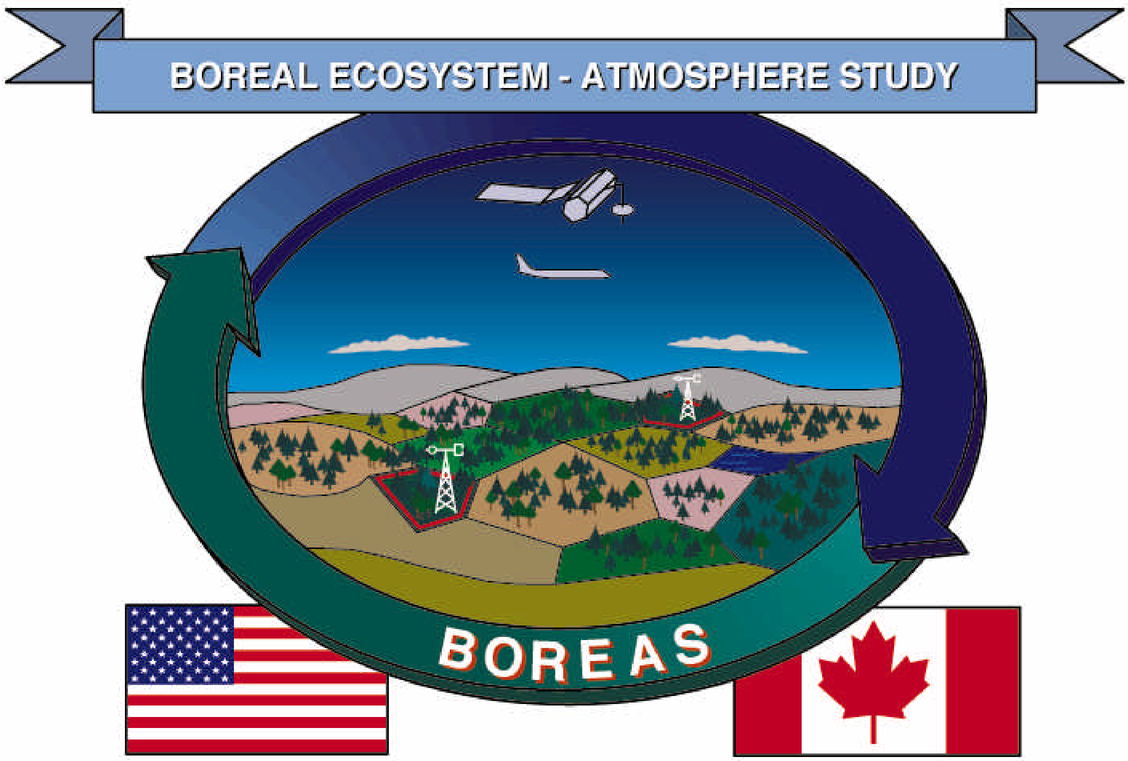
BOREAS
Experiment Plan



Chapter 1-3
Introduction
Analysis and Planning Activities
BOREAS-96 Field Activities

May 1996 Version 2.0

BOREAS Executive Summary

This document is the Experiment Plan (EXPLAN-96) for BOREAS field operations to be conducted in 1996 (BOREAS-96). This work will consist primarily of a set of extended eddy correlation (H, LE CO_2) measurements at a number of tower flux sites from March through November 1996, supported by ecophysiological, hydrological, and biogeochemical observations. There will be a small winter campaign (FFC-W) to explore the physics of remote sensing over snow-covered forests, and three growing season field campaigns (thaw, midsummer, fall) in which the bulk of the in situ measurements and aircraft operations (airborne remote sensing and flux measurements will be concentrated.

Chapter 1 reviews the science issues and objectives of BOREAS; the overall design of the field observation component of BOREAS; the field operations and some preliminary results from BOREAS-94; and the shortcomings of the BOREAS-94 data set. The last item provides the motivation for the return to the field; i.e. for BOREAS-96.

Chapter 2 reviews the analyses and planning activities that took place in the period 1994-1995. These resulted in three white papers which are summarized in the text.

