ExtremeEarth

H2020 - 825258

Deliverable

ExtremeEarth Polar Use Case Training Dataset

User Instructions

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2 March 2020

Status: **Version 1.0.0 (doi:10.5281/zenodo.3695276)**

Scheduled Delivery Date: **N/A**

Executive Summary

This is a set of sea ice, and iceberg, analysis data prepared for the ExtremeEarth project. The intention is that this dataset is useful for training and validating automated methods for processing satellite images, although it could also be applied to ice analyst training. The region chosen for the analysis was Danmarkshavn on the east coast of Greenland. This has a wide variety of sea ice and iceberg conditions, and was continuously monitored by key European Sentinel satellites during 2018. The dataset consists of 12 days, approximately monthly, throughout the year, covering winter and spring, summer melt, and autumn freeze-up. The presence of extensive (land) fast ice in the area ensures that classifications on those areas can be applied to additional dates. The sea ice classification includes primary and secondary ice types, including partial concentrations and form (floe size).

The initial version contains basic ice/water classification, and otherwise the polygons remain unclassified for sea ice concentrations, ice type and form. This information will be added in later versions.

Document Information

Contract Number	H2020 - 825258	**Acronym**	ExtremeEarth
Full title	From Copernicus Big Data to Extreme Earth Analytics		
Project URL	http://earthanalytics.eu/		
EU Project officer	Riku Leppänen		

Deliverable	**Number**	N/A	**Name**	Polar Use Case Training Data		
Task	**Number**	T5.2	**Name**			
Work package	**Number**	WP5				
Date of delivery	**Contractual**		N/A	**Actual**	M15	
Status	draft ☑		final ☐			
Nature	Prototype ☑ Report ☐					
Distribution Type	Public ☑ Restricted ☐ Consortium ☐					
Responsible Partner	MET Norway					
QA Partner						
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Version History

Version	*Date*	*Description*
1.0.0	2020-03-02	Initial release. Ice concentration, type and form labelling not complete. Simple ice/water classification only. doi: 10.5281/zenodo.3695276

Project Information

This document is part of a research project funded by the IST Programme of the Commission of the European Communities as project number H2020-825258. The beneficiaries in this project are the following:

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1. Introduction

The training dataset consists of sea ice and iceberg analysis derived from 12, approximately monthly, dates from the area of the Greenland Sea east of Danmarkshavn (76° 46’ 8” N 18° 39’ 53” W, -18.664722 76.768889). The location is shown in Figure 1. The primary data source is Sentinel-1 Extended Wide (EW) mode dual-polarisation (HH+HV) synthetic aperture radar (SAR) images, supplemented by optical data from Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR) and Sentinel-2 Multispectral Instrument (MSI).

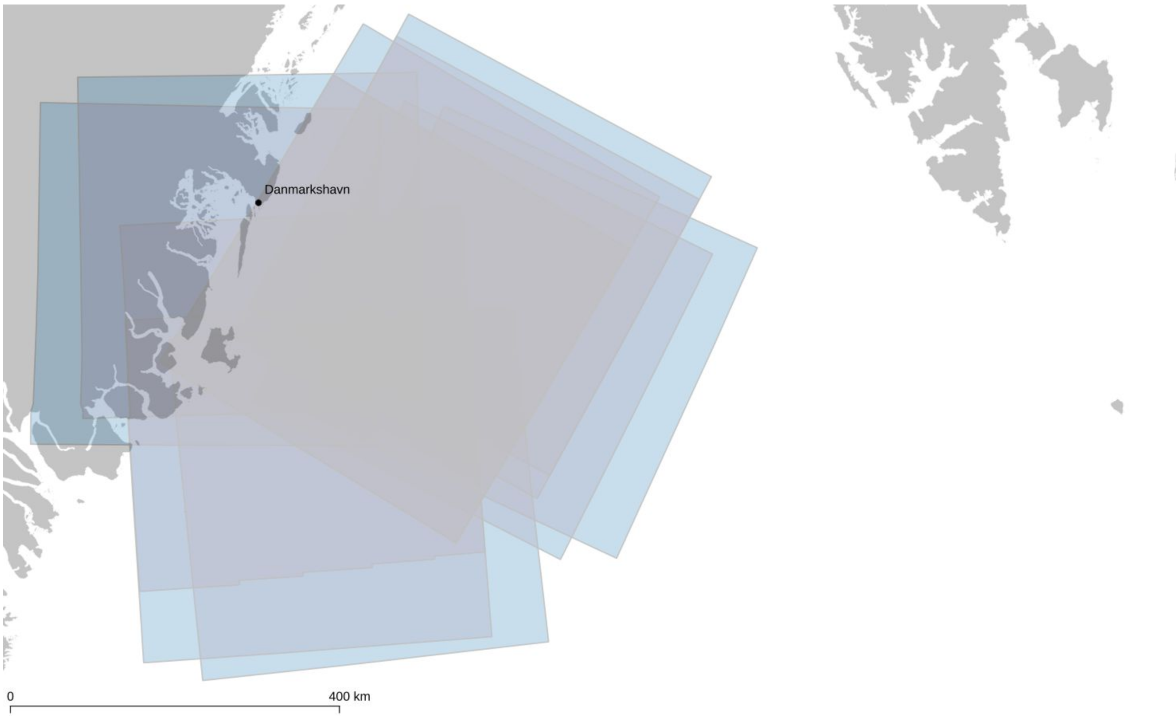

Figure 1: Location of Sentinel-1 satellite coverage in relation to Greenland and Svalbard.

The region experiences a wide variety of sea ice conditions and has a large number of icebergs. A key feature is the formation of an extensive (land) fast ice fringe along the coast in the winter, some of which can develop into multi-year ice if anchored by grounded icebergs. This is a southward extension of the Norske Øer Ice Barrier (NØIB) reviewed in Hughes and others, 2011. The fast ice allows the development of extensive areas of new ice in flaw lead systems and offshore of these is a variable drifting ice cover transiting southward on the East Greenland Current (EGC).

As the fast ice is immobile it provides a useful laboratory for remote sensing investigations, where the effects of SAR incidence angle and polarimetry, and temporal changes in the ice surface, can be evaluated. The analysis dataset provided here is an interpretation at 12 dates throughout the year. The classifications can be extended to further dates, thus multiplying the number of samples.

For the satellite remote sensing, the location is sufficiently far south to have both descending (morning) and ascending (afternoon) overpasses by Sentinel-1 satellites thus permitting a review of the effects of the look direction in addition to incidence angles on target radar response. The lower latitude also allows for a longer period when optical (visible) satellite sensors can be used to provide additional data, in particular the very high resolution coverage of Sentinel-2.

The analysis follows international ice charting standards defined by the World Meteorological Organization (WMO) and Intergovernmental Oceanographic Commission (IOC) Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) Expert Team on Sea Ice (ETSI) and uses a subset of the SIGRID-3 vector archive format for sea ice georeferenced information and data (JCOMM, 2014), that is itself based on the ESRI Shapefile format. The data is therefore readable through software tools including QGIS (QGIS Development Team, 2020) and the Geospatial Data Abstraction Library (GDAL) (GDAL/OGR contributors, 2020).

2. Sentinel-1 Processing

Sentinel-1 data was processed using the European Space Agency (ESA) Sentinel Application Platform (SNAP) to provide a calibrated, despeckled and terrain-corrected geolocated image. The processing graph for this is shown in Figure 2 and XML-file provided in Annex A.

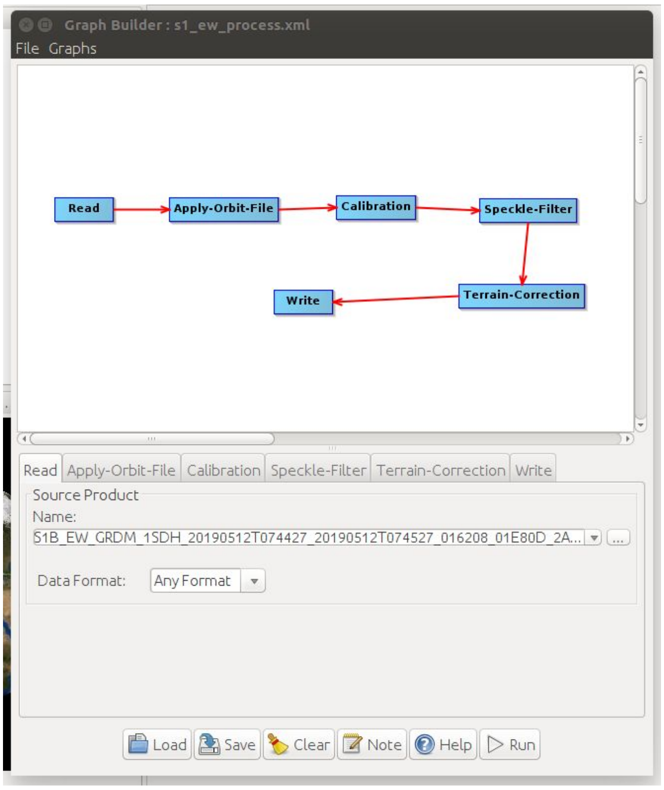

Figure 2: SNAP processing chart for Sentinel-1 EW processing.

The terrain correction step is essential for proper geolocation of ascending overpass Sentinel-1 images on the east coast of Greenland.

The GeoTIFF image from SNAP was subsequently processed to a reduced file size, with lossy JPEG compression, using GDAL utilities. This generated a false colour RGB composite using HV/HH (cross/co-polarisation ratio), HV and HH. The (Bash) shell script for this is provided in Annex B.

