



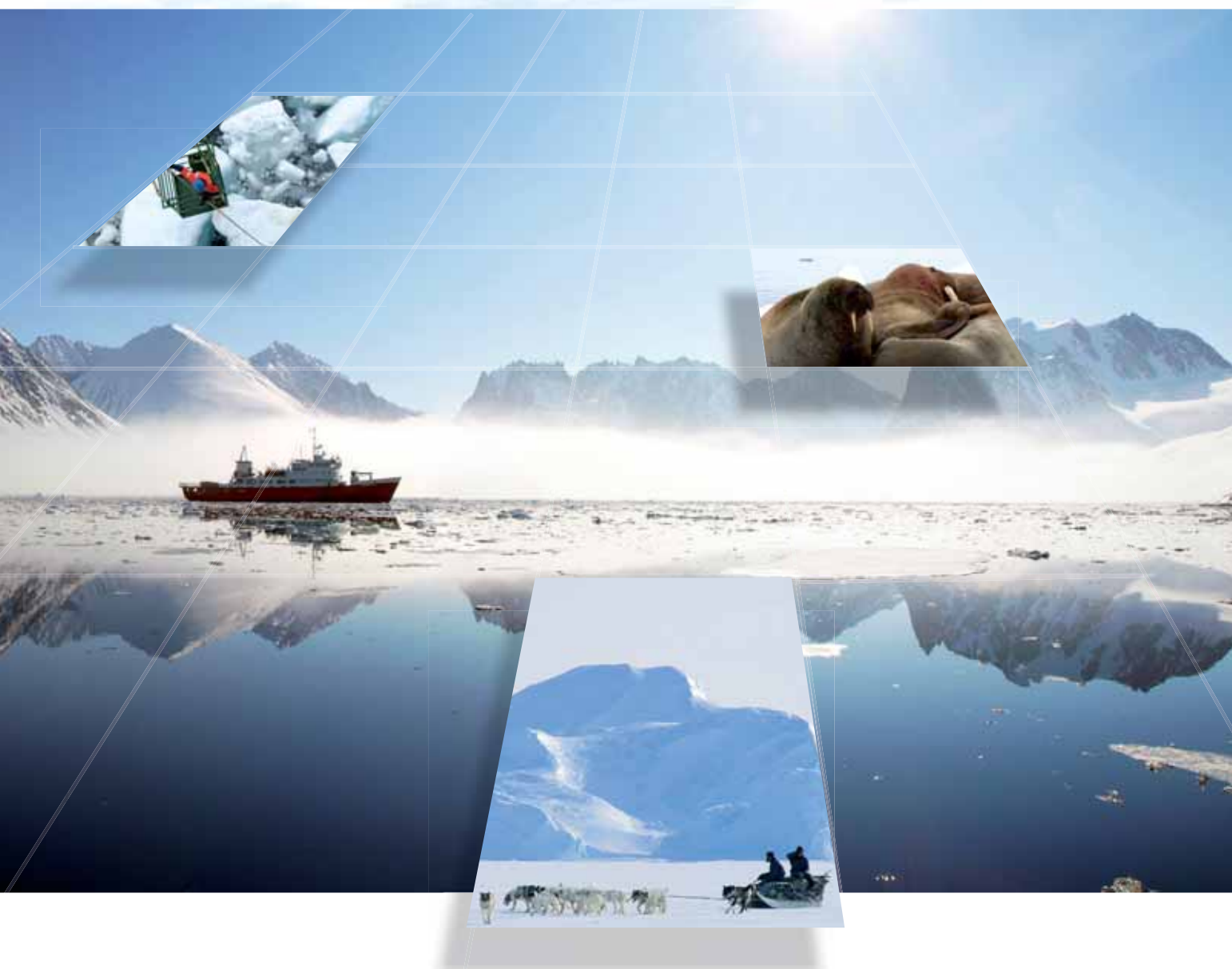
United Nations  
Educational, Scientific and  
Cultural Organization



Intergovernmental  
Oceanographic  
Commission

# Why monitor the Arctic Ocean?

Services to society from a sustained ocean observing system





© Hugo Ahlertius, UNEP/GRID-Arendal

### Topography and bathymetry of the Arctic.

The Arctic is often defined as the area in which the average temperature for the warmest month is below 10 °C.

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- Young walrus in northwest Svalbard. Credit: Thomas Hallermann/Marine Photobank.
- Retrieving an ocean monitoring transponder with a crane. Credit: Chris Linder, Woods Hole Oceanographic Institution.
- Dog sled on sea ice in Greenland. Credit: Royal Greenland.
- A Norwegian government vessel in Magdalena Fjorden. Credit: Thomas Hallermann/Marine Photobank.

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# Introduction



A research expedition in the Beaufort Sea © NOAA

**T**he Arctic is dominated by oceans and coasts. The region is warming at roughly twice the global average rate, with a dramatic reduction in summer sea ice extent as one of the clearest indicators of this trend. Physical and biological processes are being transformed across the entire region, while climate feedback mechanisms in the Arctic's changing atmospheric and oceanic dynamics impact at global scales.

