BOREAS
Experiment Plan

Chapter 4
Science Teams

May 1994 Version 3.0

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BOREAS EXPERIMENT PLAN

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4.0 SCIENCE TEAMS

This chapter summarizes the objectives, investigations, proposed field measurements, supporting measurements and next steps for each of the science teams. The teams are as follows:

SCIENCE TEAM	ABBREVIATION	SECTION
AIRBORNE FLUX AND METEOROLOGY	**AFM**	**4.1**
TOWER FLUX	**TF**	**4.2**
TERRESTRIAL ECOLOGY	**TE**	**4.3**
TRACE GAS BIOGEOCHEMISTRY	**TGB**	**4.4**
HYDROLOGY	**HYD**	**4.5**
REMOTE SENSING SCIENCE	**RSS**	**4.6**

4.1 Airborne Flux and Meteorology (AFM)

4.1.1 Objectives

Specific investigator objectives in the AFM group, which include work with field measurements (aircraft, radar, lidar, profilers, soundings, mesonet) and models, cover a wide range of topics. The overall objectives linking these studies are to :

1) Characterize by measurement and by model the evolution of the planetary boundary layer and the boundary layer fluxes of sensible heat, latent heat, momentum, and CO_2 over the two BOREAS study areas and over a transect across the boreal forest zone (from near Saskatoon to an area northeast of Thompson), and;

2) Study and document the processes that link such fluxes from the local scale of surface measurements to the regional scale represented by the forest ecozone, and from the time spans of BOREAS measurements to those of global climate change.

4.1.2 Investigation Summaries

Ref. Number AFM-1

P.I.(s):	Crawford, T./NOAA
CO-I(s):	Baldocchi, D., Meyers, T., McMillen, R./ NOAA
Title:	Experimental and Modeling Studies of Water Vapor, Sensible Heat, and CO_2 Exchange Over and Under a Boreal Forest
Objectives and Approach:	Airborne flux measurements and modeling of air-surface exchange rates of water vapor, sensible heat, and CO_2 over a boreal forest, and study of the abiotic and biotic factors that control the fluxes of scalars in this landscape. Aircraft is the NOAA Long-EZ, (FL), see section 5.2.1.10.

Ref. Number AFM-2

P.I(s).:	Kelly, R./Univ of Wyoming, Lenschow, D./NCAR
Title:	Airborne Investigation of Biosphere--Atmosphere Interactions Over the Boreal Forest
Objectives and Approach	The primary scientific goal of the investigations using the Wyoming King Air (FK) and NCAR Electra (FE) is to characterize the fluxes of momentum, sensible and latent heat and carbon dioxide over the boreal forest. More specifically, variations in these fluxes as related to time of day, season, weather, soil and vegetation type and maturity (e.g., new growth vs. old growth forests), surface features and location within the boreal forest zone (e.g. southern vs. northern edge) will be investigated.

The objective is to determine the suitability and reliability of these factors as predictors of these fluxes.

Crucial to this is the question of variability as a function of scale; namely, how are the scales and magnitudes of the flux variations related to the scales and types of surface variations? Flux variations are also generated by variability in cloudiness. Patchy low-level cumuliform and stratiform clouds are common in this region, and a fundamental question to be investigated is how the transient variations induced by cloudiness can be distinguished from those induced by surface variations. These issues are part of a more general problem to be addressed when characterizing fluxes over particular regions of interest: describing and estimating errors in flux measurements, and developing measurement strategies appropriate for characterizing fluxes over inhomogeneous surfaces, see also section 5.2.1.10.

Ref. Number AFM-3

P.I.(s): Lenschow, D./NCAR, Kelly, R./Univ of Wyoming

Title: Airborne Investigation of Biosphere--Atmosphere Interactions Over the Boreal Forest

Objectives and Approach: Same as AFM-2.

Ref. Number AFM-4

P.I.(s): MacPherson, J.I./NRC, Desjardins, R.L./Agriculture Canada,

CO. P.I.(s): Schuepp, P.H./McGill University

Title: Areal Estimates of Mass and Energy Exchange from a Boreal Forest Biome

Objectives and Approach: The NRC Twin Otter (FT) will be used to develop various techniques to obtain large area flux estimates of mass and energy using the aircraft; tower and spectral data combination. Measurements recorded along a transect between the SSA and NSA will be used to characterize the spatial variations of canopy conductance and determine its usefulness for inferring mass and energy exchange of radiatively important trace gases (CO_2, O_3, etc.), see also section 5.2.1.10.

Ref. Number AFM-5

P.I.(s): Atkinson, B./Env. Canada

Title: Upper Air Network

Objectives and Approach: Provide large scale definition of the atmosphere for scientific research for by by supplementing the existing Atmospheric Environment Service (AES) aerological network, both temporally and spatially. Establish 3 or 4 additional aerological aerological stations,with communications. Coordinate with AES additional releases from existing stations. Assure that observations are being made according to established procedures and reach national and international communication systems in real time, see section 3.2.2.

Ref. Number AFM-6

P.I.(s):	Banta, R./NOAA
CO. I(s):	Eberhard, W. ,Wilczak, J. ,Martner, B./NOAA
Title:	Outer-Boundary-Layer Effects on Surface Fluxes of Momentum, Heat, Moisture, and Greenhouse Gases from the Boreal Forest
Objectives and Approach:	Mean wind and turbulence properties of the outer atmospheric boundary layer (OABL) and lower troposphere above about 100 m will be measured using ground-based remote sensing instrumentation, including a UHF profiler equipped with RASS, a Doppler radar, and a Doppler lidar. The measured properties will include profiles of wind, turbulence quantities, and temperature as functions of time. The radar will also measure the structure of clouds overhead. The radar will be located near the NSA-OJP site.

Ref. Number AFM-7

P.I.(s):	Shewchuk, S.
Title:	Mesonet Meteorological Data
Objectives and Approach:	The Saskatchewan Research Council, located in Saskatoon, will implement and maintain a meso network of nine (9) or ten (10) automated meteorological stations located in the Northern and Southern study areas and the intervening transect. Standard meteorological and radiation data will be collected and 15 minute average values produced for BORIS, see Section 3.2.1. Some limited analysis of fields will also be available. These data will be available beginning in the fall of 1993 through the 1994 fall season, see section 3.2.1.

Ref. Number AFM-8

P.I.(s):	Betts, A./Atmospheric Research
CO-I.(s):	Hollingsworth, T./European Centre for Medium Range Weather Forecasting
Title:	Boundary Layer Research for BOREAS
Objectives and Approach:	This is a modeling study designed to help us understand the diurnal evolution of the convective boundary layer over the boreal forest. The approach will be to analyze surface, boundary layer and cloud data from BOREAS using simplified conceptual models, and prepare compacted data bases for comparison with large-scale models. The PI will also assist with the design of the surface and upper air networks, and the aircraft measurement program for BOREAS, and will work to optimize the boundary layer and mesoscale components of the experiment. The ECMWF GCM will also be used to perform post-analysis work, see sections 3.2.1, 3.2.2.

Ref. Number AFM-9

P.I.(s):	Dickinson, R.,/University of Arizona
Collaborator(s):	Shuttleworth, J.; Graumlich, L.; Bonan G.; Henderson-Sellers, A.
Title:	Incorporation of Boreal Forest Ecosystem Description into Climate Modeling Framework
Objectives and Approach:	An integrative modeling investigation will be conducted that would relate the BOREAS study to land process parameterizations of the Biosphere Atmosphere Transfer Scheme (BATS) for application in global climate models. The PI and graduate students will carry out modeling studies to establish the relative sensitivity of surface-atmospheric exchanges of energy, moisture and carbon to various parameters and processes for boreal forests, as defined through the PI and Core measurement programs and their analyses.

Ref. Number AFM-10: **DELETED**

Ref. Number AFM-11

P.I.(s):	Mahrt, L./Oregon State Univ
Collaborator(s):	Scanlan, R./Oregon State Univ, MacPherson, I./NRC Kelly, R./Univ of Wyoming, Lenschow, D./NCAR
Title:	Fluxes Over Inhomogeneous Surfaces in BOREAS
Objectives and Approach:	This study will analyze aircraft data from the Wyoming King Air, the Canadian Twin Otter, the NCAR Electra, and the NOAA Long-Ez to compute fluxes of heat, moisture, momentum, CO_2, and other chemical species. It is essential that sampling criteria are satisfied and the impact of surface heterogeneity is assessed before flux estimates are provided for BORIS. Variations over inhomogeneous surfaces and estimates of spatially averages fluxes over regional scales will be investigated using repeated flight legs over the same terrain and partitioning the flight track according to the greenness index and other indicators of surface conditions. Collaboration with NMC through Dr. Kalnay.

Ref. Number AFM-12

P.I.(s):	Pielke, R./Colorado State Univ., Lee, T.J./ Colo. State Univ.
CO. I(s):	Kittel, T./Colorado State Univ Loveland, T./USGS Steyaert, L./USGS
Title:	Modeling Biosphere-Atmosphere interactions at Various Scales in Support of BOREAS
Objectives and Approach:	This modeling study is designed to improve our understanding of the interaction between a heterogeneous sub-Arctic landscape and the overlying atmosphere. The Regional Atmospheric Modeling System (RAMS), which includes sophisticated parameterization of vegetation and soils will be used for this purpose. Simulations with RAMS will be performed to develop an improved understanding of soil/vegetation/atmospheric interactions and to develop a

parameterization of heterogeneous landscapes for use in larger scale models (e.g., general circulation models-GCMs).

Ref. Number AFM-13

P.I.(s):	Schuepp, P./McGill Univ
CO. I(s):	MacPherson, J./NRC, Desjardins, R.L./Agric. Canada, Leclerc, M.Y./Univ. of Quebec
Title:	Analysis and Interpretation of Airborne Flux Observations Over the BOREAS Sites
Objectives and Approach:	In this modeling and analysis study, NRC Twin Otter data and TF data will be analyzed to define realistic footprint functions over the BOREAS sites, so that airborne observations are related to the correct ground surface with its biological and ecological characteristics. This will permit site-wise and inter-site 'mapping' of the exchange of momentum, heat, moisture, CO_2, CH_4, and O_3 (and maybe NMHCs). We will also study the effects of intermittent cloudiness on the structure of turbulent transfer and its effects on airborne flux mapping.

Ref. Number AFM-14

P.I.(s):	Sellers, P.J., Hall, F.G./NASA/GSFC
Title:	Use of Biophysical Models and Satellite Remote Sensing to Quantify the Climate/Land surface Interactions Over a Boreal Forest Biome
Objectives and Approach	Photosynthesis and transpiration models (e.g., SiB2 of Sellers et al., BGC of Running et al., the model of Bonan et al.), will be used in conjunction with remote sensing inputs of canopy process and biophysical parameters, landscape level disturbance and successional patterns to (i) simulate changes in energy and water exchange as a function of climate change scenarios, and (ii) simulate associated changes in growth rates and carbon storage associated with the successional stages in the boreal forest. We will use the linked stomatal resistance-photosynthesis SiB2 model in the inverse-mode to calculate canopy photosynthetic capacities, bulk stomatal conductance etc., appropriate to each BOREAS flux site and compare the model predictions to tower measurements.

Ref. Number AFM-15

P.I.(s):	Verseghy, D./Canadian Climate Centre
Title:	Improvement of Boreal Forest Modelling in the CCC GCM
Objectives and Approach:	It is proposed that field data collected during BOREAS be used to place on a firm theoretical footing the modeling of the boreal forest in CLASS (Canadian Land Surface Scheme), a second-generation land surface model which has been developed for the Canadian Climate Centre GCM by the investigator . Data from BOREAS will enable the testing, refinement, and improvement of CLASS in the areas of bulk stomatal resistance, interception of rainfall and snowfall, and the evolution of the snowpack .

4.1.3 Field Measurements

4.1.3.1 In-Situ Measurements

4.1.3.1.1 Overview

A wide variety of measurements will be taken by various AFM investigator groups during BOREAS, see Table 4.1.3.1a. Roughly half of the AFM (AFM-8 through AFM-15) investigators will not be collecting field data, but will be concerned with various modeling studies. In summary, the planned field measurements can be divided roughly into two general, but overlapping, categories:

1) Direct measurements by aircraft of dynamic and thermodynamic variables in the boundary layer. Of these, the flux measurements (momentum, sensible heat, latent heat, CO_2, and other trace gases) are summarized in Table 4.1.3.1a. Aircraft flight hours, basing and flight plan summaries are provided in Chapter 5.

2) Remotely sensed measurements of various ABL parameters, including temperature and wind profiles, ABL depth, degree of cloudiness, turbulence, and momentum flux. These are summarized in Table 4.1.3.1b. The locations for the ground-based AFM remote sensing instruments will be as follows: The lidar (IFC-2 only) will be located near the Candle Lake area tower cluster, just southwest of Lower Fishing Lake, near the intersection of highways 120 and 106, where high ground allows 360-degree scans. The profiler (IFCs 1-3 desired) will be on the access trail to SSA-OJP. The radar (IFC-2 only) will be located above a gravel pit near the NSA-OJP, just north of the sharp bend in the road between Thompson and Nelson House, see maps in Section 2.1.1. A lidar ceilometer will be located at the NSA-OJP.

Other measurements under the AFM umbrella include 1) supplemental rawinsonde data from the Canadian network, and 2) mesonet surface station measurements. AFM has participated in the decision of where these measurements should be taken, as shown in the map of Figure 4.1.3.l, see also Section 3.2.

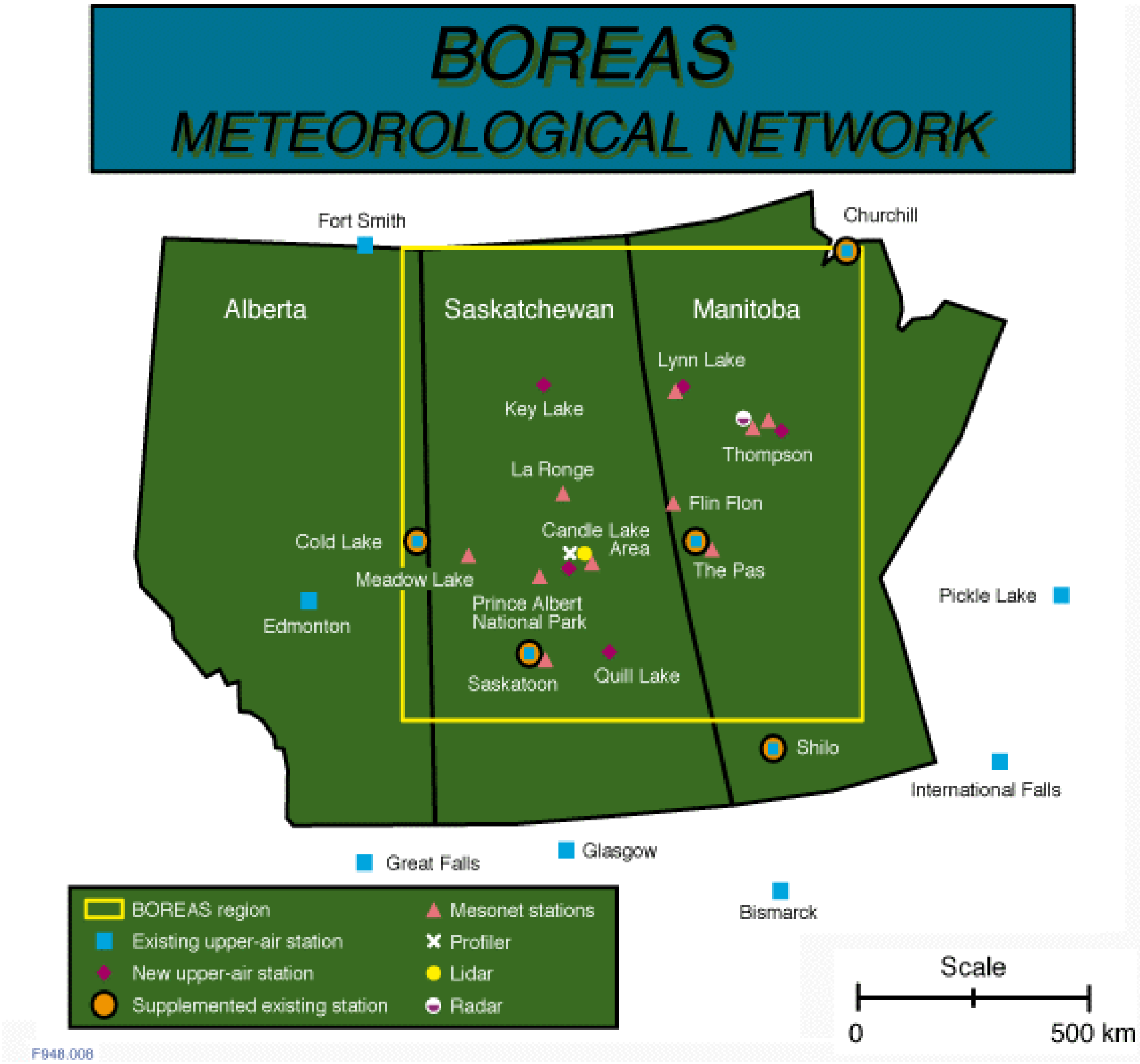


Figure 4.1.3.1 - Map of Proposed Placement of Rawinsondes, Mesonet, Lidar, and Profiles, same as Figure 2.1.1.2c

Aircraft	IFCs	Flt Hrs	Hrs/ Flt	Flux Measurements**							
				Mom.	SH	LH	CO_2	CH_4	CO	O_3	Other
UW King Air*	1,2,3	90	4	F	F	F	F	--	--	--	--
NRC Twin Otter	1,2,3	165	3	F	F	F	F	(F)	-	F	NMHC A
NCAR Electra*	1,2,3	180	6-10	F	F	F	F	(I)	(I)	F	(NMHC) (I or M)
NOAA Long-EZ	1,2,3	270	8	F	F	F	F		--	F	(NO_2) F

Flux Technique:
F = Eddy Correlation
I = Intermittent Sampling
A = Accumulation
M = Mixed-Layer Gradient

* Pending approval by NSF Panal
** All will measure position, height, Heading, TAS, p, T, q, winds, statistics
() or Possible

Aircraft	IFCs	Flt Hrs	Hrs/ Flt	Other Measurements				
				Down Rad.	Up Rad.	Sfc Temp	NDVI/ Green.	Other Meas.
UW King Air*	1,2,3	90	4	Y	Y	N	N	Cloud Probes
NRC Twin Otter	1,2,3	165	3	Y	Y	Y	Y	Satellite Simulator
NCAR Electra*	1,2,3	180	6-10	Y	Y	Y	Y	Cloud Probes
NOAA Long-EZ	1,2,3	270	8	Y	--	Y	--	Net Rad.

Table 4.1.3.1a Airborne Flux Measurements

Instrument (contact)	Parameters Measured	Typical Height Ranges (m,AGL)	Height Resolution (m)	Typical Time Resolution (min.)	BOREAS Locations	IFCs	Velocity Accuracy (cm 5^{-1})
Wind profiler/ RASS (1) (Wilczak)	WS, WD, T_v, Z_i	100-4000 for wind 100-1000 for R_v	100	60	On Access to SSA-OJP	1,2,3 (and between)	150
Doppler Lidar (1) (Banta)	WS, WD, TMF, Z_i aerosols, clouds	100-BL top for winds and fluxes - much higher for louds	<50	1 for wind, TME profiles	Candle Lake Area	2	10-20
Doppler radar (1) (Martner)	WS, WD, TMF, Z_i Clouds	200-BL top for winds and fluxes-much higher for Clouds	37	2 for wind, TME profiles 0.01 for clouds	Near NSA-OJP	2	10

s = wind speed profile
wd = wind direction profile
T_v = virtual temperature profile
TMF = turbulence and momentum-flux profiles
Z_i = mixed-layer height

Table 4.1.3.1b NOAA/WPL Ground-Based Remote Sensor Measurements of Atmosphere

4.1.3.1.2 Strategies and priorities of aircraft flux measurements:

The highest priority for the Electra will be the SSA-NSA transects (FE-RT), covering a significant part of the boreal forest zone. In response to the diversity of this biome (vegetation, water, land use, etc.), the transect path(s) will consist of a series of interconnected line segments, placed to sample this diversity and to document the SSA-NSA gradients and their variability. The Electra will also be the main platform for ABL chemistry, potentially available to accommodate projects in collaboration with other researchers. Its mission will also include targets of opportunity, such as fire plumes, intrusions of polluted air, and cloud effects on photochemistry.

The other three flux aircraft (Twin Otter, King Air, LongEZ) will focus more on measurements within the two study areas, but will collect data along the same transect used by the Electra during any ferry flights between the supersites. A variety of flight patterns have been formulated for the flux aircraft, ranging from highly focused patterns over specific surface locations (e.g., over the TF sites) to grids over parts of the NSA and SSA modeling areas to 100+ km "mesoscale" transects across various paths within the two study areas. Details of these flight plans and the aircraft deployment are given in Chapter 5.

4.1.3.1.3 Aircraft-tower comparisons: Poor comparisons between aircraft-based and surface-based flux measurements has tarnished the reputation of several recent major field programs. Most of these discrepancies could have been prevented by taking into account various sampling problems and needed instrumentation checks. More specifically, planning the tower-aircraft comparisons must include an adequate number of sequential aircraft passes and the need to include sufficiently large scales in order to provide useful quantitative flux estimates from the aircraft. This in turn requires homogeneity of the tower site, preferably on a scale of at least 5 km.

As a numerical example, an aircraft flight level of 30 m over a homogeneous site of 5 km width requires a flight track on the order of 10 km and requires about 8 passes under quasi-stationary conditions (usually mid-day or early afternoon without rapid cloud development) in order to estimate the flux with error of 10% or less. With partly cloudy conditions, a larger number of runs may be needed. At higher levels, the flight path should be longer. We recommend choosing 2 or 3 tower sites for participation and devote one or more Twin Otter and LongEz flight days to these sites. Specific flight patterns have been suggested to accomplish these comparisons (see Section 5.2). If the above conditions cannot be met, formal error estimates should be recognized prior to final decision for implementation of tower-aircraft comparisons. The comparisons will be coordinated by Larry Mahrt (AFM-11)

4.1.3.1.4 Role and effects of lakes: Because of the large range of sizes and areal distributions of lakes in this region, they must be expected to exercise a complex role in affecting regional and local gradients and fluxes. They also provide the best defined contrast in surface characteristics over the sites. ABL structure and development over lakes is complicated and size- and stability-dependent. Some allocation of flux aircraft to the study of land-lake interfaces or, alternatively, the sampling of transects with characteristically different percentages of lake surface area is proposed.

Mesoscale circulations are of particular interest to some of the modelers. The main goal, with respect to the rest of BOREAS, will be to estimate the contribution of the lakes to the area-averaged fluxes.

4.1.3.1.5 Possible impacts of abrupt land-use and land-cover boundaries: The abrupt transition from "forests" (i.e., forest, lakes, logged areas, bogs, etc.) in the SSA to agricultural lands just south of the SSA may cause development of significant mesoscale gradients in moisture, temperature, density, and pressure. Even within the "forest," abrupt changes such as burned to un-burned and logged to un-logged also occur and may also have effects on gradients and fluxes. Some aircraft flight time will be allocated to document these changes, since they could have significant impacts on the daily and longer-term fluxes and budgets at both SSA and NSA.

4.1.3.1.6 Importance of modeling studies: The wide range of surface and airborne observations will provide input into models that will be essential if conclusions of general validity are to be drawn from observations made over a limited range of space and time. Such models will include: large-scale ABL modeling based on reduced data sets from long time series of observations and application of the ECMWF model for prediction of hourly maps of meteorological variables; LES models (at grid scales down to 200 m for integration with aircraft and lidar observations); RAMS nested down to individual sites and for individual project days, for process-driven prediction of heat and mass fluxes linked to landscape-based modeling at a resolution of 500 m; and CLASS land-surface modeling, including snow masking. The challenge, in general, will consist in scaling up from the patchy surface measurements to the regional scale, to link up with the sub-grid scale of GCMs.

4.1.3.1.7 Footprints and intrasite variability: Specific flight plans to address the objectives of AFM-13 include the following: 1) grid flights over surfaces with pronounced, relatively large-scale heterogeneity, such as the Nipawin complex and the NSA, and including lake and burn contrasts if possible, 2) repeated line transects over typical BOREAS ecosystems, i.e., with a variety of surface cover upwind of flight lines spaced at scales of 1 to several km, 3) tests of effective footprints over the TF sites by a series of vertically stacked short transects, normal to the mean wind, and downwind of a tower releasing a tracer at canopy height (e.g., SF6), under different conditions of ABL stability, and 4) runs over the same ecosystem under conditions of time-varying radiation input (cloud shadows).

4.1.3.1.8 Candle Lake Modelling and Measurement (Coordinator-Mahrt): The Candle Lake run (Fx-CS) used by the Twin Otter in 1993 is especially attractive for modelling application because it consists of approximately 5-km segments of relatively homogeneous sections of a burned area, a mixed forest, a partially logged area, Candle Lake, and a black spruce area. It can be extended to include a Jack Pine area and the OJP and OA TF sites. The CSU RAMS model (Pielke) will be applied to study mesoscale circulations in and above the BL, including that component responding to surface heterogeneity. Mixing by coupled mesoscale motions above the BL will be given special attention. The OSU 1-D soil-ABL model will be applied with simple cloud effects to study development of the ABL and to test resistance formulations. Vertical motion and advection can be incorporated from the RAMS model. Details of the aircraft measurements planned for this focus are given in Section 5.2, as plans CL-1,2,3. Ground measurements planned include soil moisture, ground-based photography, and Candle Lake water temperatures. AFM has also included a request for C-130 and Landsat Imagery to cover the transect.

4.1.3.2 Data to be submitted to BORIS

At an aircraft operations workshop in January 1994, aircraft investigators settled on the following as a description of a "minimum" submission to BORIS, i.e., as the submission to be provided by each aircraft for each pass. The philosophy here is that given the variety of platforms and BL processes to be seen by those platforms (e.g., contrasting the LongEZ at 15 m and the Electra at 100+ m agl), and given the wide spread of disciplines that will make use of the data, it was not practical to find one "best" treatment (e.g., one ideal filter) for the data. The scheme we settled on, then, is intended to be "simple". It will give everyone a good look at the extent of the flux aircraft data set and what it represents. More complex data treatments (filters, etc.) can be undertaken by individuals and groups tackling specific problems.

If the aircraft pass is "long", i.e., if it covers more than just one relatively homogeneous surface patch, then data for the entire pass (A-B) and segments of that pass will be archived.

```
A------------------------------------------------------B
  a----------b
      c----------d
          e----------f
              g----------h
                    ------------ etc.
```

A list of variables from the treatment just described is given in Table 4.1.3.2. Treatment of the pass and its segments for submission to BORIS may be summarized as follows:

1. Linearly detrend entire A-B series to determine the perturbation series for each variable (a'=a - abar), then compute statistics and fluxes and entire A-B path. this would represent a first pass estimate of the "total" fluxes, i.e., the sum of the mesoscale and the turbulent scale fluxes.

2. Subdivide A-B into shorter, overlapping segments (like e-f). The segment lengths and the amount of overlap are to be determined by each investigator. For each segment submit the following:

   a. means, trends, and other statistics for the raw data from each segment,
   b. statistics and fluxes obtained after removal of the simple arithmetic means from each variable series,
   c. statistics and fluxes obtained after linearly detrending each variable series.

3. For shorter passes over relatively homogeneous patches, e.g., the site-specific and asterisk runs, the submission would be equivalent to 2: statistics for the raw data from each pass, statistics and fluxes for each pass after removal of arithmetic means, and statistics and fluxes for each pass after linear detrending.

Further submissions are optional, i.e., at the choice of the investigator. Examples that were discussed include tings like filtering the entire A-B series with a high-pass (low cutoff frequency filter, then computing statistics for A-B and the shorter segments.

4.1.3.3 Special Concerns of AFM Field and Modeling Investigations

The effects of clouds and precipitation on BOREAS measurements and results: during the periods of operation that have been proposed, to quote Atkinson (AES), we "can expect 80% of the days to have EITHER clear morning hours with cumuli by 1000, then afternoon showers, OR a synoptic situation bringing in altocumuli, altostratus, or cirrus which will reduce the incoming radiation and thereby reduce or eliminate the chance of showers."

In other words, we have both limitations and opportunities represented by a high-percentage chance of daily cloudiness at many levels. Challenges introduced by variable cloudiness not only include variability in ABL dynamics, but possible bias in some flux observations caused by species-specific response.

4.1.4 Supporting Measurements

4.1.4.1 Needs from other groups:

- Surface and canopy height fluxes during each IFC.
- Surface radiation measurements across the study sites and the boreal zone.
- Model predictions of surface fluxes
- Comparison of flux measurement techniques, standards, and error analysis.

4.1.4.2 Support and Staff Science Needs identified by AFM:

The following two items are still highly desirable in support of the flux aircraft and modeling efforts:

-- all-sky digitized cloud camera for SSA.
-- laser ceilometer for SSA

4.1.5 Internal Organization

Bob Kelly - coordinate flight planning for the four aircraft planned to be used in 1994 (Electra, Twin Otter, King Air, Long-EZ).

Roger Pielke - coordinate focused measurements to characterize effects of local land use changes, such as the southern forest-agriculture boundary, on measurements at the southern "study area."

Larry Mahrt - coordinate measurements devoted to examining the numerous lake- land transitions in the BOREAS area, and their effects on aircraft and surface measurements, and coordinate aircraft-tower flux comparisons..

Alan Betts - coordinate overall modeling efforts.

Ian MacPherson-coordinate assessment of impacts of aircraft operations and how they may be effected by regulations and needs of the national and provincial parks (PANP, NPP in the SSA) and the Nelson House band in the NSA. Obtain permits for low-flying operations, if necessary.

Table 4.1.3.2
Table of Parameters (draft) for Entry Into Boris by the Flux Aircraft

Set	Parameters	Units
1. Indent	'NRC Twin Otter'	-
	Flight date, YYMMDD	-
	Mission of day	-
	Run number	-
2. Location	Run start time, GMT	GMT
	Starting latitude	deg
	Starting longitude	deg
	Starting BORIS grid N	-
	Starting BORIS grid E	-
	Run end time, GMT	GMT
	Ending latitude	deg
	Ending longitude	deg
	Ending BORIS grid N	-
	Ending BORIS grid E	-
3. Averages	Aircraft heading	deg
	Mean pressure altitude	m
	Mean radar altitude	m
	Mean wind direction	deg
	Mean wind speed	m/s
	Air temperature	deg C
	Potential temperature	deg C
	Mixing ratio, H_20	g/kg
	U, westerly wind component	m/s
	V, southerly wind component	m/s
	Static pressure	mb
	Surface radiative temperature	deg C
	Downwelling total radiation	W/m^2
	Upwelling total radiation	W/m^2
	Downwelling longwave radiation	W/m^2
	Upwelling longwave radiation	W/m^2
	Greenness index	-
	$C0_2$ concentration	ppm mass
	Ozone concentration	ppb mass
	Methane concentration	ppb mass

Set	Parameters	Units
4. Std deviation	Air temperature	deg C
	Potential temperature	deg C
	Mixing ratio, H_2O	g/kg
	U, westerly wind component	m/s
	V, southerly wind component	m/s
	Static pressure	mb
	Surface radiative temperature	deg C
	Downwelling total radiation	W/m^2
	Upwelling total radiation	W/m^2
	Downwelling longwave radiation	W/m^2
	Upwelling longwave radiation	W/m^2
	Greenness index	-
	$C0_2$ concentration	ppm mass
	Ozone concentration	ppb mass
	Methane concentration	ppb mass
5. Linear Trends	Trend in air temp.	degC/m
	Trend in potential temp.	degC/m
	Trend in mixing ratio	g/kg/m
	Trend in u	1/s
	Trend in v	1/s
	Trend in static pressure	mb/m
	Trend in surface radiative temperature	degC/m
	Trend in downwelling total radiation	W/m^3
	Trend in upwelling total radiation	W/m^3
	Trend in greenness index	1/m
	Trend in $C0_2$ conc'n	ppb mass/m
	Trend in 0_3 conc'n	ppb mass/m
	Trend in CH_4 conc'n	ppb mass/m
The following variables are referred to as the "flux variables:"	vertical gust, we	m/s
	westerly wind comp., u	m/s
	southerly wind comp., v	m/s
	along wind comp.	m/s
	crosswind comp.	m/s
	potential temp.	deg C
	H_2O mixing ratio	gm/kg
	O_3 concentration	ppb mass
	CH_4 concentration	ppb mass
These variable pairs are referred to as the "flux variable pairs":	w, u	
	w, v	
	w, alongwind comp.	
	w, crosswind comp.	
	w, potential temp.	
	w, H_2O mixing ratio	
	w, CO_2 mixing ratio	
	w, O_3 concentration	
	w, CH_4 concentration	

Set	Parameters	Units
List of fluxes:	Momentum flux, south comp	N/m^2
	Momentum flux, west comp	N/m^2
	Momentum flux along mean wind	N/m^2
	Momentum flux across mean wind	N/m^2
	Sensible heat flux, H	W/m^2
	Latent heat flux, LE	W/m^2
	CO_2 flux	$mg/m^2/s$
	Ozone flux	$ug/m^2/s$
	Ozone deposition velocity	cm/s
	Methane flux	$mg/m^2/d$

In the following sets of parameters, 6-10 are included whenever the flight segment in question is one subdivided from a longer segment (such as the CL runs, Electra transects, or the MS passes), or is originally a "short" segment such as those from the asterisks, and site-specific passes. Sets 6-10, 11, and 12-16 are included in all cases (long runs, segments of long runs, or short original runs).

6. Standard deviations for the "raw" flux variables
7. Skewness for the raw flux variables
8. Kurtosis for the raw flux variables
9. Correlation coefficients for the raw flux variable pairs
10. Fluxes using the raw data
11. Constants used in the flux calculations:

Set	Parameters	Units
Parameter sets 6-16	Air density	kg/m^3
	Specific heat at constant pressure	J/kgK
	Latent heat of vaporation	J/kg
	Dry air gas constant	J/kgK

12. Standard deviations for the detrended flux variables
13. Skewness for the detrended flux variables
14. Kurtosis for the detrended flux variables
15. Correlation coefficients for the detrended flux variable pairs
16. Fluxes using detrended data

4.2 TOWER FLUX (TF):

4.2.1. Objectives

A primary objective of the TF Group is to obtain time-series of surface fluxes of heat, moisture, CO_2 and CH_4 using micrometeorological techniques at a variety of surface types characteristic of the boreal forest. They are designed to be complementary to chamber observations and process-oriented studies on smaller scales (TE, TGB), and aircraft studies (AFM, RSS) to provide the basis for extrapolation of results to obtain regional flux estimates over periods of days to seasons. Analysis and modeling of these observations will provide a basis for improving surface-atmosphere exchange models.

A single site in the SSA (SSA-OA; TF-1, TF-2) and one in the NSA (NSA-OBS; TF-3) will operate continuously from late 1993 onwards. Other TF sites, except for TF-6, will operate between the beginning of IFC-1 and the end of IFC-3.

4.2.2 Investigation Summaries

Ref. Number TF-1

P.I.(s):	Black, T.A./Univ of British Columbia, Thurtell, G.W./Univ of Guelph
CO. I.(s):	K.M. King, P.M. Voroney. G.E. Kidd, Univ. of Guelph; M.D. Novak, Univ. of British Columbia
Title:	Boreal Forest Atmosphere Interactions: Exchanges of Energy, Water vapor and Trace Gases (SSA-OA)
Objectives and Approach	The objectives are to measure the fluxes of sensible (H) and latent heat (LE), momentum, CO_2, and trace gases (CH_4, CO, O_3, and NO_2) above the canopy of the SSA-OA stand in Prince Albert Park during the year and to investigate the processes controlling these fluxes. Fluxes will be measured using the eddy correlation method with three-dimensional sonic anemometry and closed-path gas analysis (mainly tunable diode lasers (TDL) and open and closed path IRGAs). H and LE will also be measured using the Bowen ratio/energy balance method. Below the overstory, H, LE and CO_2 fluxes will be measured using the eddy correlation method. Concentration profiles of CO_2,H_2O and the above trace gases will be measured in and above the stand. Soil manipulation experiments will be carried out to determine the response of microbial activity and gas production to changes in soil nitrate and carbohydrate levels. The flow of C and N through the litter/soil system will be measured in situ using ^{13}C and ^{15}N substrates. This project is complementary to TF-2.

Ref. Number TF-2

P.I.(s):	den Hartog, G./AES
CO-I(s):	Mickie, R.E., Neumann, H.H., Trivett, N.B.A./AES
Title:	AES Flux Tower Measurements for BOREAS: Exchange of Energy, Water vapor and Trace Gases Project (SSA-OA)
Objectives and Approach:	The objectives of this proposal are to quantify and examine the controlling factors for CO_2, O_3, CH_4, N_2O exchange at the SSA-OA site in PANP and to determine diurnal and seasonal surface energy fluxes at the same site. This study complements TF-1. The broader objectives of the combined proposals include determination of the annual cycle for carbon and nitrogen at the site, with trace gas measurements now also including CO, NO, NO_2, NH_3, and possibly terpenes. Four categories of measurements are proposed - (i) eddy correlation flux measurements of momentum, sensible heat, latent heat, CO_2, O_3, CH_4 and N_2O above the canopy; (ii) within and above canopy profiles of temperature, CO_2 and O_3; (iii) half-hour means of wind speed, wind direction, incoming solar radiation, net radiation, PAR, temperature, relative humidity, wet precipitation, CO_2, O_3, CH_4 and N_2O above the canopy, IR canopy temperature, and soil heat flux and temperature; and (iv) tethersonde profiles including O_3.

Ref. Number TF-3

P.I.(s):	Wofsy, S.C./
Co-I(s):	Munger, J.W., Daube, B.C., Goulden, M.L., Boering, K.A., Burley J.D./
Title:	Eddy Correlation Flux Measurements of CO_2, and H_2O for BOREAS (NSA-OBS)
Objectives and Approach:	Eddy-correlation flux measurements for CO_2, and H_2O will be made at the northern black spruce site from the late summer of 1993 at least through the fall of 1994. Our principle objective is to directly determine the net ecosystem exchange of CO_2, and the surface energy budget, over diurnal, seasonal and annual time scales, and to couple these observations with a comprehensive characterization of the physical environment (PAR, soil temperature, etc.). A low-power automated array will be installed to measure: eddy fluxes and forest column content of CO_2, sensible heat, and water vapor; soil temperatures and moisture, and incident and intercepted PAR. The system will be operated continuously from installation in 9/93 through at least 10/94. Additionally, we will measure the flux of CO_2 from the soil during the summer of 1994 using an array of automated open chambers. Among other things, these long-term measurements should allow us to assess the importance of winter respiration, and assimilation during transitional periods, to the annual carbon balance of the boreal forest.

Ref. Number TF-4

P.I.(s):	Anderson, D.E. and Striegl, R.G./USGS
CO. I.(s):	McConnaughey, E. and Stannard, D.J./USGS

Title: Exchange of Trace Gases, Water and Energy in Disturbed and Undisturbed Boreal Forests (SSA-YJP)

Objectives and Approach: We will investigate carbon, water and energy fluxes in boreal forests through an integrated approach involving flux estimates across the atmosphere-forest and soil-atmosphere boundaries. Eddy correlation measurements of CO_2 latent and sensible heat fluxes, and momentum will be made above a young Jack Pine stand in SSA. Concentration profiles of CH_4, $^{12}CO_2$, and $^{13}CO_2$ will be determined within the canopy during one IFC. Soil-atmosphere flux studies will employ soil depth vs. gas concentration measurements, flux chambers and diffusion modelling to determine source and movement of CH_4, $^{12}CO_2$, and $^{13}CO_2$ in the air-soil-water continuum. The distribution and storage of carbon species in the soil profile will also be determined. Long-term carbon accumulation will be evaluated by ^{14}C decay of soil carbon.

Net, incoming and PAR radiation, leaf photosynthesis, and certain soil parameters (heat flux, thermal profile) will be measured at the site.

Ref. Number TF-5

P.I.(s):	Baldocchi, D/NOAA
CO-I(s):	Crawford, T., Meyers, T., McMillen, R./NOAA

Title: Experimental and Modeling Studies of Water Vapor, Sensible Heat, and CO_2 Exchange Over and Under a Boreal Forest (SSA-OJP)

Objectives and Approach: We propose to measure and model air-surface exchange rates of water vapor, sensible heat, and CO_2 over and under a boreal forest and to study the abiotic and biotic factors that control the fluxes of scalars in this landscape. This study is is related to AFM-1. Scalar flux densities will be measured with tower-mounted eddy correlation flux measurement systems over an Old Jack Pine stand in the Prince Albert area. Tower-mounted flux measurement systems will be implemented above and below the canopy. This configuration will allow us to investigate the relative roles of vegetation and the forest floor on the net canopy exchange of mass and energy. We will also use the tower-mounted flux measurement system to study temporal patterns (diurnal and seasonal) of mass and energy exchange at a point in the landscape. Core Measurements include the mass and energy exchange studies just described, as well as measurements of meteorological variables.

A hierarchy of single and multi-layer mass and energy (water vapor, heat, and CO_2) exchange models - bases on Eulerian and Lagrangian frameworks and on micrometeorology, radiative transfer, plant physiology, and biochemistry theory - will be developed and tested using the data obtained over a boreal forest.

Ref. Number TF-6

P.I.(s):	Bessemoulin. P.,
CO-I(s):	Breon, F-M./CNRM Mahfouf, J.F., Noilhan, J., Roujean, J.L./CNRM Deschamps, P.Y./USTL, Kerr, Y./CNES, Vanderbilt, V.C./NASA/AMES
Title:	Study of the Boreal Forest Effects on Surface/Atmosphere Fluxes (SSA-YA)
Objectives and Approach:	Our research program includes measurement of the turbulent and radiative fluxes modelling of interactions between the surface (soil, vegetation, snow) and atmosphere at local, meso and large scale (CNRM); radiative fluxes and atmospheric optics measurements (LOA, LERTS); airborne remote sensing measurements with the POLDER instrument (LOA, LMCE, NASA). The equipment will operate at the Young Aspen site in the SSA in IFC-2 only. Measurements of the fraction of PAR and NIR radiation intercepted by NSA-OJP and NSA-OBS forest continuously, that is from sunrise to sunset and from May to September (including IFC-1, IFC-2, and IFC-3). Sample within the forest using a large number (around 100) of small optical sensors located at different levels on a vertical 12-meters mast. FPAR and LAI can be estimated as a result.

Ref. Number TF-7

P.I.(s):	Desjardins, R.L., Pattey E./Agriculture Canada, MacPherson, J.I./NRC
CO-I.(s):	Schuepp, P.H./McGill, Nakane K., Hayashi M./Japan, St-Amour, G./Agriculture Canada
Title:	Areal Estimates of Mass and Energy Exchange from a Boreal Forest Biome (SSA-OBS)
Objectives and Approach:	The objective of this study is to develop techniques for studying the contribution of the boreal ecosystem to the greenhouse gas composition of the atmosphere and how this ecosystem responds to environmental conditions. Tower-based flux measurements of heat, momentum, CH_4, CO_2, NMHC, N_2O, NHMC, and H_2O will be obtained during intensive field campaigns in 1994 over an Old Black Spruce stand in the Prince Albert area. These measurements will be compared with measurements from other research groups in order to evaluate their accuracy and combined with them to model the boreal forest ecosystem. Techniques will be developed to arrive at a spatial and temporal description of energy, water and carbon fluxes on a large scale basis. The Japanese section of this team lead by Prof. Nakane will measure CO_2 fluxes in the ofrest canopy by chamber technique. In addition, soil carbon cycle work will be done in the SSA-OBS and nearby clear-cuts.

Ref. Number TF-8

P.I.(s):	Fitzjarrald, D.R./Atmospheric Sciences Research Center
CO-I(s):	Moore, K.E./Statue Univ of New York, Albany
Title:	Surface Exchange Observations in the Canadian Boreal Forest Region (NSA-OJP)
Objectives and Approach:	This study will focus on long-term measurements of radiation, heat, moisture, carbon dioxide and momentum budgets from the tower at the Nelson House Old Jack Pine site. Turbulent fluxes are to be determined using the eddy correlation technique and radiative fluxes in the short, long, near infrared, and PAR wavelength bands will be acquired as well as soil moisture content. Collaborating with other groups the CO_2 gradient inside and just above the canopy will be acquired. In addition, we will deploy a digital cloud camera to obtain a seasonal record of cloud fraction and, possibly, cloud type.

Ref. Number TF-9

P.I.(s):	Jarvis, P.G.,Moncrieff, J.B.// Univ of Edinburgh
CO-I(s):	Massheder, J.M., Hale, S.E., Rayment, M.B., Scott, S.L./Univ. of Edinburgh; Morse, A.P./Univ. of Liverpool
Title:	The CO_2 Exchanges of Boreal Black Spruce Forest (SSA-OBS)
Objectives and Approach:	The objectives of this study are to measure and model the CO_2 exchanges of boreal black spruce forest and to determine whether the soils and vegetation are significant global sinks for atmospheric CO_2. Stand CO_2fluxes will be measured using eddy covariance and respiration components will be measured using chamber based techniques. The CO_2 concentration profile will also be measured to allow estimation of the atmospheric storage of CO_2 within the canopy. Further measurements of the photosynthetic components and of stand structure and radiation properties will be obtained by collaboration with other groups. These measurements will be used to construct carbon budgets and to test models (especially Maestro) that will be used to scale up the carbon budgets in space and time.

Ref. Number TF-10

P.I.(s):	McCaughey, J.H./Queen's Univ
CO-I(s):	Jelinski, D.E./State Univ of New York at Buffalo, Lafleur, P.M./Trent Univ
Collaborator(s):	Ponce-Hernandez, R/Trent Univ, Price, J.S./Queen's Univ; Buttle, J./Trent Univ
Title:	Surface Energy and Water Balances of Forest and Wetland Subsystems in the Boreal Forest: Surface-Atmosphere Links and Ecological Controls (NSA-YJP; NSA-Fen)
Objectives and Approach:	We plan to carry out an intensive series of field experiments on the climatological implications of contrasting ecological controls on surface energy and water balances of forest and wetland subsystems of the northern Boreal Forest. The young-dry jack pine site and the fen site at the NSA have been selected for the work. For both surfaces, a complete suite of microclimatic (energy, radiation, and water balance data) and biophysical measurements will be taken. We propose to measure the flux of CO_2 at both sites.

As part of the study concerning ecological controls on the hydrology and water balance of a wetland subsystem of the northern boreal forest, TF-10 will be conducting field work during the FFC-T at the fen site at Thompson. A spatially-distributed snowmelt model will be developed from measurements of net radiation, temperature, relative humidity and wind speed at both the fen tower and a nearby forested site. A snow survey consisting of a stratified random sample based on terrain types will be conducted and will include depth-stratified (snow pits) and depth integrated measurements of snow density and snow water equivalent. Other supporting measurements will include meltwater chemistry, depth to frost table, snow and soil temperature profiles as well as gap fraction measurements with a LAI-2000 prior to green-up.

Ref. Number TF-11

P.I.(s): Verma, S.B./Univ of Nebraska-Lincoln

CO-I(s): Arkebauer, T.J.. Ullman, F.G./Univ of Nebraska, Parton, W.J., Schimel, D.S.,Valentine, D.W./Colorado State University

Title: Field Micrometeorological Measurements, Process-Level Studies and Modeling of Methane and Carbon Dioxide Fluxes in a Boreal Wetland Ecosystem (SSA-Fen)

Objectives and Approach: We propose an integrated program of research on field micrometeorological measurements, process studies and modeling of methane and carbon dioxide fluxes at a boreal wetland site (fen at SSA). The proposed research has the following four components.

