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JERS-1 SAR L-Band Sigma Naught Signatures of Glacier Facies on Bagley Ice Valley, Alaska, From 1992 to 1998 (Extended Abstract)

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Abstract: This study investigates the normalized sigma naught cross-section intensity, σ^0, of the NASDA Japanese Earth Resource Satellite, JERS-1, L-Band SAR for detecting changes of radar glacier facies/zone relative of environmental factors from 1992 to 1998 on Bagley Ice Valley and Waxell Glacier, located in the Chugach-St. Elias Mountains of coastal south-central Alaska. As this glacier is part of the largest glacier and ice field complex in continental North America, wastage of the glacier system as a consequence of recent climate change could have impacts to other physical and biological systems of coastal Alaska and neighboring Arctic.

1. Introduction

A warming trend in the areas of the Arctic and Antarctic regions has been observed in the last decade (Weller, 1998). The 2001 meteorological year was the second warmest in more than a century of instrumental data on a global average with one of the largest warm anomalies occurring in the Alaska-Canada region (Hansen and others, 2002). The spatial distribution and exchange of water in the components of the Earth's hydrologic cycle are important factors of climate change (Rind and others, 1991). The spatial pattern, moisture transport and temperature have intensified most recently (Moore and others, 2002)

Glacier facies, the total assemblage of characteristics defining the environment of formation is the key link between the glacier and climate (Paterson, 1994). Depending on liquid water content, grain size, density and distribution of snow/firn/ice layers, backscattered radar pulses allow direct investigation into the physics of the glacier facies, their changes over time and the near surface dynamic properties (Rott and Mätzler, 1987; Fahnestock and others, 1993; Bindschadler and others, 1999). Benson (1962) defined glacier facies to include ice facies (glacier ice), the superimposed ice zone (previous year firn and ice), the wet-snow facies, the percolation facies and the dry-snow facies. The location of the glacier facies is a function of water content and altitude (ice facies is the lowest and dry-snow facies is the highest in altitude). Because of the altitude dependency, a temperate glacier may not have all the glacier facies present. Within SAR imagery, the boundaries of the glacier facies have a definable characteristic in backscatter intensity (Fahnestock and others, 1993).

In this study JERS-1 L-band SAR σ^0 response of glacier facies and their change over

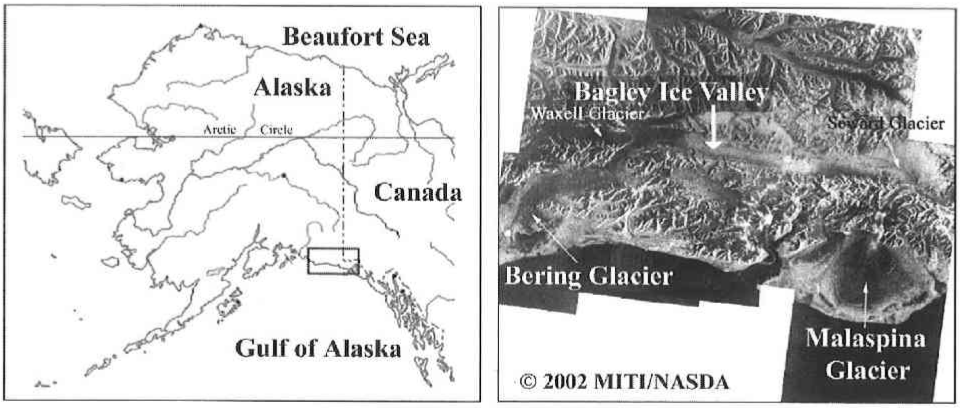

Fig. 1. Location of Bagley Ice Valley (within the Bering-Malaspina Glacier system) in the St. Elias-eastern Chugach Mountains of coastal south-central Alaska : (left) outline of Alaska (parts of Canada on the right and Siberia on the Left) and the glaciers bounded by the box, (right) is a visual mosaic of JERS-1 SAR images of the glaciers from January to April 1993 (rotated for geographic orientation without terrain correction). The horizontal line in the left outline is the latitude of the Arctic Circle. Waxell Glacier is a west linear extension of Bagley Ice Valley across from Bering Glacier.

time from 1992 to 1998 are derived. The location of the study is the Bagley Ice Valley and Waxell Glacier in the St. Elias-eastern Chugach Mountains of coastal south-central Alaska (Figure 1). The mountains mark the Pacific-North America plate boundary. As part of the largest glacier and ice field complex in continental North America, wastage of these glaciers can potentially affect other physical and biological systems in coastal Alaska and neighboring Arctic. Research on the surface changes of glaciers over a 28 year period shows complex patterns of spatial non-uniform thinning and thickening is a response to climate change (Muskett and others, this volume ; Muskett and others, 2002 a, b).

