RemoteID

Identification of Atlantic walrus at haul out sites in Greenland using high-resolution satellite images

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In collaboration with Asiaq Greenland Survey

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ASIAQ GREENLAND SURVEY

PINNGORTITALERIFFIK
GRØNLANDS NATURINSTITUT
GREENLAND INSTITUTE OF NATURAL RESOURCES

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1. English summary

Greenland Institute of Natural Resources and Asiaq Greenland Survey have analysed satellite images of very high resolution for three case study areas of Greenland to observe and detect the presence of Atlantic walrus. We chose this species because individuals or groups hereof rest at particular areas on land or ice for hours in calm and sunny weather between periods of feeding.

The study areas are diverse in time and environment, covering sandy beaches in August at Sandøen and Lille Snenæs in North East Greenland and on moving floes of sea ice in late May and early June at Wolstenholme Fjord in North West Greenland. Similarly, the results of the case studies are varied including unquestionable observations of walrus at Sandøen and not a single certain recognition of walrus at Lille Snenæs and Wolstenholme Fjord. The project has provided insight into the capabilities and limitations of very high resolution satellite images and analysis thereof.

The analyses have included visual inspection, application of change detection using the Multivariate Alteration Detection algorithm, Principal Component Analysis and Independent Component Analysis.

We have proven the technology to be very successful under ideal circumstances, but also inadequate under unfitting environmental conditions.

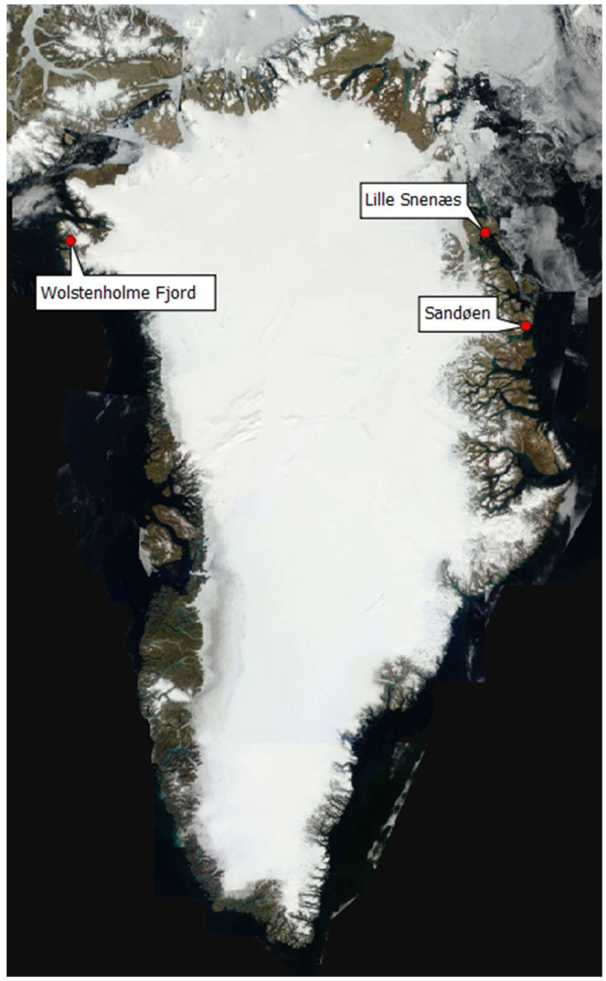

Figure 1: Overview map of Greenland including the selected haul out sites or areas for walrus.

2. Greenlandic summary – Kalaalissut Naalisarneqarnera

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3. Danish summary – sammenfatning på dansk

Grønlands Naturinstitut og Asiaq Greenland Survey har analyseret satellitbilleder af meget høj opløsning for tre studieområder i Grønland med det formål at observere og påvise tilstedeværelsen af hvalros. Denne art blev valgt, fordi individer eller grupper heraf hviler i bestemte områder på land eller is i timer i roligt og solrigt vejr mellem fourageringsperioder.

Undersøgelsesområderne er forskellige i tid og miljø, og dækker sandstrande i august ved Sandøen og Lille Snenæs i Nordøstgrønland og på havis i bevægelse i slutningen af maj og begyndelsen af juni ved Wolstenholme Fjord i Nordvestgrønland. Tilsvarende er resultaterne fra casestudierne forskellige, inklusive sikre observationer af hvalros i individer og grupper ved Sandøen, men derimod ingen bestemmelser af hvalrosgrupper eller individer ved Lille Snenæs og Wolstenholme Fjord. Projektet har givet indsigt i mulighederne og begrænsningerne ved satellitbilleder af meget høj opløsning og analyse deraf.

Analyserne har inkluderet visuel inspektion, anvendelse af ændringsdetektion ved hjælp af multivariat alterationsdetektionsalgoritme, hovedkomponentanalyse og uafhængig komponentanalyse.

Vi har bevist, at teknologi og analysemetoder kan sikkert anvendes under ideelle omstændigheder, men også utilstrækkelig under uegnede omgivelser.

4. Introduction

Greenland Institute of Natural Resources (GINR) has conducted a pilot project on observation of mammals under Arctic conditions using satellite images in partnership with Asiaq Greenland Survey.

The aim of the project was to explore the temporal and spatial capabilities of satellite images of high to very high resolution as an alternative, or as a supplement to aerial surveys of mammals conducted by GINR. Statistically treated data from such surveys form the basis for the biological advice given to the Government of Greenland by GINR concerning determination of hunting quotas or eventually measures of protection. While aerial surveys occur several years apart, earth observation satellites operate all year around, so the idea was that it could be also a cost-efficient method of registration.

On the technological side, the project should further develop the competencies of Asiaq and GINR on management and analysis of very high-resolution satellite images, particularly within the fields of detection of moving and changing objects in dynamic contexts, and the methods of object-based feature extraction. By performing geographically limited but in-depth tests on detection of certain species in the images, the partners should be able to expand the studies to wider areas using automatic or semiautomatic recognition processes.

Satellite imagery of high and very high resolution are expensive to acquire, so a part of the project has been to investigate the possibilities of obtaining participation in the satellite data services for research and education institutions in the United States provided through the agreements between the US National Geospatial Agency and the provider DigitalGlobe Inc.

The environmental aid scheme Danish Cooperation for Environment in the Arctic (DANCEA) of the Government of Denmark, managed by the Environmental Protection Agency at the Ministry of Environment and Food of Denmark, have funded the project, in addition to self-financed contributions by the participating partners.

5. Background information

5.1. Overview of available very high-resolution satellite imagery

To study mammals with optical satellites, the ground resolution of the images needs to be able to unmistakably define the form and colour of the individual mammal, and consequently, best resolution possible is desired.

The US military optical “Key Hole KH-11 Kennan” reconnaissance satellite series have since 1980’s observed the surface of the Earth with a c. 5-10 cm ground sampling distance within a small window or footprint. In fact, the satellites were of comparable construction to the Hubble Space Telescope.

However, this technology is unavailable to public or commercial applications and only reserved for US military use, as regulations prohibit in the United States of America for the satellite businesses to construct sensors of similar specifications and orbits. Detailed commercial imagery became available from 2001 with the Quickbird satellites of DigitalGlobe, and in 2008, their competitors launched GeoEye-1 with 41 cm resolution. The company was in 2013 acquired by DigitalGlobe, which has added the multispectral (colour and near-infrared) WorldView-2 of 46 cm resolution, WorldView-3 of 31 cm resolution and in 2016 the WorldView-4 of 31 cm resolution as well. The resolutions mentioned cover only the panchromatic (greyscale) channels of the imagery, while the multispectral resolutions are around 1.2 meter.

DigitalGlobe has a European competitor in the AirBus Defence and Space providing 0.5 m multispectral data available commercially to a lower price and with less popular tasking demands and consequently more easily available. Airbus also market the SPOT-6 and SPOT-7 satellites of lower resolution (1.5 m panchromatic and 6 m multispectral). The medium resolution sensors cover a greater footprint area on the ground, than those of very and ultra-high resolution, and consequently a larger number of very high and ultra-high resolution images are needed to cover an area similar to the medium resolution images. The SPOT satellites are constructed to assist map production in scale 1:25,000.

The satellites orbit the Earth in tracks, covering strips of the surface of the Earth called swaths, and two or more orbits might be needed to cover larger areas. The operators can programme satellites to cover an area within a decided range of days as the cloud conditions or other variables permit, agreed between the customer and the operator. The satellites can move internally to point towards the area in an angle from the course of the satellite. This procedure is named “tasking” and is of higher cost than archived imagery acquired from the usual orbit of the satellite. The capabilities and details of the named satellites are described later.

5.2. Recent studies of remote sensing methods on polar mammals

Newer studies provide optimism that it is possible to make counts of animals staying in well-defined areas using satellite imagery. A study on an island in Southern Pacific shows convincingly how Elephant Seals located on land in large colonies can be relatively easily counted using high-resolution GeoEye satellite images from DigitalGlobe (McMahon et al. 2014).

The method gives hope that animals, such as walruses, on well-defined landing places can be counted periodically through the season, which would be an absolute advantage over previous surveys from airplanes, which only provide a snapshot of the day and the minute the airplane passed. Possible areas where this technique can be tested is Walrus landing sites in East Greenland such as Sandøen Island and Lille Snenæs peninsula and walrus on sea ice at Wolstenholme Fjord close to Thule Air Base, Pituffik, in North West Greenland.

In another study, images from WorldView2 (also from DigitalGlobe) have been used for counting of Right Whales in 2012 in Argentina (Fretwell et al. 2014). The method showed that it was possible to count the whales, but also can lead to difficulties in their identification on the images. However, some of these problems will be solved with new satellite facilities that are operational in 2014-15. In Greenland, we have only few or none similar specific and small areas of comparable concentrations of whales at a specific time, and consequently the possibility was not tested.

Finally, a study of polar bears has proven it is to some degree possible to use the same type of data as the Right Whale study for counting polar bears on land (Stapleton et al. 2014). The geographical area of the study is relatively small, as the mammals concentrate on an island in Hudson Bay. The polar bears of Greenland are in general more widely spread and more difficult to detect within a small very high resolution footprint. Accordingly this possibility has not been examined further.

The team decided to test the few known haul out sites and areas of sea-ice for resting of walrus only. In the following, the particulars of walrus population and behaviour is described.

5.3. Walrus populations in Greenland

The Atlantic walrus (Odobenus rosmarus rosmarus) is found in West and Northwest Greenland and in Northeast Greenland. There are three ‘subpopulations’ or ‘stocks’ of Atlantic walrus in Greenland (Wiig et al. 2014).

The Central West Greenland walrus stock occurs off the central coast of west Greenland during winter and spring (Andersen et al. 2014). The walruses belonging to this stock stay at two different feeding grounds in the area between the towns Sisimiut and Aasiaat area at Store Hellefiske Bank and off the west coast of Disko Island. In spring, around May, when sea ice retreats from the area walruses leave West Greenland to move to summering grounds in eastern Canada.

The Baffin Bay stock inhabits the coastal waters of Northwest Greenland and the northern Canadian Arctic Archipelago. The walruses in Northwest Greenland move from their feeding banks along the coast in June-July and return from the summering grounds in eastern Canada to the wintering area in Northwest Greenland in October.

In East Greenland one stock is recognized which is called the East Greenland stock. This stock occurs from Scoresby Sound (71° 30' N) and north up to Nordostrundingen (81° 26' N). There have been observations of walruses south of Scoresby Sound however main distribution is north hereof (Born et al. 1995).

In historic time the walruses in both West and East Greenland have been severely depleted. Large herds of several thousands of animals as seen in the Bering Strait area are not seen in Greenland. However, flocks of some hundred's animals have been observed in west and Northwest Greenland (Born and Kristensen 1981, Vibe 1950).

Most recent abundance estimates found 1408 (range: 922-2150) walruses in West Greenland (2012 estimate) (ref) and a stock trend that is not increasing; 2544 (range: 1513-4279) walruses in Northwest Greenland (2014 estimate) and a stock trend that is also not increasing (Heide-Jørgensen et al. 2016), and 1429 (range: 616-3316) walruses in East Greenland (2009 estimate) (Born et al. 2009) and an increasing stock trend.

5.4. Walrus characteristics and behaviour

Adult male Atlantic walruses are about 3 m long and reach a body mass of 1200-1500 kg. Females are somewhat smaller with a body length of about 2,5 m and a body mass of 600-700 kg (Born et al. 1995). Pups are 1-1.4 m in length and weigh from 33-85 kg at birth. The upper canine teeth develop into tusks as the animal grows older. The tusks that grow throughout life are a unique feature of the walrus. Walrus coloration is yellowish to reddish-brown. When the walrus remains in the cold water for longer periods, the coloration fades to pale grey, due to reduced blood flow to the skin. Calves are darker with grey fur (Jefferson et al. 2015).

Figure 2: Walrus hauling out on Sandøen island. Photo: Fernando Ugarte

Walruses are unmistakable on land, ice and in most sightings at sea as long as more than the back is at the surface (Jefferson et al. 2015).

