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Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)

Forrest G. Hall and Jaime Nickeson, Editors

Volume 67

BOREAS RSS-15 SIR-C and Landsat TM Biomass and Landcover Maps of the NSA

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National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

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BOREAS RSS-15 SIR-C and Landsat TM Biomass and Landcover Maps of the NSA and SSA

K. Jon Ranson

Summary

As part of BOREAS, the RSS-15 team conducted an investigation using SIR-C, X-SAR, and Landsat TM data for estimating total above-ground dry biomass for the SSA and NSA modeling grids and component biomass for the SSA. Relationships of backscatter to total biomass and total biomass to foliage, branch, and bole biomass were used to estimate biomass density across the landscape. The procedure involved image classification with SAR and Landsat TM data and development of simple mapping techniques using combinations of SAR channels. For the SSA, the SIR-C data used were acquired on 06-Oct-1994, and the Landsat TM data used were acquired on 02-Sep-1995. The maps of the NSA were developed from SIR-C data acquired on 13-Apr-1994.

Note that some of the data files on the BOREAS CD-ROMs have been compressed using the Gzip program. See Section 8.2 for details.

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1. Data Set Overview

1.1 Data Set Identification

BOREAS RSS-15 SIR-C and Landsat TM Biomass and Landcover Maps of the NSA and SSA

1.2 Data Set Introduction

Relationships of backscatter to total biomass and total biomass to foliage, branch, and bole biomass were used to estimate biomass density across the landscape. The procedure involved image classification with Synthetic Aperture Radar (SAR) and Landsat Thematic Mapper (TM) data and development of simple mapping techniques using combinations of SAR channels.

1.3 Objective/Purpose

The purpose of this study is to provide maps of dry biomass over the modeling grids in the BOReal Ecosystem-Atmosphere Study (BOREAS) Southern Study Area (SSA) and Northern Study Area (NSA). Such information is useful for determining a portion of the carbon stored as woody biomass and for estimating the potential maintenance respiration of trees on a per area basis.

1.4 Summary of Parameters

The data products include landcover and biomass maps covering most of the NSA and SSA modeling grids. Specific map products are:

- SSA Landcover Map
- SSA Total Above Ground Dry Woody Biomass
- SSA Stem Dry Biomass
- SSA Branch Dry Biomass
- SSA Foliage Dry Biomass
- NSA Total Above Ground Dry Woody Biomass
- NSA Landcover Map

1.5 Discussion

The total biomass product was generated using multiple linear regression of SAR channels and field-measured above-ground woody biomass. Forest stand measurements of stem diameter and species were used with allometric equations (weight tables) to estimate biomass within several fixed radius circular plots. Forest data from the BOREAS Terrestrial Ecology (TE)-06 and TE-20 (auxiliary sites) were used for the analysis. Over 60 plots were measured in 1993 and 1994 by Remote Sensing Science (RSS)-15, RSS-16, and TE-20. These measurements were used to develop and test the biomass vs. SAR relationships. Another part of the study was to determine component-level biomass estimates for foliage, branches, and boles. This required classification of the area into three major forest types: pine, spruce, and aspen. It also required separate biomass equations for each of the forest types. Component biomass was estimated from total biomass using relationships developed from data acquired by TE-06.

A seven-class map was developed for both NSA and SSA that included spruce-, pine-, and aspen-dominated forest categories. Classification accuracy's of training areas were greater than 90% for both forest and non-forest classes. Accuracy's determined from the classifications of small forest stands, including auxiliary sites, were better than 90% for pine and aspen stands, but only about 70% for spruce stands. Most of the errors were the result of spruce being misclassified as pine.

The results indicate that above-ground biomass can be estimated to within about 1.6 kg/m^2 for the range of measured stands (0-30 kg/m^2). Because of increased variance and lack of data points at higher average stand biomass levels, there is greater uncertainty for total biomass levels above 15 kg/m^2. For the SSA only, biomass mapping was extended to bole, branch, and foliage components from relationships with total above-ground biomass developed from detailed tree measurements. Average biomass within the imaged area was estimated to be about 7.3 kg/m^2 with biomass components of bole, branch, and foliage comprising 83%, 12%, and 5% of the total. Average biomass within the NSA imaged area was found to be about 4.6 kg/m^2.

1.6 Related Data Sets

BOREAS TE-06 Biomass and Foilage Area Data
BOREAS TE-06 Allometry Data
BOREAS TE-06 NPP for the Tower Flux, Carbon Evaluation, and Auxiliary sites
BOREAS TE-13 Biometry Data
BOREAS TE-20 SSA Site Characteristics Data

2. Investigator(s)

2.1 Investigator(s) Name and Title

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2.2 Title of Investigation

Distribution and Structure of Above Ground Woody Biomass

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3. Theory of Measurements

It has been demonstrated that SAR's capability to penetrate forest canopies can provide improved estimates of above-ground woody biomass. Because of the correlation between the different biomass components of vegetation canopies (i.e., foliage, branch, bole), SAR images with different wavelengths that each contain information related to total biomass, can be used together to estimate total biomass.

Previous studies using airborne SAR (AIRSAR) and Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar SIR-C/X-SAR by Ranson and Sun [1994] and Ranson et al. [1995a] have shown that total above-ground dry biomass (transformed by logarithm or cube root) has a strong linear relationship with radar backscattering coefficients (in dB). The combination of cross-polarization backscattering (HV, horizontal transmit-vertical receive, or VH, vertical transmit-horizontal receive) of a longer wavelength and a shorter wavelength (e.g., PHV-CHV, P and C bands, or LHV-CHV, L and C bands) was successfully used in biomass estimation for a northern forest in Maine and BOREAS sites in Saskatchewan, Canada. In these studies, the two-band combination was found to be useful in increasing the sensitivity of radar signature to total biomass and in reducing the effects of radar incidence angle, forest species, and spatial structure. In view of the complexity of forest structure, especially in the Maine study site, these previous studies have emphasized reducing these effects so that a more general, simple model may be used for biomass retrieval for forests with various spatial structures and species compositions.

In general, researchers have noticed that the sensitivity of biomass to backscatter is diminished at levels between 10 kg/m^2 and 25 kg/m^2 depending on the radar wavelength(s) used [e.g., LeToan et al., 1992; Ranson et al., 1995b; Dobson et al., 1995]. It is well documented that the shorter the radar wavelength, the lower the sensitivity to forest biomass. Studies using the Earth Resources Satellite-1 (ERS-1) C-band VV (CVV) have shown limited utility for mapping forest cover type or biomass [Leckie and Yatabe, 1994; Rignot et al. 1994a]. Dobson et al. [1995b] recently demonstrated improved forest classification using a combination of ERS-1 and the Japanese Earth Resources Satellite-1 (JERS-1) data. Harrell et al. [1995] reported poor sensitivity of ERS-1, but slightly better results using JERS-1 data to estimate to boreal forest biomass in Alaska. The ability to estimate biomass up to 15-25 kg/m^2 such as reported by Ranson et al., [1995a] and Dobson et al. [1995a] using longer wavelength radar (i.e., L-band) makes SIR-C data suitable for boreal zone forest studies.