2. JERS-1 L-Band Sigma Naught

The normalized backscatter cross section amplitude intensity sigma naught (σ^0), is a unit of aerial scattering and key parameter for target identification (Shimada and Hirosawa, 2000). σ^0 is a function of the radar equation and a function of the complex dielectric constant, surface roughness and slope/aspect of reflector surfaces (on ground and at depth). Changes in the dielectric constant of materials composing the ground surface or transmissive media will cause attenuation of the radar signal (Rott and Mätzler, 1987 ; Hanssen and others, 1998). Changes in glacier ice, such as in percent of glacier melt, grain size and surface temperature of the snow/firn/ice will change the complex dielectric constant and thus attenuate the backscatter signal. Temporal changes of the glacier can then be monitored by acquiring radar data displaced over

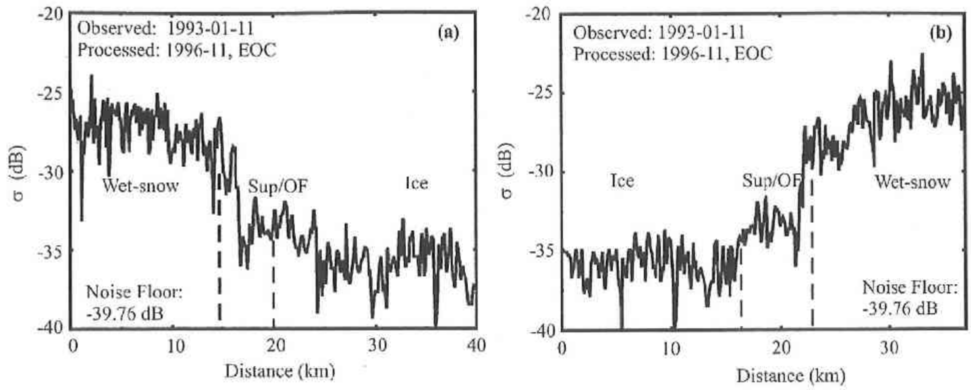

Fig. 2. JERS-1 L-Band SAR σ^0 radar glacier facies/zone observed Jaunary 11, 1993. (a) is Waxell Glacier (east-facing slope) and (b) is Bagley Ice Valley (west-facing slope). Sup/OF refers to superimposed ice and old (previous year) firn.

months and years.

The JERS-1 of the National Space Development Agency of Japan (NASDA) was launched in 1992 and its operational service ended in 1998. JERS-1 Synthetic Aperture Radar (SAR) sensor has a wavelength of 24 cm, 1.27 GHz frequency (L-Band), HH polarization and 34-43° incidence angle.

The data used in this study come from the descending mode, 100 m-by-100 m pixel size, geocoded 8-bit [no terrain correction] (down sampled from 16-bit 256-look) images processed at the NASDA Earth Observation Center, Japan. The digital number (DN) values were converted to the normalized radar cross section σ^0 by using the equation (Shimada, 1998): $\sigma^0 = 20 \log_{10} DN + CF$. CF is the calibration factor of -68.2 dB (11-1996 processing date).

Inspection of image backscatter data on the west-east slopes of Bagley Ice Valley and Waxell Glacier shows that σ^0 varies from about -38 dB to -24 dB. In Fig. 2 an example is shown of the σ^0 response on the glacier facies. The interpreted radar glacier facies/zones on Bagley Ice Valley, in particular the superimposed ice/old-firn facies (Sup/OF) is based on field observations of Mayo (1986) of the equilibrium line altitude and on similar σ^0 response behavior of ERS-1 on Wrangell-Nebesna Glacier (Partington, 1998). Change detection on the order of 1 dB is possible with high multi-look images (Rignot and Zyl, 1993).

3. Results and Discussion

The images analyzed correspond to 14-16 October 1992, 11 January 1993, 9 April 1993 and 1 May 1998. Linear and radial transects on the west and east facing slopes were used to extract DN data for conversion to σ^0. The linear transects were partitioned by relative σ^0 into three parts corresponding to apparent glacier facies. The apparent

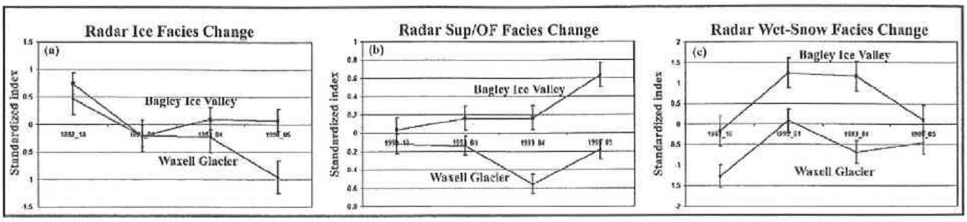

Fig. 3. Standardized time series of JERS-1 L-Band SAR radar glacier facies/zone change from October 1992 to May 1998 on Bagley Ice Valley (west-facing slope) and Waxell Glacier (east-facing slope).

difference in the width of the radar superimposed ice/old-firn facies is a function of slope aspect and sensor incidence angle. From the σ^0 values, averages and standard deviations were computed. The averaged σ^0 values were then standardized into time series with standard error bars shown in Figure 3.

