BOREAS Science White Papers

BOREAS Science Team
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BOREAS Science White Papers

This document contains three BOREAS Science White Papers which address shortcomings in the BOREAS-94 data sets and argue for remedial field activities in 1996.

The data gathered during the BOREAS-94 field season is the most comprehensive and complete of its kind, see Sellers et al. (1995). However, follow-up analyses and discussions have highlighted some major shortcomings in the data set.

(i) Beginning and End of the Growing Season: The first field campaign started in May 1994, by which time many of the coniferous species had started photosynthesis. As a result, we do not have a clear picture of how the boreal system emerges from winter dormancy. Similarly, the last field campaign ended in late September 1994; measurements by a team who stayed in place (TF-3) indicated that significant photosynthetic uptake was maintained through November 1994, while significant soil respiration fluxes were measured in the NSA throughout the winter of 1994--1995. The bulk of the 1994 measurements did not extend through the thaw and freeze-up periods, leaving a significant gap in our understanding of the processes controlling carbon and energy fluxes as these times.

(ii) Role of Moss: Analysis of some field measurements and some preliminary modeling studies have indicated that the moss layer may play an important role in carbon assimilation, particularly in the wet coniferous sites. The data gathered in 1994 was not sufficient to construct a credible model of moss photosynthesis and water relations. More detailed measurements which extend over the entire growing season are needed.

(iii) Smoke in IFC-2: Heavy smoke from forest fires in the mid-season intensive field campaign prevented the team from acquiring useful remote sensing data over half of the important ground targets (the entire NSA).

(iv) Snow Cover and Radiation Balance: We do not have the data that will help us to understand how the snow-covered forest absorbs and releases radiative energy and how such scenes appear to remote sensors.

In addition to these points, there are some open issues or gaps in our understanding.

(v) 1994: a Record Warm, Dry Year: 1994 was a record frost-free year for most of the region studied in BOREAS. In a very real sense, our 1994 data set is atypical.

(vi) Positive Surface-Atmosphere Feedback: The high temperatures and dry air masses of 1994 acted on the vegetation to inhibit evapotranspiration which perhaps reinforced the drying trend. We need to understand this mechanism better and how it operates during a 'normal' year.

A BOREAS science team meeting was held at Turf Valley, Maryland in March 1995 to discuss the above issues. Three white papers were written:

I. Fluxes and Processes at the Stand Level (Eds.: Jarvis / Baldocchi)
II. Surface and Boundary Layer Studies (Eds.: Betts / Kelly)
III. Remote Sensing Science (Eds.: Miller / Ranson)

These papers have since been updated and are now being used to formulate an experiment plan for the BOREAS-96 field activities. On the basis of the science arguments presented in the papers, we propose to conduct the following operations in 1996.

(1) Winter Field Campaign: Airborne and surface measurements will be used to address item (iv) during February-March.

(2) Extended Measurements: Tower flux (TF), terrestrial ecosystem (TE), hydrological (HYD), and Trace gas and biogeochemistry (TGB) measurements will be centered at a subset of tower flux sites during the period March through November. Micrometeorological and remote sensing observations will be acquired continuously.

(3) Intensive Field Campaigns: Three growing season intensive field campaigns (IFC's) will be executed. These will be much reduced in scope compared with the 1996 items (i), (ii), (iii), and (iv). The IFC's will see the execution of a set of specific, coordinated in situ experiments, some airborne remote sensing work, and a limited surface - ABL experiment.

The final versions of the White Papers are attached.

Reference

Sellers, P. J., F. G. Hall, H. Margolis, B. Kelly, D. Baldocchi, J. denHartog, J. Cihlar, M. Ryan, B. Goodison, P. Crill, J. Ranson, D. Lettenmaier, D. E. Wickland (1995), "The Boreal Ecosystem-Atmosphere Study (BOREAS): an overview and early results from the 1994 field year", B.A.M.S, Sept. 1995.

Editor: P.J. Sellers, BOG.

I. Fluxes and Processes at the Stand Level

1.0 Introduction

1.1 Goal

The main goal of this Working Group has been to develop an integrated approach to understanding fluxes and processes at the stand scale. Specifically, the proposed suite of 1996 measurement addresses the existing BOREAS objectives and the gaps in the 1994 data set cooperation amongst groups from TF, TE and TGB. HYD should also be included in this coordinated action to some extent but they were not well represented at the Workshop and consequently their participation is implied rather than explicit.

1.2 Background

A major focus of BOREAS is to establish relationships between remotely sensed environmental and plant variables and to use this information to assess fluxes of water, carbon and energy between boreal forests and the atmosphere.

Consequently, the original main focus of the original Experiment Plan was on the three representative periods of the growing season (intensive field campaigns) during 1994 when remote sensing equipment could be deployed. However, as questions regarding terrestrial sinks for carbon became more of a global issue, with developments in technology, and to maximise benefits from the investment in infrastructure, the Experiment Plan was modified to include measurements of stand scale fluxes and other variables right through the 1994 season from the beginning of the first IFC to the end of the third IFC. This development of the Experiment Plan proved to be extremely appropriate and timely, but at the same time has pointed up the need for even more extensive periods of measurement to define annual carbon and water budgets.

In the original Experiment Plan, activities of TF, TE, TGB and HYD were defined very largely in relation to the internal priorities of those groups, measuring and modelling the processes that they were concerned with, and their relationships to remotely sensed data. Some cross links amongst the groups, of course, were planned and some eventuated in the field. Developments in modelling processes of stands have led to an increased emphasis on attempts to obtain closed budgets for carbon, water, nutrients and trace gases at stand scale. A great opportunity exists to achieve this within BOREAS but this requires closer integration amongst the teams than has occurred so far.

1.3 Objectives for Stand-Level Work in BOREAS

Arising out of these general considerations, we have defined the following four General Objectives for future activities at stand scale.

a. To find out whether the main vegetation types - forest and fen - are sources or sinks for atmospheric carbon, water and trace gases on an annual basis, and whether the direction of fluxes is likely to change in an altered climate.

b. To determine the main controls on the exchanges of CO_2 and water vapour by the vegetation.

c. To provide measurements within stands for the parameterisation of stand scale models and measurements at the scale of the stands to constrain stand scale models.

d. To provide stand scale fluxes and parameters for scaling up to regional scale.

e. To link up with coordinated atmospheric boundary layer measurements, so as to obtain a complete picture of surface-atmosphere controls on fluxes.

2.0 Science Issues Arising from BOREAS-94

2.1 Ecosystem Fluxes

In 1994, the majority of the BOREAS TF sites ran for the four-month growing season period. Important periods that were missed included the spring and fall transition periods and winter. The exceptions were year long flux measurements at the SSA-OA and the NSA-OBS. Assimilation of carbon by the SSA-OBS stand, for example, was already in full swing when the University of Edinburgh team (TF-9) began measurements on 23 May, although at that time part of the soil profile still contained ice and there was water over the ground surface at temperatures of close to 70°C. When measurements were terminated at the end of IFC-3, the net ecosystem influx of carbon was continuing at a substantial daily rate and may well have continued through October and into November before CO_2 efflux exceeded influx. It is clear that to obtain a complete carbon balance, canopy scale flux measurements should have begun during or immediately after the main part of the thaw and continued through until the system froze up again some time in November. It is likely that the estimate of a carbon sink of about 1.8 tons/hectare may be an underestimate if there was significant assimilation both before and after the 140 days of measurements or an overestimate if respiration predominated, but any assumptions in this regard depend on knowing more about the balance between assimilation and respiration during these periods. Without additional information, it is impossible to model what may have happened because the environmental conditions during the thaw and freeze-up lie well outside conditions during the measurement period. Data from the SSA-OA and NSA-OBS sites show that significant C fluxes occurred in the spring, autumn, and transition periods and that these fluxes are of considerable significance to the annual carbon balance. At NSA-OBS CO2 effluxes in October and November substantially reduced the C gain over the previous four months.

2.2 Component Fluxes

At NSA-OBS, photosynthesis appeared to continue well into November. For both NSA-OBS and SSA-OA, substantial tree and soil respiration occurred in autumn, winter, and spring. While respiration rates were relatively low outside the growing season, the non-growth period is lengthy compared with the relatively short growing season, so that the cumulative C efflux is a significant portion of the annual net flux balance. Additionally, efflux through the snowpack can also be a large component when accumulated over a long winter (Sommerfeld et al. 1993).

The importance of studying component fluxes can also be demonstrated with preliminary data derived from measurements of carbon fluxes above and below the SSA-OJP stand. Measurements of net canopy carbon fluxes at the SSA-OJP stand showed little seasonality over the course of the growing season. Yet, when above and below canopy flux measurements are used to interpret net fluxes due to apparent photosynthesis, plant and soil respiration, considerable seasonality was observed in the components. And these components were forced primarily by seasonality in PAR and air and soil temperature.