The walrus is a gregarious and social species that nearly always occur in groups – from a few individuals to many thousands. Terrestrial haul out sites in the Bering Strait hold the largest aggregations of walruses in the world when tens of thousands of Pacific walruses haul out simultaneously. In Greenland, the Atlantic walrus populations are significantly smaller - depleted in historic times by hunting, and it is unusual to see herds larger than a few hundred animals.

In Greenland, the sexes are separated for most of the year. Females live in herds with young and juveniles and males live separately from the females except during the mating season. This separation ensures that the big males do not compete with females and young for food (Born 2005).

Walruses are benthic feeders and that forage mainly on benthic invertebrates. Bivalves (clams) represent their preferred food items with the species Mya sp., Hiatella sp. and Serripes sp. making up the bulk of their diet (Born and Acquarone 2007). The benthos invertebrate fauna is mainly found in coastal waters no more than 100 – 200 meters deep. The walrus is therefore most often found in coastal areas with shallow water banks.

In between foraging trips at sea, the walruses spend time resting or hauled out on land or ice. In West and Northwest Greenland, the walrus only haul out on ice. All previous haul out sites on land have been abandoned because of historic hunting (Born et al. 1995). In Northeast Greenland the adult males use the haul-out sites in Dove Bay and Young Sound during summer, while the females stay year-round at Nordostrundingen further north (Born 2005).

From studies on walruses in East Greenland, it has been estimated that walruses spend approximately 30% of their time on land or ice (Born and Acquarone 2007). The walruses are normally hauling out for about 1.5 day after which they are at sea to forage for days in a row (Born 2005). The feeding sites can be located as far as a whole day of travel away from the haul out site and after returning from the feeding expeditions, the animals rests on land or ice. Resting in the sun ensures food can be converted into blubber, which is the walrus energy depot during winter. In August-September when the walruses shed their coat much of their time are spend hauled out on land or ice.

When in the water, the walruses spend a large proportion of time submerged and therefore out of sight. During feeding, the walrus dive for 5-7 minutes where after it is at the surface for about one minute and then it dives again (Born and Acquarone 2007). It can be eating for about 20 hours a day when at the shallow feeding banks (Born 2005).

Mating can take place between November and July, but peak mating time is from February – April. The mating takes place in the water and a delayed embryonic development ensures that birth takes place at the end of May – beginning of June when it is warmer, and the sea ice is breaking up. Females give birth either in the water or on the ice and the weaning period lasts for at least two years (Born 2005, Jefferson et al. 2015).

5.5. Periods and regions of interest

We have identified the most likely sites and periods for remote sensing observation of walrus on land or ice: The island Sandøen in the mouth of Young Sound, where a group is monitored several times in the summer (late July to early September) every year via the nearby scientific monitoring projects; the peninsula Lille Snenæs farther north, as well as the Wolstenholme Fjord in March during the break up period of sea ice and abundance of walrus; exactly the year 2015 field work of tagging walrus with satellite transponders were carried out in the fjord area.

6. Case study areas selected

6.1. Case study Sandøen

Sandøen (“Sand Island”) is an island in North East Greenland at the position N74°16' W20° 9' in the entrance of Young Sound, on a sill formed by deposits of gravel and sand. The dynamical geological developments of the leached deposits have constantly changed the size and form of the island documented in the satellite images of the project. In 2015, the island is of a cutlet shape, c. 850-900 m long from north to south and 100 m and 500 m wide from east to west, totally 18.5 hectares.In 2012, the island was larger towards south where 3 hectares was lost between 2012 and 2015, whereas the eastern part gained 0.8 ha and the northern tip gained 0.3 ha in the same time period. Aerial images from 1987 (Korsgaard et al. 2016) depict the island as being 1,100 m long and of 27 ha. Since that time, areas to the south and east have been lost to the sea, in the western part, area has been gained. Generally, the island is flat and low with wetlands and higher ground in the south-eastern area.

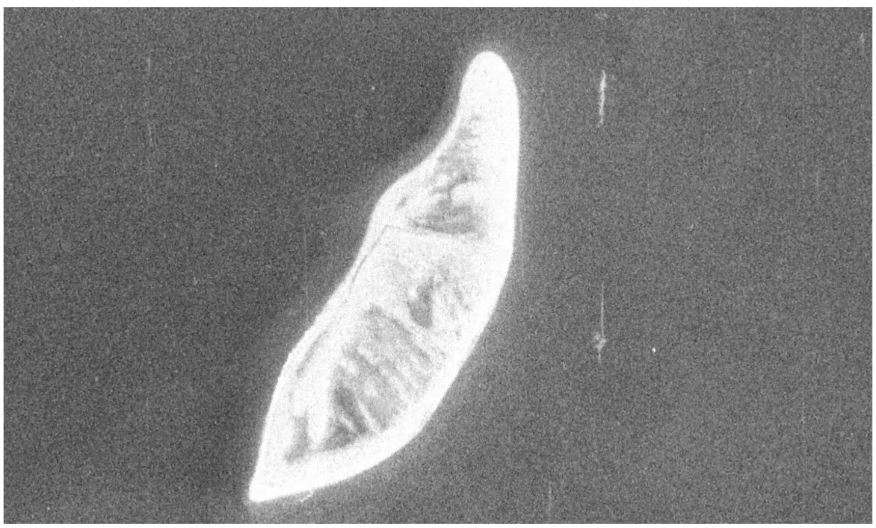

Figure 3: Sandøen Island captured from topographical aerial photography in 1985

Figure 4: Sandøen Island captured on WorldView-2 image of 2012. Courtesy of DigitalGlobe Inc.

Figure 5: Sandøen Island captured on WorldView-3 image of 2015, courtesy of DigitalGlobe Inc.

Sandøen is one of two remaining terrestrial haul-out sites for the Atlantic walrus in Northeast Greenland. Walruses have been observed on land at other sites in Northeast Greenland, but Sandøen and Lille Snenæs are the only two remaining haul out sites known to be regularly used by walruses during summer and early fall. Both sites are mainly used by males, while females are distributed along the coast farther north (Born et al. 1995, 1997). Previous terrestrial haul out sites in Northeast Greenland, West Greenland and Northwest Greenland have been abandoned due to hunting. In Northeast Greenland these includes two sites north of Sandøen, one in Dove Bugt and two in the area close to Scoresby Sound. These two latter sites are the most southern haul out sites known (Born et al. 1995).

In 1995, Born et al. estimated that the haul out site at Sandøen was regularly used by a group of 20-50 male walruses. During August of 2002 and 2003, ID photos of 27 and 37 walruses hauling out on Sandøen were taken, respectively, and in 2002 and 2004 biopsies were taken from 38 and 81 walruses at Sandøen, respectively. Maximum walrus day counts were 47 in 1991, 48 in 1994 and in 2004, 60 walruses were observed to haul out simultaneously on Sandøen (see refences in Born and Aquarone 2007). In 2009, it was estimated that 1429 (range: 616 – 3316) walruses summer in East Greenland (Born et al. 2009).

A study with the purpose of quantifying the trophic role of walruses in Young Sound equipped three male walruses with satellite transmitters to record movement and diving activity in Young Sound (Born and Aquarone 2007). The study was carried out during the open-water season in 1999 and 2001. One of the three walruses was tracked both years. The study showed that overall the walruses spent on average about 44% of their time in the Young Sound. When at sea inside Young Sound, there was a clear preference for the shallow water areas in the northern parts of the fjord west of Zackenberg. During the open water season, haul out time was on average 31,4% (range: 21 – 66%) and the walruses spent on average about 29,5% (range: 11 – 45%) of their time in the water in the Young Sound area. Remaining time was spent along the coast north and south of Young Sound and offshore in the Greenland Sea.

When at sea, about 32% of the time the walruses appeared at depths from 0-6 m and 11% of this time they were at the surface. The remaining time was spent at depths below 6 m.

The monitoring programme BioBasis at Zackenberg Basic of the Greenland Ecosystem Monitoring Programme of University of Aarhus regularly observe walrus, during the month of July near the Zackenberg field station and the surroundings.

In 2010 GINR, conducted studies of walrus on Sandøen including satellite tags and normal observations within the BioBasis programme were not performed (Hansen, J. et al 2011). During the study's core timeline of 22th July to 7th August a daily maximum count was 23.2 individuals on average with the largest number on 31st of August (Born, E. et al 2011). The satellite tag transmitters displayed travels to Sabine Island, Shannon, Hochstetter Forland and Dove Bay, all north of Sandøen, in the period August-October.

In the 23rd of July 2011, 12 walruses were observed by the Zackenberg BioBasis team hauling out, and on 12th September one was seen on the surrounding drift ice.

In 2012 the team achieved one visit observing 12 individuals hauling out, and in 2013, the team observed 11 walruses on haul out on the island and additionally four in the water near the beach. (Hansen et al 2012, Hansen et al 2013).

6.2. Case study Lille Snenæs

Lille Snenæs ("Little Snow Headland") is located in Dove Bugt ("Dove Bay") also in North East Greenland, but farther north than Sandøen. The isthmus and nearby coasts are located west of Danmarkshavn station populated by the Sirius military patrol. The patrol members and other visitors regularly observe walrus at the site, which also holds a small cabin "Lille Snenæs hytten". The coastline, Winge Kyst, is much rockier and varied than at Sandøen, but also incorporates strips of beaches of gravel and sand.

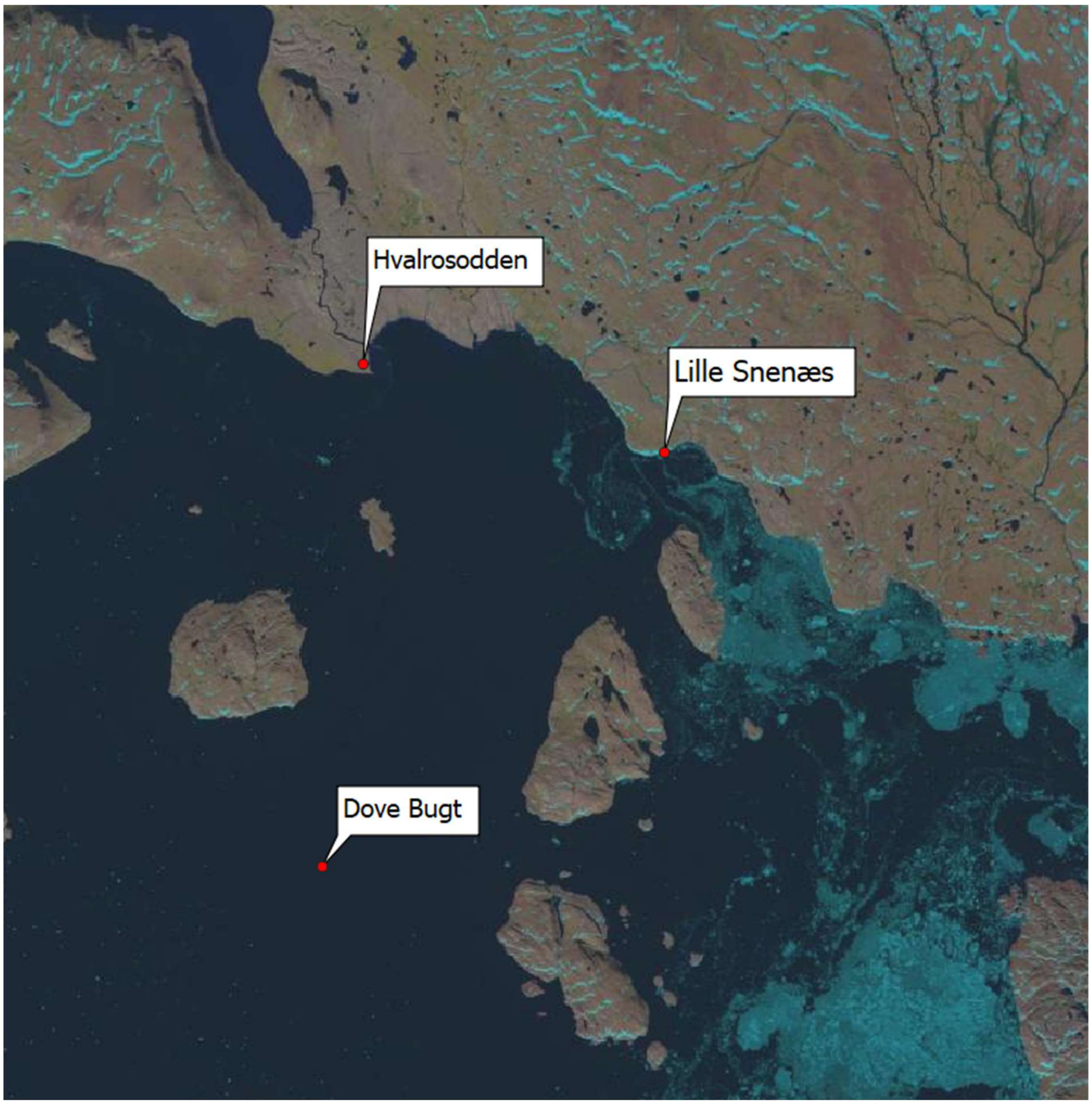

Figure 6: Lille Snenæs case study area with the Dove Bugt (bay) and Hvalrosodden locations marked. Satellite image: USGS Landsat 8 of 6/8-2015.

