Ice Watch: Standardizing and expanding Arctic ship based sea ice observations

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1. Introduction

Visual observations of ice from airplane or ship are an integral part of sea ice monitoring for operational and research support. These observations provide information about sea ice morphology that is not obtainable or ambiguous in remotely sensed data. We present Ice Watch, a program coordinating visual observations of sea ice in the northern hemisphere conducted from ships. Following from efforts to standardize sea ice observations in the Antarctic (Worby and Alison, 1999) observation protocols and software have been developed to aid in the standardization of ship-based visual sea ice observations in the Northern hemisphere and globally.

2. Observing Arctic Sea Ice from Ships

In the past there have been a variety of methodologies used to record visual ship-based observations of the Arctic ice pack. These range from the use of the ASPeCt convention (Worby and Alison, 1999), which was designed for Antarctic sea ice, to ad-hoc systems designed for particular ships (e.g. custom designed software has been used on the United States Coast Guard Cutter *Healy*, Eicken et al., 2009). In general the systems used adhere to the World Meteorological Organisation (WMO) nomenclature (WMO, 2014) for describing sea ice characteristics.

With differences between methodologies used by different researchers, and divergence in the description of Arctic specific features, such as melt ponds, there was need to unify reporting of sea ice bridge observations from Arctic research vessels. This need was discussed during a World Climate Research Program Climate and Cryosphere (CliC) sponsored workshop in 2009 (Gerland et al. 2009), and a plan implemented to standardize Arctic bridge observations. Over the following 3 years discussions were instigated between Arctic sea ice researchers who participate in ship-based field campaigns to find consensus on the common elements of a bridge observations recording system for the Arctic. These discussions resulted in the design of a standardized recording system and software to facilitate collection and archival of standardized data. The recording system resulting from these discussions has been implemented into a standard protocol for performing sea ice bridge observations in the Arctic. The Ice Watch program was founded to facilitate uptake of the new standard methods by researchers and to assist in data archival.

Since 2012 the Ice Watch program has expanded its network of participating observers and ships. In this year data was collected during 13 separate cruises and has coverage of much of the perennial ice pack, figure 1.

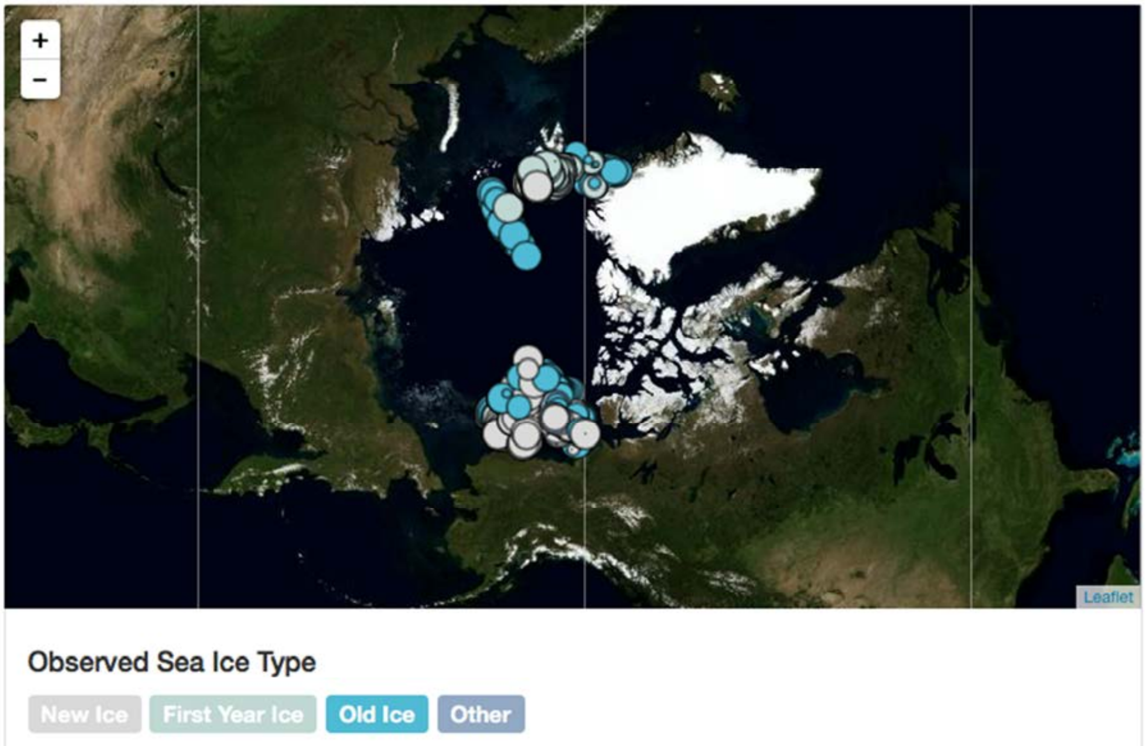

Figure 1 Location of Ice Watch data collected during 2015. This is not the full set of data collected in 2015, we are anticipating contributions in the Bering Sea and central Arctic from the Sikuliaq and Healy.

2.1 Software to record bridge observations

To facilitate accurate recording of observations following the Ice Watch Program standard protocols software was developed for recording data and archiving the data.

The Arctic ship-borne sea ice standardization tool (ASSIST) is a stand-alone web interface that guides an observer through recording visually estimated properties of the sea ice. The ice is viewed within 1 nautical mile (nm) from the ship during a 10 minute observation period that is normally performed on the ship's bridge. The philosophy of ASSIST is to guide users through the observation process, and ensure standardized data is recorded accurately. ASSIST guides the observer with basic quality control, reducing erroneous records. It has an intuitive interface (see figure 2), and runs on Windows, Mac and Linux platforms.

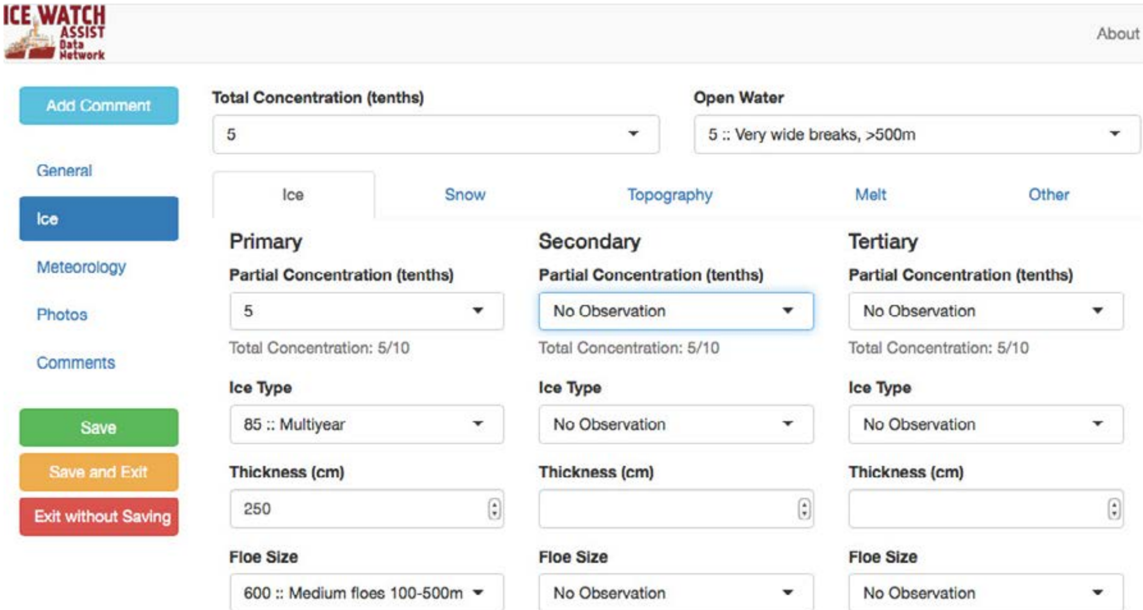

Figure 2: A screen shot showing the layout of the ASSIST data entry

Data is archived through a website hosted by the Geographic Information Network of Alaska (GINA), using the same web interface as ASSIST for error correction and checking. Both ASSIST and the Ice Watch archive allow upload of CSV data files, such that experienced observers do not need to use the web interface, and quality control can be conducted offline.