Change in the Arctic Ocean environment is also leading to a wealth of interconnected social transformations. Arctic states dispute territorial claims as the Arctic reveals its increasing economic and strategic potential, while the international community also seeks to have a voice and a guaranteed research presence in the region. The oil and gas industry is sizing up the arctic sea bed for exploitation, and economically important shipping lanes are predicted to open. With industrial development, increasing numbers of people are migrating to the Arctic. The region's indigenous peoples are stepping up their efforts to gain control over the developments taking place in their territories, while maintaining their cultural continuity. Meanwhile, conservationists are increasingly highlighting the need to protect the fragile arctic environment.

Vulnerability in the Arctic Ocean is therefore increasing. Its environment and peoples are under growing stress from climate change. Industrial infrastructure and shipping

**An ocean observing system must be created and sustained in the Arctic. The system should be tailored to provide distinct services to society, with attention to the needs of specific user-groups.**

create further pressures, while simultaneously being at risk themselves in this often hostile ocean.

Never has accurate information been more important, yet at present we know very little about the Arctic Ocean. Critical physical processes are poorly understood,

ecosystems remain unstudied and undiscovered, and indigenous voices go unheard. This lack of knowledge thwarts efforts to detect, predict or manage the interrelated physical, biological and social impacts of climate change, making sustainable development almost impossible. A coordinated observing system must therefore be created for the Arctic Ocean and its coasts, to provide baseline data and ensure sustained monitoring.

But what should such a system look like? To be sustained in the long term, Arctic Ocean observation must move beyond academic research. It must respond increasingly to 'user pull', providing products and services of direct utility to the burgeoning number of stakeholders in the region.

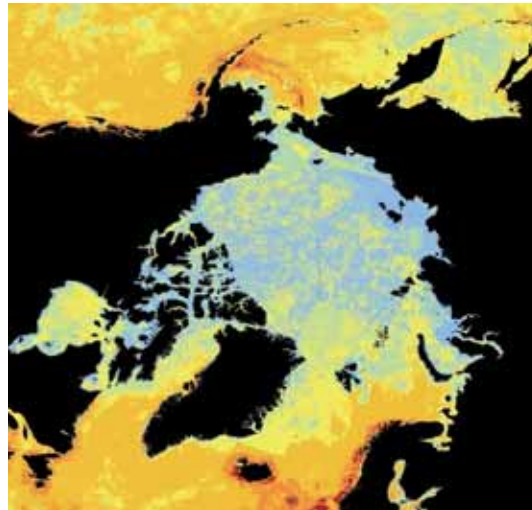
In so doing, the ocean observing system will take a central role in efforts to adapt to the challenges and opportunities of a transforming Arctic. This will be a multidisciplinary endeavour, for adaptation is essentially a social and cultural issue. It must nonetheless be founded on the sound knowledge-base of environmental processes that an ocean observing system can provide.

# Conservation and natural resource managers

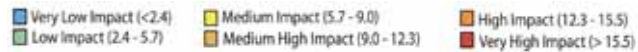
Growing pressures on the Arctic Ocean ecosystem highlight an ever greater need for data and monitoring.

The Arctic Ocean boasts one of the most pristine ecosystems on earth, including iconic species such as the polar bear, walrus, narwhal and beluga whale, as well as economically important fish stocks. Tourists are increasingly drawn to the area by its dramatic scenery and wildlife. Hunting and fishing activities in the ocean underpin the food security and cultural practices of coastal indigenous peoples. Ecosystem services provided by this ocean also include carbon regulation and nutrient transformation.

However, stresses on the arctic ecosystem are growing. Climate change threatens to transform the environment completely, and oil and gas exploitation, industrial development and increased shipping bring with them risks of pollution and ecosystem disturbance.



A map of human impact on marine ecosystems. It has been estimated by Halpern et al. (2008) that only 3.7% of the world's oceans can be classified as areas of very low human impact. These areas occur only in the Arctic and Southern oceans.



A humpback whale off the coast of Greenland.

## Biodiversity monitoring

Research ships, sea floor observatories, dredging, autonomous underwater vehicles, gliders and stationary instruments sample and monitor benthic or ocean-column microorganisms.

The health and distribution of fish stocks can be mapped by monitoring commercial and subsistence fish harvests for fish numbers and sizes.

For larger animals, monitoring is challenging, particularly in hostile Arctic conditions. Often a human presence is needed to directly observe and count animals. Fortunately, efforts can be concentrated on 'biological hotspots' located throughout the Arctic, such as seabird colonies.

There are also promising innovations. Tagging provides data and maps on animal locations and movements, and 'smart tags' equipped with GPS and satellite transmitters can be fitted to 'animal oceanographers' – from fish to walrus and whales – to monitor movements and feeding patterns, as well as ambient sea water depth, salinity and temperature. Thermal imaging from ships may make it easier to monitor whales in the Arctic, for fluid droplets in the animals' blow are warmer than the polar air.

