

Evaluating the Floe Edge Service: how well can SAR imagery address Inuit community concerns around sea ice change and travel safety?

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In response to increasing environmental and social changes in the past few decades, some Inuit hunters have been turning to scientific tools to help evaluate sea ice conditions. Simultaneously, there has been more scientific interest in understanding local scale processes through Inuit knowledge in order to develop a broader comprehension of dynamic sea ice conditions and implications of long-term change. Building on several years of collaborative research with Inuit sea ice experts in Cape Dorset, Igloolik, and Pangnirtung, Nunavut, and local expressions of interest in increased access and availability of satellite imagery of sea ice, the Polar View Floe Edge Service was expanded to each community in the spring of 2007. Follow-up workshops in November 2007 helped to evaluate and improve the service by considering previous local uses of satellite imagery and tailoring Floe Edge Service regions of interest to local areas of sea ice use. Through workshop discussions, several opportunities for the use of synthetic aperture radar (SAR) imagery emerged, including: seeing what is on (or within/under) the ice; monitoring seasonal and long-term sea ice changes; hazards assessment; planning travel routes; and facilitating search and rescue operations. A number of challenges were also identified, such as: SAR image interpretation; image spatial resolution; frequency of image acquisition; SAR image representation capabilities; and technological limitations. The workshops also provided some insights into intercultural and intergenerational exchanges and led to a number of recommendations to continue expanding and improving the Floe Edge Service. This case study shows how remote sensing can be incorporated into the suite of traditional indicators and technological tools that hunters draw upon in their evaluations of complex human-animal-environment assessments. In the face of declining and unpredictable sea ice conditions, bridging scales and knowledge systems will be essential in developing integrated monitoring systems to respond to increased political and economic pressures as well as safety concerns for travelling on or within ice-covered oceans.

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Évaluation du Service d'information sur la lisière de la banquise : dans quelle mesure les images RSO peuvent-elles répondre aux préoccupations des collectivités locales des Inuits à l'égard des changements de la glace de mer et de la sécurité des déplacements ?

Pour relever les défis posés par les changements environnementaux et sociaux, des chasseurs Inuits ont favorisé, au cours des dernières décennies, l'utilisation d'outils scientifiques pour mesurer l'évolution des conditions de la glace de mer. En parallèle, il existe de plus en plus de travaux scientifiques susceptibles d'éclairer, à partir des connaissances des Inuits, les processus qui opèrent à des échelles locales, afin d'élargir la compréhension des conditions de la glace de mer en évolution et des incidences des changements sur le long terme. Se situant dans le cadre des recherches menées sur plusieurs années en collaboration avec des experts sur la glace de mer utilisée par les Inuits dans les localités du Nunavut de Cape Dorset, Igloolik, et Pangnirtung, et suite à une demande formulée à l'échelle locale pour accroître l'accessibilité et la disponibilité des images satellitaires de la glace de mer, l'initiative Polar View du Service d'information sur la lisière de la banquise a pris de l'ampleur. Depuis le printemps 2007, elle s'étend à l'ensemble de ces collectivités. En novembre 2007, des ateliers de suivi ont été organisés afin d'évaluer et d'améliorer le service en tenant compte des usages locaux antérieurs de l'imagerie satellitaire et en adaptant les régions ciblées par le Service d'information sur la lisière de la banquise aux contextes locaux de l'utilisation de la glace de mer. Les discussions engagées lors des ateliers ont dégagé de nouvelles perspectives sur l'utilisation de l'imagerie radar à ouverture synthétique (ROS), notamment pour : visualiser ce qui se trouve sur, dans, ou sous la glace; surveiller l'évolution des changements saisonniers et à long terme de la glace de mer; évaluer les risques naturels; établir les itinéraires; et organiser les opérations de recherche et de sauvetage. Parmi les enjeux qui ont également été soulevés, soulignons : l'interprétation des images ROS; résolution spatiale de l'image; la définition de la résolution des images; la fréquence d'acquisition des images; les modalités de représentation des images ROS; et les limites des technologies. D'ailleurs, les ateliers ont permis de dégager de nouvelles pistes de réflexion sur les échanges interculturels et intergénérationnels et de proposer une série de recommandations en vue de développer et d'améliorer le Service d'information sur la lisière de la banquise. Cette étude de cas met en évidence la manière dont la télédétection peut s'intégrer, avec des indicateurs classiques et des outils technologiques utilisés par les chasseurs, dans les bilans des relations complexes entre les êtres humains, les animaux et l'environnement. Compte tenu du recul de la glace de mer et de son caractère imprévisible, il importe de réduire le décalage entre les échelles et les systèmes de connaissance, afin de soutenir l'élaboration de systèmes de surveillance intégrés pour réduire les pressions politiques et économiques de plus en plus fortes et pour assurer la sécurité des déplacements effectués sur ou à travers les océans couverts de glace.

Mots clés : mer de glace, connaissances inuites, radar ouverture synthétique (ROS), télédétection, Nunavut, Île de Baffin, sécurité, changements climatiques

Introduction

Recent trends in declining sea ice cover and reduced ice thickness (Serreze *et al.* 2007), along with predictions for future ice-free summers in the northern hemisphere (Wang and Overland 2009), have led to increased attention on: (i) understanding physical sea ice processes and trends of change; (ii) local observations of sea ice change; and (iii) characterizing the human and biophysical implications of such change from global to local scales. This interest is reflected in

an increasing number of studies on remote sensing of sea ice and climate modelling at the same time as emerging community-based research focusing on northern community observations and experiences of change. Inuit communities in particular have been expressing concern over the unpredictability of sea ice, and related wind and weather changes, which affect assessments of travel safety and raise concern for young hunters using the sea ice. Therefore, local observations of sea ice change and increased unpredictability have led to heightened community interest

in working together with scientists studying similar topics (Riedlinger and Berkes 2001; Gearheard *et al.* 2006; Laidler 2006a; Nickels *et al.* 2006), as well as receiving enhanced technological support to help deal with uncertainty (George *et al.* 2004; Aporta and Higgs 2005; Meier *et al.* 2006; Environment Canada 2007; Laidler *et al.* 2008; Druckenmiller *et al.* 2009).

