POLAR ICE BY SATELLITE REMOTE SENSING

Antony Liu
Ocean Sciences Branch, NASA Goddard Space Flight Center, Greenbelt MD USA

Keywords: Satellite remote sensing, Sea ice drift, Ice extent, Ice concentration, Marginal ice zone, Wavelet transform, Feature tracking, Northern Sea Route

Contents

Summary

Polar region can now be observed easily by satellite remote sensing, especially for the global climate change. Besides it provides synoptic information, satellite remote sensing is critical to several aspects of field observation, including providing the ice extent and concentration, tracking the ice motion, and locating the ice edge and floes. Three space-borne microwave sensors: passive radiometer, active scatterometer, and synthetic aperture radar have been designed and used for sea ice processes observation and study in the polar region. The wavelet transform-based ice tracking method has been developed and used for these satellite data to obtain daily sea-ice drift information for both the Arctic and Antarctic. The overall comparison of satellite-derived ice motion with Arctic buoy data shows good agreement. Satellite data show the ice extent in the Arctic Ocean is shrinking fast and so the melting ice is opening up the Northern Sea Route which includes both Northeast route and Northwest passage.

1. Introduction – Importance Of Satellite Remote Sensing

The Arctic ice cover is constantly in motion and is very dynamic. It undergoes changes in ice drift patterns and wind circulation. Wind stress acting on the ice surface causes the ice cover to open up to form leads, and later under convergent stress, refrozen leads and thicker ice elements are crushed to form pressure ridges. This results in a redistribution of ice from thinner to thicker categories, accompanied by the creation of open water areas. Sea-ice motion therefore influences the sea-ice mass balance. It also affects the redistribution of latent and sensible heat flux since thicker ice insulates the atmosphere from the oceans and thin ice or open water allows more heat to escape from the ocean to the atmosphere. Also, the wind-driven motion in the central Arctic alternates between anti-cyclonic and cyclonic circulation, each alternative pattern persisting for 5–7 years.

The advent of satellite technology has provided human beings with an amazing new ability to observe the Earth in a new way, especially for the climate change. Polar ice can be detected much more easily from space than can many other physical parameters. For the sensors observing at visible wavelengths, clouds obscure the view of the ice cover, and visible images cannot be obtained during the polar night. A different type of satellite instrument that avoids these complications and that can also be used to detect sea ice is a microwave sensor (Parkinson, 1997). Besides it provides synoptic information, satellite remote sensing is critical to several aspects of field observation, including providing the ice extent and concentration, tracking the ice motion, and locating the marginal ice zone (MIZ). Overall, the sensors that have been used successfully in the polar regions are the microwave sensors, the ocean-color sensor, the high-resolution visible sensors, and the medium-resolution visible and infrared sensors.

The ocean color systems include the Coastal Zone Color Scanner (CZCS), the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), and the Moderate Resolution Imaging Spectroradiometer (MODIS). The high-resolution visible sensors are the Thematic Mapper (TM) on Landsat, and the System Pour l'Observation de la Terre (SPOT). The infrared systems are suitable for measuring ice or sea surface temperatures. Among these systems are the Temperature Humidity Infrared Radiometer (THIR), the Advanced Very High Resolution Radiometer (AVHRR), and the Along Track Scanning Radiometer (ATSR). In several months of the year, darkness and twilight dominate in the Arctic, and for much of the year, clouds and fog persists. Therefore, in the following section, the usage of microwave sensors which penetrate clouds and for day-and-night operation are focused and discussed in details on polar regions application.

In January 2003, NASA launched the Ice, Cloud, and land Elevation Satellite (ICESat) with a precision laser altimeter system for measuring surface elevation. The precision of ICESat measurements of mean surface elevations provides a powerful new tool for studying sea-ice freeboard and thickness. Sea-ice freeboard heights are determined relative to an ocean reference level detected over areas of open water and very thin ice. Estimates of snow depth along with nominal densities of snow, water, and sea-ice are used to estimate sea-ice thickness according to Archimedes buoyancy principle. It is a first assessment of thickness obtained from the derive freeboards using ICESat data. Additional in-situ measurements such as sea-ice freeboard, and thickness are necessary to further calibrate and validate ICESat derived results.