A relationship between radar backscatter and field-measured biomass transformed by the cube root was developed using a stepwise regression routine to determine a best set of SIR-C/X-SAR channels from LHH, LHV, LVV, CHH, CHV, CVV, and XVV backscatter (s°). A two-step approach to retrieve forest biomass was used: 1) classify forests using SIRC/X-SAR data; and 2) develop models for each category and retrieve total biomass. The three major types of forests (pine, spruce, and aspen) discussed earlier were considered. Overall, the two methods produced similar results; however, the two-step method is required to estimate component biomass.

4. Equipment

4.1 Sensor/Instrument Description

SIR-C/X-SAR has three radars, C-band and L-band with HH, VV, HV, and VH polarizations and X-band with VV polarization. The table below summarizes the characteristics of the radars. The mission was a cooperative experiment between National Aeronautics and Space Administration (NASA) and the Jet Propulsion Laboratory (JPL), which provided the C- and L-band multipolarization radars, and the German and Italian Space Agencies, which jointly provided the X-SAR.
SIR-C/X-SAR data were used in this study because of the relatively large area covered (80 by 20 km) and the small change in illumination angle (< 5°) across an image.

Characteristics of SIR-C/X-SAR

Radar	Band	Frequency (GHz)	Wavelength (cm)	Polarization
SIR-C	L-band	1.25	24.0	HH, HV, VV, VH
	C-band	5.3	5.7	HH, HV, VV, VH
X-SAR	X-band	9.6	3.1	VV

4.1.1 Collection Environment

Selected meteorological parameters from the Saskatchewan Research Council (SRC) tower located at the SSA-Old Jack Pine (OJP) site for SIR-C/X-SAR data takes in April and October 1994. Data are 15-minute averages.

Date 1994	GMT_Time hhmm	Sol_Down W/m^2	Air_Temp deg C	Soil_10 cm deg C
10-April	1528	245.03	-0.34	-0.16
11-April	1510	249.69	9.87	-0.09
12-April	1452	234.18	7.29	-0.02
13-April	1432	238.18	4.37	0.02
14-April	1413	37.69	-0.30	0.02
15-April	1352	252.62	-1.76	0.03
16-April	1331	169.14	2.34	0.02
17-April	1310	61.92	6.83	0.02
18-April	1249	49.18	1.617	0.05
1-Oct.	1540	23.53	2.93	7.25
2-Oct.	1521	16.99	3.65	7.03
3-Oct.	1502	41.35	-0.11	4.50
4-Oct.	1443	110.22	0.12	4.50
5-Oct.	1424	56.67	3.62	5.51
6-Oct.	1404	51.20	5.08	6.27
6-Oct.	1536	243.68	7.60	6.17
7-Oct.	1344	35.75	-1.30	4.17

4.1.2 Source/Platform

SIR-C/X-SAR is part of a series of spaceborne imaging radar missions that began with the June 1978 launch of Seasat SAR and continued with the November 1981 SIR-A and October 1984 SIR-B missions. The SIR-C/X-SAR missions were successfully conducted during 09-Apr through 19-Apr-1994 and 30-Sep-1994 through 10-Oct-1994 and demonstrated the design and capabilities of a spaceborne multifrequency polarimetric SAR.

SIR-C/X-SAR was launched on space shuttle Endeavour and acquired multiple data takes covering over 6% of Earth's surface, including a variety of land, ocean, and polar ice targets. The BOREAS study areas were added to the mission plan in 1991 as Backup Supersites, ensuring several data takes during the missions.

4.1.3 Source/Platform Mission Objectives

SIR-C/X-SAR mission objectives were to demonstrate the capabilities of multifrequency and multipolarization data for Earth science research.

4.1.4 Key Variables

Backscatter coefficient (dB)

4.1.5 Principles of Operation

Active microwave, SAR.

4.1.6 Sensor/Instrument Measurement Geometry

The advantages of the SIR-C/X-SAR system are its three-dimensional illumination parameters (wavelength, polarization, and angle of incidence). The SIR-C instrument, developed for NASA at JPL, uses active phased array antennas for L-band and C-band that not only provide images of magnitudes of HH, VV, and HV polarization, but also provide images of the phase difference between the polarized returns. In addition, the electronic beam steering capability in the range direction (23°) from a fixed antenna position of 38° look angle makes it possible to acquire multiple incidence angle data (15° - 55°) without tilting the antenna. The X-SAR radar, built jointly by the Deutsche Forschungsantalt Für Luft-und Raumfarht (DLR) in Germany and the Agenzia Spaziale Italiana (ASI) in Italy, operates at 9.6 GHz and has only VV polarization. The SIR-C/X-SAR design includes bandwidths of 10, 20, and 40 MHz with the 40-MHz bandwidth providing better resolution. Data acquisitions for BOREAS sites used the 20-MHz bandwidth and 4-look averaging, resulting in a ground resolution of approximately 25 m.

4.1.7 Manufacturer of Sensor/Instrument

NASA/JPL
4800 Oak Grove Drive
Pasadena, CA

4.2 Calibration

4.2.1 Specifications

During the two SIR-C/X-SAR missions, April 1994 (Space Radar Laboratory, SRL-1) and October 1994 (SRL-2), the BOREAS study area was imaged on several orbits [Ranson et al., 1995a]. The absolute calibration of SIR-C data was found to be +2.3 dB and +2.2 dB for L-band and C-band, respectively, for SRL-1. SRL-2 calibration was reported to be +2.0 dB and +3.2 dB for C-band and L-band, respectively [Freeman et al., 1995]. X-SAR calibration was very good and reported to be +1 dB for both missions [Zink and Bamler, 1995]. The mission plan called for similar orbits and radar parameters (e.g., illumination, data take mode, resolution) during the two missions, which facilitated the use of the temporal data. In addition, a Landsat TM image was also used for the forest type classification. The image was acquired on 02 Sep-1995 (Path 37, Row 22-23).

4.2.1.1 Tolerance

See Section 4.2.1.

4.2.2 Frequency of Calibration

See Freeman et al. [1995].

4.2.3 Other Calibration Information

None.

5. Data Acquisition Methods

The data were acquired from NASA and JPL, which provided the C- and L-band multipolarization radars, and the German and Italian Space Agencies, which jointly provided the X-SAR. The BOREAS Landsat TM imagery was acquired through the Canadian Centre for Remote Sensing (CCRS).

6. Observations

6.1 Data Notes

None given.