Lille Snenæs is, as Sandøen, a terrestrial haul-out site for walrus in Northeast Greenland. Many of the terrestrial haul-out sites previously used by walrus in the area are now abandoned, e.g. Hvalrosodden ("walrus point") in northwestern Dove

Bugt, because of historical hunting (Born et al. 1995). Lille Snenæs is located approximately 10 km east of Hvalrosodden and in the summer of 1933, 50 walruses were seen on the beach (see references in Born et al. 1995). A later study suggested that about 50 males used the haul out site at Lille Snenæs (Born and Knutsen 1990). The walruses migrate into Dove Bay during the open water season to feed intensively on the mollusc's banks and to rest and moult on land at Lille Snenæs between feeding excursions (Born and Knutsen 1992). During late July until late September/early October, the shore-fast ice is usually absent in northeastern Greenland, and this is when the walruses can exploit the inshore mollusc feeding banks. The Lille Snenæs haul out site is exclusively used by males and it is the same individuals that occupy the beach during the open water season, and also in subsequent years (Born and Knutsen 1992).

In the fall, during late September and early October, the formation of a dense cover of land fast ice forces the walruses offshore into the Greenland Sea. Here they winter in leads and cracks in the pack ice from 80 – 82°N off the coast of Northeast Greenland (Born and Knutsen 1992).

Born and Knutsen (1997) observed a group of about 50 male walruses at Lille Snenæs during August and September 1989 and 1990. Eight of the males were equipped with satellite-linked radio transmitters. The study showed that the walruses that use Lille Snenæs for feeding and resting haul out for approximately 30% of their time. When ice floes are available the walruses spend about 11% of this time on ice, while when ice is absent they haul out more on land (Born and Knutsen 1997). During the late summer and early fall (August-September) duration of haul-out periods for walruses at Lille Snenæs averaged 11 hours on ice (range: 1 – 29 h) and 38 h on land (range: 13 – 64 h). Walruses at Lille Snenæs haul out less on land when the weather is wet, windy and cold, which seem to be a general trait for walruses, that prefer to haul out in warm and calm weather. When foraging, walruses are submerged for about 81% of the time (Born and Knutsen 1997).

6.3. Case study Wolstenholme Fjord

The third site, Wolstenholme Fjord, Ummannap Kangerlua, is located in Northwest Greenland off Thule Air Base, Pituffik, at 76°35'N 69°11'W. The area of interest is located at the entrance to the fjord between Moriusaq hamlet and Thule Air Base, Pituffik, around the island Appat (Saunders Ø).

The walruses found in the area around and in Wolstenholme Fjord belong to the Baffin Bay stock. These walruses stay approximately 2/3 of the year in Northwest Greenland from October–June/July. In June/July when sea ice retreats from the area the walruses cross Smith Sound and summer in shallow fjords and inlets at the Canadian side of Smith Sound. In Canada, the most frequently used summering grounds are in the eastern part of Ellesmere Island (Heide-Jørgensen et al., in press).

In winter, when the Wolstenholme Fjord area is largely covered by sea ice, sea birds and marine mammals, including the walruses, rely on the open-water polynya, the North Water Polynya. The North Water Polynya that is found west of Wolstenholme Fjord is highly productive and is considered key habitat for overwintering animals. The walruses that winter here have access to shallow molluscs' banks and are therefore able to find food throughout the winter months (Heide-Jørgensen et al. 2016).

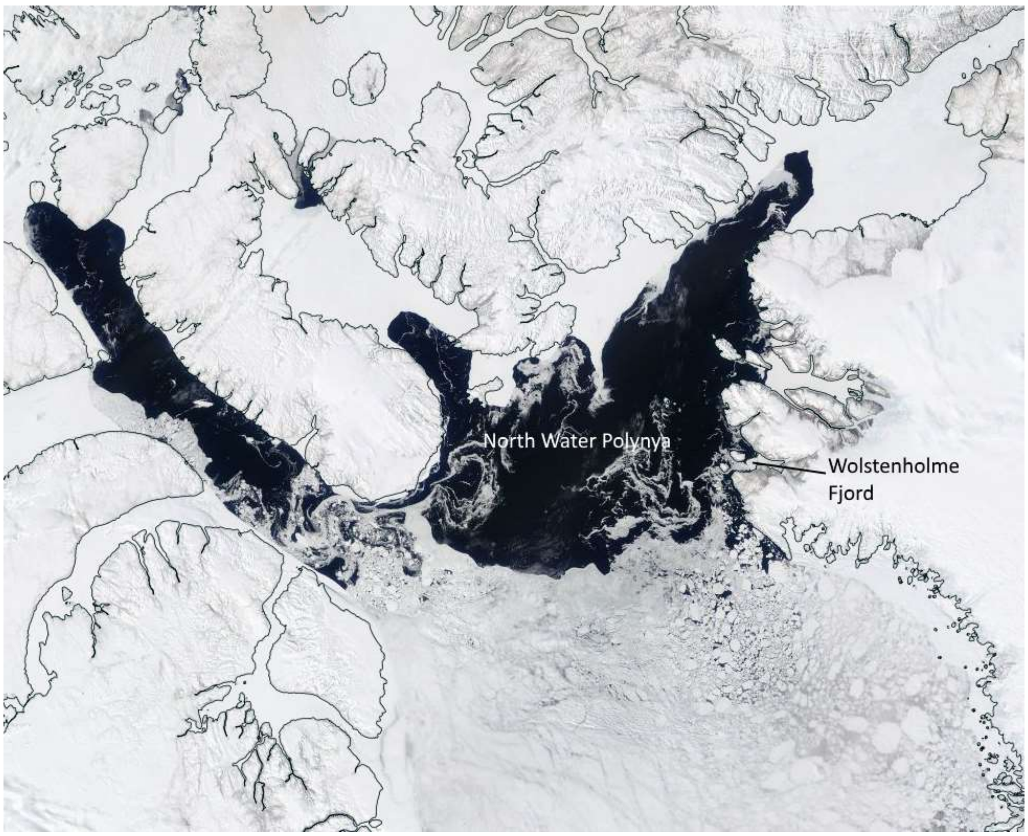

Figure 7: North Water Polynya open water and Wolstenholme Fjord. MODIS satellite image from the NASA Worldview service.

There are no terrestrial haul-out sites in Wolstenholme Fjord and walruses here haul out on the sea ice. Vibe (1950) mentioned a terrestrial haul-out at Udvle on the south coast of Wolstenholme Fjord east of Thule Air Base but this site is now abandoned. Vibe (1950) also described walrus foraging banks in Northwest Greenland. Foraging banks ranged from the south-eastern part of Smith Sound to Kane Basin constituting the northern boundary of walrus distribution. Foraging grounds in the Wolstenholme area was described to be mainly located around Wolstenholme Ø and Saunders Ø and north to Kap Parry.

According to Vibe (1950) males were in surplus in the Wolstenholme area, an observation that was supported by Born and Kristensen (1981) that described that mainly males were taken in the hunt around Saunders Ø. Heide-Jørgensen et al. (in press) also found that females with calves were generally rare in Wolstenholme Fjord.

Born and Kristensen (1981) studied the occurrence and hunting of walrus in the Thule area. They described that when the sea ice is forming in the fjords during fall the walruses are forced away from the area and the shallow feeding grounds. However, heavy storms will often break up the sea ice in the fjord and the walruses will then move back into the banks where they stay until the ice one again is too thick. The walruses have no way of maintaining a breathing hole but will instead try to break the ice with its head and shoulders. This is doable until the ice is approximately 5-10 cm thick after which the walruses are forced to leave the area. Born and Kristensen (1981) also described that the hunt for walruses near Saunders Ø in February is occurring when the sea ice is still thin. Hunters locate the walruses by their exhales when at the surface to breath and harpoon them while still in the water. In spring, the walruses sunbathe on the floating ice floes between their foraging trips and they are then hunted when on the ice or in the water.

7. The capabilities of very high-resolution imaging satellites

This project involves the utilization of Earth observation imagery satellite data as the core data source for methods of identifying and counting animals. The applied satellites are of high and very high resolution and have low, polar, sun-synchronous orbits around Earth. The satellites can, when tasked and programmed, change course and angle slightly for observation of specific areas of the earth at certain periods.

For observation of radiation of light from the Earth's surface, the satellites measure a number of optic bands, each recording selected wavelengths of light including near infrared and infrared wavelengths, measured as the spectral resolution. Standard bands are the panchromatic band (PAN) recording greyscale in high detail, and the multispectral (MS) bands of less high detail recording wavelengths for red, green and blue colours (RGB) as well as near-infrared (NIR). Other wavelength bands might also be recorded, such as Short Wave Infrared (SWIR), albeit at a lower resolution.

Each band is stored as a numeric raster image file divided into equally sized pixels representing a part of the observation on the surface of the Earth and as such a geometric area. The size of each pixel on ground is the spatial resolution or Ground Sample Distance, GSD, which varies between the imagery product as primarily a function of the altitude of the satellite and the capabilities of the satellite's lens and image sensor. The angle of observation from satellite to ground (off-nadir) also affect the GSD, as the larger the off-nadir values the larger the GSD values. An off-nadir angle below 20 degrees is often recommended.

The multispectral bands of red, green and blue is mixed to a natural colour RGB image and resampled to a higher detail (pan sharpening) using the panchromatic band. For the current analysis also the near-infrared band (NIR) to calculate brightness of the image and furthermore the NIR-ratio, which assists the detection of particular objects in the image such as walrus individuals and changes in values indicating moving objects.

High and Very High Resolution Satellites are available only commercially, unlike governmental satellites such as the low to medium resolution MODIS, Landsat and Sentinel satellite families, which are free of charge. The most dominant distributors are the US company DigitalGlobe Inc. with WorldView-2 and -3, QuickBird and others, and the European company Airbus Defence and Space.

Satellite/ GSD	PAN	RGB & NIR	Other MS
WorldView-3	0.31 m	1.24 m	Coastal, yellow, red edge, near-infrared2
WorldView-2	0.46 m	1.84 m	Coastal, yellow, red edge, near-infrared2
QuickBird	0.61 m	1.63 m	None
Pléiades 1A/B	0.50 m	2.00 m	None
Spot-6	1.50 m	6.00 m	None

Table 1: General capabilities of applied satellites

7.1. Request and search for data

In order to receive this commercial satellite imagery data, it is necessary to either request new observations via tasking, or archived imagery. For tasking requests, the customer is required to set a timeframe, an area of interest geographically, a maximum cloud cover, and a desired number of revisits needed. The success of the tasking inquiry in obtaining observation results will rely on possibilities of revisits by the satellite, weather in the area of interest at the visit, and eventual conflicting or more important requests for observation. Tasking of the highly capable WorldView-2 and WorldView-3 is popular within the US government and research organisations and consequently, foreign inquiries are often of lower priority.

Concerning archived data, a timeframe, maximum cloud cover, and area of interest is also required from the customer in search for available data. The outcome of the inquiry is dependent on whether observations are generally available in the area as a result of previous tasking, and popularity of the area, e.g. areas of high activity such as urban centres are more likely to have good and repeated coverage than wilderness of low human activity. In the case of Greenland, some satellites like Spot-6 and Pléiades 1 A/B only have very few imagery scenes available, while the archives of DigitalGlobe (WorldView-2, -3 and Quickbird) hold numerous scenes across the country, and particularly of the areas of interest to US research projects such as for large outlet glaciers from the Greenland Ice Sheet. However, the number of scenes per year varies greatly, and for some areas, there can be months or years between the observations.

The cost for requisition of tasked imagery is much higher than archived imagery, particularly for the Very High Resolution imagery, so if possible archived imagery should be requested due to the costs. It was the aspiration of the project that data could be requested via the EnhancedView agreement between the imagery data provider DigitalGlobe Inc. and the Government of the United States' organisation National Geospatial-Intelligence Agency, NGA. This agreement makes it possible for US governmental as well US research organisations to request and utilize imagery of very high resolution, and the Arctic-Antarctic imagery data is handled by Polar Geospatial Center at University of Minneapolis, whom Asiaq, and to some extent GINR collaborate with. However, our inquiry was not entirely within the scope of the agreement, which should primarily support US researchers working on grants from National Science Foundation, NSF, or the National Space Agency, NASA, who unfortunately are not involved in this project directly. This fact made it impossible for Polar Geospatial Center, PGC, to accommodate the inquiry of the project fully; however, the centre assisted in tasking of DigitalGlobe satellites. The project was able to receive research and educational discount through the customer account of University of Copenhagen. DHI GRAS A/S, a Danish consultancy company, assisted as inquiry agent for the project.