Indigenous peoples can also provide in-depth information about species distributions, interactions and health.

At present we know too little about this ecosystem to understand, predict or manage changes.

## >> Ocean observing services

>> **Monitoring species numbers and distributions.** Reduced sea ice and warmer waters will dramatically impact primary production of algae and phytoplankton in the Arctic. In the short and efficient arctic food webs, this will have rapid cascading effects on higher trophic organisms. Also, new species may migrate north into the Arctic as the waters warm and ice retreats, leading to new species assemblages.

>> **Interdisciplinary monitoring of ice cover and animal behaviour.** Ice dependent fauna such as polar bears, seals, walrus and caribou herds which migrate over sea ice will be directly impacted by a reduction in ice cover. For example, polar bears use sea ice to hunt for seals. Sea ice data and extensive animal observation and tracking are needed to determine if the bears can adapt to other food sources or hunting strategies.

>> **Monitoring contaminants in the ocean and the food chain.** Air-borne pollutants accumulate in the Arctic as they partially evaporate in the south and then condense in the cold arctic air to fall as precipitation (the 'grasshopper effect'). Prevailing worldwide sea and air currents also bring pollutants to the region, to give levels that can exceed those of densely populated urban areas. Some contaminants, such as PCB's (polychlorinated biphenyls) and mercury, are further concentrated as they move up the food chain, reaching harmful levels in top predators and humans.

>> **Monitoring shifts in commercial fish stocks.** A moderate warming of the ocean is predicted to benefit the most important commercial fish stocks, which are currently limited in the Arctic. This interaction is complex, however, and some areas may see a decline in fish. Monitoring would aid the creation of management plans, partly so fishing fleets can invest in the appropriate equipment and infrastructure to sustainably harvest a given species.

>> **Monitoring the impacts of large-scale commercial fishing.** Over-fishing could disrupt the entire ecosystem, which is already under stress from climate change. Potential by-catch of unwanted fish, marine mammals and birds is also an important area for observation, as are environmentally destructive fishing techniques such as bottom trawling. The ongoing viability of indigenous subsistence fisheries in the face of commercial competition would also require monitoring, through harvest studies and community consultations.

>> **Seasonal monitoring of ocean acidity and carbon.** The global oceans are a major carbon sink, containing 50 times more carbon than the atmosphere. Increasing carbon dioxide in the atmosphere means that more is absorbed by the oceans. As carbon dioxide is absorbed it forms carbonic acid. The temperature and chemistry of the Arctic and Southern oceans make them exceptionally vulnerable to ocean acidification. Some arctic surface waters have already become seasonally corrosive for calcareous organisms, which include shellfish, sea urchins and some species of algae and plankton, many of which are key species in the arctic food web. To determine impacts on these organisms, monitoring in the field can be combined with laboratory studies.

>> **Baseline data and monitoring of protected areas, biosphere reserves and World Heritage sites.** There are very few protected areas in the Arctic Ocean, but they are increasing. Existing protected areas include World Heritage sites such as Greenland's Ilulissat Icefjord. The site is sheltered from development, but its physical environment and biodiversity are still vulnerable to climate change.



**Top:** An iceberg in Greenland's Ilulissat Icefjord, a UNESCO World Heritage site.  
**Right:** Polar bear.

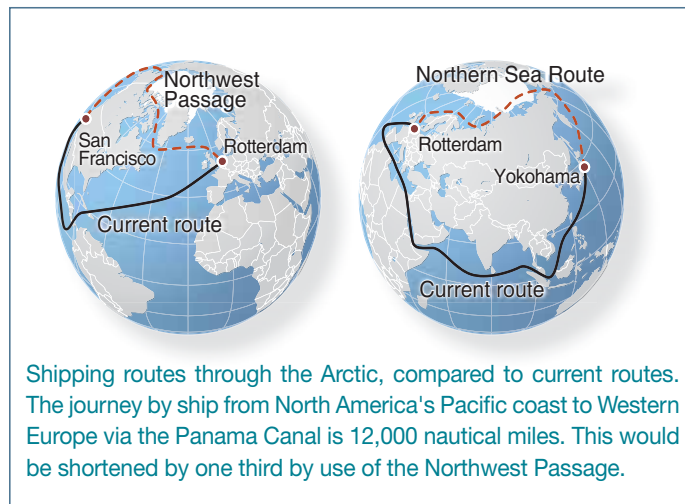


# Shipping

Monitoring the Arctic Ocean and providing regular, reliable information is essential to safely guide Arctic shipping.

Shipping in the Arctic takes many forms. Vessels include commercial ships, tourist cruises, research ships, coastguard icebreakers and fishing fleets. Commercial vessels carry products and equipment to and from the Arctic's already thriving mining industry, and arctic communities are mostly supplied by ship due to a lack of road and rail networks and the expense of air transport. All shipping is set to increase as sea ice retreats and as the Arctic opens up to further industrial development. However, summer and winter weather and sea conditions will remain harsh, and may even grow more severe with climate change.