1. Quantifications of surface exchange rates of methane and carbon dioxide at a boreal wetland site. The micrometeorological eddy correlation technique will be employed to obtain 'areally integrated' fluxes.
2. Evaluation of soil surface carbon dioxide flux and characterization of its response to controlling variables.
3. Process studies will include field experimental manipulations to quantify the degree of substrate or pH limitations of methane production and oxidation. The responses of leaf photosynthesis, plant respiration and stomatal conductance of dominant plant species to relevant controlling variables will be quantified experimentally.
4. Integration of the first three components to test and improve a model of decomposition and methane emission responsive to variability in moisture, temperature, and pH in northern wetland ecosystems.

4.2.3 Field Measurements

4.2.3.1 In-Situ Measurements

Table 4.2.3.1a shows which investigators are assigned to which TF sites. The P.I.s act as site captains for each TF site, see Section 5.2.

Table 4.2.3.1a Location of TF Sites

Project #	Principal Investigator	Cover Type	Site_ID	Study Area	Site Maps
TF-3	Wofsy*	Old Black Spruce	T3R8T	NSA	4.2.3.2a
TF-8	Fitzjarrald*	Old Jack Pine	T7Q8T	NSA	4.2.3.2b
TF-10	McCaughey*/*Jelinski	Young Jack Pine	T8S9T	NSA	4.2.3.2c
TF-10	Jelinski*/LaFleur*	Fen	T7S1T	NSA	4.2.3.2d
TGB-4	Roulet*	Beaver Pond	T4U6T	NSA	4.2.3.2e
TF-1	Black/Thurtell	Old Aspen	C3B7T	SSA	4.2.3.2f
TF-2	den Hartog*	Old Aspen	C3B7T	SSA	4.2.3.2f
TF-4	Anderson*	Young Jack Pine	F8L6T	SSA	4.2.3.2g
TF-5	Baldocchi*	Old Jack Pine	G2L3T	SSA	4.2.3.2h
TF-6	Bessemoulin*	Young Aspen	D6H4T	SSA	4.2.3.2i
TF-7	Desjardins/Pattey	Old Black Spruce	G8I4T	SSA	4.2.3.2j
TF-9	Jarvis*	Old Black Spruce	G8I4T	SSA	4.2.3.2j
TF-11	Verma*	Fen	F0L9T	SSA	4.2.3.2k
HYD-5	Harding*	Namekus Lake and Clear cut	E7B7C	SSA	4.2.3.2l

* = Site Captain

Table 4.2.3.1b lists the measurements to be made at each of the tower flux sites by the teams listed. In general,the data will be provided on a half-hourly basis starting on the hour and half hour.

Maps showing the layout of each TF site and one TGB site are shown as figures 4.2.3.2a through 4.2.3.2k. In each case, the left hand panel shows the site infrastructure layout, the right hand panel shows the orientation of the wind aligned blobs (WABs or flux-emission zones or footprints). References for each figure are shown in Table 4.2.3.1a. More information may be found in Section 2.2.2.

Destructive sampling within the WABs and/or from the flux towers is not permitted. Specific permission is required from the site captains to gain access to the WABs. Access to the flux towers requires advance notice to the site captains and may not be possible.

Note that destructive sampling within the WAB and/or from the flux tower without the site captain's permission is forbidden.

Northern Study Area – Old Black Spruce site (NSA-OBS)

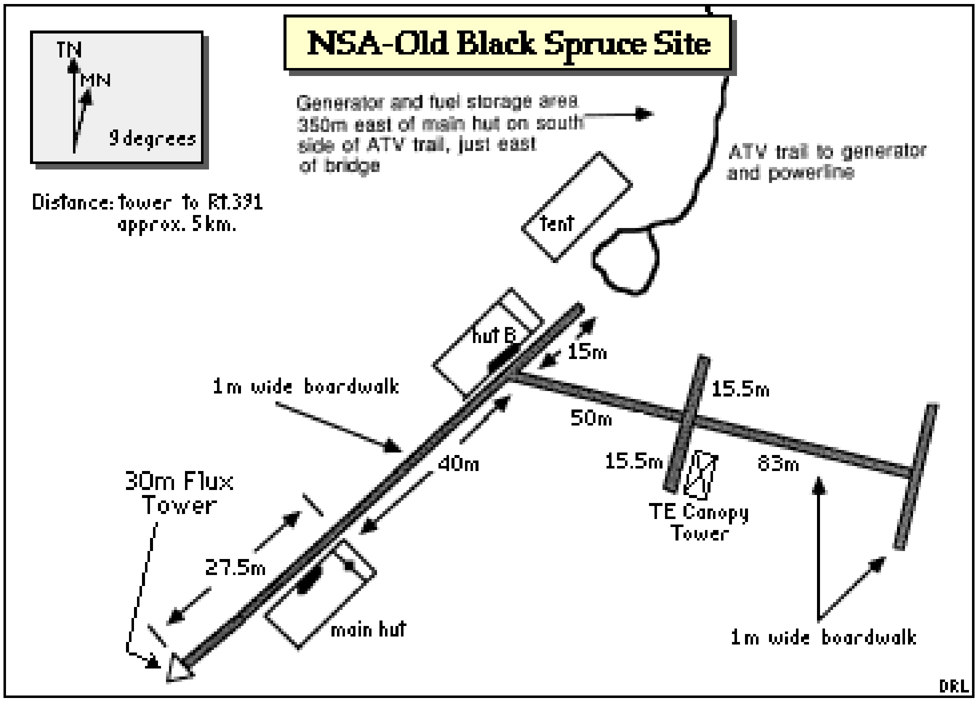
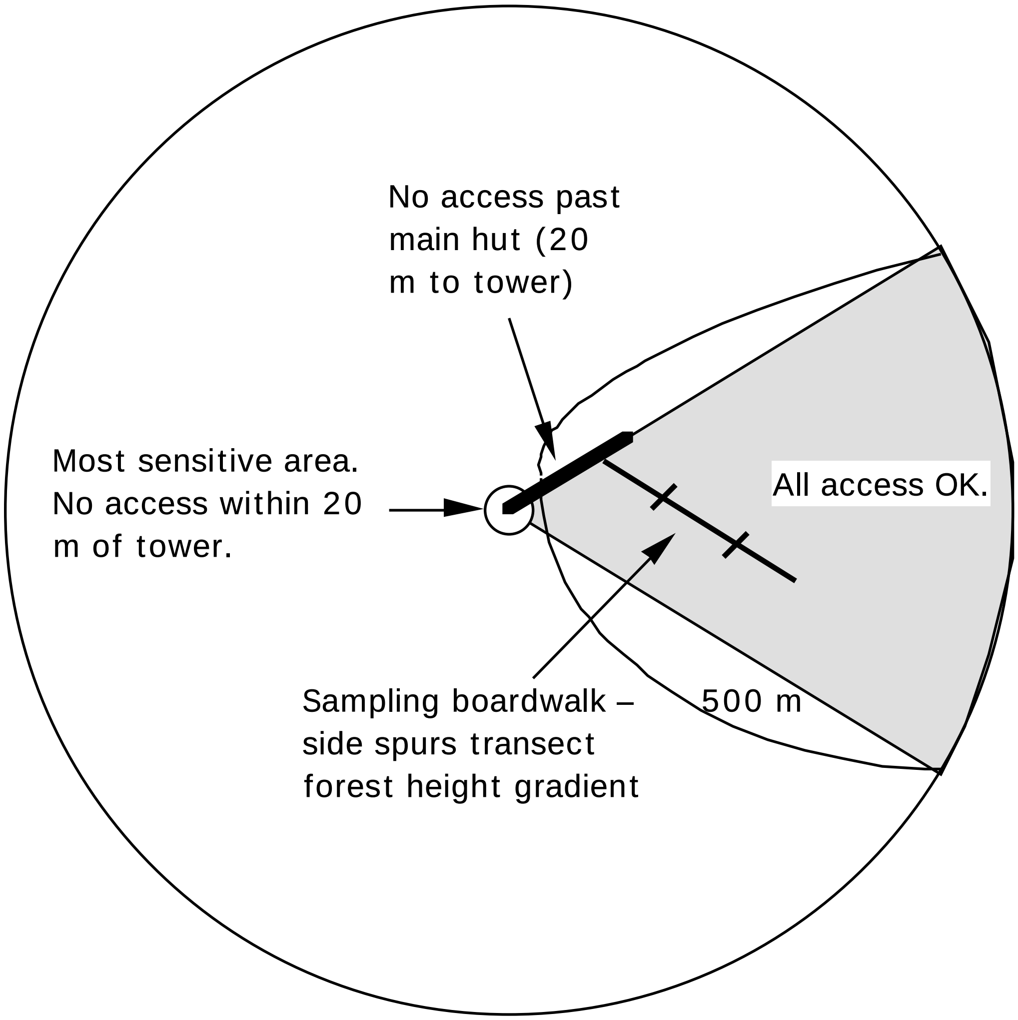


Figure 4.2.3.2a: TF-3 Site Map (NSA-OBS)
i) Site Layout and Infrastructure

Northern Study Area – Old Black Spruce site (NSA-OBS)



Please concentrate measurements along sampling boardwalk. No access in WAB without permission. No harvests.

Site Captain: Steve Wofsy

Figure 4.2.3.2a: TF-3 Site Map (NSA-OBS)
(ii) Orientation of WAB

Northern Study Area – Old Jack Pine site (NSA-OJP)

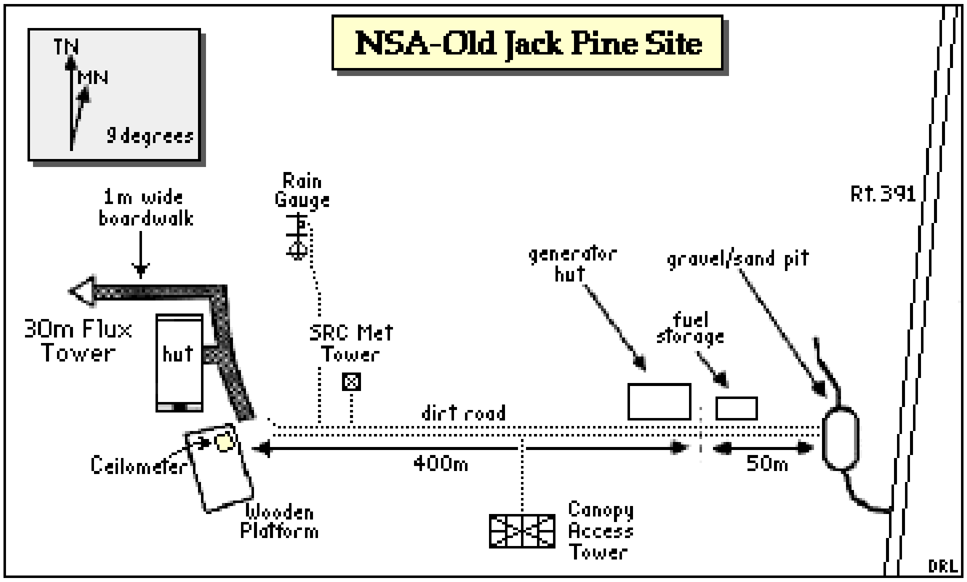
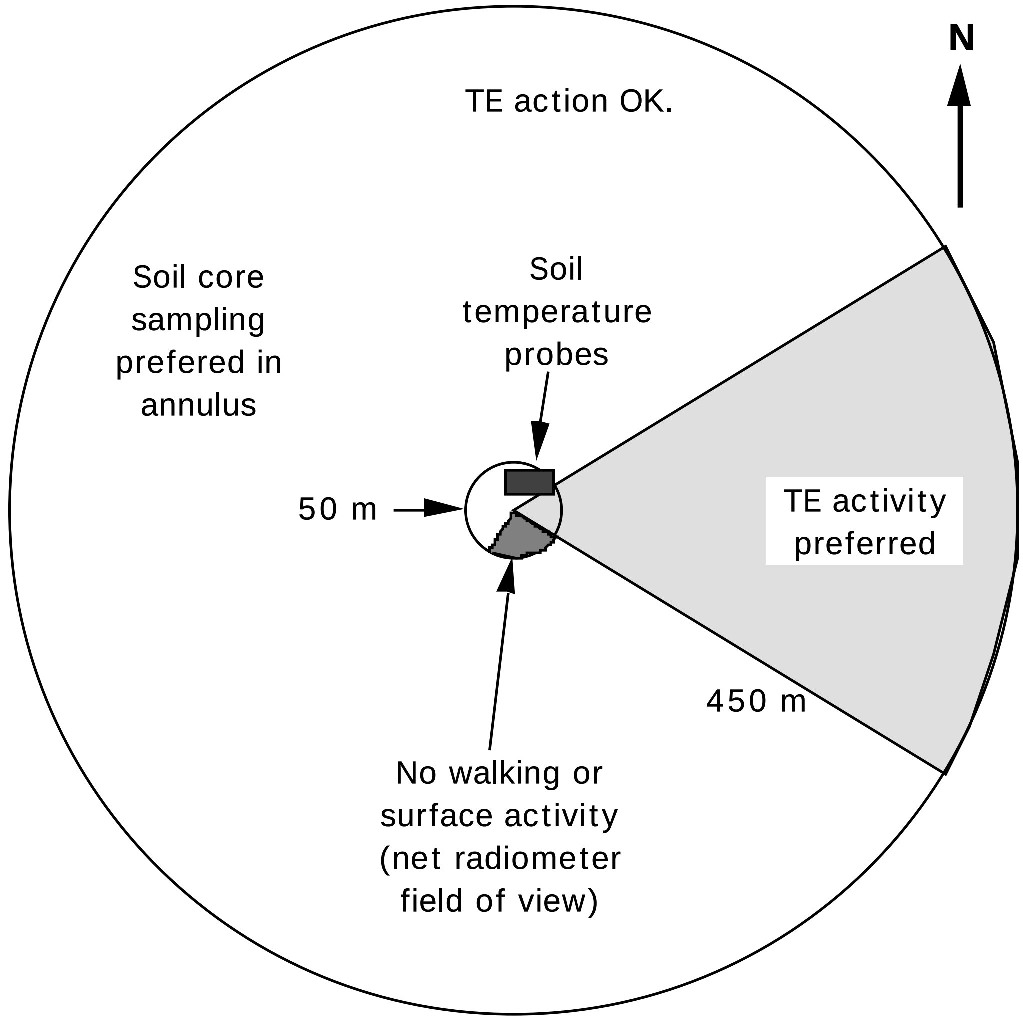


Figure 4.2.3.2b: TF-8 Site Map (NSA-OJP)
(i) Site Layout and Infrastructure

Northern Study Area – Old Jack Pine site (NSA-OJP)



Please do not march around indiscriminately – lichen could be damaged. Please check with fitzjarrald/Moore. We are very willing to work with other groups.

Site Captain: Dave Fitzjarrald

Figure 4.2.3.2b: TF-8 Site Map (NSA-OJP)
(ii) Orientation of WAB

Northern Study Area – Young Jack Pine site (NSA-YJP)

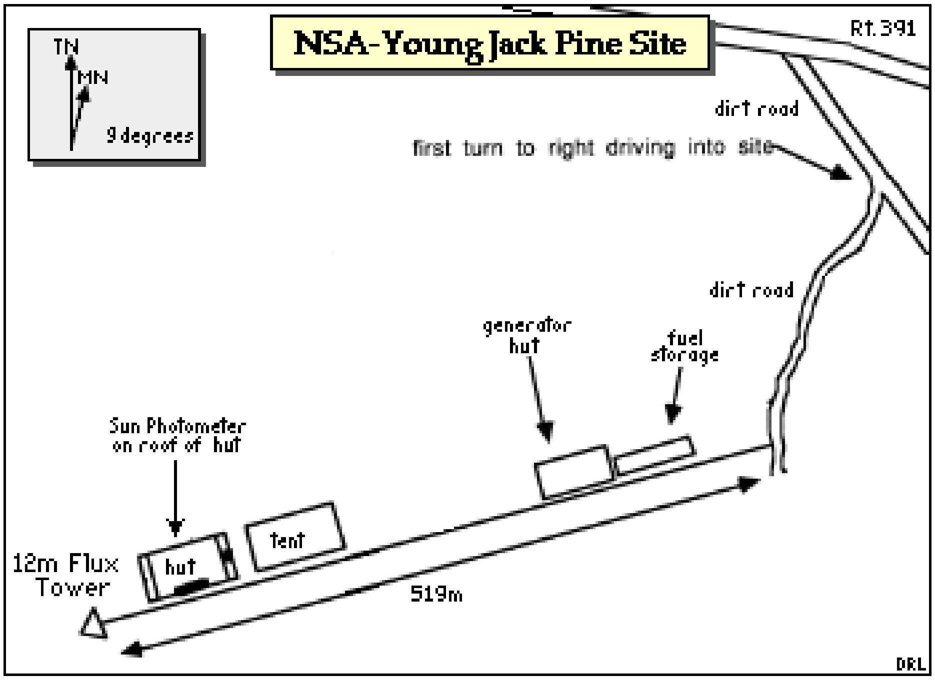
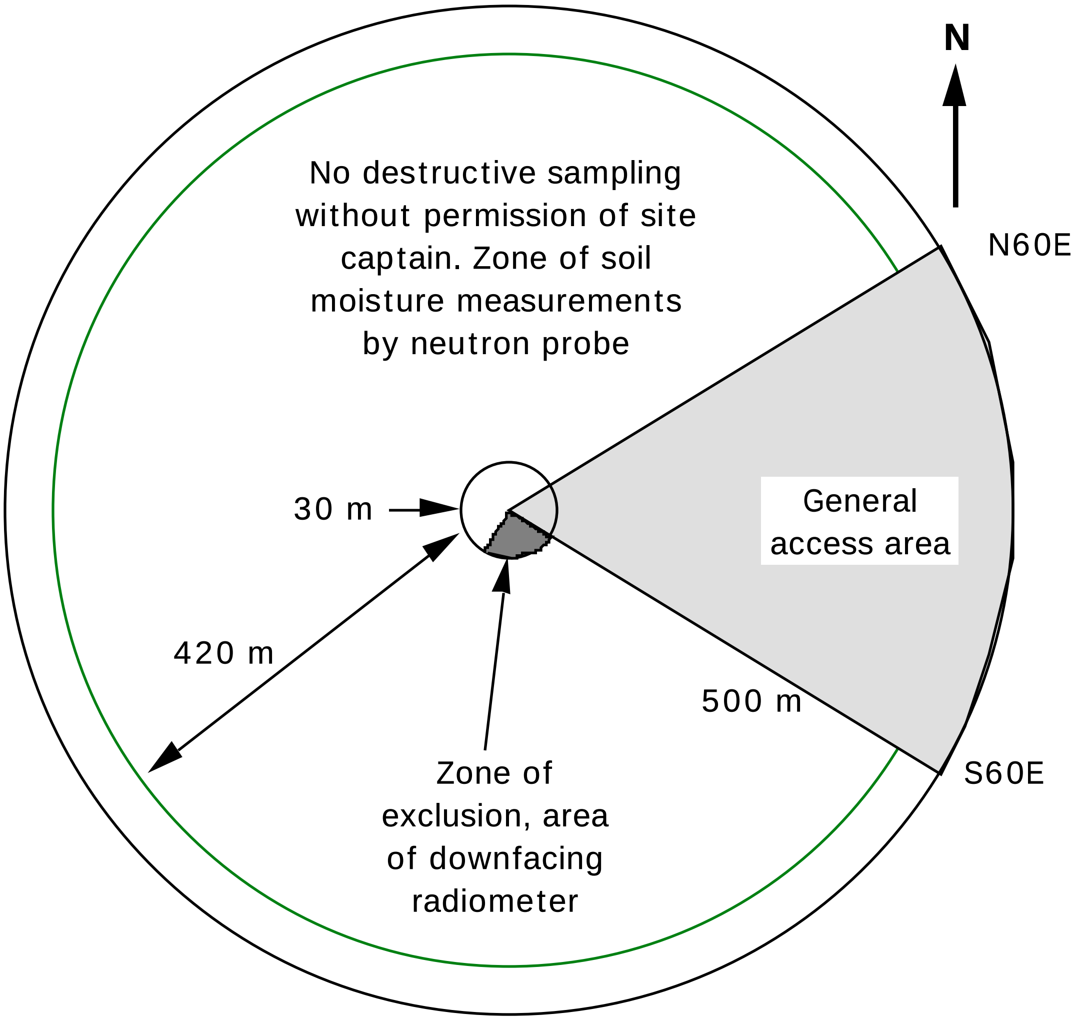


Figure 4.2.3.2c: TF-10 Site Map (NSA-YJP)
(i) Site Layout and Infrastructure

Northern Study Area – Young Jack Pine site (NSA-YJP)



Site Captain: Harry McCaughey/Dennis Jelinski

Figure 4.2.3.2c: TF-10 Site Map (NSA-YJP)
(ii) Orientation of WAB

Northern Study Area – Fen site (NSA-Fen)

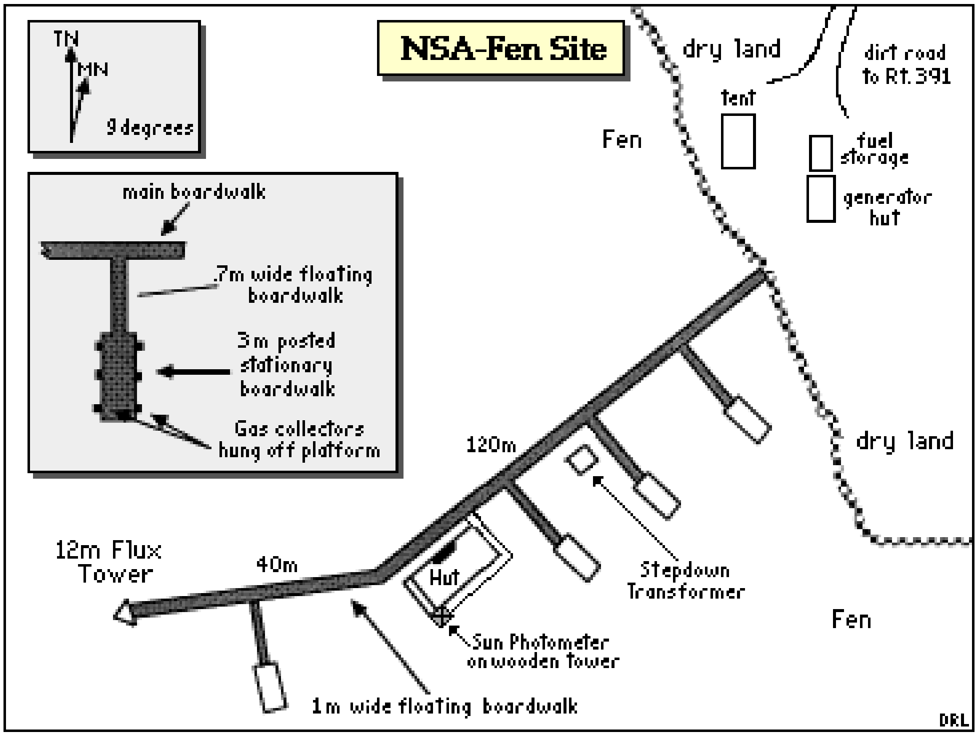
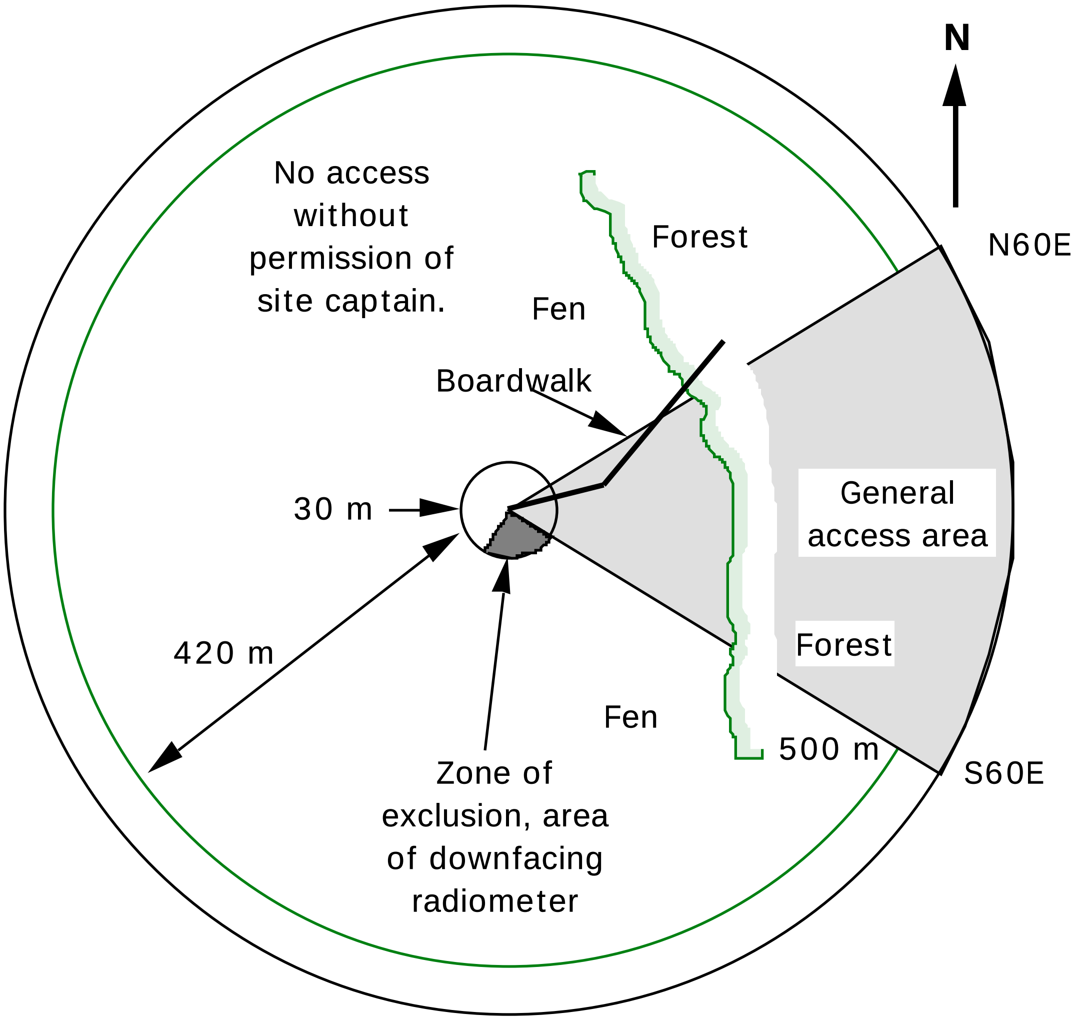


Figure 4.2.3.2d: TF-10 Site Map (NSA-Fen)
(i) Site Layout and Infrastructure

Northern Study Area – Fen site (NSA-Fen)



No access to WAB without the specific permission of the site captain.

Site Captain: Dennis Jelinski/Peter La Fleur

Figure 4.2.3.2d: TF-10 Site Map (NSA-Fen)
(ii) Orientation of WAB

Northern Study Area – Beaver Pond site (NSA-BP)

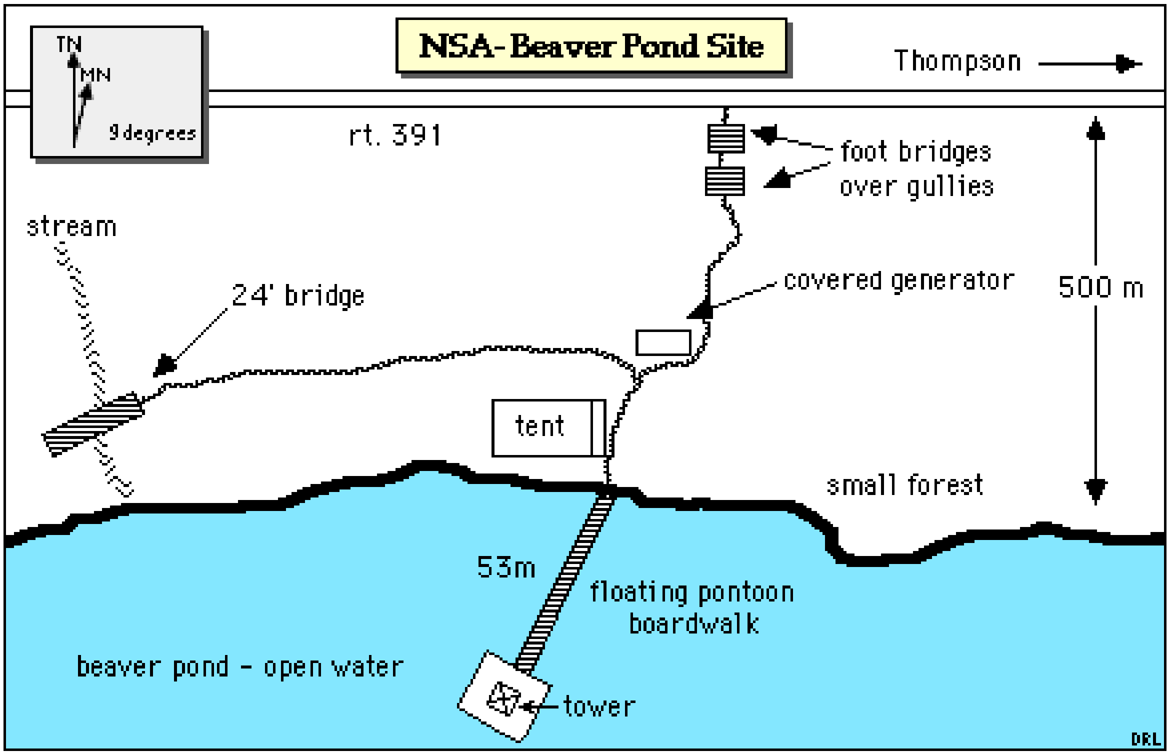
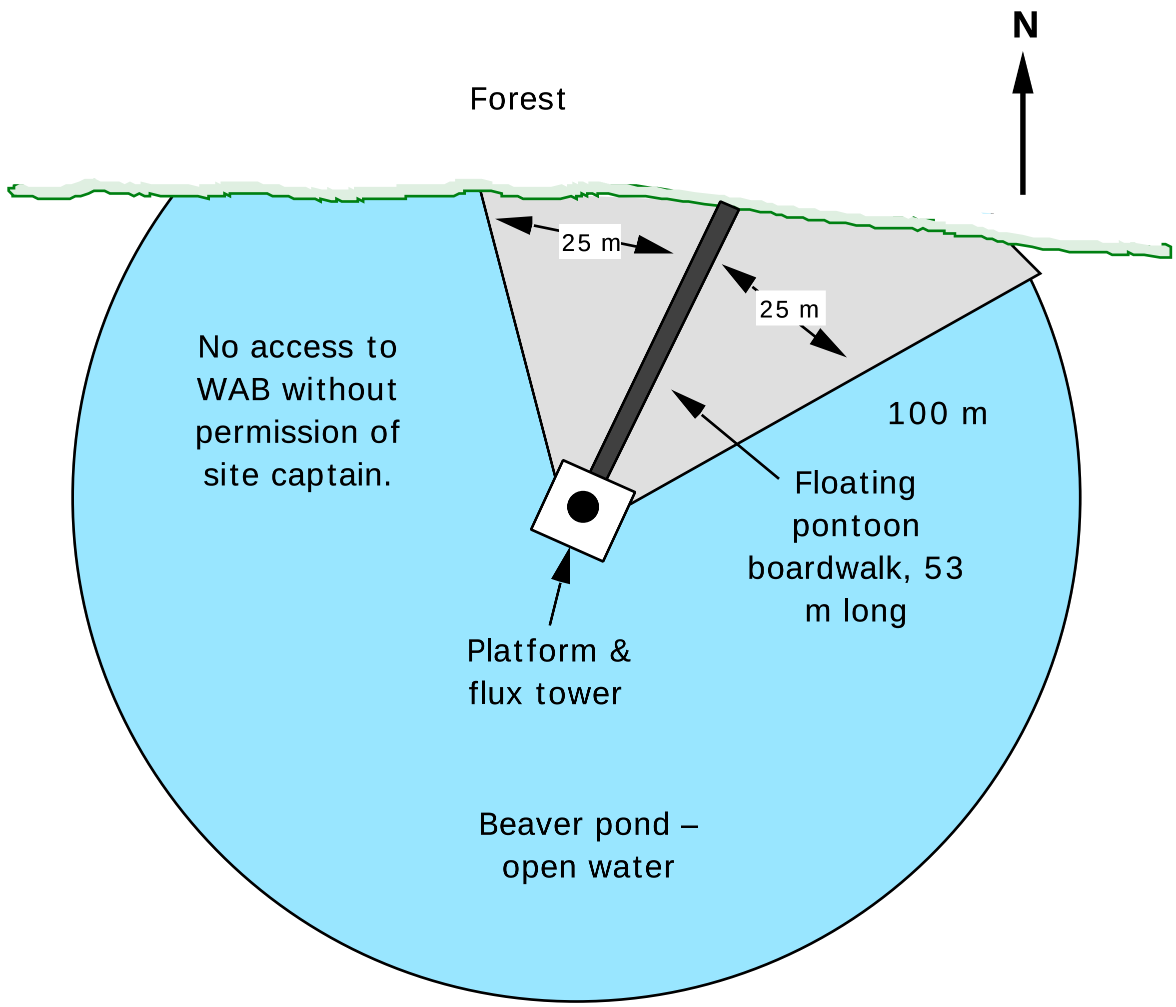


Figure 4.2.3.2e: TGB-4 Site Map (NSA-BP)
(i) Site Layout and Infrastructure

Northern Study Area – Beaver Pond site (NSA-BP)



No access to WAB without the specific permission of the site captain.

Site Captain: Nigel Roulet

Figure 4.2.3.2e: TGB-4 Site Map (NSA-BP)
(ii) Orientation of WAB

Southern Study Area – Old Aspen site (SSA-OA)

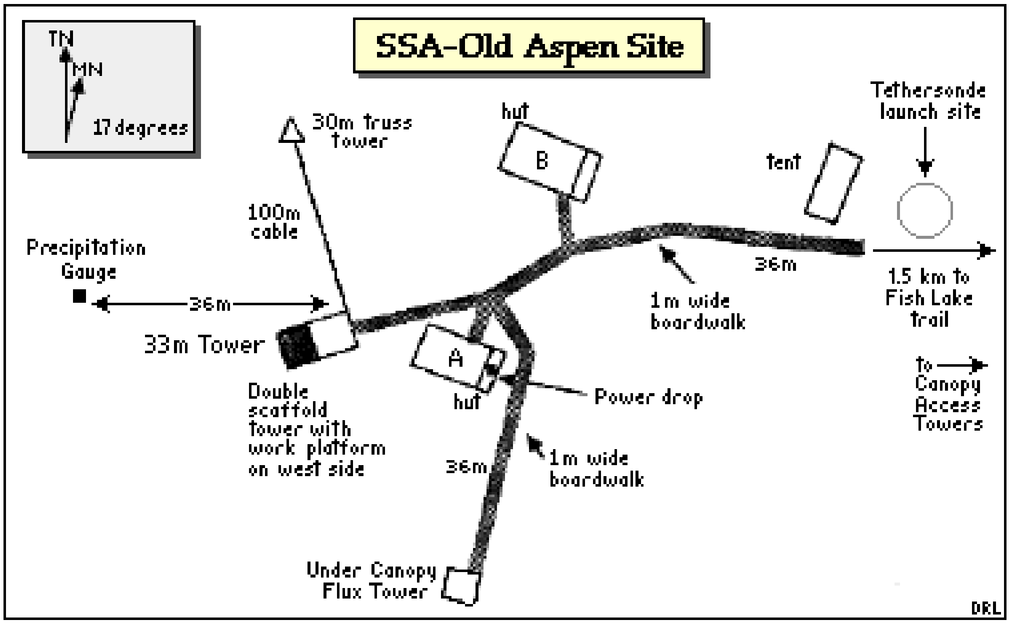
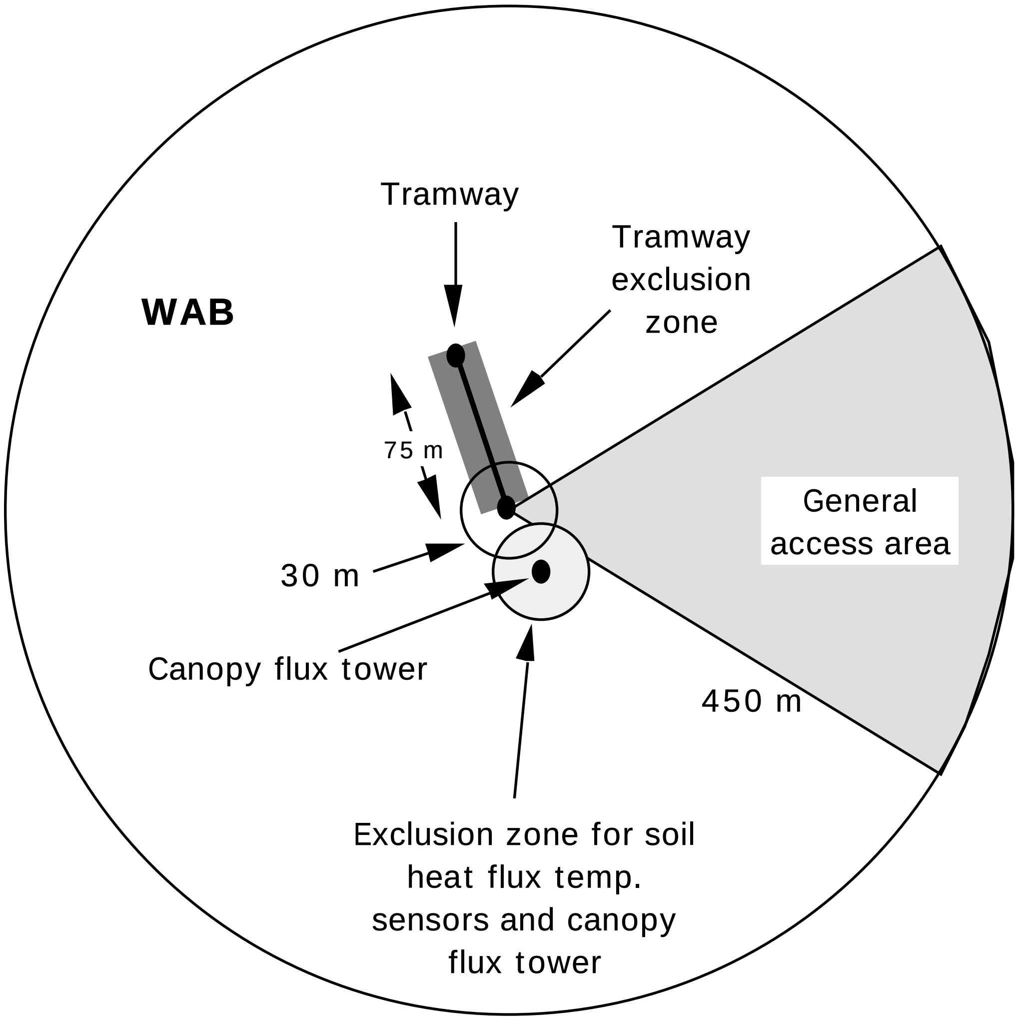


Figure 4.2.3.2f: TF-1 and TF-2 Site Map (SSA-OA)
(i) Site Layout and Infrastructure

Southern Study Area – Old Aspen site (SSA-OA)



It is desirable to have no disturbance in (i) the tramway corridor (15m on either side of the tramline-tramway exclusion zone), (ii) in the soil temperature and heat flux measurement area (152 degrees, true) 10-12m from reference location, and (iii) in vicinity of the canopy flux tower (aboput 30m south of the main tower).

The "footprint" (WAB) is the zone between the 30m and 450m radii. A detailed soil survey is requested for the 30-450m footprint area. It is preferable that this be done greater than 450m to the west, north, or south.

No destructive plant sampling should occur in the WAB. Please check with the site captain on when and where activities close to the flux towes are going to occur.

Site Captain: Gerry den Hartog

Figure 4.2.3.2f: TF-1 and TF-2 Site Map (SSA-OA)
(ii) Orientation of WAB

Southern Study Area – Young Jack Pine site (SSA-YJP)

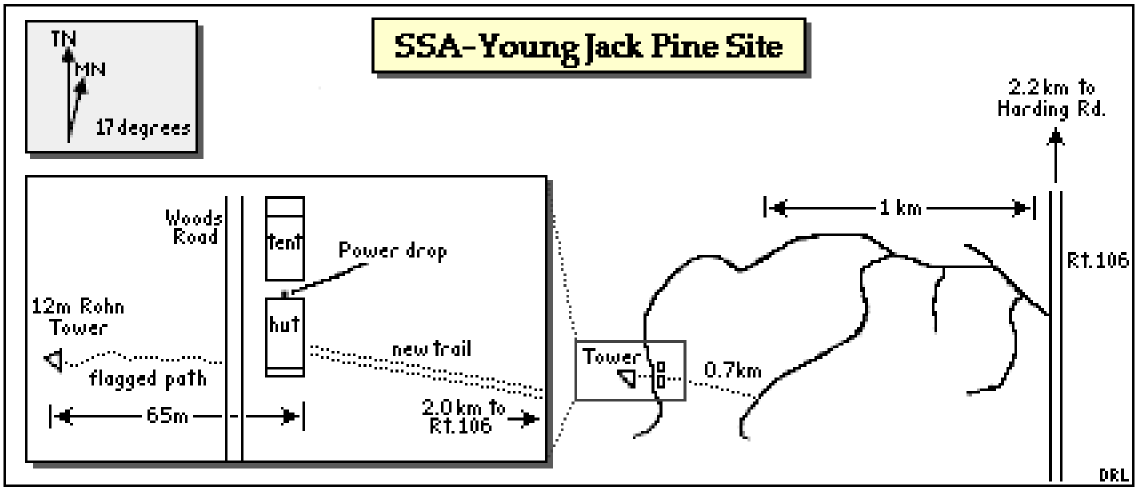
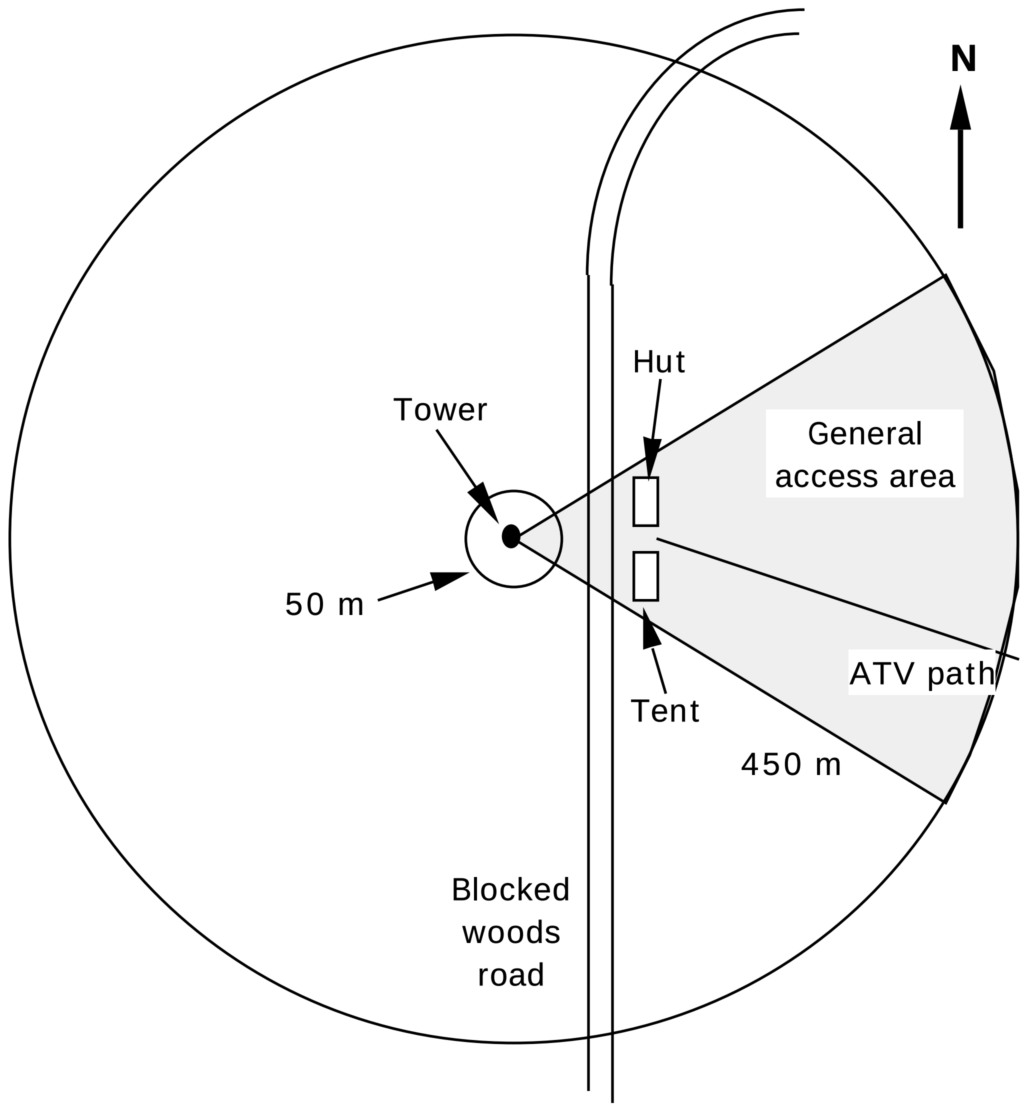


Figure 4.2.3.2g: TF-4 Site Maps (SSA-YJP)
(i) Site Layout and Infrastructure

Southern Study Area – Young Jack Pine site (SSA-YJP)



Inner circle of 50m radius is a no trespass zone. Visits may be made anytime outside of outer circle of 450m. Visits inside the 450m radius may be made under certain wind conditions – please contact the tower flux crew before entering the area on each visit.