All Sentinel-1 images are dual-polarisation (HH+HV) Ground Range Detected, Medium resolution (GRDM). These have a sensor spatial resolution of 93x87 m, provided with a pixel resolution of 40x40 m with 6x2 looks and an equivalent number of looks (ENL) of 10.7. The Sentinel-1 User Guide provides more details on this and the other operating modes available at https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/resolutions/level-1-ground-range-detected

3. Data Format

3.1. Map Projection

The analysis Shapefiles use a Polar Stereographic map projection with WGS84 ellipsoid and datum, centred at 90° N and rotated to 0° E. The Well-Known Text (WKT) for this is:

```
PROJCS["Stereographic_North_Pole",
    GEOGCS["GCS_WGS_1984",
        DATUM["unknown",
            SPHEROID["WGS84",6378137,298.257223563]],
        PRIMEM["Greenwich",0],
        UNIT["Degree",0.0174532925199433295],
        AUTHORITY["EPSG","4326"]],
    PROJECTION["Polar_Stereographic"],
    PARAMETER["latitude_of_origin",90],
    PARAMETER["central_meridian",0],
    PARAMETER["false_easting",0],
    PARAMETER["false_northing",0],
    UNIT["Meter",1]]
```

The PROJ library (PROJ contributors, 2020) representation of this is:

```
+proj=stere +lat_0=90 +lat_ts=90 +lon_0=0 +ellps=WGS84 +datum=WGS84
```

3.2. Land Mask Dataset

A coastline has been applied to the sea ice polygons. This has been derived from Open Street Map land polygon data available at
https://osmdata.openstreetmap.de/data/land-polygons.html

3.3. Sea Ice

The analysis contains a subset of the information fields available in the full SIGRID-3 format, as listed in Table 1.

Table 1: Sea ice Shapefile data fields.

Field name	*Data type*	*Description*
id	Integer	Unique serial number for polygon in the Shapefile.
poly_type	String	Single character string providing basic classification into: L = Land W = Open water (ice-free) I = Sea ice or iceberg N = No data S = Ice shelf / ice of land origin (iceberg)
area	Float (16)	Area of polygon in square metres.
perimeter	Float (16)	Perimeter of polygon in metres.
CT	Integer	Total ice concentration, CA+CB, encoded as per SIGRID-3. See Table 2.
CA	Integer	Concentration of primary (thickest) ice type A, encoded as per SIGRID-3. See Table 2.
SA	Integer	Thickness of ice or stage of development for primary (thickest) ice type A, encoded as per SIGRID-3. See Table 3.
FA	Integer	Form of ice or floe size for primary (thickest) ice type A, encoded as per SIGRID-3. See Table 4.
CB	Integer	Concentration of secondary (thinnest) ice type B, encoded as per SIGRID-3. See Table 2.
SB	Integer	Thickness of ice or stage of development for secondary (thinnest) ice type B, encoded as per SIGRID-3. See Table 3.
FB	Integer	Form of ice or floe size for secondary (thinnest) ice type B, encoded as per SIGRID-3. See Table 4.

In SIGRID-3 only the poly_type, area and perimeter fields are mandatory. For this study the focus on detail reduced the need for additional ice classes beyond the primary and secondary ones.

The values for sea ice concentration (CT, CA and CB), ice type (stage of development) (SA and SB), and form of ice (floe size) (FA and FB) are provided in Tables 2, 3 and 4 on the following pages.

Table 2: Ice concentration, as per SIGRID-3 Appendix E - Code Tables for SIGRID-3 Variables "Table 1: Concentration codes for variable identifiers CT, CA, CB, CC, AV, AK, AM and AT" (page 31)

Definition	*Code Figure*
Ice Free	98
Less than 1/10 (open water)	01
Bergy Water	02
1/10	10
2/10	20
3/10	30
4/10	40
5/10	50
6/10	60
7/10	70
8/10	80
9/10	90
10/10	92
Concentration intervals (lowest concentration in interval followed by highest concentration in interval)	
9/10 –10/10 or 9+/10	91
8/10 – 9/10	89
8/10 – 10/10	81
7/10 – 9/10	79
7/10 – 8 /10	78
6/10 – 8/10	68
6/10 – 7/10	67
5/10 – 7/10	57
5/10 – 6/10	56
4/10 – 6/10	46
4/10 – 5/10	45
3/10 – 5/10	35
3/10 – 4/10	34
2/10 – 4/10	24
2/10 – 3/10	23
1/10 – 3/10	13
1/10 – 2/10	12
Undetermined / Unknown	99

Table 3: Ice type, as per SIGRID-3 Appendix E - Code Tables for SIGRID-3 Variables "Table 2: Thickness of ice or stage of development codes for variable identifiers SA, SB, SC, CN, and CD." (page 33)

Stage of Development	*Thickness*	*Code Figure*
Ice Free		01
Ice Thickness in cm	1-2 cm	02
	3 cm	03
	4 cm	04
	…	…
	50 cm	50
Ice Thickness interval, 5 cm	55 cm	51
	60 cm	52
	65 cm	53
	…	…
	95 cm	59
Ice Thickness interval, 10 cm	100 cm	60
	110 cm	61
	120 cm	62
	…	…
	190 cm	69
Ice Thickness interval, 50 cm	200 cm	70
	250 cm	71
	300 cm	72
	350 cm	73
Ice Thickness interval, 100 cm	00 cm	74
	500 cm	75
	600 cm	76
	700 cm	77
	800 cm	78
Brash Ice	Given by AV, AT, AM, AT	79

Table 3 continued: Ice type, as per SIGRID-3 Appendix E - Code Tables for SIGRID-3 Variables "Table 2: Thickness of ice or stage of development codes for variable identifiers SA, SB, SC, CN, and CD." (page 33)

Stage of Development	*Thickness*	*Code Figure*
No Stage of Development		80
New Ice	< 10 cm	81
Nilas, Ice Rind	< 10 cm	82
Young Ice	10 - <30 cm	83
Grey Ice	10 - <15 cm	84
Grey - White Ice	15 - <30 cm	85
First Year Ice	≥30 cm	86
Thin First Year Ice	30 - <70 cm	87
Thin First Year Stage 1	30 - <50 cm	88
Thin First Year Stage 2	50 - <70 cm	89
For Later Use		90
Medium First Year Ice	70 - <120 cm	91
For Later Use		92
Thick First Year Ice	≥120 cm	93
Residual Ice		94
Old Ice		95
Second Year Ice		96
Multi-Year Ice		97
Glacier Ice		98
Undetermined/Unknown		99

Notes:

a) This table has been extended to conform with the original SIGRID (1981) specification with two exceptions:
   - Code 01 has been used to represent Ice Free instead of an ice thickness of 1 cm. To conform with S-57 standards, code 00 is not used. There is little significant difference between an ice thickness of 1 cm and 2 cm.
   - Code 79 has been used for brash ice instead of a thickness of 900 cm as in the original SIGRID. The maximum ice thickness that can be reported by this code is therefore 800 cm instead of 900 cm.

b) To differentiate dark and light nilas gradations, use stage of development codes '03' and '07' respectively.

Table 4: Form of ice or floe size, as per SIGRID-3 Appendix E - Code Tables for SIGRID-3 Variables "Table 13: Form of ice codes for variable identifiers FA, FB, FC, FP and FS." (page 35)

Form	*Size/Concentration*	*Code Figure*
Pancake Ice	30 cm - 3 m	22
Shuga/Small Ice Cake, Brash Ice	< 2 m across	01
Ice Cake	< 20 m across	02
Small Floe	20 m - <100 m across	03
Medium Floe	100 m - <500 m across	04
Big Floe	500 m - <2 km across	05
Vast Floe	2 km - <10 km across	06
Giant Floe	≥10 km across	07
Fast Ice		08
Growlers, Floebergs or Floebits		09
Icebergs		10
Strips and Patches	concentrations 1/10	11
Strips and Patches	concentrations 2/10	12
Strips and Patches	concentrations 3/10	13
Strips and Patches	concentrations 4/10	14
Strips and Patches	concentrations 5/10	15
Strips and Patches	concentrations 6/10	16
Strips and Patches	concentrations 7/10	17
Strips and Patches	concentrations 8/10	18
Strips and Patches	concentrations 9/10	19
Strips and Patches	concentrations 9+/10	91
Strips and Patches	concentrations 10/10	20
Level Ice		21
Undetermined/Unknown		99

4. Description of Data

12 dates, separated by about one month, were chosen for analysis to provide a representation of sea ice and iceberg conditions throughout the seasonal cycle. In the Danmarkshavn dataset used for ExtremeEarth, the coverage is a full calendar year (2018).

The dates and Sentinel-1 images chosen are listed in Table 5.

Table 5: Dates, times and Sentinel-1 images.

Month	*Date / Time*	*Sentinel-1 Filename*
January	2018-01-16 07:54:30	S1A_EW_GRDM_1SDH_20180116T075430_20180116T075530_020177_0226B9_9FE3
February	2018-02-13 17:54:44	S1B_EW_GRDM_1SDH_20180213T175444_20180213T175544_009608_011511_8266
March	2018-03-13 18:12:25	S1A_EW_GRDM_1SDH_20180313T181225_20180313T181325_021000_0240E1_8163
April	2018-03-13 18:12:25	S1A_EW_GRDM_1SDH_20180313T181225_20180313T181325_021000_0240E1_8163
May	2018-05-15 17:46:33	S1B_EW_GRDM_1SDH_20180515T174633_20180515T174733_010935_01403A_A84D
June	2018-06-12 18:04:23	S1A_EW_GRDM_1SDH_20180612T180423_20180612T180523_022327_026AB3_AC33
July	2018-07-17 07:38:09	S1A_EW_GRDM_1SDH_20180717T073809_20180717T073909_022831_0279B9_EBF1
August	2018-08-14 07:53:44	S1B_EW_GRDM_1SDH_20180814T075344_20180814T075444_012256_016952_B1DC
September	2018-09-11 17:55:48	S1A_EW_GRDM_1SDH_20180911T175548_20180911T175652_023654_0293F5_7CA2
October	2018-10-16 07:29:58	S1A_EW_GRDM_1SDH_20181016T072958_20181016T073058_024158_02A460_DA8F
November	2018-11-13 07:45:29	S1B_EW_GRDM_1SDH_20181113T074529_20181113T074629_013583_019254_D382
December	2018-12-18 07:54:37	S1A_EW_GRDM_1SDH_20181218T075437_20181218T075537_025077_02C472_1DB2