To understand controls over the fluxes both within and outside the growing season, so that models can be built, modified, or validated, focused experiments are needed to determine how fluxes of the different ecosystem components respond to environmental variables. This requires concurrent chamber and tower flux measurements. Within the growing season (i.e. IFC 1 to IFC 3), chamber measurements made on TF sites by teams from TE, TGB and TF were not optimally coordinated and were insufficiently focused on the interpretation of the NEE being obtained by TF. While the SSA-OA and NSA-OBS flux towers have provided very useful information about the seasonal cycles and magnitudes of NEE outside the main growing season, few comparable chamber data were collected outside the growing season. Even at these long-term measuring sites, tower flux measurements were rarely coupled with the chamber measurements necessary to evaluate the significance of the component processes and to upscale them to stand scale. It was usually not possible for leaf gas-exchange groups to measure continuously CO_2 and H_2O exchange of leaves in several positions in the canopy for 2-3 days at one site. Such measurements are necessary to validate measurements by TGB and TE groups using lysimeters and chambers to test models of H_2O and CO_2 exchange at the forest floor . This is particularly true in the case of the moss surfaces in the OBS sites in the SSA and NSA.

2.3 Understory Vegetation

In addition to the tree and moss layers, there is an additional layer of understory vegetation on all sites comprising small shrubs, herbs and grasses. The significance of this layer to ecosystem functioning has largely been ignored. Very few measurements of any kind (e.g. biomass, leaf area, CO2 and water vapour fluxes, stomatal conductance, etc) were made on this layer in 1994. Thus it is not now possible to evaluate the significance of the understory layer to whole system NEE, either through direct comparison or modelling.

The sparse nature of boreal forests also allowed a significant portion of incident sunlight to reach the canopy floor. Few studies addressed the relative transmission of light through the canopy. Yet, this information is crucial to interpret and model fluxes of the understory biota.

The role of the moss layer was not adequately appreciated during the run-up to BOREAS-94 and consequently few measurements were made on the ground vegetation comprising mosses and lichens in the tree stands in 1994. Bryophyte dominated peatlands are controlled by subtle gradients in hydrology and chemistry (e.g. Glaser et al. 1990) which determine not only species distribution but rates of production and decomposition as well (Johnson and Damman 1993). For example, a broad range in net primary productivity (NPP) was observed by Bubier and Moore during the 1994 BOREAS field season across a range of plant communities near the NSA Fen site. This variability in NPP appears to be associated with the type of plant community.

Bryophytes have very different physiological requirements to vascular plants and therefore show both seasonal and spatial differences in production and decomposition. Because they lack vascular structure, their ability to obtain and hold moisture is critical. Boundary layer resistance, growth form, and microtopography are all important in determining water retention and loss. Unlike vascular plants, bryophytes cannot withstand long periods of drought and they grow faster in low irradiances (Proctor 1990; Murray et al. 1993). This results in two periods of peak activity of the bryophyte community: early in the growing season during and after spring thaw before vascular plants become active and late in the growing season when vascular plant senescence and the autumnal water flux balance shift make more moisture available to the bryophyte community.

Because bryophytes lack any vascular structure to obtain water and nutrients, they are very sensitive to changes in the local hydrologic balance. In wetlands they are surrogates for the average position of the water table and are therefore good indicators of long-term hydrologic trends (Andrus 1986) and average methane fluxes on small scales (Bubier et al. 1995). Bryophytes can also contribute a significant portion of the annual net primary productivity of a site (e.g. 35-85% in an undrained Finnish forested bog, Vasander 1982). In upland boreal forests, it has been observed that dominant feather mosses such as Pleurozium schreberi and Hylocomium splendens can be more productive than the trees or shrubs (Oechel and van Cleve 1986). The net ecosystem exchange of C with the entire ecosystem as well as the moss layer is inextricably tied to the local hydrologic cycle. Hence the moisture dynamics of the moss layer needs to be understood in order to assess quantitatively the response of the moss layer and its relative contribution to NEE.

The results of a process level model of moss activity developed by Frolking (TE-19) have been compared to the continuous record of net C exchange at NSA-OBS. The model captures the variability and some very important general features of the seasonal NEE that are measured at the NSA-OBS. There are three in particular. One is the rapid onset of C uptake activity in the spring after thaw. Because measurements were not made during this period modellers were obliged to use photosynthesis-PAR response functions developed at temperatures above 10 C.

Secondly, after the early summer maximum in NEE, the model predicts a long slow decline in C uptake activity by the moss layer. Thirdly, the model indicates that the timing and magnitude of net loss of C observed during the late fall/early winter period could be directly affected by bryophyte dynamics but these were not measured during the freeze-up period.

2.4 Interannual Variability

1994 was a record warm, dry year. Measurements indicate that the atmospheric water vapour saturation deficit led to stomatal closure and that the comparatively high temperatures led to excessive CO_2 effluxes as a result of high respiration rates. Both these effects could well have diminished the net gain of carbon during the central part of the summer. Consequently there is a need to determine whether similar effects will be observed in a year likely to have rather different conditions by repeating a period of measurements.

It is necessary that this IFC take place during the growing season because; (i) this is the time of the year when carbon accumulation and water use is highest, (ii) the accuracy of the experimental results is highest in summer when fluxes are largest both above and below the forest canopy, (iii) at this time of year deciduous forests are fully leafed out and the moss layer in the black spruce stands are most active and iv) the weather in summer is more likely to ensure success of all the participating science groups.

During the summer of 1994, water vapour fluxes were generally small and Bowen ratios large. The large sensible heat fluxes generated led to the development of deep, dry, turbulent atmospheric boundary layers over the region in summer 1994. The development of these deep, dry boundary layers, combined with the strong saturation deficit responses of the vegetation, suggest that positive feedback may lead to further drying of the vegetation on a regional scale. To verify this suggestion some radiation and flux measuring aircraft, ground-based radiation measuring systems such as the PARABOLA, and radiosondes, need to be operational for a period in 1996, together with flux measurements. It is essential that these concurrent surface - ABL measurements be made at least during the summer IFC, and desirably also during the fall IFC, to ensure that we can properly interpret and understand our surface flux measurements; see other papers.

Because the low evaporation rates, the large Bowen ratios and the development of deep, dry atmospheric boundary layers are the result of small canopy conductances, much greater emphasis needs to be put on the response of the stomata of the forest tree species to environmental variables. At several TF sites in 1994, insufficient stomatal conductance data were obtained at leaf scale for physiological analysis or for comparison with estimates of canopy conductance from eddy flux data.

During 1994, TF groups logically focused on continuity and quality of overstory fluxes so eddy covariance measurements above the forest floor were infrequent or lacking on most sites. However, measurements at several forest sites by eddy flux or with chambers, have shown that a very significant fraction of stand CO_2 efflux originates at the forest floor. This flux is comparable in magnitude with the CO_2 influx to the canopy in photosynthesis and its accurate measurement is consequently very important to the daily net CO_2 balance. Chamber measurements have shown that point to point heterogeneity is large, so that both intensive and extensive sampling is required. Measurements of CO_2 efflux in the trunk space by eddy covariance average over this microscale heterogeneity. A focused experimental comparison between such measurements, in the flux footprint would give confidence to both approaches.

The half hourly CO_2 efflux data at night obtained in 1994 generally show erratic time series and dependence on wind speed (or u*) at low wind speeds. It is therefore possible that some of the night-time CO_2 efflux is not being measured by the eddy covariance system as a result of spatially distributed eddies breaking out through the temperature inversion. A summer IFC will provide an opportunity to systematically explore this possibility by carefully focused measurements.

3.0 Measurements

3.1 Overview

Some TF measurements and associated in situ observations should extend from before until after the end of the 1996 growing season; see text below. This will be augmented by a summer IFC designed to perform a well-coordinated three to four week experiment that will provide data from several key sites to test our physiological, NEE exchange and canopy-ABL feedback models.

The experiment will require continuous measurement of CO_2 and H_2O fluxes above stands at selected forest sites and concurrent eddy-covariance measurements of CO_2 and H_2O below the forest canopy. Chamber measurements of CO_2 (and other trace gas) fluxes from the forest floor should also be made during daytime and night-time throughout the IFC. Chambers should be installed to measure moss photosynthesis and respiration and tree bole respiration should also be measured continuously. These measurements are necessary to help resolve the difficult issue of estimating accurately the night-time net CO_2 efflux from the forest. Leaf or branch chambers should be operated continuously and should be complemented with porometry measurements for stomatal conductance at 3 or more levels in the overstory and at least one level in the understory and moss layers. Heat balance or heat pulse techniques should be used to provide an independent measurement of tree transpiration. Chambers and lysimeters should be used to measure moss transpiration and forest floor evaporation (a comprehensive list of measurements is given in Appendix 1).

Radiosonde and tethersonde ascents are extremely important for the testing of ABL-mixed layer models of canopy evaporation and CO_2 exchange and to establish the role of negative feedback between the ABL and the stomatal conductance of the forest. Remote sensing indices, including NDVI, the simple ratio, bi-directional reflectance (PARABOLA) must be obtained together with canopy leaf area index and structure (LI-COR LAI 2000 and TRAC). Finally high quality supplementary measurements of climate (radiation fluxes, etc) (Mesonetwork) and soil moisture (HYD groups) data must be maintained.

