A Multidecade Polar Climate Record from Radar Scatterometer Data: the Scatterometer Climate Record Pathfinder Project

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Abstract

Radar scatterometers were originally designed to measure near-surface winds from space by measuring the normalized radar backscatter of the ocean's surface. However, scatterometer backscatter measurements collected over ice-covered and land regions have proven to be very effective in wide variety of ocean, ice, and terrestrial applications. Past and present scatterometers have been providing continuous synoptic coverage of the Earth for well over a decade and the earliest scatterometer dataset is nearly three decades old. The long time series enables extensive studies of seasonal and interannual variability as well as surface changes related to climate change. This paper briefly describes the Scatterometer Climate Record Pathfinder (SCP) project (http://www.scp.byu.edu) in an effort to promote use of the long historical time series of scatterometer data for climate studies.

I. Introduction

A wind scatterometer is a real-aperture radar designed to measure the normalized radar backscatter of the ocean's surface from space. By making multiple backscatter measurements of the same location from different azimuth angles, the near-surface wind speed and direction can be determined with the aid of a geophysical model function relating wind and backscatter (Naderi et al. 1991). Spaceborne radar scatterometers have been flown in space since the late 1970's with continuous data since 1991.

Scatterometers also collect backscatter data over the ice-covered oceans and land regions of the Earth. Figure 1 illustrates a global map of Ku-band backscatter over the land and ice regions of the Earth. For ice and land, the observed backscatter is a function of the dielectric properties of the surface, as well as the roughness and geometry. Dielectric properties are functions of the physical characteristics of the effective scattering medium, including layering, snow grain size, brine concentration in sea ice, soil moisture, and canopy leaf density. The dielectric value is particularly sensitivity to the phase (liquid or frozen) state of water and is a sensitive indicator of meltwater on sea ice and land ice, re-frozen percolated melt water in glacial ice, and whether trees are frozen or actively respiring. Roughness properties and geometry that affect backscatter include topography, surface roughness, moisture content, leaf size and density, branch orientation, and preferential alignment of surface scatterers.

The sensitivity of radar backscatter to surface conditions makes scatterometer data extremely useful in a broad range of ice and land applications. The frequent, global measurements of scatterometers make the instrument particularly well-suited for global monitoring. Further, the long-time series of scatterometer measurements dating back to 1978 provide a valuable baseline for studies of climate change. The Scatterometer Climate Record Pathfinder (SCP) project has produced an extensive set of scatterometer imagery and data products designed to support land and ice studies of global change. In this paper we briefly describe some of these products and describe their application in climate studies.

II. Wind Scatterometers

Six different wind scatterometer instruments have been flown, with an additional instruments to be launched soon. NASA has flown four scatterometers: two SeaWinds scatterometers, one aboard the QuikSCAT satellite launched in 1999 and another aboard the abbreviated Japanese Space Agency's ADEOS-II which operated for 9 months in 2003; the NASA scatterometer (NSCAT) on the Japanese Space Agency's ADEOS-1 which operated 1996-1997; and the Seasat-A scatterometer system (SASS) which flew for 3 months in 1978. The European Space Agency (ESA) has flown two scatterometers aboard the Earth Resource Satel-

	SASS	ESCAT	NSCAT	SeaWinds
FREQUENCY	14.6 GHz	5.3 GHz	13.995 GHz	13.6 GHz
ANTENNA AZIMUTHS				
POLARIZATIONS	V-H, V-H	V ONLY	V, V-H, V	V-OUTER/H-INNER
BEAM RESOLUTION	FIXED DOPPLER	RANGE GATE	VARIABLE DOPPLER	PENCIL-BEAM
SCIENCE MODES	MANY	SAR, WIND	WIND ONLY	WIND/HI-RES
RESOLUTION (□°)	50/100 km	50 km	25 km	Egg: 25x35 km Slice: 6x25km
SWATH, km	~750 ~750	500	600 600	1400,1800
INCIDENCE ANGLES	0° - 70°	18° - 59°	17° - 60°	46° & 54.4°
DAILY COVERAGE	VARIABLE	< 41 %	78 %	92 %
MISSION DATES	SEASAT: 6/78-10/78	ERS-1: 92-96 ERS-2: 95-	ADEOS-I: 8/96-6/97	QuikSCAT: 6/99- ADEOS-II:1/02-10/02

Fig. 2. Summary of the characteristics of past and present wind scatterometers.

