Global Snow Signature in Ku-Band Backscatter

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Abstract – We present Ku-band backscatter signatures of snow for applications to global snow monitoring with NASA Scatterometer (NSCAT) on the ADEOS satellite and the SeaWinds scatterometer on the QuikSCAT satellite. We carried out the 1999 Alaska Snow Experiment to study the relation between Ku-band backscatter and snow physical properties. The experimental results are applied to interpret backscatter data acquired by the satellite scatterometers. Results from NSCAT show regional patterns matching various global snow types, early snow melt conditions, and the snow event leading to the 1997 Flood of the Century in the US midwest regions and in Manitoba of Canada. SeaWinds/QuikSCAT results reveal the expansion and retreat of global snow cover during the 2000 snow season. The anomalous warming event in late December 1999 was captured by the satellite data.

INTRODUCTION

Snow influences the global heat budget and has strong feedbacks with the planetary albedo and outgoing longwave radiation. Snow cover is a significant climatic index, which can be used to predict and estimate the magnitude of recent changes in climate. Temperature change in high latitudes is attributable to the albedo-temperature feedback process, and snow must be regarded as one of the key variables in the global change monitoring. Different results from various general circulation models indicate that snow feedback involves complex interactive processes in the global climate system.

Snowmelt is an important water source for irrigation and drinking in many areas of the world. Heavy snow storms with rapid snowmelt in spring were accounted for the Flood of the Century in the Northern Plains causing loss of lives and several billion dollars in flood related damages. With this regard, snow monitoring with a frequent coverage over regional scales is necessary for hazard prediction and mitigation. In this paper, we present the application of scatterometry to global snow remote sensing using Ku-band backscatter data.

PRINCIPLE

Snow grain sizes range mostly in submillimeter and millimeter scales and depth hoar crystals can develop to centimeter scales. For a snow grain much smaller than the electromagnetic wavelength, the scattering follows the Rayleigh scattering law, which dictates that the backscatter is proportional to the fourth power of the wave frequency.

Radar measurements of dry snow [1] show that backscatter agrees well with the Rayleigh-scattering fourth-power slope up to the Ku-band frequency of 14 GHz. An important indication of these results is that snow backscatter at Ku-band 14 GHz is 5.8 times stronger than that at X-band 9.9 GHz, 48 times compared to C-band 5.3 GHz, 2400 times to S-band 2.0 GHz, and 15735 times to L-band 1.25 GHz. With such a strong response to snow, a higher-frequency radar is better to detect thinner snow.

While electromagnetic waves at higher frequencies have a stronger response to snow scattering, wave attenuation needs to be considered. A scattering medium such as snow is inherently dispersive and the wave attenuation is more severe at higher frequencies. Because of the attenuation, backscatter from snow cannot increase further and becomes saturated after a certain snow depth where the waves cannot reach. The saturation effect was shown in experimental data and empirical models at 9.0 GHz and at 16.6 GHz [2].

With the above considerations, a 14-GHz scatterometer system such as NSCAT [6] is well applicable to snow monitoring. A lower frequency radar has a much weaker snow backscatter response that is harder to detect thin-
ner snow, is contaminated by more noise due to a lower
signal-to-noise ratio, and is significantly affected by other
constituents such as vegetation within the resolution cell.
A higher frequency radar is limited by the saturation that
does not cause great difficulties in detecting thicker snow depth
and requires a much higher relative accuracy.

**NSCAT AND QUIKSCAT DATA**

The National Aeronautics and Space Administration
(NASA) Scatterometer (NSCAT) was operated at about
14 GHz on the Advanced Earth Observing Satellite
(ADEOS) from September 1996 to June 1997. NSCAT
had double-sided swaths, each with a coverage of 600 km
spanning a range of incidence angles within 10° to 70°.
There were 3 beams with the vertical polarization and 1
beam with the horizontal polarization on each side. The
relative accuracy of backscatter measurements was esti-
mated to be about ±0.3 dB and further information on
NSCAT has been reported by Tsai et al. [1999]. In this
paper, we use the vertical polarization data because there
were more data at that polarization and because most
snow is isotropic. The NSCAT backscatter resolution was
approximately 7 km by 25 km on the ground and the data
were binned into 25-km cells.