With predicted reductions in summer sea ice the Northeast Passage and Northern Sea Route may open for regular commercial navigation. This will have a great impact on global shipping, which is responsible for the transport of 90% of the world's goods, and on the traffic through the Panama and Suez canals. At present, however, Arctic navigational charts are inaccurate and incomplete, and extensive hydrographic surveys are needed to determine channel depths and submarine hazards.



**In September 2008, the first ever commercial ship journey was made through the Northwest Passage. The crew 'didn't see one cube of ice'. In August 2010, a commercial supertanker navigated the Northern Sea Route for the first time, carrying 70,000 tonnes of gas from Murmansk in Russia to Ningbo in China.**

A ship at the port in Tasiilaq, Greenland.

## Ice information services

Ice information products, such as charts and forecasts, are provided by the national meteorological or oceanographic services of countries with activities in ice-affected waters. Currently, shipping is the primary user of these products. They are created by combining data from satellites, *in situ* sensors, and aerial and shipboard observations. Each source has strengths and weaknesses. *In situ* sensors, aerial surveys and ships provide specific but sparse

information, and aerial surveys are expensive. Satellite data are not as detailed, but they are systematic, cost-effective and cover wide areas. A variety of satellite sensors provide data at varying resolutions, spatial scales and costs. Because ice can be highly dynamic, ice products must be synthesised quickly (in 1-6 hours) and regularly (every 6-24 hours, every day). Synthesis of data archives allows for statistical analysis and prediction.

Source: The International Ice Charting Working Group, 2007.

## >> Ocean observing services

### >> Projections, forecasts and real-time reports of ice cover, thickness and movement.

Sea ice conditions may become more changeable and hazardous with a warming Arctic, with an increase in mobile free-floating ice. Long-term projections of ice conditions are needed for designating arctic shipping routes, while forecasts and real-time reports are needed to guide individual journeys. Tracking icebergs is also crucial, as they pose a greater threat to shipping than sea ice. Icebergs can be hidden in rafts of sea ice, making them difficult to detect by satellite or the naked eye.

### >> Projections, forecasts and real-time reports on weather and sea conditions.

Weather conditions may become more severe and changeable in the Arctic with climate change. Waves may also increase in magnitude with increasing areas of open water. Monitoring the complex interactions between the weather, a warming atmosphere and increased open water areas is also needed for longer term projections.

### >> Mapping and monitoring currents through the sea routes.

Ocean currents can change throughout the year, and can either be an obstacle to shipping, slowing voyages and bringing ships into contact with icebergs and rafts of ice, or they can be of great benefit, saving fuel and time if used correctly.

### >> Forecasts and real-time data for marine distress, search and rescue, and pollution response.

Developing strategies requires models and predictions of ocean and ice state in many given scenarios. The execution of these plans requires real-time information on weather conditions, currents, and the cover, thickness and movement of ice. International

coordination is essential. 'Safe havens' need to be designated to shelter ships in the event of extreme weather conditions, also requiring sea and ice data.

### >> Information for port design, construction and operation.

The Arctic lacks shipping infrastructure, such as ports and support stations. Their design and construction requires information on currents, ice conditions, tides, and storm and wave action. The impacts of port developments, on local water chemistry, biology and human use, will also need to be monitored.

### >> Monitoring the impacts of shipping.

Potential impacts on water quality include leakages and spills, and black carbon on sea ice. On biodiversity they include impacts of invasive species in ballast water and on hulls, and impacts on marine mammals from noise, disturbance and ship strikes. Regular ship traffic may also delay ice formation in autumn and accelerate break-up in spring.

### >> Monitoring cumulative impacts of shipping and other developments.

This will require extensive, international monitoring, and coordination of multiple data sources. Impacts may take many forms. For example, ship traffic is a main cause of oceanic noise pollution, the impacts of which combine with other noise sources. Marine animals such as beluga whales have been shown to react negatively to human induced noise from over 50 km away.

### >> Coordinating research ships.

The current fleet of Arctic research vessels could be drawn more tightly into an ocean observing system, to use their measurements and observations to maximum possible effect. Also, all ships moving through the Arctic could take basic ocean measurements at minimal costs. If coordinated and calibrated, these would be a great asset to ocean observing.

**WMO and IOC, through their Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM), continue to support the Global Maritime Distress Safety System in the Arctic. Recent activities include developing new systems for broadcasting graphical ice information to mariners, and the coordination of data from national ice services.**

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A Swedish icebreaker makes its way through the Arctic ice.