3.2 Specific Measurement Objectives

The above discussion of issues leads to the following more specific objectives.

a. To determine the net ecosystem flux and associated processes of canopy assimilation and soil CO_2 efflux during the thaw period at the start of the season to determine whether the stands pass through a period of CO_2 efflux before assimilation takes over. Secondly, to determine the net ecosystem CO_2 flux during the autumn at the end of the growing season through until the net CO_2 flux is near zero when the system freezes up.

b. To determine closed C, water and trace gas budgets for the stands over a year by measuring their fluxes in new campaigns in spring and fall. During a summer IFC, do focused experiments to establish the validity of measurements of night-time CO_2 effluxes.

c. To measure fluxes and processes of the major components within the stand system, i.e. overstory, understory, moss and soil, in relation to environmental and state variables so as to understand and explain the stand scale fluxes. To investigate in greater detail sensitivity of the net ecosystem CO_2 flux to externally caused changes in canopy assimilation and soil CO_2 efflux, with the aim of elucidating the controls that determine whether the net system flux is positive or negative.

d. To measure water vapour and CO_2 fluxes, together with stomatal conductances, during a summer IFC in conjunction with a parallel concerted program of ABL measurements by RSS teams to ascertain whether avoidance of internal water stress by stomatal closure exacerbates the degree of external stress by positive feedback.

e. To determine whether parameters obtained in 1994 are valid from year to year and in the proposed spring and fall periods in 1996 throughout the year, by an additional mid-season period of observations. To provide suitable data to parameterise and test both stand and regional scale models for those parts of the year for which data are currently non-existent or inadequate.

f. To make contributions to basic micrometeorological and ecophysiological theory, particularly with regard to processes in the atmospheric boundary layer.

3.3 Working Hypotheses

These hypotheses are the expressed primary motivation of particular individuals or teams. No priorities are attached to them.

3.3.1 Spring Thaw / Fall Shutdown

a. Photosynthesis, respiration and transpiration begin while the soil is still frozen in the spring and continue well into the freeze-up in the fall.

b. Timing of the thaw and extent of snow cover has a major impact on net ecosystem exchange of carbon.

c. As solar radiation increases, CO_2 assimilation rapidly exceeds CO_2 efflux.

d. CO_2 assimilation is strongly influenced by air temperature and CO_2 efflux is strongly influenced by soil temperature.

e. CO_2 efflux from decomposition is controlled by the freeze-up and thaw.

f. CO_2 efflux in fall and winter originates from decomposition of old, slowly decomposing soil organic matter: efflux of CO_2 in the summer originates largely from root respiration and the labile soil organic matter pool.

g. Radar can identify the freeze/thaw transition at times that relate to changes in physiological activity.

3.3.2 Understory Functioning

a. The understory vegetation of shrubs, herbs and grasses makes a significant contribution to NEE of CO_2, trace gases and water vapour at all times of the growing season from thaw to freeze-up.

3.3.3 Moss Functioning

a. The feather mosses, Sphagnum and lichens make a major contribution to net ecosystem exchange.

b. The net primary productivity of the moss layer is as important as that of the trees in determining C storage.

c. CO_2 assimilation by moss restricts loss of C to the atmosphere as a result of root respiration and decomposition of soil organic matter.

d. Moss photosynthesis and methane loss is controlled by water content and temperature, so that the significance of the moss layer varies seasonally.

e. Interception by tree crowns determines the water content of the moss layer.

f. Evaporation from the moss has an impact on the water status of the moss layer.

g. Evaporation from the moss is controlled by net radiation and canopy ventilation and makes a major contribution to the water vapour flux from the stand.

h. Hummocks and hollows determine the variability in CO_2 and CH_4 efflux.

i. Moss slows down drainage and surface run-off.

j. Moss distribution can be determined by optical and microwave remote sensing.

3.3.4 Summer IFC

a. Diurnal and seasonal coupling of fluxes of CH_4, H_2O and CO_2 at the fen sites is controlled by the water table and by temperature.

b. The radiation and temperature responses of leaf scale photosynthesis is the same throughout the growing season so that one set of parameters suffices.

c. A small increase in temperature or a decrease in solar radiation causes the system to change from a CO_2 sink to a source.

d. Carbon use efficiency is conservative with respect to species and temperature.

e. Diurnal and seasonal fluctuations in soil CO_2 efflux are controlled by physiology of tree roots and foliage.

f. Fluxes and physiology vary with the weather from one year to the next.

g. Atmospheric feedbacks determine surface conductance and physiological activity of foliage, and vice versa, rather than soil water.

h. Clouds have a major impact on the positive feedback between surface conductance and atmospheric boundary layer development.

i. Microscale variation in soil hydraulic properties is more relevant to the development of the atmospheric boundary layer than in mesoscale variation.

3.4 <u>Sites and Timing</u>

3.4.1 Priority Sites

The main elements in the landscape mosaic are extensive stands of Black Spruce and large areas of fen. Consequently these two vegetation types constitute the main priority areas at both the SSA and NSA. For logistical reasons, flux measurements are occurring at the SSA-FEN site during 1995: the NSA-FEN site will be a priority for flux measurements during the priority periods in 1996.

Flux measurements at NSA-OBS are continuing - summer and winter - throughout 1995 and 1996. Flux measurements at SSA-OBS is the highest priority for the priority periods in 1996. A concerted effort must be made to measure concurrent component fluxes with chambers at these spruce sites.

NSA-OJP. No measurements have been made outside the growing season for jack pine sites, but these sites were still net carbon sinks at the end of IFC 3 in 1994. Therefore, measurements on a jack pine site outside the growing season are a priority.

NSA-YJP. No measurements have been made outside the growing season for recently disturbed or recovering sites, but, recovering sites are a very large component of the northern boreal landscape. Additionally, we need to determine whether the differences in CO_2 and H_2O fluxes between the young and old jack pine sites continue in the spring and autumn periods.

SSA-OA. Measurements in the spring and fall were made in 1994, but need to be tied to a larger program of chamber measurements to validate scaling models.

3.4.2 Priority Periods

Priority periods comprise the following:

Spring -	March 1 to May 31;
Summer -	July 9 - August 9
Fall -	September 15 to November 30;

These periods have been selected to cover the thaw period in the spring with a one week overlap of the 1994 IFC 1 and the freeze-up period in the fall with a one week overlap of the 1994 IFC 3. For the majority of sites, measurement of fluxes in 1994 was continuous from the beginning of IFC 1 to the end of IFC 3 over a period of four months. The period March to November is more than twice as long but it is possible that one or more of the flux measuring teams (in addition to NSA-OBS) may be able to make continuous measurements over the whole period, if ancillary operators can be found to assist.

3.5 Measurement and Modeling Coordination

3.5.1 Integration Amongst Measurement Teams

For the spring, summer and fall priority periods, a fully integrated measurement program is proposed for the five flux measuring sites in 1996. A list of the measurements proposed is given in Appendix I. The involvement of particular teams and their integration into a coherent program on the individual sites remains to be worked out. Similarly, detailed measurement protocols need to be agreed upon.

3.5.2 Integration with Modelling Teams

Active participation of modelling teams in data collection during the priority periods is requested. All parts of the measurement program - overstory, understory, moss and soil - would benefit from direct involvement of modellers in the measurement program, at both the planning stage (October 1995) and measurement stages.

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Appendix I

To achieve an integrated approach at stand scale, consider fluxes and processes at the following six levels:

above the stands,
in the overstory canopy,
in the trunk space,
in the understory canopy,
in the moss layer,
* at the soil surface and in the soil,

together with

stand and tree structure.

The following schedule of measurements would go a long way to fulfilling all needs of measurement and modelling teams and would lead to closed C and water balances.

Above the canopy

Tower flux measurements Fc, E, H, t
Weather station (T, q, Q, S, Rn, u, dir, precip)
Parabola (+ Rn?)
Aircraft based fluxes
Radiosondes / tethersonde

Within the overstory canopy

Profiles - [CO2], T, q, u, v and w
Radiation - Q, S
Leaf T, wood T
Air (and foliage) d13C and other trace gases
CO2 assimilation / respiration A, gs
Trace gas fluxes
Foliage N, P and y
Foliage wetness

Within the trunk space

Flux measurements - Fc, E, H, t
Weather station (T, q, S, Rn, u, dir)
Spatial distribution of radiation - Q, S, Rn
Throughfall, stem flow
Sap flow in trunks
(Fish eye photos)

Within the understory canopy

CO_2 assimilation / respiration A, gs
Trace gas fluxes
N,P, y

Within the moss layer

Productivity
CO_2 assimilation / respiration, A, gs, d13C
Evaporation
Water content
Temperature
Gas concentration profiles

Within the soil

Heat flux
Temperature profile
Water content profile
CO_2 concentration
Root, "soil" respiration
CO_2 efflux

Structure of the stand

(tree numbers and spacing)
Understory species, distribution, leaf area
LAI

Structure of the trees

Crown dimensions
(Branch numbers, dimensions, leaf area)
LAD distribution

Key

All periods
Summer IFC only
1994 data probably adequate

List of symbols

A	wood / foliage assimilation / respiration rate
dir	wind direction
E	stand evaporation / transpiration flux density
Fc	stand CO_2 flux density
gs	stomatal conductance
H	stand sensible heat flux density
q	specific humidity
Q	photon flux density
Rn	stand net radiation flux density
S	solar irradiance
T	temperature
u,v,w	directional wind speed components
t	momentum flux density
y	leaf water potential

II. Surface and Atmospheric Boundary Layer Studies for BOREAS for 1996

1.0 Introduction

1.1 Goal

The goal of the continued collection of surface, atmospheric boundary layer (ABL) and upper air data in BOREAS is

(i) to link the surface flux measurements to the atmospheric boundary layer, and
(ii) to provide validation data sets for modeling studies on all scales from the stand level up to global models and ecosystem models.