Site Captain: Dean Anderson

Figure 4.2.3.2g: TF-4 Site Maps (SSA-YJP)
(ii) Orientation of WAB

Southern Study Area – Old Jack Pine site (SSA-OJP)

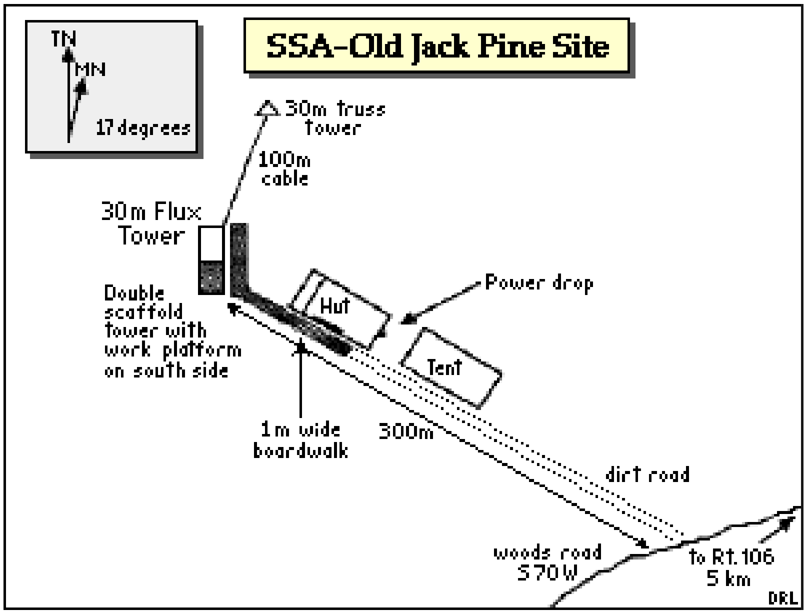
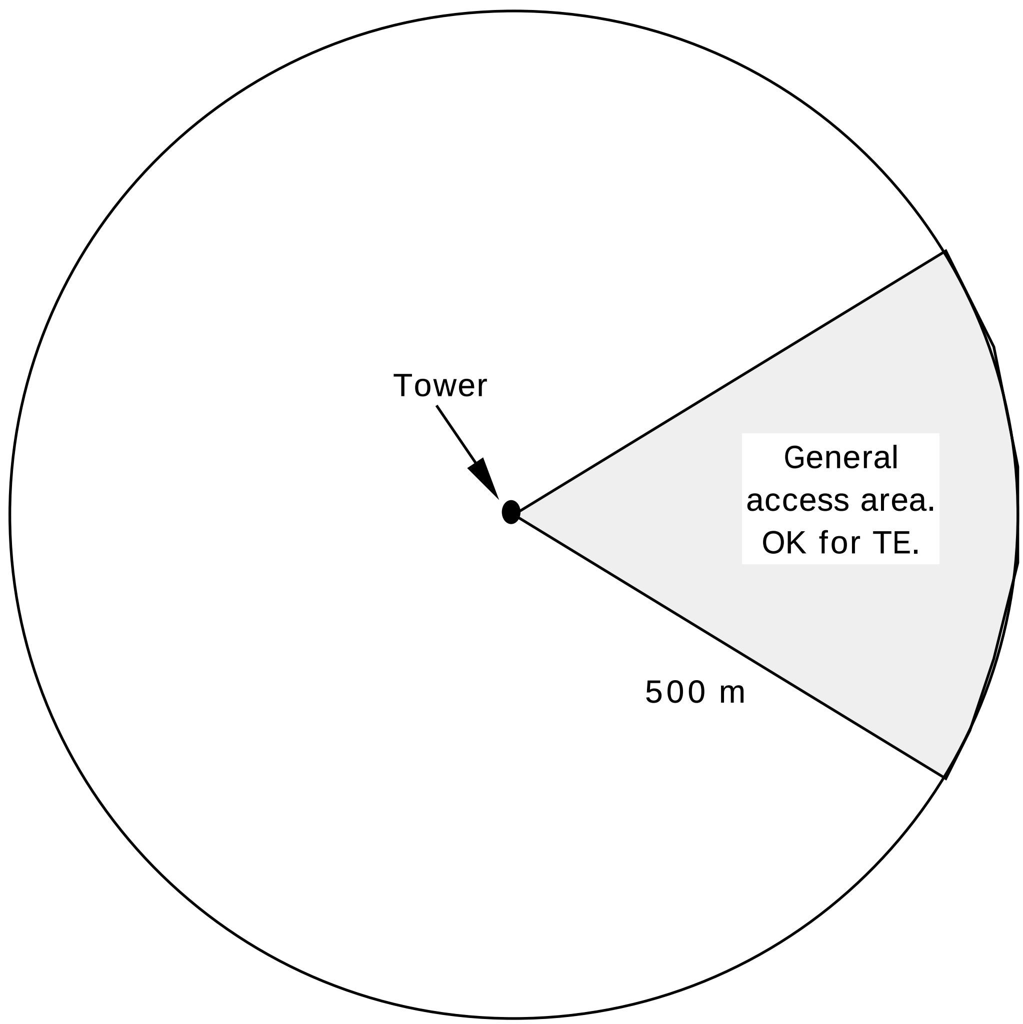


Figure 4.2.3.2h: TF-5 Site Maps (SSA-OJP)
(i) Site Layout and Infrastructure

Southern Study Area – Old Jack Pine site (SSA-OJP)



No access in WAB without permission of site captain. Stay away from Forest Floor Flux system, tram, and area of soil measurements. Willing to work with Terrestrial Ecology in a manageable manner.

Site Captain: Dennis Baldocchi

Figure 4.2.3.2h: TF-5 Site Map (SSA-OJP)
(ii) Orientation of WAB

Southern Study Area – Young Aspen site (SSA-YA)

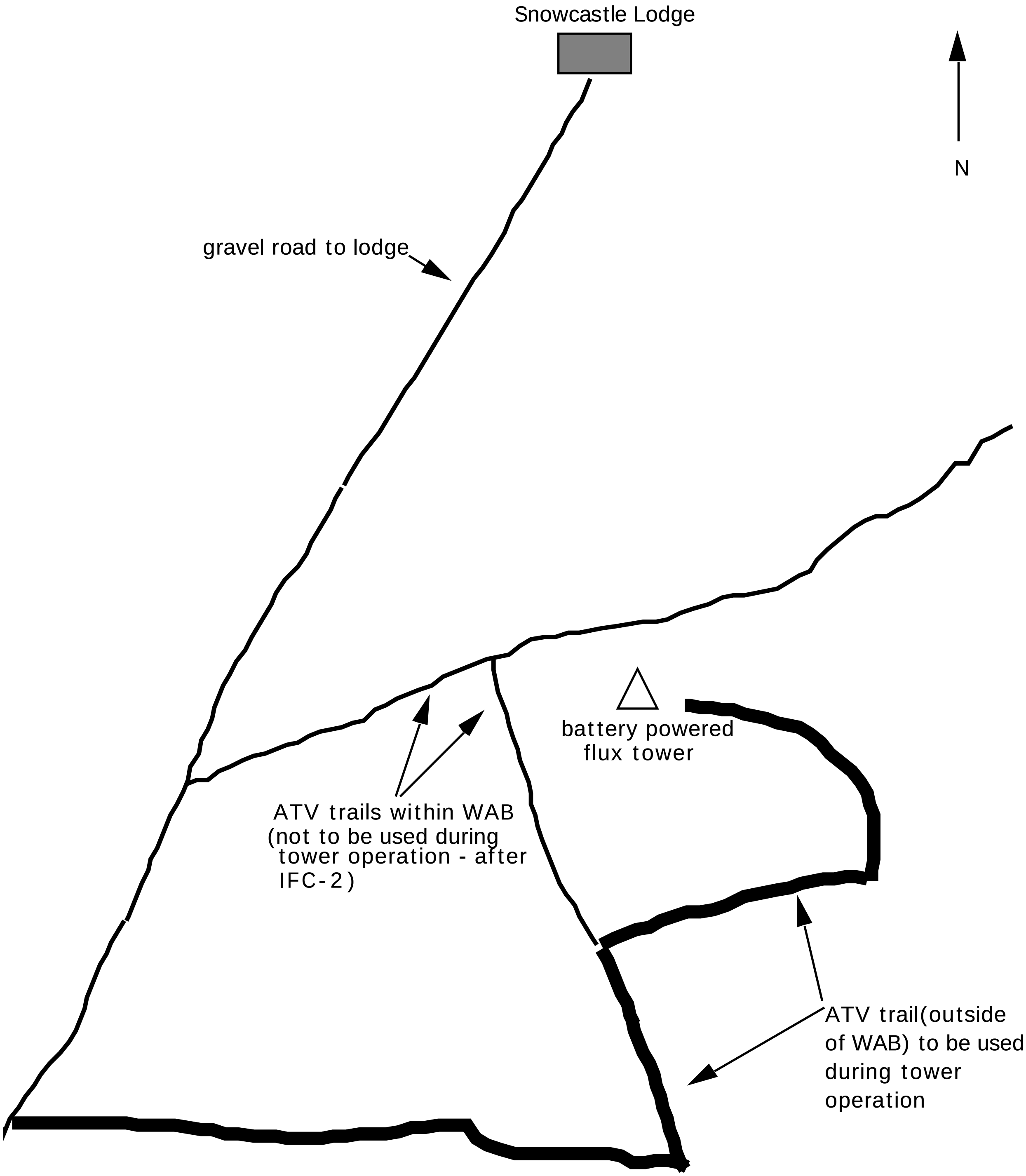
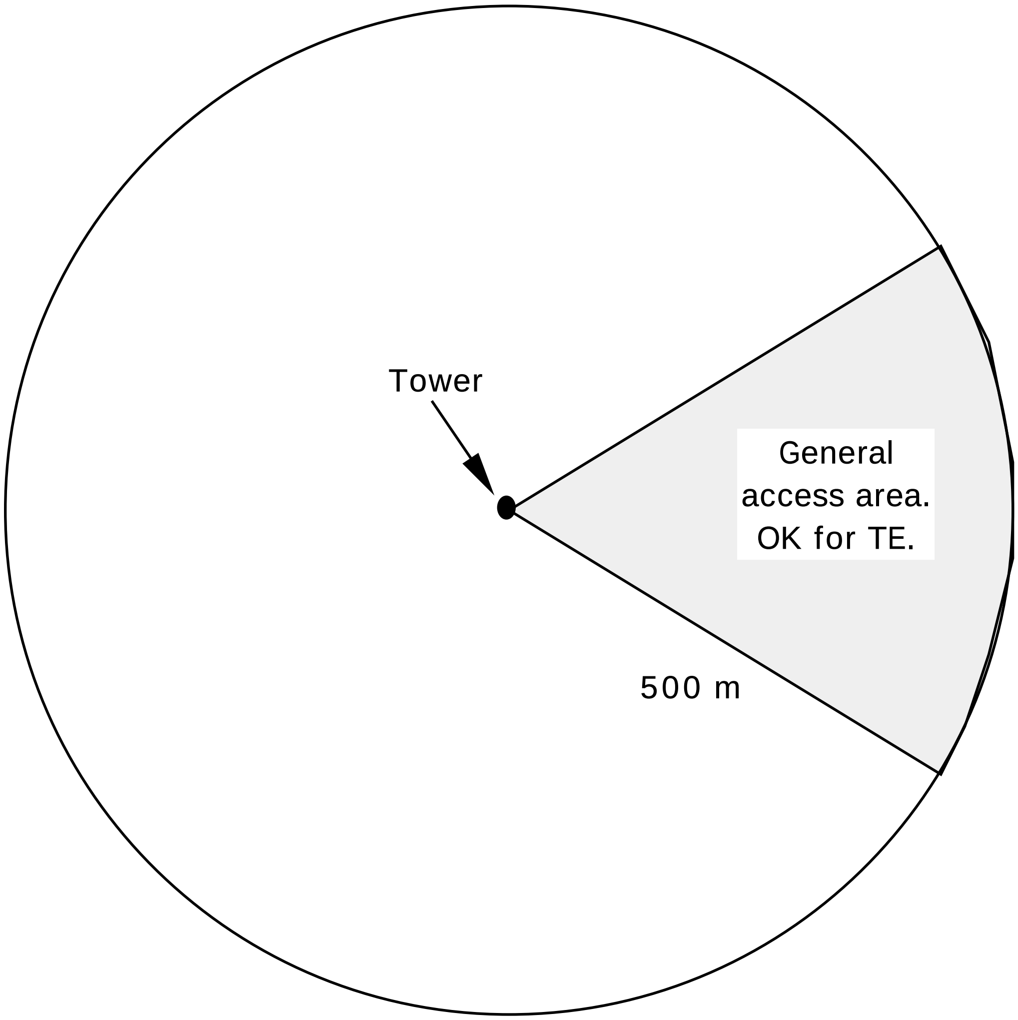


Figure 4.2.3.2i: TF-6 Site Map (SSA-YA)
(i) Site Layout and Infrastructure

Southern Study Area – Young Aspen site (SSA-YA)



No access in WAB without permission of site captain.

Site Captain: Pierre Bessemoulin

Figure 4.2.3.2i: TF-6 Site Map (SSA-YA)
(i) Orientation of WAB

Southern Study Area – Old Black Spruce site (SSA-OBS)

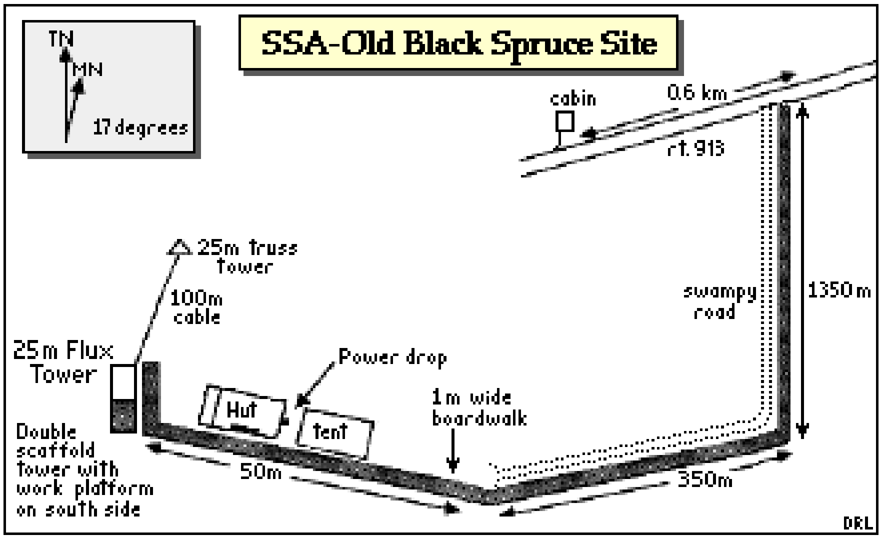
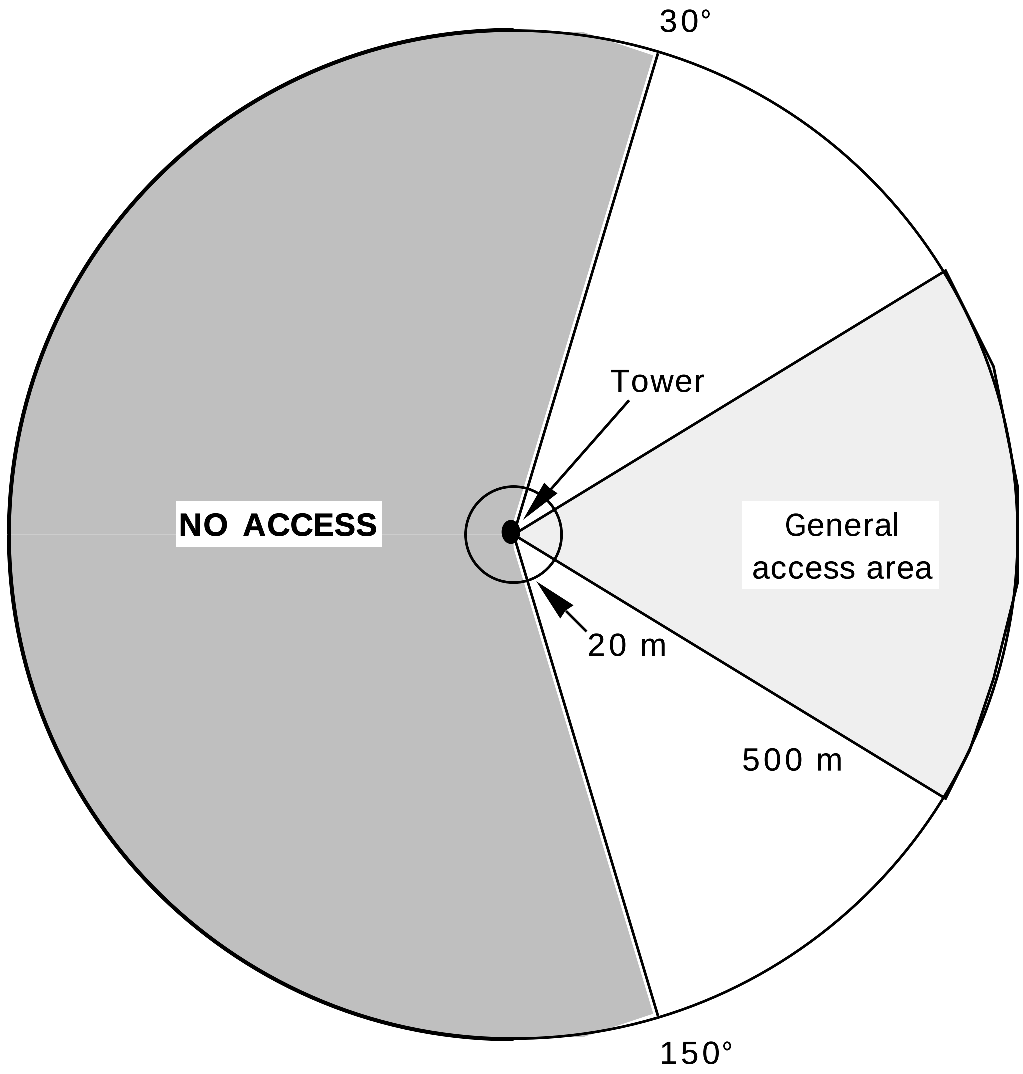


Figure 4.2.3.2j: TF-9 and TF-7 Site Map (SSA-OBS)
(i) Site Layout and Infrastructure

Southern Study Area – Old Black Spruce site (SSA-OBS)



Available for sampling anywhere outside of a 500m radius from the tower after discussion with the site captain.

Site Captain: Paul Jarvis

Figure 4.2.3.2j: TF-9 and TF-7 Site Map (SSA-OBS)
(ii) Orientation of WAB

Southern Study Area – Fen site (SSA-Fen)

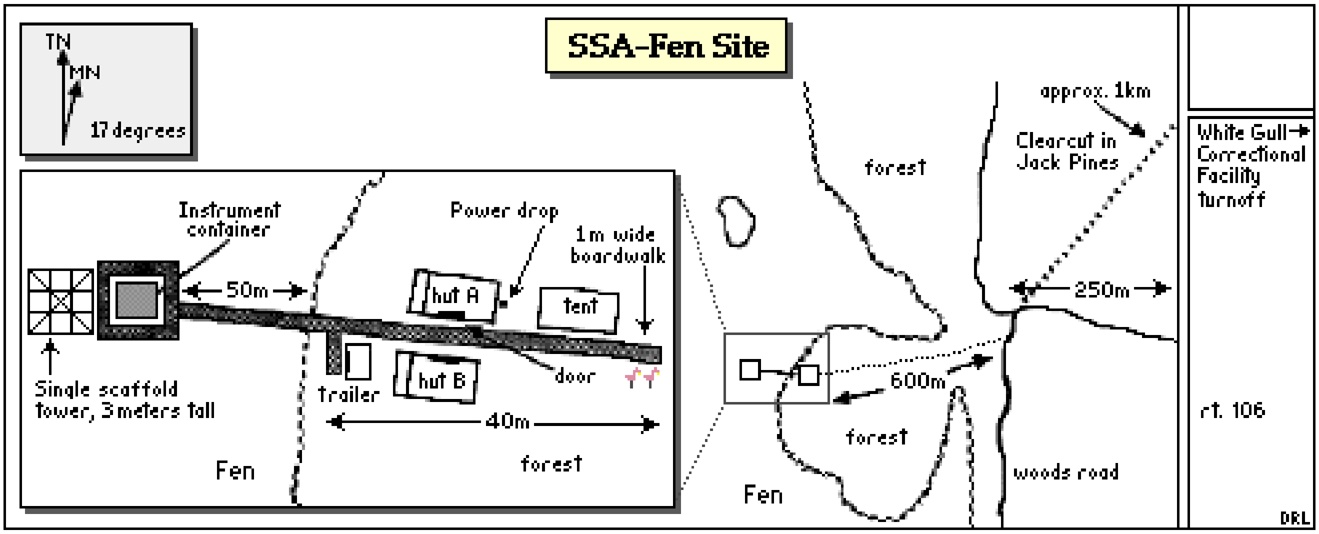
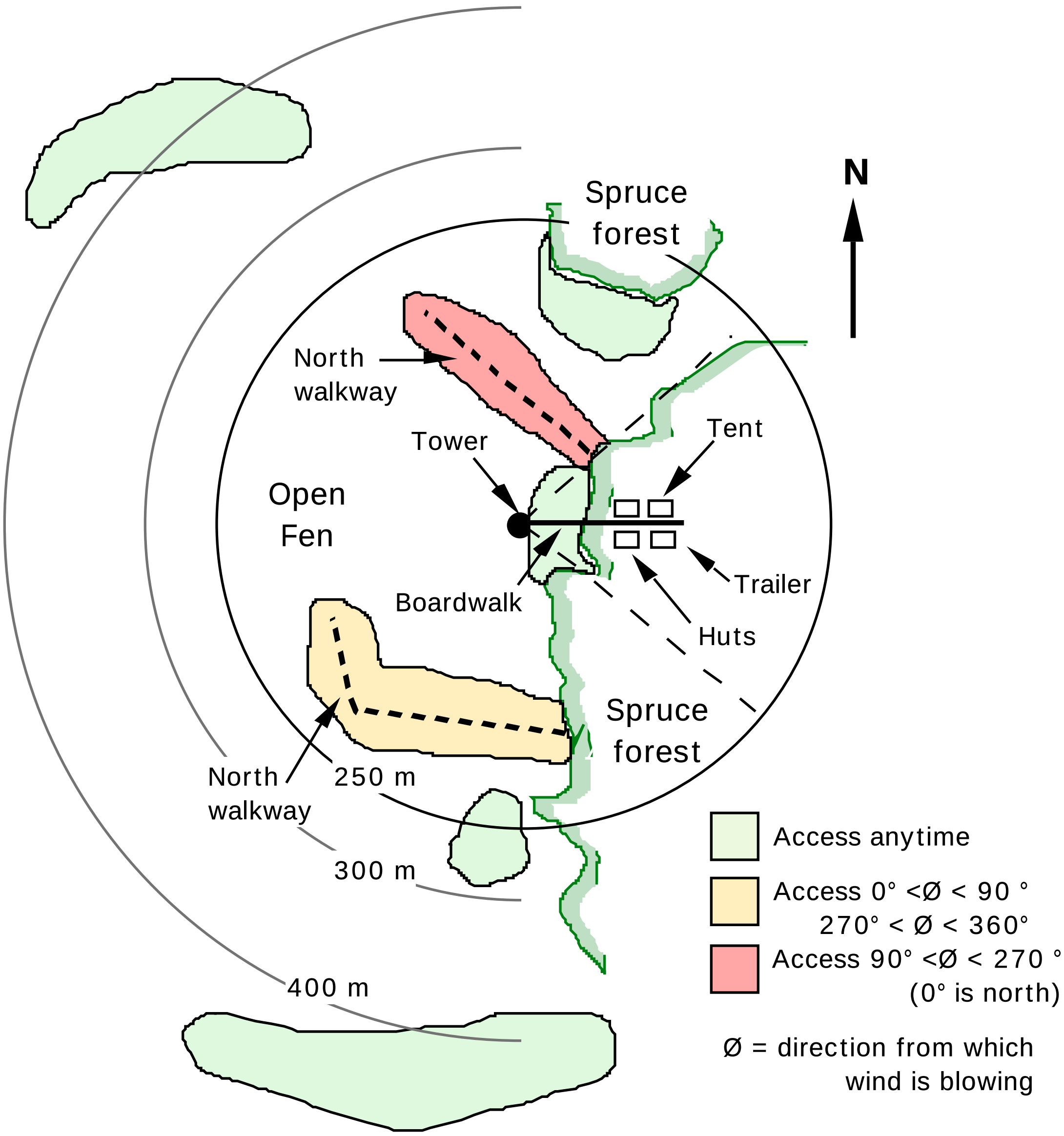


Figure 4.2.3.2k: TF-11 Site Map (SSA-Fen)
(i) Site Layout and Infrastructure

Southern Study Area – Fen site (SSA-Fen)



Site Captain: Shashi Verma

Figure 4.2.3.2k: TF-11 Site Map (SSA-Fen)
(ii) Orientation of WAB

Southern Study Area – Namekus Lake (HYD-5)

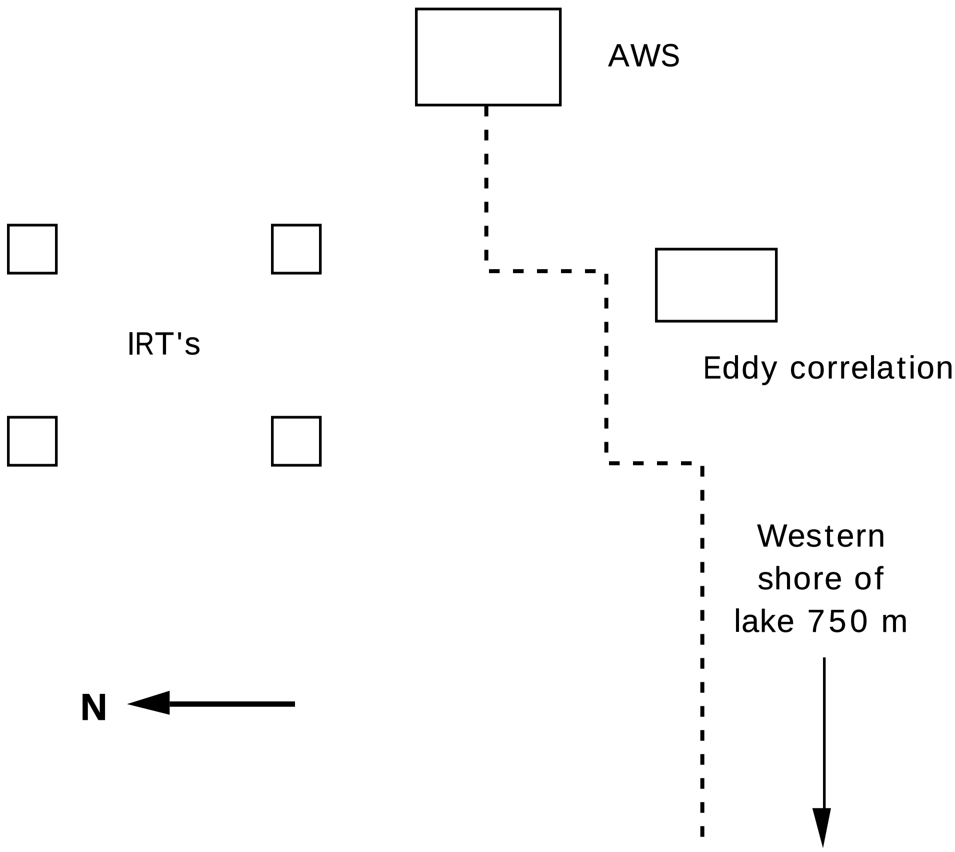


Figure 4.2.3.2l: HYD-5 Site Map (SSA-Lake)
(i) Site Layout and Infrastructure

Bear Trap Tower (HYD-5)

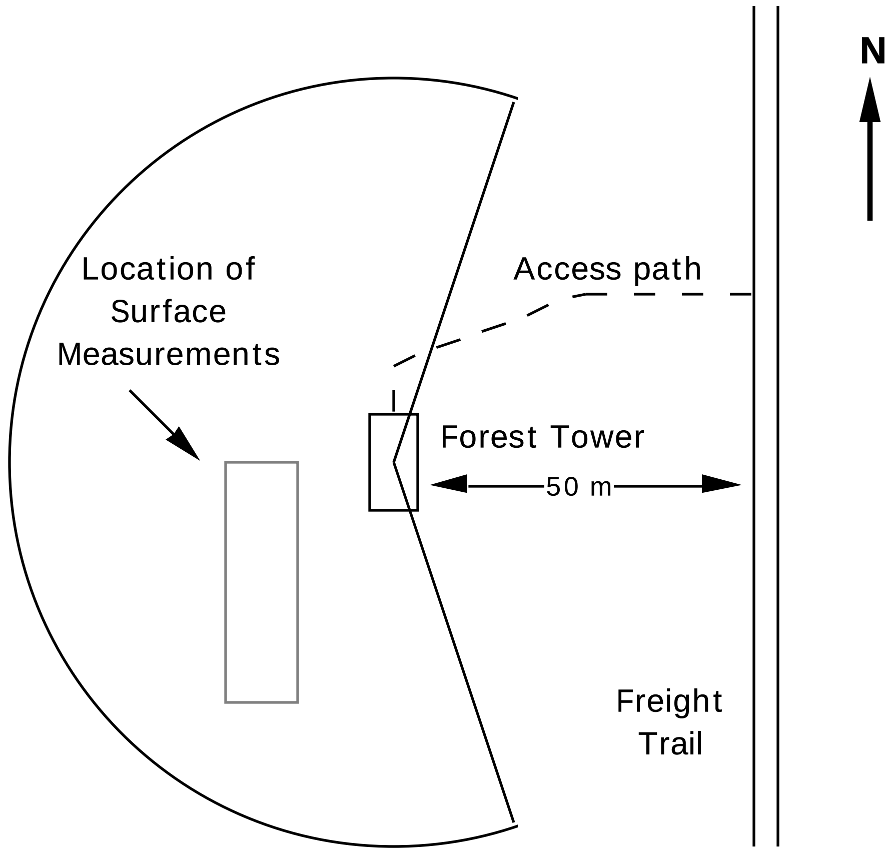


Figure 4.2.3.2l: HYD-5 Site Map (SSA-Lake)
(ii) Orientation of WAB

Table 4.2.3.1b
Tower Measurement Summary.

Team	P.I.	Site/Study Area	Radiation	Soil T,q	Turb fluxes	Profile Tq	Operation
TF-3	Wofsy	NSA-OBS	Q*,P	T,F, q-TDR	LE,H,ζ C,	yes	Cont.
TF-8	Fitzjarrald	NSA-OJP	Q*,K,L,P	T,F,q-b	LE,H,ζ C	yes	Growing season
TF-10	McCaughey/ Jelinsky	NSA-YJP	Q*,K,L	T,F,q-V	LE,H,C	yes	Growing season
TF-10	Jelinski/ La Fleur	NSA-Fen	Q*,K,L	T,F,q-TDR	LE,H,C	yes	Growing season
TF-1	Black/ Thurtell	SSA-OA	Q*	T,F,TDR	LE,H,C,M, N_2O	no	IFCs
TF-2	den Hartog	SSA-OA	Q*,K,P		LE,H,ζ C,O,M,N_2O	yes	continuous
TF-4	Anderson	SSA-YJP	Q*,P		LE,H,ζ C	yes	IFCs
TF-5	Baldocchi	SSA-OJP	K,P	T,F,q-b,q-V	LE,H,ζ C,O,M	yes	IFCs
TF-6	Bessemoulin	SSA-YA	K,L,P	T,F,q-?	LE,H	yes	IFC 2
TF-7	Desjardins/ Pattey	SSA-OBS	K	N/A	LE,H, C,M,N_2O	no	IFC 1,2,3
TF-9	Moncrieff/ Jarvis	SSA-OBS	K,P,Q*	T,F	LE,H,C,ζ	yes	IFCs
TF-11	Verma	SSA-Fen	K,P	T,F	LE,H,ζ C,M	yes	IFCs
	Harding	SSA-PA	K,L	T	LE,H	yes	FFC-T

OBS = Old Black Spruce
YJP = Young Jack Pine
OA = Old Aspen
OBS = Black Spruce
OJP = Old Jack Pine
FEN = Fen
YA = Young Aspen
PA = Frozen Lake and Forest Sites in Prince Albert Park

Q*, net radiation; K shortwave global radiation; L longwave; P PAR;
T,F Soil temp/heat flux; q-b soil moisture block; q-TDR soil moist. by TDR;
LE latent ht flux; H sensible heat flux C CO_2 flux; M methane flux;
O ozone flux;NO nitric oxide flux; N_2O nitrous oxide flux
ζ momentum flux; q-V soil moisture by volume

4.2.3.2 Data to be Submitted to BORIS

Data to be submitted to BORIS and desired units are shown in Table 4.2.3.2. This data list is very preliminary and has been adapted from the FIFE data base.; it will be revised in due course. Comments have been provided by Ken King on suggested changes to the format and contents of the data base; these follow the table.

TABLE 4.2.3.2

Preliminary Proposed Tower Flux Variables For BOREAS

The nominal averaging period for the meteorological data will be 30 minutes starting on the hour and half hour

Heights and depths at which measurements were made are to be appended to the variable name in place of HEIGHT and DEPTH e.g. SOIL_TEMP_25MM is soil temperature measured at a depth of 25 mm (heights and depths should be given as integers and units for the height or depth chosen to allow this).

Values for wind components (u,v,w) and their standard deviations should be after axis rotation.

OBS_YEAR	: year of observation (e.g. 1993)
OBS_DAY	: day of year (001 to 365)
START_TIME	: time (HHMM in GMT) recording start time
END_TIME	: time (HHMM in GMT) recording end time
SITEGRID	: site grid number where data was collected
R_NET_HEIGHT	: net radiation (W m^{-2})
LATENT_HEAT_FLUX_HEIGHT	: latent heat flux (W m^{-2})
SENSIBLE_HEAT_FLUX_HEIGHT	: sensible heat flux (W m^{-2})
DIF_SOLAR_RAD_IN_HEIGHT	: incoming diffuse solar radiation (W m^{-2})
SOLAR_RAD_IN _HEIGHT	: incoming solar radiation (W m^{-2})
SOLAR_RAD_OUT_HEIGHT	: going solar radiation (W m^{-2})
NET_SOLAR_RAD_HEIGHT	: net solar radiation (W m^{-2})
PAR_IN_HEIGHT	: incoming PAR on forest floor (W m^{-2})
PAR_OUT_HEIGHT	: outgoing PAR on forest floor (W m^{-2})
LONGWAVE_IN_HEIGHT	: incoming long wave radiation (W m^{-2})
LONGWAVE_OUT_HEIGHT	: outgoing long wave radiation (W m^{-2})
TOTAL_RAD_IN_HEIGHT	: total incoming radiation (W/m^{-2})
TOTAL_RAD_OUT_HEIGHT	: total outgoing radiation (W/m^{-2})
SOIL_HEAT_FLUX_DEPTH	: soil heat flux at soil depth 1 (W/m^{-2})
SURFACE_ALB	: surface short wave albedo (percent)
PPFD_IN_HEIGHT	: incoming photosynthetic photon flux density (μmol^{-2} s^{-1})
PPFD_OUT_HEIGHT	: outgoing photosynthetic photon flux density (μmol^{-2} s^{-1})
HEAT_STORAGE_DEPTH	: heat storage in top soil layer (J m^{-3})
SOIL_MOISTURE_DEPTH	: soil water content (m^3 m^{-3})
SOIL_WATER_POTENT_DEPTH	: soil water potential (Mpa)
SOIL_WATER_DEPTH	: soil temperature (˚C)
RAINFALL	: amount of rain fall (mm)
SURFACE_AIR_PRESSURE	: surface air pressure (kPa)
WIND_SPEED_HEIGHT	: wind speed (m s^{-1})
WIND_DIR_HEIGHT	: wind direction (degrees from North).
WIND_SPEED_STDEV_HEIGHT:	: standard deviation of wind speed (ms^{-1})
WIND_DIR_STDEV_HEIGHT:	: standard deviation of wind direction (deg. from North)
FRICTION_VELOCITY_HEIGHT:	: friction velocity (m s^{-1})
U_MEAN_HEIGHT	: mean horizontal windspeed (m s^{-1})
V_MEAN_HEIGHT	: mean lateral windspeed (m s^{-1})
U_STDEV_HEIGHT	: standard deviation horizontal windspeed (m s^{-1})
V_STDEV_HEIGHT	: standard deviation lateral windspeed (m s^{-1})
W_STDEV_HEIGHT	: standard deviation vertical windspeed (m s^{-1})
SPECIFIC_HUMIDITY_HEIGHT	: specific humidity (g kg^{-1})

SPECIFIC_HUMIDITY_STDEV_ HEIGHT	: standard deviation of specific humidity (g kg^{-1})
VAPOR_PRESSURE_HEIGHT	: vapor pressure (kPa)
VAPOR_PRESS_STDEV_HEIGHT	: standard deviation of vapor pressure (kPa)
AIR_TEMP_OTHER_HEIGHT	: air temperature (˚C)
AIR_TEMP_STDDEV_HEIGHT:	: standard deviation of air temperature (˚C)
SOIL_TEMP_IRT	: infra red soil surface temperature (˚C)
SOIL_TEMP_STDEV	:standard deviation of infra red soil surface temperature (˚C)
H2O_FLUX_HEIGHT	: water vapor flux (mg m^{-2} s^{-1})
CO2_FLUX_HEIGHT	: carbon dioxide flux (mg m^{-2} s^{-1})
CO2_CONC_HEIGHT	: carbon dioxide concentration (ppmV)
CH4_FLUX_HEIGHT	: methane flux (μg m^{-2} s^{-1})
CH4_CONC_HEIGHT	: methane concentration (ppbV)
C3_FLUX_HEIGHT	: ozone flux (μg m^{-2} s^{-1})
C3_CONC_HEIGHT	: ozone concentration (ppbV)
N2O_FLUX_HEIGHT	: nitrogen dioxide flux (μg m^{-2} s^{-1})
N2O_CONC_HEIGHT	: nitrogen dioxide concentration (ppbV)
CO_FLUX_HEIGHT	: carbon monoxide flux (μg m^{-2} s^{-1})
CO_CONC_HEIGHT	: carbon monoxide concentration (ppbV)
NO_FLUX_HEIGHT	: nitric oxide flux (μg m^{-2} s^{-1})
NO_CONC_HEIGHT	: nitric oxide concentration (ppbV)
MOMENTM_FLUX_HEIGHT	: momentum flux (N m^{-2})

Note that in Table 4.2.3.2

a. The order of variables needs to be changed with climatological ones first and then grouping to put Beta with other energy balance variables, etc.

b. The start and ending times need to be specified somehow for fluxes and other variables that are averaged over time. Start and end times on the half-hour.

c. There needs to be provision for measurements that average over depth/height like TDR soil moisture and air temperature or concentration profiles.

d. There needs to be a standard way of specifying the height/depth of each measurement. The list shows SOIL TEMP depths 1, 2 etc. but there is no provision for a wind profile, CO_2 flux profile, etc. and one would have to look up in documentation to find what depth "2" means for a particular experiment. Perhaps all the variable names might be something like SOIL TEMP 10 CM. We need to specify what the depths and heights are relative to.

e. It would be nice to have a way of flagging in the database a change or replacement of a sensor, change in height of sensor and information on data quality such as dew on radiometer, failure of ventilation fan etc.

f. The sign convention should be the same for all tower flux projects (eg. positive up, negative down).

g. Some of the variables that need to be looked at because of the need for different heights, etc. are flagged in the table with an asterisk. A DELETE is used to flag variables that probably should be omitted from the data base. A lot of the rest should go in a climatological group.

h. The variable names for the u,v,w wind components have been changed.

i. A standard method for reporting fluxes. Suggestion is to report in [M/L^2/T], e.g. mass/m^2/s].

j. Additional variables such as T-q, T-C correlations etc.??

k. Coordinate rotation on the wind data etc. It is assumed that BORIS data will have this incorporated.

l. SOIL HEAT FLUX 1,2,3 (different levels or 3 at same level). If former why only 1 heat storage.

m. WIND DIR. use meteorological convention.

n. A note about start and end times which may differ for the various data using reporting time as the centre of the interval. Notes to be included with a tagged text file to the data file in BORIS.

o. A text file in BORIS identifying the data and interval linked to the data file describing problems with data.

Participants should read the article by Reifsnyder et al. in Agric. For. Meteorol. (1991, 54 389-394)

4.2.4 Supporting Measurements

4.2.4.1 Needs from Other Groups

The following list contains parameters needed to complete the measurement programs at each of the tower flux sites.

Soil Moisture

TDR (high quality) soil moisture measurements are required at all flux tower sites, except possibly at fen sites. Three of the sites list these measurements so that it will be required as an additional measurement at six or seven sites. Fen sites should be included and perhaps areas surrounding the fen sites. **(Completed: HYD-1, see section 3.2.3.4)**

Carbon Dioxide

Additional carbon dioxide measurements are required at some sites.

1. CO_2 flux at NSA fen and young jack pine (both soil respiration and photosynthesis) have been added.
2. CO_2 chamber measurements have been identified (see TE and TGB and Table 4.3.4.1).

Radiation

Albedo measurements at all sites.

4.2.4.2 Needs from Staff Science

Details of requirements by investigation are given in Table 4.2.4.2.

Desired Enhancements: Background allometric data for the various tree species at each site. Soil characteristics (texture, density, hydraulic conductivity, etc.) at each site. Canopy descriptive parameters (LAI) including a measurement of the understory. Climate data (wind speed, wind direction, temperature, humidity) is planned at some sites and may need enhancement at some. **(Completed: see sections 3.2.4 and 4.3)**

Total carbon pool: Measurements of carbon pool components. **(Completed: see section 4.3)**

4.2.5 Next Steps

4.2.5.1 1993 and 1994 Activities

1993 Activities are summarized in Table 4.2.5. All teams except TF-1, 2, 3, and 6 participated in IFC93. Teams TF-1, 2 and 3 started operations in the fall of 1993. Team 3 began continuous flux measurements at the Old Black Spruce site in NSA. Teams TF-1, 2 conducted a 3-week intensive experiment at SSA-OA. Climatological measurements continued over the winter period at SSA-OA.

Table 4.2.4.2
Staff Science Measurements Required by TF Group

Investigation	Site	Requirements
TF-1&2	PA Old Aspen Site	a. Vegetation and soil classification, species composition. b. Above and below ground-biomass-beginning and end of season. c. LAI (relationship between LAI and effective LAI from PCA-2020) d. Water table depth, soil water content or potential soil water retention & hydraulic conductivity, texture, bulk density, etc. e. Rooting depth of aspen f. Twig water potential during growing season.
TF-4	Young Jack Pine	a. Vegetation and soil classification, species composition. b. Above and below ground-biomass-beginning and end of season. c. LAI (weekly). d. Daily water table. e. (Same as TF 1 & 2, c,d, and e; before and after season).
TF-5	Old Jack Pine	a. Vegetation and soil classification, species composition. b. Above and below ground-biomass-beginning and end of season. c. Satellite imagery of site. d. Leaf water potential. e. LAI measurements.
TF-7	Old Black Spruce	a. Soil moisture as often as possible b. Soil properties-physical and chemcial c. LAI measurements
TF-10	NH Young Jack Pine and Fen	a. satellite data: SPOT, TM, AVHRR b. (GIS based) DEM c. Soil properties-physical and chemical d. LAI weekly e. Allometric data for Jack Pine
TF-11	PA Fen Site	a.-c. [Same as TF 5] d. Regular soil moisture measurements

1994 Activites are summarized in Table 4.2.5. TF-3 is continuous from fall 1993. TF-2 began continuous operation during the IFC winter experiment. All other sites except TF-6 and TF-2 will run continuously from the beginning of IFC-1 through IFC-3. Funding for TF-1 operations between IFC's is under consideration. TF-6 operations will likely be the Young Aspen site near Candle Lake during IFC-2.

Precipitation Measurements at Tower Flux Sites

Table 4.2.5.1b lists precipitation measurements carried out at TF sites,

Table 4.2.5.1b Precipitation measurements at TF sites.

NSA	
TF-8	Old Jack Pine: Tipping buckets on tower at canopy top Tipping bucket in open area below canopy (trough)
TF-3	Old Black Spruce: No measurements but site PI (Wofsey) would like a precip measurement near (within a few km) of this site
TF-10	Fen: Tipping bucket canopy top 3 tipping bucket gauges in the small basin (also reported in HYD section)
TF-10	Young Jack Pine: Tipping bucket mounted at canopy top
SSA	
TF-1,2	Old Aspen: Weighing gauge in clearing (operational Nov. 1993) Tipping bucket (to be installed on tower near canopy top)
TF-5	Old Jack Pine: No measurements
TF-9	Old Black Spruce: No measurements
TF-4	Young Jack Pine: Tipping bucket in clearing (just meets specs for 45 deg)
TF-11	Fen: ?

Tethered Balloon Flights: During IFC's a tethered balloon system will be in operation at the SSA-OA. The systems will measure profiles of wind speed, temperature, humidity, and ozone to 400 meters. A NOTAM will be issued for this operation. The balloon is approximately 5 meters long and bright red. It will be operated in both fixed level and profiling mode. Operations Center will be notified regarding balloon operation.

4.2.5.2 TF Internal Organization

Tower group organization	(SSA)	Gerry den Hartog
Tower group organization	(NSA)	Harry McCaughey
Biometry requirements		S. Verma and Andy Black
Evaporation/transpiration, coordination with the hydrology and ecology groups.		Andy Black

Gas standards | Neill Trivett (AES,TF2), Betsy Middleton (TE Group)

See section 3.2.6 on gas calibration. In particular AES can perform a second calibration for CO_2 (300-400 ppm) and methane (0.5-9 ppm). Allow enough lead time; it generally takes an overnight calibration for each tank (no weekends).

Radiation standards | G. den Hartog [Bruce McArthur AES]

If required, the radiation calibration facility at AES can perform calibration for all of the radiation instruments for the tower flux groups. Eric Smith (RSS-14) will organize a round-robin radiation instrument calibration effort, see Table 4.2.5.1.a.

Soil moisture group | Dean Anderson

To coordinate comparison of indirect (blocks and TDR) soil measurements to be made at towers with direct gravimetric (and others?) planned by other groups.

Calibration facilities | D. Jelinsky

To work toward developing a field facility for calibrating CO_2, H_2O standards at NH & PA.

BORIS Data base and Units | Andy Black

Preliminary list of units for flux and other quantities is included in this report.

Flux computation standards | Dave Fitzjarrald and Tilden Meyers

Turbulent fluxes can vary depending on their calculation method. We decided that a "standard" data set of velocity, temperature, and a time-lagged scalar will be circulated among the tower flux group. If appreciable flux estimation differences are revealed, the group will decide on a uniform calculation method.

Table 4.2.5.1a: TF site radiation instrument calibration plan; round-robin visit by Eric Smith (RSS-14) during IFC-2. Participants: Eric A. Smith, Henry J. Cooper, and William L. Crosson RSS-14.

Day	Date MM-DD-YY	Action
Day 1	07-18-94	Set-up Saskatoon AMS
Day 2	07-19-94	Measurement Saskatoon AMS. Set-up Meadow Lake AMS
Day 3	07-20-94	Measurement Saskatoon AMS. Measurement Meadow Lake AMS
Day 4	07-21-94	Measurement Saskatoon AMS. Take-down Meadow Lake AMS
Day 5	07-22-94	Set-up Old Aspen TF-1. Set-up PANP AMS. Take-down Saskatoon AMS
Day 6	07-23-94	Set-up Nipawin AMS. Measuring Old Aspen TF-1. Measuring PANP AMS
Day 7	07-24-94	Take-down Old Aspen TF-1. Take-down PANP AMS. Take-dpwn Nipawin AMS
Day 8	07-25-94	Set-up YJP TF-4. Set-up OJP TF-5. Set-up Fen TF-11
Day 9	07-26-94	Measure Fen TF-11. Take-down YJP TF-4. Take-down OJP TF-5
Day 10	07-27-94	Set-up TF-9. Set-up LaRonge AMS. Measure Fen TF-11
Day 11	07-28-94	Measure TF-9. Measure LaRonge AMS. Measure Fen TF-11
Day 12	07-29-94	Measure LaRonge AMS. Take-down TF-9. Take-down Fen TF-11
Day 13	07-30-94	Set-up Flin Flon AMS. Set-up The Pas AMS. Take-down LaRonge AMS
Day 14	07-31-94	Measure Flin Flon AMS. Measure The Pas AMS
Day 15	08-01-94	Take-down Flin Flon AMS. Take-down The Pas AMS
Day 16	08-02-94	Set-up Thompson AMS. Set-up OJP AMS. Set-up OJP TF-8
Day 17	08-03-94	Take-down OJP AMS. Take-down OJP TF-8. Take-down Thompson AMS
Day 18	08-04-94	Set-up Fen TF-10. Set-up BS TF-3. Set-up YJP TF-10
Day 19	08-05-94	Measure BS TF-3. Measure YJP TF-10. Take-down Fen TF-10
Day 20	08-06-94	Set-up Lynn Lake AMS. Measure YJP TF-10. Measure BS TF-3
Day 21	08-07-94	Measure Lynn Lake AMS. Measure YJP TF-10. Measure BS TF-3
Day 22	08-08-94	Take-down Lynn Lake AMS. Take-down YJP TF-10. Take-down BS TF-3
Day 23	08-09-94	Travel Thompson to Candle Lake
Day 24	08-10-94	Travel Candle Lake to Saskatoon, fly out

Table 4.2.5
TF Activity Schedule

Team	Site	IFC-93	FFC-W	FFC-T	IFC-1	Inter	IFC-2	Inter	IFC-3
			SSA						
TF-1	OA	Start							
TF-2	OA								
TF-4	YJP								
TF-5	OJP								
TF-6	YA								
TF-7	OBS								
TF-9	OBS								
TF-11	Fen								
			NSA						
TF-3	OBS								
TF-8	OJP								
TF-10	Fen								
TF-10	YJP								

4.3 TERRESTRIAL ECOLOGY (TE)

4.3.1 Objectives

The objectives of the Terrestrial Ecology (TE) group are (a) to examine the biophysical controls on carbon, nutrient, water, and energy fluxes for the major ecosystems in the boreal landscape, and (b) develop logic and algorithms to scale chamber measurements to stand, landscape, and regional scales so that whole-system flux estimates, remotely sensed data, and model simulations can be interpreted. To meet these objectives will require:

1) Development and testing of methods to scale chamber measurements to the stand, landscape, and regional scales.

