POLARIMETRIC BACKSCATTERING BEHAVIOR OF RIVER ICE COVER

S. Mermoz¹,², I. Gherboudj²,³, S. Allain¹, M. Bernier², E. Pottier¹

¹ Institut d’Électronique et des Télécommunications de Rennes, Campus de Beaulieu, Bat. 11D, Université de Rennes 1, 262 avenue Général Leclerc 35042 Rennes Cedex, France. Email: stephane.mermoz@univ-rennes1.fr
² Institut National de la Recherche Scientifique, Centre Eau, Terre et Environnement, 490 rue de la Couronne, Québec (Québec), G1K 9A9, Canada. Email: Monique.Bernier@inrs.ete.ca
³ Centre d’Applications et de Recherches en Télédétection, 2500 boulevard de l’université, Sherbrooke (Québec), J1K2R1, Canada (current address). Email: Imen.Gherboudj@USherbrooke.ca

ABSTRACT

In many northern rivers of Canada, the formation of the ice covers leads to important situations: ice jamming, and then flooding of large areas. Thus, the monitoring of river ice is necessary. Gherboudj has developed a model in order to understand the interactions of the radar signal with the river ice cover. The model is improved to simulate the fully polarimetric response of a river ice cover. The aim of this work is to analyse the results of the simulations.

1. INTRODUCTION

In many northern rivers of Canada, the development of ice covers in cold weather leads to important situations: ice jamming, and then flooding of large areas; reduction of power generation at hydroelectric generating stations; navigation hindrance; and structural damage. In addition, hydroelectric companies and government services require spatially distributed information about the types and characteristics of river ice. So far, the monitoring of the river ice cover has been focused on the use of monopolarized or multipolarized data. In order to study the interaction of the radar waves with the river ice cover variations, Gherboudj has studied the modelling of radar backscattering from river ice with the co- and cross-polarization [1]. Since the potential of fully polarimetric SAR (PolSAR) has been demonstrated on diverse natural materials such as sea ice [2], this model is improved to simulate the fully polarimetric response of a river ice cover. The aim of this work is to analyse the results of the simulations in order to understand the relations between polarimetric parameters and river ice characteristics. The second section introduces a river ice cover description. The third section deals with the electromagnetic model. The results of the simulations are presented in the fourth part, followed by the conclusions.

2. RIVER ICE COVER DESCRIPTION

The ice cover initially forms horizontally near riverbanks and artificial obstacles (e.g., bridges), where the stream flow is slow and water is calm [3]. This ice is usually solid and clear, and is called thermal ice. However, the extension of this type of ice to the middle of the river is often prevented by water flow of high speed and turbulence. Depending on the atmospheric conditions, other types of ice can also form on the river: frazil ice and snow ice [4]. An ice cover layer is typically comprised of a number of sublayers, with each displaying its own specific characteristics. The backscattered signal from the ice cover is composed of surface and volume scattering contributions. Fig.1 shows the different interactions between the ice and the signal. The surface scattering is mainly influenced by the snow-ice and ice-water interface roughness and dielectric constant [5]. Volume scattering is caused by all the impurities inside the ice matrix. Air inclusions are usually the most significant scatterers [4]. As a function of the frequency, they influence the signal according to their density, dimension and form. In C-band, the wavelength is 5.3cm and air bubbles with a cross sectional diameter of more than 0.53cm are considered as scatterers, according to the Rayleigh criteria. The following definitions of three ice classes are based on their formation process:

- The Snow Ice (SI) is a superimposed ice which contains closely bunched spherical air bubbles (0.001-0.25cm).
- The Thermal Ice (TI) contains irregularly spaced spherical or tubular air bubbles (0.1-0.3cm).
- The Frazil Ice (FI) contains closely bunched spherical and irregular bounded air inclusions (0.2-1.3cm).

The entire ice cover formed may be constituted of one ice type or of a superposition of two or more ice types.
3. THE ELECTROMAGNETIC MODEL

The proposed model describes the river ice medium as presented in Fig.1. It is considered as a multi layer inhomogeneous medium which is subdivided into four main regions: snow, air, ice and water (or ground, when the ice is frozen to the bottom). The ice matrix is embedded with scatterers representing air inclusions. As mentioned above, these inclusions may be present in the ice sublayers, and will display distinct physical properties according to the properties of the three ice types to be modelled. The scatterers are assumed to be uniformly distributed within each ice sublayer.