Chapter 3 describes the field operations planned for BOREAS-96. These are based directly on the requirements from the white papers summarized in Chapter 2. Chapter 3 is divided into six sections: overview; monitoring; NSA growing season studies; SSA growing season studies; and AFM and RSS growing season activities.

Chapter 4 describes operations procedures; the facilities to be made available by the project; and the schedules for site support.

Chapter 5 describes the aircraft operations. Complete summaries of all the mission plans for all the BOREAS-96 aircraft are included.

Chapter 6 provides a "quick look" summary of field campaign objectives, including tables showing which teams and aircraft will be present during IFC's.

Chapter 7 describes emergency procedures in case of accidents in the field.

Appendices A-H contain further details on investigator contact information; shipping and customs; data documentation; references; satellite overpass schedules; team activity write-ups; directions to BOREAS auxiliary sites, and an acronym list.

BOREAS Experiment Plan 1996

Table of Contents

Appendices A-H

1. INTRODUCTION

1.1 Background Science Issues and Objectives of BOREAS

The Boreal Ecosystems Atmosphere Study (BOREAS) is a large-scale, international investigation focused on improving our understanding of the exchanges of radiative energy, heat, water, CO_2 and trace gases between the boreal forest and the lower atmosphere. A primary objective of BOREAS is to collect the data needed to improve computer simulation models of the important processes controlling these exchanges so that scientists can anticipate the effects of global change, principally altered temperature and precipitation patterns, on the biome.

The scientific issues at stake are as follows:

I. **Sensitivity of the boreal forest biome to changes in the physical climate system.** A number of simulation studies have been carried out to assess the climatic impact of increasing atmospheric CO_2, see the reviews of Schlesinger and Mitchell (1987), Harrington (1987) and Houghton et al. (1990). Many of these studies indicate that the greatest warming engendered by increasing CO_2 will occur at higher (45°N-65°N) latitudes with the most marked effects within the continental interiors; for example, the doubled-CO_2 experiment of Mitchell (1983) produced differences of 3K to 10K in the mean winter surface temperature for much of the land surface area of this zone. Other studies have indicated that there may be significant warming and drying in the summer months in the same region. Studies by Davis and Botkin (1985) and Solomon and Webb (1985) suggest that this warming and drying could modify the composition and functioning of the boreal forest, see Figure 1.1.

II. **The carbon cycle and biogeochemistry in the boreal forest**. The study of Tans et al. (1990) was one of the first to present evidence for the existence of a large terrestrial sink for fossil fuel carbon in the mid-latitudes of the Northern Hemisphere. This has since been followed by the work of Denning et al. (1995) and Ciais et al. (1995) whose results indicate that this sink may be larger than previously estimated, on the order of 2-3 GtC/year for 1992-1993, for example. The exact mechanisms involved and the spatial contributions to this sink are as yet unknown, but the implication is that carbon is being stored in either living tissue or in the soil. However, any sustained increase in surface temperature, combined with changes in soil moisture, could result in changes in the cycling of nutrients in the soils with associated releases of CO_2, CH_4 and other trace gases from the surface. If this occurs on a large enough spatial scale, the oxidative capacity of the lower atmosphere could be significantly altered. Additionally, changes in the temperature and moisture regime could alter the biomes exposure and response to discontinuous disturbance, i.e. fire