Local interest was expressed in having more frequent access to satellite imagery of sea ice when we worked closely with the communities of Cape Dorset, Igloolik, and Pangnirtung, Nunavut from 2003 to 2006. We followed up on this interest through the Inuit Sea Ice Use and Occupancy Project (ISIUOP), supported by Canadian International Polar Year (IPY, 2007–2008) and Environment Canada funding. As part of the ISIUOP sub-project ‘Mapping Inuit Sea Ice Knowledge and Use’ (see Aporta this issue), new partnerships were established connecting social science and community researchers with remote sensing sea ice experts. We were then able to expand the Polar View Floe Edge Service to each of the three communities in the spring of 2007. The Floe Edge Service (FES) is a web-based service that provides regular access to satellite imagery across communities in the Northwest Territories, Nunavut, and Nunavik (northern Québec). This imagery is annotated to create products that delineate areas of landfast ice, moving ice and open water, the position of the current floe edge, locations where ice may fracture and break off, and an average historical ice edge location. We used the expansion of the FES to Cape Dorset, Igloolik, and Pangnirtung as a case study to evaluate the local utility of increased access to satellite imagery of sea ice in northern communities (i.e., does it help to address Inuit community concerns around sea ice change and travel safety?). This afforded us a unique opportunity to work together to build on earlier research and to tailor the service to local needs. To undertake this evaluation we had two key objectives:

- 1) to learn from community members about their perspectives on the utility of synthetic aperture radar (SAR) imagery to address community concerns around sea ice change and travel safety; and,
- 2) to explore how discussions around remote sensing of sea ice, and related image prod-

ucts, may facilitate knowledge exchanges and more comprehensive understandings in both community and scientific contexts.

This article begins with an overview of the importance of sea ice in each of the three communities and how times of change are drawing people together. As important background, we outline previous local uses of satellite imagery in each of the three communities and how FES image products were tailored to locally meaningful regions of sea ice use. We then evaluate the opportunities and challenges in community uses of satellite image products, based on understanding image interpretation from local perspectives and the ability of SAR imagery to resolve important indicators of ice safety. There are both advantages and drawbacks to attempting to incorporate the use of high technology with experiential Inuit knowledge, but exploring these potential connections helps to characterize satellite imagery as a useful tool (among many) that hunters can draw upon in going about their daily activities.

Background

The importance of sea ice

In Cape Dorset, Igloolik, and Pangnirtung, Nunavut (see Figure 1, from Aporta *et al.* this issue), sea ice remains a key way of travelling and hunting animals for subsistence or commercial purposes, visiting nearby communities, and enjoying leisure time (Laidler 2007; Laidler *et al.* 2010). Seasonal sea ice formation and decay processes dominate cycles of land and ocean use around each community as the presence, absence, or state of sea ice determines mode of travel, harvesting destinations, travel routes, and numerous safety considerations. Much has changed since Inuit moved to permanent settlements, but the sea (whether frozen or open water) continues to be deeply ingrained as part of Inuit culture, while also providing important food sources and income potential (e.g., from skins or related clothing/craft products) as part of the northern mixed economy (Wenzel 1991; Aporta 2002; Takano 2005; Dowsley 2010).

Regional ice conditions and local uses vary between the communities and have been described

previously in Laidler (2007), Laidler and Elee (2008), Laidler and Ikummaq (2008), and Laidler *et al.* (2008, 2009, 2010). Here, only a brief summary is provided as general context for later discussions. Igloolik experiences the greatest extent of ice formation in Fury and Hecla Strait, where ice cover extends between Melville Peninsula and Baffin Island for the winter months. Moving ice dynamics are important for hunting off the floe edge (mainly for walrus), but polynyas (areas of open water within landfast ice that remain unfrozen throughout the winter) and tidal cracks in landfast ice are also used for hunting other marine mammals. Ice conditions around Pangnirtung are dominated by the geography of local fiords and strong current and wind influences in Cumberland Sound. Landfast ice and polynyas are used most often, although floe edge hunting is conducted when it is nearby and stable enough. Cape Dorset has the least ice extent, as it is influenced by its more southerly location and strong Hudson Strait currents. Hunters in Cape Dorset can use boats year round, so they focus their efforts along the floe edge and at polynyas, as well as tidal cracks. Therefore, each of these communities may experience sea ice changes differently, based on variations in ice uses and local geographies.

Times of change drawing people together

Satellite monitoring. Remote sensing has been the most effective scientific means of monitoring large areas of sea ice extent and characteristics since the introduction of satellite sensors in the early 1970s (Johannessen *et al.* 1999; Parkinson 2000; Norton and Gaylord 2004). Some of the most commonly used sensors to monitor circumpolar sea ice extent, concentration, area, and trends are summarized in Table 1. Passive-microwave sensors are generally used for circumpolar and coarse scale monitoring as they cover more expansive areas but have lower spatial resolution. Active-microwave sensors using synthetic aperture radar (SAR) tend to be incorporated for regional or finer scale analyses because of their higher spatial resolution.

By the late 1990s, remote sensing records for the circumpolar Arctic were already indicating that the polar ice pack was shrinking in extent, changing in concentration, and thinning

(Johannessen *et al.* 1999; Parkinson 2000). The typical maximal ice extent in March is approximately 16 million kilometres² and the minimal extent in September is around 7 million kilometres² (Serreze *et al.* 2007), but it is now estimated that between 1979 and 2006, annual circumpolar sea ice extent shrank approximately 3.6% per decade (8.4% per decade for September sea ice extent) (Meier *et al.* 2007). Sea ice change has consistently accelerated since 2001 (NSIDC 2010), with the record summer sea ice minima coming in 2007 (4.28 million kilometres²) (Drobot *et al.* 2008; Kwok and Rothrock 2009). Furthermore, pan-arctic winter ice thickness at its peak in 1980 (i.e., 3.64 metres) is estimated to have thinned to nearly half the thickness in 2008 (i.e., 1.89 metres) (Kwok and Rothrock 2009). Thinning can also be inferred based on decreasing replenishment of multi-year ice (MYI) cover (Kwok 2007) and younger perennial pack ice (Maslanik *et al.* 2007). With trends towards later freeze-up and earlier melt onset across the circumpolar Arctic (Markus *et al.* 2009), the ice-free season is lengthening. In the eastern Canadian Arctic, trends are similar. For example: (i) the length of the open water season in the summer months has been increasing (Stewart *et al.* 2007; Laidler *et al.* 2009); (ii) sea ice extents since 2002 have been well below the long-term average (Meier *et al.* 2006); and (iii) trends show later freeze-up timing and earlier melt onset dates (Meier *et al.* 2006; Laidler *et al.* 2009). Regional variations may occur based on the presence and concentration of MYI (Stewart *et al.* 2007), and seasonal variations in ice extent and concentration are also important to evaluate apart from interannual trends (Meier *et al.* 2006; Laidler *et al.* 2009). Although these trends are dramatic, the numbers are not easily associated with particular ice conditions, nor are they easily translated into local implications for ice use around northern communities. So it is important to understand local conditions observed in northern communities.