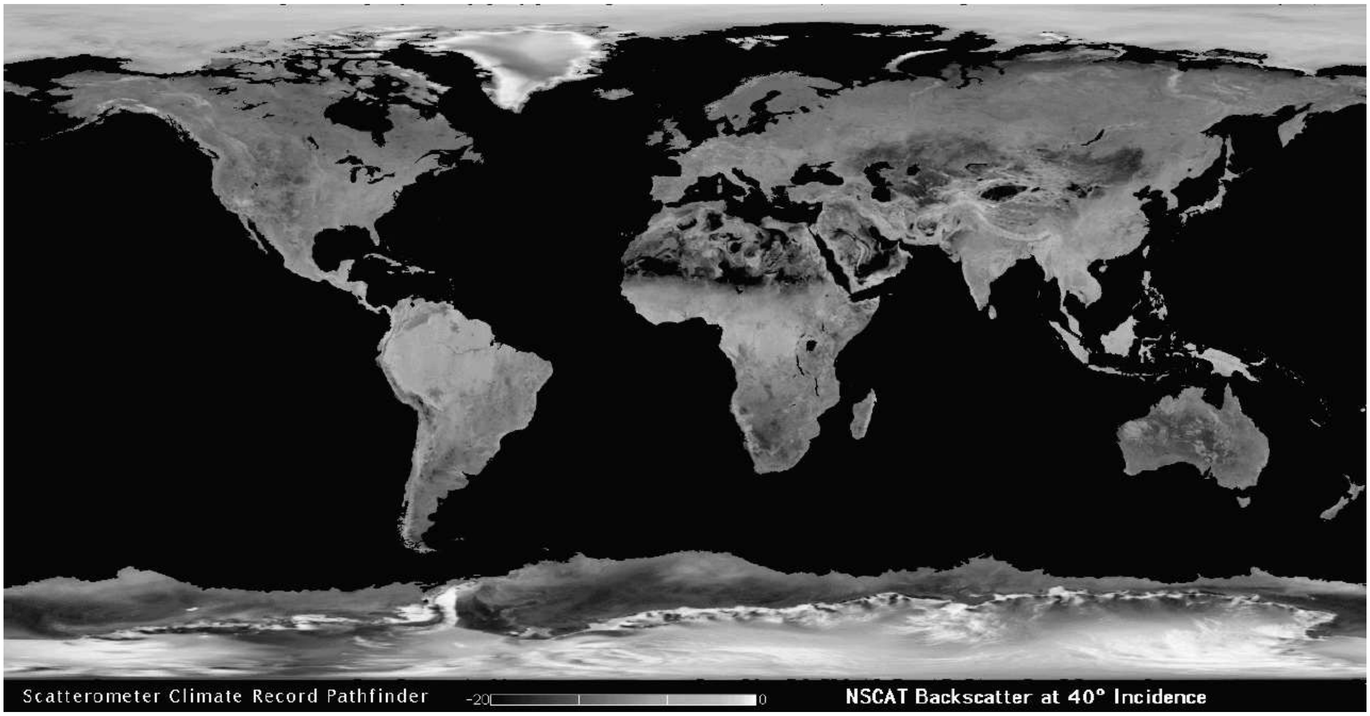

Fig. 1. Global land and ice normalized radar cross-section at 40° incidence angle observed at Ku-band by NSCAT. In this image the ocean has been masked out.

lite (ERS) spacecraft, ERS-1 and ERS-2, with continuous operation since 1991. ESA plans to launch an advanced scatterometer (ASCAT) next year. Taken together, scatterometers provide a very long historical data record that can support multidecade change studies. A summary of scatterometer missions and instrument characteristics is shown in Fig. 2.

To achieve their original design goal of accurate wind measurements, scatterometers are accurately calibrated, typically to better than a few tenths of a decibel (dB), and exhibit excellent long-term stability and precision. NASA scatterometers have all operated at Ku-band (13.6-14.6 GHz), while ESA scatterometers have operated at C-band (5.3 GHz). NASA scatterometers make both vertically-polarized and horizontally-polarize measurements, while ESA scatterometers have been single polarization. Most scatterometers have used fan-beam antennas which make backscatter measurements at a diversity of incidence angles and several azimuth angles. The SeaWinds scatterometer uses a rotating pencil-beam antenna design in which measurements are made at only two incidence angles but over a wide range of azimuth angles. Since the scattering properties of surfaces are different at different frequencies, incidence angles, and azimuth angles, the differences between the various sensors can be exploited to study and better understand surface properties and characteristics. Compared to microwave radiometers, scatterometer data is less sensitive to atmospheric effects than the passive microwave sensors and provides complementary information (Long et al. 2001).