6.2 Field Notes

An additional nine stands were measured in August 1996 (i.e., sites with numbers greater than or equal to 70). These were used for testing purposes only. A summary of the data is given in the following tables.

```
Summary of SSA biomass sampling points.
---------------------------------------
Site: from RSS15-TE20-1 to -36 were 'randomly' sampled along major roads
      during Intensive Field Campaign (IFC)-2 and described by TE-20.

Other names:
AL      - an old jack pine stand shaped like the head of an alligator, located
          to the south of SSA-Young Jack Pine (YJP) tower site
NofAL   - young jack pine, north of 'Alligator'
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SofYJP  - young jack pine south of SSA-YJP tower site
YJP     - SSA young jack pine tower site
EofOJP  - east of SSA-OJP
EofYJP  - east of SSA-YJP
OJP     - SSA old jack pine tower site
OJPstem - stem map near SSA-OJP
WS+ASL  - white spruce and aspen mixture near Swan lake
BSmed   - medium density black spruce along the boardwalk to SSA-Old Black
          Spruce (OBS) tower
BSwet   - small density black spruce along the boardwalk  to SSA-OBS tower
BS      - black spruce near SSA-OBS tower
JPsl    - Jack Pine near Swan Lake
OAop    - old aspen near SSA BOREAS Operations Center
MoA     - medium aspen
WsAcl   - white spruce and aspen mixture near Candle Lake

Class: 1 - aspen, 2 - dry conifer, 3 - wet conifer

Image Windows for each site:
st-ln: starting line
st-px: starting pixel
nl: number of lines
np: number of pixels

Biomass:
mean, stdv: mean and standard deviation of field measured biomass (kg/m²).
radar: estimated biomass extracted from radar-derived biomass image (kg/m²).
```

site	name	Class	st-ln	st-px	nl	np	mean	stdv	radar
1	rss15-te20-1	1	1582	837	3	3	11.050	6.913	9.4771
2	rss15-te20-2	3	1533	902	3	3	4.182	1.047	2.2484
3	rss15-te20-3	3	1487	950	3	3	6.528	3.048	8.1438
4	rss15-te20-4	0	1452	1007	3	3	0.100	0.100	2.3791
5	rss15-te20-5	2	1398	1047	3	3	0.100	0.100	0.8758
6	rss15-te20-6	2	1332	1037	3	3	6.902	4.996	9.7647
7	rss15-te20-7	3	1266	1017	3	3	7.846	2.638	8.4706
8	rss15-te20-8	3	1201	1046	3	3	10.114	4.254	12.1180
9	rss15-te20-9	3	1165	1106	3	3	8.678	5.273	10.6930
10	rss15-te20-10	1	1113	1115	3	3	8.174	3.988	10.0000
11	rss15-te20-11	3	1053	1140	3	3	5.874	3.564	7.3464
12	rss15-te20-12	3	1000	1180	3	3	4.062	4.849	3.8301
13	rss15-te20-13	3	968	1228	3	3	11.758	3.001	10.1570
14	rss15-te20-14	1	961	1294	2	2	5.452	4.912	7.1765
15	rss15-te20-15	2	962	1360	2	2	1.317	0.898	2.5294
17	rss15-te20-17	1	943	1492	2	2	2.040	1.680	4.4412
18	rss15-te20-18	3	919	1556	3	3	2.844	2.683	6.5621
19	rss15-te20-19	3	888	1620	3	3	13.984	8.394	13.1900
20	rss15-te20-20	3	848	1669	3	3	4.230	3.888	4.5098
21	rss15-te20-21	3	818	1729	3	3	11.124	4.290	14.9670
22	rss15-te20-22	2	796	1795	3	3	0.304	0.615	0.0000
23	rss15-te20-23	2	753	1841	3	3	7.070	2.367	9.4771
24	rss15-te20-24	2	689	1862	3	3	12.960	2.316	12.6280
25	rss15-te20-25	2	627	1890	2	2	14.876	5.633	19.2050

26	rss15-te20-26	2	580	1942	3	3	1.714	2.126	3.6471
27	rss15-te20-27	2	522	1985	3	3	0.032	0.072	1.7908
28	rss15-te20-28	2	474	2030	3	3	0.880	1.311	5.1634
30	rss15-te20-30	2	508	2051	3	3	1.400	1.416	5.0196
31	rss15-te20-31	2	569	2070	2	2	0.324	0.511	0.1471
32	rss15-te20-32	1	631	2099	2	2	6.142	8.998	8.0588
33	rss15-te20-33	1	700	2101	2	2	28.752	14.172	23.4710
34	rss15-te20-34	2	762	2126	3	3	7.426	5.072	8.5752
35	rss15-te20-35	2	827	2139	3	3	5.798	1.473	5.2288
36	rss15-te20-36	3	887	2158	3	3	8.992	9.708	14.7060
37	rss15-te20-37	2	916	1937	3	3	7.485	5.916	7.0980
38	rss15-te20-38	1	895	2218	3	3	15.544	6.162	13.7910
39	rss15-te20-39	2	1047	2037	2	2	15.210	5.200	8.9412
40	rss15-te20-40	2	1035	2023	3	3	8.210	8.270	8.4314
41	F7J0P	3	968	1221	3	3	7.893	1.792	12.0920
42	G4K8P	2	838	1855	3	3	7.960	7.357	8.7712
43	G9I4S	3	541	1082	3	3	10.030	2.190	10.2220
44	G1K9P	2	873	1885	3	3	8.057	2.409	8.8105
45	NofAL	2	986	2086	3	3	0.640	0.300	0.3007
46	SofYJP	2	999	2125	3	3	1.000	0.500	4.8497
47	YJP	2	986	2119	3	3	2.400	1.050	5.7778
48	EofOJP	2	855	2117	3	3	8.430	4.380	11.3730
49	AL	2	1002	2069	3	3	11.540	3.000	16.5360
50	EofYJP	2	986	2128	3	3	11.340	3.290	10.1960
51	OJP	2	842	2000	10	10	6.400	2.000	7.5424
52	OJPstem	2	851	2027	3	3	7.810	2.500	6.7190
53	D9G4A	1	1495	302	3	3	9.001	2.868	16.9410
54	D9I1M	3	1546	879	3	3	8.654	2.676	6.7451
55	F1N0M	1	1252	2358	3	3	17.163	4.176	14.3400
56	F5I6P	2	1032	1088	3	3	7.037	2.123	7.9346
57	F7J1P	2	973	1262	3	3	13.318	2.800	9.8824
58	G2I4S	3	795	1025	2	2	13.065	10.585	13.1470
59	G2L7S	3	891	2126	3	3	3.367	1.115	3.7386
60	G4I3M	1	767	1022	3	3	16.670	2.495	17.8430
61	G6K8S	3	740	1861	3	3	13.620	1.346	14.1180
62	G7K8P	2	680	1833	3	3	9.007	0.525	9.6601
63	G8L6P	3	673	2132	3	3	1.258	0.634	1.7647
64	G9L0P	2	624	1907	3	3	14.347	1.929	16.1170
70	BSmed	3	567	1089	3	3	8.710	1.910	8.3791
71	BSwet	3	549	1084	3	3	3.400	0.790	4.0261
72	BS	3	556	1113	3	3	13.250	2.440	9.9608
73	JPsl	2	532	1113	3	3	14.690	4.870	16.2880
74	WsAsl	3	478	1146	3	3	8.470	5.250	8.4837
77	OAop	1	1479	787	3	3	16.040	2.800	21.5950
78	MOA	1	1368	1022	3	3	9.300	2.270	10.4710
80	WsAcl	3	1418	823	3	3	16.850	11.160	16.8890

NSA biomass data were derived from data provided to the BOREAS Information System (BORIS) by TE-06 or TE-13. The values used are listed below. Also included are the SIR-C image locations for measured above-ground total dry biomass for NSA stands.

