Antarctic Firn Characterization through Wideband Microwave Radiometry

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***Abstract*--Global Precipitation Measurement (GPM) constellation is utilized in this study as a single multifrequency wideband radiometer to profile subsurface properties of the Antarctic firn. Initial analyses focusing on the Concordia station in Antarctica indicate that GPM brightness temperature measurements provide important information regarding the physical and thermal properties of the firn down to a few tens of meters depth from the surface. Thus, wideband microwave radiometry provides an excellent opportunity for characterizing the Antarctic firn with broad spatiotemporal coverage.**

Keywords— global precipitation measurement; GPM; microwave radiometry; remote sensing; Antarctic firn

I. Introduction

With the recent impact of climate change, especially on the Cryosphere, it is important to understand the physics and dynamics of the Antarctic firn to predict future changes in its mass and volume and its overall effect on the climate of Earth. Therefore, wide scale measurements of Antarctic firn subsurface temperature, density, and grain size, which are the important indicators of polar ice mass balance, are desired. Airborne and spaceborne passive microwave remote sensing are the most suitable techniques for measuring these parameters due to the extreme environmental conditions of the polar regions. As the electromagnetic penetration depth in ice changes with frequency, we can use wideband radiometers to profile important physical and thermal properties of the Antarctic firn with respect to depth. In this work we present an initial study to characterize the Antarctic firn by utilizing the Global Precipitation Measurement (GPM) satellite constellation as a wideband multifrequency radiometer (11 frequency channels at 6.9 GHz, 7.3 GHz, 10.65 GHz, 18.7 GHz, 19.35 GHz, 22.235 GHz, 23.8 GHz, 36.5 GHz, 37 GHz, 89 GHz, and 91.665 GHz) using radiation simulations and satellite measurements at the Concordia station.

II. Firn Physics

Delving into the Antarctic firn properties, the Antarctic firn density is expressed as the sum of average firn density (based on in-situ measurements in Concordia which increase exponentially with depth) and finer scale density fluctuations due to different layers which can be expressed as correlated damped noise as described in [1]. Grain size is considered to increase with depth, assuming constant accumulation of snow as shown in [2]. Lastly, subsurface firn temperatures are assumed to be similar to monthly averaged physical temperature profiles measured at the Concordia station of Antarctica between 2006 and 2010 down to 21 meters depth [3]. Below 21 meters, deep ice is considered isothermal with no temperature variations.

III. Radiation Model

A simple microwave radiation model has been developed where the brightness temperatures at the firn surface are calculated analytically using a 0^{th} order radiative transfer equation:

$$T_B(z=0,f,\theta_i,p) = \int_{z_{deep}}^{z=0} \left[\prod_{z'=z}^{z'=0} \Gamma(z',\theta(z'),p)\right] \kappa_e(f,z)\sec\theta(z) * T(z) e^{-\int_{z'=z}^{z'=0} \kappa_e(z',f)\sec\theta(z')dz'} dz \quad (1)$$

where $\Gamma(z',\theta(z'),p)$, $\theta(z')$ and $T(z)$ are the amplitude squared of the Fresnel transmission coefficient at the ice layer interface at depth z' for polarization p, the angle of incidence at the ice layer interface at depth z', and the physical firn temperature at depth z, respectively. κ_e is the extinction coefficient. It is calculated here as the sum of scattering and absorption coefficients which are calculated using the Microwave Emission Model of Layered Snowpacks (MEMLS) developed by Mätzler and Wiesmann for the frequency range 5 to 100GHz [4]. We also follow the Rec ITU-R P.835-6 [5] expressions and data for reference standard atmospheres required for the calculation of atmospheric attenuations and brightness temperature contributions, and thereby calculate the top of the atmosphere brightness temperature described as:

$$T_{B\,\text{toa}}(f) = T_B(z = 0, f, \theta_i, p) * K(f) + T_{B\,\text{atm}}(f) \quad (2)$$

where $K(f)$ is the atmospheric attenuation factor as a function of frequency and $T_{B\text{atm}}$ is the atmospheric brightness temperature contribution.