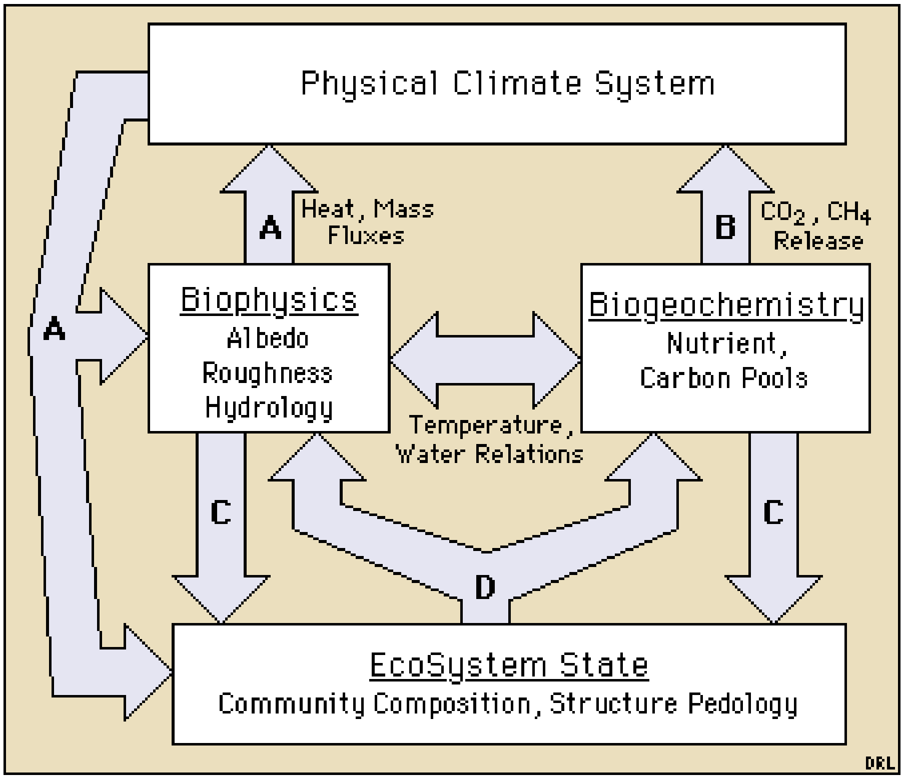


Figure 1.1 Important interactions between the boreal forest and the atmosphere with respect to global change

(A) Influence of changes in the Physical Climate System on biophysical processes. These may feedback to the atmosphere through changes in energy, heat, water and CO_2 exchange.

(B) Changes in nutrient cycling rates; release of CO_2 and CH_4 from the soil carbon pool back to the atmosphere.

(C) Changes in biogeochemical processes and water and nutrient availability influence community composition and structure.

(D) Change in species composition results in changes in surface biophysical characteristics and biogeochemical process rates.

frequency, which could substantially affect the carbon cycle within the biome. As yet, we do not know enough about the processes which control the carbon cycle to be able to predict or even to simulate the carbon source/sink dynamics within the region.

III. **Biophysical feedbacks on the physical climate system**. Research work has indicated (See I. above) that changes in the ecological functioning of the biome could be brought about by changes in the physical climate system. It is anticipated that these may be accompanied by alterations in the biophysical characteristics of the surface; namely albedo, surface roughness and the biophysical control of evapotranspiration (surface and internal resistance). Any changes in these may have feedback effects on the near-surface climatology (temperature, humidity, precipitation and cloudiness fields), see Sato et al. (1989), Bonan et al. (1992, 1995).

These scientific issues provided the motivation for the design and execution of a cooperative field experiment involving elements of land surface climatology, biogeochemistry and terrestrial ecology with remote sensing playing a strong integrating role. A coordinated multidisciplinary approach to the design of BOREAS was adopted from the outset to ensure the maximum benefit from each discipline's participation, see Sellers et al. (1994).

The immediate experimental phase of BOREAS was planned to run over two to three years, 1993-1996. Obviously, this is too short a period for us to directly measure the ongoing effects of global change but it should allow us to observe important processes under a wide range of conditions so that we can develop and test key process models. The experimental strategy was specifically directed toward this: measurements were to be taken throughout the annual cycle and at a variety of 'representative' sites to capture the range of significant climatic, edaphic and ecophysiological conditions to be found within the biome. Initially, these measurements will be used to improve our models and apply them over large areas to see how well we can describe the present situation. If this can be done convincingly over one or two annual cycles, then we will have more confidence in applying them as predictive tools to address the scientific issues listed above. In addition, the knowledge gained should enable us to design better, more cost-effective long-term monitoring programs to track future changes in the biome. The governing objectives of BOREAS can therefore be stated as follows:

(I) **Improve the process models which describe the exchanges of radiative energy, water, heat, carbon and trace constituents between the boreal forest and the atmosphere**.

