Remote Sensing of Environment 142 (2014) 44–56

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Declassified high-resolution visible imagery for Arctic sea ice investigations: An overview

Ron Kwok

Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, United States

ARTICLE INFO

Article history:
Received 30 September 2013
Received in revised form 12 November 2013
Accepted 15 November 2013
Available online 8 December 2013

Keywords:
Declassified visible imagery
Arctic sea ice
Remote sensing

ABSTRACT

Since 2009, subsets of declassified satellite images of Arctic sea ice have been released as literal image derived products (LIDPs) with one-meter resolution for scientific use. The collections include imagery acquired over six fixed locations in the Arctic Basin since 1999. Targeted acquisitions over drifting ice parcels, from 2009 on, provide an added dimension to the LIDP archive. This mode of acquisition is especially useful for capturing time-varying processes during the melt season. In this paper, we describe the characteristics of LIDPs, the extent of the current archive, and highlight their uses for Arctic sea ice science. At this writing, the archive of LIDPs is still quite limited, and thus this paper illustrates the potential utility of the imagery. We provide an overview of the retrieval of five sea ice parameters that would benefit significantly from the surface details afforded by the higher resolution LIDPs. They include: melt pond coverage, open water fraction, ridge height, floe size, and, openings and closings. Two other uses are suggested: measurement of lateral melt and the interpretation of radar backscatter. The intent is to motivate geophysical uses of the LIDP and future acquisitions. Results here suggest that the effective observations of sea ice parameters and especially their changes require more focused sampling strategies to address specific spatial and temporal sampling needs. Presently, acquisitions of this type of imagery at fixed locations and drifting sites are being continued, and LIDPs are added to the archive as they are released.

1. Introduction

In 1995 a group of government and academic scientists (called *Medea*) were appointed by the Vice President of the United States to review and advise on acquisition of imagery obtained by classified national technical means (NTM), and to recommend the release of such declassified data sets for the benefit of understanding environmental change. The group, first described by Richelson (1998) (see also Medea, 1995), was disbanded in 2000 but re-assembled in 2008. Subsequently, in June 2009, the United States Geological Survey (USGS) under the auspices of Medea released to the public numerous classified satellite images (from a panchromatic imager) with one-meter resolution as literal image derived products (LIDP). The collections include imagery acquired since 1999 at six fixed locations in the Arctic Basin (designated Beaufort, Canadian Arctic, Fram, Siberia, Chukchi, and Barrow). The locations are named fiducial sites with the intent to establish a baseline image archive for understanding recent and future changes. A National Research Council report (NRC, 2009) published at the same time as the first data release described the potential scientific value and utility of continued acquisition of these LIDPs for Arctic research. It is recognized that the great value of the LIDPs is the potential to augment the interpretation of data obtained by other, unclassified, lower-resolution sensors.

In early 2009, a 'Lagrangian' mode data acquisition capability that allowed tracking of the same ensemble of drifting sea ice floes over the course of the summer was added. The image acquisitions are guided by near real-time locations of drifting buoys (supplied by the International Arctic Buoy Program — IABP) in the vicinity of these floe assemblages. Typically, image acquisitions begin prior to melt in early spring and terminate sometime after freeze-up. These sequences of high-resolution imagery provide a time record of the melt processes for understanding the surface development and evolution of drifting ice parcels. Currently, this unique capability has not been demonstrated with civilian assets.

To date, acquisitions of this type of imagery at fixed locations and of drifting ice parcels have continued, and LIDPs are being added to the archive as they become declassified. Additionally, these capabilities have been used to provide co-incident coverage in support of airborne campaigns of NASA's IceBridge program and to support ONR's program to understand the emerging dynamics of the marginal ice zone.

The aim of this paper is to describe the characteristics of the data product (i.e., LIDPs), the extent of the archive at this writing, highlight the potential uses and limitations of this data set for Arctic sea ice science, and motivate the uses and acquisition of this type of data set. We provide examples to illustrate and suggest the types of information, often unique in its detail, that the LIDPs could provide and contribute to the understanding of Arctic sea ice processes. We note that this does not represent an exhaustive survey as the remote sensing investigations,

E-mail address: ron.kwok@jpl.nasa.gov.

0034-4257/$ – see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.rse.2013.11.015

conducted here and by other scientists, to use of this type of imagery are at different stages of maturity.

The paper is organized as follows. The next section describes the known geometric and radiometric properties of the imagery, the temporal and spatial coverage of the image archive, and the limitations of the observations. Section 3 discusses the analysis and potential uses of the LIDPs for understanding: melt pond coverage, open water fraction, sea ice ridges, floe size, and openings and closings. This section also suggests other uses that could be explored. The last section presents conclusions.

2. Data description

The LIDPs described here reside in the Global Fiducials Library (GFL) and can be browsed (as thumbnails) and downloaded via the following URL: http://gfl.usgs.gov/. This data repository and website are updated by the USGS as additional data become available.