The total quantity of raw data from the tasking and archive requests is 52 Gigabytes, of which the majority covers Wolstenholme Fjord, which is a geographically larger area than Sandøen and Lille Snenæs and consequently requires more data for coverage.

Data from the distributors are often automatically pre-processed products. To some extent, the imagery is corrected for distortions from the acquisition angle from the satellite sensor to the ground level and topographically for distortions of the terrain morphology which obscures how the image display the ground geometrically. Other distortions are usually radiance of light in the atmosphere (TOA, Top of Atmosphere Reflectance) from the sunlight reflecting in the clouds, or sunlight reflected from the surface of the Earth (Surface Reflectance). Usually it is possible to depend on the pre-processed data, but in some cases, it is necessary to perform calibrations custom to the image. None of the images used for the project needed special calibrations.

Data from the distributors are delivered in the generally used digital format, GEOTIFF, including metadata on the observation and chain of pre-processing, and can thus be readily applied to geographical information systems. The product are slightly different depending on their family of satellite, e.g. DigitalGlobe or AirBus.

Satellite	Format	Metadata	Map projection	Other
WorldView-3	GEOTIFF	IMD	Local UTM	Tiled, not pansharpened
WorldView-2	GEOTIFF	IMD	Local UTM	Tiled, not pansharpened
QuickBird	GEOTIFF	IMD	Local UTM	Pansharpened
Pléiades 1A/B	GEOTIFF	DIM	EPSG:4326	Pansharpened
Spot-6	GEOTIFF	DIM	Local UTM	Pansharpened

Table 2: Satellites, formats in use, map projection and initial steps for pansharpening.

The full list of acquired imagery for the case studies areas was as follows:

Site	Name	Satellite	Date
Sandøen	2012-08-16_144211-WV2	WorldView-2	2012-08-16
Sandøen	2015-08-04_134323_PHR1A1	Pleiades-1A	2015-08-04
Sandøen	2015-08-06_141647_PHR1B1	Pleiades-1B	2015-08-06
Sandøen	2015-08-19_132753_PHR1B1	Pleiades-1B	2015-08-19
Sandøen	2015-08-28_135823_PHR1A1	Pleiades-1A	2015-08-28
Sandøen	2015-08-28_140127-WV3	WorldView-3	2015-08-28
Lille Snenæs	2015-08-02-1357496_PHR1A	Pleiades-1A	2015-08-02
Lille Snenæs	2015-08-06-1553504_PHR1B	Pleiades-1B	2015-08-06
Lille Snenæs	2015-08-20-1320064_PHR1A	Pleiades-1A	2015-08-20
Lille Snenæs	2015-08-20-1458000_PHR1A	Pleiades-1A	2015-08-20
Lille Snenæs	2015-08-30-1342419_PHR1A	Pleiades-1A	2015-08-30
Lille Snenæs	2015-08-30-1520286_PHR1A	Pleiades-1A	2015-08-30
Wolstenh. Fjord	2010-05-31_R1C1-QB2	Quickbird	2010-05-31
Wolstenh. Fjord	2011-06-12_R1C1-WV2	WorldView-2	2011-06-12
Wolstenh. Fjord	2015-06-08_R1C1-SPOT6	SPOT-6	2015-06-08
Wolstenh. Fjord	2015-06-09_R1C1-WV3	WorldView-3	2015-06-09

Table 3: List of all images purchased, their site location, image name, satellite and date of acquision.

8. Processing the data before extraction

8.1. Pre-processing the data

Before the procedures of analysis and extraction of objects of interest can commence, the images must be processed somewhat further by fusion of the black and white image band with the multicolour bands by pansharpening, transformation into a ground true coordinate system and aligning of the images for each site with each other.

8.1.1. transformation and Pansharpening

In order to use the imagery for observation and analysis at a detailed local scale it is necessary to use the map projection in Universal Transverse Mercator, UTM, which provides best description of features on the ground concerning their length, area and form true to reality on the specific spot. In the UTM system, the Earth is divided into a number of local zones perpendicular to the Equator, and Greenland is covered by the zones 19 to 28. The areas of interest to the project fall within the zones 27 for Sandøen and Lille Snenæs and zone 19 for Wolstenholme Fjord. Consequently, un-projected imagery in longitude-latitude must be transformed to UTM, which is the case for Pléiades imagery. In order to view and analyse at the imagery at the highest available detail, a process of pansharpening is applied. This process provides nuances to the multispectral bands from the panchromatic band using its raster cell (pixel) size and thus multiplying the multispectral detailing as well as the storage size from e.g. 250 megabytes to 8 gigabytes.

8.1.2. Aligning the images of each site

Although multiple satellite images cover the same areas of Sandøen and Lille Snenæs, the geo-location of the imagery is not precise enough. This results in coordinate values of the same spot on the ground varying between image. The cause of this error is that georeferencing of the satellites is not robustly calibrated over the areas due to the large distances to Ground Control Points on the surface of the Earth. There were no local Ground Control Points available to the project within the Areas of Interest that could be used for custom calibration of positioning. For Sandøen, it was possible to identify a spot on the ground, which could be identified in all images and consequently used as a common reference point positioned relatively between the images and to which all images were shifted and repositioned. This simple one-point linear transformation worked well for the scenes covering Sandøen.

For the area of Lille Snenæs, a comparable process was applied without the same success. It was necessary to identify five, relatively positioned, artificial Ground Control Points in a base image to perform a transformation of the other images to this base image, but the result displayed great distortions to the images. Other methods using more advanced algorithms such as polynomial 1, 2 or 3 was applied as well as Thin Plate Spline and Projective transformation algorithms. These algorithms take into account non-linear deformations between two images but were however not successful in aligning the coastline between the images.

For unknown reasons, it was not possible to do a complete internal alignment of the images without large errors. These positional differences between the images affected the later calculations and processes of automatically detecting changes and anomalies between the images.

For Wolstenholme Fjord, the walruses were potentially situated on drifting ice floes. Within the time frame of the project, detecting changes within a moving background was not possible. Consequently, it was not necessary to mutually align the images, so the original positioning of the images was kept unchanged.

8.2. Further processing to analytical raster data

The pre-processing steps described above sharpened and aligned the positions of the image scenes for each site, so further analyses are possible for extraction of specific objects on the ground, possibly walruses. The further analyses utilize the image bands: red, green, blue and near-infrared.

8.2.1. Land-Sea interaction mask and proximity to sea analysis

The satellite images cover both land and sea areas, and for the sites of Sandøen and Lille Snenæs, much of this was not of interest to the study as the walrus haul out close to the coast. For both sites a polygon of the coastline was manually digitized in GIS. Using the gdal_proximity script from GDAL in GIS, a raster matrix of distance from any spot on the ground to the nearest coastline was calculated.[1]

[1] Frank Warmerdam: gdal_proximity.py. Application for computing raster proximity maps. http://www.gdal.org/gdal_proximity.html

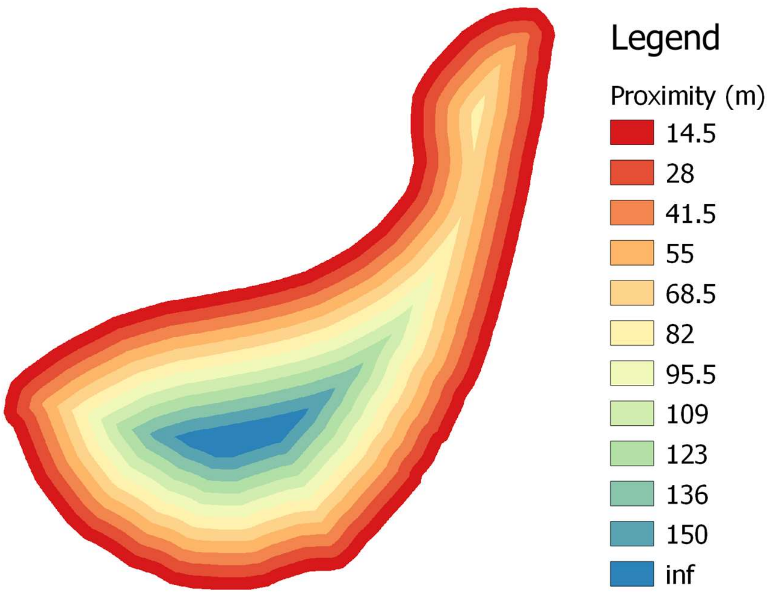

Figure 8: Proximity map of Sandøen Island. Distances from coastline.

8.2.2. Brightness and NIR ratio

Other data analysis to be fed into the feature extraction is NIR ratio taking into account the near-infrared values reflected from the objects on the ground to the satellite sensor's near-infrared band. The analysis is done as arithmetic calculations of addition and division between the values of the individual raster bands of the image.

The Brightness analysis is done by addition of all four bands, red, green, blue, and near-infrared; and assists the feature extraction by emphasizing elements in the raster such as abrupt differences such as darker shadows.

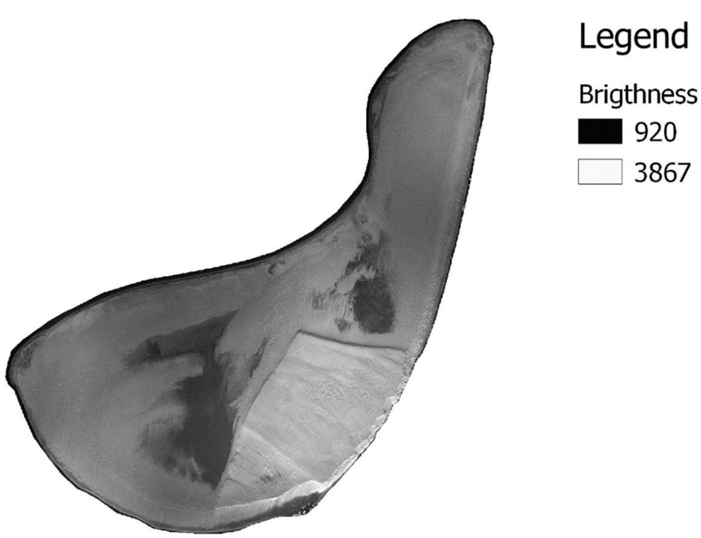

Figure 9: Brightness analysis of Sandøen.

The NIR ratio analysis takes the brightness analysis a step further by dividing the values of the near-infrared band with the newly calculated brightness raster.

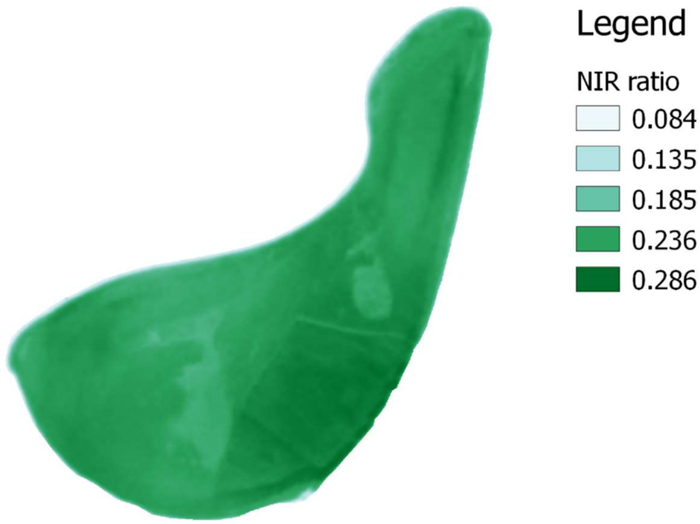

Figure 10: NIR ratio raster calculated from the near-infrared values divided by brightness

8.2.3. Multivariate Alteration Detection

For the Sandøen and Lille Snenæs sites we have obtained a series of images throughout the month of august 2015. The algorithm of Multivariate Alteration Detection (MAD) can be used to identify changes between the images and the supporting analytical raster data sets. The method is developed by Nielsen and Conradsen, and the application is incorporated into Orfeo Toolbox (OTB), which is included in QGIS. The MAD algorithm analyze the difference between two rasters positioned at the same place. The images of Sandøen have been analyzed using Multivariate Alteration Detection as the images are aligned strictly one over the other. This is not the case for Lille Snenæs, meaning the algorithm could not be applied to the data set.

Using the MAD algorithm is simple within QGIS 2.x and Orfeo Toolbox: an input image from the first date and an input image from a later date is selected, and the name of the resulting change raster image is determined.