2.2 The Ice Watch Observing System

The foundation of sea ice characterization is the Egg Code (Canadian Ice Service, 2005), where ice within a region is classified in up to five categories based on the ice type. Three ice types, referred to as, in order of decreasing thickness, the primary (P), secondary (S) and tertiary (T) ice types, are recorded with detailed information. Two additional types can be noted: a thick ice type (the thickest ice that has less than 10% cover) and one additional ice type. In the Egg Code each P, S or T ice type the stage of development of the ice and form of the ice is recorded. Both ASPeCt and ASSIST preserve this convention in their recording system. However there is much additional information recorded in ASSIST that is of interest to sea ice researchers. See the Appendix for a summary of observational fields in ASSIST. Both ASPeCt and ASSIST characterize sea ice topography and snow cover, following ASPeCt convention (Worby and Dirita, 1999). ASSIST includes additional ice type and floe size options to reflect ice chart conventions (Canadian Ice Service, 2005). ASSIST also includes stage of melt information that is absent from ASPeCt, but included in observations supporting ice charting (Canadian Ice Service, 2005).

2.3 Key differences between ASPeCt and ASSIST

ASSIST is fully backward compatible to ASPeCt (Toyota 2015) , such that any ASSIST observation can be transformed into the ASPeCt format. Additional fields are included in ASSIST to characterize ice conditions more typically found in the Arctic than the Antarctic. These include fields describing the ice surface melt, sediment and algae in ice, fauna additional ice types and meteorological fields, and information about ship travel.

Table 1: Stage of Melt Classification for different ice types. Following Russian ice observer convention (pers. comm. Vasily Smolyanitsky 2003).

	Stage of Melt	Description
Young Ice	0	No melt
	1	Surface darkened, snow melt single thaw holes
	2	Greatly disrupted surface thaw holes everywhere
	3	Level ice completely melted. Only deeply seated in water remains, ridges still found
First Year Ice	0	No melt (or pack freezing, young ice forming over thaw holes)
	1	Some puddles on surface. Ice structure destruction from warming begun, brine channels enlarging.
	2	Surface darkened, snow partially melted. Big puddles, some melt ponds.
	3	Melt ponds everywhere, some thaw holes. Ice is stage of drying, ice color whitening.
	4	Greatly disrupted ice. Thaw holes everywhere. Disruption of brine channel structure complete, ice dried. Underwater ramps on ice cakes.
	5	Rotten ice. Greatly melted formless blocks. Dark grey color, greatly watered.
Multiyear Ice	0	No melt (or pack freezing, young ice forming over melt ponds/thaw holes)
	1	Snow melting on top of hummocks. Melt ponds / patches of wet snow in low places.
	2	Some ponding, <40% melt ponds. Snow melting. Places with no snow may occur.
	3	Well-defined melt ponds everywhere. Connected freshwater output through cracks. Area of melted water on surface is decreased due to output.
	4	Ice floes cracked. Area of melted water on surface is decreased from drainage, <30%. Thaw holes.
	5	Floes have become cracked and blocks, due to

intensive melt. Rotten ice.

Sea ice stage of melt can be characterized in a 5 point scale (table 1) that follows the WMO standard convention for describing melt. In North American ice charting this scale is reproducible from the standard observations (Canadian Ice Service, 2005) outlined in table 2. In ASSIST the full 5 point scale can be reproduced provided all melt fields are entered for an ice type. The pertinent information is whether thaw holes are present in melt ponds, if ice has dried or become rotten and whether ponds are freezing over. In addition to the stage of melt information, area of ice covered by melt pond and pond characteristics, such as whether melt ponds are discrete or linked (see figure 3) and the depth of melt ponds can be recorded.

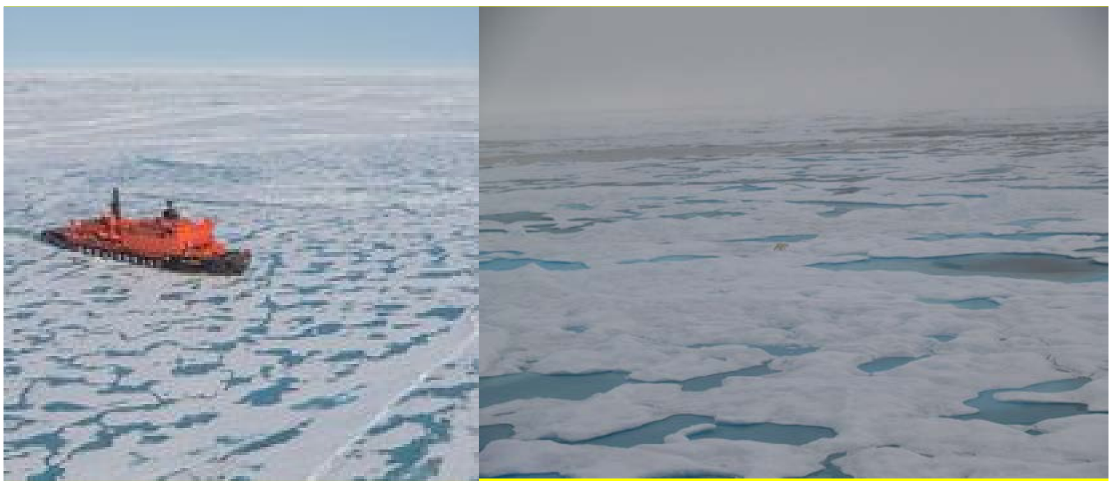

Figure 3: Photographs of linked melt ponds typical on level first year ice (left) and discrete melt ponds on older ice (right).

Table 2: MANICE characterization of stage of melt, which is somewhat less detailed that the Russian convention described in table 1

Puddles	The presence of melt ponds or puddles is noted
Thaw Holes	Thaw holes in melt pond bottoms
Dried Ice	Ice surface as dried and whitened, equivalent to stage 4, table 1
Rotten Ice	Honeycomb ice, equivalent to stage 5, table 1
Flooded Ice	Flooded ice is heavily loaded with water or water and wet snow

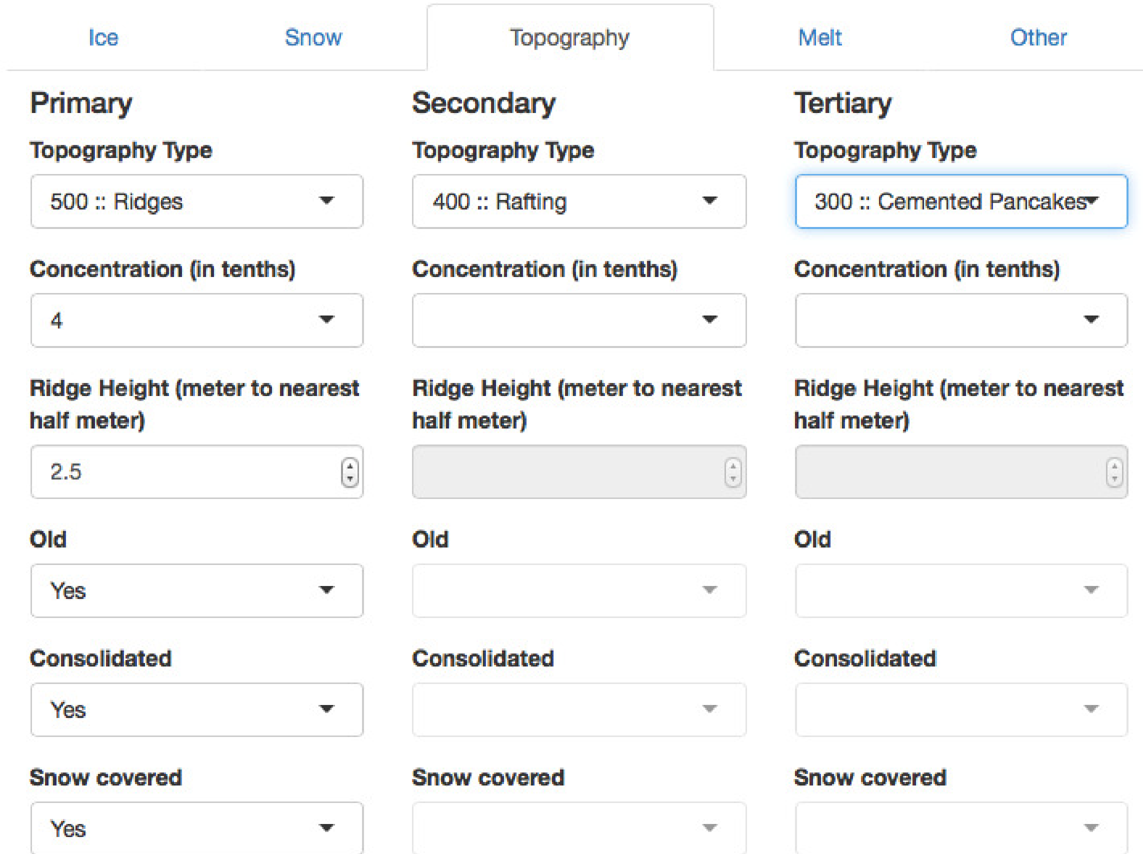

Figure 4: Ridge data entry in ASSIST.