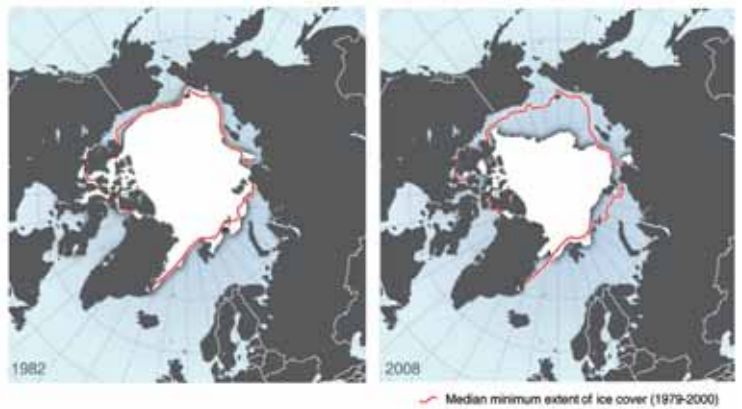
# Global climate science

The International Polar Year (2007-2009) catalysed Arctic climate research, yet there remain many uncertainties about

The Arctic Ocean is globally important as a key indicator and driver of climate change. As the Arctic is transformed by the changing climate, positive feedback mechanisms in the region's atmospheric and oceanic dynamics serve to further enhance climate change at global

scales. The region will also contribute to sea level rise, particularly through the melting of Greenland's ice cap. Due to the global implications of the changing Arctic, the international research and decision-making communities are major users of Arctic Ocean data.

Thirty years ago, Arctic late summer sea ice extent was 8 million km<sup>2</sup>. In 2007 and 2008 it was only around 4 million km<sup>2</sup>. The average ice thickness also decreased, from more than 3 m in the 1970s to about 1.5 m now. As the area and thickness of sea ice have both been halved, this amounts to a loss of 75% of late summer sea ice volume and mass. Perennial ice has consequently reduced significantly, to be replaced by young, unstable ice, which is highly vulnerable to melting. This means that any recovery in sea ice extent is most likely temporary. Recently, the drift of sea ice has also increased significantly (Gascard, 2009).



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Retrieving an autonomous underwater vehicle that is in danger of being crushed by shifting ice.

## Ocean monitoring

The Arctic represents a significant gap in ocean observations. It is a challenging environment to monitor. The region is not well covered by satellites, and heavy cloud cover often limits their use. Shifting ice and icebergs make it difficult to deploy sea surface equipment over long periods, and restrict access for research vessels.

Nonetheless, unprecedented technological innovations now exist. Satellites provide charts of ice extent and thickness at various spatial scales. A small number of buoys, ice tethered profilers and coastal stations are operational in the Arctic, monitoring sea level pressure, surface air temperature, sea ice motion, thickness

and temperature, snow depth, ocean temperature and salinity and ocean circulation. There is also a small tide gauge network in the Arctic Ocean, which provides information on sea levels. New wind and solar powered energy generators can supply power in remote regions to monitoring equipment such as high frequency radar.

Monitoring below thick ice cover has always been a challenge, but is now possible with subsurface floats, autonomous gliders and undersea communication via acoustics and cabled observatories. As the ice retreats, there is growing potential for a full ocean surface monitoring system.

© Chris Linder, Woods Hole Oceanographic Institution



## >> Ocean observing services

### >> Monitoring the extent of arctic sea ice.

Sea ice serves the planet as a vital climate regulator, reflecting between 25% and 85% of incoming solar radiation back into the atmosphere. Open water reflects less than 10%. An increasingly ice free Arctic will therefore lead to the ocean absorbing more heat. The consequent warming of the water further reduces ice extent and thickness.

### >> Monitoring the velocity and direction of ocean currents, and the temperature and salinity of sea water.

The Arctic Ocean plays a major role in driving the world's ocean circulation, which impacts the distribution of heat across the globe and the global climate. Waters cool as they enter the Arctic, releasing heat to the atmosphere, and salt is discharged as sea ice forms. The resulting cold, salty waters have a high density and they sink, before slowly moving out of the Arctic through the deep ocean. This critical process may slow or cease due to the warming of the Arctic, and as increasing amounts of fresh water are released into the Arctic Ocean due to the melting of both sea ice and ice and snow on the surrounding landmasses.

© Ellen Fjellanger



Eqa Glacier, Greenland.

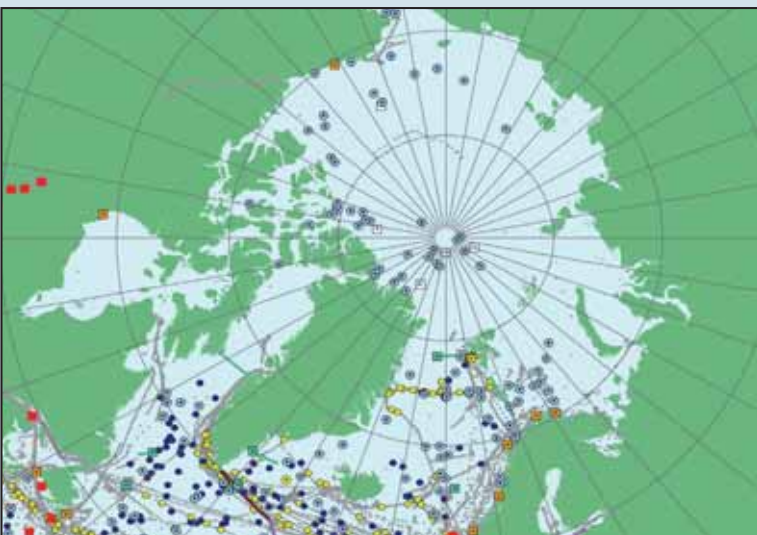
### >> Monitoring methane release from permafrost in the arctic sea bed.

