本論文の内容の要旨

論文題目：**Development of a Microwave Radiative Transfer Model for a Soil Layer and its application to Satellite Remote Sensing of Soil Moisture**
土層のマイクロ波放射伝達モデルの開発と土壌水分の衛星観測アルゴリズムへの適用

氏　　名：盧　 麾（LU, Hui）
（るー　ほい）

This thesis presents the development and validation of a radiative transfer model for soil medium and its application to the microwave remote sensing of soil moisture and physical temperature.

A conventional radiative transfer (CRT) model is derived from radiative transfer theory with the assumption that soil is a scatter-free medium and applied to the Mongolia match up data set. The predicted apparent emissivity of CRT model is compared with the observed one. The comparison results show that the CRT model give good predictions for wet soil and overestimation for dry soil. We suppose that this failure of CRT is due to the scatter-free assumption, which is invalid for dry soil. Therefore, we propose a hypothesis that there is appreciable volume scattering effect in dry soil and it should be taken into account to develop a reliable RTM.

Series field experiments are designed to prove our hypothesis and to create a data set which can be used to evaluate the performance of radiative transfer models. The experiments employ Ground Based Microwave Radiometers (GBMR) to observe brightness temperature of soil at the same frequencies as those equipped on the Advanced Microwave Scanning Radiometer on Earth Observing system (AMSR-E) and AMSR on Japanese Advanced Earth Observing Satellite-II (ADEOS-II).

In order to verify the existence of volume scattering effects, we use perfect dry soil as target materials, which dampening the absorption loss and clarifying the scattering effects. In order to observe the scattering emission effects, we use metal plates as background, which providing a cold bottom boundary for RTE and then observe the brightness temperature of dry clay which is introduced above the metal plates with various depth. The observed brightness temperature variation patterns demonstrate that there is volume scattering effect inside dry clay. The comparison of the apparent emissivity of three different sands over metal plate shows that the scattering emission plays dominative role in dry soil.

In order to identify the scattering extinction effects of dry soil, we use dry sand as target material with considering that it is easier to control the status of sand than to control that of clay, since sand is structurelss and has clear particle size, texture and dielectric parameters. We observe brightness temperature of dry sand over metal plates and absorbers, while the latter is providing a warm bottom boundary. By comparing observed emissivity of absorber background with that of metal plate background, the extinction effect of dry sand can be identified. Moreover, by comparing the apparent emissivity of coarse sand and fine sand over absorber background, the dominative role of scattering extinction effect of soil has been identified for frequencies of 18, 22 and 36 GHz vertical polarization.

Based on the results of field experiments, a radiative transfer model special for soil medium is developed with considering the volume scattering inside soil medium and the surface scattering at the soil-air interface. The soil medium is treated as a multi-layer structure, composing with many plane-parallel and azimuthally symmetric slabs. The volume scattering effects inside each slab is investigated firstly by discretizing soil as a mixture which is consisting of many densely packed scatterers embed in a host medium. Then the correlated scattering effects which taken place in such medium are simulated with Dense Medium Radiative Transfer theory (DMRT) under Quasicrystalline Approximation with Coherent Potential (QCA-CP). The microwave radiation traveling from the bottom slab to upper slab is simulated by solving the radiative transfer equation with Discrete Ordinate Methods (DOM) and using the Henyey-Greenstein phase function. The surface scattering effects which occur at the soil-air interface is simulated with Advance Integral Equation Methods (AIEM).

The capability of our model to simulate the volume scattering in dry soil is checked by applying it to the data observed in field experiments. The observed apparent emissivities are compared with simulated results by our model and a coherent model in which the volume scattering effects are not included. The comparison shows that our RTM with considering volume scattering effects by DMRT is successful to represent observation results, while the coherent model fails.

The coupled volume scattering effects and surface scattering effects are investigated by experiments which observe the moderate wet sand with various roughness patterns at surface. The simulation results of couple DMRT-AIEM model show that it is capable to represent the coupled volume scattering and surface scattering effects of sand medium.

The impacts of particle size on the emission of soil are investigated through experiments which use the natural sand, the coarse sand and fine sand as target material. The observed apparent emissivities of those three sands are compared. And it is found that the volume scattering effects of dry sand medium depend more on the larger particles than on small particles.

In order to validate the proposed RTM on satellite remote sensing data, it is applied to the CEOP Mongolia match-up data sets which consist of satellite brightness temperature observation and in situ soil properties observation. With the in situ measured moisture and temperature as input, predicted brightness temperature of our RTM is in good agreement with the one observed by spaceborne sensor, AMSR-E and SSM/I.

An algorithm based on our proposed radiative transfer model is developed to retrieval soil moisture and physical temperature from AMSR-E brightness temperature data at 10 and 18 GHz. The retrieved soil moisture data by our algorithm is compared with in situ observed one and with the one retrieved by a commonly used algorithm based on Q-H model. The comparison shows that our algorithm gives reliable estimation and performs better than the commonly used algorithm does. Moreover, our algorithm also estimates soil physical temperature in a good quality with comparing to the in situ observation.