Local observations. Inuit hunters and elders have acquired detailed knowledge of the physical and biological processes of sea ice through years of personal engagement and from knowledge and skills handed down over generations (Aporta 2002; Norton 2002; George *et al.* 2004; Nichols *et al.* 2004; Gearheard *et al.* 2006; Meier

Table 1

Summary of satellite sensors most commonly used to monitor and assess sea ice conditions in the circumpolar Arctic

Satellite	Launch	Sensor	Resolution	Swath width	Repeat times	Origin
SMMR ¹	1978	Passive Microwave	22–100 km	780 km	6 days	USA
RADARSAT-1 ²	1995	Active Microwave (C-Band)	8–100 m	100–500 km	24 days	Canada
SSM/I ³	1999	Passive Microwave	25 km	1,226–1,427 km	14 days	USA
ENVISAT ASAR ⁴	2002	Active Microwave (C-Band)	30–1,000 m	5–400 km	35 days	Europe
MODIS ⁵	2002	Optical	250 m–1 km	2,330 km	8 days	USA
AMSR-E ⁶	2002	Passive Microwave	5.4–56 km	1,445 km	16 days	USA
RADARSAT-2 ⁷	2007	Active Microwave (C-Band)	4–100 m	20–500 km	24 days	Canada
NOAA AVHRR 19 ⁸	2009	Optical	1.1 km	2,900 km	daily	USA

¹Scanning Multi-channel Microwave Radiometer (SMMR) (http://nsidc.org/data/docs/daac/smmr_instrument.gd.html); ²RADARSAT-1 (<http://www.asc-csa.gc.ca/eng/satellites/radarsat1/default.asp>); ³Special Sensor Microwave Imager (SSM/I) (http://microwave.nsstc.nasa.gov:5721/sensor_documents/ssmi_sensor.html); ⁴ENVISAT Advanced Synthetic Aperture Radar (ASAR) (<http://envisat.esa.int/instruments/asar/>); ⁵Moderate Resolution Imaging Spectroradiometer (MODIS) (<http://modis.gsfc.nasa.gov/data/>); ⁶Advanced Microwave Scanning Radiometer-Earth Observing System (AMSR-E) (http://www.ghcc.msfc.nasa.gov/AMSR/instrument_descrip.html); ⁷RADARSAT-2 (<http://www.asc-csa.gc.ca/eng/satellites/radarsat2/default.asp>); ⁸Advanced Very High Resolution Radiometer (AVHRR) (<http://earth.esa.int/NOAA-AVHRR/>).

et al. 2006; Laidler *et al.* 2009). This forms a basis of comparison over a lifetime of experience using the sea ice, and within collective living memory, from which a number of sea ice changes are being noted. Sea ice changes have been noted by communities across the Canadian Arctic (e.g., McDonald *et al.* 1997; Krupnik and Jolly 2002; Nickels *et al.* 2006), and Cape Dorset, Igloolik, and Pangnirtung are no exception. Although interannual variations are emphasized as being part of life, ‘unique’ or ‘unexpected’ sea ice conditions were described as starting around 2000, and are typically compared to expected ‘normal’ conditions within living memory (i.e., approximately the 1960s) (Laidler 2007; Laidler *et al.* 2010). Residents of Cape Dorset, Igloolik, and Pangnirtung have been observing slower freeze-up progression and later freeze-up timing, faster melt progression and earlier break-up timing, generally thinner sea ice, less presence of MYI, and increased proximity of the floe edge to their communities (Laidler *et al.* 2010). These changes are closely tied to observations of weather changes, and the magnitude and timing of these changes vary by community based on local sea ice indicators and ice uses. Changes seem most dramatic in Pangnirtung with freeze-up and break-up timing being altered by nearly two months from past conditions (Laidler *et al.* 2010). In Igloolik, there is more emphasis on variability, as local ice conditions are strongly influenced by the presence or absence of MYI (Laidler *et al.* 2009). And in Cape Dorset, with

the least ice extent, small or moderate changes are having large influences on the safety and timing of local sea ice use (Laidler *et al.* 2010). However, it is not simply the physical changes that community members are worried about, but their implications, including: travel safety and cost; the reliability of traditional weather and sea ice prediction techniques; longer transitional stages (i.e., freeze-up and break-up processes); shifts in marine wildlife habitat, health, and behaviour; local livelihoods; and food security (George *et al.* 2004; Gearheard *et al.* 2006; Meier *et al.* 2006; Environment Canada 2007; Ford *et al.* 2009; Laidler *et al.* 2010). An erosion of land-based knowledge and skills among younger generations of Inuit is also recognized as exacerbating the potential implications of sea ice change, particularly in terms of travel safety and harvesting success (Meier *et al.* 2006; Laidler *et al.* 2009). It is in this context of change that Inuit and scientific communities are being drawn together.

Linking remote sensing and local observations. Efforts have already begun to attempt to bring Inuit and scientific knowledge of sea ice together in a complementary manner (e.g., George *et al.* 2004; Gearheard *et al.* 2006; Tremblay *et al.* 2006, 2008). In particular, the significant overlap between temporal (length of record) and spatial (resolution) scales of traditional knowledge and satellite imagery identified by Riedlinger and Berkes (2001) render them of great interest to explore potential practical

linkages. Investigations linking satellite imagery (or derived products, such as ice charts) and Inuit observations of sea ice change have already been initiated in the Eastern Arctic (Meier *et al.* 2006; Ford *et al.* 2009; Laidler *et al.* 2009), the Central Arctic (Environment Canada 2007), and in Alaska (George *et al.* 2004; Norton and Gaylord 2004; Druckenmiller *et al.* 2009). In these studies, local observations were used to tailor or contextualize remote sensing analyses, through discussion of significant ice events or observations of change. However, there are no studies focusing specifically on how Inuit sea ice experts interpret imagery themselves, or how they would characterize the utility of remote sensing to be used directly in a northern community context. Therefore, this article builds on these earlier and ongoing efforts, aiming to share feedback from Inuit elders, hunters, and community organization representatives regarding the potential local uses of SAR satellite imagery. These insights may not only help improve image interpretation for local uses, based on local sea ice indicators, but they also have the potential to inform others seeking to draw on satellite imagery for local ice assessments such as: shipping (for industry or tourism), search and rescue operations, and integrated sea ice observing systems.

Methods

Community-based sea ice research

Our six-year working relationship with the communities of Cape Dorset, Igloolik, and Pangnirtung (see Figure 1 from Aporta *et al.* this issue) began with preliminary community visits in 2003/2004. Then, between 2004 and 2006, nearly nine months were spent in the three communities over 10 different trips, with ongoing efforts to communicate interim and final results between community visits (Laidler 2007).