Methane is being released at higher rates than previously supposed. It is hypothesised that this is the beginning of a destabilisation process in sea bed permafrost caused by warming waters, which could lead to a sudden venting of great quantities of trapped methane. As methane is a greenhouse gas 23 times more potent than carbon dioxide, this would lead to catastrophic global warming. As sea level rises, permafrost on flooded coasts may also melt, further adding to methane release.

**>> Monitoring arctic sea levels.** Sea level rise is not globally uniform. At a local level, sea level changes with variations in the temperature and salinity of the water column, and local geography. Sea level is also impacted by wind and ocean currents, and by water being added by precipitation, ice melt, or river runoff, or being removed by evaporation or conversion to ice. For example, around Greenland there is significant spatial variation in sea level due to the melting ice cap injecting cold, fresh water into the ocean. Despite advances in satellite technology, *in situ* tide gauges along arctic coasts remain vital for sea level monitoring.

### >> Monitoring the impact of sea temperature on glacier dynamics.

Greenland's glaciers are retreating, accelerating, thinning and breaking up due to climate change. The crucial role that the ocean plays in this process is only just beginning to be understood. The ice tongue that extends out over the sea at the front of a glacier may be weakened from below by warmer ocean waters, causing it to collapse. This generates large icebergs and allows the entire glacier to accelerate.



The array of observing systems in place in the Arctic.

# Indigenous peoples

Indigenous peoples should be active partners in research and monitoring processes: setting agendas, contributing

The Arctic region is home to some 4 million people, about one-third of whom are indigenous peoples. Many arctic indigenous peoples live on the coast, and depend on the ocean for food and transportation. They are thus directly impacted by changes to the ocean system. Yet they are not passive observers; they are resilient and adaptable people who are actively responding to ongoing changes in the Arctic.

Indigenous peoples have their own systems of knowledge about the Arctic Ocean, which stretch back further in time than most scientific records. They are therefore essential partners in understanding the ocean environment and managing the transformations taking place. Engaging effectively with indigenous knowledge requires commitment and personal interaction, and it is necessary to recognise that science also has its own uncertainties and culturally-specific assumptions. Efforts to engage in these ways have led to fascinating research taking place

in the Arctic, often with very different results and learning processes to those normally envisioned by scientists, for example the *Siku-Inuit-Hila* (Ice-People-Weather) project, in which scientists and Inuit travel together across the Arctic, sharing first-hand experiences and knowledge about sea ice (see Holm, 2009).

Many indigenous groups are calling for more natural and social science research to take place in the Arctic. However, they want to take a leading role in setting the research agenda, and in determining methodologies and communication strategies, so that research supports their desires for cultural continuity and self-determination. They see that the current prioritisation of climate change research leads to the neglect of more locally pressing issues, such as economic development, health and social problems. They have also experienced the negative impacts of insensitively-communicated scientific results, for example the social disorientation and fear caused by reports on contaminants in marine animals.

A team of Inuit and scientists sharing knowledge of sea ice during an expedition for the Siku-Inuit-Hila project.



## Adaptation to global climate change

Adaptation to global climate change will take place at local levels. Arctic indigenous peoples are masters of adaptation and resilience, and much can be learned from them.

Many Inuit have begun to modify their hunting and travelling practices in response to climate change, using their environmental knowledge to focus on different species and adjust the routes, locations, timings and methodologies of hunts. Their ability to adapt is enhanced by distinct philosophies in which change and uncertainty are embraced rather than resisted.

In Norway, the traditional Saami fishing economy has the flexibility to adapt to change, as the Saami utilise a wide range of fish species. Conversely, Norway's fishing economy may not be as resilient, as it is reliant on fewer species, particularly the Atlantic cod (*Gadus morhua*).

Ocean monitoring can provide physical and biological information that can support indigenous adaptation to climate change. It can also play a key role in drawing lessons from indigenous adaptation strategies.

expertise and benefiting from the services and products derived from ocean observations.

## >> Ocean observing services

**>> Weather and ice reports.** Arctic Ocean travel is now more risky due to the growing unpredictability of ice, water and weather conditions. Observing systems provide data for weather forecasts and reports, which are broadcast by television and radio. They can also contribute to satellite maps of local ice cover and thickness, open water areas and the position of the floe edge. Many hunters and fishers already use these information sources, integrating them with their own knowledge of local conditions. Indigenous observations of environmental changes can in turn provide important information to ocean observing systems.

**>> Ecosystem monitoring.** Subsistence hunting of marine mammals and fishing continue to be of importance for indigenous cultures and food security throughout the Arctic. Indigenous peoples are observing shifts in species due to climate change and industrial development. They ask that adequate ocean ecosystem monitoring and baseline assessments take place, to which they want to contribute their own extensive knowledge. Reports and updates on biodiversity trends, and the results of monitoring the impacts of industry and shipping, can be provided to indigenous organisations and communities.