Our approach here is to measure the fluxes of energy (radiation, heat) and mass (water, CO_2 and important trace gases) over a wide range of spatial scales together with observations of the ecological, biogeochemical, and atmospheric conditions controlling them. These data will be used to develop and thoroughly test process models before we apply them to the 'global change' issues described above.

As defined in late 1992, the plan was to start out with a focus on validation and improvement of local-scale energy balance, mass balance and biophysical process models that operate at relatively short time scales (seconds to seasons) and which are amenable to measurement within a two-year field program. The results of this effort will also be useful for the study of ecosystem level dynamics and land surface/climate interactions at regional and local scales over longer time periods (years to decades).

The field observations which support this model development work include measurements of water, CO_2 and trace gas fluxes at the plot or leaf-scale (chambers, porometers), the stand scale (tower-mounted devices) and the mesoscale (airborne eddy correlation). These measurements were coordinated with a series of ecological, meteorological and edaphic observations which link these fluxes to appropriate state variables.

(II) **Develop methods for applying the process models over large spatial scales using remote sensing and other integrative modeling techniques**.

The process studies described in (I) above have been coordinated with remote sensing investigations using satellite, airborne and surface-based instruments which focus on methods for quantifying the critical state variables. These remote sensing studies, combined with mesoscale meteorological studies, will allow us to scale-up and apply the process models at regional and ultimately global scales. Some large-scale validation techniques were incorporated in the experiment design to test our scale-integration methods directly. These techniques include airborne eddy correlation, meteorological observations and modeling.

Further details on the design of BOREAS may be found in Sellers et al. (1995), and in the BOREAS Experiment Plan, (Sellers et al.; 1994), hereafter referred to as EXPLAN-94.

1.2 Experiment Design

The principal objectives of BOREAS defined in (I) and (II) above relate to two different spatial scales that must be reconciled within the experiment design. The primary focus of objective I is best addressed by local scale (a few centimeters to a few kilometers) process studies which involve detailed coordinated in-situ observations; e.g., leaf and soil plot scale, CO_2 and water flux measurements, and tower-mounted eddy correlation. These local-scale studies have to be connected to the larger-scale measurement and analysis tools associated with objective II which is directed toward defining regional-scale (10 to 1000 kilometers) fluxes and states. In BOREAS, as in previous field experiments such as FIFE (Sellers et al.; 1992) and HAPEX-Sahel (Goutorbe et al.; 1994), the science team adopted a nested multiscale measurement strategy to integrate observations and process models over a wide range of spatial scales, see Figure 1.2a.

The overall goals of the project emphasize the need to study the biome's biophysical, chemical and ecological functioning under different conditions. The governing climatological variables controlling these in the biome are temperature (associated with length of growing season, radiation budget, etc.) and moisture availability (associated with precipitation, snow hydrology and surface hydrological processes). Essentially, the northern ecotone (transitional boundary) of the forest is delineated by temperature (growing degree days) while the southern boundary is determined by moisture stress and fire frequency in central and western Canada, and by ecological competition with temperate deciduous forest to the east of the Great Lakes. Also, in most of Central Canada, agriculture has pushed up to the southern boundary of the forest. Most global change scenarios predict warming and drying in the mid-continent. A minimum of two intensive study areas is therefore desirable as these allow the observation of processes associated with the controlling factors (temperature in the north, moisture in the south) which are most likely to undergo significant change within the biome as a whole. Two study areas were selected in 1990 with final tower flux sites specified within them in 1992. The northern study area (NSA) is located close to Thompson, Manitoba while the southern study area, (SSA) 600 km away to the southwest, but almost directly 'downhill' in terms of temperature and precipitation isolines, is located near Prince Albert, Saskatchewan, just north of the agricultural belt, see Figure 1.2b.

Each study area covers a spatial domain large enough to allow the acquisition of useful airborne flux measurements and satellite observations but small enough to conserve a reasonable density of surface instrumentation. Almost all of the land surface climatology, nutrient cycling and tropospheric chemistry process studies (i.e. flux towers and other flux measurement efforts) and most of the remote sensing validation work is being conducted within these areas, see Figure 1.2a. The distance between the two study areas is roughly 600 km: large enough to resolve the ecological gradient but small enough to permit the ferrying of research aircraft and specialized equipment.