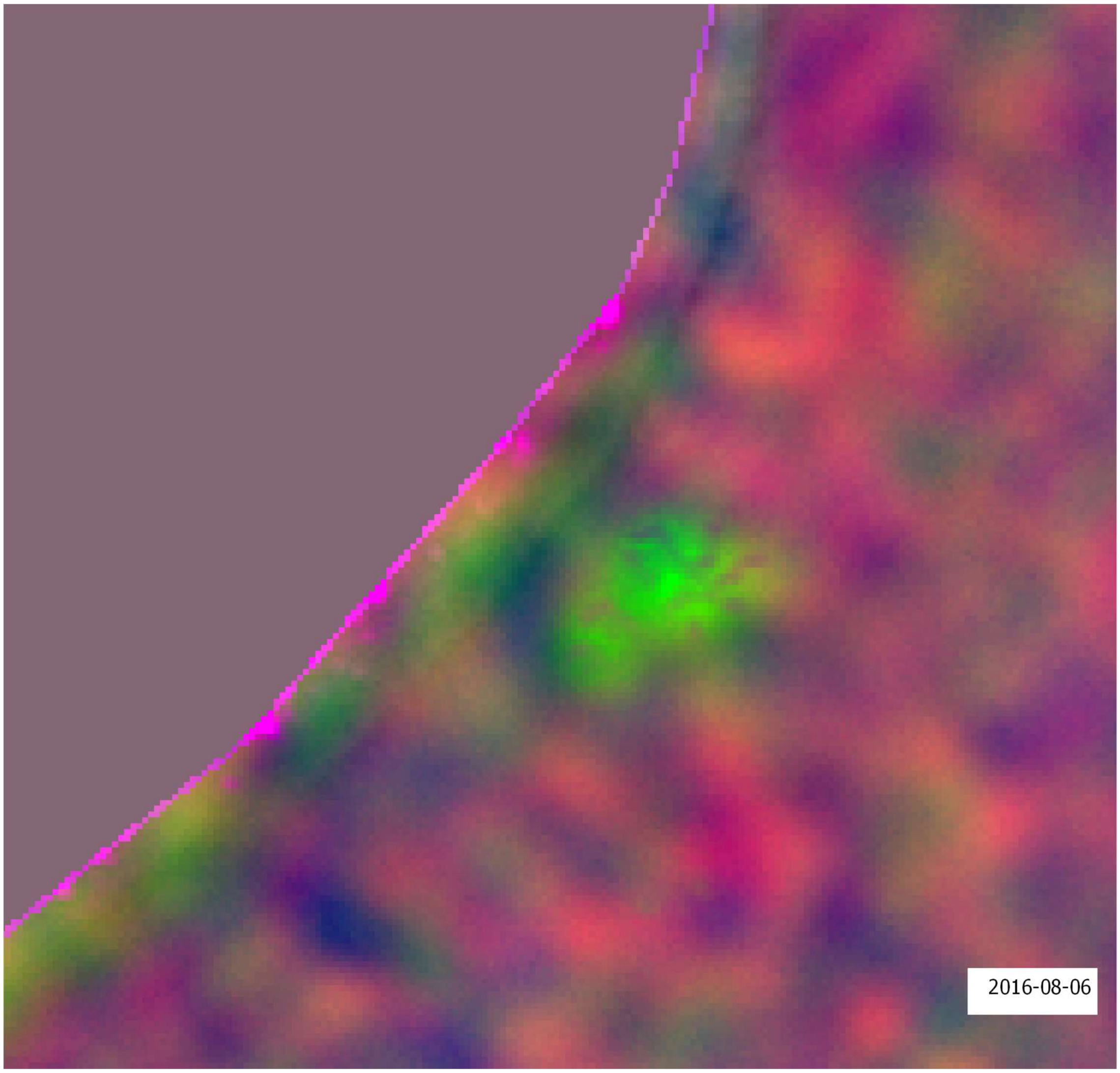

Figure 11: Multivariate Alteration Detection from two images from Sandøen – from 2015-08-04 to 2015-08-06. The green colors mark intense change between the images – at the beach concerning tide waves and for the group of walruses.

9. Object based feature extraction

Within remote sensing classification calculations, you can either use pixel-based extraction of features pixel by pixel, or object based feature extraction connecting a group of pixels into regions sharing similar properties, eventually across different imagery bands and by searching for specific types of shapes.

The software package, eCognition (http://www.eCognition.com/), was chosen to help localize walruses on the satellite images. It is an object-based image analysis software, meaning that it operates in a more human like fashion by considering groups of pixels in context, as opposed to the traditional pixel-based methods. This can be a beneficial approach when trying to identify features in an image that do have certain specific characteristics regarding shape, size and colour.

The image is subdivided, or segmented, into objects of varying sizes depending on the properties and context of neighbouring pixels and depending on the minimum object size defined by the user. Further classification and feature extraction can then be carried out on these objects.

In the following sections we outline the methods and results of the image analyses for two regions in NW Greenland; Sandøen and Lille Snenæs. A discussion of the results for each region is given and finally recommendations are suggested based on experience gained so far.

9.1. Principle Component Analysis and Independent Component Analysis

In order to assess the benefits, specifically simplicity and robustness of the processing scheme; and to include as much potential information as possible in the analyses, Principle Component Analysis (PCA) (Comon, 1994) and Independent Component Analysis (ICA) (Hyvärinen and Oja 2000) were derived for selected scenes. Both of these methods are commonly used to extract hidden signals from multivariant datasets, such as multiband satellite scenes. It is assumed that the dataset is a linear mixture of unknown variables. All the variance in the image is analysed allowing a linear transformation of the data onto new un-correlated axes. The resulting new set of components are equal to the number of bands in the original image and are as independent as possible. The greatest amount of variance is captured in the first component, with progressively less in successive components. The PCA is based on second-order statistics; limited to defining orthogonal axis; and relies on Gaussian features. The ICA method is based on higher-order statistics and assumes that data is non-gaussian. The original image can be reconstructed from all the components, but data redundancy can be minimised by selecting only certain components.

9.2. Feature extraction at Sandøen site

The Sandøen scenes were processed first since there are easily identifiable walrus in the images (Fig. 1). This is a homogeneous sand island, with little extra material to create noise in the images.

Figure 12: Sandøen, Pleiades-1B image (2015-08-06_141647_PHR1B1) of Sandøen. Red box indicates a group of walrus.

9.2.1. Methods used for Sandøen case study

Each satellite scene (Table 3) was analysed as an individual project in eCognition. The input files for each project included the files created in the previous processing steps, i.e. 1) the clipped scene; 2) brightness image; 3) NIR-ratio image; 4) all MAD images that used the selected scene; 5) the distance_to_ocean raster. Sandøen is a small enough island that the clipped image (section 8.1 Pre-processing the data) with the entire island could be included in the eCognition analysis.

In order to limit the search area to regions most likely containing walruses, a segmentation was first applied using the distance_to_ocean raster with thresholds of 5 and 50. This created a zone round the coast in which further analysis was carried out. Focussing the area of interest to a coastal band assumes that the walruses do not move large distances inland, an assumption that is supported by animals identified in the Sandøen scenes.

The processing steps used for each scene are listed in Table 4.

SCENE	1. Multi-threshold segmentation	2. Multi-resolution segmentation	3. Assign class; mean b3	4. Assign class; mean NIR ratio	5. Assign class; length/width	6. Assign class; Dist to AOI	7. Assign class; mean b8	8. Export AOI
0804 PH	<=5 < unclassified <=50 < notAOI on dist_to_sea	10	unclassified < 440: b3low	b3low > 0.24 : NIRhigh				X
0806 PH	<=5 < unclassified <=50 < notAOI on dist_to_sea	10	unclassified < 500: b3low	b3low > 0.27 : NIRhigh				X
0819 PH	<=5 < unclassified <=50 < notAOI on dist_to_sea	10	unclassified < 474: b3low	b3low > 0.21 : NIRhigh		NIRhigh < 100Pxl : AOI		X
0828 PH	<=5 < unclassified <=50 < notAOI on dist_to_sea	10	unclassified < 330: b3low	b3low > 0.21 : NIRhigh	NIRhigh < 2 : AOI			X
0816 WV2	<=5 < unclassified <=50 < notAOI on dist_to_sea	10	unclassified < 364: b3low				b3low >=146 : AOI	X
0828 WV3	<=5 < unclassified <=50 < notAOI on dist_to_sea	10	unclassified < 310: b3low				b3low > 163 : AOI	X

Table 4: eCognition processing steps used to locate walruses in Sandøen scenes.

1. Assign class based on distance to sea to create zone of interest near coast (multithreshold segmentation).
2. Multiresolution segmentation using all available data (except distance raster)
3. Assign class based on thresholding band 3
4. Assign class based on thresholding NIR ratio
5. Assign class based on thresholding length/width ratio of objects
6. Assign class based on distance of objects to class AOI (removes individual spatial outliers)
7. Assign class based on thresholding band 8
8. Export AOI shape files (be sure to assign class as meta data

9.2.2. PCA and ICA analyses for Sandøen case study

Before performing the PCA and ICA, the images were masked so that only the region of interest, i.e. the coastal band remained. This limits the amount of unnecessary information in the image that may reduce the usefulness of the derived components.

The analyses were carried out in the software ENVI using the Thor anomaly detection tool. For each satellite scene, a visual inspection was made to identify the components which gave the best visualisation of the walruses. The component and associated band in the original image, which most influences that component are given in Table 5. The PCA component 1 was used for segmentation (Table 4, step 2) in the eCognition project.

Analysis	PCA component								ICA component							
Component	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
150804(PH)	b3															
150828(PH)	b3								b1			b1				
150819(PH)	b3	b4 track														
150806(PH)	b3								b2 edge							
120816(WV2)	b3			b4												
150828(WV3)	b3, b5, b7	b1,b5	b 7								b2, b5, b8		b5			

Table 5: PCA and ICA results for each Sandøen satellite scene. PH = Pleiades; WV= WorldView. (b1-b8 are the band numbers of the original scenes, where PH has 4 bands and WV has 8 bands)

9.2.3. Results for Sandøen case study

Table 4 shows that using the original satellite scenes with standard derived products of brightness, NIR ratio and MAD, the first three steps were highly effective at reducing the number of potential objects and were common to all scenes. The fact that the threshold used in step 3 is scene dependent limits the ability to automate the procedure.

Process 4 (or 7 for the WorldView scenes) was then sufficient for 4 of the 6 scenes to select the walrus objects. For the remaining two cases a spatial or geometric condition was set to remove remaining noise.

An example of the resultant classification is shown in Figure 13, with all scenes given in Appendix 1.

Figure 13: Sandøen, WorldView 2 scene (2012-08-16_144211-WV2). Green shading are areas outside of the region of interest defined by distance from the sea. The red outlines are the objects identified with the processing steps given in Table 4.

The PCA and ICA results are given in Table 4. A visual check showed that the PCA was more effective at capturing the walruses (Figure 14). For all scenes, component 1 of the PCA was the best, suggesting that this may also be relatively robust. This is not surprising since the first component contains most of the variance in the data. It is interesting to note that it is band 3 that most influences the PCA component 1, and also band 3 that determines step 3 in Table 4. The ICA analyses on the other hand were not so effective at capturing the walruses and were less consistent in the component that fared best.

Using the PCA component 1 together with the original clipped image for segmentation in eCognition, good object definition was obtained in that the walrus bodies were captured as objects. However, the values of the PCA component 1 are scene dependent, meaning that a standard threshold for identifying the walrus could not be used.

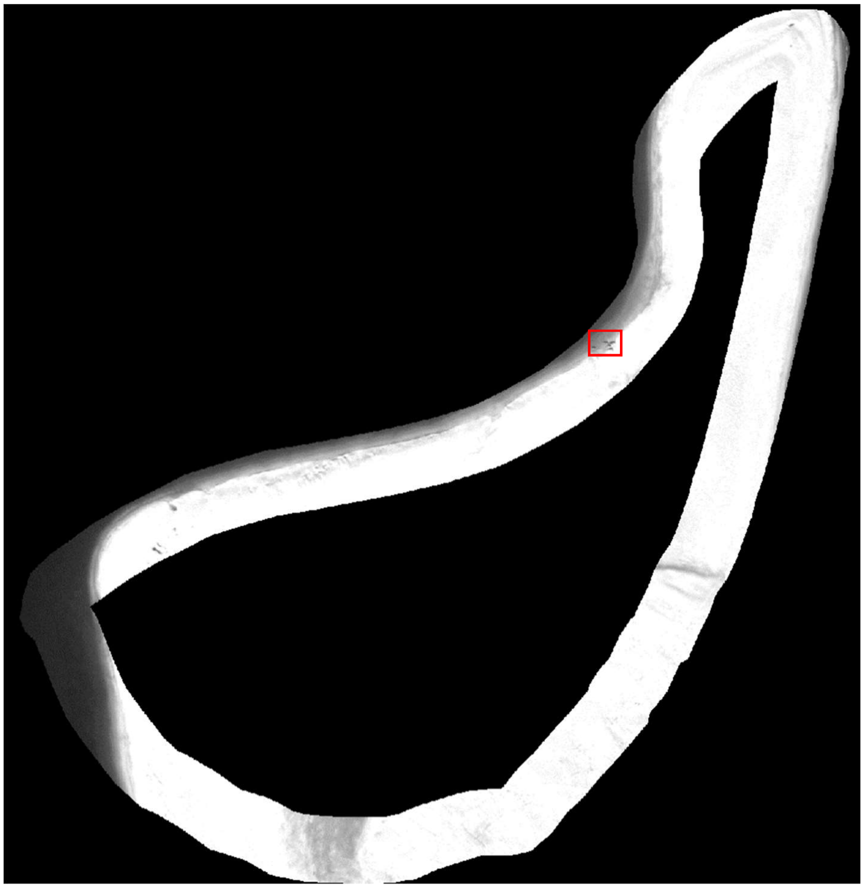

Figure 14: Sandøen, World View 2 scene (2012-08-16_144211-WV2). PCA component 1. Red box indicates location of the walruses

9.2.4. Discussion concerning the case study Sandøen

Sandøen is a relatively small and homogeneous area where walruses are easily identifiable in the scenes. The scenes were well co-registered meaning that the MAD analyses showed actual changes in the environmental as opposed to shifts in the scene location. In essence, Sandøen is a perfect example for deriving a simple processing scheme. Full automation of the processing is however problematic since thresholds are used in many of the key steps and these are scene dependent.