In ASSIST the ASPeCt topography code convention (Worby and Alison, 1999) is followed. The ASSIST software eases recording of the topography codes by guiding the observer through menus characterizing the ridging (see figure 4). The observer can enter ridges as present, and record area cover and sail height of these ridges. Additional questions identify if the ridges are snow-covered, consolidated or old, negating a need to remember the codes for each of these scenarios when recording observations. While the ASSIST data is not provided as ASPeCt codes, these codes are easily recreated from the ASSIST data (see table 3).

Table 3: Conversion between ASSIST and ASPeCt Topography Codes. The ice fraction, x, and thickness, y, are recorded in the same way in both systems.

ASSIST						**ASPeCt**
topography	**old**	**consolidated**	**snow cover**	**fraction**	**thickness**	
500	no	no	no	x	y	5xy
500	no	no	yes	x	y	6xy
500	no	yes	yes/no	x	y	7xy
500	yes	yes	yes/no	x	y	8xy

3 Supporting Operational Needs

As ASSIST data follows the Egg Code convention and is compliant with WMO standards, it can be directly compared to and used in ice charts. The national and regional organizations that create ice charts have standardized data formats that are formalized through participation in the WMO JCOMM Expert Team on Sea Ice (ETSI). This group has developed a conventional shape file format for Ice Chart data that allows sharing of data and products between organizations. This data format is version 3 of Sea Ice GeoReferenced Information and Data, SIGRID-3 (JCOMM Expert Team on Sea Ice, 2014). Ice Watch provides SIGRID-3 format data download from the icewatch.gina.alaska.edu archive.

We are currently beta testing the SIGRID-3 format for ASSIST data, in partnership with the U.S. National Ice Center. Though we do not currently have the ability to provide SIGRID-3 data in near-real time, we are discussing how to provide software to perform the conversion from ASSIST data sent by email from ships. Near-real time data will enhance utility for ice charting and forecasting, and requires some operational support from the national ice services to manage.

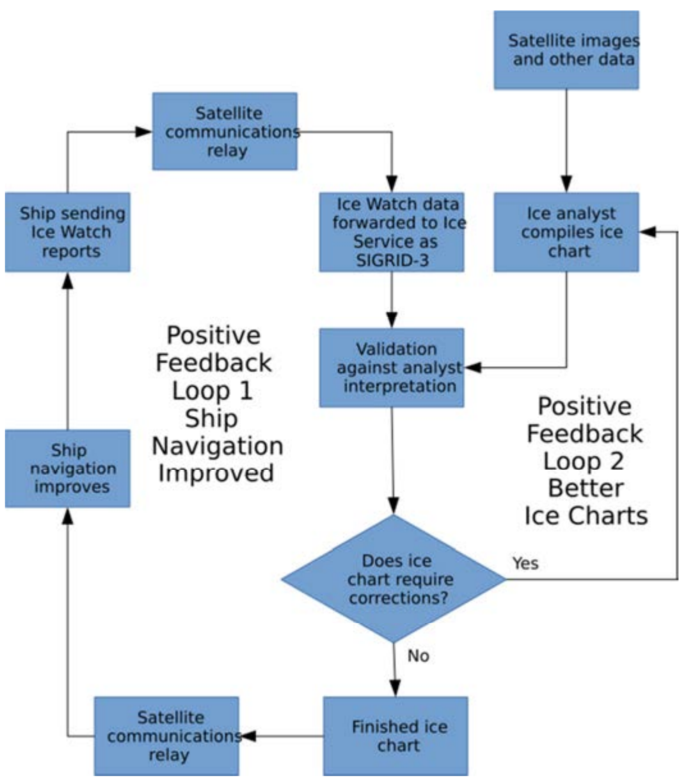

Figure 5: Schematic showing how Ice Watch data is integrated into improving accuracy of ice charts.

ASSIST data can be used to validate ice charting practices between different agencies and the ice analysts employed in producing ice charts. Ice analyst interpretation of ice conditions is subjective, and can vary according to factors including: the different types of satellite and in situ observations available; the amount of time taken to compile the ice chart particularly if working to a set deadline; and the individual level of training of the ice analyst. Near-real time availability of the data would allow this process to be undertaken during the ice chart production process, by providing the analyst with an independent and non-subjective measurement from the location that can be used to improve their interpretation of the other available data, typically synthetic aperture radar (SAR) satellite images.

Testing of Ice Watch SIGRID-3 format data ingestion into ice charts will be organized through the national ice charting agencies group, the International Ice Charting Working Group (IICWG), which arranges regular Ice Analysts Workshops to allow experimentation with new methods and cross-comparison of ice charting procedures between agencies.

4. Utility of Ice Watch Data

While the coverage of Ice Watch data is limited to one nautical mile along ship tracks, it does provide a richer data set than is possible with remote sensing alone. Sea ice characteristics that are not inferable from remote sensed data over large regions include melt pond characteristics, detailed determination of the surface roughness including area and volume estimates for ridges, and thickness of the snow and ice.

The detailed morphological description Ice Watch provides is both a tool to focus the researchers observational awareness and record detailed information that can help in future interpretation of field experiments, and inform ice charts used in navigation and hazard mitigation. The data can be used in investigating the variability of sea ice morphology and how sea ice interacts in the climate system. For example in mapping sea ice thickness (Worby et al., 2008), identifying melt pond cover (Itoh et al., 2011), tracking floe size and areas of mixed ice types (e.g. Perovich et al., 2009) .

It is the utility of the data that motivates us to grow the Ice Watch network and become closely integrated with other groups operating and supporting operations in ice covered waters.

5. Developing Partnerships

Since 2009, researchers on board vessels from Japan, China, Norway, Canada, The U.S.A, Germany, Korea, Sweden, Russia and the non-governmental organization Greenpeace have participated in Ice Watch. We are expanding participation from the Oil and Gas industry, with participation from StatOil in recent years.

In Summer 2015 Ice Watch conducted its first citizen science experiment. Tour operators on the Russian icebreaker *50 Let Pobedy* participated in Ice Watch recording bridge observations and provided a comprehensive description of evolving ice conditions between Franz Joseph Island and the North Pole over a 6 week period in July and August. This use of ASSIST demonstrated that data collection can be implemented on a cruise with little disruption to the pre-existing tour program and also provides significant additional value to the paying passengers, who were unequivocal in expressing their enjoyment in taking part in Ice Watch. The polar tourism industry is open to sharing their access with researchers and there is considerable interest within the industry in this pilot project.

Expedition cruise operators have sustained and repeated access to polar regions and are becoming increasingly aware of the value of this access for data collection. There are approximately 20 vessels in the industry, the majority ice-strengthened and one or two of icebreaking class, working for up to 5 months at a stretch in various parts of both the Arctic and Antarctic. Ice Watch is interested in engaging these cruise operators in future data collection.

Other opportunities for data collection have occurred through partnerships with researchers on field campaigns funded by oil and gas companies. We wish to expand these partnerships, providing data collection training and support to merchant navy ships. From experience worked with two industry supported cruises and Greenpeace's Arctic Sunrise we are developing strategies to engage merchant navy officers in Ice Watch. To be successful and provide observations useful for ice hazard avoidance and scientific research this program needs centrally funded organization. Services to merchant navy must include training packages and simple electronic transfer of data to the national ice charting organizations.

6. Integration into Observing Networks

Ice Watch data does not lend itself to gridding or direct comparison with model fields. It is best utilized in concert with remote sensed data. In ice charting, where synthetic aperture radar, visual, thermal and passive microwave satellite images are used to identify zones of uniform ice characteristics, a small number of visual observations within a zone are invaluable for ground truth and providing data not obtainable from the imagery such as ice thickness during summer, melt pond characteristics and snow depth. Hence the most value of the Ice Watch program in observing networks would be to (i) provide near-real time data to meteorological and ice charting groups and (ii) ensure a large network of sea ice observers are recording Ice Watch data with the ASSIST code and archiving this data for research use.