BOREAS Op-Grid	st-ln	st-px	nl	ns	Mean Biomass kg/m2	Sdev Biomass kg/m2
T2Q6A	1186	484	4	4	9.96	0.7
T3R8T	1203	888	4	4	9.47	0.63
T3U9S	1384	1931	4	4	3.77	1.16
T4U5A	1326	1794	3	3	4.93	4.7
T4U9S	1385	1920	3	3	8.3	1.88
T5Q7S	1083	559	3	3	13.42	0.49
T6R5S	1107	812	3	3	11.04	1.18
T6T6S	1210	1510	3	3	3.76	1.67
T7Q8P	1041	590	3	3	3.81	0.46
T7R9S	1084	957	3	3	2.39	2.08
T7S9P	1151	1263	3	3	4.4	1.76
T8Q9P	1000	644	3	3	14.53	2.25
T8S4S	1072	1116	3	3	1.85	0.45
T8S9T	1152	1289	3	3	0.96	0.37
T8S9P	1122	1299	3	3	0.86	0.57
T8T1P	1114	1343	3	3	1.4	0.24
T9Q8P	1017	622	3	3	1.85	0.06

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The SSA images represent a 20- x 80-km swath covering 75% of the SSA modeling grid. The center point coordinates are approximately 104° 45' W, 53° 52' N, see map below. The North American Datum of 1983 (NAD83) coordinates of the corner points of the SSA images are:

	UTM Easting (m)	UTM Northing (m)	Longitude X (deg)	Latitude Y (deg)
Northwest	460059.160	5999525.927	105.61141° W	54.14229° N
Northeast	550596.384	5999525.	104.22549° W	54.14135° N
Southwest	460059.160	5942856.342	105.60403° W	53.63297° N
Southeast	550596.384	5942856.342	104.23484° W	53.63205° N

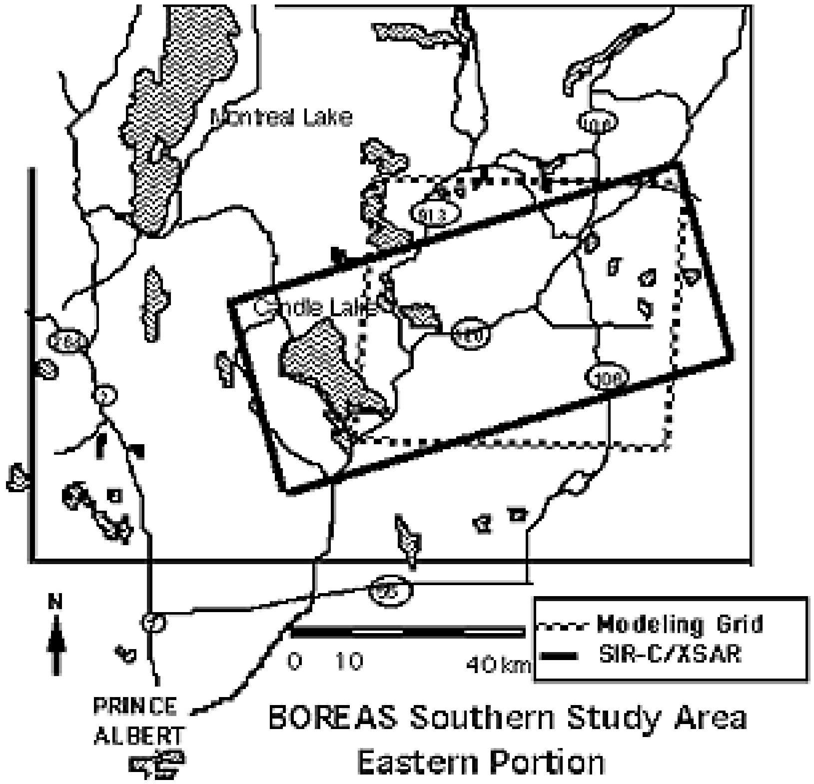
The NSA image covers most of the modeling grid, except for the small extension on the western edge. The center point coordinates are approximately 98° 18' 07.7" W, 55° 54' 17.3" N, see map below..

The corner points of the NSA images are:

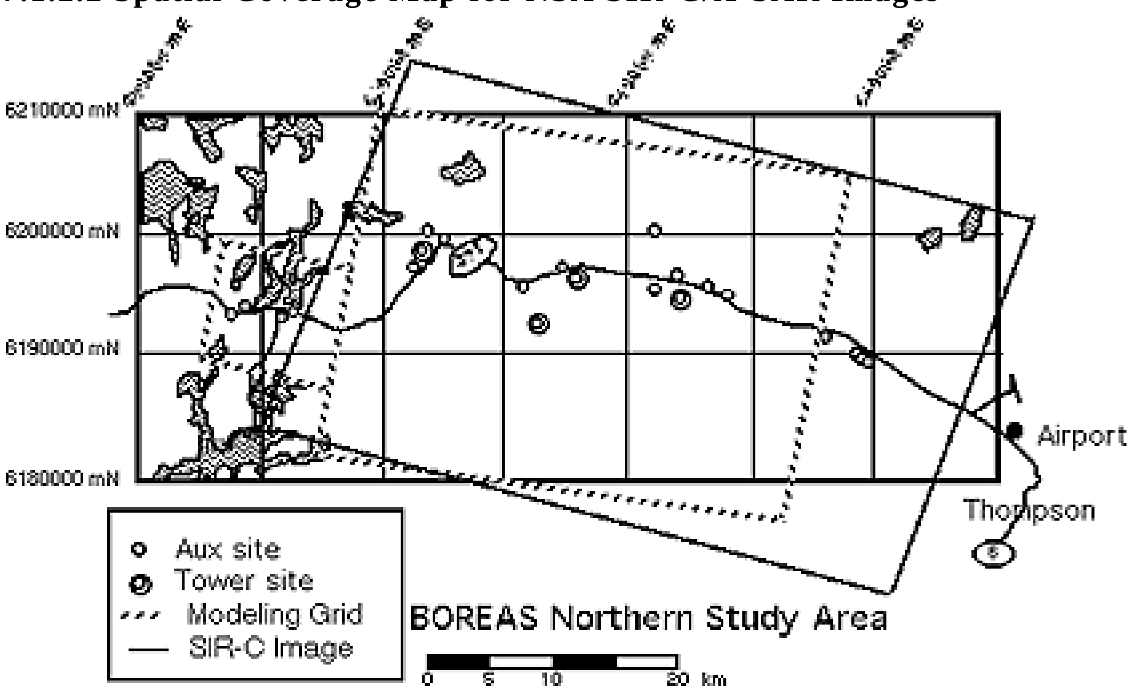
	UTM Easting (m)	UTM Northing (m)	Longitude X (deg)	Latitude Y (deg)
Northwest	505789.00	6229238.100	98.90668° W	56.20804° N
Northeast	577489.00	6229238.100	97.75100° W	56.20177° N
Southwest	505789.00	6153818.100	98.90829° W	55.53030° N
Southeast	577489.00	6153818.100	97.77255° W	55.52427° N

7.1.2 Spatial Coverage Map

7.1.2.1 Spatial Coverage Map for SSA SIR-C/X-SAR Images



7.1.2.2 Spatial Coverage Map for NSA SIR-C/X-SAR Images



7.1.3 Spatial Resolution

The data were acquired at about 25-m spatial resolution and were resampled to 30-m resolution in Albers Equal Area Conic (AEAC) projection selected by BOREAS.

