AN EXAMPLE OF ANALYSES OF THE ECHO OBTAINED BY A RADIO ECHO SOUNDER NEAR THE SHIRASE GLACIER, EAST ANTARCTICA, USING AN ORIGINAL RADAR EQUATION (EXTENDED ABSTRACT)

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A survey of bedrock topography and its layer structure of ice sheet with airborne radio echo sounder was carried out on the Mizuho Plateau, East Antarctica, in 1980. A great deal of A-scope data and 35 mm continuous film taken on an oscilloscope with range/time display were obtained near the Yamato Mountains and the Shirase Glacier. The structure and properties of ice sheet and bedrock are conjectured from analyzing the intensity of the radar echo. The detailed apparatus of the sounder and surveying route were reported in previous paper (WADA and MAE, 1981; WADA *et al.*, 1981). In order to analyze radar echo data, especially A-scope records (records of reflective echo intensity *vs.* depth), assuming a model of ice structure, an analysis of the A-scope record which was obtained near the Shirase Glacier (70°30′S, 38°45′E), as shown in Fig. 1, is described in this paper as one example.

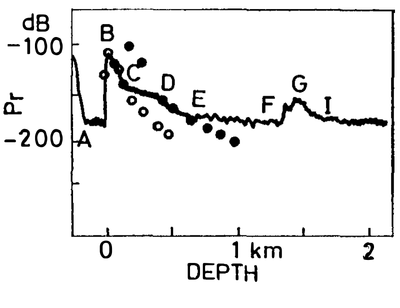

Fig. 1. A-scope record obtained by a radio echo sounder near the Shirase Glacier.

The perpendicular axis in Fig. 1 is the echo intensity, and the horizontal axis is the depth below the surface. B indicates the echo from the snow surface and G is thought to be the echo from the bedrock. In order to estimate the properties in the ice sheet from A-scope data, as shown in Fig. 1, some calculations were done using a formula. The dielectric constant in ice sheet is assumed to be expressed by the following equation:

$$\frac{\varepsilon-1}{\varepsilon+u}=v^i\frac{\varepsilon^i-1}{\varepsilon^i+u}+v^a\frac{\varepsilon^a-1}{\varepsilon^a+u}\,, \tag{1}$$

where ε, ε^i and ε^a are dielectric constants of the ice sheet, ice, and air, respectively, v^i and v^a are the volumes of ice and air with respect to the unit volume of the ice sheet respectively, and u is the wetness factor. $u=2$ and $\varepsilon^a=\varepsilon_0$ (dielectric constant in vacuum) is thought to be dry. From the approximation formula of RAY (1972), the real and imaginary parts of ε_r^i and ε_i^i can be expressed by the following equations

$$\varepsilon_r{}^i=\varepsilon_\infty+\frac{(\varepsilon_s-\varepsilon_\infty)[1+(\lambda_s/\lambda)^{1-a}\sin(a\pi/2)]}{1+2(\lambda_s/\lambda)^{1-a}\sin(a\pi/2)+(\lambda_s/\lambda)^{2(1-a)}}\,, \tag{2}$$

$$\varepsilon_i{}^i=\frac{(\varepsilon_s-\varepsilon_\infty)(\lambda_s/\lambda)^{1-a}\cos(a\pi/2)}{1+2(\lambda_s/\lambda)^{1-a}\sin(a\pi/2)+(\lambda_s/\lambda)^{2(1-a)}}+\frac{\sigma\lambda}{18.8496\times10^{10}}\,, \tag{3}$$

where λ is the wavelength of the radio waves and the other symbols are shown as follows:

ε_∞ is the dielectric constant at high infinite frequency,
σ is the electric conductivity,
λ_s is the relaxation wavelength,
ε_s is the dielectric constant in the static field,
a is the value of the experiment.