To support operational needs data transfer could be provided in coordination with the Autonomous Volunteer Observation System (AVOS) and the World Meteorological Organisation's (WMO) Global Telecommunication System (GTS).

Achieving integration in to the Global Observing System requires management support to translate ASSIST data to AVOS and GTS fields, interface with the relevant WMO World Weather Watch committees, shepherd the technological and software development required, expand the data network and interact with users. We also need to identify communities of mariners to engage through training and observation involvement to expand Ice Watch further. We are developing technology to facilitate near real time transfer of Ice Watch data such that we can integrate into global networks supporting ice charting and forecasting.

As an ice watch is an integral tool in the sea ice field workers kit, such data has been collected on cruises that pre-date the inception of the Ice Watch Program. We are interested in data rescue and working with our partners to convert older data formats into the Ice Watch standard format. While this will require some additional funding, the effort will be rewarded with increased utility of the data archive for climate investigations. The Ice Watch database is interested in building links to Polar and Global observational databases.

5. Future Sustainability of Ice Watch and its Partnerships

As shipping increases in the Arctic there is a need for increased and improved now-casting and forecasting of ice conditions ships will encounter. A key tool in providing accurate ice charts is in-situ observations. Ice Watch is interested in providing merchant and research ships the capability to deliver such observations to ice charting agencies world-wide. In the next year we will be developing a streamlined version of ASSIST for use by non-experts. In designing this tool we are interested in identifying the data needs of industry and operational centers.

Ice Watch will maintain a database of ASSIST data at both the University of Alaska Fairbanks, USA, and the Alfred Wegner Institute, Germany. The data is freely available, easily searchable and appropriate for a variety of sea ice studies. As the program has grown to include increasing number of ships and researchers over the last 6 years, with a small amount of support for data archival, data and software management it is poised to become an integrating resource for sea ice research. The creation of a program office, perhaps as part of a larger effort to integrate Arctic marine observations into the Global Observation System and support citizen observers, would facilitate expansion of observations. The link between Ice Watch as a research tool and Ice Watch's direct involvement in operational support of Arctic shipping should be exploited to grow the program to fulfill the needs of increasing human activity in ice covered waters.

For more information and to participate visit www.iarc.uaf.edu/icewatch. Ice Watch data is freely available at icewatch.gina.alaska.edu.

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Utilizing the IARC-JAXA Information System (IJIS) and Satellite Imagery". The Climate of the Cryosphere (CliC) has provided logistical support in developing the Ice Watch collaboration and hosts a technical working group facilitating conversations and integration with the SCAR/ASPeCt team. The design of the Ice Watch standardized observing method and ASSIST software has been developed from numerous conversations with many Arctic field researchers both informally and during CliC Sea Ice Working Group meetings. Many thanks to John Falkingham for discussions invaluable in developing the SIGRID-3 conversion of Ice Watch data.

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Appendix: Ice Watch Observation Codes

Ice Watch observations are organized in the ASSIST data input interface into a series of pages: General, Ice, Meteorology, Photos and Comments. In the description of the observation codes below we present the data in tables associated with each page and tab on the page. Data is output in comma separated value, CSV, format and the header for the data column is given in brackets next to the observable name in the following tables.

General: Observation

PRIMARY OBSERVER (PO) **ADDITIONAL OBSERVER/S (AO)**
Full name *Add your name to the menu on first observation.*
OBSERVATION DATE/TIME (Date)
YYYY-MM-DD HH:MM:SS UTC *Converts computer time to UTC automatically.*
LATITUDE (LAT) **LONGITUDE (LON)**
DDD.DDD or DDD MM SS or DD MM.MMM *Converts to decimal degrees automatically.*

General: Ship

SHIP HEADING (ShH) degrees	**SHIP SPEED (ShS)** knots
Nearest degree	Nearest knot
SHIP POWER (ShP)	**SHIP ACTIVITY (ShA)**
Not Specified	Not Specified
0	10 :: Traveling in leads
1/4	20 :: Traveling in ice
1/2	30 :: Back and ramming
3/4	40 :: On station
Full	

General: Fauna

FAUNA NAME (FN)
Common or scientific name *Any number of fauna types can be added*
FAUNA COUNT (FC)
Number of reported species

General: Notes

NOTES (note0, note1, & note2)
Observer's notes, free format

Three free format fields that can be used to include additional data entries of the observers choice.

Ice

TOTAL ICE CONCENTRATION (TC) PARTIAL ICE CONCENTRATION (*C)	Tenths
0 :: 1/10	
1 :: 1/10	
2 :: 2/10	
3 :: 3/10	
4 :: 4/10	
5 :: 5/10	
6 :: 6/10	
7 :: 7/10	
8 :: 8/10	
9 :: 9/10	
10 :: 10/10	

OPEN WATER (OW)
0 :: No openings
1 :: Small cracks
2 :: Very narrow breaks, <50m
3 :: Narrow breaks, 50-200m
4 :: Wide breaks, 200-500m
5 :: Very wide breaks >500m
6 :: Leads
7 :: Polynya
8 :: Water broken only by scattered floes
9 :: Open sea
10 :: Strips and patches

In the Ice, Snow, Topography, Melt and Other tabs information is entered for each ice type. The ice types are Primary (P), Secondary (S) and Tertiary (T). CSV data headers for the P,S and T fields are prefixed by P, S or T respectively. The letter codes following this prefix are given in the tables below with a * prefix.

Ice: Ice

Partial Ice Concentration (*C) is entered following the table for TC.

ICE TYPE (*T) OTHER ICE TYPE THIN (OT) OTHER ICE TYPE THICK (TH)
10 :: Frazil
11 :: Shuga
12 :: Grease
13 :: Slush
20 :: Nilas
30 :: Pancakes
40 :: Young Grey Ice, 10-15cm
50 :: Young Grey Ice, 15-30cm
60 :: First Year, < 70cm
70 :: First Year, 70-120cm
80 :: First Year, > 120cm
75 :: Second Year
85 :: Multiyear
90 :: Brash
95 :: Fast Ice

ICE THICKNESS (*Z)	cm
Total ice thickness in cm	

FLOE SIZE (*F)
100 :: Pancakes
200 :: New sheet ice
300 :: Brash/Broken ice
400 :: Cake ice, < 20m
500 :: Small floes, 20-100m
600 :: Medium floes, 100-500m
700 :: Large floes, 500-2000m
800 :: Vast floes, >2000m
900 :: Bergy floes

Ice: Snow

SNOW TYPE (*SY)
00 :: No snow observation
01 :: No snow, ice or brash
02 :: Cold new snow, <1 day old
03 :: Cold old snow
04 :: Cold wind-packed snow
05 :: New melting snow(wet new)
06 :: Old melting snow
07 :: Glaze
08 :: Melt slush
09 :: Melt puddles
10 :: Saturated snow
11 :: Sastrugi

SNOW DEPTH (*SN)	cm
Depth of surface snow	

Ice: Topography

TOPOGRAPHY TYPE (*Top)
100 :: Level ice
200 :: Rafted Pancakes
300 :: Cemented Pancakes
400 :: Rafting
500 :: Ridges

TOPOGRAPHY CONC (*TopC)	Tenths
0 :: 0/10	
1 :: 1/10	
2 :: 2/10	
3 :: 3/10	
4 :: 4/10	
5 :: 5/10	
6 :: 6/10	
7 :: 7/10	
8 :: 8/10	
9 :: 9/10	
10 :: 10/10	

*TopC is the fractional area of ice, separately for each type, covered by ridges or rafts

RIDGE HEIGHT (*RH)	m
To nearest half meter	

TOPO FEATURE OLD? (*Old) TOPO FEATURE CONSOLIDATED? (*Cs) TOPO FEATURE SNOW-COVERED? (*SC)
Yes :: True
No :: False

Ice: Melt

MELT POND CONC (*MPC)	Tenths
0 :: 0/10	
1 :: 1/10	
2 :: 2/10	
3 :: 3/10	
4 :: 4/10	
5 :: 5/10	
6 :: 6/10	
7 :: 7/10	
8 :: 8/10	
9 :: 9/10	
10 :: 10/10	

*MPC is the fractional area of ice, separately for each type, covered by meltponds

MELT POND PATTERN (*MPP)
1 :: Linked
2 :: Discrete

MELT POND SURFACE TYPE (*MPT)
1 :: Frozen
2 :: Open
3 :: Bottom up

MELT POND FREEBOARD (*MPF)	cm
Height of MP freeboard above MP surface	

MELT POND DEPTH (*MPD)	cm
1 :: 0-10cm	
2 :: 10-30cm	
3 :: 30-50cm	
4 :: >50cm	
-9 :: Unknown	

MELT POND BOTTOM TYPE (*MBT)
1 :: Solid
2 :: Some have thaw holes
3 :: All have thaw holes

DRIED ICE? (*MDI) ROTTEN ICE? (*MRI)
Yes :: True
No :: False

Ice: Other

ALGAE CONC. (*A) SEDIMENT CONC. (*SD)	%
0 :: 0%	
1 :: <30%	
2 :: <60%	
3 :: >60%	

*A and *SD is the percentage area of the ice, of any given type, with algae or sediment present.