7.1.4 Projection

The projection is AEAC.

7.1.5 Grid Description

The origin of the grid is at 111° W, 51° N and the standard parallels are set to 52.5° N and 58.5° N as prescribed in 'Map Projections - A Working Manual,' USGS Professional Paper 1395, John P. Snyder, 1987.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

Characteristics of data takes over BOREAS sites for SIR-C/X-SAR flights SRL-1 (09-Apr through 19-Apr-1994), SRL-2 (30-Sep-1994 through 10-Oct-1994). PA is Prince Albert (SSA), and NH is Nelson House (NSA).

Site	Orbit #		Date (1994)		Look Angle (deg)		Orbit Dir	
Name	SRL-1	SRL-2	SRL-1	SRL-2	SRL-1	SRL-2	Asc/Desc	Mode*
PA	20.1	20.2	10-April	1-Oct	28.86	29.42	A	16X
PA	36.3	36.3	11 April	2-Oct	33.14	33.41	A	16X
PA	52.3	52.3	12-April	3-Oct	39.97	36.86	A	16X
PA	68.2	68.2	13 April	4-Oct	39.50	39.52	A	16X
PA	84.2	84.12	14-April	5-Oct	42.00	41.77	A	16X
PA	100.2	100.12	15 April	6-Oct	43.50	43.63	A	16X
PA	-	101.1	-	6-Oct	55.83	55.55	D	11
PA	116.3	116.22	16 April	7-Oct	44.86	45.17	A	16X
PA	132.4	-	17 April	-	45.86	-	A	16X
PA	148.2	-	18 April	-	46.69	-	A	16X
PA	164.2	-	19 April	-	47.25	-	A	16X
NH	21.1	21.1	10-April	1-Oct	24.96	25.35	D	16X
NH	37.1	37.1	11 April	2-Oct	23.18	23.68	D	16X
NH	53.1	53.1	12-April	3-Oct	21.50	21.90	D	16X
NH	69.1	69.1	13 April	4-Oct.	19.62	19.69	D	16X
NH	70.0	70.1	13-April	4-Oct	58.06	58.04	D	11X
NH	85.1	85.1	14 April	5-Oct	17.98	17.84	D	16X

*16X = C-,L-band quad-polarization, X-band VV 11X = C- ,L-band HH, HV polarization, X-band VV 11 = C-, L-band HH, HV polarization only

7.2.2 Temporal Coverage Map

The SSA biomass map was developed from 06-Oct-1994 SIR-C data. The NSA biomass map was developed from 13-Apr-1994 SIR-C data. Landsat TM data used for the SSA landcover map were acquired on 02-Sep-1995.

7.2.3 Temporal Resolution

See Section 7.2.1.

7.3 Data Characteristics

7.3.1 Parameter/Variable

- Land cover classification
- Total above ground dry woody biomass
- Dry woody stem biomass
- Dry woody branch biomass
- Dry foliage biomass

7.3.2 Variable Description/Definition

The data products include landcover and biomass maps covering most of the NSA and SSA modeling grids. Individual parameter maps include: Land cover map with categories of Pine, Spruce, broadleaf Aspen, shrubland, fen, clearing, and water. (See table below): Total above ground dry woody biomass in each image resolution cell (nominally 30 meters squared): Dry woody stem biomass, Dry woody branch biomass and dry foliage biomass - SSA only .

Land cover classification set

```
Class         Description
----------    ---------------------------------------------------------
Pine          Consists of mature jack pine with lichen, mature jack pine
              with alder, young jack pine and regenerating jack pine.
Spruce        Includes black spruce and white spruce.  Also includes
              areas of low biomass treed muskeg.
Aspen         Consists of mature, intermediate and young aged aspen stands.
Shrubland     Treeless areas of willow and other deciduous shrubs.
              Includes very young aspen regeneration.
Fen           Treeless wetlands mostly covered with bog birch or other low shrubs.
Clearing      Areas of recent logging activity where tree cover is removed.
Water         Lakes, ponds and larger rivers.

SSA Land Cover Map
 class 0 - background
       1 - pine
       2 - spruce
       3 - aspen
       4 - shrub land
       5 - clearing
       6 - fen
       7 - water

NSA Land Cover Map
 class 0 - background
       1 - pine
       2 - spruce
       3 - aspen
       4 - shrub land
       5 - clearing
       6 - fen
       7 - water
```

Total above ground dry woody biomass - kg/m^2 of total standing woody biomass.
Dry woody stem biomass - kg/m^2 of woody stem or bole biomass
Dry woody branch biomass - kg/m^2 of woody branch biomass
Dry foliage biomass - kg/m^2 of woody foliage (leaves or needles) biomass (SSA)

7.3.3 Unit of Measurement

Classification maps - coded but unitless values.

In the following biomass images, the pixel values 0 - 255 correspond linearly to the specified ranges of biomass

- Dry above ground woody total biomass, 0 - 30 kg/m^2 for total biomass image. To calculate biomass as Kg/m2, divide image values by 8.50
- Dry woody stem biomass in gridded (image) format. 0 - 27.13 kg/m^2 for stem biomass image. To calculate biomass as kg/m2, divide image values by 9.40
- Dry woody branch biomass in gridded (image) format. 0 - 4.07 kg/m^2 for branch biomass image. To calculate biomass as Kg/m2, divide image values by 62.65
- Dry foliage biomass in gridded (image) format. 0 - 3.95 kg/m^2 for foliage biomass image. To calculate biomass as kg/m^2, divide image values by 64.56

7.3.4 Data Source

The data described here are derivative products of SIR-C/X-SAR and Landsat TM data.

7.3.5 Data Range

Classification maps, 0-7. Biomass maps, 0-255.

7.4 Sample Data Record

Not applicable to image data.

8. Data Organization

8.1 Data Granularity

The smallest unit of data tracked by BORIS is the entire set of images from each of study area.

8.2 Data Format

8.2.1 Uncompressed Files

This data set contains the following 9 files:

```
 file       description                          samples   lines
------  -----------------------------            -------   -----
  1    *NSA list                                   NA       NA
  2     NSA SIR-C Cover Map                       2390     2500
  3     NSA SIR-C Total Biomass Map               2390     2500
  4    *SSA list                                   NA       NA
  5     SSA SIR-C Branch Biomass Map              3023     1887
  6     SSA SIR-C Cover Map   3023                3023     1887
  7     SSA SIR-C Foliage Biomass Map             3023     1887
  8     SSA SIR-C Stem Biomass Map                3023     1887
  9     SSA SIR-C Total Biomass Map               3023     1887
-----------------------------------------------------------------------------
*contain the list of sites, image coordinates and biomass measurements used
to construct and/or test the SSA and NSA biomass algorithms.
```

All images (files 1, 2, 5-9) are single byte binary image files with no headers. Pixel size is 30 m x 30 m. Files 1 and 4 are ASCII files with 80 characters per line.