4.1. January

Filename:	Sea_Ice/seaice_s1_20180116t075430.dbf Sea_Ice/seaice_s1_20180116t075430.prj Sea_Ice/seaice_s1_20180116t075430.shp Sea_Ice/seaice_s1_20180116t075430.shx			
Satellite Images:				
Primary	S1A_EW_GRDM_1SDH_20180116T075430_20180116T075530_020177_0226B9_9FE3			
History	S1B_EW_GRDM_1SDH_20180115T174643_20180115T174743_009185_010726_6FB4			
Optical	Cloudy			
Number of Polygons:	Land	Water	Ice	**Total**
	4	1	179	**184**

a) b)

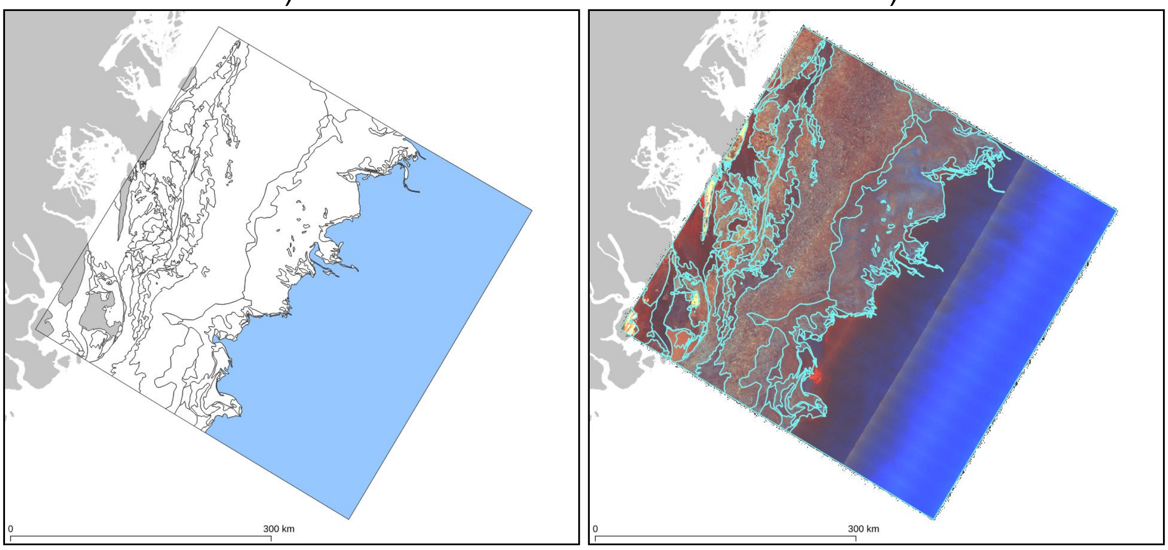

Figure 3: a) Sea ice polygons, and b) Sentinel-1 quicklook for 16 January 2018.

4.2. February

Filename:	Sea_Ice/seaice_s1_20180213t175444.dbf Sea_Ice/seaice_s1_20180213t175444.shp Sea_Ice/seaice_s1_20180213t175444.prj Sea_Ice/seaice_s1_20180213t175444.shx			
Satellite Images:				
Primary	S1B_EW_GRDM_1SDH_20180213T175444_20180213T175544_009608_011511_8266			
History	S1A_EW_GRDM_1SDH_20180212T180416_20180212T180516_020577_02336E_5855			
Optical	Cloudy			
Number of Polygons:	Land	Water	Ice	**Total**
	13	1	156	**170**

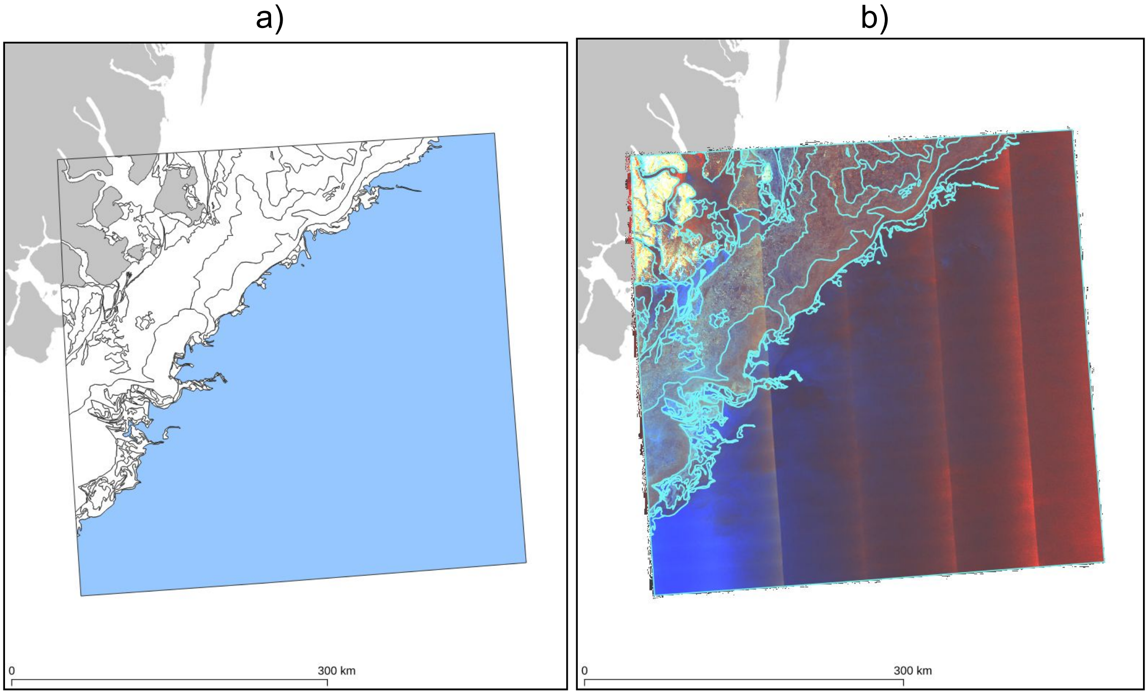

Figure 4: a) Sea ice polygons, and b) Sentinel-1 quicklook for 13 February 2018.

4.3. March

Filename:	Sea_Ice/seaice_s1_20180313t181225.dbf Sea_Ice/seaice_s1_20180313t181225.shp Sea_Ice/seaice_s1_20180313t181225.prj Sea_Ice/seaice_s1_20180313t181225.shx			
Satellite Images:				
Primary	S1A_EW_GRDM_1SDH_20180313T181225_20180313T181325_021000_0240E1_8163			
History	S1A_EW_GRDM_1SDH_20180312T074605_20180312T074705_020979_02403B_43FE			
Optical	S3A_SL_1_RBT____20180313T194506_20180313T194806_20181006T075041_0179_029_028______LR1_R_NT_003 S2A_MSIL1C_20180313T134041_N0206_R067_T27XWD_20180313T171631 S2A_MSIL1C_20180313T134041_N0206_R067_T28XDJ_20180313T171631 S2B_MSIL1C_20180313T142949_N0206_R139_T27XWE_20180313T163024 S2B_MSIL1C_20180313T142949_N0206_R139_T28XDL_20180313T163024			
Number of Polygons:	Land	Water	Ice	**Total**
	319	1	249	**569**

a) b)

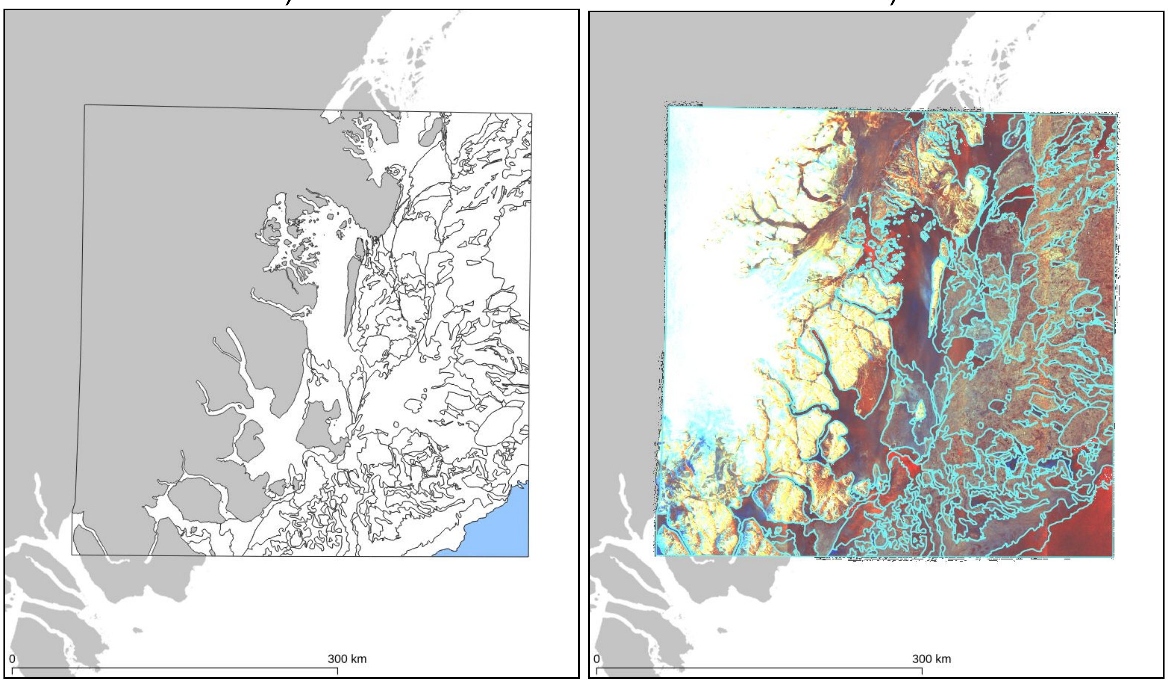

Figure 5: a) Sea ice polygons, and b) Sentinel-1 quicklook for 13 March 2018.