The standardized time series show a σ^0 dependency on reflector slope aspect and reflector surface roughness (at depth). Overall, west facing slopes (Bagley Ice Valley) have σ^0 values 1.2 dB on average higher than east facing slopes (Waxell Glacier). The radar glacier ice facies on Bagley Ice Valley has σ^0 of 0.62 dB higher than that facies on Waxell Glacier. Likewise, the radar wet-snow facies σ^0 is 1.85 dB higher on average. Although the last surge of Bering Glacier-Bagley Ice Valley started in early 1993, the slope aspect-surface roughness effect predates this. However, the west-east relative difference in σ^0 increased over time for the radar glacier ice and superimposed ice/old-firn facies (Fig. 3a, b). The east-most 15 km of Waxell Glacier showed crevasse patterns in late August 1995 (end of surge) but was otherwise not affected by the surge of Bering Glacier-Bagley Ice Valley (Herzfeld and Mayer, 1997). Surge effects such as heavy crevassing of the surface will not persist due to return to steady flow (Austin Post, per. comm.). The σ^0 response per radar facies as seen in the standardized time series changed similarly on west facing and east facing reflector surfaces (at depth).

Increase in precipitation (both snow and water fractions) is expected from a warming climate with increasing atmospheric CO_2 (Manabe, 1983, Rind and others, 1991). Data from and ice/firn core on Mount Logan (60°35′N, 140°35′W, 5,340 m a.s.l.) shows that accumulation to the glaciers in coastal Alaska has been increasing by about 16% over the 20th century (Holdsworth and others, 1995). New field work at the core site shown that winter accumulation (1976–2000) is intensifying (Moore and others, 2002). At the low altitudes of the radar glacier ice and superimposed ice/old-firn facies (Fig. 3a, b) the increased accumulation would have had an increased fraction of water. An increase in interstitial water to the radar glacier ice facies would have been followed by a decrease in the σ^0 backscatter over time due to attenuation by the imaginary part (loss factor) of the complex dielectric constant (Fig. 3a). At the higher altitude of the radar superimposed ice/old-firn facies (Fig. 3b), this would have allowed for an increase of ice lenses per unit volume and an increase in firn crystal size thus producing an increase in σ^0 over time due to an increase in radar scatters in the facies within the glacier at depth.

Similar radar backscatter response has been derived in L-Band SARs on the Langjökull ice cap in Iceland (Rott and Mätzler, 1987), South Patagonian Ice Field (Forster and others, 1996) and Glacier San Rafael, Chile (Rignot and others, 1996). L-Band SAR penetration depths on temperate glaciers in Alaska are on the order of 7 to 10 ± 4 m at elevations below 1,500 m (Rignot and others, 2001). However, due to the lower than expected power output of JERS-1, the depth of penetration may have been less (Chapman and others, 2002).

The change in the radar wet-snow facies, higher up on both glaciers, from October to May shows a seasonal effect (Fig. 3c). From October, σ^0 increased to a plateau value then subsequently decreased. This would have been due to increased accumulation in the form of coarse relatively dryer snow (high σ^0) in the winter months, followed by wetter conditions (low σ^0) in the early melt season of May.

4. Conclusions

The changes of the JERS-1 L-Band SAR σ^0 from October 1992 to May 1998 on Bagley Ice Valley and Waxell Glacier reflect changes in radar glacier facies. Change in glacier facies arise from change in seasonal environment (temperature, moisture, accumulation and ablation) which reflect climate change. Regression trends in the standardized time series show that moisture input to the glacier facies is intensifying. Further research with ERS-1 standardized σ^0 time series will better quantify the trends. This research has established L-Band SAR glacier facies/zones for comparison with the next generation of L-Band SAR, PALSAR, when it is launched onboard the Advanced Land Observation Satellite (ALOS) sometime in 2004, to further quantify the effects of climate change on the glaciers of the Bering-Malaspina Glacier complex, in the St. Elias-eastern Chugach Mountains of coastal south-central Alaska.

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