1.2 Background Scientific Issues

The 1996 measurement campaign is driven by the need to get a complete seasonal cycle to address the annual carbon balance, and the desire to understand better the component fluxes, and the contributions by the understory (especially the moss layer, see paper I). The 1994 measurement campaigns did not adequately sample the transitional seasons of spring and fall, nor provide adequate measurements of the understory except at the Old Aspen site.

The ABL measurements are largely in support of the tower flux measurements, as well as modelling studies. In 1994, the continuous surface flux and meteorological measurements and the more detailed ABL measurements by aircraft, rawinsondes, a wind profiler, cloud radar, lidar ceilometer and a cloud camera provided a detailed data set to analyse the interactions between the surface and the overlying atmosphere. Much of this analysis is still in progress. The 1994 campaign confirmed the importance of the feedbacks between deep dry ABL's, which produce large vapor pressure deficits at the surface, which reduce evapotranspiration though stomatal closure. In addition, studies at the NSA OJP site by TF8 suggest the need for further studies of the links between cloud cover, and stomatal controls. The 1994 measurements were however probably not adequate to address the diurnal cycle of CO2: there is a large storage component at night in the shallow nocturnal ABL, which is vented as the daytime ABL grows (on most but not all days). There were some deficiencies in the aircraft flux measurement program; the fluxes of energy and CO2 from the lakes were not measured in autumn when the lakes are warm and fluxes are high. In addition, the 1994 aircraft measurements of absolute carbon dioxide concentration were not accurate enough to assess spatial variability above different land-cover elements or to be of much use to atmospheric tracer modeling studies.

It is important to maintain the surface meteorological network to provide long-term data for land surface and ecosystem models, and to make supporting

ABL measurements during some of the 1996 IFC's. We believe that aircraft flux and upper-air measurements are integral to the overall BOREAS objective of upscaling tower fluxes and closing the surface carbon and water budgets at the regional scale. Aircraft flux measurements are needed to assess the spatial heterogeneity of surface energy and carbon fluxes and to quantify fluxes from different land-surface elements. Rawinsondes are needed to provide local atmospheric conditions for large-scale atmospheric models. The atmospheric models in turn produce gridded analyses for nesting column and mesoscale atmospheric models and for driving large-scale hydrologic and ecological models. Boundary-layer depth (as measured by vertical profilers and rawinsondes) is needed to relate the diurnal cycle of surface fluxes and climate to boundary-layer evolution.

At present, the surface meteorological measurements from BOREAS are being used to drive both local stand level SVAT models and regional ecosystem models. These models require long continuous time-series of forcing variables. Beyond the few years of surface data being collected for BOREAS, ecosystem models must use surface climate data (which typically lack the surface radiation budget) and global model products, which are limited by model accuracy. The BOREAS ABL data are being used to link the surface stand-scale measurements to the overlying atmosphere, and to address the difficult problem of scaling tower site fluxes up to larger scales (such as the 50km grid scale of a global forecast model). In addition these data are being used to directly test and improve the surface and ABL parameterizations in large-scale models. All these modelling studies will benefit greatly from a second data validation period within the longer period of background data.

1.3 Objectives for Surface and ABL Measurements for 1996

These are the specific objectives for continued measurements:

a) Continue the time-series of surface meteorological and radiation measurements for modelling studies through 1996.

b) Provide monitoring of ABL depth (especially at night) and cloud fields (base and fraction) to support TF measurements, spring through fall of 1996.

c) Use aircraft and radiosondes during the summer and fall IFC's to measure area averaged fluxes and daytime ABL evolution to scale from tower sites up to regional scale.

d) To use these integrated data-sets for summer and fall IFC's for the further test and development of large-scale models within the long-term framework of the BOREAS surface observations.

1.4 Large-Scale Modelling Overview

Figure 1 summarizes some of the important feedback loops for the land-surface-atmosphere interaction (from Betts et al, 1995). The figure distinguishes a diurnal loop (heavy solid lines) and a longer time-scale "seasonal" loop (heavy dashed lines) associated with the longer time-scale memory of soil temperature and moisture. A "century" time-scale loop between vegetation and aerosol has been indicated as a light dashed line as a reminder of the periodic burning of forests, which add aerosols to the atmosphere and reduce the incoming net radiation. The light line marked 'stomatal closure' represents the vegetative control on evaporation in warm dry atmospheric conditions. The surface radiation budget (SRB) drives the strong diurnal surface cycle over land. The partition of the SRB into the sensible and latent heat fluxes, which drive the diurnal cycle of the ABL, is controlled by the vegetation (through feedbacks involving light levels, soil moisture, temperature and humidity). The formation of clouds and precipitation is linked to ABL equivalent potential temperature, which depends not only on the surface fluxes but the deepening of the ABL by entrainment. In turn, the cloud fields reduce the incoming solar radiation; while precipitation replenishes the soil moisture. At night, a shallow ABL forms which traps gases in a stable layer near the surface often only one or two hundred meters deep, until the sun rises the next day.

2.0 Measurements for 1996

Some continuous measurements are needed: monitoring of the ABL depth and cloud parameters. Some measurements are only practical for intensive measurement periods and we will deal with them first.

2.1 Intensive Measurement Periods in 1996

The primary purpose of a 1996 measurement campaign is to fill gaps in the seasonal cycle. However, aircraft flux and upper-air measurements are practical only for focused IFCs and are best suited to periods when fluxes are high. We recommend a summer IFC as a first priority, and an autumn IFC as a second priority.

2.2 Boundary-Layer Flux Aircraft for 1996

Flux aircraft are needed to add a spatial perspective to local tower flux data. The flux aircraft provide area-averaged surface fluxes of heat, moisture, carbon dioxide and momentum; quantify spatial heterogeneity in the surface fluxes; confirm whether tower flux sites are representative of their land cover types; and characterize land covers not sampled from towers, including lakes, burns, and mixed and regenerating forest. They also measure spatial heterogeneity in carbon dioxide concentration, a measurement which may be critical in upscaling the surface carbon budget. Aircraft flux data are also essential for interpreting the observed 1996 seasonal and 1994-to-1996 tower flux differences in a larger area context.

In 1996, particular attention should be paid to accurate measurements of absolute carbon dioxide concentration and to the estimation of surface carbon dioxide fluxes using upper-air budget methods. Night-time carbon dioxide efflux should be measured in the early morning using budget methods for the nocturnal boundary layer. In addition, lake fluxes should be measured in early morning and autumn, when lakes may contribute significantly to regional moisture and (possibly) carbon dioxide fluxes.

The Twin Otter should be flown in the summer IFC, extending the SSA "agricultural run" line pattern into the southern SSA forest and repeating the SSA "Candle Lake run" line pattern, the SSA-NSA transect and the 1994 SSA and NSA grid patterns. The Twin Otter will use its new facility for methane flux measurement, if available. The Long EZ should be flown in the SSA in the autumn IFC, paying particular attention to lake fluxes and autumn changes in surface flux heterogeneity.

The flux aircraft should occasionally be used in a profiling mode to (i) gather statistics on turbulent components (TKE and u', v', w') under various cloud cover conditions and (ii) to obtain daytime CO2 profiles through the ABL.

2.3 Upper-Air Measurements in 1996

Rawinsonde releases from the two principal 1994 BOREAS upper-air sites (Candle Lake and Thompson zoo) are needed during the 1996 IFCs. Rawinsondes provide large-scale models with local inputs for defining atmospheric fields. These fields are required to initialize column and nested models. Rawinsondes also provide boundary-layer depth and structure for interpreting surface flux measurements, and facilitate the regional estimation of surface fluxes and entrainment by upper-air budget methods. A morning (near 1200 Zulu) sounding shows the depth of the nocturnal ABL, and an evening sounding will give the depth reached by the ABL on that day. Sequences of soundings every 2 hours permit the calculation of ABL budgets which, given the surface fluxes, can estimate entrainment level fluxes using composite methods. Because upper air data is costly in terms of manpower and expendables, a launch program only during selected IFC's is feasible. The 1996 upper-air campaigns should overlap the flux aircraft measurements. We recommend a schedule of 6 launches/day during Summer and Fall IFC's at 1115, 1515, 1715, 1915, 2115, 2315 Zulu at Candle Lake and Thompson. The sondes at 1515, 1915, and 2115 will be dropped on days that are rainy at 1430 Zulu in the morning. A total of 400-500 sondes will be needed depending on the length of the IFC's and the weather. Two sondes per day at synoptic times at nominally 1200 and 2400 Zulu are launched operationally from Saskatoon, The Pas and Churchill. In 1994 these sites launched extra sondes at 1800 Zulu during IFC's. This would be again be desirable for the summer and Fall IFC's of 1996, but it is a lower priority than launches at the 2 BOREAS sites.

2.4 Surface Meteorological Measurements in 1996

The surface meteorological network is an integral part of the BOREAS measurement program. It provides a standard and consistent data set for input into hydrologic and ecosystem models, and for validating atmospheric models. The surface meteorology network installed by SRC (AFM-7) became fully operational in the spring of 1994. Some stations and sensors were installed as early as December, 1993. The continued operation of its principal sites through 1996 is essential to any continued BOREAS field activities.

