Title

MONITORING TEMPORAL CHANGE IN ALASKAN FORESTS USING AIRSAR DATA

Journal

IGARSS 91 - REMOTE SENSING : GLOBAL MONITORING FOR EARTH MANAGEMENT, VOLS 1-4, 3(2)

Authors

WAY, J
RIGNOT, E
MCDONALD, K
et al.

Publication Date

1991

MONITORING TEMPORAL CHANGE IN ALASKAN FORESTS USING AIRSAR DATA

JoBea Way and Eric Rignot
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109 USA

Kyle McDonald
University of Michigan

Gordon Bonan
National Center for Atmospheric Research

INTRODUCTION

The role of boreal forests in the carbon cycle is particularly important because experiments with atmospheric general circulation models indicate significant northern hemisphere high latitude climatic warming with doubled atmospheric CO_2 concentrations (e.g., Schlesinger and Mitchell 1987). The ecological implication of such a climatic change is unknown, but the seasonal amplitude of atmospheric CO_2 concentrations in northern latitudes has increased with time, and this may reflect increased metabolic activity of ecosystems in northern latitudes due to warmer air temperatures and "CO_2 fertilization".

A process-oriented ecophysiological model that summarizes our current understanding of productivity and decomposition in boreal forests has recently been developed (Bonan 1991a,b). This model requires stand level physiological measurements as well as characterization of the spatial (in terms of forest species) and temporal (in terms of phenologic and environmental state) patterns for validation. Recent results of radar signature modelling and measurement of multi-temporal changes in radar backscatter using the JPL aircraft synthetic aperture radar (AIRSAR) indicate it is possible to use spaceborne imaging radars such as the European Space Agency's (ESA's) Earth Remote Sensing (ERS-1) synthetic aperture radar (SAR) to monitor both phenologic and environmental change in forests, as well as map forest species by taking advantage of seasonal forest signatures. These results also demonstrate the importance of knowing the seasonal state of the forest when estimating canopy properties from SAR.

TEST SITE AND AIRSAR DATA SET

In order to determine the feasibility of using imaging radars to monitor the seasonal cycles of boreal forests and map forest types, experimental work is ongoing at the Bonanza Creek Experimental Forest (BCEF) just southeast of Fairbanks, Alaska. The site is a floodplain succession forest consisting primarily of balsam poplar, white spruce and black spruce. Approximately 30 stands in BCEF have been identified for this study. To date, canopy characteristics have been collected for 12 stands.

Airborne SAR data using the Jet Propulsion Laboratory's (JPL's) P-, L- and C-band (.450, 1.26 and 5.31 GHz, respectively) quad polarized AIRSAR mounted in NASA's DC-8 aircraft were acquired over the BCEF test site on March 13, March 17 and March 19, 1988. The data were calibrated radiometrically to +/-1.9 dB. The measured difference in L-band backscatter for the frozen and thawed days for the 12 stands and two clearcuts is large (2-6 dB) at all three polarizations with the greatest difference at vertical and cross polarizations. A large change in the bole dielectric constant between warm and frozen conditions can account for the large change in backscatter.

PREDICTED SEASONAL MICROWAVE SIGNATURES

A typical seasonal cycle in the soil-tree system for each of the primary floodplain species may be arbitrarily divided into several stages which should correspond to distinct signatures in the ERS-1 data; these are shown in Figure 1.

Previous studies on the application of radar signatures to the water relations of trees have shown a marked change in the dielectric constant of the stem with (1) stem freezing and thawing (Way et al. 1990), and (2) diurnal water potential and/or water content variations (McDonald et al. 1990). Given the specified seasonal cycle described in Figure 1 and the stand characteristics, a microwave scattering model may be used to generate the expected backscatter over a seasonal cycle. The Michigan Microwave Canopy Scattering (MIMICS) model, a fully polarimetric first-order radiative transfer model developed at the University of Michigan specifically for modelling radar backscatter from tree canopies was used in this study (Ulaby et al. 1990). Backscatter as a function of seasonal state was simulated using the ERS-1 radar parameters (C-band, VV polarization, 23° incidence angle) for the 13 conditions shown in Figure 1. The results are shown in Figure 1.

For all three species, there are large total changes in the backscatter over the year at C-band VV polarization of 6.8 dB for balsam poplar, 4.3 dB for white spruce and 10.6 dB for black spruce. The last curve in Figure 1 shows the seasonal backscatter for balsam poplar, white spruce and black spruce plotted together. Clearly, at C-band VV, white spruce may be separated from black spruce/balsam poplar (BS/BP) best when the trees are thawed and the ground is frozen (conditions 3 and 4). Black spruce and balsam poplar are best separated when the soil and trees are frozen (condition 1).