**>> Predicting and monitoring the frequency, severity and impacts of storm events.** Erosion and inundation of indigenous villages are already occurring on some Arctic coastlines. Protective coastal ice is now absent in key storm seasons, and permafrost is thawing, weakening the coast. Waves and storm surges may increase in magnitude due to larger stretches of open water with reduced sea ice. Monitoring systems can provide early warning for storm surges, and predictions of the frequency and impacts of future storm



*A cabin slides down the erosion edge in Svalbard, which is on Norway's Tentative List for potential World Heritage status.*

**Arctic archeological heritage, including sites with a potential for inscription on the World Heritage List, is increasingly threatened by climate change. Explorer's huts, monuments, shipwrecks, grave sites and early Inuit camps are mostly located on coasts, and are impacted by changes in the Arctic Ocean, such as increased erosion. They also now suffer from rotting and rusting caused by rising temperatures and humidity, which are also tied to oceanic processes (Barr, 2009).**

events. Such predictions inform the construction of adequate coastal defences, and are used to calculate the costs of coastal defense versus village relocation.

**>> Community-based monitoring programmes.** Groups of local people can take their own measurements of weather, snow, ice and water using scientific techniques and equipment. Coordinated community networks using standardised techniques can provide valuable measurements, and generate community involvement in ocean research.

*Fish drying in the Varangerfjord, Norway.*



*Inuit on sea ice, Kangirsuk, Quebec, Canada.*

## Industry, energy and economic development

The data and monitoring capacities needed for planning and safely operating oil and gas extraction in the Arctic

The U.S. Geological Survey estimates that the Arctic holds 90 billion barrels of undiscovered oil reserves - worth about US\$1 trillion and roughly equivalent to Russia's existing total oil reserves - along with a further 1.6 trillion cubic feet of natural gas. Approximately 84% is expected to occur in offshore areas. The potential returns on exploiting this resource are therefore enormous, and technological advancements, combined with the promise of reduced ice cover and easier access, make this more feasible.

However, the Arctic will remain hostile for industrial operations. The pressure of shifting sea ice is a particular obstacle to permanent installations in the ocean. A major

oil spill in these ecologically fragile waters could be an environmental disaster, with clean-up efforts hampered by ice, storms, seasonal inaccessibility and distance from clean-up support infrastructure. Unlike oil spills in the warm, biologically active waters of the Gulf of Mexico, an oil spill in the Arctic would take many years to biodegrade, causing more disruption to arctic ecosystems.

For indigenous peoples oil and gas development is contentious. For some it represents an unacceptable risk to their environment and cultures, for others a much needed opportunity for economic development. Even so, most indigenous communities are calling for the utmost caution possible.

*A ship in Arctic sea ice. Freezing temperatures, fierce storms and shifting ice pose serious obstacles to industrial activities in the Arctic Ocean.*

### Lessons from the Deepwater Horizon

On 20 April 2010 the Deepwater Horizon oil rig sank into the Gulf of Mexico after an explosion two days earlier. Oil continued to gush from the well, causing the largest oil spill in history. Efforts to clean up the spill demonstrated the importance and utility of a functional ocean observing system. For example, recent achievements in making satellite data available in real-time now allow emergency responders to track a spill more effectively.

However, the spill also demonstrated the inadequacies of the systems in place. High frequency coastal radar provided real-time data on surface currents and oil movement, yet this was offline when the spill first occurred, and once functional had significant gaps in coverage. Systems of buoys that would have provided further real-time data on surface currents had decayed due to a lack of funding. An observation system for the gulf's shifting deepwater currents was not in place, making it impossible to track or predict the movement of oil beneath the surface.

As a result, oil arrived without warning on many parts of the ecologically fragile coastline, and the underwater extent and impacts of the oil remain a mystery. If drilling for oil is to take place in the Arctic Ocean, a robust ocean observing system will be essential.

do not exist. They must be in place before oil and gas extraction is further considered.

## >> Ocean observing services

**>> Assessing the implications of oil and gas extraction.** An effective assessment would require detailed baseline data on the natural and human systems tied to the Arctic Ocean. If oil and gas extraction does proceed, the infrastructure and funding would also need to be in place to activate and maintain a full monitoring system of all potential impacts for each site.

**>> Monitoring cumulative impacts.** The process of considering, planning and monitoring industrial development would also need to account for the impacts of a network of oil rigs, shipping routes, ports and other installations within the entire Arctic Ocean system, as well as other pressures on the environment. Coordination of all monitoring data would be needed.

**>> Projections, forecasts and real-time information on sea state, ice and weather.** To design an oil rig that could withstand the hazardous conditions of the Arctic Ocean, long-term projections would be needed of ice movement and thickness, freeze-up and break-up times, extreme weather events, wave action, tides, currents, and the movements of large icebergs. For a rig's construction and operation, forecasts and real-time data would be required for the same variables.

