Tropical Forest Monitoring using Synthetic Aperture Radar
- Theories and Applications -

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合成開口レーダによる熱帯森林のモニタリング
― 理論と応用 ―

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Declaration

This document certifies that the research and its results in this dissertation have never been submitted elsewhere for an award of any degree or diploma.

Chiba, January 2002

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To my lovely wife Innes Indreswari, son Johannes Pandhito Panji Herdento,
parents Michael Suman Juswaljati and Florentina Srindadi
for their love, support and encouragement.

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Abstract

Recently, remote sensing technology, especially Synthetic Aperture Radar (SAR) sensor, has been an efficient and helpful tool to monitor tropical forest area where always in cloudy condition. However, SAR data are not easily interpreted due to the complex relations of the radar scattering mechanism between microwaves and tropical forest parameter (i.e. diameter of tree trunk, thickness of burnt coal seam, surface roughness and soil moisture). Hence, in this research, numerical methods were developed to analyse the interaction of L Band microwaves with a tree trunk of tropical forest and burnt coal seam of forest fire scars.

In analysis of scattered wave from a tropical tree trunk, the proposed method approximates a trunk as an infinite length of two and three layers of cylindrical dielectric media. These layers are skin and heartwood; and skin, xylem and heartwood. The horizontally and vertically polarised scattered fields are derived in order to calculate the relationship between trunk diameter and backscattering coefficient. The analysis result is confirmed by simulating the scattered wave from a tree trunk using Finite Difference Time Domain (FDTD) method. The model uses the equations of scattered electromagnetic fields that are derived from Maxwell's equations. Both analysis and simulation results are similar. Then the relationship is used to estimate tree trunk diameters of pine forest around Saguling lake and tropical forest at Mount Gede Pangrango National Park, west Java, Indonesia from Japanese Earth Resources Satellite (JERS-1) SAR data.

In analysis of scattered wave from burnt coal seam, two types of methods (simple and complicated) are conducted to analyse scattered waves from burnt coal seam in order to estimate thickness of forest fire scars. The model is composed of three media namely; free space (air), burnt coal seam and peat (a perfectly conductor). For computation purposes, the equivalent circuit of this model is conducted using classical transmission line circuit method for a simple analysis, and the advanced stationary-phase approximation is used to analyse scattered wave from complicated rough burnt coal seam. The relationship between backscattering coefficient and thickness of burnt coal seam is obtained. The analysis result is confirmed by simulation using FDTD method. The simulation is done using a two-dimensional finite-difference model for scattered waves from the burnt coal seam. Both analysis and the simulation results are similar. Subsequently, the developed model is applied to estimate the thickness of burnt coal seam in central Borneo fire events in 1997 using JERS-1 SAR data. The estimated result agrees with ground measurement that was collected in period of 1995 to 1997.

論文概要

近年、リモートセンシング技術の進歩によって、特に合成開口レーダ（ＳＡＲ）による熱帯森林を対象とする地球表面のモニタリングがローカルからグローバルなスケールまで容易に行われるようになった。しかし、インドネシアのような熱帯地域では雲、霧、煙が多いため、この地域を観測するためには、これらの影響を最も受けにくいＳＡＲの利用が有効である。しかし、ＳＡＲ画像からマイクロ波と熱帯地域特性（樹幹の直径、森林火災の痕跡の深さ、土壌水分、地表面の粗度など）の相互作用を解明するために複雑な解析が必要となる。そのため、本研究ではL バンドのマイクロ波と熱帯森林における樹幹と森林火災痕跡の相互作用の数値解析方法を提案した。さらに、その応用も紹介する。

熱帯森林の樹幹による散乱電磁波の解析では、樹幹は無限長の円柱媒質二層と三層のモデルを仮定した。これらのモデルでは媒質層はそれぞれ皮と心材、皮と木部と心材である。レーダの後方散乱係数と樹幹直径の関係を計算するために水平偏波と直交偏波の散乱電磁波を導出した。この解析結果を検証するために、時間領域差分法を利用して、樹幹による電磁波散乱のシミュレーションを行った。その結果、解析結果とシミュレーション結果が一致することが分かった。そこで、本研究の結果を日本の地球資源観測衛星（ＪＥＲＳ－１）のＳＡＲセンサーから取得された画像よりインドネシアのサグリング湖の周辺とゲデパンラングオ国立公園における松(*Pinus Merkusii*)とラサマラ(*Altingia exelsa*)の直径の推定に応用した。推定結果は現地調査データとほぼ一致することが分かった。

本研究では、森林火災痕跡の深さを推定するために燃焼した石炭層による散乱電磁波の解析方法に対してシンプルな方法と複雑な方法の２とおりを提案した。解析モデルは３つの媒質である自由空間、燃焼石炭、泥炭地から構成される。シンプルな解析方法を導出するために古典的な伝達線路法を利用して、各媒質の等価回路を求めた。一方、複雑な解析方法では停留近似法で粗な地表面からの散乱電磁波を解析した。その結果、レーダの後方散乱係数と森林火災痕跡の深さの関係が得られた。シンプルな方法から得られた解析結果を検証するために、本研究では時間領域差分法を用いて燃焼石炭層による散乱電磁波の２次元的なシミュレーションを行った。その結果、解析結果とシミュレーション結果が一致することが分かった。しか

し、シンプルな方法と複雑な解析方法による両結果は誤差が生じた。これは地表面の組度による影響から生じたものと推測される。本研究の結果を、ＪＥＲＳ－1ＳＡＲ画像を用いて１９９７年に起こった東南アジア森林火災地域の中部ボルネオ島における森林火災痕跡の深さの推定に応用した。この結果、本研究による推定結果と現地調査データが一致した。

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Contents

Chapter III. Analysis of Scattered Waves from Three Layers of Tree Trunk

Chapter IV. Analysis of Scattered Waves from Burnt Coal Seam

Chapter V. Analysis of Scattered Waves from Rough Burnt Coal Seam

List of Appendices

List of Figures

List of Tables