8.2.2 Compressed CD-ROM Files

On the BOREAS CD-ROMs, the image files been compressed with the Gzip (GNU zip) compression program (file_name.gz). These data have been compressed using gzip version 1.2.4 and the high compression (-9) option (Copyright (C) 1992-1993 Jean-loup Gailly). Gzip uses the Lempel-Ziv algorithm (Welch, 1994) also used in the zip and PKZIP programs. The compressed files may be uncompressed using gzip (with the -d option) or gunzip. Gzip is available from many Web sites (for example, the ftp site prep.ai.mit.edu/pub/gnu/gzip-*.*) for a variety of operating systems in both executable and source code form. Versions of the decompression software for various systems are included on the CD-ROMs.

9. Data Manipulations

9.1 Formulae

Forest Type Classification

The purpose of the landcover classification was to identify areas of forest and non-forest and stratify the forest classes into three major forest categories: pine, spruce, and aspen. The separation of the forest types allows the use of type-specific biomass vs. backscatter relationships as discussed below. L-band (HH, HV, VV), C-band (HH, HV, VV), and X-band (VV) channels from 15-Apr and 06-Oct SIR-C/X-SAR images were combined into a common radar data set. In addition, the six reflective channels from a 02-Sep-1994 Landsat TM image, Channel 1 : 0.45-0.52 mm, Channel 2: 0.52-0.60 mm, Channel 3: 0.63-0.69 mm, Channel 4: 0.76-9.90 mm, Channel 5: 1.55-0.1.75 mm, and Channel 7: 2.08-2.35 mm were included. A principal component analysis was performed to transform the data set and reduce the number of channels used. The first eight components accounted for over 90% of the variance. After each of the principal component images was examined, components 1, 2, 3, 4, 7 and 8 were selected for use in the classifier. Principal components 5 and 6 were not selected because the apparent information content of the images was low or redundant with other components. See Ranson et al., 1997, for a complete description. SIR-C channels for October data and TM channels contributed the most to the classifier information content. For radar channels, L-band contributed more than C-band channels and X-band contributed the least. Near-IR and shortwave-IR bands contributed the most from the TM data, while visible band 2 contributed the least of any channel.

Commercially available imaging processing software (PCI) was used for image classification. Training set locations were identified on the images for the three forest classes and four non-forest classes listed in Section 7.3.2. Global Positioning system (GPS)-derived site coordinates and aerial photography were used to aid in site location. Spectral signatures were extracted from the transformed images and used as inputs for the Maximum Likelihood Classifier (MLC) to produce a forest type map. Classification performance was determined by analyzing classified training sets and also checking classification results for the measured stands discussed in Section 10.2.3.

Biomass Estimation

A set of forest stand measurements was acquired by BOREAS investigators during the summers of 1993 and 1994 that consisted of identifying tree species, measuring diameter and heights, and determining age. Eight stands were sampled in August 1993, and 40 stands were sampled in 1994. The sites covered a wide variety of forest types and in many cases, were very heterogeneous within and between plot samples (these data are described elsewhere by Knox et al., TE-20). An additional nine plots were sampled in August 1996. Above-ground dry woody biomass (kg/m^2) was determined by using the measured dbh (diameter at breast height or 1.3 m from the ground) for every tree in a plot and by applying biomass or weight tables developed for boreal forest species occurring in the Prairie Provinces of Canada. The weight tables were derived from equations developed on-site by University of Wisconsin personnel (Gower et al., 1997) and from other published studies (Young et al., 1980; Singh, 1982). In addition, the study used data made available by Forestry Canada (Haliwell and Apps,

1997) [TE-13] and University of Wisconsin personnel [TE-06] for BOREAS auxiliary and tower flux sites. The University of Wisconsin allometry results were expressed as kg carbon/ha. Since dry biomass contains approximately 50% carbon [Waring and Schlesinger, 1985], the expression:

Biomass density = kg Carbon/ha . CF / 10000

was used with a conversion factor (CF) = 2.0 to convert mass of carbon to woody biomass density. A CF equal to 2.222 was used for the foliage component. Plot data were then averaged.

It was desirable to use larger, more homogeneous stands (determined from between sample plot density variance) to extract at least a 3 x 3 array of SIR-C/X-SAR pixels to obtain a representative sample size. A total of 62 of the stands were suitable for this purpose and were assumed to represent most of the forest conditions. Data from these stands were used for algorithm development and testing as discussed below.

9.1.1 Derivation Techniques and Algorithms

The method for mapping biomass from SAR uses a relationship between radar backscatter and field-measured biomass transformed by the cube root. A stepwise regression routine was used to determine a best set of SIR-C/X-SAR channels from LHH, LHV, LVV, CHH, CHV, CVV, and XVV backscatter. A two-step approach to retrieve forest biomass was used: 1) classify forests using SIR-C/X-SAR data; and 2) develop models for each category and retrieve total biomass. The three major types of forests (pine, spruce and aspen) discussed earlier were considered. To examine the importance of forest type, the results from the two-step approach will be compared with results obtained from a general relationship that combines data without regard for forest type.

To explore the usefulness of the SIR-C/X-SAR backscatter channels for total biomass estimation, a routine for stepwise selection of the best independent variables was used to determine the multiple regression models [MathSoft, 1993]. Average backscatter in each of the seven SIR-C/X-SAR channels was used as the independent variable with dependent variable, biomass, for multiple linear regression analysis. The routine starts from an intercept-only model, i.e., no independent variable (SAR channel backscatter), and calculates an ANOVA table showing the residual sum of squares and Cp statistics. (Cp is the estimator for the standardized total squared error.) An independent variable is added to the model and the resulting Cp value compared with the original. The routine automatically adds or drops variables based on a criterion of minimum Cp value. The stepwise selections were conducted for data sets for the three forest categories separately and for data for all forest types combined. As discussed above, data from 62 stands were used to develop the regression model from the SIR-C/X-SAR data. Of these 62 stands, there were 30 with pine, 21 with spruce, and 11 with aspen, including two with very low biomass. The independent variables selected by the stepwise process are shown in below. In addition, the next variable to be added if the process were to be continued one more step is also shown.

Each of the equations listed for forest type is different since either the bands selected or the magnitude of the coefficients is different. This indicates that biomass estimation is dependent to a certain degree on forest type as discussed by Dobson et al. [1995]. Note that each of the forest type biomass equations contains L- and C-band cross-polarized channels with positive and negative coefficients, respectively. If the absolute value of the coefficients were equal for LHV and CHV, the form of the equation would be similar to that reported by Ranson et al. [1994, 1995a].

Results for mapping with individual forest type biomass equations were compared with those from a single combined biomass equation and very little actual difference was found. For total-above ground biomass, either method could be used. For component biomass, individual forest type equations must be used. The biomass equations listed were applied on a pixel-by-pixel basis to the SAR image data to create biomass images or maps. The SAR-predicted biomass of all sample stands was extracted by averaging over a 3 x 3 window from biomass maps. Since the variation in field biomass measurements introduced an uncertainty in the comparisons of field-estimated and SAR-mapped biomass, a weighted least squares analysis was used. The weights used were the inverse of the standard deviations for field-sampled biomass.