2) Collection of data required for parameterization of models

3) Development of carbon, nitrogen, water, and energy budgets for the major ecosystem types for different climates and overstory ages.

4) Measurement of different sample locations in order to characterize the variability of the different boreal ecosystems present across the landscape.

Studies by members of the TE group will characterize stocks of organic material and nutrients, estimate fluxes of carbon and nutrients, characterize optical properties of foliage, estimate productivity of lakes from remote sensing, and model fluxes, stocks and populations from ground-based or remote sensing data.

Many of the TE studies are oriented towards one of three goals: 1) estimating the components of a complete annual carbon budget for comparison with the tower flux measurements, 2) estimating photosynthesis and stomatal conductance from remotely-sensed data, and 3) modelling productivity and carbon storage of the boreal forest from remotely-sensed data.

4.3.2 Investigation Summaries

TE Projects are summarized below. PIs and CO-Is and project titles are given in Table 4.3.2. Full investigator summaries are given in Appendix N.

Ref. Number TE-1

P.I.(s):	Anderson, D.W./Univ of Saskatchewan
CO-I(s):	Schoenau, J.J., Nisbet, E.G./Univ of Saskatchewan, Pluth, D./Univ of Alberta
Title:	Stores and Dynamics of Organic Matter in Boreal Ecosystems
Objectives and Approach:	The objective of the proposed research is to characterize the various soil-plant systems along a transect in one of the ecosystems selected for study at the Southern Study Area. Particular emphasis will be on nutrient biochemistry, the stores and transfers of organic carbon and on soil properties and pedogenesis, and how the characteristics are related to measured methane fluxes. The transect in Prince Albert National Park will include the major plant communities and related soils that occur in that section of the boreal forest. Soil physical, chemical and biological measurements along the transect will be used to characterize the static environment, which will then be related to methane fluxes. Chamber techniques will be used to provide a measure of methane production/uptake. Chamber measurements coupled with flask sampling will be used to determine the seasonality of methane fluxes.

Ref. Number TE-2

P.I.(s):	Ryan, M.G./USDA
Collaborator(s):	Lavigne, M./Forestry Canada
Title:	Autotrophic Respiration in Boreal Ecosystems
Objectives and Approach:	Because respiration increases exponentially with temperature, and because warming is expected to be the greatest at high latitudes, autotrophic respiration strongly affects dry-matter production and carbon storage in boreal forests. The research will (1) estimate instantaneous and annual fluxes of CO_2 from all respiration for the footprint of tower flux measurements in three ecosystem types (Spruce, Jack Pine, Aspen) at the two BOREAS study areas, (2) test the use of tissue nutrient content as a general estimator of CO_2 flux from respiration, (3) use paired comparisons at the two locations to determine whether respiration rates differ with genotype, and (4) estimate an annual carbon budget for these sites (in cooperation with other scientists) to determine whether the ratio of respiration to photosynthesis differs among species and climates. Results from these investigations will be used to develop better models for estimating CO_2 flux from autotrophic respiration, and clarify of autotrophic respiration in regulating productivity and carbon storage in ecosystems.

Ref. Number TE-3 Transferred to TGB-12

Ref. Number TE-4

P.I.(s): Berry, J.A./Carnegie Institution of Washington
CO-I(s): Collatz, G.J./Carnegie Institution of Washington, Gamon, J./California State University, Los Angeles

Title: Measurement and Prediction of CO_2 and H_2O Exchange from Boreal Forest Tree Species

Objectives and Approach: We propose to measure steady-state gas exchange and spectral reflectance responses to temperature, light, CO_2 and humidity in leaves of aspen, jack pine, and black spruce. Some of these measurements will be made within canopies of these species in the intensive field campaigns of 1994 and some will be made under more controlled laboratory conditions. Effects of leaf age, and conditions (temperature, light, nitrogen, water) will be measured. Specialized chambers and portable field instruments are being developed for use with broad leaf and conifer tissue. This data will be used to develop algorithms for predicting photosynthesis and transpiration from bidirectional reflectance and to parameterize our mechanistic leaf and canopy models of CO_2 and exchange for the boreal forest.

Ref. Number TE-5

P.I.(s): Ehleringer, J.R./Univ of Utah
CO-I(s): Flanagan, L.B./Carleton Univ

Title: Vegetation-Atmosphere CO_2 and H_2O Exchange Processes: Stable Isotope Analyses

Objectives and Approach: The objectives of this project are: (i) to determine the influence of vegetation on changes in the carbon and oxygen isotopic composition of atmospheric CO_2 (ii) to determine the extent of recycling of CO_2 within forest canopies; (iii) to determine the water sources used by different tree species within a growing season; and (iv) to reconstruct past temporal patterns of leaf gas exchange (ratio of assimilation to stomatal conductance). The first two objectives will be accomplished by combining leaf gas exchange measurements with measurements of the concentration and isotopic composition of CO_2 in flask samples of air collected diurnally at different vertical positions within a forest canopy. Water source use will be determined by analysis of the stable isotopic composition of water extracted from stem xylem tissue. The carbon isotopic composition of cellulose from tree rings will be used to reconstruct past temporal patterns of gas exchange.

Ref. Number TE-6

P.I. (s): Gower, S.T./ Univ. of Wisconsin

Co. P.I.(s) Norman, J.M./Univ. of Wisconsin

Title: Measurement and Scaling of Carbon Budgets for Contrasting Boreal Forest Sites

Objectives and Approach: The objective of this project is to examine the influence of vegetation, climate and their interaction on the major carbon fluxes for aspen, jack pine and black spruce forest ecosystems at the Southern Study Area and Northern Study Area.(Four, 15 x 15 m plots will be established at each site during the fall 1993 IFC. We will measure above- and below ground net primary production and use leaf respiration, autotrophic respiration and soil surface CO_2 flux data from other PI's to construct stand-level carbon budgets. Above-ground net primary production will be calculated annually for a 10-year period (1985-1994) from annual stemwood radial increment cores and site-specific allometric equations which will be developed in conjunction with M. Apps (TE-13). Below-ground net primary production will be estimated using sequential coring and carbon balance methods. Soil surface CO_2 flux will be measured weekly for the northern aspen stand during the IFC's using a LI-COR 6200 and soil respiration chamber. Soil surface CO_2 flux estimates obtained by this method will be compared to estimates obtained by PI's measuring soil surface CO_2 flux (using similar or different methods) at all mature forested sites at least once during 1994. We will develop a method to scale leaf-level photosynthesis measurements to the canopy level using measurements of canopy architecture and models of radiative transfer. The scaled canopy-level CO_2 fluxes will be compared to tower fluxes that are based on micrometeorological methods. We will develop and explore the utility of a new multi-band vegetation imager for indirectly determining forest canopy architecture in aspen and jack pine sites.

Deliverables to the Project

1) Carbon distribution in above and below-ground overstory and understory, forest floor and mineral soil for old aspen, jack pine and black spruce in SSA and NSA.
2) Annual net above- and below-ground net primary production and detritus production for overstory and understory for old aspen, jack pine and black spruce in SSA and NSA.
3) Soil surface CO_2 flux measurements for old aspen stand in NSA.
4) Archived plant tissue samples (stem wood, stem bark, branch, and foliage by age class and canopy position) for old aspen, jack pine and black spruce in SSA and NSA.

Ref. Number TE-7

P.I.(s):	Hogg. E.H./Forestry Canada
Co P.I.(s):	Ian Campbell, P.A. (Rick) Hurdel, Thierry Varem, Harjit Grewal, Lavigne, M., Penner, M./Forestry Canada
Title:	Climate Change Effects on Net Primary Productivity of Productivity of Aspen and Jack Pine at the Southern Limit of the Boreal Forest
Objectives and Approach	Regional climate-vegetation relationships indicate that the southern limit of the boreal forest is presently governed by moisture stress. This investigation aims to use a combination of field studies and modelling to predict how forest communities at the boreal forest's southern limit could respond to future changes in climate. The investigation includes short-term measurements of transpiration, photosynthesis, stem respiration and LAI, plus longer term studies of stand development, growth (tree ring analysis) and regional forest composition (palynology). This work will also form part of an ongoing Canadian study (BFTCS) of climate change effects on the functioning and carbon balance of the Canadian boreal forest.

Ref. Number TE-8

P.I.(s):	Kharuk , V.I. /Russian Academy of Sciences
Title:	The Tree's Bark Input in Tree-Atmosphere Interactions

Objective and Approach:

The principal aim of this investigation is to evaluate the input of tree bark into tree-atmosphere interactions (i.e., the photosynthetic process). Tree-atmosphere interaction is considered usually as "leaf" interaction with the atmosphere. But the input of tree bark is not negligible, especially during "leafless" periods (e.g., spring, fall, as well as after defoliation caused by insects or pollution), when the bark is the single source of hydrocarbons. The comparative analysis of biophysical properties of bark versus those of leaves must be done.

A. The studies should include:

1. Comparative analysis of optical properties (transmittance, reflectance, polarization) of bark and leaves
2. Comparative analysis of bark versus leaf pigment content
3. Estimation of LAI versus "BAI" ("bark area index")
4. Comparative analysis of bark photosynthesis/evapotranspiration versus leaf photosynthesis/evapotranspiration.
5. Comparative analysis of deciduous (Populus tremuloides) versus coniferous species.

Ref. Number TE-9

P.I.(s):	Margolis, H.A., Edwards, G., Thomson, K.P.B., Viau, A. (Université Laval)
Title	Relationship Between Measures of Absorbed and Reflected Radiation and the Photosynthetic Capacity of Boreal Forest Canopies and Understories

Objectives and Approach:

This project will examine the relationship between net photosynthetic (net Ps) capacity, N concentration and percent photosynthetically active radiation (%PAR) of three major boreal forest cover types (jack pine, black spruce and aspen) as well as their link to remotely-sensed and land-based measures of reflected and absorbed radiation. We will attempt to establish general relationships which can be used to predict the vertical distribution of the net Ps capacity for these cover types, including their understories, when neither water nor temperature is greatly limiting. We will also determine how these relationships will vary over the growing season and among six different stand conditions at the Northern Study Area (NSA). Furthermore, the photosynthetic response surface of foliage from the three main cover types with respect to light, temperature, vapor pressure deficit and internal CO_2 will be determined during each IFC using a laboratory-based photosynthetic system with cut branches. The effects of in situ frost exposures on the photosynthetic characteristics of the three main cover types as well as their patterns of recovery will be determined in order to introduce more realistic algorithms of the effects of frost on carbon flux. PAR measurements taken within the the canopy will be supplemented with geometry measurements of the different canopy constituents and the spatial variability of these measurements within the stand will be examined. Additionally, the BRDF of soil and understory components, the spatial variability of the spectral signatures of soil and understory components, and the spectral distribution of hemispherical downwelling radiation will be characterized in order to drive and validate a forest canopy reflectance model (TRELITE). This model will be used to estimate PAR levels within the various forest canopies and these estimates will then be used as input to the photosynthetic model. Depending on the availability of additional resources, canopy biochemistry (lignin, cellulose, starch, sugars, chlorophyll and terpenes) will be followed over the growing season for six stands.

Ref. Number TE-10

P.I.: Middleton, E. /NASA Goddard

Title: CO_2 and Water Fluxes in the Boreal Forest overstory: Relationship to *f*APAR and Vegetation Indices for Needles/Leaves

Objectives and Approach: In this study we will correlate physiological processes at the leaf/needle level with optical measurements amenable to remote sensing. Specifically, *in situ* measurements for gas exchange flux rates for CO_2 and water, plant stress as indicated by chlorophyll-a fluorescence, and other supporting measurements will be acquired for dominant species of the boreal forest overstory at the BOREAS Southern sites (mature aspen, mature jack pine, young jack pine, black spruce, and mixed aspen/white spruce). In the laboratory, further measurements of photosynthetic capacity will be made in conjunction with continuous visible/near-infrared spectral optical properties and pigment analyses. Nitrogen will be determined from dry foliar material. This data set will be utilized to estimate the vertical gradients of carbon assimilation, nitrogen use efficiency, and photosynthetic efficiency for different species as a function of phenology and environmental conditions, especially available water, nitrogen, and PAR. These data will be used to examine the relationships between the physiological parameters, especially photosynthesis and conductance rates, and the optical parameters (*f*APAR and spectral vegetation indices, or SVIs). They will also be used to parameterize the canopy level radiative transfer and physiological models utilized in landscape in landscape analyses by other investigators.

Ref. Number TE-11

P.I.(s): Saugier, B./ Universite Paris
CO-I(s): Deleens, E./CNRS, Granier, A./INRA, Rambal, S./CNRS
Collaborator(s): Dedieu, G/LERTS, Ducoudre, N./LMCE

Title: Seasonal Variations of Net Photosynthesis and Transpiration at the Tree Level

Objectives and Approach: The objective is to monitor the net assimilation and transpiration rate of trees throughout the 1994 growing season, at the Prince Albert Old Jack Pine site (and short sapflow measurements in P.A. mixed-stand). For this we propose the following steps using several original methods:

1. Installation of sapflow probes in the trunk of 6 representative trees in PAOJP at the end of FFC94-T, monitoring of sapflow from May to September 1994 (Prince Albert mixed Site will be equipped with sapflow probes during the IFC92-2 campaign only).. The probes are laboratory made, constant heated needles.

2. Measurements during IFC94-2 of CO_2 and H_2O exchanges of 2 representative branches (PAOJP). Estimation of the water use efficiency (WUE: CO_2 assimilation/transpiration). The gas-exchange is measured in home-made cuvettes operating in a closed system for 5 minutes every half-hour.
3. Modelling of photosynthesis, transpiration and WUE of the branch. WUE varies with VPD and may vary through the season (needle age). This will be checked by measuring the delta ^{13}C of growing shoot samples collected monthly (collaboration with TF-5).
4. Use of 1., 2. and 3. to predict trees transpiration and carbon uptake during whole season.

Sap flow measurements will be compared with eddy correlation measurements of H_2O and CO_2 fluxes above the forest. Simple models of forest productivity will be tested using data form the site: a "top-down" model of the Monteith type and a mechanistic "bottom-up" model, both developed in the laboratory.

Forest inventories, geostatistic models and remote sensing data will be used to extend the plot measurement to the region.

1, Diameter at breast height inventories will be used to extrapolate single trees transpiration measurements to the stand.
2. Extensive LAI measurements (from other teams will be used for geostatic purposes.
3. Continuous and discrete algorithms of radiative transfer will be tested to derive surface parameters (PAR interception and LAI) from remote sensing data, and from cover maps. to extrapolate to the whole BOREAS region.

Tentatively, we'll try to measure CO_2/H_2O exchange of the lichen layer at SSA-OJP using plastic enclosures, including a T/RH sensor, connected to a portable IRGA (collab. with TE-5).

Ref. Number TE-12

P.I.(s): Walter-Shea, E.A./Univ of Nebraska
CO-I(s): Arkebauer, T.J./Univ of Nebraska

Title: Radiation and Gas Exchange of Canopy Elements in a Boreal Forest

Objectives and Approach: Coordinated research program emphasizing measurements of radiation and gas exchange characteristic of canopy elements and resulting interactions of radiation and gas exchange within canopy environments in a boreal forest ecosystem with the following components:

1. Characterization of foliage element and substrate optical properties during critical periods. Leaf, needle, twig, substrate and shoot optical properties will be measured and conifer shoot geometry will be characterized. Models will be used to aid the in understanding of key variables influencing canopy element optical properties.
2. Characterization of gas exchange of canopy elements during critical periods. Responses of CO_2 exchange and stomatal conductance to environmental factors and diurnal courses of photosynthesis, respiration and stomatal conductance of

canopy elements will be determined. Models will be used to describe the influence of relevant controlling variables on CO_2 and water vapor fluxes.

3. Integration of foliage optical properties and gas exchange characteristics. Models will be used to couple radiation and gas exchange of canopy elements under diffuse and total radiation conditions.

Ref. Number TE-13

P.I.(s): Apps, M./Forestry Canada
CO-I(s): David Price, Werner Kurz/Forestry Canada

Title: Annual carbon budget and climate induced changes in boreal forest ecosystems at the landscape level.

Objectives : and Approach: Ecological and climatic controls on annual carbon cycling in boreal forest ecosystems to landscape level will be incorporated in process-driven linkages to an existing larger scale carbon budget model of the Canadian forest sector. Scaling of process controls on net ecosystem productivity will be performed both spatially and temporally to match the ecological/climatological classification and annual time step resolution of the CBM-CFS, using a metamodel (response surface) approach. Annual changes in forest ecosystem C pools (soils, litter and biomass), explicitly accounting for the influence of disturbances, will be simulated to provide estimates of annual carbon fluxes with the atmosphere (and within the terrestrial carbon pools) along a transect which extends beyond the Northern Study Area to the subarctic woodland (Gillam Manitoba) and south of the Southern Study Area to the aspen parkland carbon pools at selected pure stands of the dominant species, at mixed wood stands at the southern and northern BOREAS study areas, and at sites in the mid-transect region will be used to test the model synthesis. Subject to funding confirmation, biometry and allometry measurements will be made in these stands in conjunction with other BOREAS investigators (TE-6, TE-7) to provide the observational database for these validations. The sites will be selected to reinforce other TE measurements and tower flux measurements and will be part of the Forestry Canada contribution to the core measurements program.

Ref. Number TE-14

P.I.(s): Bonan, G. B./NCAR

Title: Estimating Regional Biosphere-Atmosphere Exchange of Carbon Dioxide and Water in Boreal Forests with Ecosystem Models

Objectives and Approach: Models provide a means to extrapolate processes to large spatial and long temporal scales. I will conduct simulation analyses with coupled ecosystem and land surface process model to: (1) identify key physiological processes and ecological variables needed for a general predictive model of biosphere CO_2 and water fluxes; (2) quantify errors produced by parameter uncertainty; (3) derive seasonal and annual $CO_2$and water budgets for several BOREAS tower sites and the two regional sites.

Global extrapolation will proceed by coupling the land surface process model to the NCAR Community Climate Model. Regional estimates of CO_2, water, and energy exchange obtained from the off-line modeling will be used to test the representation of sub-grid scale land surface heterogeneity for the land surface process model.

The major deliverables to BOREAS are seasonal and annual CO_2 and water budgets for individual tower sites and the two regional sites. This will require from other groups ground truth data for particular forest types to initialize and validate the models. It will also require from the BOREAS Project Staff meteorological data to force the models (30 minute resolution, collected for one full year); and maps of ecosystem and soil cover for the southern and northern sites.

Ref. Number TE-15

P.I. and Co-Is: Bukata, R.P/NWRI, Jerome, J.H./NWRI, Miller, J.R./York U., Evans, M.S./NHRI, Armstrong, R.A.,/NASA/ARC, Wrigley, R.C./NASA/ARC, Fee, E.J./FI Winnipeg, Gallie/Laurentian Univ.

Title: Utilizing Remotely Sensed Data to Model Limnological Carbon Budgets and Primary Production in Boreal Ecosystems

Objectives: and Approach: Remotely-sensed data will be acquired by the Compact Airborne Spectrographic Imager (CASI) and the Airborne Ocean Color Imager (AOCI) from NASA/Ames Research Center, to determine the co-existing concentrations of aquatic chlorophyll, dissolved organic matter, and suspended inorganic matter. The chlorophyll estimates will be used to model primary production through calculable transfer coefficients, and the dissolved organic matter estimates will be used to model the carbon content of selected lakes within the BOREAS test area. Targetted study sites include Crean and Waskesiu Lakes in the Prince Albert National Park. These two lakes are the only lakes in which direct optical measurements can be complemented with direct biological measurements. Coordination of direct optical measurements, remote sensing overflights, and water sample collection for off-site laboratory analyses, however, is possible for several other Prince Albert lake sites accessible to boat launchings (e.g., Anglin, Halkett, Emma, Christopher, Whiteswan, and Candle Lakes). Whether or not the intensive hydrology test site at Gull Lake can be accessible for the required optical studies is to be determined.

The inherent optical properties of aquatic chlorophyll, dissolved organic matter, and suspended inorganic matter will be determined by direct sampling and in situ mid-lake measurements using the WATERS instrument. The water samples will be analyzed at laboratory facilities at NWRI, NHRI, and CIMMER.

Ref. Number TE-16

P.I.(s): Cihlar, J./CCRS
CO-I(s): Z. Li, Y.M. Chen/CCRS, R. Desjardins/Agriculture Canada

Title: Land Cover and Primary Productivity in the Boreal Forest

Objectives and Approach: The study is aimed at addressing the use of satellite data in ecological monitoring with emphasis on two parameters, land cover and ecosystem productivity. For land cover, the objective of the research is to determine improvements in land cover type identification with data from future sensors (simulated MODIS, Radarsat SAR), compared to research presently underway which emphasizes AVHRR. For productivity, the principal objective is to assess the feasibility of estimating forest primary productivity and net primary productivity using models that can be realistically applied over large areas yet have high spatial resolution. To be practical, the models should require a minimum of data that (i) can be obtained from satellites or (ii) can be cost-effectively obtained over large areas. Such models have been formulated and tested in recent years, and will be included among those models studied in other BOREAS investigations. The intention in this study is to focus on the contribution of remote sensing data at the landscape and regional levels, and to collaborate with modelers in validating remote sensing inputs and model performance. Specific tasks to be carried out include: improvement in land cover determination and information on seasonal dynamics from simulated MODIS and RADARSAT SAR data; derivation of site and landscape ecosystem parameters (bidirectional surface reflectance, vegetation indices, vegetation density) from optical data in relation to the sensor spatial resolution (10^2m to $> 10^3$m); feasibility of direct APAR estimation from AVHRR and similar data; the relationship of instantaneous gas (CO_2, H_2O) exchange to satellite-derived reflectance and emission quantities; and derivation of the above and related quantities for testing ecosystem productivity models at the regional level.

Ref. Number TE-17

P.I.(s):	Goward, S.N./Univ of Maryland
CO.I.(s):	Prince, S.D., Dubayah, R., Townshend, J./Univ. of Maryland, Tucker, C.J./NASA/GSFC
Title:	Biospheric Dynamics in the Boreal Forest Ecotone
Objectives and Approach:	A study of primary production in the boreal forest ecotone using regional scale models driven by coarse-resolution satellite data. The primary scale of interest is the BOREAS inter-site transect and the entire N. American Boreal Forest biome. Net primary production (NPP) will be modelled using production efficiency models (PEM), parameterized using the detailed field site measurements planned at the Intensive Study site scale (400km^2). A multi-scale analysis will be used to address the problem of scaling of information from the ISS to the regional scales.

Ref. Number TE-18

P.I.(s):	Hall, F.G., Sellers, P.J./NASA/GSFC
Title:	Regional-Scale Carbon Flux from Modeling and Remote Sensing
Objectives and Approach:	To use long-term satellite remote sensing to characterize the successional and disturbance dynamics at a regional scale and to associate, via the use of carbon flux models, these dynamics with carbon flux. Landsat MSS and TM, SPOT and AVHRR data will be acquired for the BOREAS region, including the Southern and Northern Study Areas and the intervening transect for the period of record of each satellite (Landsat back to 1972). Key successional stages will be identified using pattern recognition and image analysis. The rates of changes between successional stages will then be quantified using change analyses. These results will be combined with ecophysiological models that relate carbon flux to the successional state and climate history to estimate regional carbon flux.

Ref. Number TE-19

P.I.(s):	Harriss, R.C./Univ of New Hampshire
CO-I(s):	Aber, J., Frolking S.E./Univ of New Hampshire

Title: Modeling Climate-Biosphere Interactions in the Boreal Forest

Objectives and Approach: We propose a research program which integrates and advances two separate models we have recently developed for understanding carbon and nitrogen cycling in soil and vegetation. The primary product of this model integration will be a capability for assessing and understanding the sensitivity of boreal ecosystem carbon and nitrogen pools and fluxes to climate variability. The proposed modelling research program will be coordinated with the BOREAS field measurements program. Field measurement at BOREAS sites will be used to test and validate our model. Our model will provide conceptual framework for testing which components of the boreal ecosystem especially sensitive to climate change. The results of the combined field and studies will provide a sound rationale for the design and implementation of a measurement program in the boreal forest ecosystem using the Earth Observing System (EOS).

Ref. Number TE-20

P.I.(s):	Knox, R.G./NASA/GSFC
CO-I(s):	Levine, E.R., Ranson, K.J., Goltz, S.M./NASA/GSFC

Title: Multidiscipline Integrative Models of Forest Ecosystem Dynamics for the Boreal Forest Biome: Modeling Gas and Energy Fluxes from Landscapes

Objectives and Approach: This effort is collaborative with TE-22 which has as its objective the development of a model-based synthesis of the influence of water and nutrients on forest community composition, and of evaluating the feedback from community composition to surface biophysical characteristics for the BOREAS project. The models involved in this synthesis are:

1. ZELIG, a spatial individual tree model. ZELIG is currently part of the FED model;
2. FED, a model shell allowing the interfacing of several different models of forest ecosystem dynamics and, hence, several different ecosystem processes;
3. HYBRID, a combination model including forest growth; canopy physiology; and soil moisture, carbon and nutrients (see Friend, Shugart, and Running, 1993);
4. Residue, a physical, multilayer soil temperature and moisture model (Bidlake et al. 1992).

The ZELIG and HYBRID models will be parameterized and implemented for the BOREAS test sites, and will be used to project the composition and canopy structure of forests over relatively long time spans for different regions. This will also provide a capability to predict CO_2 and H_2O fluxes from the forests. ZELIG predictions of forest structure will be related to results of remote sensing (in collaboration with RSS-15) and compared with field data from soil and stem maps and auxiliary sites. Simple transport models will be used to relate spatio-temporal variation in flux predictions, from the combination of HYBRID and Residue, to temporal variation in tower flux measurements.

Ref. Number TE-21

P.I.(s): Running, S/Univ of Montana

CO-I(s): Nemani, R./Univ of Montana, Peterson, D., Dungan, J., Coughlan, J./NASA Ames Research Center, Harding, D. NASA/GSFC. Wood, E./ Princeton Univ, Scuderi, L./Boston Univ, Price, A.,Carleton, T./Univ of Toronto

Title: Simulation of Boreal Ecosystem Carbon and Water Budgets: Scaling from Local to Regional Extents

Objectives and Approach: To simulate boreal landscape/atmosphere exchange processes and the scaling behavior of these processes from local to regional extents. Our emphasis is boreal ecosystem water and carbon flux processes, which will be simulated using a suite of models based on the processes of photosynthesis, respiration, evapotranspiration and surface and subsurface hydrologic flow. The implications of model and data generalization on the agreement between simulated and measured flux rates will be explored by constructing a hierarchy of modeling and surface parameterization methods. Each level in the hierarchy will vary in the degree of complexity of process and surface representation. The set of computed surface flux rates in combination with flux rates measured by other science groups will be used to quantify the impact of process and parameter generalization in terms of model bias at each level of the hierarchy, and the scaling behavior of flux processes computed over the range of parameter resolutions we will sample. We hypothesize that the spatial patterns of surface/atmosphere flux is strongly influenced by the distribution of available soil moisture and inundation areas in the study sites, which, in conjunction with disturbance regime, may provide a key organizing framework for scaling stand to regional simulations. We will develop surface parameter sets for the models with a combination of field measurement of hydrologic processes, remotely sensed canopy information and laser and radar altimetry. This effort will collaborate with HYD-7.

Ref. Number TE-22

P.I.(s): Shugart, H.H./Univ of Virginia

CO-I(s): Smith, T.M./Univ of Virginia

Title: Multidiscipline Integrative Models of Forest Ecosystem Dynamics for the Boreal Forest Biome

Objectives and Approach: The development of a model-based synthesis of the influence of water and nutrients on forest community composition, and of evaluating the feedback from community composition to surface biophysical characteristics for the BOREAS project. The models involved in this synthesis are:

1. ZELIG, a spatial individual tree model. ZELIG is currently part of the FED model;
2. FED, a model shell allowing the interfacing of several different models of forest ecosystem dynamics and, hence, several different ecosystem processes;
3. HYBRID, a combination model including ZELIG, a photosynthesis model and a coupling with a canopy biophysical model (GBC, Running and Coughlan 1990).

The ZELIG and HYBRID models will be parameterized and implemented for the BOREAS test sites, and will be used to project the composition and canopy structure of forests over relatively long time spans for different regions. This will also provide a capability to predict CO_2 and H_2O fluxes from the forests. Several of the data sets being developed in conjunction with the BOREAS project will be used to test these model implementations.

Ref. Number TE-23

P.I.(s):	Rich,P.M./Univ of Kansas
Title:	Canopy Architecture of Boreal Forests: Studies of Solar Radiation, Leaf Area Index, and Forest Dynamics
Objectives and Approach:	The primary goal of this project is to characterize canopy architecture as it influences within-canopy solar radiation regimes, with implications for forest ecosystem dynamics and remote sensing. The project will also provide indirect estimates of fPAR and LAI, measurements of canopy surface topography, and detailed maps of stand architecture. Hemispherical (fisheye) photography will be used 1) to measure the angular distribution of canopy openings, 2) to estimate fPAR, and 3) to estimate LAI and leaf inclination for the BOREAS project study sites (tower flux, auxiliary, and mixed boreal forest sites). Acquisition of arrays of hemispherical photographs will permit examination of horizontal variation within each site and vertical variation in the understory and throughout low canopies. Photographs taken from towers will permit examination of complete vertical profiles for Tower Flux and TE Tower Sites. Estimates of fPAR (direct, diffuse, and total) from photographs will be validated using PAR sensor measurements, while LAI and leaf inclination estimates will be validated using both direct and indirect methods. Field measurements, construction of detailed stand maps, and analyses will be coordinated with TE-9, TE-13, TE- 20, RSS-7, RSS-19, BOREAS staff efforts and Canadian contributions to biometric measurements.

TE-23 SCHEDULE

- May 12-15 Southern Study Area (Rich + 2 assistants) set up mapped forest plots at all sites
- May 16-18 Northern Study Area (Rich + 2 assistants) set up mapped forest plots at all sites
- May 19-June 5 Southern Study Area (2 assistants) hemispherical photography at all sites
- June 6-16 Northern Study Area (2 assistants) hemispherical photography at all sites
- June 17-July 11 Auxiliary Sites hemispherical photography, characterize sites
- July 12-14 Northern Study Area (Rich + 2 assistants) characterize mapped plots at all sites
- July 15-18 Southern Study Area (2 assistants) characterize mapped plots at all sites
- July 19-28 Southern Study Area (2 assistants) hemispherical photography at all sites
- July 29-Aug 8 Northern Study Area (2 assistants) hemispherical photography at all sites

Table 4.3.2 Terrestrial Ecology Projects and PI/Co-PI's

Team	P.I./CO-I.	Title
TE-1	Anderson, DW; Schoenau, JJ Nisbet, EG, Pluth, Ruth	Stores and dynamics of organic matter in boreal ecosystems
TE-2	Ryan, MG ; Lavigne, M.	Autotrophic respiration in boreal ecosystems
TE-3	Transferred to TGB-12	
TE-4	Berry, JA; Collatz, GJ; Gamon, J	Measurement and prediction of CO_2 and H_2O exchange from boreal forest tree species
TE-5	Ehleringer, JR ;Flanagan, LB	Vegetation-atmosphere CO_2 and H_20 exchange processes: stable isotope analyses
TE-6	Gower, ST; Norman, J.M.	Measurement and scaling of carbon budgets for contrasting boreal forest sites
TE-7	Hogg, EH	Climate change effects on net primary production across a boreal forest transect
TE-8	Kharuk, VI	Tree's bark input in tree-atmosphere interaction
TE-9	Margolis, H; Edwards, G; Thomson, K	Relationship between measures of absorbed and reflected radiation and the photosynthetic capacity of boreal forest canopies and understories
TE-10	Middleton, EM; Sullivan, JH; Knox, RG	CO_2 and water fluxes in the boreal forest overstory: relationship of fAPAR and vegetation indices for needles/leaves
TE-11	Saugier, B; Granier, A; Deleens, E; Dedieu, G; Ducoudre, N; Bottner, P; Couteaux, MM	Seasonal variations of net photosynthesis and transpiration at the tree level
TE-12	Walter-Shea, EA; Arkebauer, TJ	Radiation and gas exchange of canopy elements in a boreal forest
TE-13	Apps, M	Annual carbon budget and climate induced changes in boreal forest ecosystems at the landscape level
TE-14	Bonan, GB	Estimating regional biosphere-atmosphere interchange of carbon dioxide and water in boreal forests with ecosystem models
TE-15	Bukata, RP; Jerome, JH; Fee, EJ; Wrigley, RC; Armstrong, RA; Miller, JR	Utilizing remotely sensed data to model limnological carbon budgets and primary production in boreal ecosystems
TE-16	Cihlar, J; Li, Z; Chen, YM; Desjardins, R.	Landcover and primary productivity in the boreal forest
TE-17	Goward, SN; Prince, S; Dubayah, R; Townshend, J; Tucker, C.J	Biospheric dynamics in the boreal forest ecotone
TE-18	Hall, FG ; Sellers, PJ	Regional-scale carbon flux from modeling and remote sensing
TE-19	Harriss, RC ; Aber, J; Frolking, SE	Modeling climate-biosphere interactions in the boreal forest
TE-20	Knox, RG ;Levine, ER; Ranson, KJ; Goltz, SM	Multidiscipline integrative models of forest ecosystem dynamics for the boreal forest biome
TE-21	Running, SW; Nemani, R; Peterson, D; Dungan, J; Coughlin, J; Harding, D; Wood, E; Scuderi, L; Price, A; Carleton, T	Simulation of boreal ecosystem carbon and water budgets: scaling from local to regional extents
TE-22	Shugart, HH; Smith, Tim	Multidiscipline integrative models of forest ecosystem dynamics, for the boreal forest biome
TE-23	Rich,PM	Canopy Architecture of Boreal Forests: Studies of Solar Radiation, Leaf Area Index, and Forest Dynamics

4.3.3 Field Measurements

4.3.3.1 In Situ Measurements

Field measurements are summarized in Table 4.3.3a-c. Table 4.3.3a covers carbon and nutrient distribution or content and Table 4.3.3b covers flux measurements (e.g., photosynthesis, autotrophic respiration, above-and below-ground net primary production, heterotrophic respiration and above- and below-ground detritus production. Collectively these two tables and Table 4.3.4.1 (Soil CO_2 flux measurements) describe the major C pools and fluxes that will be measured at each of the tower flux sites. For several of the sites, namely the young jack pine in the south, both the southern and northern fen sites and the mixed aspen - white spruce site, the C cycle cannot be closed by TE scientists. Table 4.3.3c describes additional measurements by the TE scientists and the vegetation type where the measurements will be made. Abbreviations used in these tables are defined in Appendix P.

Subsections discuss biometry measurements (4.3.3.2), canopy access and destructive sampling (4.3.3.3), and planned visits by TE teams (4.3.3.4).

Note that destructive sampling within the TF site WABs and/or from flux towers is forbidden unless the site captain gives specific permission

TABLE 4.3.3a
Field Measurements of Organic Matter or Nutrient Distribution

		- Organic Matter or Nutrient Distribution -					
Site	**Veg Type**	**Soil C Nutrients**	**Root Bio-mass**	**Wood Bio-mass**	**Leaf Area**	**Leaf Bio-mass**	**Biomass Nutrients**
SSA	OA	TE-1 TE-6	TE-6	TE-6	TE-6	TE-6	TE-2 (Wood, leaf, root N, P) TE-4 (Leaf N) TE-10 (Leaf N)
SSA	OJP	TE-1 TE-6	TE-6	TE-6	TE-6 TE-7	TE-6	TE-2 (Wood, leaf, root N, P) TE-4 (Leaf N) TE-10 (Leaf N) TE-11 (Leaf C, N)
SSA	YJP	TE-1					TE-4 (Leaf N)
SSA	YA	TE-1					TE-4 (Leaf N)
SSA	OBS	TE-1 TE-6	TE-6	TE-6	TE-6	TE-6	TE-2 (Wood, leaf, root N, P) TE-4 (Leaf N) TE-10 (Leaf N)
SSA	Mixed Spruce, Aspen			TE-7	TE-7		TE-10 (Leaf N)
SSA	Batoche Aspen				TE-7		
SSA	Fen						
NSA	OJP	TGB-12 TE-6	TE-6	TE-6	TE-6 TE-7	TE-6	TE-2 (Wood, leaf, root N, P) TE-9 (Leaf N)
NSA	YJP	TGB-12					
NSA	OBS	TGB-12 TE-6	TE-6	TE-6	TE-6	TE-6	TE-2 (Wood, leaf, root N, P) TE-9 (Leaf N)
NSA	OA	TE-6	TE-6	TE-6	TE-6 TE-7	TE-6	TE-2 (Wood, leaf, root N, P) TE-9 (Leaf N)

TABLE 4.3.3b
Field Measurements of Carbon or Water Fluxes

		Carbon or Water Fluxes					
Site	**Veg. Type**	**Soil CO_2**	**Litter-fall**	**Leaf Respir-ation**	**Wood Respir-ation**	**Photo-synthesis**	**Stomatal Conductance**
SSA	OA	TE-1 TF-1	TE-6	TE-2 TE-4 TE-12	TE-2	TE-4 TE-5 TE-10 TE-12	TE-4 TE-10 TE-12 TE-5
SSA	OJP	TE-1	TE-6	TE-2 TE-4	TE-2	TE-4 TE-5 TE-10 TE-11	TE-4 TE-10
SSA	YJP	TF-4		TE-4		TE-4 TE-10	TE-4 TE-10
SSA	OBS	TE-1 TF-7	TE-6 TF-7	TE-2 TE-4 TE-12	TE-2	TE-4 TE-5 TE-10 TE-12	TE-4 TE-10 TE-12 TE-5
SSA	Mixed Spruce, Aspen	TE-6		TE-2 TE-4	TE-2	TE-4 TE-5 TE-10	TE-5 TE-10
SSA	Batoche Aspen		TE-7			TE-7	TE-7
SSA	Fen	TF-11 TE-1		TF-11		TF-11	TF-11
NSA	OJP	TGB-12 TGB-1	TE-6	TE-2 TE-9	TE-2	TE-9 TE-5	TE-9 TE-10
NSA	YJP	TGB-3/1				TE-9	TE-9
NSA	OBS	TGB-12 TF-3 TGB-1	TE-6	TE-2 TE-9	TE-2	TE-9 TE-5	TE-9 TE-5
NSA	OA	TGB-12 TE-6	TE-6	TE-2 TE-9	TE-2	TE-9 TE-5	TE-9

TABLE 4.3.3 b (continued)
Field Measurements of Carbon or Water Fluxes

		Carbon or Water Fluxes					
Site	**Veg. Type**	**ANPP**	**BNPP**	**Net Ecosystem Flux**	**Soil CO_2 and CH_4 Flux**	**Bark Photosyn-thesis**	**Dissolved Organic C**
SSA	OA	TE-6 Staff	TE-6 Staff	TF-1 TF-2	TE-1 TF-4	TE-8	
SSA	OJP	TE-6	TE-6	TF-5	TE-1 TE-5		
SSA	YJP			TF-4	TF-4	TE-8	
SSA	OBS	TE-6	TE-6	TF-9	TE-1, TF-7		
SSA	Mixed				TE-6		
SSA	Batoche Aspen	TE-7	TE-7		TE-7		
SSA	Fen			TF-12	TF-11		
NSA	OJP	TE-6	TE-6	TF-8	TGB-1		TGB-3
NSA	YJP			TF-10	TGB-3/1		
NSA	OBS	TE-6	TE-6	TF-3	TGB-1 TGB-3		TGB-3
NSA	OTA	TE-6	TE-6		TGB-3		
NSA	Fen	TGB-3	TGB-3	TF-10	TGB-3		TGB-3

TABLE 4.3.3c Other Field Measurements by Site

Site	Veg. Type	Leaf Optical Props	Other Measurement
SSA	OA	TE-4 TE-10 TE-12	• δ–13_C of leaf, wood, air; δ-18_O, of air and water (xylem, soil, and precip.), TE-5 • NPP and Canopy Architecture, TE-6 • Soil Moisture and temperature; Sap flow, Palynology, Dendrochronology, Clone boundaries, Permanent growth plots, TE-7 • Bark Photosynthesis, transpiration, optical properties, chlorophyll, TE-8 • Maximum photosynthesis, TE-10 • Substrate optical properties and water potential, TE-12
SSA	OJP	TE-14 TE-10	• δ-13_C of leaf, wood, air; δ-18_O, of air and water (xylem, soil, and precip.), TE-5 • NPP and Canopy Architecture, TE-6 • Specific leaf area, TE-7 • Maximum photosynthesis, TE-10 • Sapflow, δ-13_C of shoots, TE-11
SSA	YJP	TE-4 TE-10 TE-12	• Bark Photosynthesis, transpiration, optical properties, chlorophyll, TE-8 • Substrate optical properties and water potential, TE-12
SSA	YA	TE-4 TE-10	• Bark Photosynthesis, transpiration, optical properties, chlorophyll, TE-8
SSA	OBS	TE-4 TE-10 TE-12	• δ-13_C of leaf, wood, air; δ–18_O, of air and water (xylem, soil, and precip.), TE-5 • NPP and Canopy Architecture, TE-6 • Maximum photosynthesis, TE-10 • Substrate optical properties and water potential, TE-12
SSA	Mixed Spruce, Aspen	TE-4 TE-10	• Soil moisture and temperature; Sap flow, Palynology, Dendrochronology, Clone boundaries, Permanent growth plots, Specific leaf area, TE-7
SSA	Batoche Aspen		• Soil moisture and temperature; Sap flow, Palynology, Dendrochronology, Clone boundaries, Permanent growth plots, TE-7
SSA	Fen		
NSA	OJP	TE-9	• δ-13_C of leaf, wood, air; δ–18_O, of air and water (xylem, soil, and precip.), TE-5 • NPP and Canopy Architecture, TE-6 • Specific leaf area, TE-7 • Seasonal Canopy photosynthetic capacity, PAR within canopy, photosynthetic response surface, TE-9 • Maximum photosynthesis, TE-10
NSA	YJP	TE-9	
NSA	OBS	TE-9	• δ-13_C of leaf, wood, air; δ–18_O,,of air and water (xylem, soil, and precip.), TE-5 • NPP and Canopy Architecture, TE-6 • Seasonal canopy photosynthetic capacity, PAR within canopy, TE-9
NSA	OA	TE-9	• NPP and Canopy Architecture, TE-6 • Specific leaf area, TE-7 • Seasonal canopy photosynthetic capacity, PAR within canopy, TE-9

4.3.3.2 Biometry Measurements

For the purpose of this report, biometry will be used to refer to the species composition and vegetation structural characteristics for the various vegetation layers and soil characteristics (Budd, A.C., 1979. Budd's Flora of Canadian Prairie Provinces. Revised by J. Loomas and K. F. Best. Reasearch Branch, Agricultural Canada, Publication #1662, Ottawa). The stand-level biometric measurements will be largely based on allometric relationships between the biomass, area or volume of a species part (i.e. foliage, stem, branch, coarse roots, sapwood volume, etc.) and an independent plant variable such as stem diameter, basal area or plant height.

This section addresses the parameter requirements, measurements to be made and methods to be used for measuring biophysical and radiative characteristics for radiative transfer "intensive sites" (i.e. aspen at PANP and jack pine and black spruce in the Candle Lake area), forested tower flux sites and auxiliary sites. Each parameter has a different time constant associated with it. For example, many of the characteristics listed in the stand-level structural properties can probably be measured once in 1993. Allometric equations for estimating biomass and area of the various tree components, however, can vary with season, and therefore should be determined at a time closely corresponding to the highest level of remote sensing activity. Currently, the destructive harvesting of the trees is planned to occur immediately after the 1994 IFC-2. The trees will be harvested outside the TF WAB's; the exact location of the allometry measurements will be mutually decided upon by TE-6 and respective tower flux site captain. In the early and late part of the growing season, characteristics such as LAI and leaf optical and microwave properties may vary and should be measured frequently (i.e. at least weekly). Measurements listed below will be determined for the following species: In the Southern Study Area, old aspen, white spruce/aspen, old jack pine, old black spruce and for the Northern Study Area, aspen, old jack pine, old blackspruce. Those parameters with a * in front of them will be determined for auxiliary sites also; the staff science team will be responsible for making similar measurements. In instances where more than one group is making similar measurements, the groups are strongly encouraged to coordinate activities and standardize field and laboratory methods. The activities will be closely coordinated with the staff work described in Section 3.2.5.

4.3.3.2.1 Biometry Work Plan

In August 1993, four 25 x 25 m plots were established in mature aspen, jack pine and black spruce stands at the southern (PANP and Nipawin) and northern (Nelson House) sites. Except for the aspen stand at Nelson House, the plots will be located near the flux towers; the location of the plots has been approved by the site manager of each flux tower. The aspen site in the north is located on the same side of the road as the old jack pine immediately after crossing under the large power line along the road to Nelson House (approximately 10 km west of the old jack pine site.

A brief description of the proposed biometry measurements is provided in Table 4.3.3.1a.

4.3.3.2.2 Allometry Measurements

Ten trees will be harvested and sampled for select biometric measurements after the completion of IFC-2 in 1994. TE-6 will be responsible for old jack pine in the north and south and TE-13 will be responsible for old aspen and black spruce inthe north and south. Three dominant, five co-dominant and two suppressed trees for the major forest species (i.e. aspen, jack pine or black spruce) will be harvested at each site.

Trees will be cut at the soil surface and the length of the entire stem will be marked into 2 m sections. Live branches from each 2 m canopy section will be removed and weighed. One representative branch will be randomly selected from each canopy position, placed in plastic bags and returned to the laboratory. All samples will be stored at 2˚C until analyzed. In the laboratory, the branch from each canopy position will be sorted into woody tissue and four needle age classes (i.e. current, 1-2 years, 3-4 years and > 4 years), weighed, dried at 70˚C to a constant mass and reweighed. Ratios of the mass of each needle age class and total woody branch tissue to the total mass of the sampled branch will be determined; these ratios will be used with water content values to calculate dry mass of each component per canopy position and summed to estimate total dry mass of each component per tree.

Specific leaf area (SLA; hemisurface area of fresh foliage / g dry foliage mass; hemisurface area is one-half of all-sided surface area) will be determined for approximately 50 needles using the procedure described in Appendix K-4. The hemisurface leaf area (one-half of the total leaf area) of a tree will be calculated by multiplying SLA of each needle age class for each canopy position by its respective mass and summing for the entire tree.

The stem of each tree will be cut into 2-m sections and weighed. Basal disks will be taken from the bottom of each 2-m stem section for moisture determination. The disks will be weighed, dried at 70 C to a constant mass and reweighed. Percent water of each disk will be used to calculate dry stem mass for each 2 m stem section; the dry weights of all stem sections will be summed for the entire tree to calculate total dry stem mass.

Allometric measurements to be made for each forest type are described in Table 4.3.3.1b.