The wide swath of scatterometers provides near-daily global coverage, particularly in the polar regions, at intrinsic resolutions generally between 25-50 km, over incidence angles ranging from 20-55 deg depending on the sensor. To facilitate the application of scatterometer data in climate studies, techniques for improving the effective resolution of the data have been developed. These techniques combine multiple passes to improve the sampling density and produce images of the surface backscatter at spatial resolutions as fine as 5 km for some sensors (Early and Long 2001). Such algorithms can also be applied to radiometer data (Long and Daum 2001).

III. Available SCP Products

The SCP project has developed a standard suite of scatterometer images in compatible grids to facilitate intercomparison and scientific application. Recently, enhanced resolution radiometer images have been added to the SCP product suite. Value-added scatterometer-derived products are also available from the SCP. The SCP provides two basic forms of gridded scatterometer products: 1) backscatter images at the intrinsic sensor resolution and 2) enhanced resolution images which combines multiple overlapping passes over intervals of a few days. The latter are created using Scatterometer Image Reconstruction (SIR) algorithm (Early and Long 2001). The image pixel resolutions are 8.9 km/pixel for ESCAT, 4.45 km/pixel for SASS, NSCAT, and QSCAT with additional 2.225 km/pixel images for QSCAT. The enhanced products are well suited for many ice and land studies where the surface backscatter returns are comparatively stable over a 1-2 day period.

In addition to backscatter products, the SCP provides value-added products. These include various data animations, an extensive database of Antarctic icebergs, and sea ice products such as sea ice extent, ice motion, and ice concentration derived from scatterometer data. A freeze/thaw product is in development. Products which combine active and passive microwave measurements are also in development. These include sea ice extent, sea ice concentration, and melt-onset. The complementary nature of the passive and active measurements provides improved accuracy and resolution.

Scatterometer images, documentation, software, and other information are currently available through the SCP data site via the web at URL http://www.scp.byu.edu/. SCP data and raw scatterometer data are available from the Jet Propulsion Laboratory's (JPL) Physical Oceanography Distributed Active Archive Center (PODAAC) (http://podaac.jpl.nasa.gov/). SCP Data is also available through the National Snow and Ice Data Center (NSIDC) site (http://nsidc.org).

IV. Applications

Scatterometer data has proven to be remarkably effective in variety of climate studies (see, for example, Long et al. 2001). The following paragraphs very briefly describe a few of these.

The daily global coverage of scatterometer data in the polar regions and its ability to discriminate sea ice, ice sheets, and icebergs, despite the variable solar illumination and frequent cloud cover, make scatterometer data an excellent instrument for large-scale systematic observations of polar ice (Anderson et al. 2005) and for land freeze/thaw (Foster et al. 2001). To help convey some of the wealth of information available in the scatterometer land and ice images, Fig. 3 illustrates summer and winter views of both polar hemispheres while Fig. 4 illustrates seasonal change over North America.

Scatterometer backscatter over sea ice is sensitive to roughness and physical properties and has a distinct response compared to open ocean, making scatterometer data useful in observing sea ice extent. The onset of seasonal snow melt and freeze-up dramatically modifies the ice backscatter over sea ice. Such events affect the radiative budget of ice-covered regions. A recently observed trend of increasingly early melt onset and later fall freeze-up may be related to climate trends.

Ice velocity fields are a critical component in estimating heat flux between the ocean and atmosphere, and for tracking sea ice mass balance. Motion fields have been derived using scatterometer data with various algorithms and compared with radiometer-derived motion estimates. The passive data sets are found to complement each other: where one sensor has difficulties, the other provides the need information. Several recent ice type studies have shown improved accuracy when scatterometer data are combined with passive sensor data (Zhao et al. 2002).

