Microwave Remote Sensing for Monitoring Forest Vitality

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Abstract

The physiological activity of a forest stand is influenced by the vitality and health status of the trees. Our studies aim on investigating the capability of microwaves for monitoring forest vitality. Reduced forest tree vitality and reduced canopy biomass are often a consequence of disadvantageous stand conditions like lack of water supply and low nutrient availability in the soil. Pollutants in the air and the soil can negatively affect the metabolism of the trees and cause visible decline symptoms. Reduced vitality ultimately leads to a decreasing leaf or needle biomass and thus canopy density. We further assume that a direct relationship exists between the variations of the tree water status and the canopy density, stand vitality and forest decline. Since the dielectric constant of water is much higher than of other tree constituents, microwave signatures contain direct information on the water status of forest canopies. This experiment comprises three major parts: detailed ground truth collection, backscatter modeling and comparative and synergistic analysis of data from ERS-1/2 and DLR's airborne E-SAR in order to derive optimum frequency/polarization combinations to retrieve stand vitality parameters.

Keywords: Forest Vitality, Ground Truth Measurements, Backscatter Modeling, SAR Data Analysis

Introduction

The ERS Announcement of Opportunity motivated our team to propose a joint experiment on the relationship between temporal and spatial changes of dielectric constant and water status of deciduous and coniferous forests and their detection with synthetic aperture radar (SAR). Specifically, this refers to the retrieval of information on tree physiology, phenology and geometry. So far investigations with microwave remote sensing data have been performed on the correlation of forest stand parameters and canopy biomass with radar backscatter [Le Toan et.al. 1992, Dobson et.al. 1991]. Further experiments dealt with the influence of plant water status on the dielectric properties resulting in a different backscattering behavior [McDonald et.al. 1992, Way et.al. 1991].

Plant water status strongly affects tree physiology and morphology and varies dynamically with time of the day, season and availability of water in the soil [Zimmermann 1990, Kramer 1983]. Normally reduced tree vitality is due to disadvantageous stand conditions like permanent or temporal lack of water and nutrients in the soil [Oren 1993]. Pollutants and excess amounts of nutrient input via the air and the soil are changing the metabolism of the tree and often cause damage symptoms in forests. Reduced vitality and forest damage ultimately leads to a decreasing leaf or needle biomass and thus canopy density [Schulze 1990].

We assume that a direct relationship exists between the variations of the tree water status, described by the water potential and the water content in a given canopy volume, and the degree of canopy density, stand vitality and forest decline. Since water has a higher dielectric constant than other tree constituents and radar backscatter is mainly determined by the dielectrical properties of the scatterers, microwave signatures contain direct information on the water status and volumetric water content of forest canopies.

The relations between these parameters are being investigated on forest stands with different canopy geometry and water status in Southern Bavaria. For the intensive observation plan our investigation concentrates on two categories of coniferous (Norway spruce) and deciduous (European beech) forests, respectively:

favorable stand conditions, well supplied with water and nutrients, with a dense tree canopy

poor stand conditions, poorly supplied with water and nutrients, with a sparse tree canopy

In this paper we present a detailed description of the test sites in spruce forests and our ground truth monitoring station. Model calculations will be compared with SAR data and one-way attenuation measured using ground calibration receivers.

Test Sites and Ground Truth

In the area of Eichstätt (50km north of Munich) we selected the following mature test stands on flat terrain:

	test stand	**supply**	**age**	**LAI**
spruce	Eichenschacher	good	80 years	3.3
	Weinschlag	poor	100 years	2.3
beech	Palmbaumschlag	good	90 years	
	Rehberg	poor	105 years	

For a detailed geometric description of our test stands tree heights, diameter at breast height (DBH), trunk height, stand densities, branch densities and orientations have been measured. The corresponding data are summarized in Table 1.

Test stand	stand density	DBH	tree height	trunk height	crown layer
Eichenschacher	649 trees/ha 97.4% pure	35.1 cm 8.6 cm	31.1m 0.8m	22.9m 1.3m	8.1m 1.6m
Weinschlag	720 trees/ha 88.2% pure	24.3 cm 6.2 cm	21.8m 0.7m	11.4m 1.0m	10.3m 1.2m

Palmbaumschlag	308 trees/ha 99.5 pure	37.6 cm 10.4 cm	30.4m 3.2m	16.9m 1.6m	13.5m 3.6m
Rehberg	228 trees/ha 98.6% pure	35.4 cm 9.0 cm	32.7m 3.1m	12.7m 1.7m	19.9m 3.5m

Table 1: Stand geometry.