4.3.3.2.3 Aboveground Biomass and Net Primary Production

Aboveground tree biomass and leaf area will be calculated annually from at least 1972 (where feasible) to 1994 using the regression equations and stem diameter increment data for all live trees in each plot. Correction factors will be used to adjust the regression equations for systematic bias due to logarithmic transformations (Sprugel 1983). Aboveground net primary production (ANPP) will be calculated as the sum of biomass increment (B) plus detritus production (D). Herbivory will be ignored because direct estimates are difficult to obtain and previous indirect estimates suggest herbivory is commonly less than 5 % of net primary production for forests (Whittaker and Woodwell 1968, Gower and Grier 1989).

Biomass increment will be calculated from at least 1972 (where feasible) to 1994 from annual diameter increment data and regression equations. Stem wood radial increment will be measured from two stem wood increment cores taken at right angles to each other for each tree > 2.5 cm dbh. The two cores from each tree will be placed in a plastic straw and returned to the laboratory. Stem wood radial increment for each year will be measured to the nearest 0.01 mm with a Gaertner micrometer. Stem diameter increment of each tree will be calculated using the equation: stem diameter increment = stem wood diameter increment x (radius outside bark at dbh/ stem wood radius at dbh).

Ten, 40 x 60 cm litterscreens, lined with fine nylon mesh, will be randomly placed in each plot to estimate fine detritus production. We define fine detritus to include leaf litterfall, fine woody debris (< 2.5 cm maximum diameter), reproductive tissue and insect frass. Fine detritus will be collected every six weeks during the snow-free season (approximately May-October) and less frequently in the winter because the litterscreens will be covered by snow. We will collect the major pulse of leaf litterfall in the fall before the litterscreens are covered with snow. Annual estimates for fine detritus will be based on the period from April 1 to March 31 because some needles that senesce in the fall remain lodged in the canopy until after several snowstorms.

Above- and below-ground C flux measurements to be made for each vegetation type are described in Table 4.3.3b.

Below, a brief description of the proposed biometry measurements listed in Table 4.3.3.1a 4.3.3.1b is provided.

A. Structural Properties

I. Stand-Level

a density (trees/ha based on 4, 25 x 25 m plots)
b. basal area (m2/ha based on 4, 25 x 25 m plots)
c. dbh distribution -(based on 4, 25 x 25 m plots)
d. species -(based on 4, 25 x 25 m plots)
e. tree height distribution -(based on 4, 25 x 25 m plots)
f. % canopy cover -(from hemisperical photographs)
g. canopy position (dominant, co-dominant or, suppressed.)
h. canopy topography/surface roughness- Rich/Fournier
i. direct estimate of leaf area index -(destructive analysis of ten trees)
j. coarse woody detritus -(line transect surveys)
k. forest floor mass -(10, 30 cm dimeter cores per plot)
l. soil texture
m. water holding capacity
n. effective rooting depth
o. % coarse fragment (> 2 mm diameter)
p. stem mapping, canopy shape and radius - Rich/Knox (TE-20, TE-23)
q. ANPP from 1985-1994 -(biomass increment + detritus production)
r. hemispherical photographs (fPAR, indirect est. of LAI - Rich

II. Stem and Branch (w/o needles) (to be determined for 10 overstory trees at each site by 2 m vertical increments)

a. live and dead stem biomass and area -
b. stem sapwood volume -
c. total tree height and height to base of live crown -
d. sapwood area at dbh and base of live crown -
e. live and dead branch biomass and area -
f. average overall branch length -(from bole to branch tip)
g. average branch angle at bole -

III. Shoot (to be determined for 10 overstory trees at each site by 2 m vertical increment for each shoot age class)

a. shoot silhouette area -(projected in one or more directions)
b. projected needle area:shoot silhouette area ratio -

c. needle:twig biomass ratio.
d. shoot envelope dimension- (dimension of shoot envelope encompassing all the needles)

IV. Leaf (to be determined for 10 overstory trees at each site by 2 m vertical increment for each needle age class)
a. needle biomass and area -
b. specific needle area -(fresh area/dry mass, see Appendix K-4 for details)
c. leaf density - (foliage fresh mass/canopy volume)

4.3.3.2.4 Biometry and Allometry Measurements to be Made at Auxiliary Sites

In addition to the detailed biometry and allometry measurements described in Tables 4.3.3.1a-c, dbh, species, tree height, canopy position and tree density will be measured at each auxiliary site. See auxiliary site plan (section 3.2.4) for a list of the auxiliary sites. Scientists can use these measurements for the auxiliary sites and the allometric equations for the tower flux sites to estimate the biomass and area of stems, branches and foliage for the auxiliary sites. Site-specific allometric equations will not be developed for the dominant overstory species at each of the auxiliary sites, but we will develop a priority ranking for which sites where site and species-specific allometric equations will be developed to estimate aboveground biomass and production, leaf area and detailed biophysical and optical properties of species-specific allometric equations will be developed for the dominant overstory tree species at each site. The next highest priority will be given to a jack pine, aspen and black spruce forest near Flin Flon, Manitoba because of the unique parent material of this region relative to the other two study areas. Depending upon the funding, allometric equations will be developed for aspen, jack pine and black spruce trees for an auxiliary site in the NSA and SSA of contrasting productivity to that of the tower flux stand in each area (see Table 4.3.3.1b). This sampling scheme will encompass the greatest range in productivity which should benefit scientists attempting to develop regional forest C budgets, modelers interested in validating their ecosystem process models over the greatest range of environmental conditions, and remote sensing scientists interested in testing their algorithms and validating regional forest productivity estimates derived from remotely sensed parameters such a fPAR.

Although site specific allometric equations probably will not be available for all the auxiliary sites, generalized allometric equations are available for the dominant boreal tree species. These equations will provide reasonable estimates of woody biomass, but may provide less than satisfactory estimates of leaf area and foliage biomass.

Table 4.3.3.1a
Stand-level structural properties

	SSA				NSA			
Measurement	**OA**	**OJP**	**OBS**	**YJP**	**OA**	**OJP**	**OBS**	**YJP**
*a. density (trees/ha)	TE-13 TE-23 RSS-16 RSS-19	TE-6 TE-23 RSS-16 RSS-19	TE-13 TE-23 RSS-16 RSS-19	RSS-19 TE-23	TE-13 RSS-16	TE-6 TE-23 RSS-16 RSS-19	TE-13 TE-23 RSS-16 RSS-19	TE-23 TF-10 TF-10 RSS-19
b. basal area	TE-13 TE-23 RSS-19	TE-6 TE-23 RSS-19	TE-13 TE-23 RSS-19	RSS-19 TE-23		TE-6 TE-23 RSS-19	TE-13 TE-23 RSS-19	TE-23 TF-10 RSS-19
*c. dbh distribution	TE-13 TE-23 RSS-16 RSS-19	TE-6 TE-23 RSS-16 RSS-19	TE-13 TE-23 RSS-16 RSS-19	RSS-19 TE-23	TE-13	TE-6 TE-23 RSS-19	TE-13 TE-23 RSS-19	TE-23 TF-10 RSS-19
*d. species	TE-13	TE-6	TE-13		TE-13	TE-6	TE-13	TF-10
*e. height distribution	TE-13 TE-23 RSS-16 RSS-19	TE-6 TE-23 RSS-16 RSS-19	TE-13 TE-23 RSS-16 RSS-19	RSS-19 TE-23	TE-13 RSS-16	TE-6 TE-23 RSS-16 RSS-19	TE-13 TE-23 RSS-16 RSS-19	TE-23 TF-10 TF-10 RSS-19
*f. % canopy cover								
g. canopy class	TE-13	TE-6	TE-13		TE-13	TE-6	TE-13	
i. direct estimate of LAI	TE-13	TE-6	TE-13		TE-13	TE-6	TE-13	TF-10
j. coarse woody ditritus	TE-13	TE-6	TE-13		TE-13	TE-6	TE-13	Staff
k. forest floor mass	TE-13	TE-6	TE-13		TE-13	TE-6	TE-13	Staff
l. soil texture	------------------------------STAFF, TE-1-----------------------------							
m. water holding capacity	------------------------------STAFF, TE-1-----------------------------							
n. effective rooting capacity	------------------------------STAFF, TE-1-----------------------------							
o. % coarse fragment	------------------------------STAFF, TE-1-----------------------------							
*p. stem mapping, canopy shape & radius	RSS-19 TE-23	RSS-19 TE-23	RSS-19 TE-23	RSS-19 TE-23		RSS-19 TE-23	RSS-19 TE-23	RSS-19 TE-23
*q. ANPP from 1985-1994	TE-6	TE-6	TE-6		TE-6	TE-6	TE-6	?
*r. hemispherical photos fPAR, indirect est. of LAI	RSS-7 RSS-19 TE-23 RSS19+	RSS-19 TE-23 RSS19+	RSS-19 TE-23 RSS19+	RSS-19 TE-23		RSS-19 TE-23	RSS-19 TE-23	RSS-19 TE-23

+ hemispherical photos with CCD camera
* also measured at auxiliary sites

Table 4.3.3.1b
Allometry (to be determined for 10 overstory trees at each site by 2 m vertical increments)

	Vegetation Type							
	SSA				NSA			
Measurement	**OA**	**OJP**	**OBS**	**Mixed[1]**	**OA**	**OJP**	**OBS**	**YJP**
STEM AND BRANCH								
*a. live & dead stem biomass & area	TE-13	TE-6	TE-13		TE-13	TE-6	TE-13	
b. stem sapwood volume	TE-13	TE-6	TE-13		TE-13	TE-6	TE-13	
*c. total tree ht and ht to base live crown	TE-13	TE-6	TE-13		TE-13	TE-6	TE-13	
d. sapwood area at dbh & base live crown	TE-13	TE-6	TE-13		TE-13	TE-6	TE-13	
*e. live & dead branch biomass & area	TE-13	TE-6	TE-13		TE-13	TE-6	TE-13	
f. average branch length	TE-13	TE-6	TE-13		TE-13	TE-6	TE-13	
g. average branch angle	RSS-16	RSS-16	RSS-16		RSS-16	RSS-16	RSS-16	--
h. number of branches	RSS-16	RSS-16	RSS-16		RSS-16	RSS-16	RSS-16	RSS-16
i. branching structure	RSS-19	RSS-19	RSS-19		--	--	--	--
SHOOT (to be determined for 10 overstory trees at each site by 2 m vertical increment for each shoot age class)								
a. shoot silhouette area	TE-6 RSS-16	TE-6 RSS-16	TE-6 RSS-16		-- RSS-16	-- RSS-16	-- RSS-16	
b. shoot:needle area ratio	TE-6 RSS-16	TE-6 RSS-16	TE-6 RSS-16		-- RSS-16	-- RSS-16	-- RSS-16	
c. needle:twig biomass ratio	TE-13 RSS-16	TE-6 RSS-16	TE-13 RSS-16		TE-13 RSS-16	TE-6 RSS-16	TE-13 RSS-16	
LEAF (to be determined for 10 overstory trees at each site by 2 m vertical increment for each needle age class)								
*a. needle biomass & area	TE-13 RSS-16	TE-6 RSS-16	TE-13 RSS-16		TE-13 RSS-16	TE-6 RSS-16	TE-13 RSS-16	
b. specific needle area	TE-13 RSS-16	TE-6 RSS-16	TE-13 RSS-16		TE-13 RSS-16	TE-6 RSS-16	TE-13 RSS-16	
c. leaf density	TE-13 RSS-16	TE-6 RSS-16	TE-13 RSS-16		TE-13 RSS-16	TE-6 RSS-16	TE-13 RSS-16	

1/ Black Spruce, White Spruce and Aspen

Note: From the above measurements we can calculate the stem, branch, foliage (by 1yr-age-classes) mass and area for each 2 m vertical section above the soil surface.

Table 4.3.3.1c
Optical Properties

	Vegetation Type								
	SSA					NSA			
Measurement	**OA**	**OJP**	**OBS**	**Fen**	**YJP**	**OA**	**OJP**	**OBS**	**YJP**
LEAF									
a. leaf reflectance	TE-10 TE-12	TE-10 --	TE-10 TE-12	? --		TE-9 --	TE-10 -- RSS19	TE-9 -- RSS19	TE-9 -- RSS-19
b. leaf transmittance	TE-10 TE-12	TE-10 --	TE-10 TE-12	? --		TE-9 --	TE-10 -- RSS19	TE-9 -- RSS19	TE-9 -- RSS19
c. leaf surface bi-direction reflectance	TE-12	--	TE-12	--		--	--	--	--
TWIG & BRANCH									
a. twig reflectance	TE-12	--	TE-12	--		--	--	--	--
b. branch bi-directional reflectance	TE-12	--	TE-12	--		--	--	--	--
c. shoot reflectance	TE-12	--	TE-12	--	--	--	--	--	--
d. leaf surface bi-direction reflectance	TE-12	--	TE-12	--		--	--	--	--
STEM									
a. stem reflectance	TE-8	TE-8	TE-8	?		TE-8	TE-8	TE-8	?
UNDERSTORY									
a. in situ reflectance	RSS19 TE-8	RSS-19 TE-8	RSS19 TE-8	? ?		RSS19 TE-8 TE-9	RSS19 TE-8 TE-9	RSS19 TE-8 TE-9	RSS-19 TE-9
b. bidirectional reflectances						TE-9	TE-9	TE-9	TE-9

4.3.3.3 Canopy Access and Destructive Sampling Needs

4.3.3.3.1 Canopy Access

To access the canopy, we will erect scaffolding towers at the OBS, OJP, OA in both the SSA and the NSA and at the mixed site. Towers will reach the top of the canopy at each site. Towers will be 5' x 10' scaffolding towers with an access ladder built into the scaffold frames (which means that you will have to climb up the outside of the tower). Each tower will 1) have platforms at three levels within the canopy--no other levels will have platforms (it is possible to move the platforms easily); 2) a haul rope and pulley to lift equipment to the platforms; 3) two climbing harnesses, safety ropes, and jumars to attach climbers to the tower. Towers will be moved between each IFC in 1994. Towers will not have power, unless it can be supplied from an extension cord from the site power. Tower heights will be 65' at SSA-OA; 50' at SSA-OJP, SSA-OBS, and mixed site; and 35' at the NSA-OJP, NSA-OBS, NSA-OA (Aux.) sites. Plans for canopy access are listed in Table 4.3.3.3.1a. TE Tower Captains are:

NSA-OBS	Ryan/Hubbard
NSA-OJP	Ryan/Hubbard
NSA-Aspen Aux Site	Margolis
NSA-Upland-OBS Aux Site	Margolis
SSA-OBS	Walter-Shea
SSA-OJP	Flanagan
SSA-OA1	Middleton
SSA-OA2	Hogg
SSA-Mixed Aux Site	Collatz
SSA-YA	Arkebauer

Tower Captains are responsible for ensuing safety procedures are followed and scheduling use on the tower by all groups. Rules for using the canopy access towers:

<u>Access</u>

1. Permission by the Tower Captain, a valid Canada Parks Research Permit (in OA-South), and proof of training are necessary to use the tower.

2. Access times and sample strategy should be cleared with the Tower Captain.

3. No more than 4 people should work on the tower simultaneously.

Table 4.3.3.3.1a
Planned Canopy Access for TE Group

				-------Number of Days--------				
Site	**Veg. Type**	**Team**	**Hrs/Day**	**IFC93**	**FFC**	**IFC-1**	**IFC-2**	**IFC-3**
SSA	OA	TE-2	11	2		5	5	5
		TE-4	4			3	3	3
		TE-5	12			7	7	7
		TE-8	1	7	5	10	10	10
		TE-10	3	2		3	3	3
		TE-12	8	0		8	8	4
SSA	OJP	TE-2	11	2		5	5	5
		TE-4	4			3	3	3
		TE-5	12			7	7	7
		TE-8	1	7	5	10	10	10
		TE-10	3	2		3	3	3
		TE-11	1			2	5	2
SSA	OBS	TE-2	11	1		5	5	5
		TE-4	4			3	3	3
		TE-5	12			7	7	7
		TE-10	3	2		3	3	3
		TE-12	8	0		16	12	6
SSA	YJP	TE-4	4			3	3	3
		TE-8	1	7	5	10	10	10
		TE-10	3	1		1	1	1
		TE-12	8	5		2?	2?	2?
SSA	YA	TE-4	4			3	3	3
		TE-8	1	7	5	10	10	10
		TE-10	3	1		1	1	1
SSA	Mixed Spruce/ Aspen	TE-2	11			5	5	5
		TE-4	4			3	3	3
		TE-5	12	2		5	5	5
		TE-10	3			3	3	3
NSA	OJP	TE-2	11	1		5	5	5
		TE-5	12			7	7	7
		TE-9	6		3	3	3	3
		TE-10	3	2		2	2	2
NSA	OBS	TE-2	11	1		5	5	5
		TE-5	12			7	7	7
		TE-9	6		3	3	3	3
NSA	OA (Aux. Site)	TE-2	11	1		5	5	5
		TE-5	12			7	7	7
		TE-9	6			3	3	3
NSA	YJP	TE-9	6		3	3	3	3

4. Reserve trees adjacent to the tower for those measurements that need to be done with intact foliage under ambient conditions. Samples of branches and shoots removed for laboratory measurements must not be taken from trees adjacent to the tower, but removed with a pole pruner from more distant trees.

5. Flag locations where samples were collected or to reserve shoot adjacent to the tower for periodic measurements. Write on flagging: TE Number and Date.

6. If TE tower captain is not at the site, OPS must be contacted before using TE canopy access tower.

Safety

1. Vistually check tower before climbing. Make sure fallen trees have not affected the guy wires. Make sure safety rope is firmly attached.

2. Check climber safety equipment before using. Make sure rope knots, jumars, and carabineers are secure.

3. Wear a climbing harness at all times. Use jumars and safety line while ascending or descending. Secure yourself and your equipment to the tower while on the platforms. BOREAS has provided 2 sets of safety equipment per tower; you may wish to purchase your own (climbing harness, 1 locking carabineer, 1 standard carabineer, 1 jumar ascender, 2 m climbing rope) if you will be working on a tower that receives heavy use.

4. Before ascending or descending, check pockets and equipment for loose items. Only one person at a time should climb the tower. Wear a hardhat if you are working below the tower when the tower is in use.

5. Do not work alone. Two people must be at the site when anyone is using the tower.

4.3.3.3.2 Destructive Sampling Needs

Table 4.3.3.3.2a lists the planned harvest of material at or near the TE canopy access towers for the TE group.

4.3.3.4 TE Investigators' Field Visits Schedules

Table 4.3.3.4a lists the planned visits by each TE Team to the NSA and SSA. Table 4.3.3.4b in Appendix K gives specifics for SSA-OA.

Table 4.3.3.3.2a
Destructive Sampling at TE Towers

Study Area	Veg. Type	Team	Amount, 1993	Amount, 1994	Leaves	Shoots
SSA	OBS	TE-2	30g	100g	x	
		TE-4		600g	x	
		TE-5		1g	x	x
		TE-10	0.1 m2	30g	x	
		TE-12	54shoots	162shoots		x
SSA	OJP	TE-2	30g	100g	x	
		TE-4		600g	x	
		TE-5		1g	x	x
		TE-8	300g	600g	x	x
		TE-10	0.1 m2	30g	x	
		TE-11		100g		x
		TE-12	27?shoots	81?shoots		x
SSA	OA	TE-2	30g	100g	x	
		TE-4		300g	x	
		TE-5		1g	x	x
		TE-8	300g	600g	x	x
		TE-10	0.1 m2	30g	x	
		TE-12	27? shoots	81?shoots	x	x
SSA	YJP	TE-4		600g	x	
		TE-8	300g	600g	x	
		TE-10		30g	x	
SSA	YA	TE-4		600g	x	
		TE-8	300g	600g	x	
		TE-10		30g	x	
NSA	OA (Aux. Site)	TE-2		100g	x	
		TE-5		1g	x	
		TE-9		2000g	x	
NSA	OJP	TE-2		100g	x	
		TE-5		1g	x	
		TE-9		2000g	x	
		TE-10		30g	x	
NSA	OBS	TE-2		100g	x	
		TE-5		1g	x	
		TE-9		2000g	x	
NSA	YJP	TE-9		2000g	x	

Table 4.3.3.4a
Planned Visits by TE Teams

			No. of People		Number of Days Present at each site listed		
Super Site	**Team**	**Sites**	**IFC-93**	**FFC**	**1-94**	**2-94**	**3-94**
SSA	TE-1	OA,OJP,OBS, YJP,Fen	2	3	3	3	3
SSA	TE-2	OA,OJP,OBS, Mixed	2	1	4	4	4
SSA	TE-4	OA,OJP,YJP, OBS,YA,Mixed	2		2	2	2
SSA	TE-5	OA,OJP,OBS, Mixed	2	2	2	2	2
SSA	TE-6	OA,OJP,OBS, OBS,YA,Mixed	4		5	5	5
SSA	TE-7	OA,Mixed	3		1	1	1
SSA	TE-8	OA,OJP	1	5	5	5	5
SSA	TE-10	OA,OBS,OJP, YA,YJP	1	2	4	4	4
SSA	TE-11	OJP	2-4	12	14	28	14
SSA	TE-12	OA,OBS,YJP, Mixed,Fen	5	5	5	5	5
NSA	TE-2	OA,OJP,OBS	2	1	4	4	4
NSA	TE-5	OA,OJP,OBS	2	1	2	2	2
NSA	TE-9	OA,OBS,OJP, YJP	10	5	5	5	5
NSA	TE-6	OA,OJP,OBS	4	4	5	5	5

4.3.4 Experiment Protocols

This section lists experimental protocols for soil CO_2 flux measurements and reporting of foliage area.

4.3.4.1 Soil CO_2 flux measurements at BOREAS

Table 4.3.4.1 lists investigations making soil CO_2 meaurements at BOREAS and the location and number of those measurements.

Table 4.3.3.4b
Planned Sampling in PA Aspen Site

Team	When?	How Many People? How Often?	Purpose?
TE-1,3	before IFC in 93	2 people for several days	1) Soil survey on entire tower area 2) 3-5 soil profiles (removing samples) 3) Install 10 neutron tubes (in area designated by site captain).
	During IFC in 93	2 people, 2-3 times per week	1) Soil respiration & related nutrient measurements (in designated area, not in pac-man). 2) Measure soil moisture via neutron probe.
	IFC1-94 IFC2-94 IFC3-94	Same as IFC in 93	Same as for IFC in 93.
TE-2	IFC in 93	2 people, 8h	1) Tree respiration. 2) Obtain destructive samples.
	IFC1-94 IFC2-94 IFC3-94	2 people, 11 h night and day for 4 days	Same as for IFC in 93
TE-4	IFC1-94 IFC2-94 IFC3-94	2 people, for 4h (am) on 3 days	1) Perform chamber gas exchange from canopy scaffold tower. 2) Obtain destructive samples.
TE-5	IFC1-94 IFC2-94 IFC3-94	2 people, for 12 h on 7 days	1) Perform chamber gas exchange from canopy scaffold tower. 2) Obtain destructive samples.
TE-6	IFC1-94 IFC2-94 IFC3-94	2-4 people for 12 h on 1-3 consecutive days	Measure soil CO_2 flux on 15x15m plot (also soil temp. & moisture)
TE-7	Before IFC1-94	1 person for 2-3 days 3 people, 1 days	Install chambers on stems and branches. Estimate LAI of tower area with LAI- 200/ ceptometer
	IFC1-94	2 people for 12 h on 4 days	Measure respiration (stem, branch [possible also foliage, roots]).
	IFC2-94 IFC3-94	1 person for 12 h on 4 days	Same as above.
	IFC2-94 IFC3-94	3 people for 1 day	Estimate LAI of tower area with LAI-200/ ceptometer
TE-8	IFC in 93 Winter FFC IFC1-94 IFC2-94 IFC3-94	1 person for 1/2 day on 3 days	1) Optical properties of overstory plants (from canopy scaffolding tower) & understory plants. 2) Obtain destructive samples.

Team	When?	How Many People? How Often?	Purpose?
TE-10	IFC in 93	1 people for mornings on 1-2 days	1) Perform chamber gas exchange from scaffolding tower (if available). 2) Perform chamber gas exchange on Hazelnut understory plants. 3) Obtain in situ spectral measurements. 4) Obtain destructive samples.
	IFC1-94 IFC2-94 IFC3-94	2-3 people for mornings (9-12am) on 3-5 days AND, on 2 nights	Same as 1-4 Above. 5) Recharge 12V batteries overnight & cable storage on site.
TE-11	IFC1-94 IFC2-94 IFC3-94	1-2 people for 2-3 h, periodically	Access to Met Data from tower-based instruments
TE-12	IFC in 93	2 people for 8 h on 5 days	1) Perform chamber gas exchange on overstory from scaffolding tower. 2) Obtain destructive samples.
	IFC1-94	1-2 people for 8 h on 8 days	Same as above
	IFC2-94 IFC3-94	1-2 people for 8 h for 6 days	Same as above.
TE-20,22	1995 Post 1994 Experiment	3 people for 10 h/day, for 2 weeks	For stem mapping in the WAB.

Table 4.3.4.1
Soil CO_2 Flux Measurements at BOREAS

Site	Group	Method	Number of Locations per site	Duration	Frequency
SSA-OA	TE-1	GC Static Ch.	6-10	IFC 1,2,3	2-7/week
	TF-1	IRGA	5-10	IFC 1,2,3	Hourly
	TF-1	Eddy Correlation (height=3m)	2	IFC 1,2,3	1/2 Hourly
SSA-OJP	TF-4	GC-CO_2 grad GC Static Ch. 13CO_2 St. Ch.	1 ? ?	Melt-IFC 3 Melt-IFC 3 IFC 1,2,3	1-2/week 1-2/week 1/IFC
	TF-5	Eddy Corr.	1	IFC 1,2,3	Hourly
SSA-YJP	TF-4	GC-CO_2 grad GC Static Ch. 13CO_2 St. Ch.	1 ? ?	Melt-IFC 3 Melt-IFC IFC 1,2,3	1-2/week 1-2/week 1/IFC
SSA-OBS	TE-1	GC Static Ch. GC-CO_2 grad	10-15 ?	IFC 1,2,3 IFC 1,2,3	2-7/week 1/week
	TF-7	Eddy Corr.	1	IFC 1,2,3 ?	>1/week
SSA-Fen	TF-11	IRGA	20	IFC 1,2,3	2/week + Diurnal cycle
	TE-1	GC Static Ch. GC-CO_2 grad.	10-20 ?	IFC 1,2,3 IFC 1,2,3	2-7/week 1/week
SSA-Mixed Aspen/WP	TE-6	IRGA	10	IFC 1,2,3	2/week + Diurnal cycle
NSA-Aspen	TE-6	IRGA	10	IFC 1,2,3	Weekly + Diurnal cycle
NSA-OJP	TGB-1	GC-CO_2 grad	5-10	Melt-IFC 3	1-2/week
NSA-YJP	TGB-3/1	GC Static Ch.	5-10	Melt-IFC 3	1-2/week
NSA-OBS	TF-3	IRGA	20	IFC 1,2,3	hourly (light/dark)
	TGB-1	GC Static Ch.	5-10	Melt-IFC 3	1-2/week
NSA-Fen	TGB-3	GC Static Ch.	5-10	IFC 1,2,3	1-2/week
NSA-Beaver Pond	TGB-4	GC & IRGA	10	Melt-IFC 3	1-2/week

Explanation

Mix Aspen/WP	Mixed Aspen-White Spruce auxiliary site with special status
GC	Gas Chromatograph - syringes with static chamber and gradient
IRGA	Closed, recirculating chamber except NSA-OBS which will be automated open chambers.

Those measuring on Black Spruce should realize that with active moss growing on the surface, CO_2 fluxes with and without light will be necessary to separate out the effect of the Moss from soil microbial and root fluxes. Alternatively, some CO_2 fluxes on moss that is separated from the underlying soil or CO_2 flux measurements on soil that has moss removed may be suitable. In any event, CO_2 fluxes from mosses must be separated from soil and root fluxes. Apparently from the literature, moss fluxes are far from negligible.

A standard unit has been adopted for soil-surface CO_2 fluxes, namely micrograms CO_2 per square meter per second. Concentrations will be expressed in micromols per mol or volume parts per million.

All CO_2 flux measurements must be accompanied by at least the following ancillary data:

Soil Temperature at 5 cm and 10 cm

Soil Moisture 0-5 cm, 5-10cm, 10-20 cm.

Leaf area index of the site

Precise location in grid coordinates

Time of measurement in local time and GMT

Comments identifying whether temperature and moisture were taken at the precise location of the flux measurement or a nearby observation station. If a nearby station is used, that station must be identified by grid location.

This minimal set of ancillary measurements are essential if we are to interpolate between measurements made on a weekly basis. Some of these ancillary measurements will be made by the Staff Science group or other BOREAS investigators, and those making soil surface CO_2 measurements should determine who is making measurements at their site that they are not able to make.

TE-6 will compare their measurements with each group making soil surface CO_2 flux measurements by setting up collars nearby each group at least once during 1994. This is not meant to imply that the method used by TE-6 is a standard, but will provide a relative calibration between measurements by comparing measurements from each different group with a single measurement method.

4.3.4.2 Procedures for measuring and reporting foliage area

These are defined in detail in Appendix K-4.

4.3.5 TE modeling, scaling and links to RS

This outline of the overall plan for coordinating Terrestrial Ecology (TE) projects, and linking them with Remote Sensing Science (RSS) was developed at small workshop held in Maryland in July, 1993. Subsequent meetings by the science teams have refined the plans.

4.3.5.1 Comparison between models and tower fluxes

Flux towers that will be used to compare with models for short-term fluxes in the SSA are Old Black Spruce (OBS), Old Aspen (OA) and Old Jack Pine (OJP). Towers in the NSA are in OBS and OJP.

At each of the forest sites there will be enough measurements of weather and the vegetation to parameterize and run at least the following (diurnal) carbon balance models having sub-daily time steps: Cupid (John Norman), TCX (Gordon Bonan), SiB (run by Jim Collatz), HYBRID (run by Bob Knox) and MAESTRO (run by Paul Jarvis).

Canopy architecture will be described from biomass data and allometric relationships to be determined on a sample of 10 trees to be harvested at each site (Gower). Measurements of net carbon flux from the soil, and biomass respiration will also be made at each site. Soil hydraulic properties will be determined, allowing the calculation of water balances. Soil water content will be measured regularly and piezometer tubes will provide information about water table levels.

All of the models listed above produce short-period (minutes-hours) outputs that can be compared to the net ecosystem CO_2 and water vapor fluxes measured from the towers. Comparisons between model performance will also be of interest. Narendra Goel has a very detailed photosynthesis model which will provide valuable comparisons with the photosynthesis modules of the other models. FOREST- BGC (Steve Running) can also be parameterized and run for these sites, although it has a daily time step, so the comparison will be between the integrated daily net tower fluxes and model output.

Since the BOREAS IFC's provide a unique opportunity to make comparisons between models of this type and experimental measurements, these comparisons should be made for each day when the towers are operating without problems.

The priorities for model comparisons at towers are as follows:

1. A block of sunny days in order to catch the dry down. This will give a range of CO_2 and H_2O flux conditions.

2. A snowmelt thaw series.

3. Extended dry periods.

4. Overcast versus sunny conditions.

The first is the highest priority, the order of priority for the other three remains to be worked out.

4.3.5.2 The auxiliary sites: testing light use efficiency models and forest-BGC

Seventy-seven forested auxiliary sites - 35 in the SSA and 25 in the NSA (see section 3.2.4.) - have been selected to represent the range of density and stand age encountered in the region. Each auxiliary site is large enough to be identified and analyzed by LANDSAT TM.

The auxiliary sites will be used to test the light-use-efficiency models (Goward, Cihlar), which rely on the linear relationship between APAR and dry matter increments. The auxiliary sites will also be used to test the ability of the carbon-balance models to predict annual NPP, to compare components (e.g. below ground allocation) among models, and to test growth predictions of stand dynamics models such as Zelig.

A series of hemispherical photographs will be taken at three levels through the canopy twice during the summer of 1994 (Paul Rich; TE-23) and analyzed to provide the information needed, together with values of incoming Photosynthetically Active Radiation (PAR), to calculate Absorbed PAR (APAR). We also hope to obtain data on soil CO_2 fluxes from at least some auxiliary sites. Soil temperatures at two depths (probably near-surface and 10-20 cm) will be made at some (representative) auxiliary sites to allow improved estimates of decomposition rates.

4.3.5.3 Landscape fluxes

The remote sensing investigators will provide, as a product a modeling sub-area (see figure 5.1.5b) over the SSA and a modeling sub-area (see figure 5.1.5a) over the NSA, 30m x 30m biophysical parameter maps with information on vegetation composition, structure and density, estimates of standing biomass (green and total), LAI, *f*PAR, height, crown closure, PAR, incident, short- and long-wave radiation, and a number of other variables (see RSS research plan). These areas will include at least two gauged catchments and will cover all the tower flux sites except the OA site in the SSA. While the OA site in the SSA will be covered by flux aircraft, for logistic reasons it will not directly be part of the modeling sub-area for which the landscape level fluxes will be intensively modelled. However, the knowledge gained from the intensive analysis of the SSA-OA tower site will be applied to model the aspen stands found within the modeling sub-area grid.

When the weather is suitable and aircraft are available, stacked, gridded flux measurements will be made by aircraft of several types (King Air; Twin Otter, Long EZ) throughout the day. To provide comparisons between the "landscape scale" fluxes measured by the aircraft, CO_2 and water vapor fluxes will be calculated throughout the day(s), using the dynamic carbon balance models parameterized for the whole area on the basis of the information available from the aircraft and satellite optical/radar instruments. Weather data will come from the automatic weather stations in the area, possibly supplemented by more detailed spatial information from Pielke (AFM-12), who will be evaluating a regional (meso-scale) weather model. The result will be comparisons of measured and calculated landscape-scale fluxes, where the calculations are based on detailed information about the landscape characteristics and vegetation. Both aggregate fluxes and differences among areas within the grids will be of interest. Outflow from the gauged catchments is a "landscape flux" and will be used to validate the water balance components of the carbon balance models.

4.3.5.4 Regional fluxes

There will be a series of flux measurement transects flown between the SSA and the NSA, as weather, aircraft availability and other logistical considerations allow.

A strip (perhaps) 20 km wide of the landscape along the transect lines will be characterized, in terms of its vegetation cover, by AVHRR (1 km pixels). This may not result in anything better than categories such as young coniferous, old coniferous, recently burned, mixed stands (i.e with mixtures in the range 40:60 either way) and lakes, but the information will be used in models such as SiB (Berry), the APAR efficiency model(s) (Goward, Cihlar), and FOREST-

BGC, to calculate CO_2 and water vapor fluxes along the transect to provide comparisons with the aircraft-measured fluxes. The weather data to be used in these calculations will come from a combination of the European Center for Medium Range Forecasting (ECMWF) model, which provides daily weather conditions on a 100 x100 km grid, and the automatic weather stations set up as part of the BOREAS.

We note the need for long-term weather data for the region, to evaluate long term fluxes. It is also proposed, if possible, to establish a regional CO_2 monitoring station on a radio mast in the area or, if this is not feasible, to establish a system of flask sampling from aircraft to build up a picture of the regional patterns of CO_2 concentration in relation to global trends and short -term patterns.

4.3.5.5 Mixed stand

The most productive areas of the southern boreal forests are often covered by aspen mixed with conifers. A significant portion of the Southern Study Area (SSA) is dominated by mixedwood forests of various successional stages and species composition. The TE and RS scaling issues for such mixed stands are different, and more difficult, than those in pure stands. On the basis of the relative areas, at least one-quarter of the regional fluxes of CO_2 and water vapor observed by aircraft should be from mixedwood forests.

Many of the processes occuring in mixedwood stands are expected to differ fundamentally from those in stands dominated by a single tree species. Therefore, experimental results based exclusively on pure stands may not provide an adequate basis for modelling mixed stand forests. Since a major focus of BOREAS is to develop and refine models that link remote sensing and climatology with surface processes over large spatial scales, it is important to understand the processes occuring in all major forest types, including mixedwood. The following series of activities is proposed to characterize the processes in mixedwood, with a view to providing a firmer basis for evaluating fluxes at the regional scale.

Although the proportion of forest are occupied by mixedwood is large, both species composition and forest structure are complex and highly variable in mixed-species stands. Much of the mixedwood in the SSA is overmature, and logging operations in mixedwood have intensified over the past decade. Thus, spatial units with uniform mixedwood vegetation are typically much smaller than those associated with pure stands. Larger spatial units do occur, which qualify as mixedwood from a regional perspective, but on a smaller scale, these are found to comprise a complex mosaic of various pure and mixedwood stands.

For the small-scale, intensive studies, a mixedwood site comprised of aspen, black spruce and white spruce has been selected near Candle Lake in the SSA. Stand age is ca. 40 years and tree heights are about 12 m for aspen and 7m for spruce. The species ar well-mixed within the stand and the size of the site (ca. 200 x 200m) should be sufficient for TE and RSS measurements. The site will be characterized by ground surveys of the vegetation and by remote sensing, including radar observations in spring, before the deciduous trees have come into leaf, in summer, when they are in full foliage, and in autumn. Available funds do not allow the establishment of a flux tower in this stand, and its size is insufficient for direct aircraft flux measurements. Thus, aircraft flux measurements will be taken over larger "mixedwood mosaics", while TE and RSS activities in the Candle Lake stand are designed to characterize the processes occuring in mixedwood that are most critical for scaling up to landscape and regional scales.

At the intensive site, the canopy will be characterized by remote sensing measurements from satellite and aircraft platforms. Optical properties at the leaf and canopy level (Middleton, Arkebauer, Gamon) and modelling (Goel) will be used to develop algorithms relating remote sensing signatures to canopy structure and light interception. Information on canopy structure, leaf area and stand biomass using biometry and allometry (Apps) will be obtained using the same methods as for the other sites. Modeling of the carbon cycle will be covered by Canadian Forest Service (Apps).

The following studies of processes within the canopy will be conducted at the intensive site, with ecophysiological measurements being made on both aspen and spruce: Sapflow (Hogg, Saugier), leaf gas exchange (Berry, Collatz, Middleton, Arkebauer), soil and stem CO_2 (Norman, Lavigne), carbon and isotopic compositions of CO_2 within the canopy and released from the soil, and carbon isotopic ratios of leaf tissue (Ehleringer-Flanagan). Soil characteristics will be measured, and basic meteorological variables monitored through the growing season. These include soil temperature, moisture and fertility, air temperature and relative humidity, global radiation, PAR, wind and precipitation (Anderson, Hogg and others).

Canopy flux measurements of CO_2, water vapor and sensible heat will be made by the Long EZ aircraft (Tim Crawford), over the more extensive mosaics of mixedwood in the Candle Lake - Whitegull Creek area. This aircraft is capable of sampling at scales down to 3-5 km. Aircraft measurements of net radiation will be made and used to establish the statistical relationship between net and global solar (short wave incoming) radiation needed to simulate fluxes of CO_2 and water vapor (Berry, Collatz) at the intensive site during those periods when net radiation measurements are not available.

4.3.5.6 Working group

Most of the exercises outlined here will be retrospective. To test the procedures and to attempt to eliminate problems relating to the use of the data grid, interfacing models with remote sensing and weather data, and the formulation of outputs in terms that allow useful comparisons, a working group is to be set up during 1994 to collect preliminary/sample data and implement at least one of the dynamic carbon balance models at an early stage in the data collation/organization process. See Appendix J for a description of the preliminary model comparison exercise.

4.3.6 Internal Organization

The following TE members have agreed to perform certain tasks:

Name	Task
Mike Ryan	TE Chair
Bob Knox, Hank Margolis	Auxiliary Sites
Bob Knox	TE representative for BORIS
Larry Flanagan	TE rep. for BOREAS standards committee
Betsy Middleton	Obtain standard and other gases
Tom Gower	BOREAS Carbon Budget
Tom Gower, Mike Apps	Coordinate Biometry Measurements
Joe Berry	Develop Proposal for Mixed Site
Mike Ryan, Betsy Middleton	TE Canopy Access
Betsy Middleton, Betty Walter-Shea	Standards for Spectral Measurements on Foliage
Jim Collatz	Standards for Photosynthesis Measurements
Steve Running	Synthesis of Modelling Studies
Betsy Middleton	Gas Standard

4.4 TRACE GAS BIOGEOCHEMISTRY (TGB)

4.4.1. Objectives

The objectives of the TGB group in BOREAS are:

1. To characterize the flux of trace gases between the soil and the atmosphere, primarily for CO_2 and CH_4, and including isotopic composition, N_2O and CO along the major soil, vegetation, moisture and disturbance gradients.

2. To characterize the flux of non-methane hydrocarbons from representative boreal canopies, primarily in jack pine, aspen and spruce stands, in the SSA, with a smaller effort at NSA.

3. To establish a baseline dataset of atmospheric NMHC in the SSA to identify biogenic and industrial sources.

4. To measure long-term accumulation of carbon in boreal soils along the major soil, vegetation, moisture and disturbance gradients.

4.4.2 Investigation Summaries

Ref. Number TGB-1

P.I.(s):	Crill, P.M./Univ of New Hampshire
Title:	Magnitude and Control of Trace Gas Exchange in Boreal Ecosystems

Objectives and Approach:

We propose to examine the role of boreal soils in trace gas exchange with the atmosphere. There are three objectives to this study:

Objective 1: To quantify the exchange rates of CO, N_2O, CO_2 and especially CH_4 with representative, drained upland soil sites in the boreal forest over an entire biological "active" season.

Objective 2: To quantify the relative contributions of upland soils and lowland beaver ponds and their associated wetlands in the regional CH_4 cycle.

Objective 3: To develop techniques that will allow confident scaling of flux measurements from local to landscape to regional scales.

Location: NSA

Sites: OJP, YJP, Beaver Pond, OBS

Duration: May-September

Ref. Number TGB-2: **DELETED**

Ref. Number TGB-3

P.I.(s):	Moore, T.R./McGill Univ, Knowles, R./MacDonald Campus of McGill Univ
Title:	Carbon Dioxide and Methane Exchanges Between Wetland and Upland Soils and the Atmosphere, NSA

Objectives and Approach:

At sites representing the range of wetlands in the NSA, we shall measure methane emissions by a static chamber method. Emission rates will respond to changes in the thermal and hydraulic regimes of the soils, and used to test predictive models based on vegetation, water table or mechanisms. Carbon dioxide and methane fluxes will be measured from upland soils at the major sites, and related to microbial and environmental characteristics, as well as vegetation (e.g. post-fire succession). Samples of peat and upland soils will be incubated under lab conditions to establish the major controls on microbial production or consumption of these gases. Measurements will be made at approximately weekly intervals from late May to September 1994. DOC concentrations in soil water and streams will be measured to provide an estimate of DOC flux within the C cycle.

Location: NSA
Sites: Fen, palsa, jack pine (successional gradient), aspen and other auxiliary sites
Duration: May-September 1994

Ref. Number TGB-4

P.I.(s):	Roulet, N.T./York Univ
Title:	The Fluxes of Energy and Trace Gases from Beaver Ponds and Dry Upland Forest Floor in the NSA
Objectives and Approach:	The primary objective of the proposed research is to quantify the exchange of heat, water, and CH_4 between boreal forest beaver ponds and the atmosphere for the ice free period of BOREAS. The fluxes of heat, water and CO_2 from one beaver pond will be measured continuously using the energy balance Bowen ratio approach. The diffuse and bubble flux CH_4 will be measured several times a week using chambers. The chamber approach will be used to sample CO_2 and CH_4 flux from 4 to 5 additional beaver ponds, once every two weeks, and regional survey of the surface concentrations of CO_2, CH_4, and DOC will be carried out on accessible beaver ponds once during the IFC. The results of this work will be extrapolated from the local to regional scale in collaboration with the remote sensing project of J. Miller (York University - separate proposal). The secondary objective of the proposed research is to study the soil climate and soil characteristics at a forest site in conjunction with the flux studies of P. Crill (UNH). Soil moisture and temperatures will be measured continuously, and soil porosity will be determined; see figure 4.2.3.2e for site layout.

Ref. Number TGB-5

P.I.(s):	Zepp, R.G./U.S. EPA
Co.I.(s):	Burke, R.A./AERL, Levine, J.S. and Cofer, W.R./NASA Langley, Ojima, D.S. and Parton, W.J./Colorado State, Stocks, B.J./Forestry Canada, Bourbonniere, R.A./Environment Canada, Moran, M.A. and Hodson, R.E./University of Georgia
Title:	Trace Gas Exchange in the Boreal Forest Biome: Effects of Fire and Beaver Activity
Objectives and Approach:	This proposal describes a three year interdisciplinary effort to examine the effects of fire and beaver activity on trace gas fluxes and biogeochemical processes in burned soils and oxic zones of beaver ponds in the boreal biome. Specifically, the post-burning effects of fires on soil fluxes of trace gases (CH_4, CO, CO_2, N_2O and NO) will be determined in upland black spruce and jack pine ecosystems located in and near the BOREAS Northern Study Area (NSA). A mathematical model (CENTURY), which has been developed to simulate trace gas biogeochemistry in forest soils, will be modified to include the effects of fires. Model predictions of soil fluxes will be evaluated through a chronosequence of fires in these ecosystems. Other studies will focus on trace gas biogeochemical processes that affect organic matter cycling in the oxic zones of beaver ponds in the NSA. In conjunction with TGB-4 we will obtain a data set of CO flux measurements in selected beaver ponds and other wetlands with ancillary data relevant to process models that describe carbon cycling in these ecosystems (e.g., microbial and organic matter characterization, solar spectral irradiance). Field and laboratory studies will be conducted to develop an understanding of microbial and photochemical processes that produce and consume CO and CO_2 in beaver ponds and other wetlands of the boreal biome.

Location: NSA
Sites: mostly auxiliary recent burn sites (< 15 yrs) (total of 5; 4 upland black spruce, 1 jack pine); work on 2 beaver pond sites in NSA
Duration: May to September

Ref. Number TGB-6

P.I.(s): Wahlen, M./Scripps Institution of Oceanography

Title: Isotopic Composition of Methane Produced and Consumed in Boreal Ecosystems

Objectives and Approach: We propose to determine the isotopic composition ($d^{13}CH_4$, dD in CH_4 and $^{14}CH_4$) in methane emitted to the atmosphere from the boreal forest ecosystems, so that this source, together with the net flux, can be considered in a global isotopic methane budget. We also intend to study the relative importance of methane production versus methane consumption by oxidation in these ecosystems, using the stable isotopes ($d^{13}CH_4$ and dD in CH_4) as tracers. The isotopic fractionation induced by methane oxidation will be determined. If bacterial methane oxidation is a substantial sink globally (compared to the atmospheric sink) the isotopic consequences of this sink should be determined. Investigations of the dD for methane will allow us to determine the split in methane production from acetate fermentation and CO_2 reduction in these ecosystems. Furthermore, we propose to analyze the ^{14}C in the methane emitted from these sites, to investigate the age of the stored carbon, and, to find out if releases of methane highly depleted in ^{14}C could reconcile the discrepancy between statistical estimates for fossil methane releases and those derived from measurements of $^{14}CH_4$.

Location: NSA and SSA
Sites: SSA wet/dry - possibly fen - black spruce - aspen; NSA wet/dry - possibly beaver pond - old black spruce - jack pine.

Ref. Number TGB-7

P.I.(s): Waite, D.T./Environment Canada

Title: Atmospheric Transport of Agricultural Pesticides into the Boreal Ecosystem

Objectives and Approach: We propose to measure the deposition in the boreal forest of seven herbicides (2, 4-D, bromoxynil, dicamba, MCPA, triallate, trifluralin and diclop-methyl) known to appear in the atmosphere of the Canadian prairies, three herbicides (atrazine, alaclor and metlaclor) commonly used in the central United States and known to be deposited in precipitation in the forest and three groups of insecticides (toxaphene, lindane and breakdown products and DDT and breakdown products) reported from the literature and from unpublished data to occur in boreal and arctic food chains.

Sampling locations will be; 1 - Regina atmospheric study site (source of herbicides originating in prairie Canada); 2 - BOREAS site in Saskatchewan (southern boreal forest); 3 - Yellowknife NWT Env. Can. site (northern boreal forest); 4 - Inuvik AES meteorological station (northernmost boreal forest site); and, 5 - Iqaluit (a remote site on the eastern arctic).