To learn about the importance of sea ice processes, uses, and changes to Inuit experts in each community, Inuit elders and hunters deemed to be ice experts were invited to participate in semi-directed interviews based on recommendations from community organizations, community researchers, or other interviewees. Overall, 84 interviews (30 in Cape Dorset, 24 in Igloolik, and 30 in Pangnirtung) were conducted with 63 peo-

ple, and included a component of participatory mapping. Interviews were complemented by 14 sea ice trips ranging from day trips to the floe edge or nearby polynyas, to multiday trips to fishing cabins or hunting grounds. These were undertaken in all sea ice seasons, as it was emphasized that learning in context, on the sea ice, was critical to learning about Inuit expertise of sea ice. Four focus groups were also employed to verify Inuktitut terminology and sea ice map documentation, jointly facilitated by a community and a university researcher, with an average of three to six elders or hunters participating in each one. Our methods, and associated challenges, are described in more detail in Laidler (2007), Laidler and Elee (2008), Laidler and Ikummaq (2008), and Laidler *et al.* (2008, 2010). Building on the foundation of this earlier work, the methods most relevant to the results presented in this article include the FES expansion and follow-up workshops.

Floe Edge Service expansion

The FES gets its name from its primary monitoring function of delineating the floe edge. The floe edge is an important sea ice feature supporting northern hunting and fishing, diverse marine wildlife and is increasingly becoming an attraction (and/or navigational hazard) in the tourism industry. Being able to identify locations of interest along the ice edge enables the selection of the shortest route around ice ridges and open water, helps to minimize travel time, fuel costs, and equipment wear, while maximizing safety. The FES is a web-based service that provides satellite images three to five times per week to residents across ten communities in the Northwest Territories, Nunavut, and Nunavik. Noetix Research Inc. developed this service in 2003 and it has been expanding ever since. The expansion of the FES to Cape Dorset, Igloolik, and Pangnirtung in May, 2007 was financially and logistically supported by ISIUOP and Environment Canada's Northern Ecosystem Initiative. Standard imagery used include ScanSAR Wide mode RADARSAT-1 and 2, and wide swath mode ENVISAT ASAR (Table 1). SAR transmits microwave signals to the earth's surface and records patterns of reflected pulses. It is particularly useful for sea ice monitoring because:

- image acquisition does not require solar illumination and is not degraded by cloud cover—both of which are limitations for optical imagery, especially at high latitudes;
- SAR imagery distinguishes water from ice surfaces effectively in all seasons providing an indication of ice conditions, locations, and extent of dynamic sea ice cover;
- minute texture detail provided by microwave reflectance off the ice surface enables ice floes to be (re)identified and tracked in successive images; and
- it has high-frequency image acquisition based on polar orbit. (Norton and Gaylord 2004)

The SAR imagery is provided to Noetix through a data sharing agreement with the Canadian Ice Service (CIS), based on regular image acquisitions for operational sea ice monitoring to support ship navigation and the Canadian Coast Guard. Annotated image products are developed by Noetix staff through manual image analysis to show: (i) areas of landfast ice; (ii) areas of moving ice and open water; (iii) the location of the current floe edge; (iv) locations where ice may fracture and break off; and, (v) a 30-year average of historical ice edge locations (Plate 9). Image products are made available online for public use (<http://www.noetix.ca/floeedge/>, with a free user account) approximately 4–12 hours later. There is also at least one local host organization in each community (i.e., the Hamlet Office in the case of Cape Dorset, Igloodik, and Pangnirtung), which posts hard copy image products to ensure they are more widely accessible.

Follow-up workshops

Workshops can be effective means of facilitating knowledge exchanges and debating—and learning from—differing perspectives, especially when building on longer-term research relationships and complemented by more extensive documentation efforts (Huntington *et al.* 2002). Therefore, to follow-up on the FES expansion, we hosted local information sessions and a research workshop in each of Cape Dorset, Igloodik, and Pangnirtung in November, 2007. Six community members participated in a research workshop in each community, with at least three local sea ice

experts (experienced hunters or elders), as well as a combination of other local representatives from the Hamlet Council, Qikiqtani Inuit Association, Hunters and Trappers Association (HTA), Search and Rescue Committee, Canadian Rangers and/or the Government of Nunavut. These meetings were held to introduce the service, get feedback on initial products, tailor the service to local needs and regions of interest, and conduct preliminary evaluations. During the workshops, participants engaged in joint reviews and interpretations of large format SAR images of the marine area surrounding each community (Laidler and Kapfer 2009). Results from the workshops help evaluate the FES based on: (i) potential local uses of image products; (ii) linkages between local indicators of ice safety and those used to interpret satellite imagery; and (iii) the facilitation of knowledge-exchanges through efforts to improve image products.

Local Uses of Satellite Imagery

Previous local uses of satellite imagery

Before tailoring image products to local needs and evaluating the FES expansion, it was important to understand how satellite imagery had been used in each community previously. During interviews in 2004–2005, community members in Cape Dorset, Igloodik, and Pangnirtung were asked about their opinions on the use of satellite imagery to study sea ice. Remote sensing technology was considered useful in all three communities. Despite the interest in using satellite imagery, only a third or less of interviewees had seen satellite images before, and even fewer were regularly consulting such images. There may be several reasons for this:

- i) Internet access is slow in northern communities (although by fall 2005, high-speed broadband access was available in most communities);
- ii) Internet access is not available to everyone (e.g., hunters often rely on employees at the government building, Hamlet office, or HTA to download imagery);
- iii) not everyone knows how to use a computer, so imagery access may be limited to available printed copies;

- iv) SAR imagery can be difficult to interpret; and
- v) there is limited imagery available for free. (Laidler 2007)

Nevertheless, hunters and elders in each community clearly expressed interest in gaining more regular access to satellite imagery, which was the main reason for the expansion of the FES to each of the three communities in May 2007.

Tailoring image products

The FES typically provides each community with a regional overview image and a few subset regions to provide a closer view of select areas. Through the November 2007 workshops, community representatives were able to delineate locally relevant subset regions in order to focus the service on primary areas of sea ice use/interest (see Laidler and Kapfer 2009 for more detail). This process was critical in order to tailor the service to local needs, reflecting practical regions of use rather than arbitrary image crops based on image analysis or logistical ease alone. For all three communities, the subset areas were predominantly defined by areas of use, which means that online access to imagery is facilitated by Inuktitut place names that define locally important sea ice areas. Specific considerations in Cape Dorset included covering areas of frequent usage to the east of the island. Areas along the west coast of Foxe Peninsula were not of much interest, since few families travel west from the community due to very low tides and frequent break-off events. Nevertheless, this area was included within the regional overview for the few families that do use this area and because of the value of these areas for tour operators. Specific considerations in Pangnirtung focused on monitoring regional ice conditions to support search and rescue operations as well as travel to important traditional camps. In Igloolik, workshop contributors were keen to access SAR imagery in all seasons to help with initial assessments or planning travel routes over long distances. Therefore, discussions around potential uses of satellite imagery and defining subset areas of interest were important steps in improving the local relevance of image products. They also served as a starting point to evaluate the potential local utility of this newly expanded service.

