MEMORANDUM

To: U.S. Coast Guard; USCGC Healy
via UNOLS Arctic Icebreaker Coordination Committee

From: Peter J. Minnett, University of Miami
AICC Member

Date: March 25, 2005.

Subject: Information on Ice Conditions for Navigation during the Trans-Arctic Voyage, 2005, of the USCGC Healy

Preface

This document is in response to a request made at the AICC meeting, November 18-19, 2004, for guidance on obtaining the best information from satellite data for ice navigation during the forthcoming crossing of the Arctic Ocean via the North Pole by the USCGC Healy. Good ice condition specification is especially important because of the nature of the scientific activities which involve towing instruments behind the ship.

Requirements

Satellite-based imagery is required to reveal areas of open water, or of small amounts of ice cover. These images have to be of sufficient extent to reveal the large scale distribution of ice within the scope of several days' passage, yet have sufficient spatial resolution to delineate leads of sufficient size to permit safe and efficient navigation. The spatial area should be several hundred kilometers on a side, with a resolution of ~1 km or better. Because of the dynamic nature of the ice cap, the images have to be current, i.e. less than two days old.

Remote Sensing Option

Satellite remote sensing is divided into two basic techniques: passive and active. Passive techniques rely on forming images from reflected sunlight or emitted radiation in the infrared or microwave. Active remote sensing uses radar or lidar.

Passive data are readily available from several sensors on US and foreign satellites, but visible and infrared images of the ice surface are frequently obscured by cloud. Microwave images are largely unaffected by clouds but have poorer spatial resolution (~12 km at best). Examples of passive instruments are OLS on DMSP, AVHRR on NOAA Polar Orbiters, MODIS on NASA Terra and Aqua, ASTER on Terra, MERIS on ESA ENVISAT, SSM/I on DMSP. OLS, SSM/I and AVHRR are available on the Healy in real time by direct broadcast received using the Terra Scan System.

Active systems include Synthetic Aperture Radar (SAR) on Radarsat and ENVISAT, scatterometers on radar altimeters on ERS-2 and ENVISAT, and GLAS on ICESat. Altimeters and GLAS do not provide useful information as they take measurements only along the sub-satellite track. SARs provide ideal data, being immune to cloud effects and having very good spatial resolution. These data are not available by direct broadcast to the ship, so their use requires cooperation of a land-based station to prepare the data for transmission to the Healy.

Scatterometers have a spatial resolution of at best 6-8 km (special enhanced resolution processing of QuickSCAT) and are generated on a daily basis and distributed over the Internet by NOAA-NESDIS (The whole Arctic image of 2340 x 2340 pixels is 5348k bytes).

<u>Recommendations</u>

1. The TeraScan system on board the Healy offers the best option of providing imagery for ice navigation. It can receive the information in real-time and the images can be manipulated to provide images in the vicinity of the ship. There are no issues of data delivery to the ship from a shore-based computer, and iteration can take place between the Bridge, Scientists and TeraScan operator to provide enhanced visualizations best suited to the operational needs. In cloud-free conditions the images from OLS with a ground resolution of 550m provide the best information, followed by those of AVHRR with a ground resolution of ~1 km. In cloudy conditions the data of the 85GHz channel of SSM/I provide images at ~12.5 km resolution; while these may not resolve navigable leads they will provide an indication of areas of low ice concentrations. Combined with SSM/I measurements from lower frequency channels, a better determination of ice concentrations can be made, but at the cost of reduced spatial resolution (~25 km). Because of the measurement geometry of the SSM/I and the properties of the polar orbiting satellites, there is an area of about 200km radius about the North Pole that is invisible to SSM/I.

2. SAR images from RADARSAT and ENVISAT provide the option of high resolution all-weather images that can be interpreted to delineate leads and areas of low ice concentrations. These images must be prepared at a center on land and transmitted back to the ship. Delays of 12-24 hrs. can be expected, possibly longer. There are no SARs on US spacecraft so special arrangements will have to be made with Radarsat International (Canada) and ESA for the provision of such data. Furthermore, the SARs have several modes of operation that trade-off swath width with spatial resolution and this will require the spacecraft operators having the instrument in the appropriate configuration to provide cover of the ship's area of operation on any given day. This will be best done through the National Ice Center.

3. Communications with the ship

Because of the loss of coverage at high latitudes from geostationary communication satellites (e.g. INMARSAT) the best option for moderately high data rate communications between ship and shore are lost. The communications using polar orbiting satellites, IRIDIUM, are much poorer (2.4 kbps compared to 128 kbps, going to 432 kbps in 2005) with a corresponding ~60-fold increase in transmission time. It becomes necessary to be very careful in selecting the most efficient way of transmitting data and images to the ship. It may be most effective to send an analysis chart, which can be compressed and sent as an email attachment.

An alternative approach would be for the NIC (or other organization) to process images and place them on an ftp server for the ship to "get." This was the approach adopted as year by the *Amundsen* and the Canadian Ice Service. It places the responsibility to make the correct choice of image for transmission to the ship on the user rather than the provider. The *Amundsen* was operating in the Southern Beaufort Sea and using several communication satellites.

Actions

1. The Coast Guard is urged to take steps to ensure a competent TeraScan Operator is on board for the voyage. This could be a specially-trained MST, a contractor, or a student or scientist with the necessary skills.

2. Detailed discussions should be started between the NIC and the Coast Guard on how best to make use of NIC expertise and facilities to ensure the timely provision of correct and appropriately located SAR data to the ship. Other imagery, such as from MODIS or QuickScat should also be made available. It may be necessary to supplement NIC skills and facilities with those from additional organizations.

Acronyms & URLs

Aqua	NASA’s Earth Observing System second satellite.	http://aqua.gsfc.nasa.gov/
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer	http://asterweb.jpl.nasa.gov/
AVHRR	Advanced Very High Resolution Radiometer	http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html
DMSP	Defense Meteorological Satellite Program	http://dmsp.ngdc.noaa.gov/
ENVISAT	ESA advanced polar-orbiting Earth observation satellite	http://envisat.esa.int/m-s/
ESA	European Space Agency	http://www.esa.int/esaCP/index.html
GLAS	Geoscience Laser Altimeter System	http://glas.gsfc.nasa.gov/
ICESat	Ice, Cloud, and land Elevation Satellite	http://icesat.gsfc.nasa.gov/
MERIS	MEdium Resolution Imaging Spectrometer	http://envisat.esa.int/instruments/meris/
MODIS	MODerate resolution Imaging Spectroradiometer	http://modis.gsfc.nasa.gov/
NIC	National Ice Center	http://www.natice.noaa.gov/
QuikSCAT	NASA's Quick Scatterometer	http://winds.jpl.nasa.gov/missions/quikscat/index.cfm
OLS	Operational Linescan System	http://dmsp.ngdc.noaa.gov/html/sensors/doc_ols.html
RADARSAT		http://www.rsi.ca/index.asp
SAR	Synthetic Aperture Radar	
SSM/I	Special Sensor Microwave Imager	http://dmsp.ngdc.noaa.gov/html/sensors/doc_ssmi.html
Terra	NASA’s Earth Observing System flagship satellite.	http://terra.nasa.gov/