For the entire period	-177	178
At acquisition time	-94	162

Date	Tide [cm]	Used
2019-06-12	-94	x
2018-05-24	-87	x
2019-07-12	-86	x
2018-06-23	-83	x
2018-12-02	-81	x
2017-05-05	-77	x
2017-11-13	-77	
2017-06-04	-76	x
2019-05-13	-74	x
2018-04-24	-71	x
2019-01-01	-70	x
2016-05-16	-68	x
average(used)	-79	