The transmission of coded surface data from these stations to the GTS every 6 hours, should continue through Oct 31, 1996. BOREAS should request that those AES autostations installed in the region in 1996 continue to archive 15 min data, preferably for the entire year.

2.5 Cloud Monitoring for 1996

The 1994 BOREAS data set lacks adequate cloud observations, particularly in the SSA. Clouds cause gross heterogeneity in the surface fluxes. Additionally, cloud field evolution is a critical diagnostic in atmospheric model validation.

We recommend continuous monitoring of cloud cover and base height by lidar ceilometer and digital cloud camera during the 1996 tower flux measurement periods at both the SSA and NSA. We need to know both the fraction of ABL cloud and the depth of the subcloud layer to estimate the effect of ABL clouds on the subcloud layer budget of heat and moisture.

2.6 Continuous Boundary-Layer Depth Measurements

Boundary-layer depth is needed to place tower fluxes in the deeper boundary-layer context. ABL depth influences the diurnal variation in near-surface temperature, humidity, carbon dioxide and trace gas concentrations, which in turn provides feedback to surface fluxes. The measurement problem is different for day and night. At night the nocturnal ABL is shallow (a few 100m) and consequently CO2 from respiration is trapped in a shallow layer. Sodar measurements can provide ABL depth and a wind profile at night (they have a ceiling of order 500m). In the daytime, a wind profiler can give the depth of the ABL, as can sondes at 2hr intervals during IFC's. A lidar ceilometer gives an indication of cloud base; which is at the top of the mixed layer when ABL clouds are present.

We recommend the continuous operation of a ABL profiler / sodar at both SSA and NSA.

If funds are insufficient, we suggest sodar at both NSA and SSA OBS (for the night time ABL measurement), and rely on the lidar ceilometer for daytime ABL cloud height. This is a resource issue; the Old Aspen site has also requested continuous ABL measurements. However in 1994, there were only funds for one wind profiler.

2.7 Surface Meteorological Measurements Beyond October 1996

Plans should be made to continue a reduced network beyond October 1996, preferably for 5-10 years for long-term climate studies. BOREAS has collected a unique data set for this region, and monitoring and modeling the long-term interannual coupling between the climate and the ecosystem is of great interest.

1. We recommend 4-5 BOREAS sites be continued:

    SSA
    SSA-OA; Suite A and B
    SSA-OJP; Suite A and B
    (If SSA-OBS is instrumented, it could be continued as well)

    NSA
    NSA-YTH (near Airport); Suite A; supported by the AES
    SW, LW and Diffuse radiation data from Thompson Zoo.
    NSA-OJP / Fen; Suite A / B

2. Request SRC to continue to supply the data from their permanent site in Saskatoon.

Reference:

Betts, A. K., J.H. Ball, A.C.M.Beljaars, M.J. Miller and P. Viterbo, 1995: The land-surface-atmosphere interaction. J. G. R. (In press)

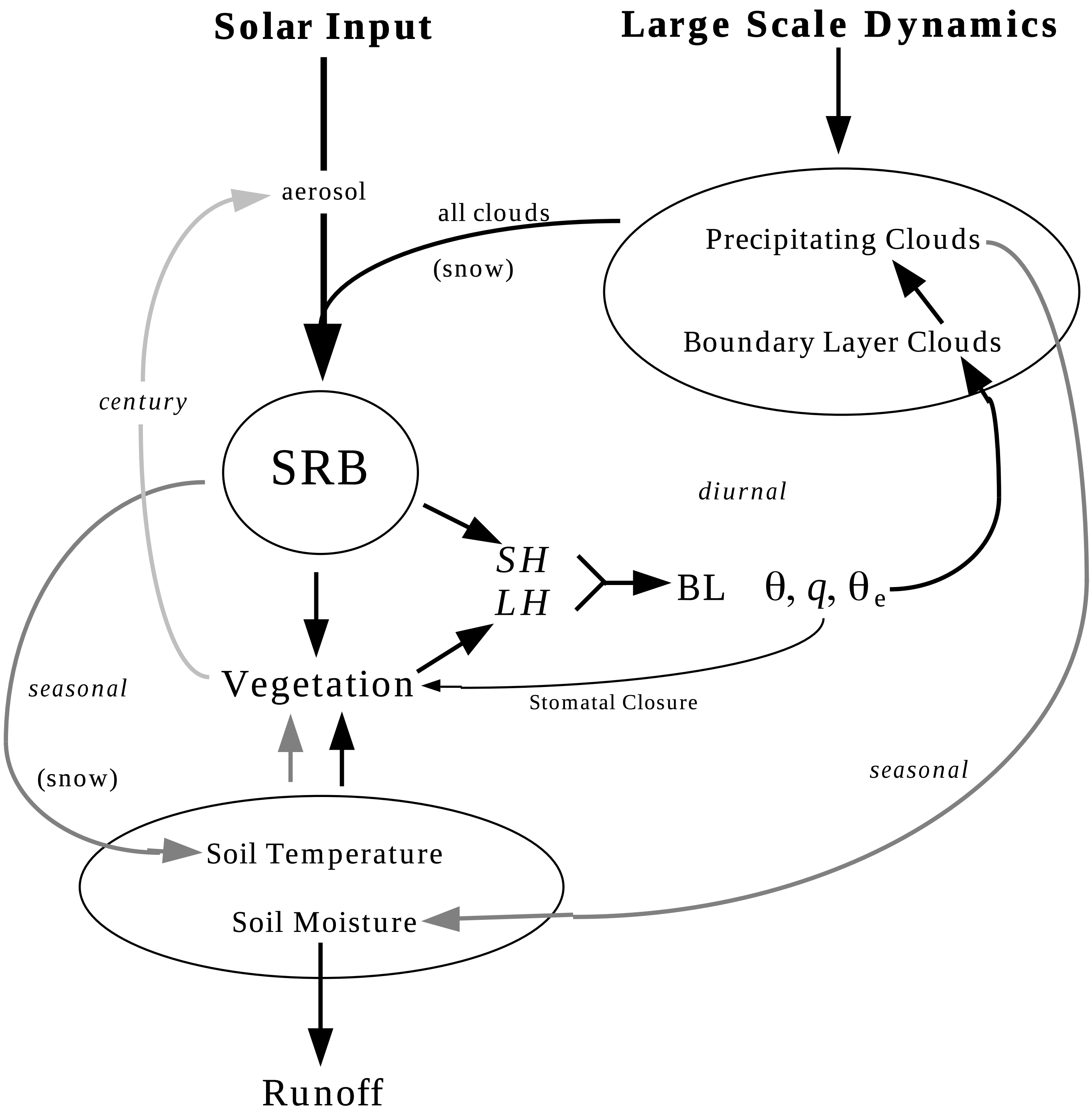
Solar Input
Large Scale Dynamics
aerosol
all clouds
(snow)
Precipitating Clouds
Boundary Layer Clouds
century
SRB
diurnal
SH
LH
BL θ, q, θe
seasonal
Vegetation
Stomatal Closure
(snow)
seasonal
Soil Temperature
Soil Moisture
Runoff

Figure 1

III. Remote Sensing Science

1. 0 Introduction

1.1 Goals

The remote sensing science initiative in BOREAS has two principal goals:

(i) to provide data for the study of the processes governing the interactions between the boreal forest and the atmosphere over a range of spatial (patch to region) and temporal (hours to decades) scales.

(ii) to provide data for the development, testing, and use of models simulating the behavior of the total ecosystem-atmosphere system under study.

These data are essential to specify the initial conditions, the boundary conditions, or the actual state for validation of the variables predicted by the models. These goals are at the core of the BOREAS science and experiment plans, and the motivation underlying all BOREAS remote sensing science (RSS) investigations is to ensure that remote sensing can deliver on its expected capabilities. Vital contributions toward these goals also come from investigators in the Hydrology (HYD), Terrestrial Ecology (TE) , and Atmospheric Flux Measurement (AFM) groups. It is against these expectations that the progress to date and future plans are considered.

1.2 Background Scientific Issues

With regard to modeling, the primary interface between RSS and the modeling activities are data products, i.e. gridded fields of parameters required by the models. Three categories of models are involved, each with somewhat different needs: ecological models optimized to represent the behavior of the ecosystem, principally during the growing season; hydrological models intended to describe the behavior of water in its various phases at and near the surface during the whole year; and atmospheric boundary layer models which characterize the energy and mass exchanges over short periods at various levels within the ecosystem and the adjacent planetary boundary layer. To address these needs, several data products to be derived from remote sensing data were defined in the BOREAS Experimental Plan Version 3.0 and BOREAS investigators undertook to produce these for the modelers. Table A-1 in Appendix A summarizes these data products and the responsible investigators.

In general, the approach of the RSS investigators has been to (i) use and apply the pre-BOREAS state-of-the-art knowledge of extracting the parameters from existing satellite or airborne data (Table 1); (ii) use ground data from 1994 for validation of these initial products; (iii) use more detailed (surface, tower, airborne) measurements from 1994 to develop algorithms for generating more accurate products; and apply these algorithms to existing data or to attempt to collect new data, within BOREAS or otherwise. In order to fully exploit the BOREAS field data set, new algorithms ought to be evaluated, exploiting the capabilities of airborne sensors, to determine our ability to use new technology such as MODIS, MISR and RADARSAT for mapping of terrestrial biophysical parameters.