CH2971-0/91/0000-1117$01.00 © 1991 IEEE

IMPLICATIONS FOR FOREST SPECIES CLASSIFICATION

The above results indicate that it is possible to monitor both phenologic and environmental change in Alaskan forests and that, by using a variety of seasonal states, it is possible to map the major forest species along the floodplain. Using the AIRSAR scene of BCEF, the ability to monitor change and map species has been demonstrated using a semi-operational geophysical processor similar to the one developed by the ice community for determining ice type and motion with ERS-1 data over the polar regions (Kwok et al. 1990a; Kwok et al. 1990b).

Using only the L-band HH results, the following classification units could be identified for WS/BP as a single forest unit:

$-9.8 \text{ dB} < \sigma_0 < -7.5 \text{ dB}$ thawed WS/BP, (1)
$-13.5 \text{ dB} < \sigma_0 < -9.8 \text{ dB}$ frozen WS/BP (2)

and for BS as a single unit:

$-13.7 \text{ dB} < \sigma_0 < -10.7 \text{ dB}$ thawed BS (3)
$-15.1 \text{ dB} < \sigma_0 < -13.7 \text{ dB}$ frozen BS. (4)

Frozen and thawed WS/BP stands were identified using the original AIRSAR data as input and equations (1) and (2).. On March 13, thawed WS/BP stands were correctly identified; thawed BS stands were mistaken for frozen WS/BP stands. On March 19, all WS/BP stands were correctly identified as frozen; most BS stands were outside the limits specified for frozen or thawed WS/BP. Frozen and thawed BS were identified using equations (3) and (4). On March 13, thawed BS stands were correctly identified. Thawed WS/BS stands were outside the limits set for frozen and thawed BS. On March 19, frozen BS stands were correctly identified, however, WS/BP stands were identified as thawed BS. These results illustrate the use of SAR to monitor freeze/thaw conditions at L-band HH.

The AIRSAR data was then segmented into classes/regions corresponding to different stands (Rignot 1990). An empirical look-up table of the backscatter characteristics of the different forest stands was then used to assign a forest type to each cluster. Finally, the entire image was classified using a minimum distance discriminant function. The results obtained using L-band HH data on March 13 produced four classes separated by more than 2.5 dB. Using the look-up table, the brightest class was identified as representing WS/BP, whereas the others represent BS, CC and RIVER, respectively. The separation of WS/BP and BS is clear and matches very well with the available ground map of WS/BP and BS.

IMPLICATIONS FOR MODELLING CARBON FLUX IN ALASKA

This ability to classify forest species and monitor environmental and phenologic stages ERS-1 data can be interfaced with Bonan's ecophysiological model in two ways using ERS-1 data. First, spatial and temporal estimates of forest physiology derived from ERS-1 data can provide critical data needed to better validate the ecophysiological model. For example, ERS-1 data can be used to distinguish when the ground and tree stem are thawed or frozen, both of which are simulated by the ecophysiological model. Additional physiological parameters such as foliage water potential may also be estimated from ERS-1 data. Second, the forest landscape near Fairbanks is a mosaic of vegetation types that reflects fire history, successional differences in litter quality, nutrient availability, soil temperature, the forest floor and stand structure and life-history characteristics of tree species. Remotely-sensed areal estimates of particular forest types (e.g., black spruce, deciduous, etc.) can be combined with the model to scale stand-level CO_2 fluxes to landscape-average fluxes.

The percent areal extent of WS/BP, BS, CC and RIVER was estimated using the classified AIRSAR scene from March 13; the scene contains 30.6% WS/BP, 32.0% BS, 24.7% CC and 12.7% RIVER (Table 1). The annual CO_2 flux for each of these landscape types was then simulated using Bonan's ecophysiological model (1991b). Table 1 shows the tree, moss, microbe and total ecosystem CO_2 fluxes where a negative flux indicates CO_2 uptake. The net annual landscape flux of the BCEF floodplain forest is estimated at -7100 $g^{-1}m^{-2}$ yr^{-1}.

SUMMARY

With the launch of ERS-1 in the spring of 1991 followed by JERS-1, RADARSAT and eventually the EOS SAR, the opportunity to begin long-term monitoring of seasonal phenologic and environmental change for use in ecophysiological and CO_2 flux models should allow important advances in our understanding of the role of the boreal forests in the global carbon cycle.