Evaluating the Floe Edge Service

Opportunities

Seeing what is on (or within/under) the ice. Inuit experience sea ice dynamics, variability, and change in ways that affect their daily lives, and can literally be a matter of survival (Laidler 2006b). Hunters develop an intimate relationship with the sea ice through sea ice travel, use, narratives, and moral codes (Aporta 2002, 2009; Nichols *et al.* 2004; Laidler 2007), emphasizing the three-dimensional nature of the sea ice system as well as its ability to record cumulative effects of various events throughout each season (Norton 2002; Norton and Gaylord 2004). Traditionally, Inuit evaluations of sea ice were bounded by the distance they could see. But an observer's distance to the visible horizon could be limited by factors such as elevation of topographic features, pressure ridges, or visibility (i.e., limitations due to fog, clouds, snow, or other atmospheric effects) (Norton and Gaylord 2004). Hunting success thus depended on having a conceptual grasp of distant unseen events or conditions and being familiar with traditional navigational techniques, common routes, and safety indicators (Aporta 2002, 2009; Norton and Gaylord 2004). In Cape Dorset, Pangnirtung, and Igloolik, hunters and elders highlighted a number of key indicators that they use to evaluate the stability and safety of sea ice, including: clouds, moon stages/tidal cycles/currents, geographic reference points, winds, snow, algae, seasonal relations, moving/multi-year ice, animal behaviour, surface ice conditions, openings and edges, and comparative changes over time (Table 2). Therefore, workshop participants wanted to learn more about the capabilities of satellite imagery to 'see' what is on (or within/under) the ice, such as: (i) seeing through snow (to estimate snow thickness); (ii) identifying when the ice is cracking; (iii) identifying dangerous ice conditions when covered by snow (i.e., thinning due to currents underneath); (iv) differentiating compact vs. less compact/dense ice; and (v) estimating ice thickness. Some examples of how satellite imagery can provide helpful information based on hunters' indicators are shown for Cape Dorset, Igloolik, and Pangnirtung (see Plates 10, 11, and 12). The interests in interpreting imagery

Table 2
Identifying local sea ice indicators in SAR imagery

Indicator	Description of local sea ice indicator	Potential to identify in SAR imagery
Clouds	—cloud formation, height, and colour are interpreted to understand pending or future weather conditions that may impact sea ice conditions	—SAR sees through clouds and allows viewing of the surface —clouds cannot be identified
Moon stages/tidal cycles/currents	—monthly lunar cycles (especially new and full moon), daily tidal variations, and bathymetric and topographic influences on current strength were prominently noted in any discussions around sea ice safety	—can identify recurring tidal cracks to validate tidal shifts —tidal cycles and currents themselves cannot be identified, but possible to infer based on tracking sea ice movements and timing in different images
Geographic reference points	—ice conditions are often evaluated based on geographic knowledge of particular areas and how terrestrial features influence sea ice formation or decay	—used to interpret ice conditions in specific areas, used as reference points for seasonal or rapid changes
Winds	—wind direction and strength are essential in traditional wayfinding and navigation as well as in anticipating sea ice conditions or change such as break-off events or ice pileups at the floe edge	—over open water, wind speed can be estimated from the SAR signal and wind direction can be inferred by alignment of new ice strips and wave patterns —winds cannot be identified on ice, but possible to infer based on tracking movements of ice floes in different images
Snow	—snowfall and accumulation (as well as related overcast conditions) figures prominently in discussions around indicators of ice safety, especially in the fall before ice has thickened, based on its potential to hide, or contribute to, thinning ice conditions	—can detect when snow pack is wet, through image tone and texture —hard to identify snow depth, depends on moisture in snow and influences on surface roughness
Algae	—indicates thin or dangerous ice, as it contributes to earlier spring melt when on (or within) the sea ice	—cannot be identified, under the ice
Moving/multi-year ice (MYI)	—helps define floe edge stability (if grounded), boating safety, and knowing general circulation movements is important for knowing landing points if stranded on the ice	—can identify various ice types through tones and textures —effective at identifying large MYI and movement of pack ice over time
Seasonal relations	—summer weather conditions, the presence or absence of moving or MYI, and fall freeze-up conditions are all considered in determining winter ice conditions and anticipated spring break-up timing, they are never interpreted in isolation	—having time series of imagery helps to evaluate regional scale seasonal changes in ice conditions but cannot account for all other factors that hunters take into account
Animal behaviour	—hunters carefully observe marine mammals and migratory birds as their behaviour provides indicators of weather or ice changes to come	—cannot be identified, but important ice habitat conditions may be inferred by hunters and detected by imagery, in conjunction with geographic reference points and seasonal relations
Surface ice conditions	—are always scrutinized during travel for their colour, texture, water accumulation on the surface, and various frost-type formations	—can be inferred based on relations to texture, water accumulation, and even frost-formations (e.g., rough vs. smooth ice, ridges, melt ponds) —ice colour cannot be identified but often thinner ice conditions show up in images as darker

Continued

Table 2
Continued

Indicator	Description of local sea ice indicator	Potential to identify in SAR imagery
Openings and edges	—the width or speed of freezing in tidal cracks, polynyas (extent variations), and floe edge positions are taken into account as spatial references, are sought out as hunting destinations, and are used to evaluate ice dynamics at various times of the month or the season	—effective at identifying openings and edges, but feature size detectable is limited by spatial resolution of image acquisition (i.e., 75–100 metres for RADARSAT-2 images acquired in ScanSAR mode, but higher resolution imagery can be acquired on request to identify finer scale details)
Comparative changes over time	—comparisons are also made to past rare events in efforts to identify potential implications of unique conditions or events and long-term cycles are kept in mind, change is not seen as a linear trajectory	—time series used to compare interannual trends, similar to seasonal changes, by date and location for ice concentration and ice type

These indicators are applied, named, and evaluated somewhat differently in each community and depending on an individual's experience, hunting techniques and target animals, and local geographies. For community-specific examples, see Laidler (2007) and Laidler and Kapfer (2009) (both available for download at <http://www.straightupnorth.ca>).

using local indicators also inform potential applications for satellite imagery to monitor seasonal and long-term changes.

Monitoring seasonal and long-term sea ice changes. Hunters saw potential value in using satellite imagery to evaluate sea ice conditions over time, in terms of seasonal ice freeze/thaw cycles, as well as interannual variability or long-term change. The entire ice season must be considered to evaluate the stability of the ice cover at a given point in time (Table 2) and so hunters organize their observations both temporally and spatially to support their daily evaluations (George *et al.* 2004). When evaluating satellite imagery, hunters preferred to have the sequence of images preceding the most recent acquisition, to have sufficient context to evaluate current ice conditions and to anticipate future conditions. It was also deemed helpful to have Noetix staff flagging noticeable changes in image products, especially along the dynamic floe edge (Plates 10–12), so that hunters could evaluate particular features based on their knowledge of the ice in the area. Having ongoing access to such time series would help not only to compare changes over time, but also to facilitate hazards assessment, plan travel routes, and support search and rescue operations.