The various models implemented as part of BOREAS (especially hydrological and ecological) can be tested by using remote sensing products under a variety of conditions. Ideally, uninterrupted data which spans several years is compared to model simulations. Within BOREAS we have the advantage of trading space for time to construct a wide range of ecosystem type and climate scenarios. However, acquiring data for important seasonal phenomena are critical for assembling the full suite of model initializing and testing data.

2.0 Status After 1994 Campaigns

During 1994, a large amount and variety of remote sensing data were collected from aircraft and satellites as well as at ground level. Many initial data products have been completed, and others are at various stages of development and verification. The 1994 data will be used to develop parameter fields for NSA and SSA (Table A-2). Nevertheless, there are three important areas where the 1994 data set does not satisfy the needs of the science teams. These are (1) winter radiation and reflectance measurements, (2) necessary mid-season satellite and aircraft optical data to estimate parameter fields, as well as to critically required development and test algorithms, and (3) as revealed at the October 1995 BOREAS Workshop, data required to characterize the type, location and status of moss and understory. These areas are covered in the subsections below.

2.1 <u>Winter Radiation and Reflectance Measurements</u>

There are two principal issues that argue for the execution of limited field studies in a BOREAS winter focused field campaign (FFC-W) in 1996:

(i) Radiative transfer in the snow-covered boreal forest.

We do not have a clear understanding of the exchanges of energy within the snow-covered boreal landscape. The combination of dark forest elements, snow-covered ground, low solar angles and complex, directional thermal radiative exchanges have introduced large uncertainties into the surface radiation models used in climate and NWP models. We have good data and reasonably reliable models for use with snow-free surfaces, so that the differences between observed and calculated albedos in GCMs is estimated to be in the order of a few (~ 5%) absolute for snow-free surfaces see Sellers et al (1996). The uncertainty for complex snow-covered surfaces is estimated to be on the order of 10 to 30% absolute, based on a straw poll of modelers at the BOREAS workshop. In most cases, modelers combine elements of existing models; for instance, snow-field reflectances, canopy reflectances, etc., in simple ways to estimate the total surface reflectance. Hydrology models also require wintertime radiation data observed from above and from within the canopy to improve radiative transfer models capable of predicting likely periods of snow melt within and outside of the forest stand (i.e., under the canopy as distinct from the gaps between the trees). Directional reflectance and emittance measurements as a function of solar zenith angle, are required for different canopies (i.e., OJP, OBS, OA) for this purpose.

Good data, particularly multiangle data as supplied by ASAS and PARABOLA in combination with in situ measurements are needed to expose the shortfalls in existing models and provide improvements. Thermal data, as supplied by TIMS, are also highly desirable.

(ii) Spatial and temporal variations in the boreal forest snow-cover and albedo.

While the measurements gathered to satisfy point (i) above will lead directly to model improvements, it is still necessary to enhance our ability to quantify the spatial and temporal variations in snow cover and albedo from satellite data. As discussed in the science review below, climate and NWP performance can only be improved by the combination of increased realism of submodel components (point i) and the direct validation of the model fields generated by these improvements. While the physics of this second issue have much in common with the first problem, the aim is distinct. To meet the need, it will be necessary to gather a range of surface, airborne and satellite data; including, in situ observations, PARABOLA, ASAS, AVIRIS (as a substitute for MAS) and atmospheric optical property measurements. Again, TIMs data are highly desirable.

The scientific background to these issues is based on the results of several recent modeling studies. In particular, results generated from GCM research work have highlighted; first, the importance of snow-albedo feedbacks in the boreal zone and; second, the uncertainties associated with estimates of winter albedos over complex surfaces.

Randall et al (1994) reviewed the size and effects of snow feedbacks associated with 14 general circulation models. Some of the GCMs produced negative or weak feedbacks while others generated strong positive climatic feedbacks. The strong feedbacks were found to be due to the treatment of melting snow, near-surface meteorology, cloudiness and radiative transfer within each model. The temperature dependence of snow albedo was a significant factor in the strong feedback treatments.

The work of Bonan et al (1992, 1995) indicated that the effects of the forest canopy on winter albedo may be highly significant in determining the winter climatology of the northern mid- and high-latitudes. This work suggests that replacement of the boreal forest by a low-lying vegetation cover, such as could happen with a northward migration of biomes following continental warming and drying, would result in a large increase in the wintertime albedo over the northern high latitudes and dramatic changes in the climate there. Their model produced a 40% increase in winter albedo following deforestation; we do not know if this is realistic. This large increase in albedo simulated a significant decrease in winter and summer temperatures at these latitudes. This kind of effect could partially counteract the classical greenhouse effect which is predicted to generate a significant warming for the same area. Bonan et al (1992) go on to suggest that the current correlations of climate indices and biome boundaries in the boreal zone is a result of a two-way interaction between the biota and the physical climate system there rather than solely a consequence of (one-way) atmospheric forcing. These simulations were performed using a land surface parameterization coupled with an atmospheric generation circulation model (AGCM) which incorporated a fairly basic description of snow-vegetation-albedo effects. The uncertainty attached to this result is large, mainly because Bonan et al (1992, 1995) did not have enough information about the physics of radiative transfer within snow-covered boreal vegetation and also because they do not know how to spatially assign winter albedo fields for the region from satellite data.

Randall et al (1996) discuss some GCM climate model results generated using an improved version of the SiB model, SiB2. SiB2 incorporates a two-stream treatment of canopy-surface radiation exchanges which addresses, in a primitive way, the effects of snow on the canopy and ground reflectances and also the effects of patchy snow cover on the total surface energy exchange. It appears that the use of a very simple (linear) relationship between fractional snow-covered area and area-averaged snow water equivalent dramatically changed the dynamics of snow-melt and surface-atmosphere energy exchanges during the thaw and also brought the simulated snow cover distributions into closer agreement with inferences gathered from ERBE data. However, we must emphasize that these improvements, while noteworthy, are qualitative; better data are required to both test the surface radiation models and to infer snow coverage and albedos from satellite data for model validation.

A valuable set of BRDF data acquisitions was acquired during 1994 by the PARABOLA instrument. However, the timing of weather and sky condition events and the delay in developing the next-generation PARABOLA instruments prevented the collection of winter data sets. The greatest value of the intended PARABOLA data sets within the context of BOREAS (and EOS) is the capability for enabling the accurate validation of the wide variety of plant canopy and related models which are used for parameter extractions both directly and through inversions. Additionally, the specific-site assessments of albedo, FPAR, BRDF characterizations, etc. are valuable as ground truth for other RSS, TE and modeling groups. The following limitations exist in the current PARABOLA data sets: 1) no BRDF data are available for the very important winter snow cover conditions (i.e., for albedo/energy budget analyses and plant canopy model validations), 2) simultaneous above- and below-canopy BRDF measurements were not acquired (above and below data sets were acquired on different dates under the best sky conditions, etc. that were available), 3) narrow-band to broadband PAR conversion analysis is limited (PAR band and additional optical bands of anticipated next-generation PARABOLA III were not available), and 4) no directional thermal data for the complete directional radiation and energy budget analysis were acquired (original PARABOLA had no thermal band). PARABOLA-III measurements of BRDF and angular thermal emittance within the forest canopies should be acquired. Measurements with snow background and snow-on-canopy and background are needed for the models.

The utility of the ASAS data acquisitions (necessary for extending the albedo and snow melt model results beyond the PARABOLA sites) during the 1994 the FFC-T is limited. Data for the SSA (Southern Study Area) OBS, OA, and OJP TF sites were collected under conditions of no significant snow cover, and though airborne measurements for the NSA (Northern Study Area) TF sites were obtained with snow cover, there were no supporting canopy-level BRDF observations. The snow radiation data that are needed for forest albedo effects parameterization in GCM's can be acquired by flying ASAS on the C-130 or P-3 over the OBS, OJP and OA TF sites and two non-forested targets such as a frozen lake and an agricultural field. Careful selection of ASAS flightlines will ensure imaging a wide variety of forest stand types. At least two sun angles are required (near solar noon and earlier or later in the day).

2.2 Mid-Growing Season Optical Data

The coverage of Landsat TM data was inadequate, particularly during IFC-2 and IFC-3 in 1994 to derive critically needed parameter fields. Because of cloud cover and/or smoke there were no acquisitions of suitable data during IFC-1 and IFC-2 over the SSA and during IFC-2 and IFC-3 over the NSA. This will result in the lack of two key products, leaf area index (LAI) and the fraction of absorbed photosynthetically active radiation (f_{PAR}). Although SPOT data are available, RSS investigators are concerned that satisfactory products cannot be developed at this stage because of radiometric sensitivity and the lack of ancillary bands for atmospheric corrections.

The forest fire smoke conditions in IFC-2 were so severe that all of the airborne optical data are compromised to some extent: the C-130 (MAS, ASAS, TMS); the Chieftain (CASI) , and the helicopter (SE-590, POLDER). Of the data gaps, the most serious is the suite of C-130 measurements, particularly the incomplete MAS and virtually unusable ASAS data acquisitions over the NSA modeling subarea and TF sites.