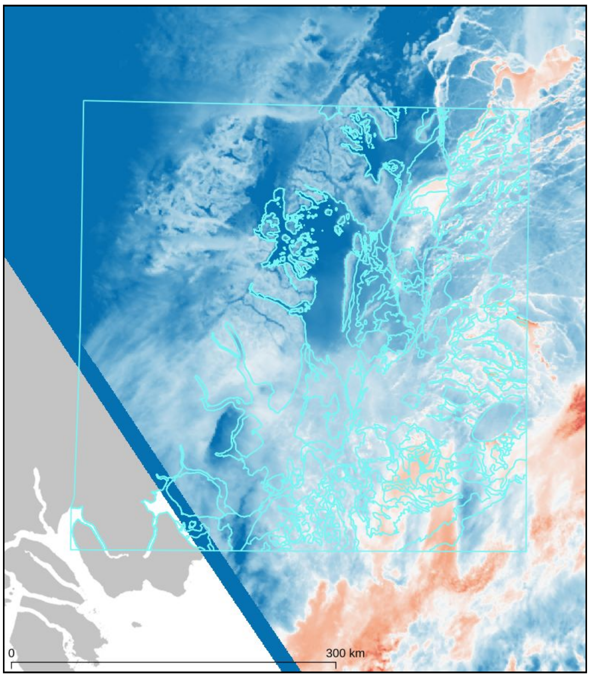

Figure 6: Sentinel-3 temperatures for 13 March 2018.

4.3.1. Icebergs

Filename:	Icebergs/icebergs_s2_20180313.dbf Icebergs/icebergs_s2_20180313.shp Icebergs/icebergs_s2_20180313.prj Icebergs/icebergs_s2_20180313.shx
Satellite Images:	
Primary Optical	S2A_MSIL1C_20180313T134041_N0206_R067_T27XWD_20180313T171631 S2A_MSIL1C_20180313T134041_N0206_R067_T28XDJ_20180313T171631 S2B_MSIL1C_20180313T142949_N0206_R139_T27XWE_20180313T163024 S2B_MSIL1C_20180313T142949_N0206_R139_T28XDL_20180313T163024
Number of Polygons:	**Total**
	4,302

Sentinel-2 data at 10 metres resolution was used to identify icebergs present in the region from 4 scenes from 13 March 2018.

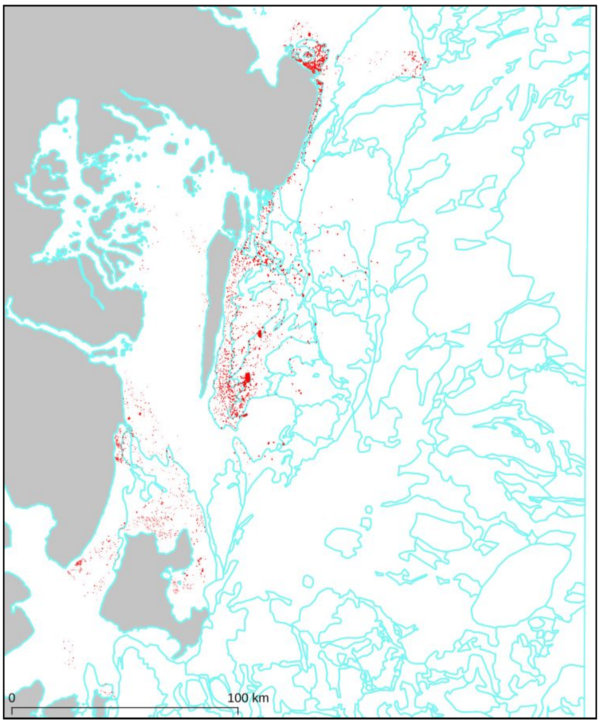

Figure 7: Icebergs overview.

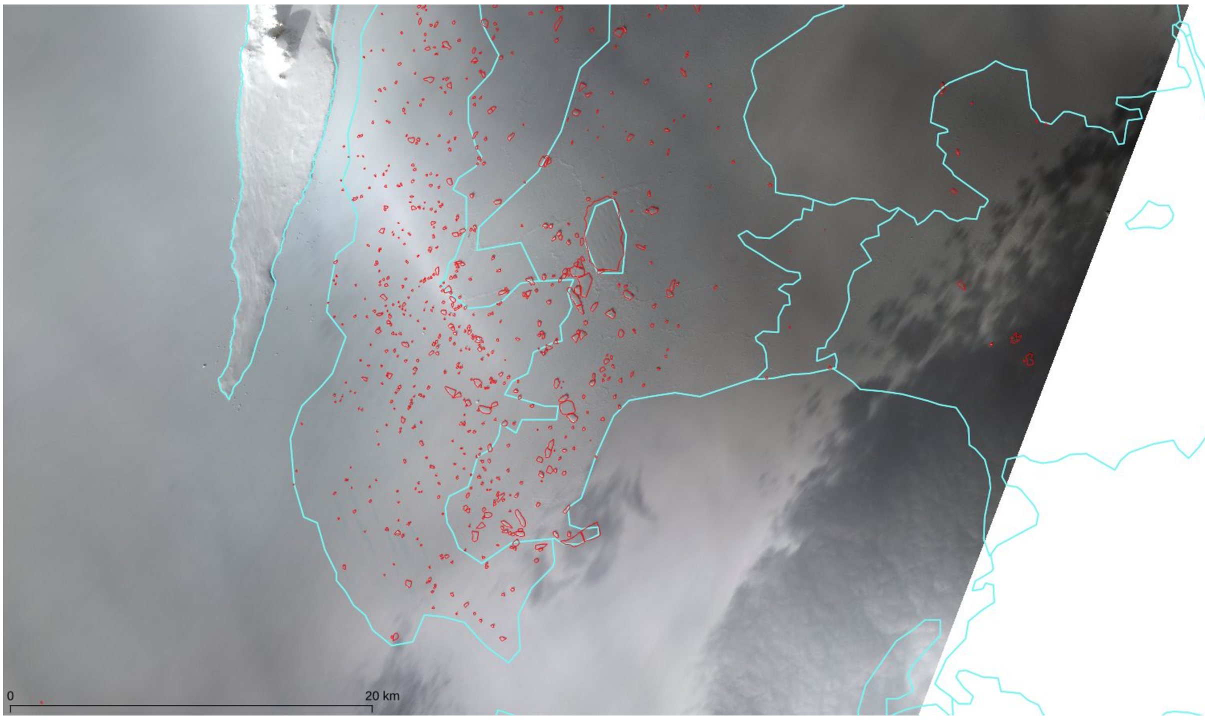

Figure 8:Sentinel-2 icebergs detail at the southern end of Store Koldewey island.

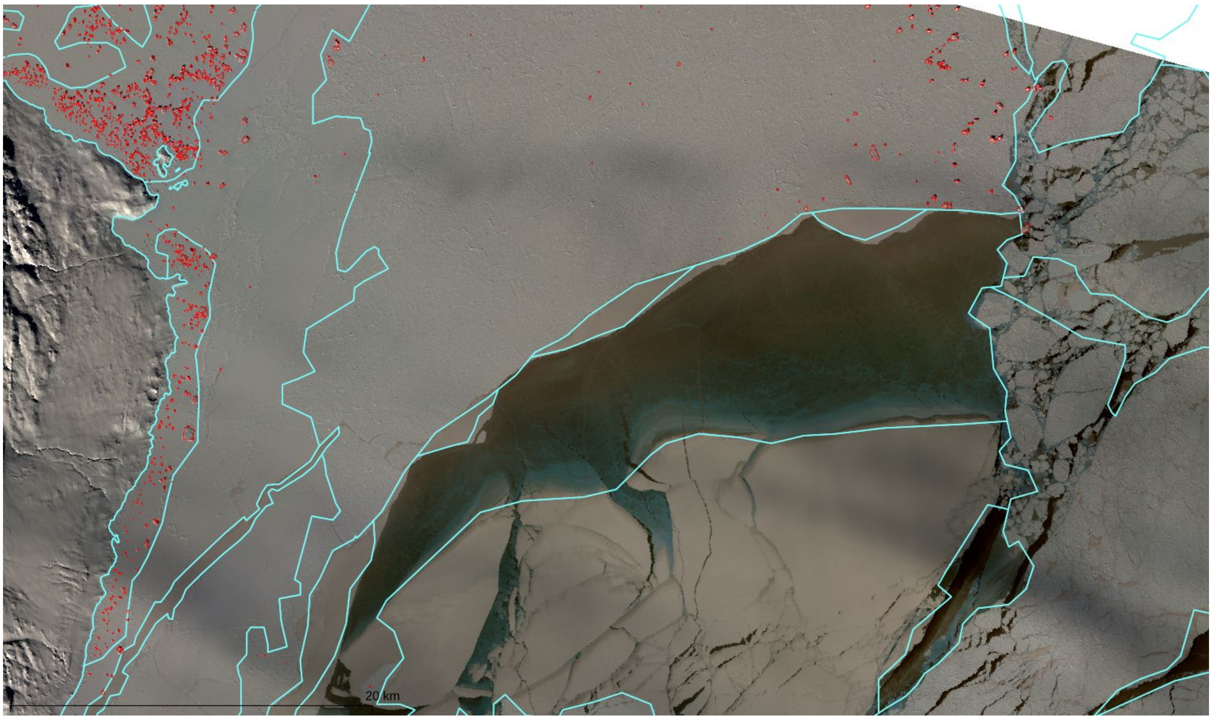

Figure 9:Sentinel-2 icebergs detail at the southern end of Belgica Bank.