Sediment core samples will be collected from Great Slave Lake (Yellowknife) in the winter of 1992 and from either Montreal L. or Waskesiu L. (BOREAS) in the winter of 1993. The cores will be sectioned and analyzed for the same pesticides as the atmospheric samples. The result will be a measurement of yearly deposition rate of pesticides.

Ref. Number TGB-8

P.I.(s): Monson, R./Univ of Colorado

Title: The Relationship Between Non-Methane Hydrocarbon Emission and Leaf Carbon Balance in the Boreal Forest: An Approach for Mechanistic Ecosystem Modeling

Objectives and Approach: We propose to investigate the mechanistic controls over non-methane hydrocarbon (NMHC) fluxes from boreal forest trees. The studies will be used to modify existing ecosystem models to include NMHC emissions and their response to seasonality and resource variability (primarily water and nitrogen). The proposed research is ordered around three general questions: (1) To what extent are leaf carbon balance and isoprene synthase activity (the enzyme responsible for isoprene emission) predictors of NMHC flux?, (2) How do leaf carbon balance and isoprene synthase activity depend on nitrogen/water availability and carbon source/sink parameters?, and (3) How do we modify the FOREST-BGC ecosystem model based on questions 1 and 2, to predict canopy-level NMHC fluxes? Studies will include seasonal monitoring of NMHC emissions and its relationship to plant phenology, photosynthesis, respiration, isoprene synthase activity, and leaf starch concentrations. Fertilization and irrigation of some plots will be conducted to discern the relationship of NMHC emission and leaf carbon balance to resource availability.

Location: SSA
Sites: OBS and OA
Duration of measurements: IFCs 1994

Ref. Number TGB-9

P.I.(s): Niki,H./York University

Title: Ambient Measurements of Ozone, Nitrogen Oxides and Non-Methane Hydrocarbons

Objectives and Approach: An intensive ground based measurement campaign of ambient concentrations of biogenic and anthropogenic C_2-C_{10} non-methane hydrocarbons at one of the Intensive Study Sites over the course of the 1994 experiment year, with full participation in the Intensive Field Campaigns (IFC) and possibly in the Focused Field Campaign during the spring thaw. A weekly to twice weekly hydrocarbon sampling schedule is envisioned through the years 1993, 1994 and 1995 to provide season distribution data on these hydrocarbons.

Location: SSA (some NSA)
Sites: young and old aspen, black spruce, pine.
Duration: August 1993, mostly IFCs 1994.

Ref. Number TGB-10

P.I.:	Westberg, H./Washington State University
Co.I.:	Hewitt, Nick/Lancaster University
Title:	Measurement of Biogenic Hydrocarbon Fluxes and Surface Exchange Processes in a Boreal Forest
Objectives and Approach:	We will measure 1) biogenic hydrocarbon emission fluxes, 2) oxidant deposition rates (ozone & hydrogen peroxide), 3) boundary layer exchange rates (via concentration gradient measurements and tracer studies), and 4) diurnal ambient concentration patterns of VOC's and oxidants. These data will be used to determine the role of biogenic hydrocarbon emissions with respect to carbon cycles in the boreal forest and to examine the atmospheric chemical fate of boreal biogenic emissions. Measurements of oxidant deposition rates will be used to investigate feedback mechanisms between atmospheric chemical cycles and forest dynamics.

We will measure Hydrogen peroxide and organic peroxides in ambient air at the southern Prince Albert field site during the July 19-August 8, 1994 second field intensive. Our objective is to examine the hypothesis that VOC emissions from the biosphere contribute to peroxide formation in the atmosphere. We will collaborate closely with Dr. Hal Westburg, Washington State University, in this.

Location: SSA (some NSA)
Sites: young and old aspen, black spruce, pine.
Duration: August 1993, mostly IFCs 1994.

Ref. Number TGB-12 Trumbore

P.I.(s):	Trumbore, S.E./Univ of California, Irvine
CO-I(s):	Davidson, E.A./Woods Hole Research Center, Harden, J., Sundquist, E./USGS
Title:	Input, Accumulation, and Turnover of Carbon in Boreal Forest Soils: Integrating ^{14}C Isotopic Analyses with Ecosystem Dynamics
Objectives and Approach:	We will combine measures of carbon inventories of soils, ^{14}C content of soil atmospheres, and rates of soil respiration to estimate the rates of carbon accumulation and turnover in soils of each of the major vegetation types of the boreal forests at the Southern and Northern Study Areas. ^{14}C measurements of physically and chemically fractionated soils will be used to partition soil organic matter into pools that turn over on annual, decadal-centennial, and millennial time scales. The understanding of soil carbon dynamics gained from these estimates will be tested against evidence from chronosequence studies which document the accumulation of carbon in physically and chemically defined pools on decadal (time since fire) and millennial (time since soil formation) scales, and estimates of rates of soil respiration and ^{14}C content of respired CO_2. We will explore several of the factors controlling soil carbon accumulation and dynamics, including quality of the detrital sustrata, and availability of CO_2 as expressed by soil moisture, gas exchange rate, or drainage class.

4.4.3. Field Measurements

4.4.3.1 In-Situ Measurements

A brief summary of the type, frequency, and duration of variables and parameters being measured by each PI of the TGB group is provided in Tables 4.4.3.1a and 4.4.3.1b. A more comprehensive list of the location of the measurements and the central focus of each PI's study is provided below and summarized in Table 4.3.4.3.1c for the NSA and Table 4.4.3.1d for the SSA. Coordination with other groups is indicated by the inclusion of some of the TEs and TFs measurement programs as they relate to TGB.

There has to be a collaboration developed between TF groups (e.g. den Hartog, Verma) and TGB and TE groups measuring trace gases in the SSA. Several of the TGB groups in Nelson House will locate their research efforts to tie into the TF-3 (Wofsy) and TF-8 (Fitzjarrald) flux towers.

In addition to the four tower sites in the North, 3 additional sites for process-based studies have been added. These include a beaver pond study site (BP) which includes an age gradient of abandoned and presently active ponds along a single stream, (TGB-4), a site located along the Gillam Road for the study of young jack pine on clay soils (YJP-aux) (TGB-3, TGB-12, and a black spruce site located just east of the boundary of the Northern Study Area (TGB-3, TGB-12). A series of burned sites along the Gillam Road from Thompson Lane have been selected by TGB-5 for their studies of the effects of fire disturbance. The exact locations of these sites have been communicated to the auxiliary site team for investigation as potential auxiliary sites, see maps in Section 2.

Plans for most TGB investigators involve installation of soil flux chamber collars and soil gas sampling probes to be used through the winter into the field campaigns of 1994 and 1995. Specific plans for numbers of people participating in the field campaigns were collected and coordinated during the Winnipeg meeting and are listed below. Work at all TF sites will be coordinated with tower flux captains on an individual investigator basis.

Table 4.4.3.1a
Summary of TGB Investigations

Group	PI	Loc.	Species	Techniques	Ecological Units	Timing
TGB-1	Crill	NSA	CH_4,CO_2,CO, N_2O, Rn, SF8	Chambers, gradients	Upland and wetland soils*, beaver ponds	May-Sept.
TGB-3	Moore	NSA	CO_2,CH_4, DOC	Chambers	Upland and wetland soils*	May-Sept.
TGB-4	Roulet	NSA	CO_2,CH_4, DOC	Chamber, tower	Upland and wetland soils, Beaver ponds*	May-Sept.
TGB-5	Zepp	NSA	CO_2,CO,CH_4, N_2O,NO, DOC	Chambers Models	Fire disturbance sites, beaver ponds	IFC's
TGB-6	Wahlen	NSA SSA	CH_4,CO_2 isotopes	Flask sampling	Various*	year-round
TGB-7	Waite		pesticides		Regional	
TGB-8	Monson	SSA	NMHC's	Cuvettes	Aspen/spruce	FFC-T, IFC's
TGB-9	Niki	SSA	NMHC's	Flask sampling	Regional*	Year-round
TGB-10	Westburg	SSA	NHMC's, peroxides	Gradients	Aspen/spruce pine	IFC's
TGB-12	Trumbore	NSA SSA	CH_4, CO_2, RN, ^{14}C in CO_2, and soil o.m.	Chambers, Flask Sampling	Upland soils*	year-round
Closely associated ground-based trace gas biogeochemistry activities by other groups						
TE-1	Anderson	SSA	CH_4, CO_2	Chambers	Upland Soils	IFC's
TF-1 14-18 Oct.	Black	SSA	CH_4, CO_2	Towers, chambers	Upland Soils	IFC's
TF-4	Striegl	SSA	CH_4, CO_2 and isotopes	Towers, chambers, gradients	Upland Soils	May-September
TF-11	Verma	SSA	CO_2, CH_4	Towers, chambers	Wetland Soils	May-September

*Requires the use of auxiliary sites, in addition to tower sites

Table 4.4.3.1b
TGB Activity Schedule

Northern Sites					
Group	**FFC-W**	**FFC-T**	**IFC 1**	**IFC 2**	**IFC3**
TGB-1	no	continuous presence of 2 (+1 during IFC's) 5/1 to 9/15			
TGB-3	no	continuous presence of 4; 5/1 to 9/15			
TGB-4	no	continuous presence of 4 (+1 during IFC's)5/1 to 9/15			
TGB-5 fire	no	no	8	8	3 or 4
b.p.	no	2	2	4	2
TGB-6	no	no	1	no	1
TGB-12	2(1 week) will visit sites throughout winter 93/4	2	2+1	2+1	2+1
Southern Sites					
Group	**FFC-W**	**FFC-T**	**IFC 1**	**IFC 2**	**IFC3**
TGB-6	no	no	1	no	1
TGB-8	no	3	3	3	3
TGB-10	no	no	2	2	2
TGB-12	no	no	day trips coordinated with TGB-6		
TE-1	no	no	2	2	2
TF-1	no	continuous presence of 2; 4/15-9/15/94			
TF-11	no	no	continuous presence of 2; 4/15-9/15/94		

Table 4.4.3.1c
NSA Measurement Program

	YJP	OJP	OBS	Fen	BP	JP-Aux	T3	Fires
Gas Flux								
CH_4	TGB-3/1	TGB-1	TGB-1	TGB-3	TGB-4	TGB-3	TGB-3	TGB-5
$C0_2$	TGB-3/1	TGB-1	TGB-1	--	TGB-4	TGB-3	TGB-3	TGB-5
C0	TGB-1	TGB-1	TGB-1	--	TGB-5/1	--	--	TGB-5
N_20	TGB-1	TGB-1	TGB-1	--	TGB-4	--	--	TGB5(plus NO)
NEE	--	--	TGB-12	TGB-4	--	TGB-12	TGB-12	--
Tracers								
SF_6	--	TGB-1	TGB-1	--	--	TGB-1	--	TGB-5
Rn	--	TGB-12	TGB-12	--	TGB-12	TGB-12	--	--
Soil Profiles								
CH_4	TGB-1	TGB-1	TGB-1	TGB-3	TGB-4	TGB-1	--	TGB-5
$C0_2$	TGB-1	TGB-1	TGB-1	TGB-3	TGB-4	TGB-1	--	TGB-5
Isotopes Flux								
$\delta^{13}CH_4$	TGB-6	TGB-6	TGB-6	TGB-6	TGB-6	TGB-6	--	TGB-6
D/H	--	--	TGB-6	TGB-6	TGB-6	--	--	--
$\delta^{13}C0_2$	TGB-6	TGB-6	TGB-6	TGB-6	TGB-6	TGB-6	--	TGB-6
Isotopes Soil Gas								
$\delta^{13}C0_2$	TGB-12 TGB-6	TGB-12 TGB-6	TGB-12 TGB-6	TGB-12 TGB-6	TGB-12 TGB-6	TGB-12	TGB-12	TGB-12
$^{14}C0_2$	TGB-12	TGB-12	TGB-12	TGB-12	TGB-12	TGB-12	TGB-12	--
$\delta^{13}CH_4$	TGB-6	TGB-6	TGB-6	TGB-6	TGB-6	--	--	TGB-6
$14CH_4$	--	--	--	TGB-6	TGB-6	--	--	--
Substrate								
^{13}C(dom)	TGB-12	TGB-12	TGB-12	TGB-12	TGB-12	TGB-12	TGB-12	TGB-12
^{14}C(dom)	TGB-12	TGB-12	TGB-12	TGB-12	TGB-12	TGB-12	TGB-12	TGB-12
mass(dom)	TGB-12	TGB-12	TGB-12	TGB-12	TGB-12	TGB-12	TGB-12	TGB-12
$D-H_20$	TGB-6	TGB-6	TGB-6	TGB-6	TGB-6	--	--	--
DOC fract'n	TGB-5	--	--	TGB-3	TGB-5	--	--	--
[DOC]	TGB-3	--	--	TGB-3	TGB-3/5	--	--	--
Tower Trace Gas								
$C0_2$	--	TF-8	TF-3	--	TGB-4	--	--	--
CH_4	--	TGB-1	--	--	TGB-1	--	--	--

Table 4.4.3.1d
SSA Measurement Program

	YJP	OJP	OBS	OA	Fen
Gas Flux					
CH_4	TF-4	TF-4	TE-1	TF-1	TF-11/TE-1
$C0_2$	TF-4	TF-4	TE-1/TE-7	TF-1	TF-11/TE-1
C0	--	--	--	--	--
N_20	--	--	--	TF-1	TF-11
NEE	--	--	--	--	--
Tracers					
SF_6	--	--	--	--	--
Rn	--	--	--	--	--
Soil Profiles					
CH_4	TF-4	TF-4	TE-1	TE-1	TF-11
$C0_2$	TF-4	TF-4	TE-1	TE-1	TF-11
Isotopes Flux					
$\delta^{13}CH_4$	TGB-6	TGB-6	--	--	TGB-6
D/H	--	--	--	--	TGB-6
$\delta^{13}C0_2$	TGB-6	TGB-6	--	--	TGB-6
Isotopes Soil Gas					
$\delta^{13}C0_2$	TGB-12/TGB6	TGB-12/TGB6	TGB-12	TGB-12	--
$^{14}C0_2$	TGB-12	TGB-12	TGB-12	TGB-12	--
$\delta^{13}CH_4$	TGB-6	--	--	--	--
$14CH_4$	--	--	--	--	--
Substrate					
^{13}C(dom)	TGB-12	TGB-12	TGB-12	TGB-12	TGB-12
^{14}C(dom)	TGB-12	TGB-12	TGB-12	TGB-12	TGB-12
mass(dom)	TGB-12	TGB-12	TGB-12	TGB-12	TGB-12
$D-H_20$	--	--	--	--	TGB-6
DOC fract'n	--	--	--	--	--
[DOC]	--	TGB-5 can support samples from SSA at Thompson lab			
Tower Trace Gas					
$C0_2$	TF-4	TF-5	TF-7/9	TF-1/2	TF-11
CH_4	--	--	TF-7	TF-1/2	TF-11
NMHC	--	TGB-9/10	TGB-9/10	TGB-9/10	--
O_3/H_2O_2	--	TGB-10	--	--	--

TGB-1 (Crill)
Location of Measurements: NSA

Site of measurements: old black spruce (OBS:TF-3), jack pine (OJP:TF-8)

Duration of Measurements: May-September, 1994

Measurements:

Half-hourly	- gradients of CH_4 (OJP, Beaver Pond)
	- soil moisture and soil temperature (5 depths) (OJP) (possibly with TGB-4)
once/4 d	- CH_4, CO_2, (dark and NEE), CO, N_2O flux for 20 runs with enclosures at 6 to 8 collar locations/site (OBS, JP)
once/10 d	- soil profiles of CH_4, CO_2, CO, N_2O (5 depths) at 3 locations/site
occass.	- SF6 diffusion experiments with flux measurements
once	- soil porosity (with TGB-4)
	- soil moisture characteristic curves (with TGB 4)

Measurements expected from other groups:
- ^{222}Rn profiles - TGB-12 (Trumbore)
- physical and chemical characterization of soils at sites
- $^{13}CH_4$ from soil flux
- trajectory analysis for sites

TGB-3 (Moore)
Location of Measurements: NSA

Locations of Sites: Fen, palsa, jack pine, aspen (successional gradient) and other auxiliary sites

Duration of Measurements: May-September, 1994

Measurements:

weekly	- CH_4 flux using enclosures at wet sites
	- water table, temperature profile
	- soil CO_2 and CH_4, exchange using enclosures at dry sites
	- soil pore CO_2 and CH_4 profiles
occass.	- samples of peat and soils from wet sites for CH_4 production and consumption studies
	- soil samples from dry sites for microbial studies

Measurements expected from other groups:
-soil characterization at sites
- soil moisture and soil temperature at sites

TGB-4 (Roulet)

Location of Measurements: NSA

Site of Measurements: Auxiliary beaver pond site, several other beaver ponds, see figure 4.2.3.2e for primary site layout.

Duration of Measurements: May-September 1994

Measurements:

Half-hourly - Net radiation, incoming and reflected solar radiation, incoming and emitted longwave, incoming and reflected PAR
- gradients (0.25, 0.5, 1.0, 2.0m) of temperature, humidity, CO_2, CH_4 (TGB-1), wind speed, open water and sediment temperature
- wind direction
- water level, atmospheric pressure, pond discharge (possibly)

Daily - surface [CO_2], [CH_4] - several dial measurements

Twice/wk - CH_4 and CO_2 diffuse flux for 20 to 120 minute runs with enclosures (with TGB-)
- CH_4 bubble flux from sediments (possibly bubbling rate with some from of sonar?)
- [DOC]

once/2wk - profile of CO_2 and CH_4 in open water and sediments on up to four additional ponds

once/3wk - CH_4 and CO_2 diffuse flux for 20 to 120 minute runs with enclosures
- profile of CO_2 and CH_4 in open water sediments
- instantaneous measurements of surface [CO_2], [CH_4], water temperature and wind speed (1m), water level, [DOC]

one IFC on as many ponds as are accessible
- instantaneous measurements of surface [CO_2], [CH_4], water temperature and wind speed (1m), water level, [DOC]

Measurements expected from other groups

- UV at NSA - Science Staff
- [DOC] and some fraction work - TGB-5 (Zepp et al.)
- $\delta^{13}CH_4$, $\delta^{13}CO_2$, δD, $^{14}CH_4$, $^{14}CO_2$ - TGB 6 (Whalen)
- ^{222}Rn flux across sediment/water and water/atmosphere interface - TE 3 (Trumbore)
- basic water chemistry on beaver ponds - TGB-5 (Zepp et al.)

TGB-5 (Zepp)

Location of Measurements: NSA and SSA

Location of Sites: mostly auxiliary burn sites of various age (5 in total), work on beaver pond site in NSA.

Duration of Measurements: May - September 1994

Measurements:

half hourly	- temperature, soil temperature, soil moisture
twice/wk	- CO_2, CH_4, CO, N_2O, NO fluxes using enclosures at burn sites (6 collars/site)
	- CO concentration profile in beaver ponds
weekly	- SF_6, ^{222}Rn exchange at flux sites
	- CO_2, CH_4, CO, N_2O, and NO profiles in soil
occass.	- water chemistry at beaver pond
	- DOM characterization on beaver ponds
	- process studies on anoxic zone in beaver ponds

Measurements expected from other groups

- UV at NSA
- physical and chemical characterization of soils at auxiliary field sites
- input variables for CENTURY model

TGB-6 (Wahlen)

Location of Measurements: NSA and SSA

Location of Sites: SSA-Fen, SSA-OBS, SSA-OA, Wet/dry sites
NSA-BP, NSA-OBS, NSA-OJP, Wet/dry sites

Duration of Measurements: IFCs 1994

Measurements:

occass.	- 100 to 150 samples distributed in time and among sites from diffuse and some bubble fluxes for analysis of $\delta^{13}CH_4$, δD, in CH_4, $^{14}CH_4$, $^{13}CO_2$, $C^{18}O_2$ and concentration of CH_4, CO_2, CO, H_2 and N_2O in samples taken, also on some samples from ambient air.

Measurements expected from other groups:

- gas fluxes TGB-3 (Moore), TGB-4 (Roulet), TE-3 (Trumbore), TE-5 (Ehleringer)

TGB-8 (Monson)

Location of Measurements: SSA

Location of Sites: OBS and OA

Duration of measurements: IFCs 1994

Measurements: (all done on upper canopy - sunlit leaves or needles)

daily
- am/pm photosynthesis rate for aspen and black spruce leaves
- am/pm/evening starch and nitrogen content in spruce and aspen tissue
- leave water potentials (pre-dawn and midday) each day during IFC

occass.
- tissue concentration and flux rate of monoterpenes for black spruce
- isoprene emission rate for black spruce and aspen

Measurements expected from other groups

- none

TGB-9 (Niki); TGB-10 (Westburg)

Location of Measurements: SSA (some NSA)

Location of Sites: OA, YA< OBS, OJP, YJP

Duration of Measurements: August 1993, mostly IFCs 1994

Measurements:

continuous
- hydrocarbon flux at black spruce, aspen, for half of each IFC, 3 1/2 hr/periods/day
- gradients on each flux tower including NH, 3/day during IFCs

daily
- hydrocarbons C_2 - C_{10}, 6/day, old aspen, IFCs (Westburg, Zimmerman)
- hydrocarbons grab sample, IFCs, two daily
- hydrocarbon profiles in lower BL, two daily during IFC
- aldehydes and organic acids, 2 to 6/day

twice/wk
- hydrocarbons grab sample, year round, old aspen (Niki)

occass.
- hydrocarbon flux, species survey during IFC, pine, spruce, aspen

- aircraft hydrocarbon flux on Twin Otter, 9/flight during IFC for a total of 20 to 30 on specified flights
- aircraft hydrocarbon flux on Electra, 8/flight during IFC for a total of 20 to 30 on specific flights
- CH_4 fluxes at tower sites where needed

Measurements expected from other groups:

- COS, CO, NO_x, CCN concentration in troposphere

TGB-12 (Trumbore)

Location of Measurements: NSA and SSA

Location of Sites: those of TGB-1, TGB-3, TGB-4, TE-1 and other auxiliary sites from wide ecological range.

Duration: to be established with TGB-1, TGB-3, TGB-4

Measurements:

- ^{14}C, ^{13}C in CO_2 and ^{222}Rn at sites and frequency to be worked out with TGB-1 (Crill), TGB-3 (Moore), and TGB-4 (Roulet)
- ^{14}C in soil organic matter at sites of TE-1 (Anderson) and selected northern sites

Measurements expected from other groups:

- litterfall TGB-3 (Moore)
- fluxes from sites TGB-1 (Crill), TGB-3 (Moore), TGB-4 (Roulet)
- soil organic matter from PA sites TE-1 (Anderson)

4.4.3.2 Data to be submitted to BORIS

Data to be submitted to BORIS will be specified by individual PIs in cooperation with the BORIS managers, but a preliminary list of the more common data to be provided by the TGB group is listed in Table 4.4.3.2.

Table 4.4.3.2

Proposed TGB variable list. Notation is taken from that used by the TF group. Only a subset of this variable list will be obtained from each site depending on PIs study.

OBS_YEAR	
OBS_DAY	
START_TIME	
END_TIME	
SITEGRID	
ECOSYTEM_TYPE	
VEGETATION_TYPE	
SOIL_TYPE	
CH4_FLUX	$mg\,m^{-2}\,d^{-1}$
CO2_FLUX	"
CO_FLUX	"
N2O_FLUX	"
NMHC_FLUX	"
CH4_SOIL Z	ppm v
CO2_SOIL Z	ppm v
CO_SOIL Z	ppb v
N20_SOIL Z	ppb v
CH4_13CISOTOPEFLUX	delta °/oo
CO2_13CISOTOPEFLUX	"
CH4_14CISOTPOEFLUX	pmc
CO2_14CISOTOPEFLUX	pmc
CH4_DISOTOPEFLUX	delta °/oo
CH4_13CSOILISOTOPE Z	delta °/oo
CO2_13CSOILISOTOPE Z	"
CH4_14CSOILISOTOPE Z	pmc
CO2_14CSOILISOTOPE Z	pmc
CH4_DSOILISOTOPE Z	delta °/oo
222RN_SOILISOTOPE Z	?
CH4_AMBIENTAIR Z	ppm v
CO2_AMBIENTAIR Z	ppm v
CO_AMBIENTAIR Z	ppb v
N2O_AMBIENTAIR Z	ppb v
CMHC_AMBIENTAIR Z	ppb v
CFCS_AMBIENTAIR Z	ppb v
OCS_AMBIENTAIR Z	ppb v
SOIL_TEMP Z	°C
SOIL_MOISTUREMASS Z	g/g
SOIL_MOISTUREVOLUME	%
WATER_TABLE	m

4.4.4 Supporting Measurements

4.4.4.1 Needs from Other Groups:

The variety of projects in the TGB groups presents some challenges in the provision of support measurements required by individual PIs to address certain questions. Much of the needed data is being obtained by the PIs themselves, but some of it can be provided by other groups such as TF, TE, and RSS. Some of the data requirements will be very difficult to obtain because of the use of auxiliary sites by some of the TGB PIs. There are two areas that require coordination at the Science Team level. First, at each site where trace gas measurements are made, some ecological characterization is needed. Secondly, almost every trace gas measure requires a good description of the physical and chemical character of the soils, and some measurement of the temporal change in soil moisture and temperature.

Some of the additional TGB data requirements are extraordinary because of site locations, while the same data could be provided by the Science Team as part of the core measurement program in the intensive field areas and at tower sites. The extraordinary data requirements are presented below.

A. Data required from groups other than PIs teams inside the TGB.

TGB-3
- (a) soil characterization at auxiliary flux sites (wetlands and forest soils)
- (b) distribution of wetlands in Nelson House area (from Remote Sensing group - discussions with J. Miller)

TGB-4
- (a) frequency and distribution of beaver ponds in Nelson House area (from Remote Sensing group - discussions with J. Miller)

TGB-5
- (a) soil characterization at auxiliary flux sites (old and new fire sites)
- (b) input variables and parameters for CENTURY model

TGB-9
- (a) CO, NO_{x3}, CCN concentrations in troposphere.

B. Data required from one TGB PI team to another TGB PI Team

TGB-1
- (a) ^{222}Rn profiles in soils at sites (TGB-12)
- (b) ^{13}C in CH_4 in soils (TGB-6)
- (c) concentration and profiles of CO, CH_4 and N_2O in sub-canopy (TF-3, TF-8)
- (d) soil moisture and soil temperature at forest flux sites (TGB-4)

TGB-4 (a) DOC and basic chemistry of beaver pond water (TGB-5)
(b) ^{222}Rn across sediment/water interface in beaver ponds (TGB-12)
(c) ^{13}C, ^{14}C, in CH_4 in beaver pond fluxes (TGB-6)

TGB-6 (a) fluxes of CH_4, CO_2 at various sites (TGB-1, TGB-3, TGB-4, TGB-12, TE-5)

4.4.4.2 Needs from Staff Science

This is a list of variables and parameters needed by TGB PIs that fall into the category of core measurements. They are assumed to be core measurements because (i) they require standardization by the Science Team (e.g. soil moisture, soil temperature, physical and chemical characteristics of the soil) (ii) they are required at the fixed towers sites, or (iii) they are standard BOREAS data (e.g. NDVI vegetation mapping). All TGB teams require at some resolution (preferably LANDSAT-TM) the characterization of the land cover (major ecosystems - e.g. forest and wetland types, shallow and deep lakes, old and new fire scars, etc.) in Prince Albert and Nelson House intensive field area. This data is required to make the extrapolation of measured fluxes to the spatial scale at which the tower and aircraft flux measurements integrate.

TGB-1 (a) Physical and chemical characteristics at NSA TF sites (OBS, OJP especially)
(b) Air trajectory analysis for NSA area

TGB-3 (a) standard soil and vegetation characterization at auxiliary sites (wetlands and forests)
(b) soil moisture and temperature at auxiliary sites

TGB-5 (a) UV measurements at Nelson House

4.4.4.3 Minimal Ancillary Field Measurements to Accompany Flux Measurements

The following was suggested at the Coolfont meeting as a minimal data set to accompany each and every flux measurement into BORIS. It would be very helpful for the TGB to know the requirements of the various modelling groups in order to finalize this list.

- Location, where on the grid.
- Temperature, moisture (what depths? 5-10 cm?).
- Minimal soil characteristics, e.g. depth to mineral layer in uplands or water table depth in wetlands.
- Minimal ground cover description e.g. lichen covered? feather moss?

R. Zepp (TGB-5) points out that the Century model data requirements include:

Climate information: monthly precipitation; monthly averaged maximum daily temperatures; monthly averaged minimum daily temperatures; nitrogen deposition estimates (wet and dry), windspeed, barometric pressure, solar radiation. N fluxes are likely to be highly episodic and linked to short-term variations in precipitation, however.

Soil properties: soil texture (percent sand, silt, and clay content); soil organic matter content by depth (C, N, and P); soil moisture; pH, cation exchange capacity, base saturation; bulk density of soils; landscape variation in soil properties or regional distribution of soils, nitrogen species.

Plant characteristics: biomass estimates by month of growing season above and below-ground production estimates chemical analysis of plant components (C, N, percent lignin).

Lists of the input requirements of other common models (e.g. DNDC) would be very helpful to coordinate sampling design.

4.4.5 Internal Organization

There are a number of areas of common interest among the TGB and other groups such as TE and TF. The following TGB science team members will act as liaisons with the various committees discussing these common issues.

Chair:	P. Crill
Rapporteur:	T. Moore
Field Organization (PA)	D. Anderson P. Crill
Soil and Ecological Characterization	T. Moore
Soil moisture and temperature	N. Roulet
Auxiliary sites	R. Zepp
BORIS Advisory:	R. Monson

4.5 HYDROLOGY (HYD)

4.5.1 Objectives

The objectives of the hydrologic investigations are to characterize the storage of moisture at and near the land surface, in both solid and liquid states, and the fluxes of moisture to and from the land surface. The combined investigations are to measure and/or allow the prediction of moisture storage at scales from tens of meters to the transect distance between the southern and northern sites, and to provide the information necessary to facilitate the transfer of information between these scales. Additionally, the hydrologic investigations will measure and simulate the interactions between subsurface, surface, and canopy hydrologic and ecological processes over a similar range of scales.

4.5.2 Project Summaries

Ref. Number HYD-1

P.I.(s):	Cuenca, R.H./Oregon State Univ
Co-I's:	
Title:	Coupled Atmosphere-Forest Canopy-Soil Profile Monitoring and simulation
Objectives and Approach:	The objective of this project is to design a coordinated program of data collection for soil properties and soil monitoring over the BOREAS sites in collaboration with ecosystem, hydrologic and staff scientists. Properties to be specified include bulk density, particle size distribution, soil water retention and hydraulic conductivity functions. The resulting data set will be used for initialization, parameterization, and verification of simulation models in the fields of remote sensing, atmospheric modeling, ecological systems modeling, hydrology and simulation of soil physical processes. In order to meet the needs of the various research teams, the measurement program will be divided into the areas of a) Core Measurement Program, b) IFC Soil Moisture Content, Water Table and Soil Property Monitoring, c) Continuous Soil Moisture Content and Temperature Monitoring, d) ``Surface Moisture Measurement, e) Soil Survey and Characterization and f) Soils Data for Auxiliary Sites. The second objective of this project will be simulation of soil physical processes. A finite element model for simulation of soil physical processes will be parameterized using the data described above, and tested and verified using soil monitoring data collected at the BOREAS tower sites. The calibrated simulation models for infiltration, soil moisture redistribution, evapotranspiration, and drainage will then be available for prediction of the soil moisture state at locations of interest to researchers working at sites where only Core Measurement Program data are collected, as well as regionally over the BOREAS experimental domain for the predominant soil types.

Ref. Number HYD-2

P.I.(s):	Chang, A.T.C./NASA/GSFC
Co-I's:	
Title:	Validation of a passive Microwave Snow Water Equivalent Algorithm Using an Energy Balance Model
Objectives and Approach:	The surface meteorological data to be collected at the tower and ancillary sites and will be used as inputs to an energy balance model to monitor the amount of snow storage in the Boreal forest region. SWE derived from an energy balance model and insitu observed SWE will be used to compare the SWE inferred from airborne and spaceborne microwave data, and to assess the accuracy of microwave retrieval algorithms. The major external measurements that will be needed are snowpack temperature profiles, and in situ snow areal exent and snow water equivalent data.

Ref. Number HYD-3

P.I.(s):	Davis, R.E./U.S. Army Cold Regions Research & Engineering Lab
Co-I's:	
Title:	Distributed Energy Transfer Modeling in Snow and Soil for Boreal Ecosystems
Objectives and Approach:	The goal of this project is to model the spatial and temporal distributions of critical snow pack properties and processes at scales up to about 1 square kilometer, several patches within the two intensive study sites, and to develop tools linking model predictions to remote sensing. The three principle objectives of the project are: 1) to classify the Boreal forest biome based on the spatial distribution of tree stands, vegetation and soils, to establish land cover units which have similar attributes in the context of the upper and lower boundary conditions required by an energy and mass transfer model; 2) to investigate methods for incorporating the effects of different tree canopy and stem characteristics into stand scale estimates of snow properties and surface energy exchange; and 3) to identify the capabilities and limitations of remote sensing measurements to monitor the state of the snowpack. The study will focus on the winter and thaw periods, and on the relatively small spatial scale (e.g. treestands and small watersheds).

Ref. Number HYD-4

P.I.(s):	Goodison, B.E.,/Walker, A.E., Climate and Atmospheric Research Directorate, Atmospheric Environment Service
Title:	Determination of snow cover variations in the Boreal forest using passive microwave radiometry.
Objectives and Approach:	This study will investigate snow cover variations within and between the BOREAS study areas using passive microwave radiometry. It will involve algorithm development and validation to derive snow water equivalent and extent from passive microwave radiometer data, incorporating variations in surface land cover. Co-incident airborne microwave radiometer (Twin Otter) and airborne gamma SWE observations are critical to algorithm development. Ground, airborne, and satellite data will facilitate scaling up to the satellite resolution. The effects of forest cover (density, type) on snow cover retrievals will be assessed and incorporated in the determination of snow cover variability. The use of passive microwave data in combination with optical and thermal IR data to improve snow cover retrievals will be explored in conjunction with RSS-19 Airborne radiometer flights during dry

snow conditions are mandatory; flights during a wet snow condition are desirable as well. The flights are mandatory during the winter FFC. The airborne radiometer and airborne gamma will not be flown during the FFC-T.

Ref. Number HYD-5

P.I.(s):	Harding, R.J./Institute of Hydrology
CO-I's:	
Title:	The Regional Representation of the Energy and Moisture Fluxes from Snow Covered Areas in the BOREAS Experiment
Objectives and Approach:	This project will seek to characterize the energy and water vapor fluxes, as well as related properties (density, depth, temperature, melt) for forested and non-forested areas. Equipment will be set up in the winter FFC and run through to the Thaw FFC. Two sites will be operated in or near the Prince Albert Park area. One is above a mixed jack pine and aspen forest stand near Bear Trap Creek (this site is being run in conjunction with the NHRI GEWEX experiment). The second site is near the centre of Namekus Lake (750 m from the western edge). It may be necessary to move the lake site to a clear cut area to the NE of Waskisiu in the Thaw FFC. Eddy correlation and full set of meteorological measurements will be made. An extensive program of meteorological and SVAT modeling is planned to investigate the problems of aggregation of surface fluxes in a snow covered landscape. One and two dimensional boundary layer models will be used to investigate scales from 100m to 10km. A three dimensional mesoscale model will be used to aggregate from 10 km to 1000 km. This latter model will require extensive meteorological and ground cover data from the BOREAS study region. Improved snow parameterisations for GCM's will be one of the important products of this research. Site layout is shown in figure 4.2.3.2k.

Ref. Number HYD-6

P.I.(s):	Peck, E.L./Hydex Corp/Carroll, Thomas/NWS NOAA
Title:	Remote Sensing of Hydrologic Variables in Boreal Areas
Objectives and Approach:	This project utilizes airborne gamma sensing to measure soil moisture (SM) in areas underlain by permafrost (northern study area) and in forested boreal areas and will cooperate with HYD-4 in the measurement of snow water equivalent (SWE). Estimates of the water content in the Moss/Humus layers, where those layers are significant, are also obtained. The airborne estimates of SWE and SM will be used with estimates from other investigators to prepare information about the distribution of SWE and SM for the BOREAS sites and to investigate the relationships of the site measurements to those observed on a regional scale. Inter-comparison studies of estimates of SWE and SM by the airborne gamma and other remote sensing techniques will be conducted. Flight lines, representing the different vegetative covers for the areas, have been established in the northern study area (NSA), in the southern study area (NSA), and along transects between the tow areas. The flight lines are primarily along roads due to accessibility constraints for the collection of ground truth data for calibration purposes. Background flights and in situ soil moisture measurements were obtained for calibration of some of the flight lines during September 1993. Airborne snow measurements will be flown using the airborne gamma system for snow course and soil moisture measurementes during February 1994 (HYD-4). Airborne soil moisture measurements and measurements of

the water content of the Moss/Humus layer will be collected during IFC-2 and IFC-3.

Ref. Number HYD-7: **DELETED**

Ref. Number HYD-8

P.I.(s):	Band, L.E./Univ of Toronto
CO-I(s)	L.E. Band, T. Price, T. Carleton, University of Toronto, J.C. Coughlan, NASA Ames Research Center,
Title:	Simulation of Boreal Ecosystem Carbon and Water Budgets: Scaling from Local to Regional Extents
Objectives and Approach:	This project is primarily a modeling effort, which will seek to describe the scaling behavior of water and carbon flux processes from local and regional extents. A suite of simulation models will be used to describe photosynthesis, respiration, evapotranspiration, and surface and subsurface flow over a range of scales. The underlying hypothesis to be investigated is that the spatial patterns of surface-atmospheric fluxes are strongly influenced by the spatial distribution of soil moisture and inundation areas in the study sites, which, in conjunction with disturbance regime, are thought to provide the key to scaling from stand to regional simulations. The smallest scales to be modeled will be essentially hillslopes or subcatchments for which the spatial resolution will be 10-30m; these subcatchments or hillslopes will probably be located in or around the catchments monitored by HYD-9, in the vicinity of the tower sites to facilitate use of the surface flux data to be collected there. The larger scale will be on the order of the size of the NSA and SSA site, with data resolution extending down to that of AVHRR. The primary external data requirements are for high resolution DEM data, particularly for the hillslope sites, and vegetation and soils data at resolutions comparable to that of the DEM. Limited monitoring of canopy interception (throughfall and stemflow), and of moss water retention will be carried out in the southern study site in association with HYD-9.

Ref. Number HYD-9

P.I.(s):	Soulis, E.D./University of Waterloo
CO-I(s):	Jasinski, J./NASA Hydrological Sciences Branch,;Kite, G./National Hydrology Research Institute; Kouwen, N./University of Waterloo; Leconte, R./University of Quebec a` Monteal; Lettenmaier, D./Univ of Washington; Marks, D./U.S. Geological Survey
Title:	From Micro-Scale to Meso-Scale Snowmelt, Soil Moisture and Evapotranspiration from Distributed Hydrologic Models
Objectives and Approach:	This project will seek to identify, through field measurements and computer modeling, the space-time distribution of meltwater supply to the soil during the spring melt period, and the evolution of soil moisture, evaporation, and runoff from the end of the snowmelt period through freeze-up. The snow modeling activity will consist of two components: The first will make use of existing, "off-the-shelf" models to forecast the onset and spatial extent of snowmelt and meltwater supply to the soil column prior to the 1994 IFCs. The second phase will extend, implement,

and verify a physically based energy balance snowmelt model of the two sites, and will evaluate approaches to aggregating snowmelt predictions and measurements based on the model to large scales, up to the size of a rectangle of several hundred km containing the northern and southern sites. The soil moisture modeling, being conducted by Soulis and Engman based on a grouped response unit method, and will allow characterization of soil moisture, evaporation, and runoff for the entire northern and southern sites. The primary external data requirements of the project are for 1) winter period surface meteorological and energy flux data, 2) high quality DEM data, 3) vegetation characterization, at the scale of the DEM, 4) supplemental snow-free period precipitation data at the local (hillslope) scale, perhaps along selected transects.

4.5.3 Field Measurements

4.5.3.1 In-situ Measurements

4.5.3.1.1 Overview

Table 4.5.3.1.1a summarizes which investigators propose to work in or near the primary towers, as well as the auxiliary sites, and, for those projects which propose to conduct field data collection, the IFCs and FFCs during which data will be collected.

Table 4.5.3.1.1b summarizes the IFCs and FFCs during which data are to be collected by project.

Table 4.5.3.1.1a

Site Summary (entry indicates site priority)

		SSA					NSA					
HYD	**PI**	**OA**	**OJP**	**YJP**	**OBS**	**Fen**	**OBS**	**OJP**	**YJP**	**Fen**	**Other**	**Notes**
1	Cuenca	1	1	1				1	1		1@NSA	
2	Chang	1										a
3	Davis	1					1					b,e,f
4	Goodison										2@NSA 1@SSA	c
5	Harding										d	e
6	Peck										S	c
7	Band et al	1	1	1	1		1					
8	Soulis et al.		1	1	1			1	1	1		

Notes:

a long-term snow temperature profiles (to be collected by Davis)
b Preference for AWS sites
c Aircraft remote sensing experiment, in situ data collection along roads
d Frozen lake (Namekus) and nearby forest site (not BOREAS tower or auxiliary)
e Sites must be unforested
f sites in small HYD watersheds

Table 4.5.3.1.1b
HYD Activity Schedule

	1994			1993	
Team Name	**Winter**	**Thaw**	**Summer**	**S**	**W**
HYD-1 Cuenca (a)			X	X	
HYD-2 Chang	X	X			
HYD-3 Davis	X	X			X
HYD-4 Goodison	X				X
HYD-5 Harding	X	X			X
HYD-6 Peck	X[b]		X		X
HYD-8 Band			X	X	
HYD-9 Soulis et al		X	X	X	

a Additional automated monitoring of soil moisture and temperature to be conducted at selected sites, including winter and thaw periods, depending on budget. Concentration on TF sites.

b In cooperation with HYD-4

Table 3.2.3.1 summarizes the responsibility for soil measurements that will be made during the experiment at both sites.

Two large watersheds (the White Gull River for the southern site, and the Sapochi River for the northern site) have been identified, which include most of the northern and southern site. The locations of these watersheds, and smaller subcatchments within them, as well as the relative location of the tower sites, are described in Section 3.2.3.1. Project HYD-9 in conjunction with BOREAS staff will coordinate the large-scale data hydrologic data collection activities (including, for instance, stream gauging and precipitation measurement) within these basins. Many of the focused data collection activities of the other hydrology projects will be conducted within the subcatchments identified in Section 3.2.3.1 but the winter program will extend well beyond these basins.

4.5.3.1.2 Summary of Project Data Collection Plans

Soil Moisture: Soil moisture profiles (HYD-1) will be measured at selected tower sites using 5 profiler tubes per site, with 10 cm vertical resolution. Samples will be collected every other day (during IFCs only) using either neutron probes or TDR in profile mode. Tensiometer measurements will be made concurrently with moisture measurements at selected tower sites, and suction infiltrometers will be applied to allow definition of soil characteristic and hydraulic conductivity functions. Soil moisture measurements using TDR will be made at certain locations as well (see table 3.2.3.4).

Soil Moisture measurements and measurements of the Moss/Humus layers, where those layers are significant, will be collected using the airborne gamma radiation system during the summer of 1994 (HYD-6) along approximately 30 transects representing different vegetative cover in the SSA, and between the two areas. The flight lines are located primarily close to roads. Additional flight lines will be established, where possible, for support of studies by other investigators.
Snowpack Properties: Long-term snow temperature profile measurements are to be collected at one site (probably, SSA, OA by HYD-3).

HYD-3 will make field measurements during the FFCs of snow water equivalence and profiles of density and temperature. Profiles of air permeability, specific surface area and equivalent extinction properties for the visible/near IR and microwave spectral regions will be obtained from analyses of snow specimens collected in the field. It is expected that two or three patches will be measured around each long-term tower site. In addition, net radiation (in three bands), air temperature, humidity and wind speed will be measured with a portable weather station to be positioned in different patches during the FFCs.

Snow Cover: HYD-4, in conjunction with HYD-2 and HYD-6 will coordinate data collection activities using a) airborne gamma measurements, to be collected under contract to the U.S. National Weather Service, and b) SWE measurements, to be collected along the flight lines, which, due to accessibility problems, are effectively constrained to the all-weather roads. Ground measurements of SWE will be collected along selected flight lines (established in Fall 1993) for calibration.

Snow Surveys: Snow depth surveys will be conducted in March and April in all three basins (southern and two northern) to augment data collected by other studies by HYD-3 and HYD-4.

Interception: Low temporal resolution information on canopy interception(on a storm event basis) and moss water retention and drainage (daily) will be collected through the growing season by HYD-9. Although this work was not originally funded, the lack of any field data collection on these processes are considered a significant hole in the water budget. Canopy throughfall will be measured by a trough system under representative canopies near tower flux sites and the gaged watershed in the southern site. Stem flow will be sampled with a gutter collection system. Moss water retention and drainage will be sampled following storm events on a daily time step. Supplementary funds to augment current budgets will be required.

A minimum-effort interception and moss uptake study will be conducted by HYD-8. Sampling locations will be selected that are convenient to the HYD-9 base camp.

Water Table: Piezometers will be installed by HYD-9 to monitor near surface water tables in each basin as described in Section 3.2.3.1. In the SSA, 17 will be placed in the White Gull Basin, including 7 in the fen draining White Gull Lake. In the NSA, 18 will be placed in the West Basin, including 6 in the hillslope transect, and 18 in the NSA East Basin. All standpipes will be perforated PVC tubing installed with a 2 inch auger to a maximum depth of 1.5 m. Piezometers will be monitored semi-weekly in accessible locations and at least bi-weekly in remote locations.

Surface Runoff: HYD-9 will coordinate the catchment data collection. A summary of the gauged catchments is in Section 3.2.3.1. Consideration is being given to collecting water samples for isotope analysis at selected locations and times. The data to be collected are:

Stream gauging -- SSA

a) Year-round gauge: Water Survey of Canada has installed a year round gauge on White Gull Creek at Hwy 106 (drainage area 574 sq km, total relief 150 m) (Figure 3.2.3.1a).

b) Summer (auxiliary) gauges (mid-April to mid-September): Three gauges will be operated in the White Gull watershed, one on each of the major tributaries.

Stream gauging -- NSA

a) Year-round gauge: Water Survey of Canada has installed a year round gauge on the Sapochi River at Hwy 391 (drainage area 436 sq km, total relief 150 km) (Figure 3.2.3.1b).

b) Summer (auxiliary) gauges (mid-April to mid-September): Two gauges will be operated on two small creeks in the Sapochi watershed, called the East Basin Creek and the West Basin Creek. Both have drainage areas of about 27 sq km (Figure 3.2.3.1c).

Summer Precipitation

The gauges will be monitored weekly and the weather radar will be operated continusouly from May 15 to September 30, 1994.

SSA

- 5 Belfort recording gauges
- 4 available from AES
- 1 to be acquired; tipping bucket may be substituted
- 5 tipping bucket recording gauges
- to be supplied by HYD-8 (E Wood) and calibrated by AES
- all gauges to be equipped with chartpak recorders or equivalent
- weather radar will produce hourly precipitation maps.

NSA

- 5 Belfort recording gauges
- 2 in each of East and West basin and 1 in the Upper Sapochi basin
- 2 to be supplied by University of Waterloo
- 3 to be acquired; tipping buckets may be substituted
- 7 tipping bucket recording gauges
- to be supplied by HYD-8 (E Wood) and calibrated by AES
- all gauges to be equipped with chartpak recorders or equivalent

White Gull Lake Data

An evaporation pan will be installed and operated near the northwest shore of the Lake. Lake level and temperature will be manually recorded semi-weekly at the southern shore of White Gull Lake. Seven piezometers will be installed in the outlet fen.