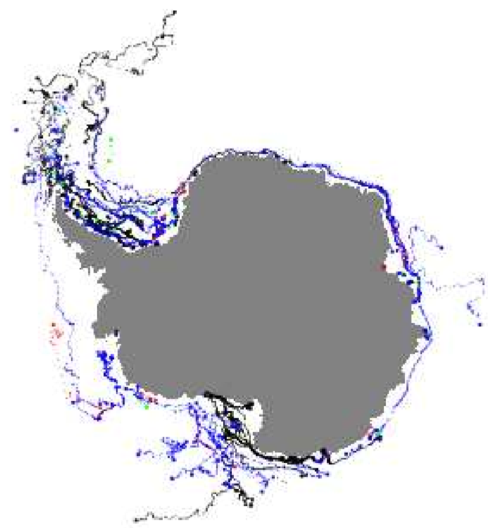

Fig. 5. Track of all icebergs in the SCP Antarctic iceberg database, 1978-2005. Many icebergs originating in the Ross Sea (at the bottom of the figure) circumnavigate the Antarctic continent and expire north of the Weddell Sea (at the top of the figure).

The sensitivity of scatterometer backscatter to the snow density and grain size makes the data invaluable in studies of the Greenland and Antarctic ice sheets (Long and Drinkwater 1999). By combining scatterometer data from multiple sensors, the long-term and inter-annual variability of accumulation rates and the extent of seasonal snow melt zones can be estimated over Greenland (Drinkwater et al. 2001).

Tabular icebergs made of glacial ice generally exhibit a high contrast with surrounding ocean and/or sea ice and are thus easily identified in scatterometer images. This enables tracking of large ice bergs and has enabled retrospective climate studies of icebergs counts (Long et al. 2002) The SCP maintains a large database of iceberg positions derived from scatterometer data. Figure 5 illustrates a multidecade plot of iceberg tracks around Antarctica.

SeaWinds-on-QuikSCAT images are currently being operationally used at the National Oceanic and Atmospheric Administration (NOAA), the National Ice Center (NIC), and other operational agencies for monitoring sea ice extent and for tracking large icebergs in the Southern