4.4. April

Filename:	Sea_Ice/seaice_s1_20180417t074606.dbf Sea_Ice/seaice_s1_20180417t074606.shp Sea_Ice/seaice_s1_20180417t074606.prj Sea_Ice/seaice_s1_20180417t074606.shx			
Satellite Images:				
Primary	S1A_EW_GRDM_1SDH_20180417T074606_20180417T074706_021504_0250C3_D211			
History	S1B_EW_GRDM_1SDH_20180416T075337_20180416T075437_010506_013270_ED66			
Optical	S3A_SL_1_RBT____20180417T193745_20180417T194045_20180418T234042_0179_030_142_1260_LN2_O_NT_003			
Number of Polygons:	Land	Water	Ice	**Total**
	0	4	479	**483**

a) b)

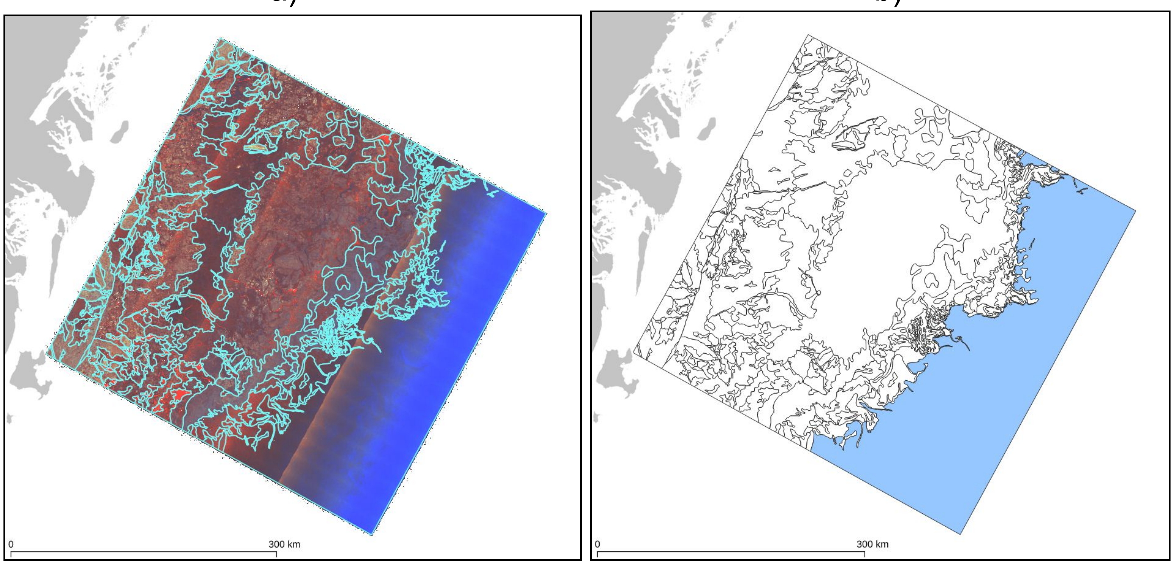

Figure 10: a) Sea ice polygons, and b) Sentinel-1 quicklook for 17 April 2018.

4.5. May

Filename:	Sea_Ice/seaice_s1_20180515t174633.dbf Sea_Ice/seaice_s1_20180515t174633.shp Sea_Ice/seaice_s1_20180515t174633.prj Sea_Ice/seaice_s1_20180515t174633.shx			
Satellite Images:				
Primary	S1B_EW_GRDM_1SDH_20180515T174633_20180515T174733_010935_01403A_A84D			
History	S1A_EW_GRDM_1SDH_20180513T072951_20180513T073051_021883_025CBD_A70C			
Optical	Cloudy			
Number of Polygons:	Land	Water	Ice	**Total**
	26	2	88	**116**

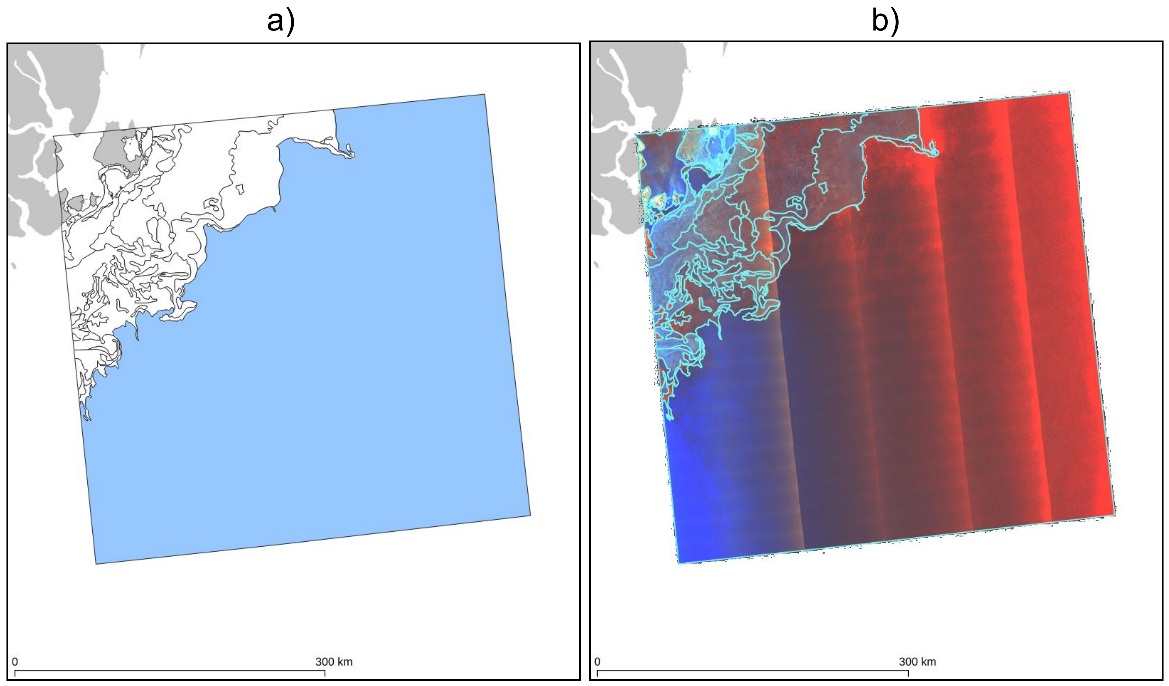

Figure 11: a) Sea ice polygons, and b) Sentinel-1 quicklook for 15 May 2018.

4.6. June

Filename:	Sea_Ice/seaice_s1_20180612t180423.dbf Sea_Ice/seaice_s1_20180612t180423.shp Sea_Ice/seaice_s1_20180612t180423.prj Sea_Ice/seaice_s1_20180612t180423.shx			
Satellite Images:				
Primary	S1A_EW_GRDM_1SDH_20180612T180423_20180612T180523_022327_026AB3_AC33			
History	S1A_EW_GRDM_1SDH_20180611T073807_20180611T073907_022306_026A0D_CC44			
Optical	S2B_MSIL1C_20180612T135729_N0206_R010_T27XWC_20180612T142456 S2B_MSIL1C_20180612T135729_N0206_R010_T27XWD_20180612T142456 S2B_MSIL1C_20180612T135729_N0206_R010_T27XWE_20180612T142456 S2B_MSIL1C_20180612T135729_N0206_R010_T28XDH_20180612T142456 S2B_MSIL1C_20180612T135729_N0206_R010_T28XDJ_20180612T142456 S2B_MSIL1C_20180612T135729_N0206_R010_T28XDK_20180612T142456			
Number of Polygons:	Land	Water	Ice	**Total**
	496	2	125	**623**

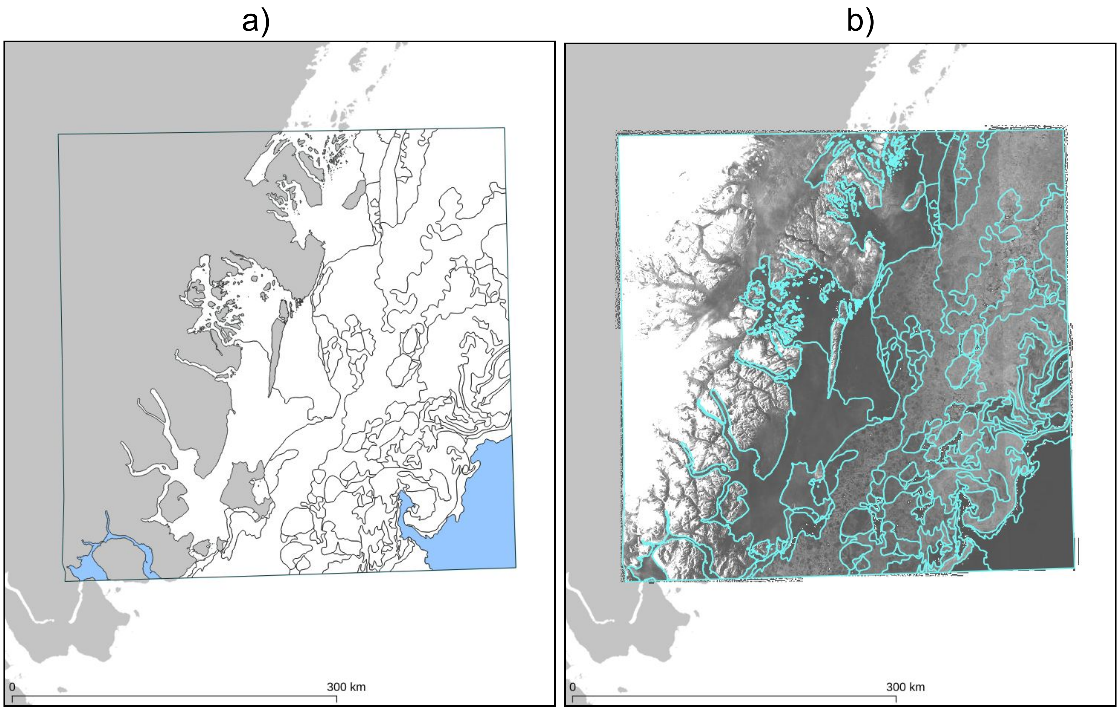

Figure 12: a) Sea ice polygons, and b) Sentinel-1 quicklook for 12 June 2018.