In this case, the use of PCA and ICA did not provide a better alternative processing option compared to the use of the other derived products, i.e. MAD, brightness, and NIR ratio.

9.3. Feature extraction at Lille Snenæs site

Lille Snenæs is a much larger area of interest covering a coastline of approximately 11 km (Figure 15). It is a highly varied coastline with snow patches, river mouths, rocky outcrops, boulders, steep cliffs and sandy beaches. No walruses have been visually identified on the available satellite images.

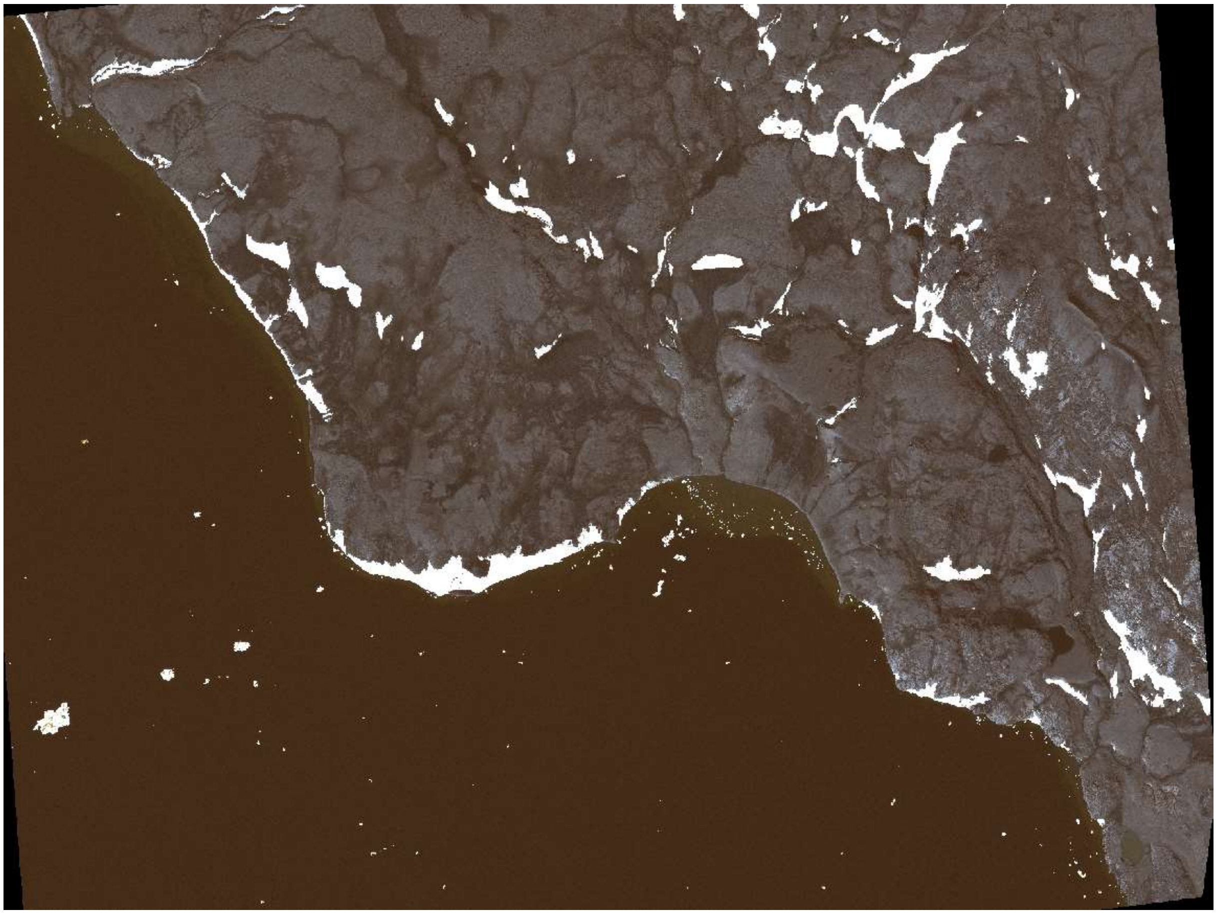

Figure 15: Lille Snenæs, Pleiades scene (2015-08-20-1458000_PHR1A)

9.3.1. Methods

As for Sandøen, the input files for the eCognition analysis included the files created in the previous processing steps (section 8.1 Pre-processing the data), i.e. 1) the clipped scene; 2) brightness image; 3) NIR-ratio image; 4) all MAD images that used the selected scene; 5) the distance_to_ocean raster. Due to the size of the region, additional steps had to be introduced to limit the data.

In addition to creating a buffer around the coast, additional segmentation was carried out to classify snow, water and steep slopes in eCognition. These shapes were exported and used to clip the image further (Figure 16: Lille Snenæs area of interest after masking out steep slopes, snow, water and 50 m inland from the coast.). Focussing the area of interest to a coastal band and removing certain ground types, assumes, as for Sandøen that the walruses do not move large distances inland, but also that they are not to be found on snow patches, nor on steep slopes.

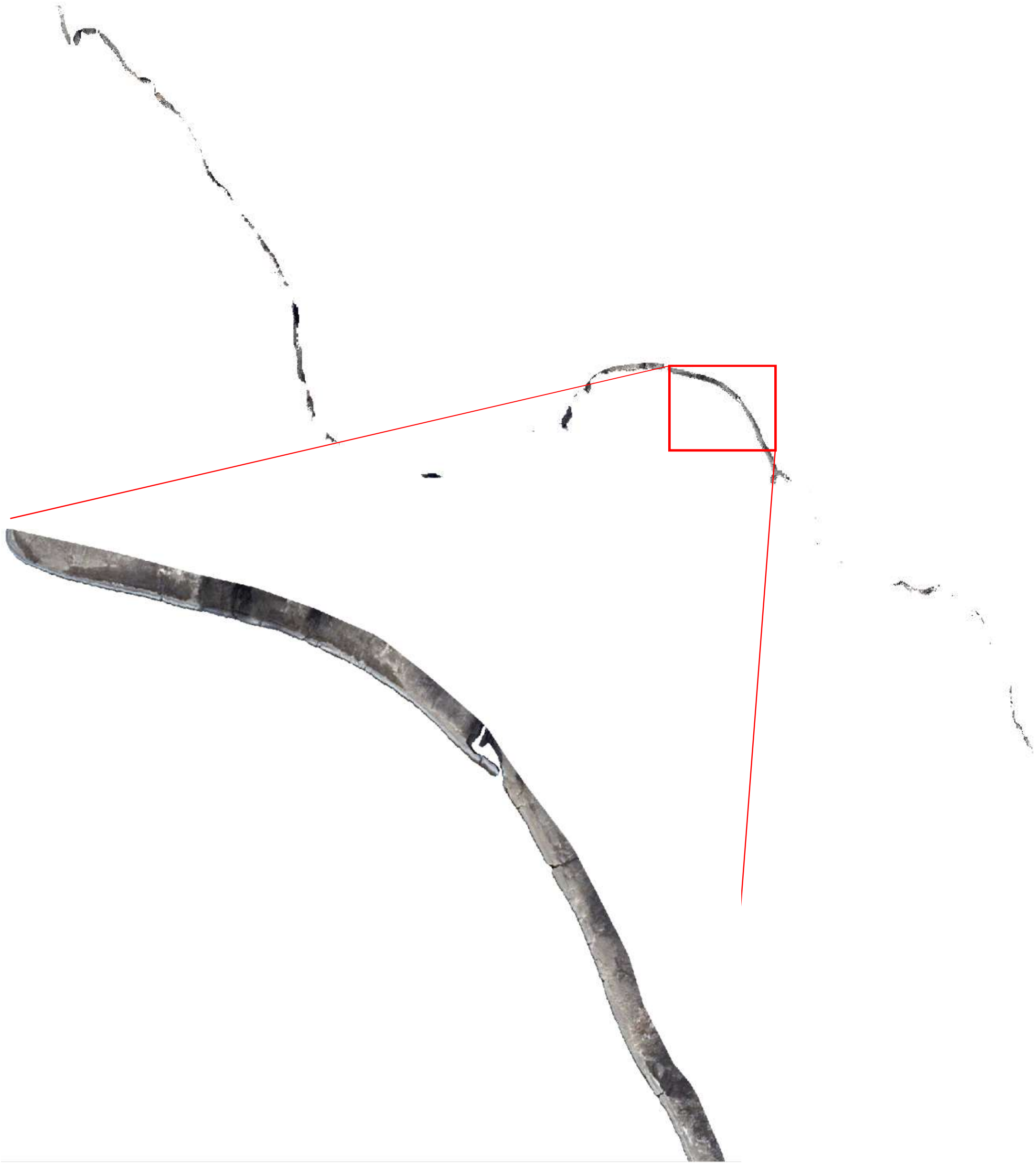

Figure 16: Lille Snenæs area of interest after masking out steep slopes, snow, water and 50 m inland from the coast.

The processing steps applied to Sandøen were applied to Lille Snenæs as a starting point and thresholds varied to experiment with the derived features.

9.3.2. PCA and ICA analyses for Lille Snenæs

The PCA and ICA analysis were again performed in the software ENVI using the Thor anomaly detection tool.

9.3.3. Results and Discussion for Lille Snenæs

Lille Snenæs presents many challenges not present in the Sandøen site, not least the size of the region and the variability of the physical environment. In order to focus to regions of interest we applied a set of rules regarding where we expected to find walrus. By clipping away regions of very steep topography, water or snow the search area and variability of within the search area decreased. In terms of computational time, this made the data much easier to work with.

The scenes from this area were extremely difficult to co-register (see section 8.1.2 Aligning the images of each site) with the result that there is a shift between them. As a result of this the MAD analyses are likely not very useful as they will show shifts in the scenes, in addition to any environmental changes. A secondary problem associated with this is that the land/ocean mask used to clip the images is less accurate.

In the absence of a known target feature, i.e. an identified walrus, it is very difficult to develop or assess any processing scheme. The processing steps documented in Table 1 require thresholds, which are scene dependent, but also environment dependent. The PCA and ICA results are scene dependent. An object in different scenes will not show up in the same PCA axis due to dependence on the temporal behaviour of other pixels in the scene.

The walruses at Lille Snenæs haul-out for approximately 30% of their time and when ice floes are available about 11% of this time is on ice. The walruses haul-out less when the weather is wet, windy and cold compared to sunny and warm. The probability of walruses hauling out on the Lille Snenæs beach or ice floes in near vicinity of the beach is thus between about 20-30%. However, if the weather was cold and windy the day the images were taken the probability are even less (only satellite images from days with clear skies are used). Walruses hauling out on that specific beach at Lille Snenæs should in theory be easily recognizable as is the case with walruses hauling out at Sandøen. However, we recommend that satellite images are obtained and analysed for each day when weather conditions are favourable from July through August to increase the probability of walruses being at the beach at that exact time when the image are taken.

9.4. Recommendations for object-based analysis

Based on the experience gained so far, the following recommendations can be made;

1) Good co-registration of the satellite images reduces processing time by allowing a single, accurate land mask to be used. It is also essential to reduce noise in the MAD analyses.

2) Images should be atmospheric corrected to eliminate atmospheric and illumination effects. This is particularly important for scenes acquired so far north where these effects are larger.

3) The accuracy of the land mask is important if used in the first step to define the area of interest, since it is very possible to cut off areas of potentially interesting coastline with a standard parameter.

4) The greater the resolution of the data, the more pixels that will cover the walrus feature. The 0.5 m resolution images used in the current study are probably an upper limit for an animal the size of a walrus.

5) PCA and ICA analyses give an alternative representation of the satellite data. The advantage with the derived components is that they reduce redundancy in the data so that not all of the components need to be used in further analysis. Selected components can be effective additional information to include in the eCognition segmentation step to help define the objects of interest. Further use of the components in classification based on mean thresholds will be scene dependent.