Besides the stand geometry the dielectric properties of the different tree constituents are the main parameters determining the radar backscatter. Therefore one important part of our experiment was the development of two ground truth monitoring station. Fig. 1 shows a schematic representation of this measurement system. It allows automatic and continuous monitoring of dielectric constants in up to eight channels. We actually installed four trees with two probes each, one in the physiologically active phloem layer and one in xylem layer, where water and nutrient transport takes place. In 1996 we concentrated on the spruce stands and performed ground truth measurements from late March to late November in Eichenschacher and Weinschlag. In addition to the dielectrics, xylem flux, tree temperature, soil moisture and micro climate including air temperature, relative humidity and solar radiation are being recorded.

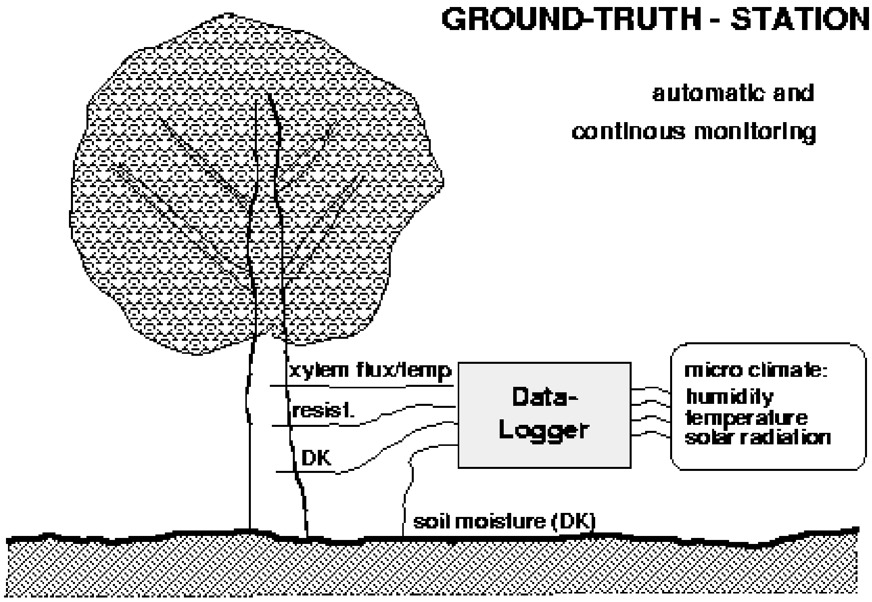

Figure 1: Principle functions of the ground truth station.

Figure 2 shows an example of measurements on one tree in our well-supplied spruce stand Eichenschacher. In the top graph the real (e') and imaginary (e") part of the dielectric constant in the phloem is plotted versus the julian date (April 14 - 19). The plots below show the dielectric constants in the xylem and the xylem flux and electrical resistance. We took this part out of our data series as it shows the begin of the physiological activity. We had a very long winter this year and the growing season started only mid April. From Fig. 3 it becomes clear that this time is related to the increase in the average daily temperature.

The phloem is a physiologically active layer and therefore the water content and in turn also the dielectric constants are higher than in the xylem (Fig. 2). We furthermore measure the flux of water and nutrients in the xylem. The diurnal variations in trunks dielectric constant are correlated to the variations in the xylem flux. A change of the salinity in the nutrient solution could also affect the diurnal behavior of the dielectric constants. Therefore the electrical resistance in the outer 30mm of the trunk is also being monitored.

Fig. 3 shows temperatures in air in the above mentioned tree and in the soil for the period of April 14 -19. It was still freezing over night but the average daily temperature is increasing. The soil is thawed. Temperatures in the soil and the tree follow the diurnal variations of the air temperature with a phase shift. The variations are attenuated in the tree and further attenuated in the soil.