4.7. July

Filename:	Sea_Ice/seaice_s1_20180717t073809.dbf Sea_Ice/seaice_s1_20180717t073809.shp Sea_Ice/seaice_s1_20180717t073809.prj Sea_Ice/seaice_s1_20180717t073809.shx			
Satellite Images:				
Primary	S1A_EW_GRDM_1SDH_20180717T073809_20180717T073909_022831_0279B9_EBF1			
History	S1B_EW_GRDM_1SDH_20180716T074525_20180716T074625_011833_015C73_2686			
Optical	Cloudy			
Number of Polygons:	Land	Water	Ice	**Total**
	0	2	87	**89**

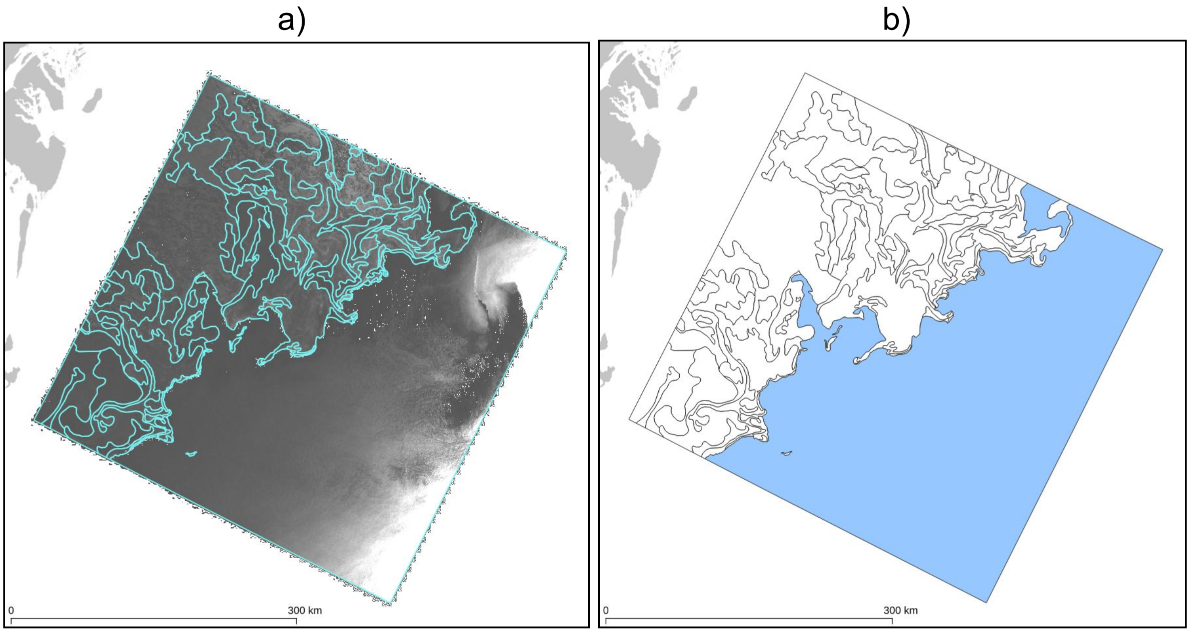

Figure 13: a) Sea ice polygons, and b) Sentinel-1 quicklook for 17 July 2018.

4.8. August

Filename:	Sea_Ice/seaice_s1_20180814t075344.dbf Sea_Ice/seaice_s1_20180814t075344.shp Sea_Ice/seaice_s1_20180814t075344.prj Sea_Ice/seaice_s1_20180814t075344.shx			
Satellite Images:				
Primary	S1B_EW_GRDM_1SDH_20180814T075344_20180814T075444_012256_016952_B1DC			
History	S1A_EW_GRDM_1SDH_20180813T174720_20180813T174820_023231_028669_AA12			
Optical	S2B_MSIL1C_20180814T140959_N0206_R053_T27XWE_20180824T150354 S2B_MSIL1C_20180814T140959_N0206_R053_T28XDJ_20180824T150354 S2B_MSIL1C_20180814T140959_N0206_R053_T28XDK_20180824T150354			
Number of Polygons:	Land	Water	Ice	**Total**
	33	1	96	**130**

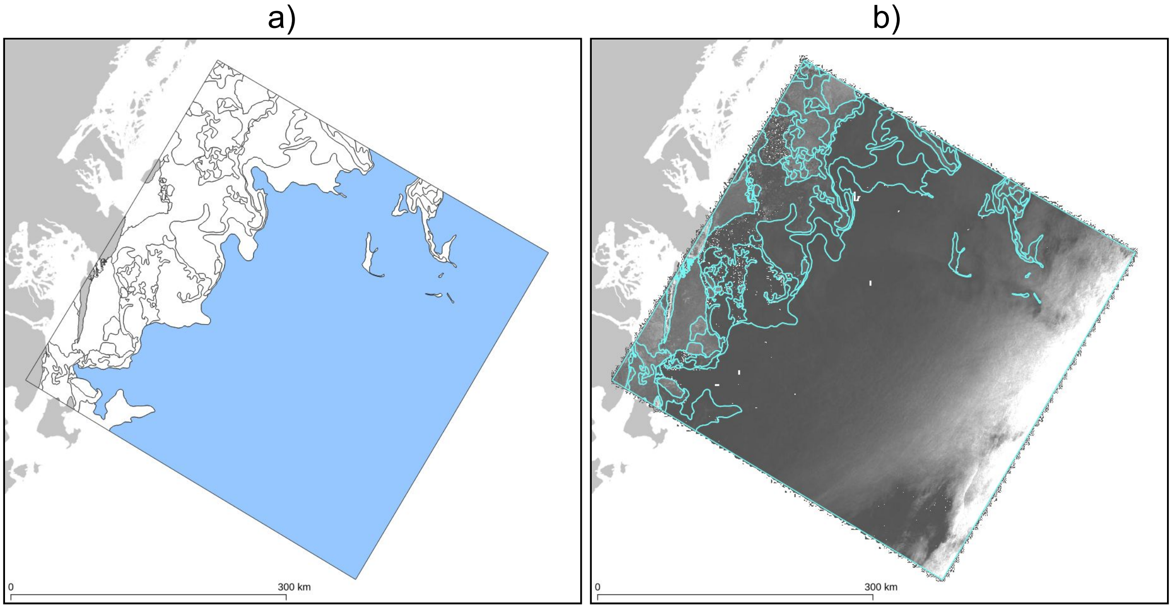

Figure 14: a) Sea ice polygons, and b) Sentinel-1 quicklook for 14 August 2018.

4.9. September

Filename:	Sea_Ice/seaice_s1_20180911t175548.dbf Sea_Ice/seaice_s1_20180911t175548.shp Sea_Ice/seaice_s1_20180911t175548.prj Sea_Ice/seaice_s1_20180911t175548.shx			
Satellite Images:				
Primary	S1A_EW_GRDM_1SDH_20180911T175548_20180911T175652_023654_0293F5_7CA2			
History	S1A_EW_GRDM_1SDH_20180910T072958_20180910T073058_023633_029346_8506			
Optical	Cloudy			
Number of Polygons:	Land	Water	Ice	**Total**
	92	3	47	**142**

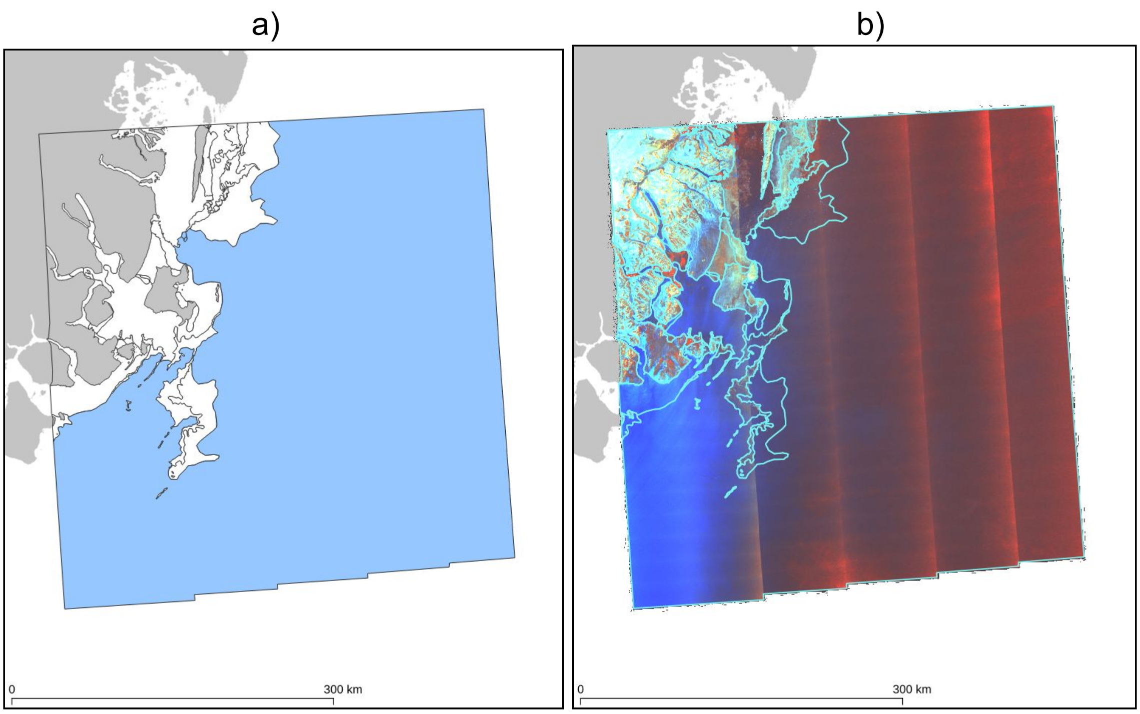

Figure 15: a) Sea ice polygons, and b) Sentinel-1 quicklook for 11 September 2018.