4.5.3.1.3 Study Gaps

Two significant gaps were noted in the science focus of the studies which constitute the Hydrology Group, and hence the data that will be collected. The study gaps identified were:

1) None of the projects proposed to measure the canopy water balance. Due to the relatively low annual precipitation, large number of overcast and/or rainy days in summer, and the extent of the canopy, a significant part of the annual water balance will be ignored if such measurements are not collected. This shortcoming is being addressed by a limited data collection program to measure interception by HYD-8 and -9.

2) None of the projects proposed to study evaporation from lakes, or evapotranspiration from the fens. To partially address this shortcoming, a lake evaporation pan will be installed in White Gull Lake (SSA) by HYD-9. No lake evaporation measurements will be made in the NSA.

4.5.3.2 Data to be submitted to BORIS

All of the hydrology projects will submit repetitively collected data (e.g., data of a time series nature) to BORIS. These include streamflow, water levels (e.g., lakes, groundwater), soil moisture, meteorological data at other than tower sites, surface measurements and flight line estimates of snow water equivalent and depth, and other similar data. Non-repetitive data, for instance, soil physical properties, will be submitted at the discretion of the PIs. Discussions need to be pursued with BORIS staff regarding the ability of BORIS to provide for dissemination of remote sensing data in image format (e.g., LANDSAT and AVHRR suitable for estimation of such surface characteristics as albedo, NDVI, snow areal extent, and vegetation type and age class. In particular, HYD-3 will produce raster-format multi-band images of snow properties. These will be available to BORIS, if sufficient disk storage space and network retrieval capabilities are provided.

4.5.4 Supporting Measurements

4.5.4.1 Needs from Other Groups or Core Measurements

HYD-1 (Cuenca): The core measurements required by this project include basic soils data at every tower and auxiliary site and for every major soil type within the experimental domain. The data listed in this category are indicated as part of the Core Measurement Program (CMP) in Section 3.2.3.3, specifically: a) Profile description - structure, depth, texture; b) Bulk density by horizon ; c) Particle size distribution by horizon; d) Core samples for laboratory analysis of hydraulic conductivity as a function of volumetric moisture content; e) Core samples for laboratory analysis of volumetric moisture content as a function of soil moisture tension at tensions of 0.01, 0.03 and 1.5 MPa.

HYD-3 (Davis): A variety of map-based information is required by this investigation: digital elevation models, digital vegetation maps and digital soils and water feature maps. Both medium and high-resolution DEMs are required. Vegetation should include species (or species mix), canopy density and stem density. Soils and water-feature maps of medium resolution are adequate. Any vector data should be in DLG-3 optional distribution format. Aircraft data are needed for both sites for thaw-period FFCs, as early as April 3, if possible. AVIRIS is requested over flight lines selected for two northern watersheds, and over the White Gull Creek watershed if snow remains. ASAS is also requested over specified target areas in the test watersheds, north and south if snow remains. Satellite data needed for this investigation include Landsat TM and AVHRR for periods from early February to the end of the thaw at the northern site. These data are needed for all reasonably clear-sky dates as soon as possible to permit early evaluation and analysis of the

1994 field data. Tower flux data from OA-SSA and BS-NSA and auxiliary sites, if collected, are required for winter and thaw FFCs.

HYD-4 (Goodison): This project requires standard meteorological data during the winter period (especially temperature, precipitation, and snow depth), airborne microwave radiometer data, airborne gamma SWE data along selected flight lines, and airborne optical and thermal IR data from core or complementary studies. Access to snowpack temperature profiles or snowpack structure data resulting from other investigations (e.g., HYD-3) would be beneficial. Access to SAR overflight data would be useful for identification of wet snow areas during the thaw FFC to compare to passive microwave satellite retrievals. The airborne passive microwave radiometer (NASA's Jim Wang's system - 18,37, 90Ghz) will be flown on the Canadian (NRC) Twin Otter during the winter FFC along pre-selected flight segments.

To implement the large scale meteorological modeling the availability of aircraft and satellite surface cover (i.e., snow) surveys will be crucial, as will be regular radiosonde sounding from PA Park and elsewhere. Aircraft (eddy correlation) fluxes would be very useful for verification of the aggregation studies.

HYD-6 (Peck): This project requires high quality data (maps or digital information) on soil types, soil density, and of the vegetative cover. All available ground measurements of SWE (by HYD-4 and others) and of SM during periods when gamma surveys are conducted will be required. Remote measurements of the SWE and SM by other investigators will be required for inter-comparison studies. Precipitation and streamflow measurements will also be required.

HYD-8 (Band): The data required are groundwater levels, soils data, a high resolution (30-90m horizontal resolution by 50cm vertical for hillslope scale, 90-250m horizontal by 1m vertical for catchment and regional studies). The hillslope sites proposed for the small scale investigations will be located in the vicinity of the primary towers, which will provide the required surface meteorological data and DEM.

HYD-9 (Soulis et al.): Vegetation and soils maps at high resolution (e.g. 1:125,000) will be required for the NSA and SSA and at lower resolution for the entire BOREAS region. Precipitation data, as well as surface flux data from tower measurements, will be required for the small scale work. The mesoscale model (about 1 km resolution) will need information about vegetation and soil types, low resolution digital elevation data, and the spatial distribution of precipitation.

4.5.4.2 Additional Core Data Collection Needs

The following core data needs were identified by one or more of the projects:

1) Digital Elevation Models (DEMs): High resolution DEMs are essential around the small catchments and hillslopes (to be studied, for instance, in HYD-8 and HYD-9). Although some of these may be located near the all-weather tower sites, this is problematic from the standpoint of hydrologic studies, as the tower sites were specifically chosen to be as flat and uniform as possible. In any event, high resolution should be interpreted as 25-90m in the horizontal and 50cm in the vertical. Moderate resolution should be interpreted as 90-250m in the horizontal and 1m in the vertical. DEM data (in vector form, digitized from 1:50,000) are available for the entire BOREAS region from the Canada Centre for Geomatics, and would be adequate to meet the high resolution needs. Lower resolution data (also in vector form, digitized from 1:250,000 maps) are available as well, and would meet the moderate resolution requirement. HYD-8 will convert the 1:50,000 vector data to raster DEM grids, which would be essential for the hydrology (and presumably other) investigators. A proposal has been developed by HYD-8 to fund a small TOPSAR experiment to gather high resolution terrain data in a small part of the northern site in and around the fen, using interferometric radar on the DC-8. The area has a variety of terrain complexity and a variety of forest cover classes.

2) Soil Moisture: Additional soil moisture measurements beyond those proposed by projects HYD-1 and HYD-9 will be required to characterize adequately the spatial variations in soil moisture over the sites. The soil moisture network consists of TDR, and neutron probes around all the tower site at resolutions reflecting the tradeoffs between budgets, and the requirements of hydrologists and terrestrial ecologists. One of the concerns is that current plans to monitor in just a few points around the towers may produce a biased representation of the spatial distribution of soil moisture, since the tower sites were selected for minimal relief. A more extensive, nested sampling design to include different terrain types, which would be feasible with portable TDR or neutron probe, has been developed by the soil moisture working group.

3) Side-by-side comparisons of instruments, especially radiation and tipping bucket gauges is recommended. This could be conducted at the AES Center for Atmosphere Research Experiments.

4) Limited groundwater elevation measurements are planned as part of HYD-9. These data may be insufficient to allow spatial characterization of the water table. Stage measurements in selected fen areas should be considered, possibly as a partial alternative. Formation of a working group to address this issue is recommended, or possibly the existing soil moisture working group

could address this as well. Data identifying the extent of inundated areas is of interest to trace gas investigators as well. The monitoring design for groundwater will be nested in different locations around upland/lowland transitions. Observation wells and/or lake and fen stage can be monitored infrequently (e.g., weekly with more frequent observations during and after snowmelt).

5) Several of the Hydrology (and other) projects have a major component during the winter and thaw periods, and plan measurements and modeling during these FFCs. There needs to be adequate background measurements during these campaigns, such as remote sensing measurements, forest meteorology and fluxes, surface snow surveys, and atmospheric observations (the latter may require both soundings and aircraft measurements).

4.5.5 Coordination and Other Issues

4.5.5.1 1993 Activities

Representatives from HYD-9 and HYD-3 completed a reconnaissance of potential specific sites for hydrological observations during IFC-93. Frost tubes was installed in September 1993. Sites for detailed snow pack analyses will be chosen. Core snow survey sites were established in September 1993 when background airborne gamma surveys (no-snow) are conducted.

4.5.5.2 Coordination with Other Groups

We believe the best way to facilitate coordination with other groups is the formation of multidisciplinary working groups. Such a group has already been formed for soil moisture measurements, which is joint between Hydrology and TGB.

One requirement of several of the hydrology projects is mesoscale model predictions (from AFM) of surface meteorological variables (e.g., air temperature, specific humidity, surface pressure, wind, and precipitation) over the BOREAS region on a continuous basis from the winter, 1994 FFC through the last summer IFC. These predictions are necessary to allow the hydrologic models to distribute point measurements (e.g., from tower measurements) to the scale of the BOREAS region. Other groups (notably TE and TGB) have similar requirements for biogeochemical and biogeographical models.

4.5.5.3 Interdisciplinary Working Groups

1) A soil moisture working group has been formed consisting of Richard Cuenca, Darwin Anderson, Elissa Levine.

2) An adhoc snow measurement working group will develop a plan for coordinating the surface, airborne, and satellite components of the various projects dealing with snow measurement and modeling., Members are Danny Marks, Bert Davis, Barry Goodison, and Al Chang.

3) An adhoc working group has been formed to coordinate precipitation measurement during the snow-free season consisting of Steve Running (TE), Ric Soulis and Larry Band. This group will address precipitation measurement and monitoring, and the resolution and accuracy of precipitation measurements required by the various modeling activities proposed in HYD, TE, and other groups.

4.6 REMOTE SENSING SCIENCE (RSS)

4.6.1 Objectives

The overall objective of the Remote Sensing Science (RSS) Group is to develop linkages between optical and microwave remote sensing and boreal zone biophysical parameters at scales that include leaf, canopy and regional levels using field, aircraft and satellite borne sensors and scattering models.

Specifically, the objectives are
1) Provide calibrated data products from optical and microwave remote sensing instruments.

2) Use optical and microwave scattering models to develop improved algorithms for inferring important biophysical properties.

3) Develop remote sensing derived biophysical parameter data sets for use with terrestrial ecosystem models.

4) Examine the effects of scaling remote sensing measurements and derived parameters from the local to regional levels.

In support of these objectives Remote Sensing Science Group Investigators will acquire fundamental measurements of reflectance, emittance, and backscatter of the canopy and background, atmospheric scattering and absorption, and in cooperation with other discipline groups, surface ancillary data.

In terms of algorithm development the RSS group will develop and test optical and microwave algorithms to produce biophysical parameter sets for the SSA and NSA modeling su-areas, and AVIRR community composition maps at the 1000 x 1000 km BOREAS region (see Section 4.3.5.3 for TE modeling discussion of parameter requirements and Appendix J). The parameter requirements are shown in Table 4.6.1a.

Table 4.6.1b
Basic Remote Sensing Parameter Data Set

Parameter	Team	Spatial/Temporal Freguency	Comment
Species Composition	TE-18, RSS-8, AFM-12	One time during 1994 is fine	
FPAR, LAI	RSS-1, RSS-3, RSS-4, RSS-5, RSS-6, RSS-8 TE-18	Once for conifers and fens (mid-summer), three times for deciduous	
Biomass	TE-18, RSS-13, RSS-15	Once during 1994 is fine	
Canopy Temperature	RSS-3		Reasonable estimates are plausible at large spatial scales, but the effects of IRT angles and canopy gaps, etc. make the data very questionable at smaller scales
Albedo	RSS-1, RSS-3, RSS-8, RSS-19	Once per IFC for deciduous once per growing season for conifers	ASAS could help to develop the nadir to hemispherical correction factors
Radiation	RSS-14	30 minute, 8 km data from GOES;	
Freeze-Thaw	RSS-17	30 m resolution every 3 days is fine	Useful since soil temperature is a key driver for TE models
Canopy Moisture	RSS-16		Could be useful if inside and outside water could be differentiated; could also interesting for LAI estimates
Soil Water	RSS-13		Appropriate as a research project

4.6.2 Investigation Summaries

Ref. Number RSS-1

P.I.: Deering, D./NASA

CO-I(s): Middleton, E./ NASA; Ahmad, S./Hughes/STX Corp.

Title: Radiative Transfer Characteristics of Boreal Forest Canopies and Algorithms for Energy Balance and PAR Absorption

Objectives and Approach: The objectives of the proposed study are 1) to characterize the multidirectional interactions of solar energy in various types of boreal forest canopies through intensive measurements and through modeling, and 2) to relate these characteristics to ecologically important biophysical parameters. Emphasis is given to the directionally-dependent absorption of photosynthetically active radiation (PAR) by the forest canopies and the directional reflection of the radiation from them (constituting the albedo). These angular radiance distribution measurements will be made both above and at various levels within the canopies, including the forest floor, to characterize the complete radiative transfer within three of the forest canopy types at the southern (Prince Albert) site, at different times.

Ref. Number RSS-2

P.I.: Irons, J./NASA GSFC
Co-I's: Dabney, P./GSFC, Martonchik, J.,/JPL, Ranson, J./GSFC,Walthall, C./U. of Maryland

Title: Dynamics of Canopy Photosynthesis and Stomatal Conductance in the Boreal Forest: A Study Using Airborne, Multi-Angle, Imaging Spectroradiometer Data

Objectives and Approach: To obtain multi-angle, high spectral resolution reflectance data of important forest components of a boreal landscape and relate these data to biophysical states (albedo, FPAR, leaf area index). The Advanced Solid State Array (ASAS) system will be flown over representative sites in BOREAS to acquire the data. Radiative transfer models will be used in combination with the multi-angle data to develop algorithms for biophysical parameter estimation.

Ref. Number RSS-3

P.I.: Walthall, C./University of Maryland

Co-I's: Williams, D./NASA GSFC
Goward,S./University of Maryland

Title: Biophysical Significance of Spectral Vegetation Indices in the Boreal Forest

Objectives and Approach: The primary objective of this study is to acquire multispectral, bidirectional reflectance and surface temperature data of the study sites for assessments of spectral, spatial, temporal and bidirectional variability, and the impacts of these variabilities on vegetation indices. Some multi-altitude data will also be acquired from the helicopter. A helicopter with a pointable, stabilized mount will be used to carry a spectrometer(Visible and Near-IR), an infrared thermometer and a video camera. A sun tracking photometer will also be deployed to provide data for calculations of irradiance an for atmospheric correction of the data. We will use the latest available version of the 6S atmospheric model for the calculations of irradiance and for atmospheric corrections. If possible, estimates of reflectance from the primary study sites will be made in the field.

Ref. Number RSS-4

P.I.:	Curran, P./University of Swansea
Co-P.I's	Plummer, S./British Nat'l Space Centre, Lucas, N. /U of Swansea, Green, R. /Univ. College of Swansea
Title:	Coupling Remotely Sensed Data to Ecosystem Simulation Models
Objectives and Approach:	Project aims to derive estimates of LAI and leaf chlorophyll/nitrogen concentration from remotely sensed data for input into Forest-BGC model. This will be accomplished using (i) empirical techniques to link remotely sensed data to forest attribute information acquired on the ground with corrections made for sensor and environmental factors (e.g. vegetation height, background and canopy cover) and ii) development of a forward canopy radiation model the results of which will be compared to the remotely sensed data to derive LAI. Model currently under consideration is the geometric optic model (Li and Strahler, 1986). The proposed research will consist of four phases. (i) Collection of i*n situ* forest biophysical/biochemical data at pre-selected plots within one of the study areas in IFC-93. Destructive and non destructive measurements at all plots will include leaf nitrogen and chlorophyll concentrations, leaf area index, tree diameter at breast height and percentage canopy cover. (ii) Derivation and validation of relationships between remotely sensed data and forest attribute data. (iii) Use of these relationships to estimate those forest variables required to drive and validate Forest BGC over the 400-600 km^2 study area.

Ref. Number RSS-5

P.I.:	Goel, N./Wayne State University
Title:	Boreal Forest Community Composition and Structure, Photosynthesis, Remote Sensing, Scaling and Net Carbon Flux
Objectives and Approach:	The overall objectives of this proposal are to address the following questions related to two quantities--photosynthesis and soil radiation absorption--for boreal forest: (1) How important is the detailed architecture and species distribution in boreal forest canopy in determining these quantities and how do they vary as a function of season when canopy architecture undergoes changes? (2) Can we estimate them using a simpler equivalent model using surrogate parameters for canopy architecture? (3) Are these parameters correlated to each other under different canopy architectural conditions, and can one estimate photosynthesis using measurement of radiation absorbed by the soil? (4) Can one estimate photosynthesis using radiation leaving a canopy? In particular, how does the relationship between FPAR (fraction of photosynthetically active radiation) and NDVI (normalized difference vegetation index) depend upon the complex forest community and architecture? (5) How can one scale up their estimation for a large collection of heterogeneous canopies such as those found in boreal forest? (6) To what degree different forest stands can be differentiated by using remotely sensed data? and (7) Can one estimate the net carbon flux over the area covered by the BOREAS site by using a combination of vegetation models, scaling strategies, ground observations, and satellite images.

Ref. Number RSS-6

P.I.:	Williams, D./NASA Myneni, R. /NASA
Title:	Modeling and Remote Sensing of Radiant Energy Interactions and Physiological Functioning in a Boreal Ecosystem
Objectives and Approach:	The Objectives of our research program are twofold: (i) to develop and validate a three-dimensional boreal forest canopy/atmosphere radiation model capable of simulating canopy reflectance, absorbance and atmospheric effects, and (ii) to develop and validate algorithms for estimating surface albedo, solar and photosynthetically active radiation absorbed by boreal forest canopies, solar radiation absorbed by the background and, boreal forest canopy photosynthetic and bulk conductance efficiencies from spectral, spatial and temporal patterns of surface radiance fields. The physical problem is posed as a 3D radiative transfer equation (RTE), describing the interaction of photons in the atmosphere/vegetation medium, the solution of which is the remote spectral measurement. We propose to develop models of boreal forest community at the BOREAS experimental sites using fractals and computer graphics.

Ref. Number RSS-7

P.I.:	Chen, J,M
Co-I;s	M.Penner/PNFI, J.Cihlar/CCRS
Title:	Retrieval of Boreal Forest Leaf Area Index From Multiple Scale Remotely Sensed Vegetation Indices
Objectives and Approach:	We propose to develop and validate an algorithm that will allow the retrieval of the spatial distribution of LAI from remotely sensed vegetation indices. Field measurements of LAI and FPAR (fraction of Absorbed Photosynthetically Active Radiation) will be undertaken for major boreal forest species (jack pine, quaking aspen, black spruce) and stand types. For each species, stands with different percentages of forest cover will be studies. Field measurements of effective LAI will be taken both along transects and on a regularly spaced grid with the LAI-2000 sensor. For selected stands (OJP ,YJP and OBS tower flux sites in both SSA and NSA), high frequency data (1 sample/cm) will be obtained from a LI-COR quantum sensor carried by a person walking along transects beneath the overstory to improve LAI calculations and to characterize the architecture of the canopy. Measurements from the moving sensor (a sunfleck-LAI instrument dubbed the Talkman) will be used to calculate FPAR. These field measurements will allow us to establish relationships between LAI, FPAR and remotely sensed radiances and their transformations including vegetation indices. These relationships will then be used to test the performance of spatial mapping of LAI by extrapolation. High resolution images will be provided by the CASI and MEIS airborne instrument which will be flown over the pre-established transects. Lower resolution images will be obtained from LANDSAT and/or SPOT and possibly from other remote sensing instruments available through other BOREAS studies.

Ref. Number RSS-8

P.I.(s):	Running,S.W./Univ of Montana
CO-I(s):	Muller, J-P./Univ. College London, Hall, D./GSFC, Kaufman, Y./GSFC, Huete, A./U of Arizona, Wan, Z./CRSEO U of Calif., Justice, C./GSFC, Carneggie, D./USGS EDC
Title:	MODIS Land Team (Modland) Algorithm Development for Boreal Forests: Participation in BOREAS
Objectives and Approach:	Ground validation measurements of (1) land cover mapping of the northern and southern sites, using both TM data and MODIS airborne simulator (MAS) data with ground derived, (3) mapping and satellite monitoring of the seasonal snowcover and snowmelt on both sites using MAS and ASAS sensors. 3) development of advanced spectral vegetation indices, predominantly using MAS and ground BRDF measurements. 4) surface temperatures, as monitored by the meteorological tower network planned for each site, and related to both aircraft and satellite measured thermal emittances.

We then plan to use carbon and water flux measurements taken from cuvette, tower and aircraft levels by other investigators to validate our hierarchical modeling of ecosystem water and carbon balances done with FOREST-BGC and our current ΔNDVI modeling. We will integrate these core products into new spatially scalable estimates of daily photosynthesis-respiration balances, evapotranspiration, and soil decomposition and CO_2 production. These products, tested and validated during the IFCs, will be extrapolated to the global boreal forest biome.

Ref. Number RSS-9

P.I.:	Strome, M
Title:	High Spatial and Spectral Resolution Image Analysis Techniques for Ecological and Biophysical Data (High Spirited)
Objectives	A major objective will be to attempt to develop techniques and algorithms to enable us to monitor changes in the test sites and to relate the remotely sensed data to forest models. The multitemporal data will be used to attempt to monitor changes resulting from phenologic events, especially those related to vegetative stress where possible. The majority of past efforts to analyze high spectral resolution data have focused upon relatively simple signal processing techniques, such as selection of optimum bands to distinguish features of interest such as species identification, vegetation stress and defoliation due to insect damage. Some techniques have examined features such as the "red shift"

Ref. Number RSS-10

P.I.(s): Holben, B./NASA

CO-I,: Bhartia, P./NASA

Title: Satellite Estimation of PAR and UV-B Irradiances and Long Term Estimates Of Trends Of UV-B from Ozone Depletion and Cloud Variability at the BOREAS Sites

Objectives and Approach: We Propose to investigate from ground and satellite observations the magnitude of daily, seasonal and yearly variations of UV-B irradiance during the course of the BOREAS field experiment and to examine the 14 year record of Total Ozone Mapping Spectrometer data over the BOREAS sites for ozone and cloud reflectance variability. We also propose to estimate the incident Photosynthetically Active Radiation by refining our existing model which utilizes TOMS reflectivity data to account for cloud attenuation. In addition, we will extend the results of our algorithm development for application to the entire circumpolar boreal forest biome.

Ref. Number RSS-11

Title: Characterization of Atmospheric Optical Properties for BOREAS

P.I.'s: Brian L. Markham/ NASA/GSFC ,Brent N. Holben /NASA/GSFC
Co-I's: Yoram J. Kaufman/NASA/GSFC, Halthore, R,/Hughes/STX Corp., Eck, T. /Hughes/STX Corp., Vermote, E./University of Maryland

Objectives : and Approach: We propose to characterize the physical and optical properties of the atmospheric aerosol and the atmospheric column abundance's of water vapor and ozone over the BOREAS study area. A network of three to four fully three to four fully automatic sunphotometers/radiometers will be established on a transect connecting the northern and southern BOREAS sites. These sites will provide hourly direct solar and diffuse sky radiance measurements in the solar almucantar in the visible to near-infrared. During the intensive field campaigns the measurements will be supplemented by additional moveable stations and sampling of the aerosol particles. Aerosol physical properties of size distribution /concentration and composition, and aerosol optical properties of optical depth, phase function and albedo of single scattering will be determined. The annual cycle of the concentration and properties of the atmospheric aerosol particles in the Boreal region and the relation between the aerosol properties and the meteorological conditions, in particular the air trajectory and origin, will be assessed. The measured atmospheric properties will be used to validate retrieval algorithms of atmospheric parameters (e.g., water vapor, aerosol optical depths) from remotely sensed data. For selected remotely sensed data, atmospheric corrections will be performed using a radiative transfer code that accounts for the non-Lambertian forest canopy reflectance. The retrieved reflectances will be compared to those measured at the surface and to those obtained using the atmospheric correction methodology used operationally by the BOREAS project.

Ref. Number RSS-12

P.I.(s):	Wrigley, R.C./NASA/Ames
Co.PI(s):	Spanner, M.A., Slye, R.E., Russell, Livingston, J.M.
Title:	Aerosol determinations and Atmospheric Correction for BOREAS Imagery
Objectives and Approach:	Acquire sun photometer data using a ground-based instrument as well as the Airborne Tracking Sun Photometer on the C-130. Derive aerosol optical depths as a function of wave length and submit them to BORIS. Use the spectral aerosol optical depths to derive aerosol and size distributions coincident with important BOREAS remote sensing data sets and use the size distributions to calculate aerosol optical properties such as phase functions and single scattering albedos necessary for our atmospheric correction model. Third, we propose to incorporate a model of contribution of skylight into our atmospheric correction model to enable calculation of surface reflectances from our surface radiances. Fourth, we propose to extend our atmospheric correction model to data collected by the Advanced Solid-state Array Spectroradiometer (ASAS), incorporate an approximate Rayleigh multiple scattering correction, and provide a detailed evaluation of the results. Finally we will process the important remote sensing data sets for BOREAS from the Thematic Mapper (TM), the TM Simulator, System Probatoire de la Terre (SPOT), and ASAS. In sum, our proposed effort will provide critical atmospheric optical measurements and derive the aerosol optical properties necessary for atmospheric correction of BOREAS data, extend our atmospheric correction model, and provide atmospherically corrected data for BOREAS.

Ref. Number RSS-13

P.I.(s):	S. P. Gogineni/The University of Kansas
GSRP Student:	G. Lance Lockhart/The University of Kansas
Title:	Helicopter-Based Measurements of Microwave Scattering Over the Boreal Forest
Objectives and Approach:	The objectives of the microwave measurement project are (1) to acquire the quantitative backscatter data required to understand better the physics of scattering from vegetative components and (2) to develop a neutral-network-based algorithm for estimating soil moisture and biomass of the boreal forest. The second objective is being supported by a GSRP fellowship from NASA-GSFC. Ultimately, we will develop a scattering model and model-based inversion algorithm to estimate soil moisture and biomass from satellite remote sensing data over the boreal forest, in particular by ERS-1, JERS-1 and SIR-C Synthethic-Aperture Radar (SAR). To accomplish these objectives, we will use a helicopter-based FM scatterometer operating at 10, 5.3 and 1.5 GHz with all four linear polarizations over incidence angles of 0^o to 50^o. This system will measure backscatter as a function of angle and frequency over the sites. Also, we will collect fine-resolution data at selected sites in an effort to determine the relative contributions of individual forest components to the total backscatter. All data will be reduced to backscatter coefficients using vector-correction techniques. After reducing the data, it will be used to train and test a feed-forward artificial neutral network (ANN). The accuracy of the ANN will be evaluated using ground-truth data collected with help from Dr. Jon Ranson and Dr. Roger Lang.

Upon completion, we will provide data related to the interpretation of SAR data to other investigators via BORIS.

Ref. Number RSS-14

P.I.(s): Smith, E.A., Cooper, P.J., Gielisse, P.J./F.S.U., Gautier, Catherine/UCSB

Title: Quality Assurance of BOREAS Net Radiation Measurement

Objectives and Approach: Because surface net radiation is generally a main determinant of how the hydrometeorological system operates and how the phenology of a canopy functions, it is a fundamental observable for BOREAS. this project is designed to ensure the highest possible accuracy and precision of the net radiation measurements taken throughout and between the BOREAS sites, and is further designed to help resolve past discrepancies in net radiation measurements based on engineering design and material properties differences in various makes of net radiometers. This project will also assess how well current geosynchronous satellite algorithms, based on 2-channel GOES VIS-IR radiance inputs, can retrieve surface net radiation at a hierarchy of space and time scales. The main deliverables of this project will be a time sequence of inter-calibrated and objectively analyzed gridded net radiation fields throughout the BOREAS IFCs, and a set of scientific papers on (1) the measured BOREAS surface net radiation field; (2) the radiometer inter-calibration issue and engineering design study; and (3) the measurement-satellite retrieval intercomparison study. The spatial resolution of the grids will be consistent with the separation distance between the radiometer sites; the time step will match that of the radiometer sampling time recommended by the BOREAS Science Team. All net radiation measurements incorporated in the objective analysis from the multiple sites will be inter-calibrated to an Eppley 4-way directional radiometer system, for which the calibrations of the directional devices would be traceable to the primary radiometer standard maintained at the Davos, Switzerland World Radiation Centre, which is calibrated on the World Radiometric Reference (WRR) scale. All radiometers used in the field will be cross calibrated at a common site prior to the onset of the 1994 BOREAS summer field phase. All net radiometer stations at and between the northern and southern study areas will then be visited at least once in the course of the summer IFCs with a copy of the standard field model deployed on a portable data station to check on residual sensitivity differences. This radiometer will have been cross-calibrated to the similar device, mounted along side the reference 4-way directional system at the calibration site. The satellite measurements needed for this research will be acquired here at FSU using my laboratory's GOES Direct Readout Ground Station.

Ref. Number RSS-15

Title : Distribution and Structure of Above Ground Biomass in Boreal Forest Ecosystems

P.I.: K. Jon Ranson / NASA/Biospheric Sciences Branch/GSFC

Co-P.I. : Roger Lang/GWU

Co-I(s): Guoqing Sun / SSAI/Biospheric Sciences Branch/GSFC
Narinder Chauhan /GWU/Hydrological Sciences Branch/GSFC

Objectives and Approach: We plan to determine the amount and distribution of above-ground biomass for ecologically distinct areas of the BOREAS study sites . We will use ground observations, ground based radars (if available) airborne radars and satellite-borne radars in combination with backscattering models to improve algorithms for biomass mapping at regional scales. In addition we plan to utilize the above measurements and models to develop inversion strategies to partition above ground biomass into foliage, branch and bole components. We will also determine the appropriate radar wavelength, resolution and incidence angle for detection of forest gaps and evaluate the ability of SAR for extraction of information on forest spatial structure. This BOREAS project will benefit from a Shuttle Imaging Radar - C (SIR-C) investigation to determine parameters for initialization and validation of forest ecosystem models. The experiment will be performed at nine sites in Prince Albert during the summer of 1994. Three of these sites, one of mature jack pine, one of mature aspen and one of mature black spruce will be collocated with sites of major optical remote sensing activity so that joint efforts in ground truth acquisition can be undertaken. The other six sites will be composed of jack pine, aspen and black spruce but will be of low and medium density.

Ref. Number RSS-16

P.I. Sasan S. Saatchi/Jet Propulsion Laboratory

CO-I's Jakob VanZyl/Jet Propulsion Laboratory, Mahta Mogaddam/Jet Propulsion Laboratory, Ted Engman/GSFC (Collaborator)

Title : Estimation of Hydrological Parameters in Boreal Forest Using SAR data

Objectives and Approach: It is the objective of this study to estimate the water content of the top layer of the forest canopy and the moisture of the forest floor and to map the snow and permafrost cover by using SAR imagery and possibly synergism between microwave and optical data. We propose to use AIRSAR, ERS-1, JERS-1, and AVIRIS data (SIR-c/X-SAR if available) in conjunction with classification techniques, forest modeling and retrieval algorithms to provide these parameters as quantitative inputs to hydrological models. In order to make the algorithms operational, we will validate the models used in SAR data analysis by working closely with other investigators for parameterizing the boreal forest surface cover and acquiring *in situ* measurements. In addition, we will also focus on the scaling problem to adjust the parameter estimation algorithms suitable for local and mesoscale hydrological modeling. We will participate in summer, fall and winter field campaigns to collect biometry data and characterizing the forest surface (snow depth, soil moisture, freeze and thaw in vegetation and soil, and understory).

Ref. Number RSS-17

P.I.	JoBea Way/Jet Propulsion Laboratory
Co-I's:	Eric Rignot/Jet Propulsion Laboratory, Reiner Zimmermann/Jet Propulsion Laboratory,Gordon Bonan (Collaborator)/National Center for Atmospheric Research
Title :	Monitoring Environmental and Phenologic State and Duration of State with SAR as Input to Improved CO_2 Flux Models

Objectives: and Approach:

Using synthetic aperture radar (SAR), we can determine the environmental and phenologic state by looking at changes in the backscatter signatures relative to frozen conditions. We propose to monitor the environmental and phenologic state using AIRSAR and SIR-C/X-SAR data, and the duration of state with ERS-1/2 data. The key is SAR's sensitivity to dielectric constant of water and the development of two algorithms called ENV and PHEN which use changes in backscatter and phase relative to winter frozen conditions, and scattering mechanism to uniquely determine environmental and phenologic state. As environmental state changes, the distribution, amount and phase of water in, on and under the forest canopy changes resulting in a dramatic change in the dielectric makeup of the forest and soil layer. To validate the relationship between seasonal state and SAR backscatter, we will install temperature and dielectric sensors, and will work with other BOREAS groups to obtain xylem flow, CO_2 flux, meteorological data and biometry data.

A functional group map of both BOREAS sites, a map of the environmental and phenologic state of both sites for each AIRSAR/CCRS SAR and SIR-C/X-SAR overflight, freeze/thaw and leaf on/off dates from ERS-1/2 data, and improved estimates of the CO_2 flux using the SAR-generated environmental and phenologic states will be delivered to the project.

Ref. Number RSS-18

P.I.(s):	Green, R. O./Jet Propulsion Laboratory
Title:	Surface and Atmosphere Measurements and Radiative Transfer Modeling for the Calibration and Validation of the Airborne Visible-Infrared Imaging Spectrometer (AVIRIS) for Quantitative Data Analysis at BOREAS

Objectives and Approach:

Spectral and radiometric calibration of radiance-measuring sensors and for quantitative comparison of data acquired from different sites, times and instruments to meet calibration and validation requirements for AVIRIS during the BOREAS experiment. Ground based surface and atmospheric measurements with rigorously calibrated field instruments will be acquired simultaneously with the AVIRIS overflights. With assessments of surface and atmospheric characteristic derived from these ground based measurements a radiative transfer code will be used to predict the total radiance incident at AVIRIS. Analysis using this predicted radiance and the AVIRIS reported radiance will allow validation and calibration of the in-flight spectral and radiometric properties of AVIRIS. Rigorous error analysis of the field measurements, derived parameters, radiative transfer models and sensor characteristics will be implemented to constrain fully the results of this experiment.

Ref. Number RSS-19

P.I.(s): Miller, J.R./York University

Title: Variation in Radiometric Properties of the Boreal Forest Landscape as a Function of the Ecosystem Dynamics

Objectives and Approach: An airborne Compact Airborne Spectrographic Imager (CASI) will be used to generate reflectance images (1km swath) on up to 8 dates spanning the Feb. to Sept. 1994 period. This database will be used along with AVIRIS, MEIS-II, SSM/I, Landsat and SPOT to determine: (i) image-based methods to obtain surface reflectances from airborne optical imagery, (ii) the effect of temporal/spatial variability of site albedos of the boreal forest in the winter- spring transition on the use of such data in numerical climate simulation models, (iii) the utility of the area and spectral properties of beaver ponds for spatial scaling of measured trace gas emissions, (iv) the role of seasonal changes in understory components to changes in reflectance of open boreal canopies, and (v) the seasonal/temporal variation in closed canopy reflectance as a function of canopy architecture, species composition, canopy biophysical parameters of LAI and biomass, and phenologic development and chemistry of foliar components.

Ref. Number RSS-20

P.I.(s): Vanderbilt, V.C./Ames Research Center

Title: Estimation of Photosynthetic Capacity using Polder Polarization

Objectives and Approach: The overall hypothesis of this proposal is that the ecosystem-dependent variability in the various vegetation indices is in part attributable to the effects of specular reflection. The polarization channels on the French sensor POLDER provide the potential to estimate this specularly reflected light and allow the modification of the vegetation indices to better measure the photosynthetic process in plant canopies. In addition these polarization channels potentially provide additional ecologically important information about the plant canopy. The expected result from this research is a series of map products providing seasonal estimates of 'minus specular' vegetation indices for flightlines at the two BOREAS test sites.

This is a companion effort to TF-6.

4.6.3 Field and Aircraft Measurements

The field and aircraft measurements to be conducted by the RSS group are summarized in Tables below.

Table 4.6.3.a
Measurements acquired by RSS investigators during field campaigns.

BOREAS RSS MEASUREMENTS (IFC-93)

	Southern Study Area						
Measurement	**OA**	**OJP**	**YJP**	**OBS**	**Fen**	**Aux.**	**Water**
Architecture	15	15	15				
Can. H_2O Pot.							
Canopy Chem.	4	4	4	4			
Canopy Cover	16	16	16	16			
Dielectrics	15	15	15				
Height	16	16	16	16			
LAI	4, 7	4, 7	4, 7	4, 7			
Sfc. Roughness	16			16			
Soil Moisture	16	16	16	16			
Soil Temp.	17	17		17			
Veg. Temp	17	17		17			
Xylem Flow				17			
APAR	1	1		1			
Backscatter							
BRDF	1	1		1			
BRF							
FAPAR	7	7	7	7			
optical thick.						12	
PAR albedo	1	1		1			
Scene Temp.							
SW albedo	1	1		1			
Boom Truck							
Aerial Photo.							
AOCI							TE-15
ASAS							
AVIRIS							
CASI							
HELO-opt							
HELO-MW							
JPL SAR	16	16	16	16	16	16	16
MAS							
NS001							
PARABOLA-(old)	1	1		1			
Polder							
sun photometer							

Table 4.6.3.b
BOREAS RSS MEASUREMENTS (IFC-93)

	Northern Study Area					
Measurement	**OJP**	**YJP**	**OBS**	**Fen**	**Aux.**	
Architecture						
Can. H_2O Pot.						
Canopy Chem.						
Canopy Cover						
Dielectrics						
Height						
LAI	7	7	7			
Sfc. Roughness	16		16			
Soil Moisture	16		16			
Soil Temp.	17	17	17	17		
Veg. Temp	17		17			
Xylem Flow	17		17			
APAR						
Backscatter						
BRDF						
BRF						
FAPAR	7	7	7			
optical thick.					11?	
PAR albedo						
Scene Temp.						
SW albedo						
Boom Truck						
Aerial Photo.						
AOCI						
ASAS						
AVIRIS	18	18	18	18	18	18
CASI						
HELO-opt						
HELO-MW						
JPL SAR	16	16	16	16	16	16
MAS						
NS001						
PARABOLA						
Polder						
sun photometer						

Table 4.6.3.c
BOREAS RSS MEASUREMENTS (FFC-W)

	Southern Study Area					
Measurement	**OA**	**OJP**	**YJP**	**OBS**	**Fen**	**Aux.**
Architecture						
Can. H_2O Pot.						
Canopy Chem.						
Canopy Cover						
Dielectrics						
Height						
LAI						
Sfc. Roughness						
Soil Moisture	16	16	16	16	16	
Soil Temp.	17	17	17	17	17	
Veg. Temp	17	17	17	17	17	
Xylem Flow				17		
APAR						
Backscatter						
BRDF						
BRF						
FAPAR						
optical thick.						
PAR albedo						
Scene Temp.						
SW albedo						
Boom Truck						
Aerial Photo.	18	18	18	18	18	18
AOCI						
ASAS						
AVIRIS						
CASI	19	19	19	19	19	19
HELO-opt						
HELO-MW						
JPL SAR						
MAS	Staff					Staff
NS001						
PARABOLA						
Polder						
sun photometer						

Table 4.6.3.d
BOREAS RSS MEASUREMENTS (FFC-W)

	Northern Study Area					
Measurement	**OJP**	**YJP**	**OBS**	**Fen**	**Aux.**	
Architecture						
Can. H_2O Pot.						
Canopy Chem.						
Canopy Cover						
Dielectrics						
Height						
LAI						
Sfc. Roughness						
Soil Moisture	16	16	16	16		
Soil Temp.	17	17	17	17		
Veg. Temp	17	17	17	17		
Xylem Flow	17		17			
APAR						
Backscatter						
BRDF						
BRF						
FAPAR						
optical thick.					11?	
PAR albedo						
Scene Temp.						
SW albedo						
Boom Truck						
Aerial Photo.						
AOCI						
ASAS						
AVIRIS						
CASI						
HELO-opt						
HELO-MW						
JPL SAR						
MAS	Staff	Staff	Staff	Staff	Staff	
NS001						
PARABOLA						
Polder						
sun photomet.						

Table 4.6.3.e
BOREAS RSS MEASUREMENTS (FFC-T)

	Southern Study Area					
Measurement	**OA**	**OJP**	**YJP**	**OBS**	**Fen**	**Aux.**
Architecture	15	15	15	15		
Can. H_2O Pot.	17*	17	17	17		
Canopy Chem.						
Canopy Cover						15
Dielectrics	15,17	15,17	15,17	15,17		15
Height						15
LAI						
Sfc. Roughness	15	15	15	15		15
Soil Moisture	16	16	16	16		16
Soil Temp.	17	17	17	17		
Veg. Temp	17	17	17	17	17	
Xylem Flow				17		
APAR	1	1		1		
Backscatter	1	1		1		
BRDF						
BRF						
FAPAR						
optical thick.						11
PAR albedo	1	1		1		
Scene Temp.						
SW albedo						
Boom Truck						
Aerial Photo.	2,16,18	2,16,18	2,16,18	2,16,18	2,16,18	2,16,18
AOCI						
ASAS	2	2		2		2
AVIRIS	18	18	18	18	18	18
CASI	19	19	19	19	19	19
HELO-opt						
HELO-MW						
JPL SAR	16	16	16	16	16	16
MAS						
NS001	Staff?	Staff?	Staff?	Staff?	Staff?	Staff?
PARABOLA	1	1		1		
Polder						
Sun Photomet.						11
Shuttle Photos	17	17	17	17	17	17

Table 4.6.3.f
BOREAS RSS MEASUREMENTS (FFC-T)

	Northern Study Area					
Measurement	**OJP**	**YJP**	**OBS**	**Fen**	**Aux.**	
Architecture						
Can. H_2O Pot.						
Canopy Chem.						
Canopy Cover						
Dielectrics			17			
Height						
LAI						
Sfc. Roughness						
Soil Moisture						
Soil Temp.	17	17	17	17		
Veg. Temp	17	17	17	17		
Xylem Flow	17		17			
APAR						
Backscatter						
BRDF						
BRF						
FAPAR						
optical thick.					11	
PAR albedo						
Scene Temp.						
SW albedo						
Boom Truck						
Aerial Photo.	16,18	16,18	16,18	16,18	16,18	
AOCI						
ASAS	2	2	2	2		
AVIRIS	18	18	18	18	18	
CASI	19	19	19	19	19	
HELO-opt						
HELO-MW						
JPL SAR	16	16	16	16	16	
MAS	STAFF	STAFF	STAFF	STAFF	STAFF	
NS001	STAFF	STAFF	STAFF	STAFF	STAFF	
PARABOLA						
Polder						
Sun photomet.					11	
Shuttle Photos	17	17	17	17	17	

Table 4.6.3.g
BOREAS RSS MEASUREMENTS (IFC-1)

	Southern Study Area						
Measurement	**OA**	**OJP**	**YJP**	**OBS**	**Fen**	**Aux.**	**Water**
Architecture	19	19	19	19			
Can. H_2O Pot.							
Canopy Chem.							
Canopy Cover							
Dielectrics							
Height							
LAI	7	7	7	7		7	
Sfc. Roughness							
Soil Moisture							
Soil Temp.	17	17	17	17	17		
Veg. Temp	17	17	17	17	17		
Xylem Flow				17			
APAR	1	1		1			
Backscatter	Staff	Staff		Staff			
BRDF	1,2	1,2	2	1,2	1,2	2	
BRF	1	1		1			
FAPAR	7	7	7	7		7	
optical thick.	11?	11?		11?		11,12	
PAR albedo	1,2	1,2	2	1	2	2	
Scene Temp.	1	1		1			
SW albedo	1	1		1			
Boom Truck							
Aerial Photo.	2,16,18	2,16,18	2,16,18	2,16,18	2,16,18	2,16,18	2,16,18
AOCI							TE-15
ASAS	2	2	2	2	2		2
AVIRIS	18	18	18	18	18	18	18
CASI	19	19	19	19	19	19	19
HELO-opt	3	3	3	3	3	3	3
HELO-MW	13	13	13	13	13	13	
JPL SAR	16	16	16	16	16	16	16
MAS							
NS001	Staff	Staff	Staff	Staff	Staff	Staff	
PARABOLA	1	1		1			
Polder	20	20	20	20	20		
sun photometer	12	12	12	12	12	12,11	

Table 4.6.3.h
BOREAS RSS MEASUREMENTS (IFC-1)

	Northern Study Area				
Measurement	**OJP**	**YJP**	**OBS**	**Fen**	**Aux.**
Architecture					
Can. H_2O Pot.					
Canopy Chem.					
Canopy Cover					
Dielectrics					
Height					
LAI	7	7	7		7
Sfc. Roughness					
Soil Moisture					
Soil Temp.	17	17	17	17	
Veg. Temp	17	17	17	17	
Xylem Flow	17		17		
APAR					
Backscatter					
BRDF	1		1	1	
BRF	1		1		
FAPAR	7	7	7		7
optical thick.	11?		11?		
PAR albedo	2	2	1,2	2	2
Scene Temp.			1		
SW albedo					
Boom Truck					
Aerial Photo.	2,16,18	2,16,18	2,16,18	2,16,18	2,16,18
AOCI					
ASAS	2	2	2	2	
AVIRIS	18	18	18	18	18
CASI	19	19	19	19	19
HELO-opt	3	3	3	3	3
HELO-MW	13	13	13		
JPL SAR	16	16	16	16	16
MAS					
NS001	Staff	Staff	Staff	Staff	Staff
PARABOLA	1		1		
Polder					
sun photometer	12	12	12	12	12

Table 4.6.3.i
BOREAS RSS MEASUREMENTS (IFC-2)

	Southern Study Area						
Measurement	**OA**	**OJP**	**YJP**	**OBS**	**Fen**	**Aux.**	**Water**
Architecture	19,15	19,15	19,15	19,15			
Can. H_2O Pot.							
Canopy Chem.							
Canopy Cover							
Dielectrics	15	15	15	15	15		
Height							
LAI	7	7	7	7		7	
Sfc. Roughness	16,15	16,15	16,15	16,15			
Soil Moisture	16	16	16	16	16		
Soil Temp.	17	17	17	17	17		
Veg. Temp	17	17	17	17			
Xylem Flow	17			17			
APAR	1	1		1			TE-15
Backscatter	Staff	Staff		Staff			
BRDF	1,2	1,2	2	1,2	1,2		
BRF	1	1		1			
FAPAR	7	7	7	7		7	
optical thick.	11?	11?	11?	11?		11,12	
PAR albedo	1,2	1,2	2	1,2		2	
Scene Temp.	1	1		1			
SW albedo	1,19	1,19	19	1,19		19	
Boom Truck	19	19	19	19			
Aerial Photo.	2,16,18	2,16,18	2,16,18	2,16,18	2,16,18	2,16,18	2,16,18
AOCI							TE-15
ASAS	2	2	2	2	2		2
AVIRIS	18	18	18	18	18	18	18
CASI	19	19	19	19	19	19	19
HELO-opt	3	3	3	3	3	3	3
HELO-MW	13	13	13	13		13	
JPL SAR	16	16	16	16	16	16	16
MAS	Staff	Staff	Staff	Staff	Staff	Staff	Staff
MEIS	7	7	7	7			
NS001	Staff	Staff	Staff	Staff	Staff	Staff	
PARABOLA	1	1		1			
Polder	20	20	20	20	20		
sun photometer	12	12	12	12	12	12	

Table 4.6.3.j
BOREAS RSS MEASUREMENTS (IFC-2)

	Northern Study Area				
Measurement	**OJP**	**YJP**	**OBS**	**Fen**	**Aux.**
Architecture	15	15	15		15
Can. H_2O Pot.					
Canopy Chem.					
Canopy Cover					
Dielectrics	16,15	16,15	16,17,15	16,15	
Height					
LAI	7	7	7		7
Sfc. Roughness	16	16	16	16	
Soil Moisture	16	16	16	16	
Soil Temp.	17	17	17	17	
Veg. Temp	17	17	17	17	
Xylem Flow			17		
APAR					
Backscatter	13	13	13	13	
BRDF	2	2	2	2	2
BRF					
FAPAR	7	7	7		7
optical thick.	11		11		
PAR albedo	2	2	2	2	2
Scene Temp.					
SW albedo					
Boom Truck					
Aerial Photo.	2,16,18	2,16,18	2,16,18	2,16,18	2,16,18
AOCI					
ASAS	2	2	2	2	
AVIRIS	18	18	18	18	18
CASI	19	19	19	19	19
HELO-opt	3	3	3	3	3
HELO-MW	13	13	13	13	13
JPL SAR	16	16	16	16	16
MAS	Staff	Staff	Staff	Staff	Staff
MEIS	7	7	7		
NS001	Staff	Staff	Staff	Staff	Staff
PARABOLA					
Polder					
sun photometer	12	12	12	12	12

Table 4.6.3.k
BOREAS RSS MEASUREMENTS (IFC-3)

	Southern Study Area						
Measurement	**OA**	**OJP**	**YJP**	**OBS**	**Fen**	**Aux.**	**Water**
Architecture	19	19	19	19			
Can. H_2O Pot.							
Canopy Chem.							
Canopy Cover							
Dielectrics							
Height							
LAI	7	7	7	7		7	
Sfc. Roughness							
Soil Moisture							
Soil Temp.	17	17	17	17	17		
Veg. Temp	17	17	17	17			
Xylem Flow				17			
APAR	1	1		1			TE-15
Backscatter	13	13		13			
BRDF	1	1		1	1		
BRF	1	1		1			
FAPAR	7	7	7	7		7	
optical thick.							
PAR albedo	1	1		1			
Scene Temp.	1	1		1			
SW albedo	1,19	1,19	19	1,19		19	
Boom Truck							
Aerial Photo.	2,16,18	2,16,18	2,16,18	2,16,18	2,16,18	2,16,18	2,16,18
AOCI							TE-15
ASAS	2	2	2	2	2		2
AVIRIS	18	18	18	18	18	18	18
CASI	19	19	19	19	19	19	19
HELO-opt	3	3	3	3	3	3	3
HELO-MW	13	13		13			
JPL SAR	16	16	16	16	16	16	16
MAS							
NS001	Staff	Staff	Staff	Staff	Staff	Staff	
PARABOLA	1	1		1			
Polder	20	20	20	20	20		
sun photometer	12	12	12	12	12	12	
shuttle photos	17	17	17	17	17	17	17

Table 4.6.3.l
BOREAS RSS MEASUREMENTS (IFC-3)

	Northern Study Area					
Measurement	**OJP**	**YJP**	**OBS**	**Fen**	**Aux.**	**Water**
Architecture						
Can. H_2O Pot.						
Canopy Chem.						
Canopy Cover						
Dielectrics	16	16	16	16		
Height						
LAI	7	7	7		7	
Sfc. Roughness	16	16	16	16		
Soil Moisture	16	16	16	16		
Soil Temp.	17	17	17	17		
Veg. Temp	17	17	17	17		
Xylem Flow	17		17			
APAR						
Backscatter	13	13	13			
BRDF	1		1	1		
BRF	1		1			
FAPAR	7	7	7		7	
optical thick.		11?		11?		
PAR albedo			1			
Scene Temp.			1			
SW albedo						
Boom Truck						
Aerial Photo.	16,18	16,18	16,18	16,18	16,18	16,18
AOCI						
ASAS	2	2	2	2		2
AVIRIS	18	18	18	18	18	18
CASI	19	19	19	19	19	19
HELO-opt	3	3	3	3	3	3
HELO-MW	13	13	13			
JPL SAR	16	16	16	16	16	16
MAS	Staff	Staff	Staff	Staff	Staff	
NS001	Staff	Staff	Staff	Staff	Staff	
PARABOLA	1		1			
Polder						
sun photometer	12	12	12	12	12	
shuttle photos	17	17	17	17	17	17

4.6.3.1 Summary of Parameters To Be Measured

Fraction of absorbed photosynthetically active radiation (F_{APAR}), PAR albedo

Deering will use PARABOLA and Ahmed-Deering reflectance model to estimate F_{APAR} from the Old Aspen, Black Spruce and Old Jack Pine Sites. PARABOLA, a multidirectional field radiometer, will be deployed on trams to simultaneously traverse and measure the directional radiance distributions at two levels within and above the forest canopies, while suspended between towers approximately 30 - 40 m apart. Measurements will be acquired at the SSA Aspen, Old Jack Pine and Black Spruce Sites. The measurements will be used by BOREAS investigators to validate physically-based models. Chen (RSS-7) will make extensive canopy measurements of FAPAR and leaf area index to develop an algorithm for retrieval of the spatial distribution of FAPAR. CASI, MEIS aircraft data and Landsat or SPOT satellite data will also be used. Walthall (RSS-3) will use helicopter based spectroradiometer measurements and models to estimate canopy APAR from spectral vegetation indices. Irons (RSS-2) will utilize multiangle ASAS data to estimate hemispherical PAR albedo and F_{APAR} over larger stands including the tower flux sites in both Study Sites. Goel (RSS-5) and Williams/Myneni (RSS-6) will employ radiosity and radiative transfer based models to facilitate understanding of forest canopy and atmospheric effects on estimates of albedo and F_{APAR}.