The MODIS Airborne Simulator (MAS) was flown in support of a key BOREAS RSS effort directed at a view to the future of ecosystem remote sensing. The MODIS Land (MODLAND) Team is working with BOREAS toward a goal of development and validation of EOS-era parameter products. Although MAS mapped the entire modeling subarea grid in the SSA (Southern Study Area) during IFC-2, cloud-free coverage was obtained for only four of the seven NSA (Northern Study Area) flight lines under less than ideal observing conditions. In addition, The full 50 band, 12-bit configuration had not yet been implemented at the time of the BOREAS flights, limiting the spectral coverage and radiometric sensitivity required to employ the data in comprehensive analyses of algorithms under development by the MODLAND Team. Most significant is the lack of spectral coverage in the blue spectral region. The shortest wavelength band available during the BOREAS overflight was centered at 549.3 nm. This represents a serious deficiency for validating algorithms under development (particularly those dealing with atmospheric correction) which will require input from one or more of the three MODIS "blue" bands to be present on EOS AM Platform. This issue can be resolved by a summertime acquisition of AVIRIS data which can be subsequently processed into MODIS-like spectral bands.

Remote sensing models for developing and testing parameters such as LAI and fPAR use detailed information about directional reflectance of forest canopies. These measurements were attempted in 1994 by planning near-coincident aircraft and field acquisitions. This was done so that the detailed canopy level observations could be extended over larger areas using the aircraft measurements, thus expanding the data set available for algorithm development and testing. In addition the use of the aircraft data provides the basis for wider area ecosystem model parameter products. ASAS was the primary airborne sensor deployed to obtain these measurements, however poor sky conditions during the 1994 IFC's resulted in limited growing season BRDF datasets. During IFC-1, a complete set of NSA TF data was collected under good sky conditions, but the only SSA data acquired by ASAS were at the OBS and Fen, with other SSA datasets compromised by clouds. For IFC-2 in the peak growing season, data for all the SSA TF sites were acquired, but the limited NSA datasets are virtually unusable due to forest fire smoke. Probably the most successful deployment was IFC-3, where ASAS collected data for all the NSA and SSA TF sites, with the exception of the SSA Young Aspen site.

These deficiencies, especially the missing mid-growing season data, have direct impacts on the ability to validate canopy radiation models and thus to develop improved algorithms for extracting parameter fields from remote sensing data. Comparisons between the northern and southern TF sites under similar conditions within the same field campaign cannot be made except at a time nearing the end of the growing season.

Additionally, all of the multiangle ASAS data from 1994 are restricted to the TF sites, which were selected for relative homogeneity. A large extent of the modeling subareas is not comprised of "pure" vegetation types but rather consists of mixed vegetation. The BRDF of the auxiliary mixed sites has not been characterized with ASAS, and this marks a gap which must be filled to facilitate successful upscaling.

2.3 The Role of Mosses and Understory

Analysis of 1994 field measurements and some preliminary modeling studies have indicated that the moss layer may play an important role in carbon assimilation, particularly in the wet coniferous sites, and specific moss species. The data gathered in 1994 was not sufficient to construct a credible model of moss photosynthesis and water relations. Modelers have requested three key pieces of information from the Remote Sensing Science teams to aide in the determination of the importance of the moss layer and broaden these modeling results across the region: (1) extent and location of moss-covered areas, (2) type of moss and understory present, and (3) moisture condition (at least wet or dry). In addition, modelers have asked the RSS teams to separate the "wet conifer" class into three classes (Black spruce with moss, Black spruce without moss, and white spruce).

The classification of moss, or other types of understory, requires a different approach from those typically used to classify land cover. Additional field data are required to allow spectral characterization of the moss according to species and moisture conditions (wet, dry). Field transects are proposed by TGB and TE investigators to define known gradients of understory characteristics. The ability for optical remote sensing to discern and map these understory features can be determined directly from CASI multispectral imagery at 1 m spatial resolution. The problem of separating the understory from the canopy over somewhat larger areas may be addressed by multi-directional data provided by ASAS. An off-nadir measurement to capture mostly tree canopy and a nadir measurement to reveal the moss understory could be combined to identify various moss types or other understory species and examine correlations between understory composition and overstory density. The field spectral data can be used in radiative transfer models to help guide mixed-pixel analysis. Since the determination of moss moisture requires SWIR bands, AVIRIS may be able to fill this need.

3. 0 RSS Objectives for 1995 and 1996

The rationale for RSS work in 1995 and 1996 is to carry out those activities which are essential for achieving the original BOREAS objectives. Briefly, these include collection of new satellite and airborne data needed for producing parameter fields and the generation of products from these data for model initialization testing and validation; and acquisition of new airborne or surface data to develop and validate improved remote sensing algorithms for extracting parameter fields and, if possible, to produce parameters for ecosystem and hydrological models. This implies the following specific activities in the next two years.

3.1 1995 Activities

- Obtain thermal radiance measurements which show structure of the emittance fields from the canopy at OBS, NSA. More measurements are needed.

- Obtain and process GOES data to generate albedo, incoming photosynthetically active radiation, incoming total shortwave radiation, net radiation, and canopy temperature products. Ensure smooth transition to GOES-Next;

- Obtain ERS-1 and RADARSAT data to generate freeze/thaw products;

- Obtain sun photometer data for atmospheric corrections of high-resolution satellite optical data;

- Obtain LANDSAT data to generate leaf area index and the fraction of absorbed photosynthetically active radiation (assuming no crippling deterioration of Landsat sensor performance or of the orbit).

- Obtain AIRSAR coverage over SSA modeling grid and nearby wildfire burn areas; sample stem and soil moisture during September, 1995..

3.2 1996 Activities

3.2.1 Parameter Fields

The following activities will ensure the integrity of the BOREAS goals, by addressing issues discussed above:

- Obtain airborne data required by BOREAS MODLAND Team to develop algorithms applicable to EOS MODIS, i.e. use the modified MAS , or AVIRIS as a substitute, and ASAS for data acquisition. MODLAND representatives indicate that continuing the MAS/AVIRIS flights over the next two years is very critical to preparations for the MODIS launch. MODIS data simulation for BOREAS can also be achieved using a combination of AVIRIS and TIMS. ASAS and PARABOLA data (with as much data as possible collected concurrently) are needed to better characterize and upscale spectral albedo, FPAR and LAI of the flux tower sites during the growing season. In addition, basic bidirectional reflectance measurements over forest stands with a snow background must be acquired, since these measurements (missing from 1994) are necessary to characterize the wintertime radiation balance of boreal forests.

- Obtain and process GOES data to generate albedo, incoming photosynthetically active radiation, incoming total shortwave radiation, net radiation, and canopy temperature products. Ensure smooth transition to GOES-Next;

- Obtain ERS-1 and RADARSAT data to generate freeze/thaw products;

- Obtain sun photometer data for atmospheric correction of high resolution satellite optical data; for the winter campaign these needs may be met by deployment of CIMEL sun photometers separately with the PARABOLA and ASAS teams;

- Obtain LANDSAT data to generate leaf area index and the fraction of absorbed photosynthetically active radiation (assuming no crippling deterioration of Landsat sensor performance or of the orbit, a shaky assumption for 1996).

- Obtain and process AVIRIS imagery of the NSA and the SSA during winter/early thaw with continuous snow cover, and later during the thaw with partial snow cover to measure snow extent. This is important to test the repeatability of mapping snow in discontinuous canopies and to link these products to models. Moreover, this product should provide a suitable reference against which to test other sensor algorithms (e.g. MODIS, SAR, Landsat TM).

3.2.2 Field Measurements

- Obtain surface bidirectional reflectance and emission measurements within conifer and deciduous canopies in winter and during the growing season over visible, shortwave infrared and thermal infrared wavelengths, including the moss layer (e.g. PARABOLA-III).

- Obtain measurements of the spatial distribution of incident shortwave and thermal radiation at the surface beneath selected canopies during the early and late thaw periods to provide key data for canopy radiation models designed to estimate wintertime albedo in boreal forests, as well as for modeling a snow melt process.

- Support ASAS/AVIRIS acquisition with surface BRDF measurements using PARABOLA-III. MODLAND investigators plan to participate in BOREAS-1996 to assess the impact of canopy backgrounds (litter, swamps, snow) on vegetation studies (LAI, FPAR, land cover).

- Support winter AVIRIS overflights with co-incident ground measurements and observations of snow reflectance and grain size. Litter on snow surface will be measured, and hemispheric measurements of canopy closure will be made to test the canopy closure product algorithm.

- Support AIRSAR overflights with ground measurements and deployment of calibration devices. Winter 1996 campaign AIRSAR data acquisition would be supported by field data collection (tree dielectric constant, snow depth and soil and snow dielectric constants) in the Northern and Southern study areas. The dielectric measurements will be conducted with the JPL TRACE TDR system and the waveguide probes that have been installed during the 1994 summer IFC. Close coordination of measurements with Hydrology group investigators will be implemented in order to reduce redundancies and expenses.

Snow cover data (depth, water equivalent, density) were acquired at NSA and SSA snow courses throughout the winter of 1994/95 (first and fifteenth of each month). This measurement program is planned to be repeated during the 1996 winter before March 1. These measurements represent a core BOREAS snow cover data set which can support remote sensing algorithm development and hydrological modeling efforts as well as other BOREAS science investigations. HYD-4 is responsible for coordinating this measurement program and providing the data to BORIS.