4.10. October

Filename:	Sea_Ice/seaice_s1_20181016t072958.dbf Sea_Ice/seaice_s1_20181016t072958.shp Sea_Ice/seaice_s1_20181016t072958.prj Sea_Ice/seaice_s1_20181016t072958.shx			
Satellite Images:				
Primary	S1A_EW_GRDM_1SDH_20181016T072958_20181016T073058_024158_02A460_DA8F			
History	S1A_EW_GRDM_1SDH_20181015T181247_20181015T181347_024150_02A420_168B			
Optical	Cloudy			
Number of Polygons:	Land	Water	Ice	**Total**
	0	1	3	**4**

Only basic ice/water classification has been implemented on the October images.

a) b)

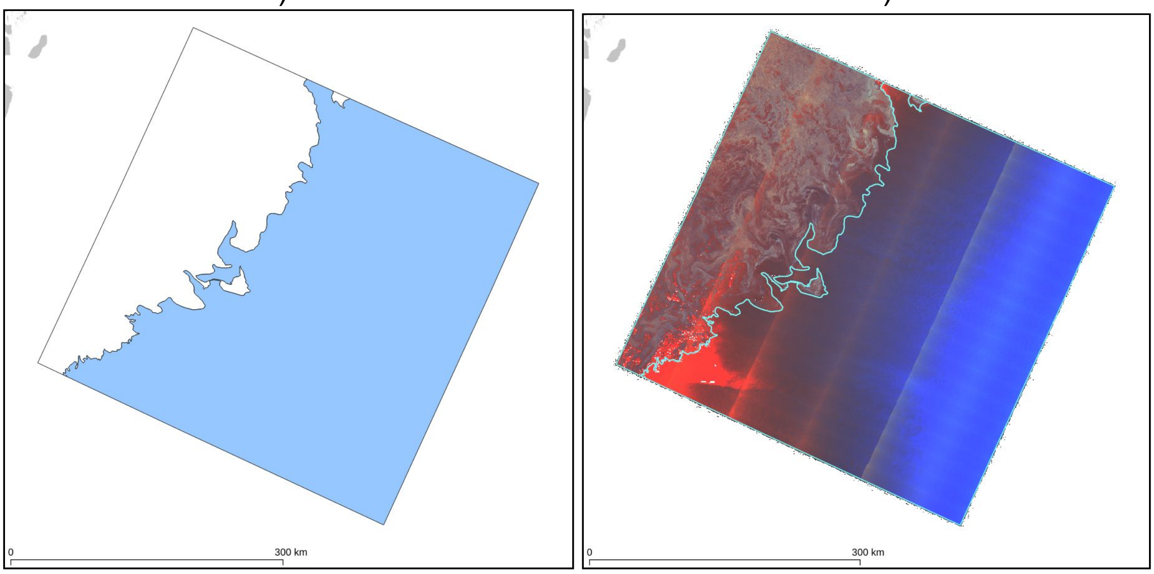

Figure 16: a) Sea ice polygons, and b) Sentinel-1 quicklook for 16 October 2018.

4.11. November

Filename:	Sea_Ice/seaice_s1_20181113t074529.dbf Sea_Ice/seaice_s1_20181113t074529.shp Sea_Ice/seaice_s1_20181113t074529.prj Sea_Ice/seaice_s1_20181113t074529.shx			
Satellite Images:				
Primary	S1B_EW_GRDM_1SDH_20181113T074529_20181113T074629_013583_019254_D382			
History	S1A_EW_GRDM_1SDH_20181112T075439_20181112T075539_024552_02B1CD_51CA			
Optical	S3A_SL_1_RBT____20181113T203352_20181113T203652_20181115T051840_0179_038_057_1260_LN2_O_NT_003			
Number of Polygons:	Land	Water	Ice	**Total**
	0	1	7	**8**

Only basic ice/water classification has been implemented on the November images.

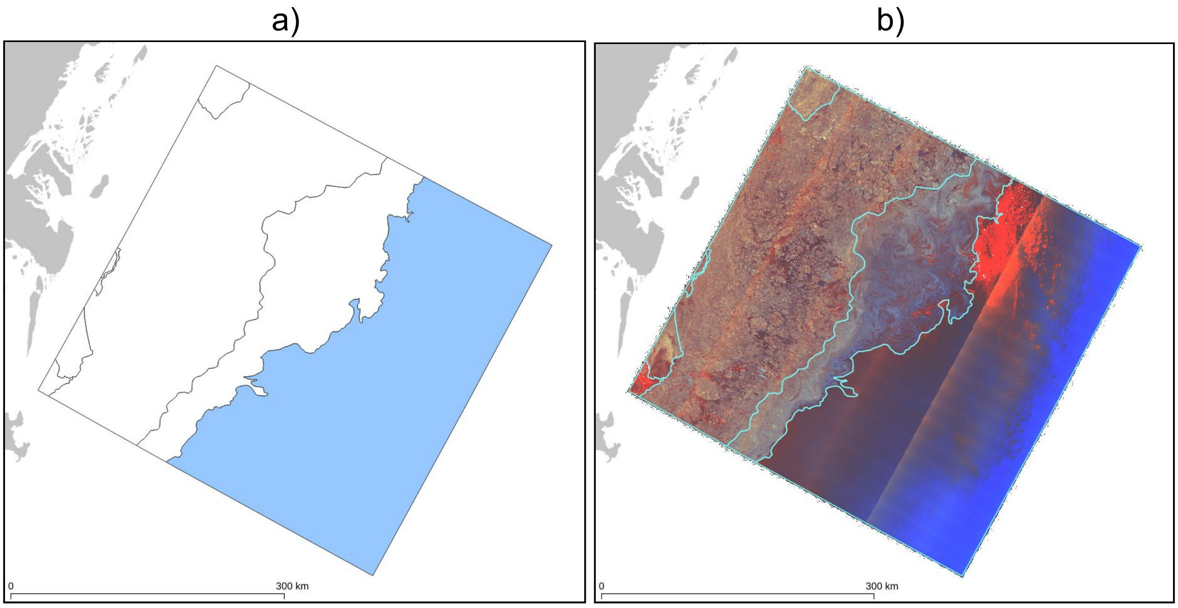

Figure 17: a) Sea ice polygons, and b) Sentinel-1 quicklook for 13 November 2018.

4.12. December

Filename:	Sea_Ice/seaice_s1_20181218t075437.dbf Sea_Ice/seaice_s1_20181218t075437.shp Sea_Ice/seaice_s1_20181218t075437.prj Sea_Ice/seaice_s1_20181218t075437.shx			
Satellite Images:				
Primary	S1A_EW_GRDM_1SDH_20181218T075437_20181218T075537_025077_02C472_1DB2			
History	S1B_EW_GRDM_1SDH_20181217T174639_20181217T174739_014085_01A27D_E7EC			
Optical	Cloudy			
Number of Polygons:	Land	Water	Ice	**Total**
	35	4	144	**183**

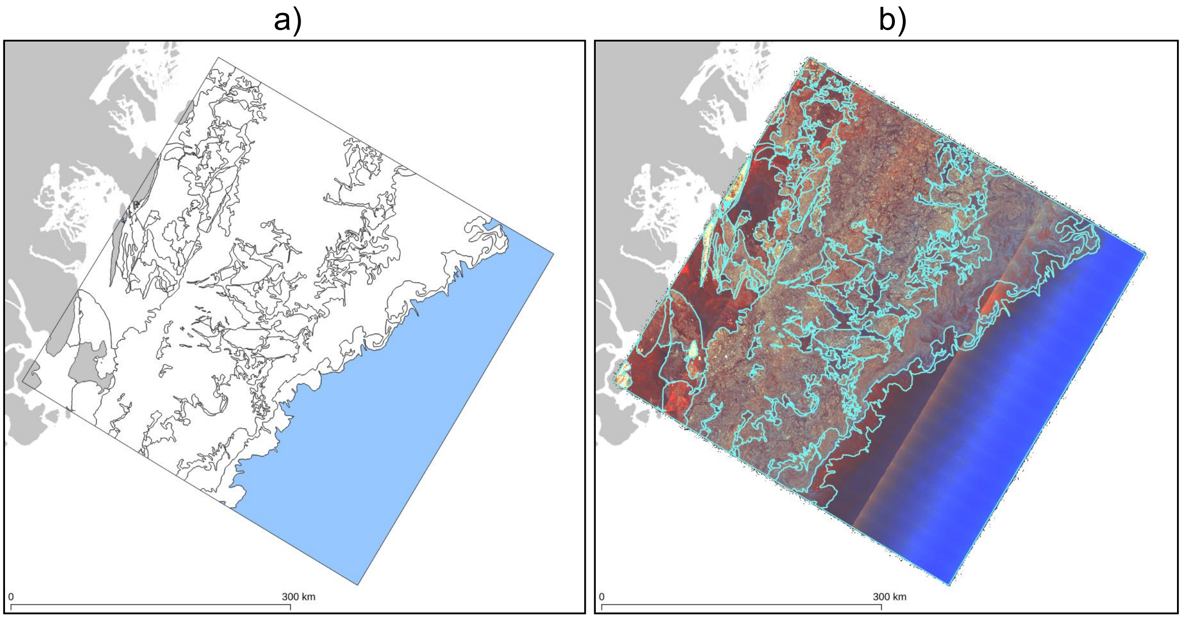

Figure 18: a) Sea ice polygons, and b) Sentinel-1 quicklook for 18 December 2018.

5. Acknowledgements

The ExtremeEarth project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 825258.