1.3 Field Operations in BOREAS-94

BOREAS started with a monitoring program in 1993 which will extend at least through 1997. This consists of satellite data acquisition, surface meteorological and radiation measurements from ten automatic meteorological stations distributed throughout the region, and continuous flux/concentration measurements from one tower in the NSA. In 1994, this program was punctuated by a series of field campaigns in which the bulk of the BOREAS scientists and specialized equipment were committed to the field to carry out coordinated studies, see Figure 1.3.

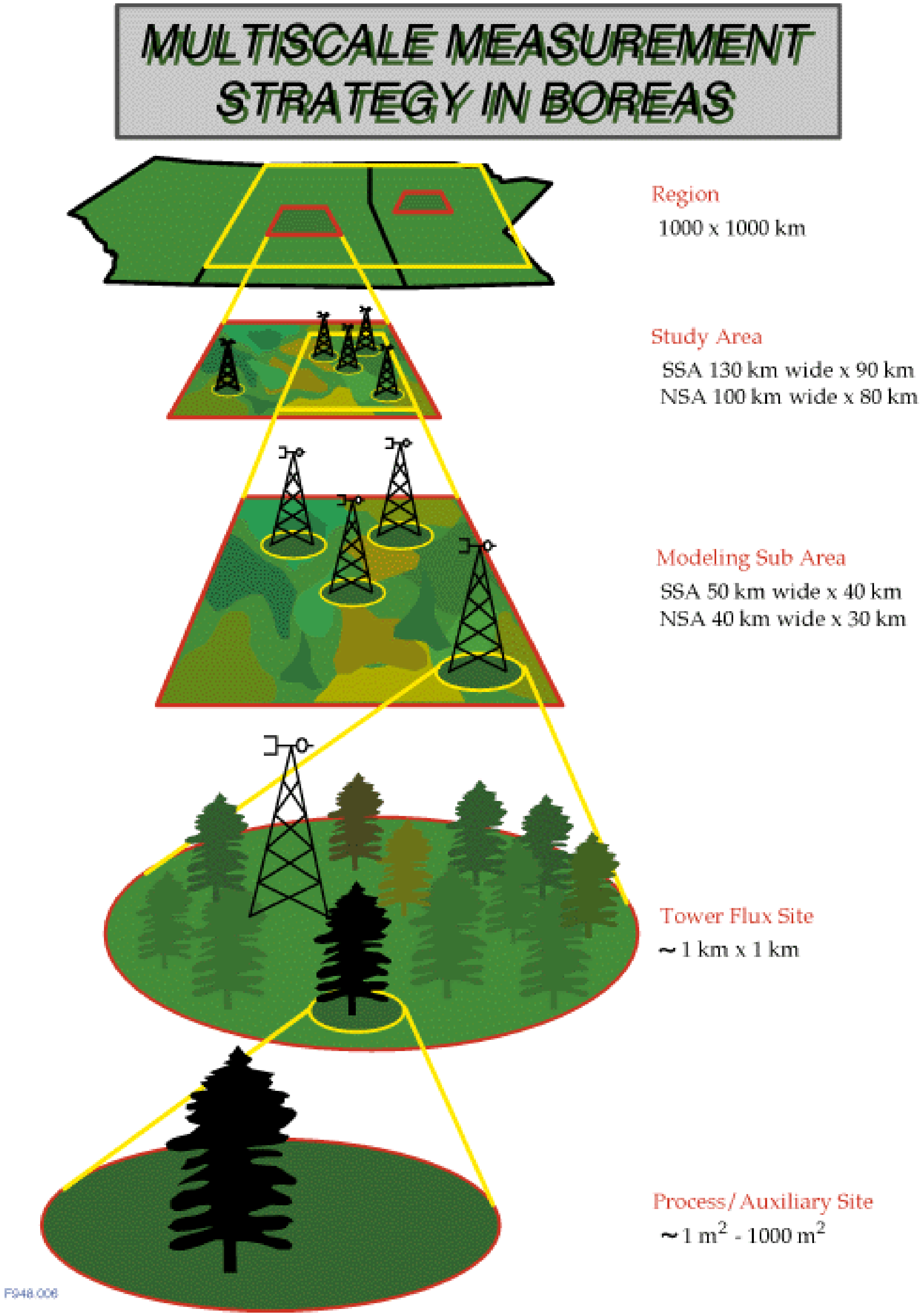


Figure 1.2a Multiscale Measurement Strategy in BOREAS, see text in Section 1.2.