Hazards assessment. There is always an element of risk involved with sea ice travel but some ice conditions are more risky than oth-

ers (e.g., moving ice, polynyas, floe edge, etc.). However, their importance as wildlife habitat and the desire or need for a successful hunt may justify the risk to a confident and experienced hunter. Hunters are continually revising their personal guidelines for making correct (i.e., life-sparing) risk-versus-reward decisions (Norton 2002; George *et al.* 2004). However, community representatives and Noetix staff suggested that using Inuit knowledge and satellite image interpretation in tandem could facilitate more comprehensive hazard assessment. For example, combining up-to-date satellite imagery with previous participatory mapping efforts (e.g., Laidler 2007; Laidler and Elee 2008; Laidler and Ikummaq 2008; Laidler *et al.* 2008) could help to focus image interpretation on locally known dangerous areas or recurring ice hazards as delineated by Inuit sea ice experts. These spatial representations of Inuit knowledge, as well as a better understanding of local indicators used to identify hazards on the ice (Table 2), can help Noetix staff to target interpretations of tidal cracks, potential break-off events, polynya size variations, floe edge position variations, ice ridges (i.e., likelihood of finding seal breathing holes), and water content in the snow (Plates 10–12). In so doing, there is increased potential to systematically monitor sea ice hazards or changes, which can then be communicated back to the community (directly or through image annotations). Ideally, such efforts used in combination with Inuit knowledge and traditional

survival techniques could help minimize accidents resulting in equipment damage, personal injury, or loss of life (Environment Canada 2007).

Planning travel routes. Satellite imagery has potential benefits to Inuit communities as it provides information beyond their local area and so can help in forecasting ice conditions and planning safer sea ice excursions (Meier *et al.* 2006; Environment Canada 2007). When planning long journeys, distant ice conditions are typically anticipated in relation to known local ice and weather conditions. So, if SAR imagery can identify poor or unstable ice conditions, the planned trip could be delayed, or travel routes adjusted, without incurring additional costs, time, and potential danger. In many cases, SAR imagery can help identify expanses of smooth seasonal ice that hunters seek for snow machine travel, as well as areas of rough ice that may be avoided for travel, but may also be sought as large old ice floes or pressure ridges are ideal ringed seal habitat (Environment Canada 2007) (Table 2, Plates 10–12). In addition, because hunters found it easiest to distinguish ice from open water in the SAR imagery, planning boat travel in the summer was identified as one of the most frequent uses of imagery (i.e., to identify areas without too much moving ice, which would thus be accessible by boat).

Facilitating search and rescue operations. Hunters were keen to access satellite imagery as an aid in search and rescue operations. Prior to launching a rescue, local search and rescue committees consult all available information, from local expertise to weather, sea ice, and other available forecasts. Satellite imagery is a critical tool in anticipating where lost or stranded people may be found, as it can help identify where ice may have broken off the floe edge, the movement of ice pans, or the formation of new cracks (Plates 11 and 12).

All of these opportunities could be enhanced through improved and ongoing collaboration between local sea ice experts, local hosts of the FES, and Noetix staff. However, it is also important to be aware of the limitations of SAR imagery, which pose several challenges for local usage.

Challenges

SAR image interpretation. Community members were already—to varying degrees—consulting satellite imagery to evaluate sea ice conditions before travel or to gauge changes over time. Some hunters brought in images they had acquired recently (and regularly) from Environment Canada, CIS, or NASA websites. Interestingly, it seemed that these were predominantly optical images (e.g., MODIS). However, such images are not able to show the sea ice or ground surface in bad weather, cloudy conditions, or darkness. These are precisely the conditions that SAR imagery is used to circumvent, but SAR imagery is inherently challenging for novices to interpret (Norton and Gaylord 2004). SAR backscatter values are often confused with visible light and dark qualities (Norton 2002), when they are actually representing variations in surface roughness, ice types, surface water accumulation, or snow moisture (Plates 10–12). Hunters preferred optical imagery because it was easier to interpret due to its closer adherence to visible conditions during travel. This is not surprising, as optical sensors acquire images that include the visible wavelengths of the electromagnetic spectrum, so they are able to show features in a familiar way based on what people can see naturally. However, microwave sensors detect energy at much longer wavelengths, interacting with the physical and chemical properties of the sea ice and thus represent features in greyscale that people may or may not be able to see on the surface. Nevertheless, hunters were adept with their initial interpretation of SAR imagery, based on their familiarity with local ice conditions. They effectively identified the influence of wind direction on moving ice or freeze-up conditions (e.g., Plate 11) and where significant distinctions were visible between open water and landfast or moving ice (e.g., Plates 10–12).

Image spatial resolution. Selection of an appropriate spatial scale over which to collect and analyze remote sensing data is critical to the success of interpreting and predicting sea ice conditions and dynamics (Norton and Gaylord 2004). Acquisitions must be at a sufficiently large scale to reveal ice features recognizable to hunters (i.e., sea ice features of 0.1 kilometres

or less in diameter, over distances of 100 kilometres or greater) (Norton and Gaylord 2004). The resolution of SAR imagery acquired by Noetix for the FES is determined by the operational mandate of the CIS. They use the wide swath mode of RADARSAT and ENVISAT ASAR sensors (i.e., 50-100 metres resolution) to maximize the acquisition frequency across the Canadian Arctic. From a community perspective, this regional scale is helpful to evaluate ice conditions at distant destinations, but most of the sea ice indicators used to evaluate ice safety cannot be clearly resolved at this resolution (Table 2). In other words, tidal cracks, leads, small polynyas, the amount of new ice growth at the floe edge, and so on would require higher spatial resolution to effectively monitor them. SAR does provide finer-scale information than passive microwave sensors (Table 1), but full insight into local scale details cannot be determined from remote sensing data alone (e.g., estimating usability based on thickness or strength/stability of ice conditions) (Norton and Gaylord 2004; Meier *et al.* 2006). Most hunters and elders wanted to see more detail about the ice conditions, and to 'zoom in' to particular areas shown in the imagery. Although the locally defined subset areas provide a closer view of important sea ice regions, users cannot zoom in beyond the spatial resolution of image products. If attempted, pixelation will occur (i.e., individual pixels become visible), meaning that the maximum detail for the digital image has been reached. FES image products are provided as .jpg images for ease of downloading and printing on letter-sized paper, but this comes at the loss of some detail. This can be further compounded by the quality of the local printer being used, where some of the richness of digital image data is lost based on diminished contrast and sharpness in the printed version.