6. References

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ANNEX A: ESA SNAP processing chart for Sentinel-1 EW mode.

s1_ew_process.xml:

```
<graph id="Graph">
  <version>1.0</version>
  <node id="Read">
    <operator>Read</operator>
    <sources/>
    <parameters class="com.bc.ceres.binding.dom.XppDomElement">

<file>S1B_EW_GRDM_1SDH_20190512T074427_20190512T074527_016208_01E80D_2A1A.SAF
E.zip</file>
    </parameters>
  </node>
  <node id="Apply-Orbit-File">
    <operator>Apply-Orbit-File</operator>
    <sources>
      <sourceProduct refid="Read"/>
    </sources>
    <parameters class="com.bc.ceres.binding.dom.XppDomElement">
      <orbitType>Sentinel Precise (Auto Download)</orbitType>
      <polyDegree>3</polyDegree>
      <continueOnFail>false</continueOnFail>
    </parameters>
  </node>
  <node id="Calibration">
    <operator>Calibration</operator>
    <sources>
      <sourceProduct refid="Apply-Orbit-File"/>
    </sources>
    <parameters class="com.bc.ceres.binding.dom.XppDomElement">
      <sourceBands/>
      <auxFile>Product Auxiliary File</auxFile>
      <externalAuxFile/>
      <outputImageInComplex>false</outputImageInComplex>
      <outputImageScaleInDb>false</outputImageScaleInDb>
      <createGammaBand>false</createGammaBand>
      <createBetaBand>false</createBetaBand>
      <selectedPolarisations/>
      <outputSigmaBand>true</outputSigmaBand>
      <outputGammaBand>false</outputGammaBand>
      <outputBetaBand>false</outputBetaBand>
    </parameters>
  </node>
  <node id="Speckle-Filter">
    <operator>Speckle-Filter</operator>
    <sources>
      <sourceProduct refid="Calibration"/>
    </sources>
    <parameters class="com.bc.ceres.binding.dom.XppDomElement">
      <sourceBands/>
      <filter>Lee Sigma</filter>
```

```
      <filterSizeX>3</filterSizeX>
      <filterSizeY>3</filterSizeY>
      <dampingFactor>2</dampingFactor>
      <estimateENL>true</estimateENL>
      <enl>1.0</enl>
      <numLooksStr>1</numLooksStr>
      <windowSize>7x7</windowSize>
      <targetWindowSizeStr>3x3</targetWindowSizeStr>
      <sigmaStr>0.9</sigmaStr>
      <anSize>50</anSize>
    </parameters>
  </node>
  <node id="Terrain-Correction">
    <operator>Terrain-Correction</operator>
    <sources>
      <sourceProduct refid="Speckle-Filter"/>
    </sources>
    <parameters class="com.bc.ceres.binding.dom.XppDomElement">
      <sourceBands/>
      <demName>GETASSE30</demName>
      <externalDEMFile/>
      <externalDEMNoDataValue>0.0</externalDEMNoDataValue>
      <externalDEMApplyEGM>true</externalDEMApplyEGM>
      <demResamplingMethod>BILINEAR_INTERPOLATION</demResamplingMethod>
      <imgResamplingMethod>BILINEAR_INTERPOLATION</imgResamplingMethod>
      <pixelSpacingInMeter>40.0</pixelSpacingInMeter>
      <pixelSpacingInDegree>3.593261136478086E-4</pixelSpacingInDegree>
      <mapProjection>PROJCS[&quot;Stereographic / World Geodetic System
1984&quot;,
  GEOGCS[&quot;World Geodetic System 1984&quot;,
    DATUM[&quot;World Geodetic System 1984&quot;,
      SPHEROID[&quot;WGS 84&quot;, 6378137.0, 298.257223563,
AUTHORITY[&quot;EPSG&quot;,&quot;7030&quot;]],
      AUTHORITY[&quot;EPSG&quot;,&quot;6326&quot;]],
    PRIMEM[&quot;Greenwich&quot;, 0.0,
AUTHORITY[&quot;EPSG&quot;,&quot;8901&quot;]],
    UNIT[&quot;degree&quot;, 0.017453292519943295],
    AXIS[&quot;Geodetic longitude&quot;, EAST],
    AXIS[&quot;Geodetic latitude&quot;, NORTH]],
  PROJECTION[&quot;Stereographic&quot;],
  PARAMETER[&quot;central_meridian&quot;, 0.0],
  PARAMETER[&quot;latitude_of_origin&quot;, 90.0],
  PARAMETER[&quot;scale_factor&quot;, 1.0],
  PARAMETER[&quot;false_easting&quot;, 0.0],
  PARAMETER[&quot;false_northing&quot;, 0.0],
  UNIT[&quot;m&quot;, 1.0],
  AXIS[&quot;Easting&quot;, EAST],
  AXIS[&quot;Northing&quot;, NORTH]]</mapProjection>
      <alignToStandardGrid>false</alignToStandardGrid>
      <standardGridOriginX>0.0</standardGridOriginX>
      <standardGridOriginY>0.0</standardGridOriginY>
      <nodataValueAtSea>false</nodataValueAtSea>
      <saveDEM>true</saveDEM>
      <saveLatLon>false</saveLatLon>
```

```
<saveIncidenceAngleFromEllipsoid>false</saveIncidenceAngleFromEllipsoid>
      <saveLocalIncidenceAngle>false</saveLocalIncidenceAngle>

<saveProjectedLocalIncidenceAngle>true</saveProjectedLocalIncidenceAngle>
      <saveSelectedSourceBand>true</saveSelectedSourceBand>
      <outputComplex>false</outputComplex>
      <applyRadiometricNormalization>false</applyRadiometricNormalization>
      <saveSigmaNought>false</saveSigmaNought>
      <saveGammaNought>false</saveGammaNought>
      <saveBetaNought>false</saveBetaNought>
      <incidenceAngleForSigma0>Use projected local incidence angle from
DEM</incidenceAngleForSigma0>
      <incidenceAngleForGamma0>Use projected local incidence angle from
DEM</incidenceAngleForGamma0>
      <auxFile>Latest Auxiliary File</auxFile>
      <externalAuxFile/>
    </parameters>
  </node>
  <node id="Write">
    <operator>Write</operator>
    <sources>
      <sourceProduct refid="Terrain-Correction"/>
    </sources>
    <parameters class="com.bc.ceres.binding.dom.XppDomElement">

<file>S1B_EW_GRDM_1SDH_20190512T074427_20190512T074527_016208_01E80D_2A1A_Orb
_Cal_Spk_TC.tif</file>
      <formatName>GeoTIFF-BigTIFF</formatName>
    </parameters>
  </node>
  <applicationData id="Presentation">
    <Description/>
    <node id="Read">
            <displayPosition x="37.0" y="134.0"/>
    </node>
    <node id="Apply-Orbit-File">
      <displayPosition x="153.0" y="134.0"/>
    </node>
    <node id="Calibration">
      <displayPosition x="322.0" y="132.0"/>
    </node>
    <node id="Speckle-Filter">
      <displayPosition x="467.0" y="135.0"/>
    </node>
    <node id="Terrain-Correction">
      <displayPosition x="446.0" y="222.0"/>
    </node>
    <node id="Write">
            <displayPosition x="259.0" y="228.0"/>
    </node>
  </applicationData>
</graph>
```

ANNEX B: Bash shell script for generating reduced file size RGB colour composite GeoTIFF

s1_to_rgb.sh:

```
#!/bin/bash

TIFFN=$1
echo `basename "${TIFFN}"`
ROOTFN=`basename "${TIFFN}"`
TMPDIR='/wdmcm/01/20191018_ExtremeEarth/tmp'

# Extract HH image
HHFN="${TMPDIR}/${ROOTFN/.tif/_hh.tif}"
echo $HHFN
gdal_translate -of GTIFF -ot Float32 -co "BIGTIFF=YES" \
  -b 1 -a_nodata 0.0 "${TIFFN}" "${HHFN}"
HH8FN="${TMPDIR}/${ROOTFN/.tif/_hh_8bit.tif}"
echo $HH8FN
gdal_translate -of GTIFF -ot Byte -co "BIGTIFF=YES" \
  -b 1 -scale 0.0 0.30 1 255 -a_nodata 0 "${TIFFN}" "${HH8FN}"

# Extract HV image
HVFN="${TMPDIR}/${ROOTFN/.tif/_hv.tif}"
echo $HVFN
gdal_translate -of GTIFF -ot Float32 -co "BIGTIFF=YES" \
  -b 2 -a_nodata 0.0 "${TIFFN}" "${HVFN}"
HV8FN="${TMPDIR}/${ROOTFN/.tif/_hv_8bit.tif}"
echo $HV8FN
gdal_translate -of GTIFF -ot Byte -co "BIGTIFF=YES" \
  -b 2 -scale 0.0 0.03 1 255 -a_nodata 0 "${TIFFN}" "${HV8FN}"

# Calculate the HV/HH ratio
RATIOFN="${TMPDIR}/${ROOTFN/.tif/_ratio.tif}"
echo "${RATIOFN}"
gdal_calc.py -A "${HVFN}" -B "${HHFN}" --outfile "${RATIOFN}"  \
  --creation-option="BIGTIFF=YES" --overwrite --calc="A/B" \
  RATIO8FN="${TMPDIR}/${ROOTFN/.tif/_ratio_8bit.tif}"
echo $RATIO8FN
gdal_translate -of GTIFF -ot Byte -co "BIGTIFF=YES" \
  -scale 0.0 0.30 1 255 -a_nodata 0 "${RATIOFN}" "${RATIO8FN}"

# Stack the 3 bands to create an RGB composite
echo "Merge"
OUTFN="${TMPDIR}/${ROOTFN/.tif/_rgb.tif}"
gdal_merge.py -o "${OUTFN}" -of "GTiff" -co "BIGTIFF=YES" \
  -separate "${RATIOFN}" "${HVFN}" "${HHFN}" \
  OUT8FN="${TMPDIR}/${ROOTFN/.tif/_rgb_8bit.tif}"
```

```
gdal_merge.py -o "${OUT8FN}" -of "GTiff" -ot Byte \
  -co "BIGTIFF=YES" -co "COMPRESS=JPEG" -separate -a_nodata 0 \
  "${RATIO8FN}" "${HV8FN}" "${HH8FN}"

# Add overviews
echo "Overviews"
gdaladdo --config COMPRESS_OVERVIEW JPEG \
  --config PHOTOMETRIC_OVERVIEW YCBCR --config INTERLEAVE_OVERVIEW PIXEL \
  -r average "${OUT8FN}" 2 4 8 16 32 64 128 256

# Clean up
rm "${HHFN}" "${HH8FN}" "${HVFN}" "${HV8FN}" \
  "${RATIOFN}" "${RATIO8FN}" "${TMPDIR}"/*.xml

exit
```