3.2.3 Improved Algorithms

- MODIS algorithms are in the final developmental stages and validation is receiving increased emphasis. MODIS simulation data over BOREAS is considered crucial by the BOREAS MODLAND (RSS-8) team. These needs can be capitalizing on the unique set of ground measurements at BOREAS in combination with the acquisition of AVIRIS, ASAS and TIMS . Flights that cover MODIS primary biome types, coniferous forests, deciduous broadleaf forests, deciduous needle leaf forest (larch), grassland, cropland and shrub and, are required for testing LAI and FPAR algorithms. The BOREAS surroundings can provide at least 5 of those cover types with modest flight lines beyond only the tower sites. Given the possibility of failure of the aging Landsat TM, MODIS-type data would be critical for CCS, LAI, NPP parameter maps.

- Produce and validate improved algorithms for extracting leaf area index and the fraction of absorbed photosynthetically active radiation.

- Produce new parameter fields from the airborne data for the modeling subareas.

- Produce and validate new algorithms for retrieving FPAR and LAI from ASAS data (e.g. Goel's multiangle vegetation indices, Hall et al.'s second derivative index). PARABOLA-III data will enable complete BRDF validations over a full range of solar zenith angles for eight spectral bands including PAR and a thermal band.

- Produce new and improved algorithms for biomass, soil and snow moisture and possibly tree height from radar data.

- Obtain winter time BRDF measurements at OJP, OBS and OA with new PARABOLA III which has additional bands including a thermal channel, to determine how snow influences the albedo and energy balance in the boreal forest.

- Obtain mid-summer BRDF measurements at the OJP, OBS and OA sites with PARABOLA III to characterize directional PAR and canopy energy balance.

- Use spectral unmixing of AVIRIS and MODIS to produce accurate maps of canopy closure - an important parameter for modeling the radiation fields within the canopy. The algorithm requires continuous snow cover beneath the canopy because the spectra of snow and vegetation are so dissimilar. Above and below canopy BRDF measurements will be valuable for validation, as the complete radiation fields are measured for radiation entering, passing through and exiting the overstory and understory.

- Obtain and process ASAS, AIRSAR and CASI imagery from the NSA and SSA tower sites, and for the moisture gradient transects during the August through September period to map understory class, moss extent and moisture state (wet, dry).

4.0 Summary

The 1993 and 1994 BOREAS field campaigns were a success in terms of the volume of field biophysical and remote sensing measurements, and aircraft and satellite remote sensing data acquired. A variety of products have been developed and tested to varying degrees using these data. However, several gaps in the data have been revealed that will limit the full understanding of seasonal radiation dynamics of the boreal forest. The acquisition of the satellite data discussed above will improve our abilities to develop and validate algorithms for LAI and FPAR. Two reduced scope field and aircraft observation periods were designed from discussions at the recent workshop: Winter (February 27- March 15) and Mid-summer (July 9 - August 9). Carefully managed observations of PARABOLA III, ASAS and AVIRIS will provide data necessary for addressing the key questions concerning the role winter time radiation and albedo; ability of EOS era sensors to produce global vegetation data products and; importance of the moss and understory to boreal forest carbon balance.

The unique remote sensing science database acquired through BOREAS is a powerful resource for advancing ecosystem observation and modeling. A more direct link with other NASA programs such as EOS can be realized with the additional activities described above.

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Appendix A

Table A-1. Planned Remote Sensing Parameter Products for Initial Modeling Studies by RSS, HYD, AFM and TE Investigators

Parameter	**Parameter Specification**	**Primary Contributing Investigators**	**Data Source(s)**	**BOREAS Study Location(s)**
1. Community Composition	• deciduous • conifer upland / wetland • fens (treed & untreed) • Jack Pine on well drained soils • mixed coniferous / deciduous: 3* • disturbed (fire & logging): 3*	TE-12 (Hall) AFM-12 (Steyaert) TE-16 (Cihlar) RSS-15 (Ranson)	Landsat TM AVHRR AVHRR SAR[1,2]	SSA, NSA BOREAS BOREAS SSA, NSA
2. Stand Biophysical Parameters	• FPAR	TE-16 (Cihlar) RSS-7 (Chen) RSS-19 (Miller) RSS-6 (Myneni) RSS-2 (Irons)	Landsat TM Landsat TM CASI ASAS	SSA, NSA SSA, NSA Tower sites Tower sites
	• LAI	RSS-7 (Chen) TE-18 (Hall) RSS-6 (Myneni) RSS-2 (Irons)	AVHRR, Landsat TM ASAS	BOREAS SSA, NSA Tower sites
	• biomass density • above ground biomass • component biomass	TE-18 (Hall) RSS-15 (Ranson) RSS-15 (Lang)	Landsat TM SAR[1,2,3] SAR[1,3]	SSA, NSA SSA, NSA SSA
3. Shortwave Stand Radiation	• albedo - snow free • surface net shortwave	RSS-14 (Smith) RSS-19 (Miller) HYD-3 (Davis)?	GOES CASI AVIRIS LandsatTM	BOREAS Tower sites BOREAS NSA
	• albedo, BRDF	RSS-1 (Deering) RSS-2 (Irons)	PARABOLA ASAS	SSA SSA, NSA
	• PAR down & SW down	RSS-14 (Smith) RSS-19 (Miller)	GOES CASI	BOREAS Tower sites
4. Longwave Stand Radiation	• surface net radiation	RSS-14 (Smith)	GOES	BOREAS
5. Freeze-Thaw	• freeze-thaw duration & timing	RSS-17 (Way)	ERS-1,2	SSA, NSA
6. Available Moisture	• soil & canopy moisture soil / humus moisture • snow water equivalent	RSS-16 (Saatchi) HYD-6)Peck) HYD-4 (Goodison)	AIRSAR Gamma rays SSM / I	SSA SSA, NSA SSA, NSA
7. Snow Cover	• snow aerial extent	RSS-16 (Saatchi) TE-18 (Hall) HYD-3 (Davis)	SAR[1,3] MAS AVIRIS, Landsat TM	SSA, NSA SSA NSA SSA,NSA

*classified in 3 levels

[1]AIRSAR,
[2]SIR-C / XSAR
[3]CCRS / SAR

Table A-2. Remote Sensing Parameter Fields

Investigation	Deliverables
RSS-1	FPAR, albedo estimate of the time-weighted mean fraction of absorbed PAR. Missing snow radiation, including thermal, measurements.
RSS-2	ASAS multiangle, multispectral (62 bands VIS / NIR), radiometrically corrected at- sensor radiance digital images of selected $1km^2$ locations. Area-averaged at-surface bidirectional reflectance factors, spectral hemispherical reflectance, PAR hemispherical reflectance, and SVIs. Missing winter and some growing season BRDF data. Missing multiangle data over Aux (mixed) sites.
RSS-3	Mean spectral radiance for each TF and measured Auxiliary site, mean reflectance factors at each measured site. Documentation including GPS, FOV video tape, sun photometer derived optical thickness from surface and at altitude during radiometer operations, barometric pressure. Surface temperature.
RSS-4	LAI and FPAR estimates within SSA in 1993 and 1994.
RSS-7	BOREAS region and study site LAI Missing important growing season Landsat data in 1994
RSS-8	BRDF measurements of study sites, digital maps of land cover, snow cover, surface temperature and MODIS vegetation indices for the intensive study sites. Simulation results from BIOME-BGC (input and output files)..
RSS-10	Magnitude of daily, seasonal and yearly UV-B radiation and incident photosynthetically active radiation.
RSS-11	Atmospheric optical properties and atmospheric column abundances of water vapor and ozone over the BOREAS study area.
RSS-12	Derived atmospheric optical properties and atmospherically corrected data for BOREAS
RSS-14	Regional Albedo, PAR, optical radiation fields.
RSS-15	Maps of portions of Southern and Northern Super Sites showing estimates of above ground biomass. Stand level partitioning of biomass into bole, branch and leaf components for jack pine stands in SSA.
RSS-16	AIRSAR image data. Retrieval algorithms and maps / images of vegetation distribution and water content, surface moisture content and the extent of snow cover.
RSS 17	Spatial dielectric measurements, temperature. ERS-1 and JERS-1 multitemporal image data Vegetation classification maps derived from SAR data Freeze / thaw classifications vs time (weekly) derived from SAR data
RSS-18	Radiometrically and spectrally calibrated AVIRIS data. Surface moisture maps.
RSS-19	CASI surface reflectances for specific sites. Derived products from the analysis of a range of RSS data: Climatological albedo for the SSA.
RSS-20	Map products providing seasonal estimates of 'minus specular' vegetation indices.
TE-10	Leaf and needle (400-1000nm) reflectance and transmittance (several canopy and understory species, ages) Missing emergent conifer needles.
TE-12	Average Leaf and needle (400-1000nm) optical properties. (several species, ages) Bark, litter, forest floor reflectance. Missing branch and shoot bidirectional reflectances.
TE-16	Regional and cover maps
TE-18	Community composition and structure, Biomass, LAI, NPP. Missing important growing season Landsat data in 1994
HYD-3	Snow extent from unmixed AVIRIS, bracketing HYD-3 golden period (FFC-T, NSA) and canopy closure (NSA). AVIRIS coverage needed for SSA when snow cover is complete, and again when partial.
HYD-4	Snow water equivalent derived from passive microwave data for the BOREAS SSA and NSA study sites.

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