6) Without a positive identification of a walrus in a given area of interest it is very difficult to assess how transferable the processing steps developed for the Sandøen region are. It is highly likely that different environmental settings will require slightly different processing steps. In view of this the following steps are considered prudent when assessing a new area;

    a. Use tagged walruses to identify regions of walrus activity.

    b. Within those regions identify areas of most likely walrus visits based on topography and geology (e.g. gently sloping sand banks).

    c. Acquire images and crop to area of interest. Use MAD analyses and visual check to spot walruses. If co-registration is poor, visually check only. Once a positive identification has been made, a processing tree can be developed.

10. Sightings of walrus in the satellite images

Besides the automated or semi-automated procedures of remote sensing algorithms done in QGIS/OTB and eCognition as described above, we did a visual revision of all acquired imagery for the locations.

10.1. Sighting at Sandøen site

Concerning Sandøen island, the area is very small, the background unchanging, and the co-location of images accurate, so the site was easy to scrutinize. Consequently, the detection of individuals and groups of walruses was straightforward. Six images were monitored (Figure 17, Figure 19): at the WorldView-2 image of 2012-08-16, a group of 5 individuals close to the shore and another in the water was sighted being on their way either from or to the island. At the Pleiades 1 image of 2015-08-04, two individuals were spotted, while at the image two days later, 2015-08-06, a large group is apparent. The group is closely lying together, so it is difficult to distinguish all individually, but we estimate the flock to be of 8 to 10 individuals. Some of the animals seem larger than other indicating that 2 or 3 might be juvenile. The shadows cast from the individuals assist in splitting the individuals from one another.

Figure 17: Satellite imagery from Sandøen island at the preferred haul out site. With red circles are marked the sightings of individuals or groups of walrus hauling out on the beach area.

Nearly two weeks later, at the image 2015-08-19, there is no group at this spot, but a group to the southeast as well as an individual at the shoreline. In this image, it is more difficult to separate individuals in the group, probably because the sunlight is less sharp or from another and higher angle than the previous scene.

On the last day in the line of obtained imagery, two different satellite scenes are available: one from Airbus Pleiades-1 and one from DigitalGlobe WorldView-3 (Figure 18). The two scenes are recorded very closely in time due to their path in space around the globe. The Pleiades-1 scene is from date 2015-06-28 and UTC time 13:58:23 while the WorldView-3 scenes is of same date and the UTC time 14:01:27 – three minutes later. The two scenes display the same situation: a single walrus in the northern part of the preferred area, apparently hauling out as no movement is apparent. The individual is equally apparent in the 50 cm pixel size Pleiades-1 image as in the 30 cm pixel size WorldView-3 image, which provides a confidence that the less costly Pleiades-1 data can be applied to the task, although the 30 cm WorldView-3 naturally more sharply defines the shape of the object and its thrown shadow.

Figure 18: Observed individual walrus on 2015-06-28 from WorldView-3. To the left at 30 cm pixel size resolution, and on the right at 50 cm resolution. In both, the walrus is apparent, however sharper defined to the left.

From the observations of the imagery from the Sandøen site, we can conclude that the environmental circumstances and the frequency of observations make it possible easily to spot walrus as individuals and in groups in both the 50 cm resolution images of WorldView-2 and Pleiades-1 as well as in the 30 cm resolution WorldView-3. Obviously, it is easier to distinguish the object in the higher resolution image, but considering the differences in costs, the 50 cm resolution sources are well fitted to the task. The relatively light background of the sandy beach of Sandøen and the shadows of the walrus individuals and groups support the detection success.

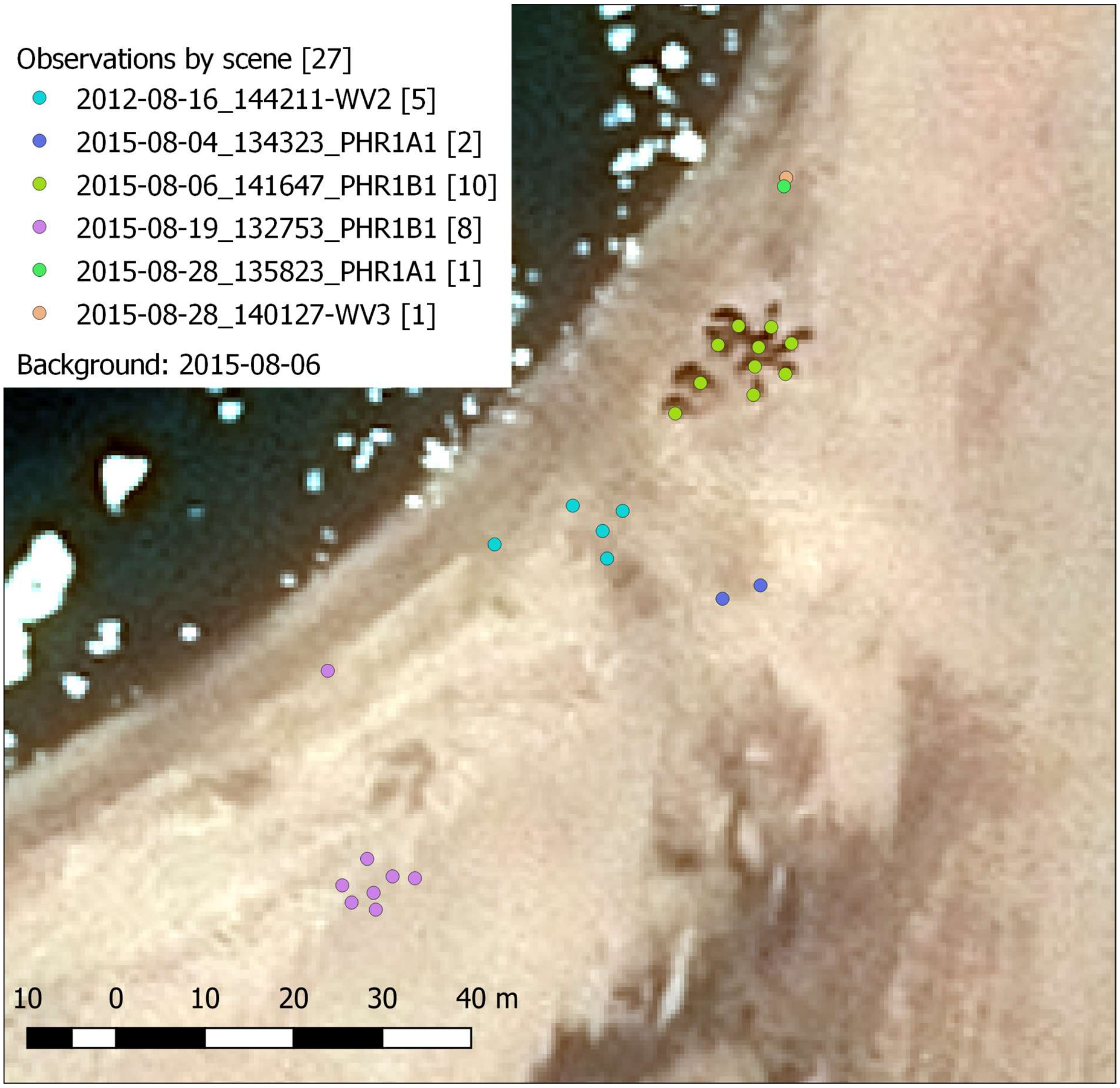

Figure 19: Observations in the satellite images covering the Sandøen site. Coloring according to the date of the image. Background image of 2015-08-06 including a larger group of walrus.

10.2. Sighting at the Lille Snenæs site

The environmental settings of Lille Snenæs area scenes are very different. At the time of satellite observation, many coasts still had an ice foot attached, the coastline is more stretched, and the beaches apparently less sandy. Furthermore, it was more difficult to geographically align the subsequent images covering the area during august 2015. This made it challenging to compare two images for identifying fixed or moving objects. The coastline was scrutinized image by image and beach by beach, but no certain observations were made, and only a number of possible observations recorded, of which we are most uncertain (Figure 20, Figure 21).

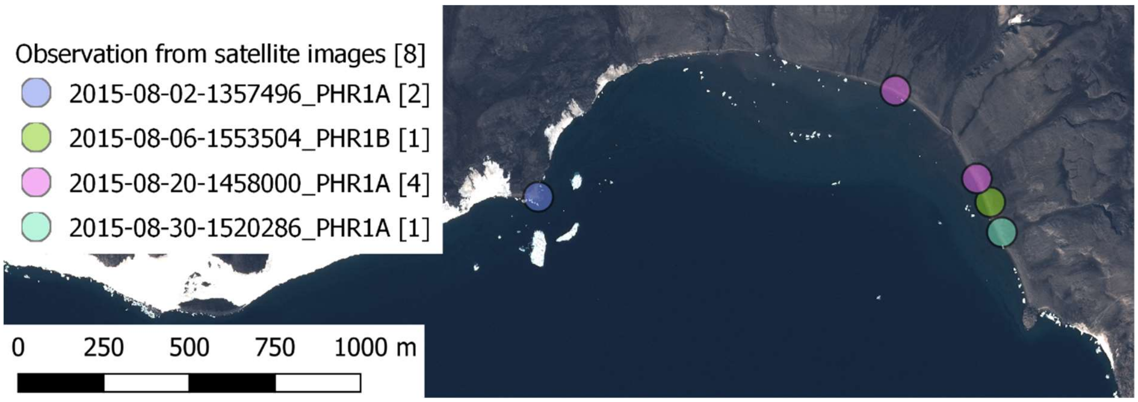

Figure 20: Observations at the Lille Snenæs site, scene by scene.

Figure 21: Observation from scene 2015-08-30. In the image it is difficult to exactly identify a walrus. It could be a stone or another object. However, it was not easily apparent in the previous scenes.

Consequently, also for the manual observation in the imagery for possible walrus individuals and groups, the procedure is dependent on the co-location of scenes and some certain observations of walrus to find other possible walruses.

10.3. Sighting at the Wolstenholme Fjord

The third site, Wolstenholme Fjord just off Thule Air Base Pituffik, is very different from the Sandøen and Lille Snenæs sites. The haul out is done on the sea ice floes in the mouth of the fjord, in between which, channels and areas of open water make room for swimming and feeding on the sea bottom between resting on the ice. The sea ice moves a considerable amount between each satellite image, so automated algorithms of changes is not possible to apply and similarly it is not visually feasible to detect whether a certain object, possibly a walrus, is moving or not. Consequently, it was only promising to methodically check every satellite image independently. However, the coverage area of the images is very large compared to the Sandøen and Lille Snenæs sites, so to cover the area systematically, a right-angled grid was laid out across the fjord in QGIS. Each grid was checked, and a point marker inserted if an object expected to be a walrus was detected.

The visual check of the satellite images revealed 535 sightings across the dates of image acquisition, the greatest part from the QuickBird image of 2010, less from WorldView-3 from the day after (2015-06-08) and the earlier WorldView-2 (Figure 22). However, similarly to Lille Snenæs, it was not possible to detect any walrus individuals or groups without great doubts, and the observers found it very hard to distinguish possible walruses from features in the ice, e.g. small pools of water.

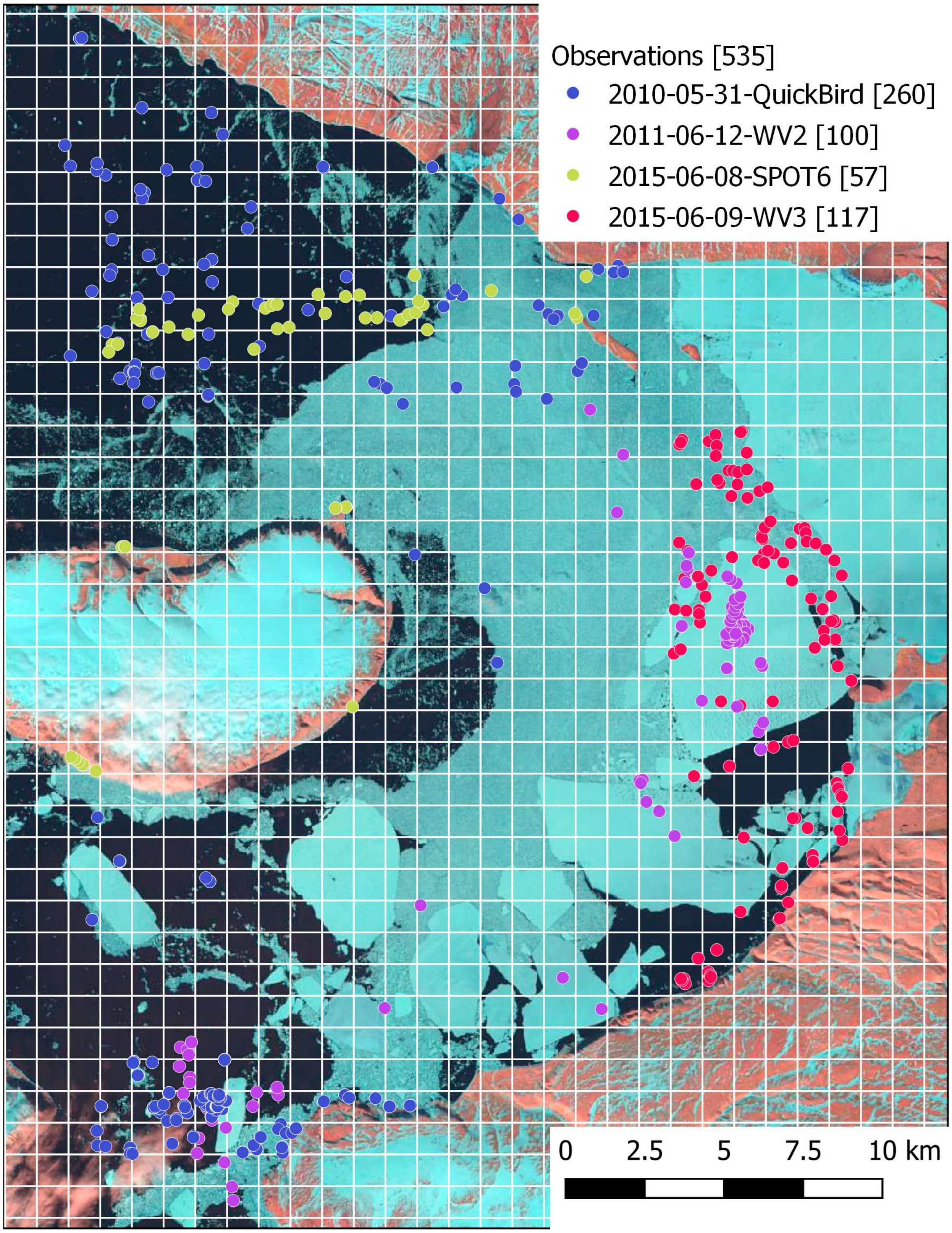

Figure 22: Observations from satellite imagery in Wolstenholme Fjord. Point colors categorized according to satellite image from which the observation was done.