ALGAE LOCATION (*AL)
1 :: Top
2 :: Middle
3 :: Bottom

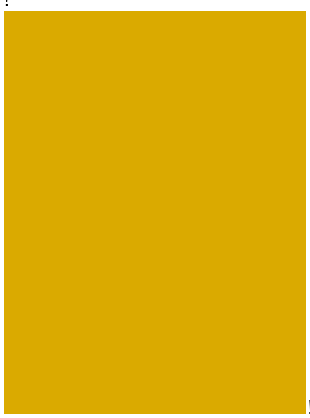
ALGAE DENSITY (*AD)
0 :: Not Visible
1 :: Trace
2 :: Light
3 :: Medium
4 :: Strong
See Colour Chart

Two fields in Ice:Other not associated with P, S or T.
Other Ice Type Thick (TH)
Other Ice Type Thin (OT)
The codes for these types are given in the ice type table.

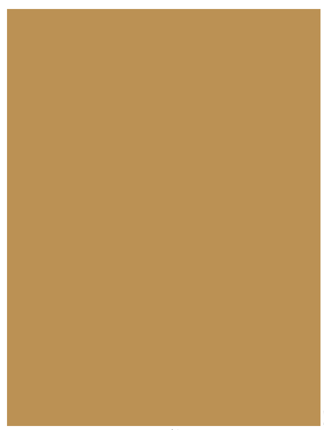
!
!!
Colour&Chart&for&Identifying&Ice&Algae&density&
!
0&Not&Visible&
!!

&
&
1!<!!3mg!chl!a!m$^{*2!!!!}$**Trace&**

!
2!~!4.5mg!chl!a!m$^{*2!!!!}$!!!!!!!!
Pantone!100c!!!**Light**!
!



!
3!~!10mg!chl!a!m$^{*2!!!!!}$
Pantone!110c!!!!!**Medium**!
!



!
4!~!30!mg!chl!a!m$^{*2!!!!}$!!
Trumatch!49b!!!!**Strong**!
!

Meteorology

VISIBILITY (V)	m-km
90 :: <50m	
91 :: 50-200m	
92 :: 200-500m	
93 :: 500-1000m	
94 :: 1-2km	
95 :: 2-4km	
96 :: 4-10km	
97 :: >10km	

TOTAL CLOUD COVER(TCC) HIGH CLOUD COVER (HV) MEDIUM CLOUD COVER (MV) LOW CLOUD COVER (LV)	Oktas
0 :: 0	
1 :: 1/8 or less, but not 0	
2 :: 2/8	
3 :: 3/8	
4 :: 4/8	
5 :: 5/8	
6 :: 6/8	
7 :: 7/8 or more, but not 8/8	
8 :: 8/8	

WIND SPEED (WS)	Knot
Nearest knot	

WIND DIRECTION (WD)	Degree
Nearest degree	

AIR TEMPERATURE (AT)	°C
Nearest degree, C	

WATER TEMPERATURE (WT)	°C
Nearest degree, C	

RELATIVE HUMIDITY (RelH)	
Nearest %	

AIR PRESSURE (AP)	mBar
Nearest mBar	

Weather (WX)

Note, the ASSIST table is keyword and number searchable from the Weather data entry box.

00-03 Sky Change During Past Hour
000 :: Clouds not observable/observed
001 :: Clouds dissolving/becoming less developed
002 :: State of sky as a whole unchanged
003 :: Clouds forming or developing
10-13 Mist and Shallow Fog
010 :: Mist (Visibility 1/2 nm or more)
011 :: Shallow fog in patches
012 :: Shallow fog, more or less continuous
40-49 Fog at the Time of Ob
040:: Fog: distance, not at ship in past hour, Vis may be >1/2nm
041 :: Fog in patches
042 :: Fog thinning in last hour, sky discernable
043 :: Fog thinning in last hour, sky not discernable
044 :: Fog unchanged in last hour, sky discernable
045 :: Fog unchanged in last hour, sky not discernable
046 :: Fog beginning/thickening in last hour, sky discernable
047 :: Fog beginning/thickening in last hour, sky not discernable
048 :: Fog depositing rime, sky discernable
049 :: Fog depositing rime, sky not discernable
50-59 Drizzle
050 :: Slight drizzle, intermittent
051 :: Slight drizzle, continuous
052 :: Moderate drizzle, intermittent
053 :: Moderate drizzle, continuous
054 :: Dense drizzle, intermittent
055 :: Dense drizzle, continuous
056 :: Freezing drizzle, slight
057 :: Freezing drizzle, moderate or dense
058 :: Drizzle and rain, slight
059 :: Drizzle and rain, moderate or dense
60-69 Rain NOT Falling as Showers
060 :: Slight rain, intermittent
061 :: Slight rain, continuous
062 :: Moderate rain, intermittent
063 :: Moderate rain, continuous
064 :: Heavy rain, intermittent
065 :: Heavy rain, continuous

066 :: Freezing rain, slight
067 :: Freezing rain, moderate or heavy
068 :: Rain or drizzle and snow, slight
069 :: Rain or drizzle and snow, moderate/heavy

14-16 Precipitation not at ship

014 :: Precipitation in sight, not reaching surface
015 :: Precipitation beyond 3nm, reaching surface
016 :: Precipitation within 3nm, reaching surface

20-29 Past Hour but NOT at observation time

020 :: Drizzle not freezing or snow grains
021 :: Rain not freezing or snow grains
022 :: Snow not freezing or snow grains
023 :: Rain and snow or ice pellets
024 :: Drizzle or rain, freezing
025 :: Showers of rain
026 :: Showers of snow, or of rain and snow
027 :: Showers of hail, or of rain and hail
028 :: Fog in past hour, not at present
029:: Thunderstorm, with or without precip

36-39 Unique Snow Conditions

036 :: Drifting snow below eye level, slight/moderate
037 :: Drifting snow below eye level, heavy
038 :: Blowing snow, above eye level, slight/moderate
039 :: Blowing snow, above eye level, heavy

70-79 Solid Precip. Not as Showers

070 :: Slight fall of snow flakes, intermittent
071 :: Slight fall of snow flakes, continuous
072 :: Moderate fall of snow flakes, intermittent
073 :: Moderate fall of snow flakes, continuous
074 :: Heavy fall of snow flakes, intermittent
075 :: Heavy fall of snow flakes, continuous
076 :: Ice prisms, with/without fog
077 :: Snow grains, with/without fog
078 :: Isolated star like crystals
079 :: Ice pellets

80-84 Rain Showers

080 :: Slight rain showers
081 :: Moderate or heavy rain showers
082 :: Violent rain showers
083 :: Slight showers of rain and snow
084 :: Moderate/heavy showers of rain and snow

85-90 Solid Precipitation in Showers

085 :: Slight snow showers

086 :: Moderate or heavy snow showers
087 :: Slight showers of soft or small hail
088 :: Moderate/heavy showers of soft/small hail
089 :: Slight showers of hail
090 :: Moderate or heavy showers of hail

Meteorology: Cloud

HIGH CLOUD TYPE (HY)	
Ci :: Cirrus	
Cs :: Cirrostratus	
Cc :: Cirrocumulus	
MED. CLOUD TYPE (MY)	
As :: Altostratus	
Ac :: AltoCumulus	
LOW CLOUD TYPE (LY)	
St :: Stratus	
Sc :: Stratocumulus	
Ns :: Nimbostratus	
Cu :: Cumulus	
Cn :: Cumulonimbus	
HIGH CLOUD HEIGHT (HH)	km
3 - 8km	
MEDIUM CLOUD HEIGHT (MH)	km
2 - 4km	
LOW CLOUD HEIGHT (LH)	km
Surface - 2km	

Photos
Any number of photos can be attached to an observation, and it can be specified if the photo is taken facing the ship's bow, port or starboard. The CSV output (Photo) only provides the number of photos uploaded with each observation.