Frequency of image acquisition. Although many potential local uses for satellite imagery were identified, hunters sought daily coverage, since ice conditions can change within hours. However, Noetix staff are limited in their provision of FES image products by the frequency they receive imagery from the CIS. Typically the highest frequency occurs during transitional stages, as well as throughout the summer. In

winter, images are updated only once a week or once every two weeks. Frequent acquisitions during freeze-up (fall) and break-up (late spring) are helpful as ice changes are rapid, as well as during the summer to track moving ice and plan boat travel. But the sea ice is predominantly used through winter and spring months, the seasons of least frequent image acquisition, and the most challenging times to identify small changes in ice thickness, tidal cracks, polynyas, or the floe edge. Thus, the imagery and the frequency of its acquisition seemed least helpful to the hunters in the seasons when the sea ice is most used.

SAR image representation capabilities. SAR imagery is used for sea ice monitoring because it is effective at distinguishing between sea ice and open water based on their different dielectric properties. The penetration of SAR microwaves and the resulting backscatter is influenced by: salinity, surface roughness, air bubbles, and snowpack moisture (Johnston and Timco 2008). But the capabilities of SAR imagery to represent locally important sea ice indicators does not always match directly with ice conditions or safety indicators of interest to hunters (Table 2). For example, gauging ice thickness is critical to evaluating the safety and stability of the sea ice for travel. Relative ice thickness of different stages of growth for first year ice can be obtained from SAR imagery (Plates 10 and 12) but neither optical nor microwave imagery can measure ice thickness with the sensitivity required to tell if the ice is thick enough to walk on versus having sufficient strength to drive on. However, experienced image analysts draw upon a number of key identifiers to interpret image brightness, tone, texture, edges, and shapes to provide meaningful observations based on SAR backscatter, including: thickness and age, freeboard (how high the ice floats above the water), floe shape and size, ponding/drainage, ice surface topography and colour, and snow cover among other considerations (Johnston and Timco 2008). Many of the local sea ice indicators used by hunters can be inferred using SAR imagery (Table 2) but hunters also always try to be aware of conditions below the ice surface. Imagery cannot see through the ice completely or identify the thickness of snow that may affect the ice below. However, satellite imagery can help identify some of

the most hazardous areas where the currents are wearing away the ice from underneath, based on interpretations of moisture content or polynya dynamics (Plates 10 and 11).

Technological limitations. There were also several technological limitations associated with accessing and using FES image products. One was that there was strong interest in all three communities in being able to access FES products directly on their Global Positioning System (GPS) for use during travel. Currently this would be limited by file size capabilities of GPS units, the large sizes of processed satellite imagery, and the fact that image files could not be updated once outside the community without a data plan through satellite phone service. Harsh climate conditions and long travel distances also push the limits of portable technology, where there are ongoing challenges of maintaining battery life, improving data storage space, and ensuring sufficiently rugged equipment.

A second technological limitation is related to the information technology (IT) infrastructure itself. As in many northern Canadian communities, IT infrastructure is limited in Cape Dorset, Igloolik, and Pangnirtung. Although rapidly improving, bandwidth is still limited and transfer times are affected by the volume of usage. FES products have been designed with these limitations in mind, but communities still report slow download times which sometimes affect the quality or access to imagery. There is interest in moving towards more web-based interactive services, but as yet local and regional infrastructure would not make such improvements feasible.

A third and critically important limitation is technology itself. Despite the enthusiasm generated by community members and Noetix staff for enhanced collaboration on the expansion and improvement of the FES, participants emphasized that Inuit knowledge must still be taken into consideration. Inuit are well-known for their ability to adopt and master new technologies, such as firearms, internal combustion engines, and GPS-assisted navigation (Norton 2002; Norton and Gaylord 2004; Aporta and Higgs 2005), but hunters and elders warned against relying solely on technology. Through long-term experience and regular communication through local and shortwave radio, local sea ice experts know

the locations of hazardous areas and the indicators needed to assess them on the ice. Therefore, imagery alone could never be used by travellers to assess the safety of ice conditions. Much more contextual information is needed to: (i) effectively interpret the imagery; (ii) safely navigate ice conditions; (iii) anticipate changes on the fly; and (iv) evaluate the chances of hunting or harvesting success (Table 2). Images provide a 'bird's eye view' of the ice, but most hunters prefer to assess ice conditions 'on the ground' as they travel. So although regional scale overviews can be helpful, just looking at images cannot do justice to the ice conditions, you have to be there to know what it is really like.

Facilitating knowledge-exchanges

Intercultural knowledge exchanges. In reviewing satellite imagery and evaluating the potential local applications of the FES, workshop contributors (re)emphasized previous statements that if scientists want to learn about the sea ice, they need to ask Inuit who have long-term experience evaluating and using sea ice conditions as part of daily life (Laidler 2006a, 2007). However for some, scepticism has developed around sharing information with government scientists or academic researchers. Elders and hunters described how what they have shared in the past has been disregarded, not credited (Laidler 2006a) and/or used against them enough times that they are now starting to withhold information. Participants explained that they were willing to share their expertise as part of the FES workshops because: (i) we were following up on earlier work; (ii) they were contributing to something that will benefit the community; and (iii) they were documenting Inuit knowledge that could help local youth. So, scepticism, misunderstandings, and numerous local concerns with research collaboration still need to be overcome, but there is also community interest in working together and learning cooperatively. Hunters see themselves as having the knowledge about ice conditions and marine environments while researchers have the technology (Laidler 2007). However, for the FES to be more useful and comprehensive, it was suggested that ongoing collaboration was needed when university researchers and Noetix staff were not around.

Emphasis was placed on finding ways to ensure continuity and more local ownership of results or service provision by more regular research undertaken and directed locally. Therefore, FES workshop discussions helped to: expand earlier collaborations, facilitate intercultural exchanges, identify ways to improve working relationships, and ultimately move towards a more comprehensive and holistic understanding of sea ice conditions, dynamics, and uses.

Intergenerational knowledge exchanges. During workshops, a gap in knowledge transfer was identified, as elders are passing away rapidly and there are fewer people in the communities skilled in traditional observation and prediction methods and capable of passing these skills along to youth. Community representatives felt strongly that youth should be taught traditional survival skills because technology alone cannot tell you where it is safe to travel or how to find your way. Those hunters who are travelling and hunting on the ice regularly, and who have extensive experience with seasonal conditions and dynamics, are those who can most effectively interpret and make use of satellite imagery. Ironically, this same group needs the imagery the least. The younger, less experienced hunters tend to rely more on technology, but without the complementary traditional skills, this can sometimes result in tragic consequences. Using the ice is no longer a way of life for today's Inuit youth (Ford *et al.* 2006a, 2006b; Heyes this issue), so they have less understanding of ice conditions, dangers, changes, variability, uses, and terminology (Laidler *et al.* 2008). Young Inuit are still active in hunting and harvesting but with less time or interest as they balance educational requirements, wage employment, shifting social norms, and intergenerational segregation (Aporta and Higgs 2005; Laidler 2007). Therefore, more youth will be invited to participate in future workshops. Inuit youth are continually having to reconcile Inuit and scientific ways of knowing and thus may provide important insights into discussions of traditional and technological indicators. Better understanding the impacts of environmental changes on intergenerational knowledge transmission would also help to understand change and stability in human-environment relations in

the Arctic and its far-reaching effects on Inuit lifestyles, safety, and identity (Norton 2002; George *et al.* 2004; Laidler *et al.* 2009).