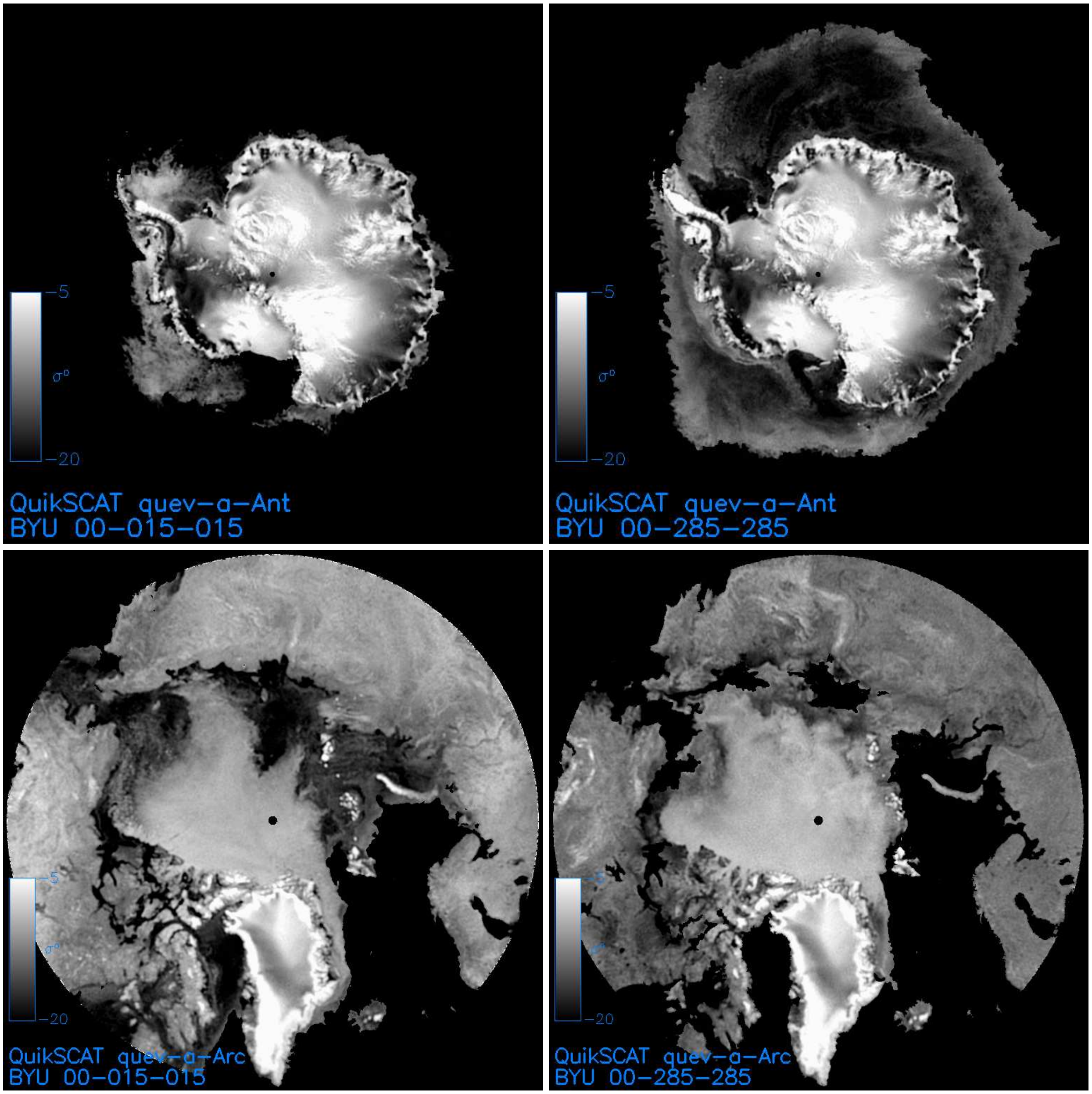

Fig. 3. Sample SeaWinds vertically polarized backscatter images from the SCP project for (top panels) Antarctica and (bottom panels) the Arctic. The left panels are for day-of-the-year 15, while the right panels are for day 285. In these images, the open ocean has been masked out. Backscatter changes over land are primarily due to freeze/thaw conditions. Backscatter variations over sea ice convey information about ice age and surface conditions.

Ocean. Scatterometer data has also proven useful in studies of vegetation, drought floods, and other terrestrial applications (Drinkwater and Lin 2000). Additional applications are in various stages of development by many investigators.

Acknowledgments

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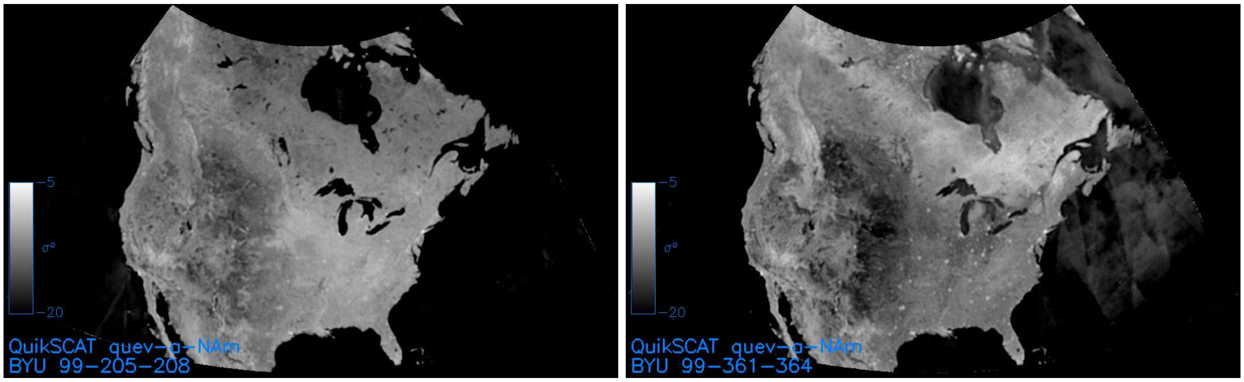

Fig. 4. QuikSCAT vertically polarized backscatter images of North America for two different periods in 1999: (left) Julian Days 205-208, (right) Julian Days 361-364. Frozen areas make winter backscatter larger than summer backscatter over tundra and forest in Canada. Reduction in seasonal vegetation density produces reduces backscatter in United States. Note that urban areas have high backscatter due to the corner effect and show up clearly in the winter image. Variations in the ocean are due to differing wind conditions.

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