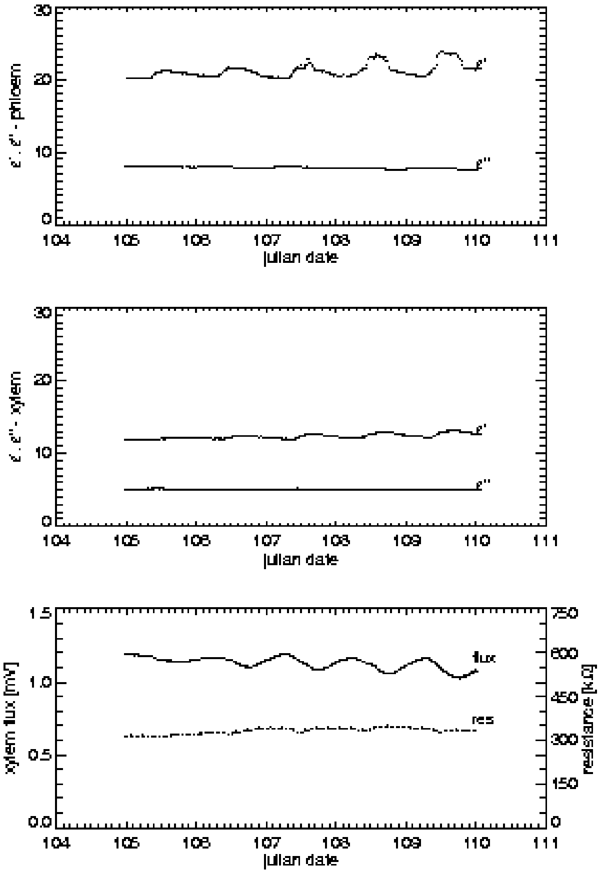

Figure 2: Dielectric constants (e', e") in the phloem (top) and the xylem (center), xylem flux and resistance (bottom) of one tree in the well-supplied spruce stand Eichenschacher

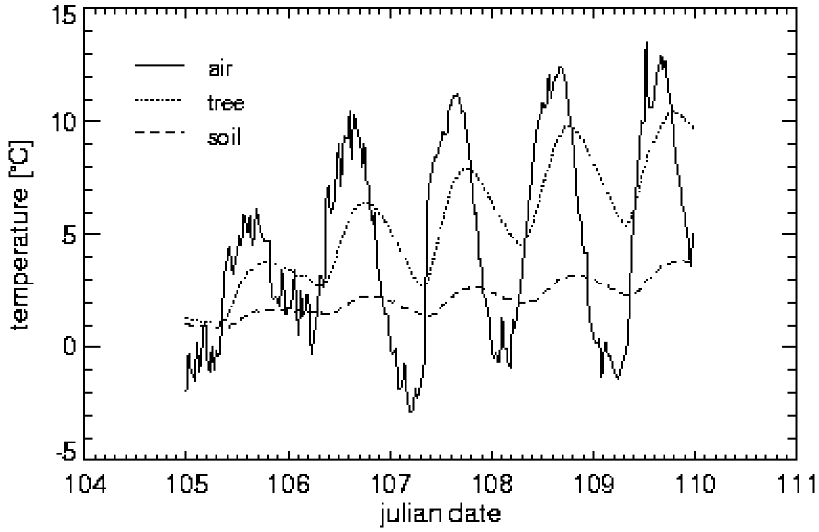

Figure 3: Temperatures in air, in a tree and in soil for the same time period as in Fig. 2

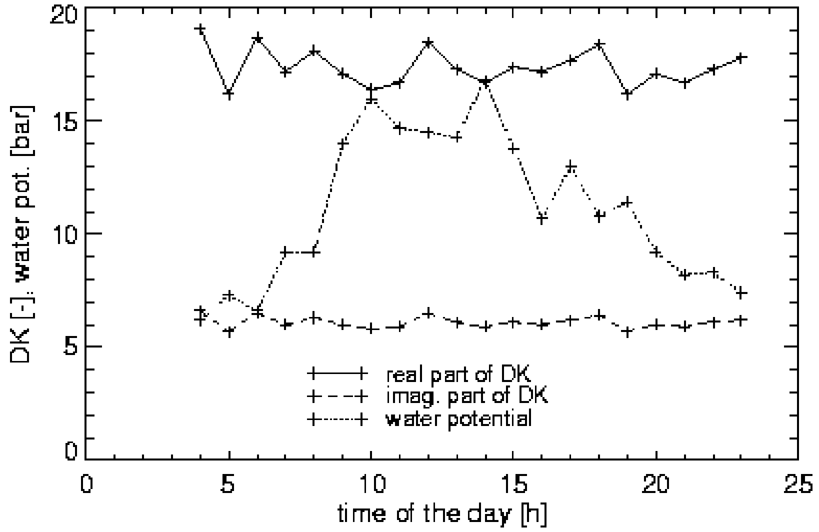

Figure 4: Dielectric constants and water potential of small twigs (taken from the crown) measured on May 30, 1996 in Eichenschacher