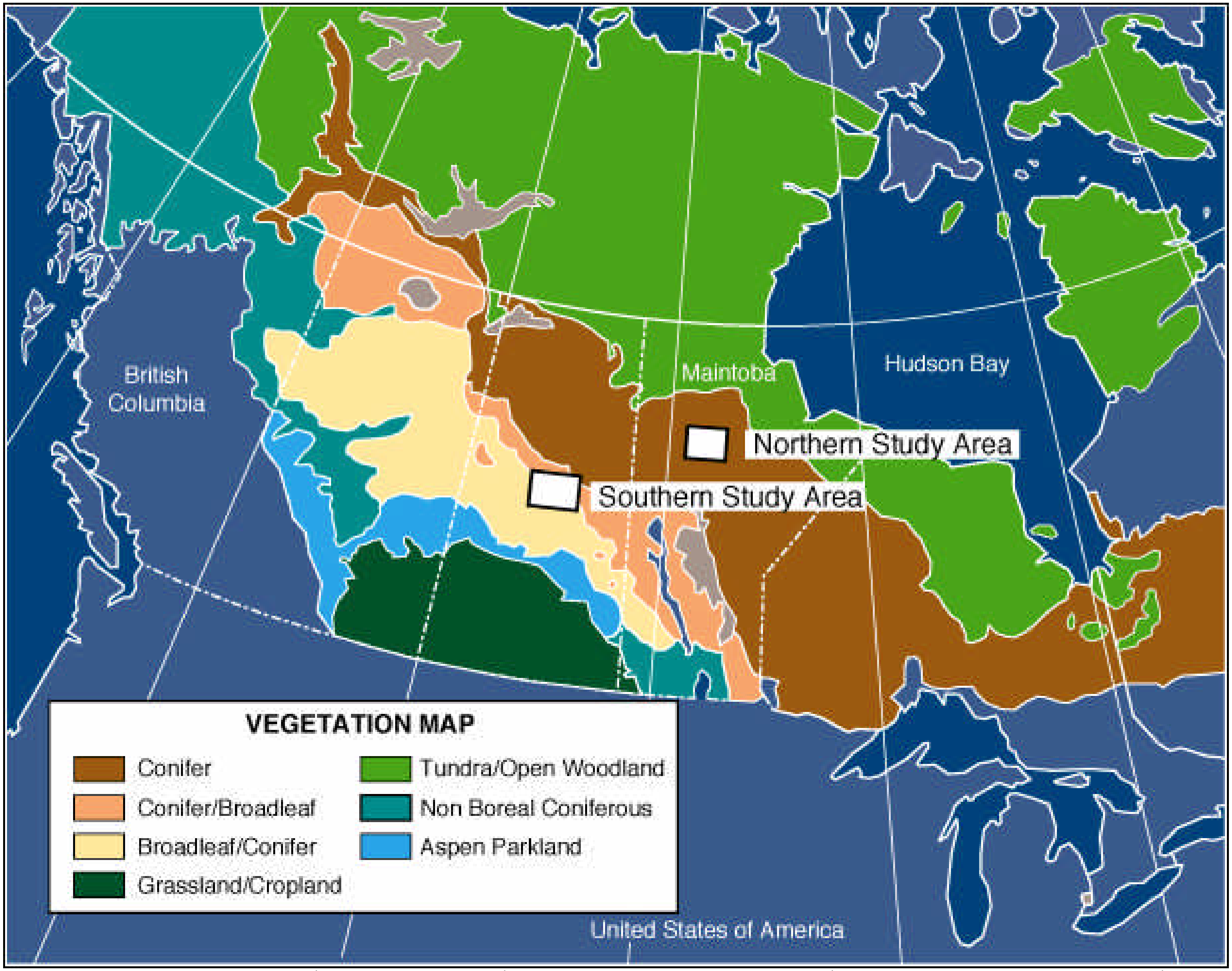


Figure 1.2b Map of Canada showing location of the two BOREAS Study Areas and the major vegetation formations of the biome.