Comments
Comments can be attached in each tab with the 'Add Comment' button. Any number of comments can be entered. Comment strings are included in CSV output in the final column, Comments. The comment string is formatted as:
"\"Comment Text – Observer Name\""//"\"Second Comment Text – Observer Name\""

CIRFA – Centre for Integrated Remote Sensing and Forecasting for Arctic Operations, a new Centre for Research-based innovation hosted by UiT-the Arctic University of Norway

Relevant to theme 2-3

By: T. Eltoft, C. Brekke, UiT- the Arctic University of Norway, Tromsø.
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J. P. Pedersen, KSAT, Tromsø

Abstract:
This whitepaper gives a brief presentation of a new centre for integrated remote sensing for Arctic industrial operations. The centre shall do research on methods and technologies that can reliably detect, monitor, integrate and interpret multi-sensor data describing the physical environment of the Arctic. The research shall also address methods for assimilating the satellite based information into models to perform predictions of sea ice state, meteorological and oceanographic conditions on both short and long timescales. The new knowledge and technologies shall be developed in collaboration between the research team of CIRFA, the maritime industry, service providers, and the international research community.

Motivation

Maritime industry faces new challenges in the High North. As is well known, the Arctic is characterized by low temperatures, remoteness, low visibility, darkness for several months of the year, and a vulnerable environment. The winter climate is harsh, with swift changes in weather and wave conditions, and the ocean circulation has more abrupt variations than are known further south along the Norwegian coast or in the North Sea. The Arctic Ocean and the adjacent shelf seas are affected by sea ice. Sea ice and floating isolated ice objects, and the quick changes in weather and wave conditions represent significant challenges to Arctic operations. These conditions represent new operating conditions for the industry, which demand new and innovative solutions both related to science and technology, and to logistics and the human dimension.

Specifically, sustainable future maritime operations in this area put new demands on monitoring and forecasting technologies with respect to accuracy, spatial and temporal resolution, reliability, robustness, and automation. Remote sensing from satellites and numerical forecast models are and will be the key tools to achieve this. Remotely Piloted Air Systems (RPAS) have the potential to provide important support.

A new Norwegian centre for research-based innovation (CRI) entitled "Centre for Integrated Remote Sensing and Forecasting for Arctic Operations (CIRFA)" was started up on September 1st, 2015. CIRFA shall create knowledge, develop new methodologies and technical innovations, which can enabling safe maritime operations in the environmentally sensitive Arctic area by combining research on multi-platform remote sensing, surface based measurements and numerical short-term forecast modelling. A CRI is an 8-year research project, where universities, research institutes and industry collaborate on common research topics.

CIRFA aims to become a knowledge hub for research and development on Arctic surveillance technologies, with leading expertise in disciplines such as remote sensing, signal processing, radar technology, RPAS technology, data assimilation and numerical modelling. CIRFA will in particular take advantage of the broad competence in remote sensing, as well as the considerable infrastructure, that has been built up in Tromsø over the recent decades.

Research and methods

Integrated remote sensing and forecasting for Arctic operations is to be understood as the process of combining remote sensing data from multiple platforms, multiple sensors, and surface based measurements, and integrating the derived information into numerical models to provide predictions of ocean and sea ice conditions on local and regional scales. The important components of the science program, will be conducted in a closed feedback process where data collection, theoretical model work and retrieval algorithms are validated by making use of in-situ data collected during field campaigns.

Remote Sensing (RS): CIRFA will combine RS from satellites and RPAS platforms. Satellite borne sensors can provide timely observations of the vast and inaccessible areas, whereas RPAS is suited for detailed local mapping. For High North monitoring, especially from space, synthetic aperture radar (SAR) sensors, operating at microwave frequencies, will be of particular interest due to their relatively high resolution, and their all-weather and light-independent capabilities. The image formation process of SAR systems is challenging for dynamic surfaces like the ocean and sea ice, where motion effects and weather conditions may cause rapid changes in the radar signal characteristics. These processes are far from being completely understood, and the development of more reliable remote sensing capabilities for sea ice and oceans relies on advances in radar RS. CIRFA will address this and other challenges related to radar RS using an integrated multidisciplinary approach.

Physical modelling is the foundation of geophysical parameter retrieval in electromagnetic RS, which involves both forward and inverse modelling (e.g., Engen and Johnsen, 1995). In sea ice, ocean, and oil spill RS there are still considerable uncertainties within the forward models. More detailed descriptions of surface roughness and the internal structure of sea ice, improved statistical models for the small-scale representation of the ocean surface, improved compound dielectric models of oil-seawater-sea ice mixtures (Brekke *et al.*, 2014), will enable development of consistent forward models. Such knowledge will be acquired *in situ* in dedicated field campaigns employing advanced ground based radars, combined with SAR and optical observations, and laser scanners on the ground as well as on-board RPAS.

Statistical models of the probability distribution of the RS measurements are key elements in the design of image analysis algorithms (Eltoft, 2005), but these also take physical models as a starting point (Doulgeris and Eltoft, 2010). In order to improve the reliability of derived geophysical quantities and to take advantage of the rich potential of multi-frequency and multi-polarization radar sensors, more advanced models for describing the multivariate dependencies are urgently needed (Cloude, 2010).

Signal Processing and Data Analysis refers to generic techniques and contains theoretical concepts and tools that must be adapted to the physical and statistical modelling, the measurement system, and the particular end application (sea ice, icebergs, oil spills, ocean winds and currents). The CIRFA consortium aims to use its expertise in emerging signal processing and pattern recognition to conceive further advances in information extraction from radar RS data (as noted in Aksoy *et al.*, 2010; Camps-Valls *et al.*, 2011). This also includes research on multi-sensor data fusion for optimally merging data or information from optical and radar sensors.

Remotely Piloted Air Systems (RPAS): RPAS borne sensors can supplement satellite borne sensors with detailed information related to specific phenomena of more local extent. Operating an aircraft safely and reliably at low altitude under arctic conditions poses a number of challenges. The main environmental challenges are to cope with icing conditions and high winds. With regard to safety and airspace access, the regulation is still under development and full integration into non-segregated airspace requires *detect and avoid* systems not yet available and whose specifications and requirements are not yet defined in regulation. The use of RPAS require robust communication for both command and control of the aircraft and for the sensor payload, as the data produced is time critical and missions might last for many hours.

To support operations in the Arctic, data on a much finer scale and accuracy is required compared to traditional data collection for environmental or climatic studies. The challenges addressed in CIRFA involve detection and tracking of growlers and icebergs, fine scale sea-ice properties, and oil spills in ice-affected areas. These activities require horizontal resolution down to the meter level and vertical accuracy down to a few centimetres. CIRFA will test new miniaturized radar sounder technologies, lidar and passive optical sensors. The goal is to find the combination of sensors that at any time will give optimal performance under the given seasonal and environmental conditions.

Numerical forecast modeling: Ocean and ice forecasting at high latitudes is challenging due to lack of observations of oceanic 'weather'. Improved operational forecast systems will require increased amounts of high-resolution observations and the *assimilation* of such data into ocean and ice models.

The most advanced assimilation systems available today are the *4D-var* systems, where observations are introduced to the model system smoothly in time and in a dynamically consistent way. This will be available in CIRFA for ocean-ice forecasting. Major challenges include the formulation of the error covariance relationships that determine the relative weights put on model estimates and observations in forming a best analysis of the state of the ocean and sea ice. This task is particularly complex in frontal zones near the sea ice edge. Here an Ensemble Prediction System (EPS) can be used to dynamically update the model error covariance matrices used in 4D-var. In addition, the adjoint model component of the 4D-var system can be used to study the model sensitivity to different types of observations and their temporal and spatial distribution. This means that the model system is used to optimize the observational sampling strategies (e.g. of RPAS). Finally, challenges remain to optimize a range of coupling parameters, e.g. ocean-ice and ocean-air drag coefficients. This is of critical importance for accurate prediction under a range of varying sea ice and ocean boundary layer conditions. Outstanding challenges to be addressed in CIRFA include (i) impact assessments of new observations (e.g. Moore *et al*., 2011), particularly of remotely sensed ocean currents, both as radial components and as velocity vectors, (ii) the evaluation of the potential of using new remotely sensed sea ice parameters, such as sea ice drift to improve the modeling of the ocean-ice interactions, e.g. by updating fluxes of momentum and energy, and (iii) the use EPS for dynamically updating the estimates of model error (e.g. Buehner *et al*., 2013).