Within the same period of the June 2015 satellite images, a group of scientists led by Professor Mads Peter Heide-Jørgensen from GINR stayed in Pituffik Thule Air Base for mounting of satellite position transponder tags on a number of individual walruses in the area (Garde, E. et al 2018). The transponder tags, here of the SPOT type, communicate with the Argos transmitting system. This is of varying positional accuracy, and not using the battery consuming GPS technology for accurate coordinates, but the Doppler Effect positioning from Argos instruments on board satellites with a lower accuracy. The advantage is, however, a lower power consumption and thus longer range. The results of the satellite tagging of walrus in the region is published in Garde et al 2018.

The recordings from the animals cover a wider area and throughout more days than the satellite images acquired. The satellite imagery of the period in June 2015 consist of a SPOT-6 image of 150 cm resolution and a WorldView-3 image of 30 cm resolution (Figure 23). The 1x1 km squares in the c. 900 sq. km. grid supported the systematic observation across the large area, however different between the scenes according to their coverage, e.g. coverage of the SPOT-6 image is very much larger than the WorldView-3 image. Testing demonstrated that distinguishing any objects in the SPOT-6 150 cm resolution images was highly uncertain, so further observations were discarded using SPOT-6 as a source.

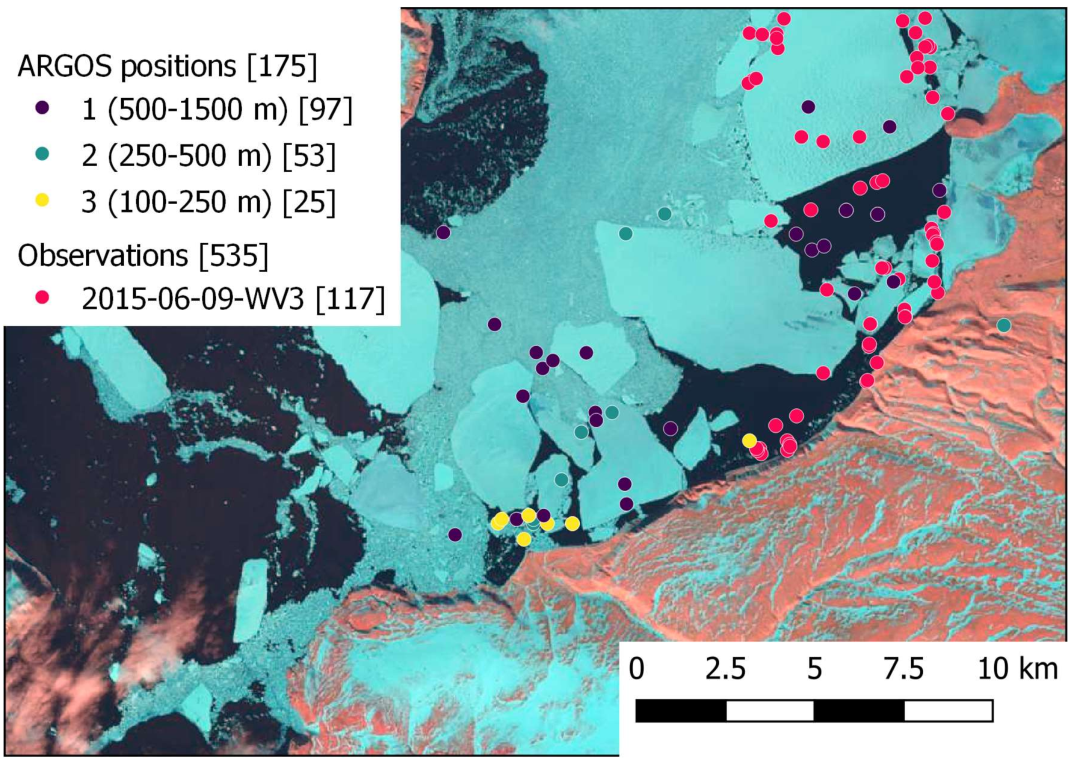

Figure 23: Positions of walrus at the date 2018-06-06 recorded with Argos transmitters. Few positions are of best quality (Argos quality 3), and more than half is of poor position quality 0 (c. 500-1500 m accuracy). The red points display the observations done from the 30 cm WorldView-3 image of three days later at the date 2015-06-09.

10.4. Recommendations from visual observations

The visual inspection of the satellite images has the same limitations as the automated and analysing methods concerning the accuracy of the co-positioning of the images for detection of moving or fixed objects, e.g. a stone or a walrus; the image resolution, e.g. 0.5 m or 1.5 m; and the environmental conditions on the ground during the image acquisition, e.g. clouds, haze, rocky or sandy surface geology and solid or fractionalized sea ice.

The most favourable conditions for walrus detection on land are a light and even sandy beach, which should be visible during the haul out season of the walrus, usually in August. For the fjord area, the sea ice should be solid and smooth, so it will appear mostly as a white background emphasizing the darker animals, but nevertheless with areas of open water and channels for the walrus to swim and feed between haul out on the ice.

The 0.5 m pansharpened image resolution of Pleiades-1A/B, WorldView-2 and WorldView-3 is sufficient for observation of walrus groups or individuals. More than a single image of each area is needed to determine moving from fixed objects. It is not possible to detect any animals from coarser resolution than 0.5 m pixels.

For larger areas, it is encouraged to lay out a 1x1 km grid to support a structured and meticulous inspection and mark each grid cell as inspected before moving to the next.

11. Discussion

Some degree of visual inspection of the high-resolution satellite imagery is mandatory to detect certain objects before any supervised, unsupervised classification or object based calculation is started. This is simply to get an idea of what properties of the object can be found through the analysis done via the classifications: the length and width, shape of shadows, and potential pixel values in visual colours (red, green, blue) and the to humans non-visual colours of near infrared (NIR) and any other bands available for possible detection.

Obviously, the choice of season and even specific weeks is of greatest importance and determines the absence or presence of animals in the area. For the Sandøen case study the usual haul out season is well known, as the group visiting the island is monitored annually. This was not the case for Lille Snenæs, which is less often monitored. For the sea ice area in the mouth of Wolstenholme Fjord, the satellite observation of 2015 coincided in date more or less the satellite tracking of animals in the area. However, the tracking coordinates didn't allow for exact positional match between a tracking point and a pixel in the image, and the environmental conditions in the images didn't allow for confident identification of animals. The observation data and procedures carried out for Wolstenholme Fjord were solid considering the possibilities with both GPS(?) tracks and available imagery, however failed due to accuracy in position of the satellite images as well as the animal tags, and moreover their timing between images and tag data and the environmental circumstances concerning floating sea ice.

A likely reason for missing observations is the absence of walrus on ice when they swim or feed in water. If the ice is thin during autumn and winter, walrus stay in the water, this is also true during more unfavourable weather conditions. The satellite photos are only purchased from days with a clear sky, as the optical satellites used are not able to observe the ground through clouds or strong haze. In spring, the walrus haul-out on drifting ice floes, which are not stationary making the time frame for observation limited.

The circumstances around the presence and absence of walrus, the environmental conditions and satellite image capabilities strongly affect the automated analysis as well. Concerning change detection through Multivariate Alteration Detection (MAD) a firm co-position between the images is ultimately required not to detect false changes: we could use the MAD on Sandøen with good positional correspondence but not on Lille Snenæs with poor positioning. The MAD analysis data is applied to the object-based feature extraction, which weight its results strongly. More simple analysis of brightness, near infrared and distance to the coast is not incorporating changes and can thus be applied independent of the MAD. However, we chose not to perform an object-based feature extraction or Principal Component Analysis (PCA) or Independent Component Analysis (ICA) to the Lille Snenæs, because of the absence of the MAD analysis.

The environmentally stable and geographically confined Sandøen island is the perfect and successful example of both visual inspection and automated analysis processing. However, our study proof that such positive factors are not at all places available. Unfortunately, the environmental conditions during the acquisitions of the satellite images of the Lille Snenæs and Wolstenholme Fjord areas did not allow for confident detections using any automated or visual methods.

12. Recommendations from the project

In this study, we have done a literature review concerning walrus ecology and behaviour, investigated the general environmental circumstances of their haul out areas on the observation dates selected, considered the abilities of the available optical satellite sensors and prepared the downloaded images for further analysis. The remote sensing analyses have incorporated data from MAD change detection, brightness and NIR ratio calculations done on the images, as well as calculations of proximity to coast. In the analysis, we have applied a Principal Component Analysis and Independent Component Analysis of the image data and used the image bands and calculations to perform object-based feature extraction. More simply, we have also visual inspection of every image for possible or actual walruses. In Wolstenholme Fjord this was assisted by actual GPS tracking of individuals.

In this study, we have done a literature review concerning walrus ecology and behaviour, investigated the general environmental circumstances of their haul out areas on the observation dates selected, considered the abilities of the available optical satellite sensors and prepared the downloaded images for further analysis. The remote sensing analyses have incorporated data from MAD change detection, brightness and NIR ratio calculations done on the images, as well as calculations of proximity to coast. In the analysis, we have applied a Principal Component Analysis and Independent Component Analysis of the image data and used the image bands and calculations to perform object-based feature extraction. More simply, we have also visual inspection of every image for possible or actual walruses. In Wolstenholme Fjord this was assisted by actual GPS tracking of individuals.

Based on our experiences from above, we recommend the following for carrying out future observations and detections of walrus or similar species from satellite imagery:

1) Thorough study of literature, experiences and tracking data available to decide on relevant and confined geographical area and the time of the year.
2) A precise coastline vector map will assist the correct outline of areas of interest used in ordering of imagery from the providers, and also to co-locate the images and produce coastline proximity maps.
3) A detailed and well positioned digital terrain model can greatly assist in identifying gently sloping or flat areas along the coast, which can possibly be used as a haul out sites by the walruses, as opposed to rough and steep coastlines.
4) Accurate co-registration of satellite images is necessary to perform good MAD analyses and produce correct proximity to coastline masks as well as the visual determination of moving objects from stationary objects.
5) The 0.5 m resolution is sufficient for the detection of walrus by visual inspection and in automated analysis. Less detailed resolution is not viable. Higher resolution, 0.3 m, although desirable, is not mandatory.

6) Multivariate Detection Analysis pointing out changes between two images performs well for highlighting walrus on land. It does not work if co-location is poor or the environment moving.
7) Visual identification of a walrus or a positive Multivariate Detection Analysis result must be used for the design of a remote sensing analysis processing tree.
8) PCA and ICA analyses can detect components in the images, which can be effectively used in the object-based segmentation and feature extraction.
9) A positive visual identification of a walrus in an image is required to assess the results of the remote sensing analyses.
10) Satellite tagging of walrus individuals is optimal for identifying the time of their presence in the area. However, to directly compare track positions with pixels in the images, the tags need to be of the more precise GPS positioning system rather than the low precision Doppler Effect system.

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Appendix 1.

Results of Table 4 processing steps for each scene. Red outlines are the potential walrus objects.

Scene: 2012-08-16_144211-WV2

Scene: 2015-08-04_134323_PHR1A1

Scene: 2015-08-06_141647_PHR1B1

Scene: 2015-08-19_132735_PHR1B1

Scene: 2015-08-28_135823_PH1A1

Scene: 2015-08-28_140127-WV3