The QuikSCAT satellite was successfully launched at
7:15 p.m. Pacific Daylight Time on 19 June 1999 from
the Vandenberg Air Force Base in California. The satel-
lite carries the SeaWinds scatterometer for ocean wind
measurements [4]. The scatterometer has been collecting
data at 13.4 GHz on both ocean and land. Backscatter
data, at a radiometric resolution of 7 km × 25 km,
are acquired with the vertical polarization (σ\text{VV}) at a con-
stant incidence angle of 54° over a conical-scanning swath
of 1800 km, and with the horizontal polarization (σ\text{HH})
at constant 46° over a 1400-km swath. Over cold land
regions, the large swath can provide two coverages per
day. The satellite orbit was stabilized, the scatterometer
performance was verified, and the calibrated science data
have been obtained since 19 July 1999 [5].

**1999 ALASKA SNOW FIELD EXPERIMENT**

To investigate the relationship between Ku-band radar
backscatter and physical properties of snow, we carried
out a snow field experiment in Ft. Wainwright, Alaska,
in March and April 1999 [7]. We obtained Ku-band
backscatter signatures from a tower-based Ku-band scatter-
rometer, together with detailed snow physical character-
istics including snow depth, density, snow water equiv-
alent, grain size distribution, temperature, wetness, and
layering.

We made simultaneous suites of measurements of the
snow cover albedo in order to link the Ku-band measure-
ments directly to a climatologically important parameter.
Measurements were obtained from three distinct phases of the melt: 100% snow cover with diurnal freeze-thaw ef-
effects, discontinuous snow cover with extreme freeze-thaw
effects, and ground thaw with residual snow (thaw depth
from 0 cm to 10 cm). In all cases, backscatter was mea-
sured over a large range of incidence angles with multi-
ple polarizations. Several special cases were also investi-
gated by artificially altering the snow and ground cover.
The snow field experimental results are applicable to the
interpretation of Ku-band backscatter data acquired by
NSCAT and QuikSCAT.

**RESULTS**

Results from the Alaska Snow Experiment show that Ku-
band backscatter is sensitive to snow properties. A few
percent change of wetness in the surface layer of snow
can cause more than 10 dB change in Ku-band backscat-
tter. This leads a strong diurnal variations during the melt
and freeze processes, which we exploit to develop an al-
gorithm to determine the timing and spatial pattern of
snow melt onset, melt duration, and snow departure. This
also indicates that Ku-band backscatter can be used as an
early indicator of snow melt conditions. Since Ku-band
backscatter is sensitive to snow properties, spatial distrib-
butions over different regions of global snow cover can be
used to distinguish the extent of different snow types.

Using global NSCAT data, we show for the first
time that global Ku-band backscatter signature in
snow-covered regions, delineated by the operational
NOAA/NESDIS and CPC snow extent product, reveals
patterns corresponding to different global snow classes de-
\textit{ined by the CRREL snow classification system [8]. Such
observations hold over regions with different vegetation
types and forest areas during the snow season. This is
an indication of the sensitivity of Ku-band backscatter to
snow physical characteristics on the global scale.}

The comparison of global NSCAT backscatter data with
in-situ snow depth and temperature data obtained from
the global weather station network over three different
and important snow-covered regions of the world, includ-
\textit{ing Alaska in U.S., Ontario in Canada, and Siberia in Russia},
shows the close correlation of the NSCAT backscatter
treat patterns with the snow melt process observed at
various weather stations. These results further indicate
the sensitivity of Ku-band scatterometer in monitoring the
global snow cover.

To illustrate the practical utility of wideswath Ku-band
scatterometer as an early indicator of large-scale snow
melt causing floods, we investigate NSCAT backscatter
signature corresponding to snow events leading to the
\textit{1997 Flood of the Century over the U.S. northern plains
and the Canadian prairie region. NSCAT backscatter
shows dramatic changes with pronounced and dynamic
patterns correlated with the April blizzard and rapid snow
melt causing the devastating flood.}

We develop an algorithm for QuikSCAT data to ac-
count for the geophysical change before the snow season
and use it to determine the backscatter change due to
snow accumulation. SeaWinds/QuikSCAT results reveal
the expansion and retreat of global snow cover during the
2000 snow season. Circumpolar patterns in the counter-
clockwise direction over snow covered regions are observed
from QuikSCAT and NSCAT data animations. Distinc-
tive melt bands over snow are identified over north Amer-
ica and across from Europe to east Siberia.
Daily QuikSCAT images reveal an anomalous warming in December in Alaska. On 12/17/99, strong backscatter due to snow cover over almost all of Alaska. However, the image on 12/22/99 exhibits a dramatic reduction in backscatter change over extensive and north-west Canada. On 12/30/99, backscatter change recovered and became even stronger than that on 12/17/99, probably due to additional snow accumulation under cold condition after the warming event. Such a warming event can introduce an ice layer in the snow pack resulting in the instability leading to snow avalanche.

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