The research in the centre is organized in 7 work packages:

WP1: Ocean remote sensing

The objective of this WP is develop the use of satellite technology to advance our understanding of the Arctic Ocean processes and dynamics, and contribute to better prediction of polar lows, now-casting, and short range forecasting of ocean state through coupling with high-resolution models. The knowledge of the meso and submesoscale processes and dynamics in the Arctic Ocean is limited, and better utilization of RS technologies in combination with numerical modelling is necessary to advance our understanding (Ardhuin et. al., 2005). The methodologies, tools and products developed here will be validated using data from WP6 and integrated with the sea ice mapping of WP2 and the modelling activities of WP5 (assimilation) to produce information products for the pilot services of WP7.

WP2: Sea ice, icebergs and growler remote sensing

This WP will further develop remote sensing methodologies and algorithms to enable detailed characterization and mapping of Arctic sea ice conditions, and to provide improved detection and characterization of icebergs and growlers. Our approach will be to apply new statistical models and signal processing methods (Ferro-Famil *et al.*, 2003; Ferro-Famil *et al.*, 2005; Brekke *et al.*, 2013), to improve the ability to detect anomalies of the radar signatures linked to icebergs. The methodologies, tools and products developed within WP2 will be integrated with the modelling activities of WP5 to produce information products for the pilot services of WP7.

WP3: Oil spill remote sensing

WP3 will develop accurate RS signal processing and information retrieval techniques for reliable oil slick detection and characterization, and to improve modelling of oil behavior and fate in sea ice covered waters. No single sensor technology is expected to fulfil the needs of all aspects of RS to monitor oil in sea ice-affected waters, hence, a suite of multiple sensors is likely to be required (C-CORE, 2013). CIRFA will carry out research on multiple RS sensors and platforms, and aims at developing robust algorithm for *slick detection and characterization* based on multi-channel SAR and combined SAR/optical data. Information about detected slicks and their characteristics derived from satellite and RPAS sensors are input to drift modelling and predictions in the next stage, linking WP3 also to WP2, WP5 and WP7.

WP 4: RPAS technology

The objective is to develop robust and efficient RPAS and sensor technologies that handle the widest possible range of environmental conditions and are capable of performing high quality measurements of sea-ice and iceberg properties as well as detecting and monitoring oil spills in ice affected areas. The maritime and oil and gas industry are moving northwards into areas with seasonal ice cover and higher probability of encounters with icebergs. Drifting sea-ice and icebergs could cause a threat to ships and installations, so detailed knowledge of the position and properties of the ice is critical for managing the operation in a safe and cost effective manner. RPAS platforms will be developed to achieve accurate high-resolution measurements but has limited spatial coverage, range, and are weather sensitive.

WP 5: Drift modelling and predictions

The objective is to assimilate new types of observations into an ensemble-based ocean-ice forecast model. To optimize the dynamic coupling of ocean and sea ice. To produce probabilistic ocean, sea ice and drift forecasts. The end product of this WP is an observation-guided Ensemble Prediction System (EPS) that will give probabilistic forecasts of ocean, sea ice and drifting objects. Assimilation of ocean observations collected under CIRFA will rely on state-of-the-art *4D-var* methods (Moore *et al.*, 2011) within the Regional Ocean Model System (ROMS; Haidvogel *et al*, 2008). Assimilation of sea ice will be based on optimal interpolation and nudging techniques. The various pieces of technology are in use by MET Norway today but will need varying degrees of refinement for Arctic conditions.

WP 6: Data collections and field work

CIRFA will implement a specific WP to highlight the importance of carefully designing field campaigns in connection with satellite and RPAS measurements. WP6 will be serving as a validation and calibration platform for RS data, as well as giving ground truth data for assessing the work conducted in WP1, WP2 and WP3. Several partners operate Arctic stations with long-term monitoring programmes and conduct field measurement campaigns. As an example, NPI is planning to freeze in *RV Lance* in Arctic sea ice north of Svalbard during the first half of 2015. This gives an excellent opportunity to collect collocated satellite, RPAS and ground based measurements, to be designed and collected specifically for RS ground truth calibration and validation purposes. Data collected during this campaign, annual NPI campaigns, and from other national and international projects (such as the planned MOSAiC drift in 2018-19, see mosaicobservatory.org) and data providers, will be used by CIRFA in the assessment and validation of algorithms and RS products.

WP 7: Pilot service demonstration

This work package shall implement the R&D results into integrated pilot services to be delivered to end-users with operational needs. The end-users are asked to provide feedback to the service provider on the operational usability, as well as on the need for further improvement or development. The experience and feedback of the end-users will be fundamental in the preparation of operational service deliveries, also in other geographical regions with challenges similar to those in the European part of the Arctic. The demonstrations will consist of three pillars as described in the following sub-tasks. All services will be optimized through feedback to the service provider.

Collaborations:

The competence and experience of the CIRFA team will be extended with a network of national and international collaborating experts in a broad range of relevant disciplines. In fact, international collaboration is a key for CIRFA to achieve its ambitious goals.

Partners

UiT the Arctic University of Norway will be the host of CIRFA. The following research institutions are signed in as research partners:

Research partners: UiT - the Arctic University of Norway (UiT), Norut - Northern Research Institute, Norwegian Meteorological Institute (MET.NO), Norwegian Polar Institute (NPI), Norwegian University of Science and Technology (NTNU), Nansen Center for environmental and remote sensing research (NERSC).
User partners: Kongsberg Satellite Services, Kongsberg Spacetec, Statoil, ENI Norge, Det Norske Oljeselskap ASA, OMW Norge AS, Toal E & P Norge, Aker Solutions, Multiconsult, Globesar, Aranica, Maritime Robotics

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Figure 1: Integration of ground-based, air-based, and satellite-based measurements

Short Statement
Arctic Observing Summit 2016

Arctic Tourism Should be used as a Vehicle for Arctic Observing Systems

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Overview

In this short statement, members of the International Polar Tourism Research Network (IPTRN) contend that Arctic tourism should be used as a vehicle for Arctic Observing Systems (AOS). Ship, airplane, and land-based Arctic tourism regularly brings observational capacity into settings that may remain otherwise unobservable, but scientists and other concerned stakeholders have not fully capitalized on this opportunity to date.

The assertion presented here is based on an article currently in publication with *Polar Research* (de la Barre et. al, Forthcoming), wherein the same authors examine the two-way relationship between Arctic tourism and AOS. The two-way relationship describes both the untapped opportunity provided by tourism to facilitate AOS, but also the need to make tourism's environmental and social impacts a key area of study for AOS – since tourism is increasing across the Arctic and predicted to continue doing so as decreasing sea ice as a result of climate change, *inter alia*, enables spatially or temporally extended marine access (e.g., Fay & Karlsdóttir, 2011; AMSA, 2009).

While the need to monitor Arctic tourism's impacts is widely accepted, ways in which tourism can play a positive role in AOS have so far not been explored nor highlighted sufficiently. This short statement demonstrates existing and potential contributions made by tourism to AOS and reviews key questions requiring attention in order to move forward.

Contributions of Arctic Tourism to AOS

De la Barre et al., (forthcoming) provide a survey of the relationship between tourism and AOS in Alaska, Arctic Canada, Iceland, Svalbard, mainland European Arctic, Russia, and Antarctica. They discuss their findings in regard to existing contributions:

> There already exist examples of tourism operations that offer additional monitoring and observation opportunities…Four examples are briefly presented…: (1) The Whales and Glacier Science Adventure ship-based tour that forms part of a community-based monitoring effort in Alaska and focuses on sampling phytoplankton, testing water quality, and collecting data on humpback whales; (2) The Churchill Centre for Northern Studies and Earthwatch's 'Climate Change at Arctic's Edge' in Canada which incorporates bird counts and plant species documentation; (3) the cruise tourism sector collaboration with the Norwegian Polar Institute which supplies data to the Svalbard

> Marine Mammal Sighting Database; and (4) the International Polar Year's (IPY) 'Aliens in Antarctica' programme, as well as the International Association of Antarctica Tour Operators (IAATO) and Antarctic Treaty System (ATS) post-visitation reports that provide data on unusual observations (e.g., high mortality events of wildlife).