IV. Simulations and Discussions

In this study we utilize two GPM instruments, Special Sensor Microwave Imager/Sounder (SSMIS) and Advanced Microwave Scanning Radiometer-2 (AMSR2), which, owing to their polar orbits, provide intercalibrated brightness temperature measurements over the Antarctic Ice Sheet between 6.9 and 91.655 GHz (Note that 6.9 and 7.3 GHz channels are not intercalibrated as the reference instrument, GPM Microwave Imager lacks these frequencies). Intercalibrated brightness temperature measurements of AMSR2 and SSMIS were collected from January 2020 to June 2021 and averaged monthly over a 0.25^{o}x0.25^o degree latitude-longitude grids centered around the Concordia station (75°05′59″S 123°19′56″E). First, to validate the firn and radiation models described in sections II and III, top of the atmosphere brightness temperatures were calculated and compared to SSMIS and AMSR2 measurements. Figure 1 depicts the calculated and measured brightness temperatures versus month of the year across 10 SSMIS-AMSR2 frequencies (22.235 GHz channel of SSMIS is not included as this channel provides brightness temperatures only in vertical polarization). It can be seen that, generally brightness temperature trends are very similar in calculated and measured brightness temperatures with only small differences between them. In case of lower frequencies, the brightness temperatures do not vary significantly throughout the year as the penetration depth is large at these frequencies. However, for higher frequencies, the seasonal variations can be large, as the brightness temperatures are mostly sensitive to the surface temperatures due to small electromagnetic penetration depths. In case of intermediate frequencies (10.65GHz-23.8GHz), the difference between the calculated and measured brightness temperatures is greater than the higher or lower frequencies. We suspect that the reason for the larger bias at these frequencies are related with atmospheric effects, specifically the amount of water vapor in the atmosphere, which we will work to model more accurately in the future. However, we still managed to achieve highly correlated simulated brightness temperatures and satellite measurements which shows the potential of the GPM constellation through its multi-frequency microwave radiometer measurements to characterize the Antarctic firn through proper retrieval studies.

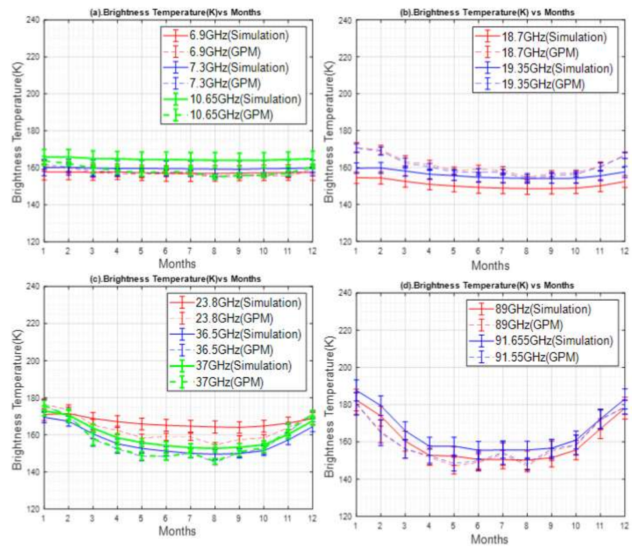

Fig. 1. Measured and simulated brightness temperatures in horizontal polarizations at frequencies (a) 6.9GHz, 7.3GHz and 10.65GHz, (b) 18.7GHz and 19.35GHz, (c) 23.8GHz, 36.5GHz and 37GHz, (d) 89GHz and 91.655GHz (Similar matches have been obtained in vertical polarization as well).

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References

[1] K.C.Jezek, J. T. Johnson,S.Tan, L.Tsang, M. J.Andrews, M.Brogioni, G.Macelloni, M.Durand, C.C Chen, D.J Belgiovane, and Y.Duan. “500–2000-MHz brightness temperature spectra of the northwestern greenland ice sheet.” *IEEE Transactions on Geoscience and Remote Sensing* 56, no.3(2017):1485-1496.

[2] L. Brucker,G. Picard, and M. Fily. “Snow grain-size profiles deduced from microwave snow emissivities in Antarctica.” *Journal of Glaciology* 56, no.197(2010):514-526.

[3] L. Brucker, G. Picard, L. Arnaud, J.M. Barnola, M. Schneebeli, H. Brunjail, E. Lefebvre, and M. Fily. “Modeling time series of microwave brightness temperature at Dome C, Antarctica, using vertically resolved snow temperature and microstructure measurements.” *Journal of Glaciology* 57, no.201(2011):171-182.

[4] M.Proksch, C.Mätzler, A.Wiesmann, J.Lemmetyinen, M.Schwank, H.Löwe,and M.Schneebeli, “MEMLS3&a: Microwave Emission Model of Layered Snowpacks adapted to include backscattering.” *Geosci. Model Dev*., no 8(2015): 2611–2626.

[5] Recommendation ITU-R P.835-6, Attenuation by atmospheric gases. Available online: https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.835-6-201712-I!!PDF-E.pdf