The backscatter model (Fig.2) is based on the Radiative Transfer (RT) theory. The scattering terms that involve the main interfaces (snow/ice or air/ice and ice/water or ice/ground) were taken into account by incorporating a surface backscattering model into the Doubling Matrix formulation. The Integral Equation Model (IEM) is used to calculate the surface scattering coefficient [6].

The total scattering phase matrix involved in this approach accounts for volume scattering, surface scattering at the boundaries, surface-volume interactions and multiple scattering occurring between scatterers of different layers. The model is built to estimate the total response (HH, VV and HV channels) from the ice cover by varying the ice parameters of each ice layer forming the entire cover. This model is improved to be a full polarimetric model (hence including the phase values). In addition to the radar parameters (incidence angle, frequency and polarization), this model requires the following input data: ice cover thickness, ice cover porosity $p$, size of scatterers (radius $r$ and length $h$) within each ice layer and boundary characteristics (surface height standard deviation ($k\sigma$), correlation length ($kL_c$) and correlation function) ($k$ is the wave number of the host medium) of the main medium (air-ice and ice-water or ice-ground).

The contribution of each the above mentioned parameters to the overall backscattering response was assessed using a series of modelling experiments, and the results are presented and discussed below.

4. RESULTS

First, the multi layer river ice model is used to simulate an ice cover made of one layer (parts 4.1, 4.2 and 4.3). Then it is used to simulate an ice cover made of two layers (parts 4.4, 4.5 and 4.6).

4.1. Roughness analysis

An increase in the surface height standard deviation of the interfaces will increase the entropy when the cover consists of clear columnar ice (Fig.3). The entropy increases more at X-band (145%) than at C-band (60%) with $k\sigma$ ranging from 0.15 to 0.65 and $L_c=0.8cm$. At C-band, the correlation length causes a very small increase in the entropy. At X-band, a decrease of the correlation length will logically increase the entropy.

4.2. Columnar ice

If tubular inclusions are present within columnar ice they cause just a small increase in the entropy (36%) when the thickness increases by 100% at C-band with high porosity (Fig.4). At X-band also, their contribution to the scattering mechanism was found to be negligible. This is probably due to the fact that these tubular inclusions are perfectly vertically oriented.
4.3. Frazil ice

The presence of large spherical air inclusions within frazil ice leads to a significant increase in the entropy (Fig.5). The entropy increases more at X-band (111% with $p=12.7\%$ and 98% with $p=18.2\%$ when the thickness increases by 100%) than at C-band (78% with $p=12.7\%$ and 72% with $p=18.2\%$ when the thickness increases by 100%). Besides, the entropy increases more at X-band than at C-band when the porosity increases.

4.4. Fixed snow ice superposed on columnar ice

Superposing snow ice and columnar ice causes a strong increase in the entropy (37% with $p=10\%$ at C-band with thickness ranging from 30cm to 40cm) when the porosity and the thickness increase and the porosity is higher than 5% (Fig.6). The thickness and the porosity do not affect the entropy when the porosity is lower than 5%. An increase in the frequency lads to a small increase in the entropy.

4.5. Snow ice superposed on columnar ice

Even At higher frequencies (such as the X-band), the snow ice cause a very small increase in the entropy when the porosity and the thickness increase (Fig.7). Thus, the snow ice is almost transparent for radar signals, and the increased entropy observed for snow ice superposed on columnar ice is caused by the multiple scattering occurring between scatterers of the different ice.

4.6. Fixed snow ice superposed on frazil ice

This is the last point.
Superposing snow ice and frazil ice causes a strong increase in the entropy (36% with $p=18.2\%$ at C-band with thickness ranging from 30cm to 40cm) when the porosity and the thickness increase (Fig.8). The entropy is logically higher at X-band than at C-band.

5. **CONCLUSIONS**

The interaction of the radar signal with the ice cover is strongly dependent on the physical properties of the ice cover itself. Simulations show that entropy is sensitive to the roughness of the interfaces, thickness and porosity in many cases. It is more sensitive at X-band than at C-band. When the cover consists of columnar ice embedded with tubular air inclusions as well as snow ice superposed with columnar ice (fixed), an increase of the thickness and porosity causes only a small increase of the entropy.

The next steps are the improvement of the accuracy of the ice type classifications and the estimation of physical parameters (thickness or porosity).

6. **REFERENCES**