We use the following values from RAY's approximation (1972) as a substitute for the above values:

$\varepsilon_\infty=3.168$,
$\sigma=1.26\times\exp(12500.0/((t+273.0)\times1.9869))$,
$\lambda_s=9.990288\times10^{-4}\exp(13200.0/((t+273.0)\times1.9869))$,
$\varepsilon_s=203.168+2.5t+0.15t^2$,
$a=0.288+0.0052t+0.00023t^2$,

where t is the temperature in degrees (°C). A density profile with depth in the ice sheet was used from the observed data at Site II (ROBIN *et al.*, 1969) and a temperature profile with depth was chosen from calculations at Mizuho Station (NISHIO and MAE, 1979). The volume, v^i and v^a, in the ice sheet were calculated by using the following equations:

$$\rho=\rho^i v^i+\rho^a v^a\,, \tag{4}$$

$$1=v^i+v^a\,, \tag{5}$$

where ρ, ρ^i and ρ^a are the densities of the ice sheet, the ice and the air, respectively. $\rho^i=0.917\ \mathrm{gcm}^{-1}$, $\rho^a=1.293\times10^{-3}\ \mathrm{gcm}^{-3}$. From eqs.(1), (2), (3), (4) and (5) the dielectric constant in ice is calculated. Figure 2 shows the profile of the dielectric constant in the ice sheet.

Suppose that the ice sheet has a layer structure which is horizontal and uniform 50 m thick and the radar reflectivity in the ice sheet is to be calculated. The backscattering cross section of each plane layer is expressed by the following equation:

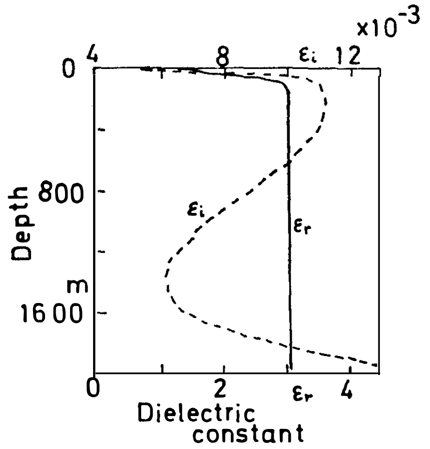

Fig. 2. A model of the dielectric constant in the glacier bed. ε_r is the real part of dielectric constant and ε_i is the imaginary part.

$$\sigma_{K,K-1}=4\pi\frac{P_R}{P_I}=\left|\frac{n_K-n_{K-1}}{n_K+n_{K-1}}\right|^2\times 4\pi\,, \tag{6}$$

$$n=\sqrt{(\varepsilon_r-i\varepsilon_i)/\varepsilon_0}$$

where P_R, P_I are the reflected power and the incident power on the plane between K layer and K–1 layer, and n is the reflective index. The attenuation factor α obtained from each layer is given by

$$\alpha=\sqrt{1/2[\omega^2\mu^2(g^2+\omega^2\varepsilon^2)-\omega^2\mu\varepsilon]}\,, \tag{7}$$

where

$\omega=2\pi\times 170\times 10^6=1.125\times 10^9$ (rads^{-1}),

$\mu=4\pi\times 10^{-7}=1.257\times 10^{-6}$ (kgmC^{-2}),

$g=\varepsilon_i^i\omega$.

The ratio between received power P_r and transmitted power P_t from the snow surface is calculated from the following equation:

$$\frac{P_r}{P_t}=\frac{G^2\lambda^2}{(4\pi)^3R^4}\sigma\,, \tag{8}$$

where G is the antenna gain, being 8 dB, and R is the distance between the transmitter and snow surface. The intensity of the radio wave along the path is attenuated in the ice sheet and the attenuation is defined by:

$$dP_r=2\alpha P_r dR\,, \tag{9}$$

were α is attenuation factor and dP_r is the incremental reduction of the back-scattered power P_r. When eq.(9) is integrated from the snow surface to the K layer, one obtains

$$P_r=P_{r0}\exp\left(-2\sum_{i=1}^{K}\alpha_i\Delta R_i\right)\,, \tag{10}$$

where P_{r0} is the reflective power in the case of no attenuation; α_i and ΔR_i are the attenuation factor and the thickness of the i layer, respectively.

Open circles in Fig. 1 show the results calculated using eq.(8). The intensity curve between B and C is suitable for these results. It is suggested that the effect of the reflection from the snow surface influences the waves to a depth of C from the surface due to the wide width of beam. Solid circles are the result of calculation of eq.(10), considering the attenuation in the ice sheet. The intensity curve between D and E is suitable for this result. Therefore in the region between D and E, the effect of the backscattering of the side beam from the snow surface due to the wide beam width diminishes and the effect of attenuation in the ice sheet layer is predominant. The intensity curve between C and D, however, dose not show good agreement with the previous analyses. This means that the layer has a different dielectric constant than the previous model in this region.

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