ACKNOWLEDGEMENTS

The authors acknowledge the work of many people who participated in the ground truth data collection, especially Les Viereck at the Institute of Northern Forestry. At JPL, the contributions of John Holt and Tony Freeman were invaluable in the data organization and calibration. We would also like to acknowledge the contributions of and discussions with Craig Dobson, Fawwaz Ulaby, Eric Kasischke, Norm Christensen and David Simonett. This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology and the University of Michigan under contract to the National Aeronautics and Space Administration.

REFERENCES

Bonan, G.B., 1991a. A biophysical surface energy budget analysis of soil temperature in the boreal forests of interior Alaska. Water Resour. Res., in press.

Bonan, G.B., 1991b. Atmosphere-biosphere exchange of carbon dioxide in boreal forests. J. Geophys. Res., in press.

Houghton, R.A., 1987. Biotic changes consistent with the increased seasonal amplitude of atmospheric CO_2 concentration. J. Geophys. Res. 92:4223-4230.

Kwok R., J. Curlander, R. McConnell, and S. Pang, 1990. An ice motion tracking system at the Alaska SAR Facility. IEEE J. of Oceanic Engineering, 15, 44-54.

Kwok R., E. Rignot, and B. Holt, 1990b. Classification of sea-ice types in spaceborne SAR data. Submitted to IEEE Trans. on Geosci. and Rem. Sens.

McDonald, K.C., M.C. Dobson and F.T. Ulaby, 1990. Using MIMICS to model L-band multi-angle and multi-temporal backscatter from a walnut orchard. IEEE Trans. on Geosci. and Rem. Sens., .28, 477-491.

Rignot E., 1990. Segmentation of multifrequency and polarimetric synthetic aperture radar data images. PhD Thesis Proposal, University of Southern California, Department of Electrical Engineering-Systems (unpublished).

Schlesinger, M.E., and J.F.B. Mitchell, 1987. Climate model simulations of the equilibrium climatic response to increased carbon dioxide. Reviews of Geophysics 25:760-798.

Ulaby, F.T., K. Sarabandi, K. McDonald, M. Whitt, and M.C. Dobson, 1990. Michigan Microwave Canopy Scattering Model. Int. J. of Rem. Sens., 11, 1223-1254.

Way, J. B., J. Paris, E. Kasischke, C. Slaughter, L. Viereck, N. Christensen, M. C. Dobson, F. T. Ulaby, J. Richards, A. Milne, A. Sieber, F. J. Ahern, D. Simonett, R. Hoffer, M. Imhoff and J. Weber, 1990. The effect of changing environmental conditions on microwave signatures of forest ecosystems: preliminary results of the March 1988 Alaskan aircraft SAR experiment. Int. J. Remote Sensing, 11, 1119-1144.

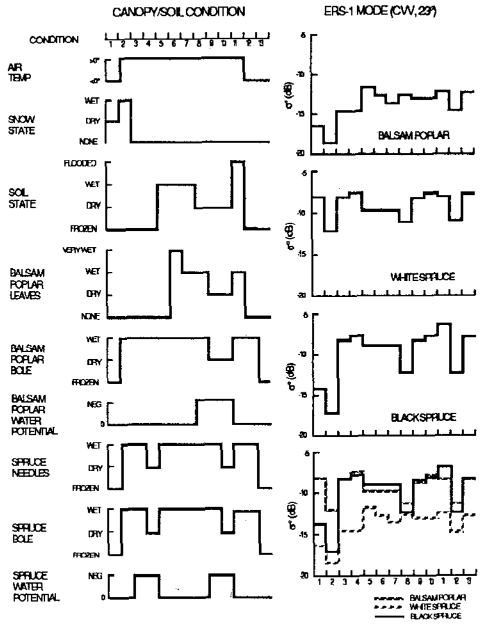

Table 1
Landscape Estimates of CO_2 Fluxes ($g/m^2/yr$)

Stand	Area	Tree	Moss	Microbe	Ecosystem
WS/BP	30.6%	-2204	-108	418	-1894
BS	32.0%	-354	-200	171	-383
CC	24.7%	0	-200	171	-29
RIVER	12.7%	0	0	0	0
Landscape	100.0%	-788	-146	225	-710

Note: Negative fluxes indicate CO_2 uptake, positive fluxes indicate CO_2 release.