2.1. Image products

Individual LIDPs are 1-meter resolution, geocoded, panchromatic images that cover an area of more than 15 by 15 km of arctic sea ice (i.e., image size >100 million pixels). Images are geometrically rectified based on imaging geometry and resampled onto a cartographic grid defined by the Universal Transverse Mercator (UTM) map projection. A subset of LIDPs are mosaics of multiple images and larger in size. Horizontal positional accuracy of the pixel samples is expected to be ~9 m. The time stamp for each image is coarse and is that of the closest day. Sun elevation angle is provided as a measure of solar illumination during time of acquisition. The sun elevation angle is useful in understanding the range of brightness and contrasts seen in the data set, i.e., when the sun is low on the horizon the image quality is expected to be poor. The image intensities have been stretched to fit within 256 levels, and thus not radiometrically consistent on an image-to-image basis. Calibration information is not provided.

Since arctic stratus clouds frequently obscure views of the surface during summer, it typically requires several acquisitions to produce a single cloud-free scene of the surface. The archive of LIDPs (discussed below) includes only those scenes that are deemed mostly cloud free. Since the number of images is small, this filtering is performed visually by inspection of individual images. As a result of cloud coverage, the time separations between LIDPs of the same area are highly variable and could be up to weeks between clear sky conditions.

2.2. Contents of the Arctic sea ice library

Tables 1 and 2 show the data sets available at the static (fixed location) and drifting sites in the GFL archive at this writing. There are six static sites (see Fig. 1) designated: Beaufort, Canada, Fram, Siberia, Chukchi, and Barrow. The selection of the locations of the four original sites (in 1999) was based on the following factors: 1) Beaufort — this has been the site of many field studies since the International Geophysical Year (IGY), a focal point for the automatic data buoy program, and many studies of the surface heat budget, as well as submarine sonar cross sections; 2) Canada — this region contains the oldest and thickest ice with the longest residence time in the Arctic Basin; 3) Fram — is the main passage for export of low salinity sea ice into the Greenland Sea. Ice export here is an important component of the basin-wide ice balance and the melt water has potential impacts on convective overturning; 4) Siberia — this region produces a large volume of first-year ice and thus most sensitive to inter-annual changes of oceanic and atmospheric forcing. Two additional sites were added after 2005: 1) Chukchi — a region of seasonal ice; and, 2) Barrow — to support the extensive real-time monitoring of fast ice by university investigators; imagery acquired here complements these and other in-situ data collections. As for temporal sampling, the requirement has been to attempt weekly coverage between May and September. As can be seen in Table 1, the sampling is variable from year-to-year. A total of 463 images, acquired between 1999 and 2011, have since been released.

With increased interest in the changing Arctic, additional resources have been allocated to acquire images of drifting sites defined by the trajectories of data buoys. Between 2009 and 2012, twenty-one ice parcels near buoy locations were tracked through the summer season (Table 2). The goal was to provide 3-day repeat viewing with as many acquisitions as needed to achieve this sampling frequency. As can be seen, for a number of buoys the acquisitions were quite successful. In 2010, two of the data buoys failed early in April; after this, an ice parcel near another set of buoys was substituted. However, due to the persistence of cloud cover, the uniformity of the sampling intervals is difficult

Table 2
LIDPs near buoy tracks.

BuoyID	Duration	LIDPs
2009		
47611	Jun 27–Sep 14	49
48534	Jul 08–Sep 05	20
48536	Jul 05–Sep 19	32
63541	Jul 03–Aug 19	13
	Total	114
2010		
42597	May 1–Jul 01	11
78227	Apr 25–Jun 27	26
86973	Apr 01–Sep 17	41
89179	Apr 01–Apr 05	3
89188	Apr 01–Apr 05	4
100013	Jul 09–Sep 02	7
586420	Aug 30–Sep 01	7
	Total	99
2011		
732080	Apr 28–Sep 15	36
735060	Jun 21–Sep 20	14
772020	May 04–Sep 06	25
	Total	75
2012		
17080	Jun 02–Jul 20	29
31220	Apr 04–May 16	10
132070	Jun 20–Jul 23	10
711490	Jun 17–Jul 20	7
711760	Jun 04–Jul 20	10
824000	Jun 05–Jul 21	9
956630	Apr 05–May 24	16
	Total	91

Table 1
Available LIDPs at the six fixed locations.

	1999	2000	2001	2002	2005	2006	2007	2008	2009	2010	2011	Total
Barrow						2	2	0	5	15	3	27
Beaufort	12	21	27	14	4	10	6	3	7	9	5	118
Canada	12	14	0	11	2	4	10	11	7	9	5	85
Fram	6	14	0	11	1	8	9	5	7	4	7	72
Chukchi						2	1	0	7	9	3	22
Siberia	0	13	32	23	3	13	4	25	6	9	11	139
Total	30	62	59	59	10	39	32	44	39	55	34	463