2. Microwave Data

2.1. Passive Radiometer

A radiometer is an instrument that measures radiation, and passive refers to the fact that instrument simple receives the radiation from elsewhere. Recently, three primary satellite passive microwave radiometers that have provided a wealth of sea ice information are the Nimbus 7 Scanning Multichannel Microwave Radiometer (SMMR), which provided data for most of the period from October 1978 to August 1987; a series of Special Sensor Microwave Imagers (SSM/I) on the satellite of the Defense meteorological Satellite Program (DMSP), which have provided data for most of the period since June 1987; and an Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E) on board NASA's Aqua spacecraft launched in May 2002. AMSR-E is a six-frequency dual-polarized passive microwave radiometer that observes water-related geophysical parameters supporting global change science and monitoring efforts. The basic parameter measured by passive radiometer is the brightness temperature which is the radiative flux expressed in temperature emitted from the surface (Comiso, 1995).

2.2. Active Scatterometer

An active instrument, in contrast to passive ones, actually send out a signal that later receive back. In 1996 the NASA scatterometer (NSCAT) rode into orbit on the Japan satellite Advanced Earth Observing System (ADEOS) and gathered 8.5 months of valuable wind data. NSCAT, the active microwave sensor, measured return signals from 600-km-wide swaths on both sides of the satellite with a resolution of 25 km. The microwaves were Bragg backscattered by short water waves in the open ocean and by ice surface roughness in the polar region. QuikSCAT, a "quick recovery" mission to fill the gap created by the loss of data from NSCAT, was launched in June 1999. QuikSCAT is an active sensor, and the sensor footprint is an ellipse 25 km x 37 km. In polar region, repeated footprints of the satellite make it possible to construct QuikSCAT images with a 12.5 km grid. The basic parameter measured by active scatterometer is the surface roughness with certain wavelength or frequency.

2.3. Synthetic Aperture Radar

Synthetic Aperture Radar (SAR) is a side-looking imaging radar that transmits a series of short, coherent pulses to the ground. Intensive signal processing involving the detection of small Doppler shifts to the moving radar produces a high-resolution image. With all-weather, day/night imaging capability, SAR penetrates clouds, smoke, haze, and darkness to acquire high quality images of the Earth's surface. The ability of SAR to provide valuable information on the type, condition, and motion of the sea-ice, ships and surface signatures of swells, wind fronts, oil slicks, and eddies has been amply demonstrated (Liu and Wu, 2001). This makes SAR the frequent sensor of choice for cloudy coastal and polar regions. What SAR sees on surface is primarily the variation of surface roughness with certain wavelength similar to scatterometer.

In 2009, there are five major SARs in orbit. RADARSAT-1 and -2, the first and second

Canadian remote sensing satellites, were launched in November 1995 and December 2007, respectively. RADARSAT has a ScanSAR mode with a 500 km wide swath and a 100 m resolution. The ERS-2, having a conventional SAR with a swath of 100 km and a resolution of 25 m, was launched in April 1995 by European Space Agency (ESA). ENVISAT-1 with an Advanced SAR (ASAR) was also launched in March 2002 by ESA. The Phased Array type L-band Synthetic Aperture Radar (PALSAR) onboard Japan's Advanced Land Observing Satellite (ALOS) was launched on January 24, 2006 for land observation. With repeated coverage, space-borne SAR instruments provide the most efficient means to monitor and study the changes in important elements of the marine environment. With more SAR sensors from various satellites, new data products such as sea-ice drift can be tracked and derived in MIZ.

-
-
-

Bibliography

Cavalieri, D. J., and C. L. Parkinson, 2008 *Antarctic sea ice variability and trends, 1979-2006*, Journal of Geophysical Research - Oceans, Vol. 113, C07004, doi:10.1029/2007JC004564, 19 pp [Analyses of 28 years of Antarctic sea ice extents and areas derived from satellite passive microwave radiometers].

Comiso, J. C. 1995 *Satellite remote sensing of the Arctic Ocean and adjacent seas*, Arctic Oceanography: Marginal Ice Zones and Continental Shelves, AGU, Coastal and Estuarine Studies, Vol. 49, 1-50 [A review article on satellite systems and sensors for the sea-ice applications].

Gloerson, P., W. Campbell, D. Cavalieri, J. Comiso, C. Parkinson, and H. J. Zwally, 1992 *Arctic and Antarctic Sea Ice, 1978-1987: Satellite Passive Microwave Observations and Analysis*, NASA Spec. Publ. 511, 289pp [A summary on the Arctic and Antarctic sea ice cover observed by the Nimbus 7 research satellite over the period 1978-1987].