SSA multiple regression models for biomass estimation from SIR-C backscatter data. Note that an additional variable CHV was added in the second model for Aspen. NS = Not Selected. Total Biomass $= b_0 + b_1 * \text{LHV} + b_2\ \text{CHV} + b_3\ \text{LHH}$.

Category	Intercept (b_0)	LHV (b_1)	CHV (b_2)	LHH (b_3)	r^2	n obs
Pine	3.031	0.245	-0.175	NS	0.80	30
Spruce	3.475	0.229	-0.131	NS	0.86	21
Aspen	5.905	0.259	NS	NS	0.81	11
Aspen	3.417	0.251	-0.161	NS	0.94	11
All	3.420	0.208	-0.163	0.092	0.85	62

Regression coefficients for estimating component biomass (kg/m^2) from measured total biomass. Component Biomass $= b_0 + b_1 *$ Total biomass.

Forest Type	Component	Intercept (b_0)	Slope (b_1)	r^2	num obs
Pine	Stem	0.0000	0.8199	0.997	24
	Branch	-0.0376	0.1370	0.901	24
	Foliage	0.0054	0.0356	0.992	8
Spruce	Stem	-0.06758	0.7500	0.982	12
	Branch	0.0294	0.1329	0.971	12
	Foliage	0.0425	0.1301	0.866	12
Aspen	Stem	0.0216	0.9037	0.999	22
	Branch	-0.02017	0.0856	0.890	22
	Foliage	-0.0015	0.0118	0.953	22

NSA multiple regression models for biomass estimation from SIR-C backscatter data.

Category	Intercept (b_0)	LHV (b_1)	CHV (b_2)	LHH (b_3)	r^2	N
All Forest Types	2.6589	0.3822	-0.3476	-0.0540	0.79	17

9.2 Data Processing Sequence

9.2.1 Processing Steps

BORIS staff copied the ASCII and compressed the binary files for release on CD-ROM.

9.2.2 Processing Changes

None.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

None.

9.3.2 Calculated Variables

None given.

9.4 Graphs and Plots

See Ranson, et al., 1997.

10. Errors

10.1 Sources of Error

Sources of error include natural stand variations, measurement errors, error in radar backscatter from speckle and noise, and location errors extracting backscatter for measured forest stands.

10.2 Quality Assessment

All field plot data were quality checked to reduce transcription errors. Several plots not included in the regression analysis were used to check the veracity of biomass and classification maps. Preliminary error analysis with SIR-C data over a portion of SSA shows residual standard error of 1.6 kg/m^2 for a range of over 30 kg/m^2. However, because of the increased error in relationship and paucity of data points at higher biomass levels, the relationship gives best results for biomass 15 kg/m^2 or less.

10.2.1 Data Validation by Source

Below is a comparison of biomass (kg/m^2) estimates for four jack pine stands from bole and branch volume measurements and allometry using dbh data. Also included are estimates from the SAR biomass equation.

	Estimated Biomass (kg/m^2)		
Stand	**Geometry**	**Allometry**	**SIR-C SAR**
RJP	0.88	1.00	0.96
YJP	1.99	2.40	2.83
OJP	9.19	7.80	8.73
MJP	9.02	11.54	11.22

10.2.2 Confidence Level/Accuracy Judgment

None given.

10.2.3 Measurement Error for Parameters

The results of the classification are presented as contingency tables of the SAR classification vs. training set class and SAR classification vs. field plot sampling data. The table below gives the classification results for training set data using the combined SIR-C/X-SAR and Landsat images. The classification accuracy for all classes is greater than or equal to 90% with no major confusion with other classes.

Classification contingency table for SAR classification of training sets. Classes are described in Table 2. Average accuracy = 94.6%

Class	Pine	Spruce	Aspen	Shrub	Fen	Clearing	Water	Training Pixels
Pine	94.1	2.6	1.0	0.1	0.2	2.1	0.0	3581
Spruce	1.5	98.0	0.0	0.0	0.6	0.0	0.0	545
Aspen	4.1	1.5	93.4	0.0	0.0	1.0	0.0	1593
Shrubland	1.4	1.7	1.8	90.0	2.5	2.5	0.0	711
Fen	2.7	1.6	0.6	0.1	95. 1	0.0	0.0	1032
Clearing	1.3	0.0	0.0	0.0	0.0	98.7	0.0	697
Water	0.0	0.0	0.0	0.0	0.0	0.0	100.0	13225

As a final check on the classification performance, the most abundant forest type recorded in the field plots was compared to the classes mapped in a 3 x 3 array of pixels for the plot locations. The test site (3 x 3 array) was labeled as the forest type occurring in 5 or more pixels. If no single forest type was dominant in the test site, the site was not included in the analysis. The results are listed in the following table and show high classification accuracy for pine (96.4%) and aspen (94.1%). However, only 71.4% of the spruce sites were correctly identified partly because most of the spruce sites were small and very heterogeneous. However, there were a few cases of spruce being misclassified as pine with alder understory, a mesic site condition. At this time, it is not clear why this is the case, but it may have implications when it is necessary to separate conifer forests on wet and dry conditions for modeling purposes and will also have an impact on the calculation of biomass using forest-type-specific biomass equations. However, given the high accuracy for the training sets for pine and spruce classes, the classification should be adequate for the purposes of this paper.

Class contingency table for SAR classification and field measurement sampling plots. Average accuracy = 87.3%

Class	**Pine**	**Spruce**	**Aspen**
Pine	96.4	4.6	0.0
Spruce	21.4	71.4	7.2
Aspen	5.9	0.0	94.1

The biomass equations listed above were applied on a pixel-by-pixel basis to the SAR image data to create biomass images or maps. The SAR-predicted biomass of all sample stands was extracted by averaging over a 3 x 3 window from biomass maps. Since the variation in field biomass measurements introduced an uncertainty in the comparisons of field-estimated and SAR-mapped biomass, a weighted least squares analysis was used. The weights used were the inverse of the standard deviations for field-sampled biomass. This reduces the effects of sample points with higher field biomass variances. The results are listed in the following table as the regression coefficients (intercept and slope), coefficient of determination (r^2), residual standard error (RSE), and a 95% confidence interval (CI) for biomass estimation.

Model	**Intercept**	**Slope**	**r^2**	**RSE (kg/m^2)**	**95% CI**
One-step	1.275	0.925	0.88	1.551	0.896
Two-step	1.507	0.943	0.89	1.527	0.895

The 95% CI listed above is the average over all sample points. The CI changes with biomass and is lower at small biomass and larger at higher biomass levels. The equivalent results for the two methods indicate that the species effects on total above-biomass estimation were not important for this data set in the study area. However, the capability of stratifying biomass by forest type lends itself to estimates of component biomass.