Tourism is therefore already contributing to AOS, but the efforts are dispersed over space and time, and uncoordinated across regions and scientific disciplines. Data verification is of the utmost importance when tourists contribute scientific observations, and can be promoted by having trained scientists oversee processes of data collection and reporting. Moreover, tour guides can be trained to serve as observers and supervisors of tourists' observations.

The article this short statement draws from develops the tourism component of a White Paper submitted to the Arctic Observing Summit 2013 (Keskitalo et al., 2013), which focuses on stakeholder participation in science more broadly. Many of tourism's contributions to AOS operate under a citizen-science model and advance the goal of integrating stakeholders into monitoring and knowledge production. When the citizen-science model is applied in the Arctic, the observational contributions of residents of the Arctic are key, and can be supplemented by observations from visitors to the region.

In addition to achieving citizen-science goals, tourism can contribute to AOS by financing scientists' research. Accepted practice at the Great Barrier Reef, for example, is a case in point. Here, tourists and marine biologists go out on the same boat to interact with whales and the tourists pay for the entire venture. A similar case exists in Iceland, where marine biologists use whale watching boats for data gathering (Bertulli et al., 2015). Perhaps scientists in the Arctic would tolerate the presence of tourists on their expeditions if the tourists paid for the trip.

Key Questions Moving Forward

De la Barre et al. (forthcoming) identify a series of questions that must be addressed to advance the integration of tourism and AOS. These include:

- How can we determine what the mechanisms are for the coordination of support, implementation, and operation of a[n] [AOS] which involves tourism as a data collection actor?
- [Could] a tourism-integrated [AOS]…fall under…the Arctic Council, particularly if these were designed to include community-based and citizen science approaches?
- How do we integrate tourism into extensive monitoring systems that already exist?
- What type of tourism stakeholder perspectives need to be included?
- [W]hile citizen science is potentially empowering and inclusive, how do we heed cautionary deconstructions of science executed in the north (and post and neo colonial interpretations and narratives of phenomena, e.g., climate change) to ensure colonial legacies are challenged and empowered Indigenous futures are supported?

Conclusion

Clearly, we – members of the International Polar Tourism Research Network – do not possess all of the answers at this time, but we are working on addressing them through our ongoing research. The purpose of this short statement is to propose the value of using tourism in the

Arctic as a vehicle for AOS, demonstrate how this is already occurring, and consider ideas for further integration. The rate and impact of change in the Arctic means that AOS efforts should utilize every resource available, including tourism, which brings knowledgeable and observationally inclined individuals into sparsely populated reaches of the world.

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Observations to support industry needs for sea ice information and predictions

- Statement for the 3rd Arctic Observing Summit -

Adrienne Tivy (Canadian Ice Service) and Chris Petrich (Norut Narvik)

A key rationale for ocean observing is to support real-time data products and forecasts for stakeholders (Calder et al., 2013). A wide range of practitioners are dealing with sea ice as part of their profession. Users include planners, managers and mariners on ships and offshore platforms. In this context sea ice information and predictions are used to make both strategic and tactical decisions. Aligning observing systems with stakeholder desired outcomes (data and forecast products) is a challenge; moving towards this goal, the first step is a clear understanding of stakeholder needs.

The needs of the offshore oil and gas and shipping industries summarized in this statement are based on a series of interviews with key industry stakeholders in Canada that were conducted by Adrienne Tivy and a 2-day workshop with Canadian Coast Guard icebreaker captains organized by Chris Petrich. As part of the Sea Ice Prediction Network (SIPN) project and to help meet the mandate of the Canadian Ice Service, key industry stakeholders are being interviewed to understand what sea ice information and forecasts are needed to inform decisions. Eight sea ice experts have been interviewed so far and were drawn from oil and gas companies (Husky, Chevron), shipping (FEDNAV, retired coast guard captains) and industry consultants with over 25 years of experience. The workshop was part of the network on Safe and Economic Operations in Seasonally Sea Ice-Covered Waters (OpSIce). Two icebreaker captains and nine researchers from five countries with Arctic interests participated in the workshop where a presentation of tactical challenges during operations at sea was followed by discussions in break-out groups that focussed on information needs in specific situations. Interviews and the workshop addressed user needs for ice information and forecasts, and the workshop also covered the translation of observations into practical products.

Sea ice information and predictions: desired outcomes

The most common desired outcome that emerged from these discussions is information and predictions related to trafficability in sea ice. Whether or not the ice cover is easy or difficult to navigate will obviously depend on the ice class of the ship but with respect the icescape there are two key parameters that emerged from the discussions that are often not considered: ice strength and ice pressure**.** There was a consensus that ice strength and ice pressure are as important, in some instances more important, than ice thickness and ice type.

To inform tactical decisions all users wanted as much detailed information as possible regarding the surrounding icescape and any predicted changes. The exact forecast lead time and spatial scale depended on the type of operation but in general 24-48 hours forecasts within the area of operation are required. It was acknowledged by most that good information is available for current ice conditions from government ice services. For short-term ice forecasts, most practitioners generated them in-house and reported good accuracy.

To inform planning decisions users wanted forecasts on much longer lead times, the length of the time is strongly dependent on the particular planning decision. For example forecasts of ice conditions along shipping routes 3-5 weeks in advance could trigger the decision to add another ship transit at the end of the season. Longer terms forecast on the order of months would impact ice management resource planning for offshore oil and gas platforms i.e. severity of the ice season will dictate how many icebreakers to have on stand-by. In general accurate and detailed forecasts are highly desired for planning purposes but there was a general acknowledgement that it is a challenging problem and may reach beyond the limits of predictability.

Key sea ice parameters: ice concentration (tactical/planning), ice type (tactical/planning), ice thickness (tactical/planning), ice strength (tactical), ice pressure (tactical), ice deformation and ice drift (tactical), break-up and freeze-up (planning), length of open water season (planning), floe size (tactical)*

*floe size came up as a key sea ice parameter for ice management, targeted icebreaking around a ship or platform to reduce the severity of ice conditions

Comments on observations

It was generally acknowledged that the cost of observing in the Arctic is a barrier but that observation efforts should target areas with high shipping/industry activity.

Using observations to inform tactical decisions often requires now-casting, particularly when it comes to satellite data products where there is latency up to a few hours. The lack of tools available for now-casting recent observations became one of the themes of the workshop. The usefulness of observations with latency could be greatly enhanced with *in situ* observations to assist in now-casting. The scientific challenge is similar to short-term ice forecasting.

A suggestion for an observing system experiment (OSE) (e.g. Fairell et al., 2013) that came out of the discussions is to assess the benefit of assimilating industry (ship/platform) met-ocean data into coupled models to provide short-term, high resolution sea ice forecasts that meet industry user needs. Although discussions of an observation strategy to support the desired outcomes for ice information and ice forecasts was well beyond the scope of the interviews and the workshop, many practitioners suggested that short-term sea ice forecasts, similar to short-term weather forecasts, could be generated by government agencies for their area of interest and would likely be accurate if they assimilated local observations. Many practitioners are generating their own short-term sea ice forecasts to inform tactical decisions. These forecasts are generated by looking at the impact of weather on sea ice over the past few days and using the weather forecast to predict into the future. The degree of complexity ranges from simple numerical modeling, using some form of the momentum equation for sea ice with data assimilation (nudging) of *in situ* observations, to more heuristic approaches. All practitioners who reported generating short-term forecasts also reported good accuracy.

Calder, J. et al. (2010). "An Integrated International Approach to Arctic Ocean Observations for Society (A Legacy of the International Polar Year)" in *Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society (Vol. 2),* Venice, Italy, 21-25 September 2009, Hall, J., Harrison D.E. & Stammer, D., Eds., ESA Publication WPP-306.

Fairall, C., *et al.*, 2013: Observational Aspects of the WWRP Polar Prediction Project. *Proceed. Arctic Observing Summit*, Vancouver, CA, 30 April – 2 May.