Kitagawa, H., 2006, *New era in Far East Russian & Asia*, Ocean Policy Research Foundation (OPRF), Tokyo Japan, 318 pp [Source on perspective of NSR, development of Far East Russia & GIS, and protection of environment for the Sea of Okhotsk].

Liu, A. K., and C. Y. Peng, 1998 *Wavelet analysis of SAR images in the marginal ice zone*, Chapter 6, in: C. Tsatsoulis, and R. Kwok, Ed., *Analysis of SAR Data of Polar Oceans*, Springer Verlag, 111-128 [Analysis of marginal ice zone dynamics using a two-dimensional wavelet transform technique for SAR data and ocean-ice interaction model to track eddies, ice edge, and ice floe motion].

Liu, A. K., and S. Y. Wu, 2001 *Satellite remote sensing: SAR*, Vol. 5, in: J. H. Steele, S. A. Thorpe, and K.K Turekian, Ed., *Encyclopedia of Ocean Sciences*, London: Academic Press, 2563-2573 [A review of synthetic aperture radar imaging mechanism, and ocean applications].

Liu, A. K., S. Y. Wu, and Y. Zhao, 2003 *Wavelet analysis of satellite images in ocean applications*, Chapter 7, in: C. H. Chen, Ed., *Frontiers of Remote Sensing Information Processing*, World Scientific, 141-162 [Discussion on ocean feature tracking technique by using wavelet transform on satellite images].

Parkinson, C. L. 1997 *Earth from Above: using color-coded satellite images to examine the global environment*, University Science Books, 175 pp [A review article on increasing the understanding of satellite data and the maps or images created from them].

Parkinson, C. L., and D. J. Cavalieri, 2008 *Arctic sea ice variability and trends, 1979-2006*, Journal of Geophysical Research - Oceans, Vol. 113, C07003, doi:10.1029/2007JC004558, 28 pp (analyses of 28 years of Arctic sea ice extents and areas derived from satellite passive microwave radiometers].

Wadhams, P. 2000 *Ice in the Ocean*, Gordon and Breach Science Publishers, The Netherlands, 351 pp [A book of "solid state oceanography" offers an introductory to modern knowledge of sea ice and icebergs and the role they play in the ocean system].

Zhao, Y., and A. K. Liu, 2007 *Interaction of Arctic sea-ice drift and atmospheric surface pressure*, J. Oceanography, Vol. 63, 505-515 [Discussion on sea-ice drift derived from satellite data and its relationship with atmospheric surface pressure field].

Zwally, H. J., J. C. Comiso, C. L. Parkinson, W. J. Campbell, F. D. Carsey, and P. Gloerson, 1983 *Antarctic Sea Ice 1973-1976 from Satellite Passive Microwave Observations*, NASA Spec. Publ. 459, 224 pp [A summary on the Antarctic sea ice cover observed by the Nimbus 5 research satellite over the period 1973-1976].

Biographical Sketch

Antony Liu received the B.Sc. degree from the National Chung-Hsing University, Taiwan in 1970, specializing in applied mathematics. He received the Ph.D. degree in mechanics at the Johns Hopkins University, Baltimore, MD, in 1976. Before he joined NASA Goddard Space Flight Center, Greenbelt, MD in 1986, he worked at Dynamics Technology, Inc., Torrance, CA, as a Section Head of Ocean Technology. He was promoted to Senior Scientist in 1992 at the Oceans and Ice Branch, Laboratory for Hydrospheric Processes at NASA/GSFC. Also, he was in a 5-year assignment detailed from NASA/GSFC's Ocean Sciences Branch to the Office of Naval Research (ONR) Global in Tokyo office from 2003-2008 as an Associate Director. He has been a Principal Investigator of many research programs of the European Space Agency (ESA), the Japan Aerospace Exploration Agency (JAXA), Canadian Space Agency (CSA), and NASA. He is also a Principal Investigator on ONR's SWADE (Surface Wave Dynamics Experiment) and ASIAEX (Asian Seas International Acoustics Experiment) and NOAA's CoastWatch projects. His research interests involve air-sea-ice interaction, satellite image processing, coastal monitoring, and nonlinear internal wave study, especially in the South China Sea.