Conclusions

Nichols *et al.* (2004, 78) suggest that '[i]n the area of remote sensing, [Inuit] knowledge can potentially fill the gap at the local scale and provide local validation'. Remote sensing relies heavily on interpretation skills and local experts have something to contribute regarding interpretation. Inuit sea ice experts can help put satellite observations into local and historical context and interpret the implications of observed changes for northern communities (Riedlinger and Berkes 2001; Norton 2002; Laidler 2006b; Meier *et al.* 2006; Druckenmiller *et al.* 2009). Ongoing monitoring of sea ice conditions through satellite imagery can also provide effective time series analysis and insights into regional scale ice conditions and dynamics to support community use (Norton 2002; Norton and Gaylord 2004; Laidler 2006b; Meier *et al.* 2006). In this article, we have provided examples of how these two ways of observing and interpreting ice conditions may be brought together for mutual benefit, through an evaluation of the local utility of the FES in Cape Dorset, Igloodik, and Pangnirtung. But there is no easy answer to our original research question. There is local interest in accessing and using satellite imagery, especially to assist Inuit to adapt to interannual sea ice changes, along with the increasingly unpredictable nature of these changes which can undermine Inuit knowledge and traditional skills. However, it was reiterated often that imagery cannot be used without adequate traditional, navigational, language, and survival skills. Images cannot show how environmental changes interact to create local-scale implications intertwined with social and cultural changes (George *et al.* 2004; Meier *et al.* 2006), nor can they instill the sense of confidence or fulfilment from being self-sufficient on the sea ice without technological aids as '[e]ngagement cannot finally be replaced by a commodity' (Aporta and Higgs 2005, 745).

The FES workshops can be considered culminating events for research undertaken between 2004-2006 but they are also important starting points for future initiatives. A number of

recommendations emerged to improve the FES over time:

1. image clarity—develop higher product clarity from the ScanSAR imagery (for better print and viewing quality);
2. spatial and temporal resolution—acquire higher-resolution and higher-frequency SAR imagery (i.e., using Standard or Fine beam RADARSAT modes);
3. classification—develop colour image products based on image classification techniques to help make image interpretation more intuitive;
4. technology transfer—investigate new options for technology transfer (e.g., accessing the FES product floe edge ‘line’ on a handheld GPS unit);
5. communication—improve two-way communication, and collaborative annotation of image products, between the local FES hosts and Noetix staff to refine image products;
6. local observations—establish a system for local observations of ice conditions to be recorded and shared with Noetix staff to improve image interpretation, provide more meaningful products to the communities, and evaluate important indicators over time;
7. help bridge the generation gap—design and run more local activities/programs to help facilitate intergenerational transfer of traditional, navigational, and survival skills for safe sea ice use;
8. training—provide additional and ongoing training in image interpretation (i.e., face-to-face and more independently online, e.g., <http://www.noetix.ca/floedge/tutor/index.html>);
9. funding—secure sustained long-term funding for the FES to ensure continuity and improvements over time (i.e., best suited to core funding in a governmental or land claims organization annual budget);
10. optical imagery—regularly post optical imagery to complement SAR image interpretation;
11. expansion—expand the FES across northern Canadian communities to provide equal access to regional sea ice information;
12. evaluation—undertake more systematic analysis of the FES based on all communities us-

ing the service, as well as potential uses for northern tourism and search and rescue; and

13. monitoring—improve targeted sea ice monitoring efforts based on local sea ice indicators, relevant Inuktitut terminology, and hazardous areas. (adapted from Laidler and Kapfer 2009).

Future work will follow-up on these recommendations to build on opportunities and address the challenges identified in workshops. For example, developing closer collaborations with host organizations of the FES and local hunters to improve ‘ground truthing’ could help improve image products and advance scientific knowledge of sea ice at local and regional scales. This could be established by receiving regular feedback from hunters on ice conditions, ideally including GPS points and photos of key ice features/changes observed during their travels. To achieve this, expanded piloting or regular use of Iglinit units (see Gearheard *et al.* this issue) were of particular local interest. Establishing a community-based ice monitoring system to measure local sea ice thickness, snow depth, and air, snow, ice surface, and water temperature (Mahoney and Gearheard 2008) could also provide critical data to aid image interpretation, contribute to an expanding network of on-ice measurements, and facilitate community decision-making. Combining these elements to develop an integrated community-based monitoring program such as in Nunavik (Tremblay *et al.* 2006, 2008) could thus provide a range of qualitative and quantitative data to support community-specific ice safety evaluations and long-term analysis. These efforts would contribute to improved ice safety forecasts for various end-users based on: (i) understanding the end-user’s needs for information, advisories, and warnings; (ii) picking the ‘right’ signals (indicators); and (iii) following signals over the appropriate scales (Norton and Gaylord 2004). Consideration must also be given to users’ assessments of risks and benefits and means of observing or interpreting environmental indicators (George *et al.* 2004). An emphasis on public safety can thus be more effective for collaboration and discussion than on climate or sea ice change specifically (Norton 2002). It is only when the community sees local utility in collaboration, with targeted

applications requiring consultation and joint efforts, that technologies such as remote sensing can realize their potential in supporting community decision-making.

Having a truly integrated sea ice observing system would involve combining different approaches to data and information across scales, interfacing local and remote observations and different forms of expertise, and ensuring that the observing system is driven by local and scientific information needs (Druckenmiller *et al.* 2009). Undertaking this in communities across the circumpolar Arctic could expand our comprehensive understanding of northern sea ice change and implications, while also maintaining community-specific context and critical indicators essential for more localized evaluations. Given the increased political and economic attention paid to the Arctic with declining ice extents (Aporta *et al.* this issue), bridging scales and knowledge systems will be essential to monitor ice conditions more effectively (for climate change research, shipping safety, and policy- and decision-making), as well as to support search and rescue operations. In working together to improve image products such as those provided by the FES, remote sensing can be incorporated into the suite of traditional indicators and technological tools that hunters draw upon in their evaluations of complex human-animal-environment assessments, to continue their cultural and commercial pursuits. However, workshop discussions also served as important reminders that technology is helpful but, on its own, it is insufficient to address local concerns about unpredictable sea ice conditions and travel safety, highlighting the value of continuing to pass on Inuit knowledge and survival skills to youth.

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