The above measurements are only possible at the trunk. There exists no method for continuous monitoring of the crown with small twigs and needles. To close this gap we carry out dedicated ground truth campaigns every month during the growing season, where we take samples from the crown and measure the volumetric moisture content and the water potential of small twigs. We also checked on the difference in water content between needles and twigs and found no significant deviation, that means that there is no need to measure needles separately. Using semi-empirical models from the literature [El-Rayes, 1987] we then converted the moisture content to dielectric constants.

The results for measurements taken on May 30, 1996 are shown in Fig. 4. The dielectric constants show no diurnal variations. This was expected after an experiment we performed September 1995 on a beech [Börner et.al. 1996], where we found out that the water content of leaves is always around 45%. The same applies to needles and only a small decrease in water content would result in wilting. The water potential on the other hand is the driving force for the xylem flux and shows a well-pronounced diurnal cycle with a maximum in the early afternoon and the lowest values after midnight. Despite this high variation in water potential, water flux and transpiration the water content of the needles and leaves remains fairly constant.

Backscatter Modeling and SAR Data Analysis

SAR-data are available from ERS-1/2 and from several E-SAR (DLR's airborne SAR) campaigns. For the main part of ERS data analysis we intend to use a new processor including interferometric tools, which is also being developed in our group as part of another PI-project. A prototype of the processor is working; the final version will be available in the next weeks. Survey processing of E-SAR data has been performed. Polarimetric calibration procedures are currently being implemented. Because of this problems and the high effort we had to spend on the ground truth acquisition the data analysis is behind the plan.

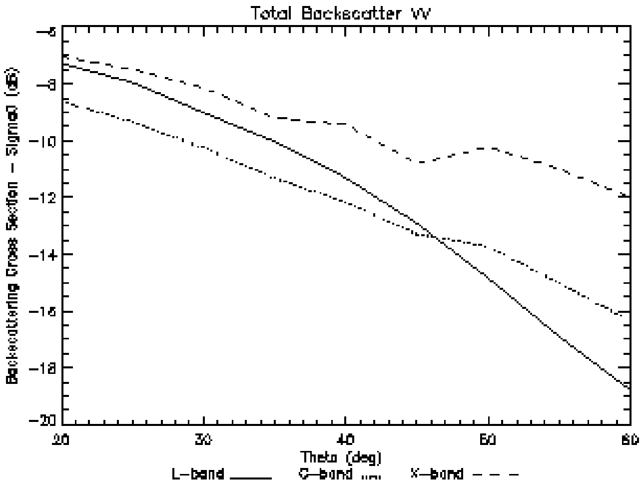

Figure 5: Backscattering coefficients for Eichenschacher calculated using MIMICS.

After some testing we are using MIMICS for model calculations. Fig. 5 shows an example of calculated backscattering coefficients for L-, C- and X-band as a function of incidence angles. MIMICS also provides data on the canopy transmissivity, which have been confirmed using ground calibration receivers. Preliminary analyses of s^{o}-values from PRI images agree well with the modeled data and show the expected results of almost constant backscatter from our test stands. A discrimination based only on backscatter amplitudes does not seem to be feasible. Therefore we will include interferometric products in our investigations. Especially the coherence is mainly determined by structural information and is expected to be helpful in discriminating stands of different vitality.

Conclusions

In the first year of our experiment we concentrated on the ground truth in the spruce stands. A complete data set over the whole growing season including dielectrics of trunks and needles has been acquired. The dielectric constants in the trunk show a well pronounced diurnal variation, but the water content of the needles is almost constant.

The SAR data analysis should include interferometric and polarimetric data and will benefit from the airborne P- and L-band data.

This experiment is being performed under a contract with the German Space Agency (DARA).

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