**>> Scenarios and real-time data for oil spill response.** An oil spill in the Arctic Ocean would be an environmental disaster, and there are many challenges to tackling a spill in this hostile and remote region. The Arctic Ocean transforms dramatically throughout the year from open water, to solid ice cover, to free-floating ice floes and ice packs. Combined with extreme weather

conditions, shifting currents and sub-zero temperatures, this presents a wealth of hazardous scenarios for a clean-up operation. Data on potential conditions is needed in advance of further industrial development, for the creation of clean-up strategies and techniques. More research is needed on the behaviour and effects of oil in cold water and ice conditions, and new technologies for spill response may have to be developed. Real-time data on currents, tides, ice conditions and local weather is also essential during a clean-up operation, for selecting the appropriate strategy and tracking and predicting spill movement. Satellite images of a spill are also invaluable. At present such capabilities do not exist for much of the Arctic Ocean.

**we are asking the government and the industry to do the baseline science before they go out in the Arctic Ocean. ... Arctic indigenous peoples have the most to lose from mistakes that are made in arctic waters.**

*Edward Itta, Mayor of North Slope Borough and Inupiat Whaling Captain, Alaska (Itta, 2009).*



Above: Controlled burning of oil in the Gulf of Mexico.

Left: MODIS/Terra satellite image of the Gulf of Mexico taken May 17, 2010, showing oil slick being entrained in the Loop Current, reaching 222 miles (357 km) from the location of the leaking well.

(Image production and analysis by SkyTruth - [www.skytruth.org](http://www.skytruth.org).)

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# Conclusions and next steps

**The next step is to develop a sustained ocean observing system for the Arctic, as a regional component of the Global Ocean Observing System (GOOS).**

Sermiŋŋaaq village © Sophie Elkhauser

## Data and monitoring needs

- There is a dearth of physical and biological baseline data for the Arctic Ocean. There is a need for more information before climate change, industrial development and shipping put further pressure on the environment. A full observing system is essential, to follow trends and predict future change.
- Further research and monitoring is needed to determine the Arctic Ocean's role in global climate processes.
- Real-time reports, short-term forecasts and longer term predictions of weather, sea and ice conditions are needed by arctic industry and shipping, and would also aid arctic residents.
- Specific monitoring techniques and equipment will have to be developed for arctic waters to account for damage and disruption by ice.
- The International Polar Year (2007-2009) was a major catalyst for arctic research, across all disciplines. This momentum must be maintained and built upon, to identify the key elements of a sustained ocean observing system.
- Ocean observing should be increasingly interdisciplinary, forming tighter links with the biological and social sciences, and with indigenous knowledge. This can be facilitated by the position of GOOS and IOC within UNESCO, an organisation with a broad interdisciplinary mandate.

## Key networks and collaborations

- Collaboration and coordination with the Arctic Council and its working groups is essential.
- An Arctic Ocean observing system must be part of the interdisciplinary SAON (Sustaining Arctic Observing Networks) framework.
- Arctic indigenous peoples must be integral partners in the ocean observing system. There is thus a need for dialogue to determine what they need and want from the system, and how they wish to contribute. Partnerships must be formed with arctic indigenous organisations.
- Shipping and industry represent key partners for ocean observing.
- With technological advancements, satellite data will become increasingly important for monitoring the Arctic. Collaboration is needed with national and international space agencies, including the Committee on Earth Observation Satellites (CEOS).
- Processes in the Arctic Ocean cross international boundaries, and have global implications. International collaboration between both Arctic and non-Arctic states is crucial. International research access is essential, as is the international coordination and standardisation of research and monitoring techniques.

## Graphics and maps

Inside cover: Hugo Ahlenius, UNEP/GRID-Arendal. Arctic, topography and bathymetry (topographic map). UNEP/GRID-Arendal Maps and Graphics Library, <http://maps.grida.no/go/graphic/arctic-topography-and-bathymetry-topographic-map>. (Accessed 27 July 2010.)

Pg 2: Halpern, B. et al. 2008. A Global Map of Human Impact on Marine Ecosystems. *Science*, 319. (5865), 948 – 952. Adapted by Ben Halpern.

Pg 4: Hugo Ahlenius, UNEP/GRID-Arendal. Northern Sea Route and the Northwest Passage compared with currently used shipping routes. UNEP/GRID-Arendal Maps and Graphics Library, <http://maps.grida.no/go/graphic/northern-sea-route-and-the-northwest-passage-compared-with-currently-used-shipping-routes>. (Accessed 27 July 2010.)

Pg 6: Hugo Ahlenius. UNEP/GRID-Arendal. Arctic sea ice minimum extent in September 1982 and 2008. UNEP/GRID-Arendal Maps and Graphics Library, <http://maps.grida.no/go/graphic/arctic-sea-ice-minimum-extent-in-september-1982-and-2008>. (Accessed 27 July 2010.)

Pg 6: GOOS/ JCOMMOPS. Map of the ocean observing system in the Arctic.

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