Species Composition/Forest Type

Aircraft and satellite image data will be used to classify the study areas into important species and/or forest type classes. Ranson (RSS-15) and Saatchi (RSS-16) will employ synthetic aperture radar data for this purpose. AVIRIS, CASI, NS001 and ASAS aircraft data and Landsat and SPOT satellite will be available, as well. It is anticipated that efforts to combine optical and microwave data will improve our ability to identify classes useful for ecosystem models .

LAI

Estimates of LAI will be derived by Curran (RSS-4) for use in the Forest-BGC model in 1993 and by Chen (RSS-7) during 1993 and 1994. Activities will focus on the comparison of methods for the estimation of LAI on the ground. Three methods will be used: LAI-2000, ceptometry and allometry. The main sites for the comparison will be the three radiative transfer 'supersites' SSA old aspen, SSA black spruce and SSA old jack pine although it is intended to visit as many of the auxiliary sites as possible during the field season 9-29th August.(see section 3.4.2.3 of BOREAS Experiment Plan). The sampling will be performed in consultation with the Biometry sub-group. Comparison of methods for estimation of plot leaf area index including LAI-2000, Walkman

(RSS-7), ceptometer and allometry. The LAI-2000 will be used in both pre-sunrise and post-sunset to measure gap fraction based on the blue wavelength region (<490 nm). It is anticipated that three 300m transects of each site will be undertaken with 30 measurements per transect to give a sample size of 90 from which to generate the average plot LAI. Reference light readings will be taken at the start and finish of each transect using (if available) a clear area (3-4x height of canopy in diameter) adjacent to sample site. The walkman currently being developed by RSS-7, will be used at all the flux tower sites (except for the fen sites) in both SSA and NSA. It measures the transmitted direct PAR through the canopy and reflected PAR from the forest floor at an interval of 10 mm along the 300 m transects. The walkman will be used in conjunction with LAI-2000 to improve LAI measurements. The ceptometer will be used this system in tandem with a continuously recording set of 4 quantum sensors (Skye SKP215) which will record incident PAR flux and provide calibration sites for the ceptometer. Measurements will be confined between approx 11am and 3pm for the same transects sampled by the LAI-2000. It may be possible to estimate plot average F_{APAR} from this system if an estimate of understory and canopy reflectance can be provided (see F_{APAR} above). Allometric estimation of LAI is a staff science project, however, if required we will be available to make measurements of DBH. This approach uses destructive sampling to provide data to link tree leaf area (TLA) and DBH. The specific leaf area (SLA) is required for each age class and canopy depth. The tree leaf area can then obtained by summing the product of SLA and dry needle weight for each sampled branch and then weighting each branch leaf area by number of branches in the whorl and summing over all whorls. Alternatively the mean SLA can be used. Plot LAI is then obtained by adjusting the TLA for the tree density and plot area.

Biomass

Stand level biomass estimates will be determined from relationships of known stand biomass and aircraft SAR data by Ranson/Lang (RSS-15). Biomass estimated derived from auxiliary site field measurements and allometric relationships will be used to construct and test a model. In addition component level partitioning of biomass (e.g. bole, branch and leaf) will be investigated by RSS-15 through microwave scattering models and helicopter and ground based scatterometer measurements. The experiment will be performed at nine sites in Prince Albert during the summers of 1993 (limited) and 1994. Three of these sites, one of mature jack pine, one of mature aspen and one of mature black spruce will be co-located with sites of major optical remote sensing activity so that joint efforts in ground truth acquisition can be undertaken. The other six sites will be composed of jack pine, aspen and black spruce but will be of low and medium density. SAR measurements, wideband CW-FM helicopter measurements and ground truth measurements will be made at these sites. The SAR measurements needed are at P, L, C and X bands and at several angles (2 or 3 angles). This will require the simultaneous presence of the NASA JPL SAR (P, L, C) and the CCRS SAR (C, X) aircraft which is planned during the FFC-T and IFC-2 campaigns. These measurements will be used to affect a frequency layered inversion of the forest biomass and structure. Helicopter based wideband L and C band measurements will also be made at the nine sites at several angles of incidence. This will provide scatterometer measurements to cross correlate with the SAR results and provide data for an alternative range dependent inversion methodology. An important part of the experiment is model validation which will be performed using ground truth measurements. It is anticipated that a full range of such data will be provided or obtained at the three major sites. This includes detailed tree geometry measurements (DBH distribution, trunk taper function, branch classes, their angular distribution and curvature statistics, needle and leave counts and, as well as, LAI), P, L, C and X band dielectric measurements at the time of over-flights and ground surface heights profiles, soil classification and ground dielectric measurements. It is anticipated that some of these measurements will be obtained at the other six sites as resources will permit.

Canopy and Soil Moisture

Saatchi (RSS-16) will estimate the water content of the top layer of the forest canopy and surface moisture of the ground. The emphasis here is to acquire parameters required for hydrological models. Primarily SAR data from aircraft and satellites will be used, but optical data analysis is also anticipated. The retrieval algorithms and maps/images of estimated parameters such as the vegetation distribution and water content, surface moisture content, the extend of the snow cover will be delivered to BORIS. The field measurements will be coordinated with E. Levine (NASA/GSFC), R. Harding and J. Stewart (UK), and other microwave groups.

Canopy Chemistry

Canopy chemistry analysis of leaf chlorophyll concentration and leaf nitrogen concentration will be conducted by Curran (RSS-4). In the 1993 field season leaf samples will not be collected for wet chemical analysis owing to problems associated with processing and storage. Instead, to obtain an idea of the distribution of leaf chlorophyll and by implication leaf nitrogen concentration it is intended to invert leaf spectral reflectance data collected by Elizabeth Middleton using the PROSPECT leaf optical model. It is anticipated that the inversion should work adequately for Quaking Aspen but it may not be appropriate for Black Spruce or Jack Pine. The output from this inversion process will be compared to data from the CASI and AVIRIS instruments.

Freeze-Thaw Duration

Way and McDonald (RSS-17) will examine the annual duration of the frost-free period and the period of leaf-on which define the active period of photosynthesis for conifer and deciduous species, respectively. Using synthetic aperture radar (SAR), the environmental and phenologic state can be determined by looking at changes in the backscatter signatures relative to frozen conditions. The environmental and phenologic state will be monitored using AIRSAR and SIR-C/X-SAR data, and the duration of state with ERS-1 and ERS-2 data. The key is SAR's sensitivity to dielectric constant of water and the development of two algorithms called ENV and PHEN which use changes in backscatter and phase relative to winter frozen conditions, and scattering mechanism to uniquely determine environmental and phenologic state. As environmental state changes, the distribution, amount and phase of water in, on and under the forest canopy changes resulting in a dramatic change in the dielectric makeup of the forest and soil layer. To validate the relationship between seasonal state and SAR backscatter, we will install temperature and dielectric sensors, and will work with other BOREAS groups to obtain xylem flow, CO_2 flux, meteorological data and biometry data. A functional group map of both BOREAS sites, a map of the environmental and phenologic state of both sites for each AIRSAR/CCRS SAR and SIR-C/X-SAR overflight, freeze/thaw and leaf on/off dates from ERS SAR data, and improved estimates of the CO_2 flux using the SAR-generated environmental and phenologic states will be delivered to the project.

Radiation Scattering Model Input Parameters

In addition to the most of the biophysical parameters discussed above optical and microwave models require other inputs describing the canopy and scene architecture, canopy component optical and dielectric properties. Several investigations are planning to make some of these measurements as summarized below.

Canopy Architecture

During IFC-3 Ranson/Lang (RSS-15) acquired preliminary tree architecture measurements near SSA OA, OJP and YJP sites. For each site one "representative tree was cut down and measurements of height location, diameter, angle from bole for each primary branch were acquired. Typical primary and secondary branches were identified from the top, middle and bottom thirds of the crown. For these typical branches measurements of total curved length, diameter at mid-points, inclination angle at mid-point, number of leaves/needles and number of next higher order branches. In addition, average leaf/needle dimensions and (length, width) and densities were determined. Similar measurements will be acquired during FFC-T and

IFC-2. A detailed set of canopy architecture are planned for the 1994 field season are described below.

TF Site WAB Transects

A complete set of 60 x 50 m mapped forest plots will be established for all tower flux sites in both SSA and NSA. These plots will be used for 3-dimensional modeling of canopy architecture, characterization of light regimes, indirect measurements of LAI and reconstruction of canopy surface topography. Plots will be installed as a collaborative effort by four science teams: Richard Fournier (RSS-19), Paul Rich (TE-23), Geoffrey Edwards (TE-9), and Jing Chen (RSS-7). Installation and sampling the plots will entail minimal disturbance to the sites. Tentatively, plots will be located in the southeast sector of each tower flux site's wab centered around LAI sampling transects. The mapped sites themselves will be a valuable resource in support of airborne campaigns and for a broad range of field studies and modelling efforts.

The following have been selected from the SSA: Young Jack Pine (YJP), Old Jack Pine (OJP), Old Black Spruce (OBS). We hope to use a dataset build on the OBS plot by TE-20 and supplement it with the missing information for our needs. The sites selected for the NSA are: Young Jack Pine (YJP), Old Jack Pine (OJP), and Old Black Spruce (OBS). Additional sites may be added if time and human resources permit.

For each mapped plot, a 60 x 50 m grid will be marked with stakes every 10 m. All trees within the mapped plots will be mapped and tagged. Stand characterization will include (1) x,y position for all trees, (2) DBH of all trees, (3) statistical sample of tree heights, (height to lowest dead branch, to lowest live branch, and to top of crown), (4) crown characterization into dominant, co-dominant, and suppressed classes, (5) description of the understorey and soil, (6) cover estimate and location of main understorey features, (7) photographic catalog of the gridded area (i.e. general context, trees, understorey and soil), and (8) estimate of the terrain topography. Also the position of nearby landmarks (visible from aerial photos) will be recorded. The sample locations used for hemispherical photography will be the same as those used for optical estimates of LAI (RSS-7). Upward looking hemispherical imagery will be collected with both photographs and a CCD digital camera (see Section 3.2.4.6). The complete data set will be compiled in database, GIS (ARC/INFO and GRID), and hardcopy formats and submitted to BORIS.

The central transects for the optical measurement have been completed (J. Chen). The grid layout and tree labelling (P. Rich, R. Fournier) are scheduled for May 11 to 21 (before IFC-1). The measurements of DBH, heights, XY_grid, understorey characterization, and photograph catalog will take place in the period between IFC-1 and IFC-2 (P. Rich, R. Fournier, and G. Edwards). hemispherical photographs will be collected for each of the three IFCs (P. Rich). Hemisphercal images using a CCD camera will be collected during IFC-2 for sites in the SSA only (R. Fournier).

Tree architecture measurements will be made within three sites (Robert Landry, RSS-19). Even if the exact location of these sites is not identified yet, tree architecture characaterization will be made for Old Jack Pine, Young Jack Pine and Old Aspen at the SSA only. Destructive sampling of three representative trees per target species will be collected. In each site, data collection will be made according to the "vectorization" method. This method involves the acquisition of topologic information and segment position (with a land surveyor instrument) of a significant subsample of the tree elements. This method allows tree reconstruction using computer algorithms and computer graphic models. The vectorization can take place where the trees and ecosystem is judged representative of the WAB or the modelled zone. This effort will take place between IFC-2 and IFC-3 from August 14th to 23rd. Agreements are still to be made with Prince Albert Provincial Park for cutting permits.

Canopy modelling studies for the BOREAS FT sites require a measure of the understorey spectral reflectance properties for each canopy under study and for each of the BOREAS field campaigns. Given the hetrogeneous nature of the understory, a scheme involving relectance measurements of individual understorey components and an estimation of aerial fractions of these components, while of interest was considered too labour intensive an activity. The proposed activity would be complementary to PARABOLA (RSS-1) which can provide spatially-averaged understory reflectance at specific spectral bands and that of other researchers who have proposed detailed spectral characterizations of individual understorey components. Instead researchers associated with RSS-19 will undertake the task of providing a mean understorey spectral reflectance (400nm to 1000nm, limited by available equipment) and standard deviation spectra for each tower site at both SSA and NSA sites for each field campaign. (Limited spectral data collection as described below was initiated at the FFC-W campaign). Understorey spectral reflectance sampling will be carried out at Flux Towers sites along the grid established by Jing Chen (RSS-7). Three parallel grid lines (spacing 10m) have been established running SE from the tower. These lines run along the border of the WAB and are marked at 10m intervals by flags. The line lengths vary from 150 to 300m thus representing 45 to 90 marked grid points. Immediately to the west of each grid point marker a field spectrometer will be used at breast height to acquire radiance spectra, compared to a standard reflectance panel, of (i) representative understory in a sunfleck, (ii) shadowed representative understory. Measurements are to be made under stable clear sky conditions between 10:30 AM and 2:30 PM local time. These measured reflectance spectra for sunlit and diffuse illumination conditions will be used to determine the mean and variance spectra for each site during each BOREAS field campaign.

Optical Measurements of Canopy Components and Understory

(RSS-19 (Miller) will perform leaf/needle reflectance and transmittance measurements with particular emphasis on NSA where the TE group is planning only limited measurements. Limited bi-directional reflectance measurements of shoots will also be conducted. Methodologies consistent with TE-12 will be adopted. In addition, (RSS-19 (Miller) Staenz, O'Neill, Rock) and TE-9 (Edwards, Thomson) will carry out in-situ spectra characterization of the primary understory components to document the seasonal change over the 400 nm to 2500 nm spectral range using field techniques that are currently being developed.

Dielectric Properties of Canopy Components and Ground Surface

Microwave properties by species will be acquired by Ranson/Lang (RSS-15) and Gogenini (RSS-14). These measurements will include dielectric constant at L band (1.25 GHz), C band (5.5 GHz), and perhaps X band (10 GHz) for leaves, stems and boles. Dielectric profiles for stems and boles as a function of depth in the wood will also be acquired. If direct measurements of leaves is not practical mixing models based on moisture content will be used. Dielectric constant of the ground surface is difficult to acquire with available probes, therefore mixing formulae that consider moisture and texture will be used.

Atmospheric Characterization

Markham et al (RSS-11) will estimate aerosol optical thicknesses, water vapor column abundances, *ozone column abundances* at hourly clear daylight intervals during the growing season at three to four sites within the BOREAS supersites during non-IFC periods, more frequent measurements during IFC periods at same stations. (Spring 1994-Fall 1995). The same measurements will be made at 2-3 moveable stations during 3 growing season IFC's. Locations are to be determined based on remote sensing measurements at the sites (to be coordinated with helicopter missions, RSS-3)(1994). Aerosol optical thicknesses and water vapor column abundances will be obtained at Landsat-5, SPOT-2 and NOAA-11/13 overpass times (<45 deg VZA) . Data to be obtained by site managers with hand-held sunphotometers at one location within each supersite (Spring 1993- Fall 1995?) Sky irradiance measurements are to be made at clear daylight hourly intervals in the solar almucanter and principal plane at the automated stations to provide aerosol size distribution phase function when condition permit. (Spring 1994-Fall 1995). Other physical/optical/chemical properties of aerosols based on filter sampling at selected times during IFC's (1994) will be determined. Retrieval of surface reflectances for selected remotely sensed data will be made during 1995 and 1996.

Wrigley et al. (RSS-12) will estimate aerosol optical thickness using data from the Airborne Tracking Sun Photometer aboard the C-130 during summer IFCs. Data will be acquired when the C-130 is on the ground prior to and after optical missions, at very low altitudes over lakes near the sites, during ascents and descents to obtain profiles, and along the flightlines at altitude. In addition, they will estimate aerosol optical thicknesses using data from an automated, 10 channel, ground-based sun photometer located in the southern site, probably at Candle Lake which is the best candidate for one of the very low altitude C-130 passes. Data from both instruments will be acquired in conjunction with all optical remote sensing opportunities (satellite and aircraft) whenever possible. In addition to providing the aerosol optical thicknesses to BORIS, selected "golden day" data will be used to calculate other aerosol optical properties such as aerosol size distributions, aerosol scattering phase functions, and aerosol single scattering albedoes. The aerosol optical properties will be used to provide atmospherically corrected remote sensing data for these "golden days" in 1995 and 1996.

Several investigations will use sunphotometers to provide aerosol optical thickness measurements at sites within the study region in the visible to near infrared region. Most of these instruments will alos measure the total column abundance of water vapor using 940 nm channel. The current deployment plans for these sunphotometers is as follows:

<u>BOREAS Sunphotometer deployment plan 1994:</u>

RSS-11(Markham and Holben):
Handheld Miami instruments (limited clear satellite overpasses):
- Thompson, MB 1/1/94-12/31/94
- Waskesiu Lake, SK 1/1/94-12/31/94

Automatic Cimel instruments with GOES DCP link (daylight measurements with measurements every 15 minutes at minimum)

NSA YJP	5/15/94-10/15/94
Flin Flon Airport	5/15/94-10/15/94
SSA YJP	5/15/94-10/15/94
Waskesiu Lake, SK	5/15/94-10/15/94
Additional site TBD	IFC's

RSS-12 (Wrigley)
Automatic Reagan instrument
- Candle Lake, SK IFC's

RSS-18 (Green and Conel)
Automatic Reagan instruments

AVIRIS/ASAS calibration site (SSA probably near airport) on potential calibration days til calibration achieved each IFC

Tower site with PARABOLA II each IFC until ASAS data acquisition achieved.

RSS-19 (Miller and Oneil)
Handheld Sonitec instruments

Calibration site during IFC 3.
Other TBD sites during IFC 1 and IFC 2

A pre and post season Langley calibration and cross calibration is planned at Mount Lemmon, AZ during April and October 1994.

Sky irradiance measurements will be made using the CIMEL instruments at clear daylight hourly intervals in the solar almucanter and principal plane to provide aerosol size distribution and scattering phase function when conditions permit(RSS-11) The spectral dependence of the aerosol optical thickness will also be used to derive size distributions and the size distributions will be used to determine scattering phase functions and albedos of single scattering(RSS-12)

Other physical/optical/chemical properties of aerosols based on filter sampling may be obtained at selected times during IFC's(RSS-11) Retrieved surface reflectances for selected remotely sensed data will be provided in 1995 and 1996 (RSS-11,12)

<u>Summary of Parameters to be Measured</u>

Optical measurements of canopy components and understory: RSS-19 (Miller) will perform leaf/needle reflectance and transmittance measurements with particular emphasis on NSA where the TE group is planning only limited measurements. Limited bi-directional reflectance measurements of shoots will also be conducted. Methodologies consistent with TE-12 will be adopted. In addition, (RSS-19 (Miller), O'Neill, Rock) and TE-9 (Edwards, Thomson) will carry out in situ spectra characterization of the primary understory components to document the seasonal change over the 400 nm to 2500 nm spectral range using field techniques that are currently being developed.

4.6.3.2 TE/RSS Gridded Parameter and Modeling Initiative

A small workshop of TE and RSS investigators was held July 19-20, 1993 to determine the nature and scope of parameters required by TE models and that can be provided by remote sensing. The role of the Remote Sensing Science group is to use remote sensing technology to develop spatially explicit (i.e., gridded) parameter sets for use in the terrestrial ecosystem and biosphere/atmosphere models in BOREAS.

The RSS group will produce maps of biophysical parameters derived from remotely sensed data for selected areas shortly after the conclusion of 1994 IFC's. Parameter maps will be developed for a 40X50 km area in the SSA containing the OBS, OJP, Fen and YJP Tower Flux sites. In the NSA, a 30X40 km area including all the Tower Flux sites and a gauged catchment will be mapped. Aircraft remote sensing data, including multiangle NS001, ASAS , AIRSAR and CCRS SAR images will be required for the areas. In addition, aircraft flux measurements in a grid pattern are needed for at least three dates during a dry-down period.

These maps will be developed using present state of the art techniques in remote sensing and produce data nominal resolution of 30 m. These 30 m resolution maps can be used as they are, input into TE models, or aggregated to coarser resolutions for study of scaling issues. In addition Tom Loveland will produce AVHRR based land-cover maps at a resolution of 1 km. See also section 3.5.

Several parameters have been identified that are necessary for the execution of the models. In this section the parameters are discussed and the appropriate RSS investigation is identified. See also Section 4.6.3.1

Parameters in priority order are:

1. Species Composition/Forest Type

Classes identified for Species/type mapping are Deciduous (mostly aspen and birch or mixtures), Conifer (mostly jack pine and black spruce or mixtures), Jack pine-dry, Fen, Mixed deciduous and conifer and Disturbed. Where possible, subclasses will be identified with remote sensing. For example, for the mixed class three sub-classes might be 20-40% deciduous, 40-60% deciduous, and 60-80% deciduous. Within the disturbed category three age or density classes may be possible, e.g., <10 years , 10 -40 years and >40 years. Aircraft and satellite image data will be used to classify the study areas into these species and/or forest type classes. BOREAS staff at GSFC (Hall) and USGS (Loveland) are preparing forest classifications for the two areas. Ranson (RSS-15), Saatchi (RSS-16) and/or Way (RSS-17) can employ synthetic aperture radar data to assist if necessary. AVIRIS, CASI, NS001 and ASAS aircraft data and Landsat and SPOT satellite are available, as well.

2. Fraction of absorbed photosynthetically active radiation (F_{APAR}),LAI

Using helicopter (Walthall RSS-3) and ground data collected at the flux and auxiliary sites along with canopy reflectance models relationships between Spectral Vegetation Indexes and F_{APAR} and LAI will be developed for each vegetation type (e.g., Deering (RSS-1, Curran RSS-4, Chen RSS-7)). BOREAS staff and Chen et al (RSS-7) will use these relationships along with the reflectance data and classification images to produce Fpar and LAI maps. Previous work in the boreal forest indicates that it is difficult to get a good value for LAI for aspen stands. LAI accuracy for these maps may be on the order of 33%. Hall will use mixture decomposition techniques to estimate fraction of sunlit canopy and radiative transfer models to estimate Fpar from function of sunlit canopy.

3. Biomass

Stand level biomass estimates will be determined from relationships of known stand biomass and aircraft SAR data by Ranson/Lang (RSS-15). Biomass estimated derived from auxiliary site filed measurements and allometric relationships will be used to construct and test a model. In addition component level partitioning of biomass (e.g. bole, branch and leaf) will be investigated by RSS-15 through microwave scattering models and helicopter and ground based scatterometer measurements. Saatchi (RSS-16) will contribute to this effort through analysis of canopy moisture. Hall (TE18) will use mixture decomposition to estimate fraction of shadow and sunlit background and will use radiative transfer models to relate these parameters to biomass, LAI, NPP.

4. Canopy Temperatures

Running et al. (RSS-8) will estimate surface temperatures, as monitored by the meteorological tower network planned for each site, and related to both aircraft (ER-2 MAS and/or C-130 NS001?) and satellite (TM,AVHRR) measured thermal emittances. The BOREAS staff and Markham (RSS-11) will atmospherically correct and evaluate radiometric temperature measurements by comparing them to lake surface temperature measurements acquired from a boat.

5. Albedo

Shortwave hemispherical albedo is important for energy budget relationships in the TE model. As a spectrally and hemispherically integrated quantity it can not be directly measured. Albedo maps, however, can be produced through modeling by using a combination of the reflectance data and a classification map. Bidirectional reflectance data from PARABOLA and ASAS can also be used in conjunction with the radiative transfer models (e.g., Goel (RSS-5) and Myneni (RSS-6) to help validate the algorithms.

6. Downwelling PAR, Downwelling Shortwave Radiation

The investigation of Eric Smith (RSS-13) is proposed to determine downward PAR and SW flux from GOES data at half- hour intervals and at a resolution of 1 km.

7. Stand Structure/Successional Stage

Remote sensing derived maps of stand structure will be provide as a BOREAS staff activity. Mixture modeling techniques will used to estimate the percentages of sunlit canopy, sunlit background and shadow within a pixel. Multi-year dynamics of the region will be produced by the analysis of multi-year Landsat data. Recent TM imagery can be compared to another image collected several years earlier using radiometric rectification. The classification maps from both registered images can be compared and a map of the successional transitions over that time period can be produced.

8. Freeze-Thaw Duration

Way and McDonald (RSS-17) will examine the annual duration of the frost-free period and the period of leaf-on which define the active period of photosynthesis for conifer and deciduous species, respectively. Using synthetic aperture radar (SAR), the environmental and phenologic state can be determined by looking at changes in the backscatter signatures relative to frozen conditions. The environmental and phenologic state will be monitored using AIRSAR and SIR-C/X-SAR data, and the duration of state with ERS-1 and ERS-2 data

9. Canopy and Soil Moisture

Saatchi (RSS-16) will estimate the water content of the top layer of the forest canopy and surface moisture of the ground. Primarily SAR data from aircraft and satellites will be used, but optical data analysis is also anticipated.

Schedule

The goal of this exercise is to have preliminary TE model results for review by the BOREAS science community by December 1, 1994. In order to meet that deadline, parameter data sets provided by the Remote Sensing Science Groups and BOREAS Staff must be developed, implemented in the BOREAS grid (see section 4.3.4.), and disseminated to TE investigators by October 15, 1994. The caveat arising from this tight deadline is that the products will be the best available, but are not infallible. A TE/RSS working group to oversee the implementation and delivery of this data set will be formed by Joe Landsberg (NASA HQ). Volunteers are welcome.

Future Studies

Following the production of the above set of parameter maps, future RSS studies and products fall into two categories: (i) improved algorithms and (ii) scaling studies. In the following, we will discuss improved algorithms in terms of optically-based algorithms and microwave-based algorithms. An effort involving joint optical-microwave algorithm and development remains to be designed and will be a major focus of the next few months activity.

(i) Improved algorithms

Optical

The focus here will be on the use of multi-angle, multi-date data sets to simultaneously infer the several biophysical properties that influence reflectance in the optical regions. These approaches can involve the inversion of radiative transfer models for these parameters, using multiple band, multiple look angle, multi-date data, or the development of vegetation indices (other than NDVI or SR) to reduce the effects of background variables. Four investigations will focus on the improved algorithms: RSS-5, Narendra Goel will focus on the inversion of a three-dimension radiative transfer model to estimate Fpar and other structural parameters, as well as investigate the use of different vegetation indices. RSS-8, S. Running will develop algorithms to use various spectral vegetation indices based on MODIS bands to map land cover classes and structural parameters such as LAI. TE- 18, Forrest Hall will investigate the use of the multi-angle, data sets available from AVHRR to infer Fpar, and mixture modeling to infer stand structural parameters.

Microwave

Component biomass of single specie forest stands will be obtained by using a discrete scatterer model. When this model is employed, needles, branches, and trunks are represented by appropriate sized cylinders while dielectric discs are used for leaves. The inversion process makes use of SAR data to determine the size, density, and orientation statistics of these scattering elements. To simplify the inversion procedure, allometric relationships between element characteristics are used. For example, if the species and average DBH are known, then an empirically measured allometric relation can be employed to determine the branch size distribution. This greatly simplifies the inversion procedure.

Initially, X Band data from the CCRS SAR will be used to determine needle and leaf characteristics. At this frequency, the signal does not penetrate deeply into the canopy, thus further simplifying the inversion process. Making use of these simplifications, an inversion routine will be developed for average leaf or needle area. By considering lower SAR frequencies (NASA/JPL C, L, and P Bands) successive canopy parameters are obtained. From a C/L band inversion, leaf or needle density, as well as the branch distribution can be found. P band frequencies can be used to determine forest height along with surface moisture.

The above procedure makes many assumptions, some of which may not be satisfied for certain stands. Optical and other remotely sensed data, as well as apriori knowledge of the ecological composition of the stands will be used wherever possible to simplify the inversion methodology. Once the structural parameters have been sensed, quantities such as component biomass, i.e., the biomass of boles, branches and leaves or needles can be computed, as well as LAI.

Other topics of importance are modeling of the freeze/thaw transition, inversion procedures for open canopy stands and the treatment of mixed species patches. The application of the inversion process of mixed stands will be important when up-scaling from patch to regional characteristics.

(ii) Scaling studies

All the algorithms will be evaluated for their scale dependence. To accomplish this, both vegetation indices and reflectance-derived biophysical parameters will be mapped at 30 meters and their performance investigated. Then, satellite and aircraft-acquired spectral data will be aggregated to lower spatial resolutions (e.g. 250, 500, 1000m) and the algorithms reapplied and the result compared to the 30 meter products to look at the effects of spatial resolution on performance The aggregated products will include individual band reflectances, vegetation indices and derived parameters, and will be available to the TE and other models that use spectral and other remote sensing-derived inputs, to investigate the effect of scale on TE model performance.

4.6.3.3 Data to be Submitted to BORIS (Deliverables)

Table 4.6.3.3 summarizes the data to be submitted to BORIS by the RSS group.

Table 4.6.3.3
RSS Group Deliverables

Investigation	Deliverables
RSS-1	Validation of Ahmad-Deering model; FPAR, albedo. Test hypothesis that the bidirectional reflectances for PAR obtained at a radiation-weighted time mean solar zenith angle provide a good estimate of the time-weighted mean fraction of absorbed PAR.
RSS-2	ASAS multi-angle, multispectral (62 VIS/NIR bands), radiometrically corrected at-sensor radiance digital images of selected 1km^2 locations. Limited number of tables of area-averaged at-surface bidirectional reflectance factor spectra, hemispherical reflectance spectra, area-averaged values for PAR hemispherical reflectance, and various vegetation indices.
RSS-3	Mean radiance for each site, mean reflectance factors, documentation including GPS derived coordinates, FOV, video tape during collection, sun photometer derived optical thickness from surface and at altitude during radiometer operations, barometric pressure measurements. Surface temperature
RSS-4	Leaf nitrogen, chlorophyll concentrations, LAI, tree DBH and % canopy cover for several plots within one prime study sites in 1993.
RSS-5	Determination canopy architecture effects on FAPAR and NDVI, Methods to simplify canopy structure in models.
RSS-6	Computer codes that simulate canopy bidirectional reflectance, radiation absorption, top of the atmosphere reflectance and, canopy photosynthetic and stomatal conductance rates where applicable. The package will also contain inversion schemes based on merit function minimization and neural networks. Complete documentation and help with implementation.
RSS-7	Retrieval of spatial distributions of LAI from vegetation indices. LAI and FAPAR measurements.
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). Final global boreal mapping product to be delivered to BORIS.
RSS-9	Algorithms for detection of vegetative stress from multi-temporal, fine spectral resolution data.
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-13	X,C, and L band scatterometer data for transect runs over Old Aspen, Young Jack Pine, Old Jack Pine, Black Spruce and selected auxiliary sites.
RSS-14	GOES derived surface net radiation field for BOREAS Grid.

Investigation	Deliverables
RSS-15	Algorithms for extraction of boreal forest biomass information at local and regional scales. Maps of Southern and Northern Super Sites showing estimates of above ground biomass for leaf-on, leaf-off conditions. Maps of forest spatial patterns, i.e., gaps, openings and fragmentation. Stand level partitioning of biomass into bole, branch and leaf components.
RSS-16	AIRSAR images collected during the IFC's will be processed and calibrated. Retrieval algorithms and maps/images of estimated parameters such as the vegetation distribution and water content, surface moisture content, the extent of the snow cover. •Inversion algorithms •Hydrological model sensitivity analysis
RSS 17	Bole, root and soil temperature-Oct. 93-Oct. 94 (5 sites) Xylem flow-Oct. 93-Oct. 94 (3 sites) ERS-1 multitemporal image data Vegetation classification maps derived from ERS-1, JERS-1, SIR-C/X-SAR and AIRSAR Freeze/thaw classifications vs time derived from ERS-1 SAR data
RSS-18	Radiometrically and spectrally calibrated AVIRIS data.
RSS-19	CASI spatial and spectrometer mode imagery converted to surface reflectances images for all tower sites for all FFCs and IFCs. Reflectance imagery and/or site average reflectance spectra for selected auxiliary sites, and for transects across several lakes near PA to be selected by TE-15.
RSS-20	Map products providing seasonal estimates of 'minus specular' vegetation indices.

4.6.4 Supporting Measurements

4.6.4.1 RSS Group Data Needs

RSS Group needs from other scientists are summarized in Table 4.6.4.a, and needs from the support staff are summarized in Table 4.6.4.b.

Table 4.6.4.a

Needs from Other Scientists

Investigation	Requirements
RSS-1	Required measurements include reflected solar radiation, global radiation, direct solar radiation, diffuse solar radiation, incident PAR, and longwave radiation at flux tower locations. Also required at each of 3 RSS-1 sample sites are LAI, lead and bole optical properties, biomass and understory biophysical characteristics.
RSS-2	Multi-angle bidirectional reflectance factor spectra from field and helicopter borne spectroradiometer, Field measurements of canopy PAR hemispherical reflectance and FPAR, Multispectral aerosol optical thickness from field based sun photometer and sun photometer on C-130.
RSS-4	Precipitation, Max/Min air temperature, dew point, shortwave radiation (ABL), Soil type, vegetation type distributions, soil water capacity (TE), Snow pack duration, distribution, (HYD), Airborne remotely sensed data per proposal, ideally corrected to reflectance (RSS), DEM,LAI and vegetation cover, plot location and boundary maps (BORIS)
RSS-6	Experimental data to parameterize the model. Data of surface reflectance (ground, aircraft and satellite level), PAR and solar radiation absorption, canopy photosynthetic and stomatal conductance rates to validate the model.
RSS-7	CASI data (spatial and spectral mode) radiometrically calibrated and geocoded so reflectance can be computed, over examined stands. Laboratory spectral measurements of different overstory and understory species and background. MIES II images with different pixel resolutions over examined stands, also fully calibrated and registered, coincident with LAI and APAR measurements. Dimensional analysis of trembling aspen including direct estimate of LAI over time during growing season. Detailed stand biometrics.
RSS-12	Aerosol physical properties (index of refraction, size distribution, chemical composition -- in order of importance), water vapor profile, surface radiances and reflectances at known sites, and level 1 image data with associated ancillary data.
RSS-16	Vegetation related needs: Special classification at each BOREAS site (type, age, area of uniform stand, successional state), Surface topography, structural parameters (DBH, height, crown length, crown projected area, proportional tree area, branch size and density, branch angular distribution), LAI, Canopy water content, plant water potential (top layer of canopy), Biomass, Temporal dielectric profile, Xylem flow measurement, Temperature, Freeze/thaw properties Soil related needs: Soil type and bulk density, Soil moisture, Roughness profile, Snow cover (depth, liquid water content), Biomass or water content of the understory and vegetation in open areas, Soil surface temperature.

Investigation	Deliverables
RSS- 17	1.Soil Moisture 2.Biometry (obtained once only) Stand geometry description including: Stand density, DBH, trunk height, crown shapes/sizes, branch number density, branch sizes and orientations, LAI, leaf/needle size, understory and ground cover, 3.Moisture (obtained weekly all year and daily during FFCs and IFCs); Vegetation water content, Soil moisture content, 4.Continuous measurements: CO_2 flux, water potential(during FFC, IFCs) 5.Met Data: temperature, relative humidity, snow depth, rainfall, PAR, wind
RSS-19	Surface and radiosonde meteorological data from AFM-5 & AFM-7 will be needed to provide above canopy measurements of: atmospheric pressure, relative humidity, wet and dry bulb temp., winds, total integrated water content.
RSS-20	Level 2 polarization data of test sites (POLDER). Ground truth of test sites: maps showing dominant species, LAI, biomass, stocking density, canopy height, average crown diameter, Level 2 TMS data - or equivalent- of test sites, maps of NDVI and SR of test sites.

Table 4.6.4.b
Needs From Staff

Investigation	Requirements
RSS-1	Auxiliary towers and cabling system for trams between flux towers and auxiliary tower ~40-50 m apart with power for motorized tram system conveyance.
RSS-2	Fixed wing aircraft platform for ASAS.
RSS-7	NOAA/AVHRR images (fully calibrated and registered). Dimensional analysis of coniferous trees including direct estimate of LAI.
RSS-8	Carbon flux measurements, water flux measurements, land cover maps, LAI map from ground study, snow pack maps.
RSS-11	Access, space and power at several sites for the automated sunphotometers. Require clear view of full sky to within 5 degrees of horizon. Limited power required (120 volts/60 HZ /<<100 watts). Prefer to be at high priority sites for other investigators. Permission for data transmission through GOES satellite. Personnel to check automated sites on a regular basis. Personnel to take optical depth measurements with sunphotometers at times of satellite overpasses (1993-1994). Radiosondes, Satellite remotely sensed data (SPOT-HRV, Landsat-TM, NOAA-11/13 AVHRR), Aircraft remotely sensed data (Helo, AVIRIS, ASAS, others as available), ground reflectance/temperature data.
RSS-12	AVIRIS, Landsat, SPOT, ASAS, and N5001 Level 1 Data
RSS-15	Tested allometric relationships for important forest species, drying ovens. Interface with local labor for forest plot sampling (short term use of several DBH tapes, hippsometers and 25m tape measures for sampling teams would be helpful.) Access to trees sacrificed for tower construction immediately upon felling. Chain saw.
RSS-19	Records of ground GPS stations operated at each of the PA and NH sites during all FFCs and IFCs to permit differential-mode georeferencing of airborne imagery. Digitized photographs (from color IF photography on C-130 Aug 93 campaign?) with "official" locations of tower sites and auxiliary sites outlined for use in site information extraction from RS imagery. High resolution aerial photography (scale 1:3,000) of tower sites.
RSS-16&17	Meteorological data (TF sites, AMS sites) Net radiation (W m^{-1}) above canopy Net radiation (W m^{-1}) at forest floor Leaf or branch xylem water potential status (MPa) diurnals during FFCs and IFCs (hourly); pre-dawn and mid-afternoon from Aug. 93-94 Observer report 1:250,000 1:50,000

4.6.4.2 RSS Group Infrastructure Needs

Access Requirements

Deering (RSS-1) requires auxiliary towers and cabling above canopies (3) and below canopies (at forest floor) to support PARABOLA tram system. **(Completed)**

Power Requirements

Deering (RSS-1) requires 120 VAC power at flux towers where PARABOLA trams are located. **(Completed)**

Way/MacDonald need 120 VAC line power, or 12VDC from two dry lead batteries (60-100Ah capacity) at SSA-OBS, NSA-OBS, SSA-OA. Also need access to 12 data logger channels for each tower site from Aug. 93-94.

Additional Needs

Chen (RSS-7) requires drying ovens, oven thermometers, refrigeration space (1-2 m^{3}), lab weighing scale ($\pm$ 0.005 gr), lab. space for AgVision System to measure leaf areas and shoot ratios. **(Partially completed)**

Ranson/Lang (RSS-15) have similar lab requirements for weighing and drying smaller amounts of leaf and branch samples. **(Partially completed)**

Aircraft Data

See sections 3.3.2 and 5.2.

Satellite Data

ERS-1

ERS-1 data are plentiful over the BOREAS sites and the majority of the accessible ERS-1 coverage has been collected and is being processed at the Alaska SAR Facility (ASF). The data are also being collected and processed by Canada. Our plan assumes data only from ASF however we are happy to address options for obtaining some data from Canada.

Table 4.6.4.3 summarizes the accessible data over the BOREAS sites for August 1991-August 1993. TA portion of this data set will be processed and distributed in early FY94. Similar coverage will continue throughout 1994, these data will be processes as the are acquired.

Table 4.6.4.2
Accessible ERS-1 Data for BOREAS, 1991-1993

Site	Coverage Frequency	Transect/Scene Length	Number of Scenes per Year
Low Resolution(100m) Prince Albert	Daily transects of 1000 x 1000 km area 17-day maps of 1000 x 1000 km area	1000 km	4000*
Nelson House	Weekly night transects of 1000 x 1000 km area	1000 km	
	Total Low Res		1560
Full Resolution (30m) Prince Albert	Monthly Day Time (6 scenes)	100 km	72
Nelson House	Monthly Day Time (1 scene)	100 km	12
	Total Full Res		84*

*Subset will be selected for analysis

A subset of the accessible data will be processed and analyzed based on actual seasonal transitions. These data sets would be mosaicked together, documented and delivered to BORIS. From the transects, freeze/thaw state will be derived and delivered to BORIS.

JERS-1

JERS-1 data have been requested from the JERS-1 Validation Project. The planned data acquisitions are for one scene at each site for each FFC/IFC, thus only 12 scenes will be analyzed. This limited data set is based of the JERS-1 mission strategy of mapping the world as opposed to providing multitemporal data sets.

SIR-C/X-SAR

The SIR-C/X-SAR mission currently includes the BOREAS sites as backup supersites (2nd highest priority). Both the Prince Albert and the Nelson House sites are included. There are many options for coverage scenarios. An initial plan includes multitemporal data at 60º at Prince and 25º-30º at Thompson throughout the mission and multi-data from Prince Albert. Once the BOREAS super and superduper sites have been selected, the SIR-C/X-SAR coverage will be adjusted. We are currently requesting L-and C-band quad pol data and X-band VV. The approximate swath width is 20 km (varies with incidence angle).

Optical Satellite Data

Group Investigators will also need AVHRR, Landsat TM and Spot digital image data. Specific requirements are to be determined with BOREAS staff, see also Section 3.3.1.

4.6.5 Next Steps

4.6.5.1 1993 Activities

Among the issues that remain to be addressed are:

(i) identification of "remote sensing science sub sites" with species and density differences suited to testing both optical & microwave remote sensing interpretation algorithms/models. **(Completed: auxiliary sites)**

(ii) how do we proceed with the arrangements for accommodations at the 2 sites, space for laboratory facilities, part time personnel at NSA and SSA who could assist with field data collection in 1993 and 1994, coordination of aircraft flights in and out of the area. **(Completed: see Chapter 5)**

Need to know availability of extra data logger channels at tower sites to accommodate add-on instruments.

4.6.5.2 Internal Organization

RSS Group Chair - K. Jon Ranson NASA/GSFC

Rapporteur - John Miller - York University

BORIS Representative - Don Deering NASA/GSFC

Subgroups
Biometry - RSS Group members - Alan Strahler Boston - Univ. (Chair), Roger Lang - George Washington Univ., Margaret Penner - PNFI.

Tree Architecture and LAI - K. Staenz (Chair), R. Landry- CCRS, M. Penner-PNFI, R. Fournier - CCRS, M. Penner - PNFI.

1993 RSS Equipment Installation JoBea Way (Chair)

Calibration Sites/Atmospheric Calibration Experiment Rob Green (Chair)