The component biomass results discussed above were used to produce the maps for bole, branch, and foliage biomass. From these data it can be seen that the highest bole biomass estimates occur in areas of pine and aspen. Most of the SSA clearings identified in the classification maps are located primarily in the high biomass pine areas. Areas with greatest foliage biomass are located within predominantly spruce forests. Spruce trees have a much greater proportion of foliage biomass than the other forest types as seen by comparing slope coefficients in Section 9.1. Dobson et al. [1995a] showed higher levels of crown layer biomass for "lowland conifer," which includes black spruce and tamarack in northern Michigan. On average, the total biomass was about 6.8 kg/m^2 across the entire image or 7.3 kg/m^2 for only forested areas. Boles, branches, and foliage comprise about 83%, 12%, and 5%, of the total biomass, respectively. Coupling these data with ecosystem models should improve estimates of maintenance respiration and decomposition rates across the landscape.

10.2.4 Additional Quality Assessments

None.

10.2.5 Data Verification by Data Center

BORIS staff has viewed the biomass images to verify image size, type, and value range.

11. Notes

11.1 Limitations of the Data

The results indicate that above-ground biomass can be estimated to within about 1.6 kg/m^2 and up to about 15 kg/m^2 across the SIR-C image evaluated. A general method also produced results equivalent to those obtained by treating forest types separately.

11.2 Known Problems with the Data

None given.

11.3 Usage Guidance

Because of the increased error in the relationship and paucity of data points at higher biomass levels, the relationship gives best results for biomass 15 kg/m^2 or less. Before uncompressing the Gzip files on CD-ROM, be sure that you have enough disk space to hold the uncompressed data files. Then use the appropriate decompression program provided on the CD-ROM for your specific system.

11.4 Other Relevant Information

None given.

12. Application of the Data Set

These data may be used as estimates of forest type and above-ground woody biomass for ecosystem modeling purposes.

13. Future Modifications and Plans

Similar analysis for NSA is ongoing.

14. Software

14.1 Software Description

Software used in the analyses included commercial packages: PCI, ARC/INFO, and IDL. A public-domain image analysis software package called Image Processing Workbench, developed at the University of California-Santa Barbara, was also used. Gzip (GNU zip) uses the Lempel-Ziv algorithm (Welch, 1994) used in the zip and PKZIP commands.

14.2 Software Access

Gzip is available from many Web sites across the Internet (for example, FTP site prep.ai.mit.edu/pub/gnu/gzip-*.*) for a variety of operating systems in both executable and source code form. Versions of the decompression software for various systems are included on the CD-ROMs.

15. Data Access

The SIR-C and Landsat TM biomass and landcover data are available from the Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

15.1 Contact Information

For BOREAS data and documentation please contact:

ORNL DAAC User Services
Oak Ridge National Laboratory
P.O. Box 2008 MS-6407
Oak Ridge, TN 37831-6407
Phone: (423) 241-3952
Fax: (423) 574-4665
E-mail: ornldaac@ornl.gov or ornl@eos.nasa.gov

15.2 Data Center Identification

Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) for Biogeochemical Dynamics http://www-eosdis.ornl.gov/.

15.3 Procedures for Obtaining Data

Users may obtain data directly through the ORNL DAAC online search and order system [http://www-eosdis.ornl.gov/] and the anonymous FTP site [ftp://www-eosdis.ornl.gov/data/] or by contacting User Services by electronic mail, telephone, fax, letter, or personal visit using the contact information in Section 15.1.

15.4 Data Center Status/Plans

The ORNL DAAC is the primary source for BOREAS field measurement, image, GIS, and hardcopy data products. The BOREAS CD-ROM and data referenced or listed in inventories on the CD-ROM are available from the ORNL DAAC.

16. Output Products and Availability

16.1 Tape Products

The image data are available as band-sequential files on 8-mm tape media.

16.2 Film Products

None.

16.3 Other Products

These data are available on the BOREAS CD-ROM series.

17. References

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17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

CHH - Radar channel designation for C-band frequency and Horizontal transmit - Horizontal receive polarization
CHV - Radar channel designation for C-band frequency and Horizontal transmit - Vertical receive polarization (also known as cross-pol)
CVV - Radar channel designation for C-band frequency and Vertical transmit - Vertical receive polarization
LHH - Radar channel designation for L-band frequency and Horizontal transmit - Horizontal receive polarization
LHV - Radar channel designation for L-band frequency and Horizontal transmit - Vertical receive polarization (also known as cross-pol)
LVV - Radar channel designation for L-band frequency and Vertical transmit - Vertical receive polarization
PHV - Radar channel designation for PL-band frequency and Horizontal transmit - Vertical receive polarization (also known as cross-pol)
XVV - Radar channel designation for X-band frequency and Vertical transmit - Vertical receive polarization

19. List of Acronyms

AEAC - Albers Equal-Area conic
AIRSAR - Airborne SAR
ASCII - American Standard Code for Information Interchange
ASI - Agenzia Spaziale Italiana
BOREAS - BOReal Ecosystem-Atmosphere Study
BORIS - BOREAS Information System
CCRS - Canada Centre for Remote Sensing
CD-ROM - Compact Disk - Read-Only Memory
CF - Conversion Factor
CI - Confidence Interval
DAAC - Distributed Active Archive Center
DBH - Diameter at Breast Height
DLR - Deutsche Forschung santalt Fur Loft-und Raumfahrt
EOS - Earth Observing System
EOSDIS - EOS Data and Information System
ERS-1 - Earth Resources Satellite-1
GIS - Geographic Information System
GMT - Greenwich Mean Time
GPS - Global Positioning System
GSFC - Goddard Space Flight Center
HTML - HyperText Markup Language
IFC - Intensive Field Campaign
JERS - Japanese Earth Resources Satellite-1
JPL - Jet Propulsion Laboratory
MLC - Maximum Likelihood Classifier
NAD83 - North American Datum of 1983
NASA - National Aeronautics and Space Administration
NSA - Northern Study Area
OBS - Old Black Spruce
OJP - Old Jack Pine
ORNL - Oak Ridge National Laboratory
PANP - Prince Albert National Park

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RADAR  - RAdio Detection and Ranging
RSE    - Residual Standard Error
RSS    - Remote Sensing Science
SAR    - Synthetic Aperture Radar
SIR-C  - Shuttle Imaging Radar, C-band
SRC    - Saskatchewan Research Council
SSA    - Southern Study Area
SRL    - Space Radar Laboratory
TE     - Terrestrial Ecology
TM     - Thematic Mapper
URL    - Uniform Resource Locator
X-SAR  - X-band Synthetic Aperture Radar
YJP    - Young Jack Pine
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As part of BOREAS, the RSS-15 team conducted an investigation using SIR-C, X-SAR, and Landsat TM data for estimating total above-ground dry biomass for the SSA and NSA modeling grids and component biomass for the SSA. Relationships of backscatter to total biomass and total biomass to foliage, branch, and bole biomass were used to estimate biomass density across the landscape. The procedure involved image classification with SAR and Landsat TM data and development of simple mapping techniques using combinations of SAR channels. For the SSA, the SIR-C data used were acquired on 06-Oct-1994, and the Landsat TM data used were acquired on 02-Sep-1995. The maps of the NSA were developed from SIR-C data acquired on 13-Apr-1994.

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