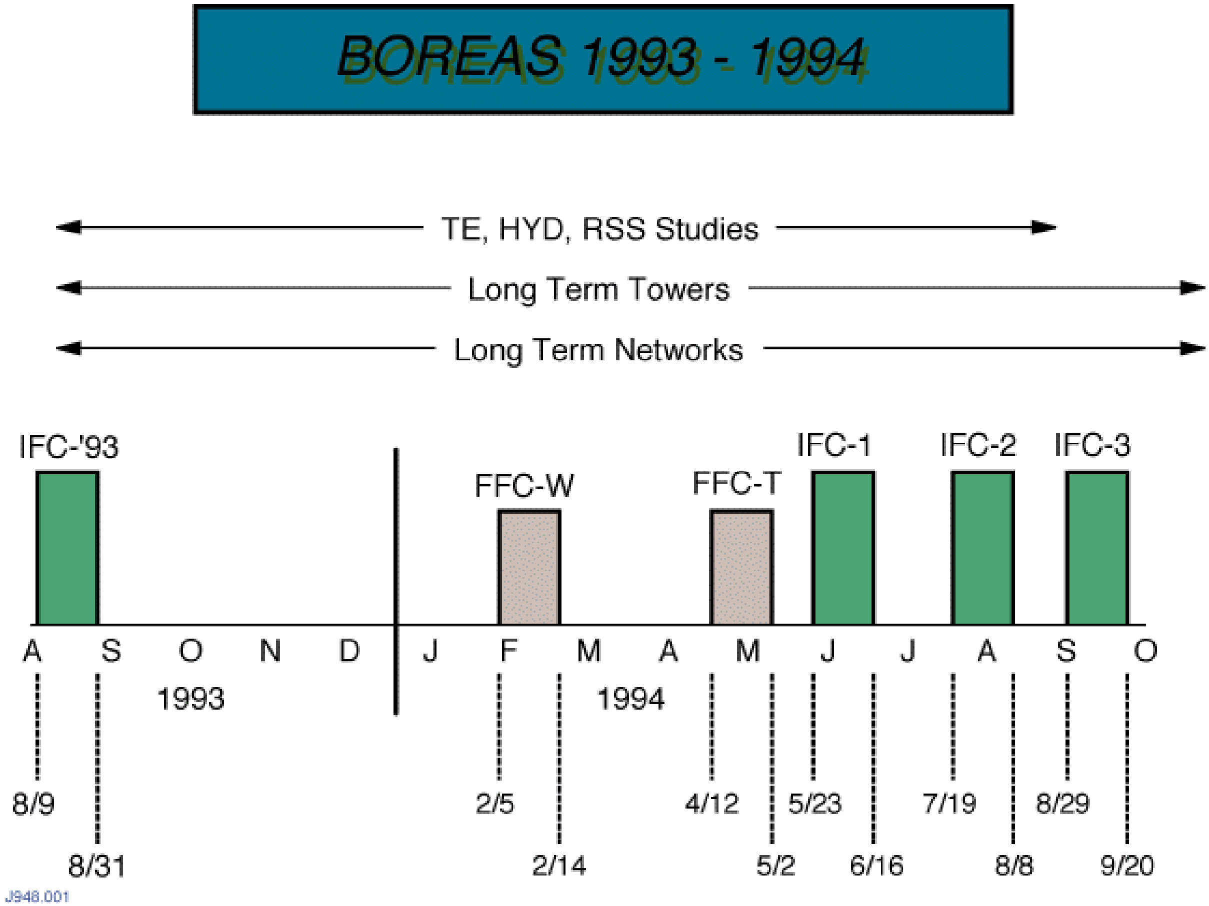


Figure 1.3 Timing of field campaigns in 1993-1994.

In 1992, 85 science teams were selected out of over 240 proposals to take part in BOREAS. These were organized into six disciplinary groups for easier organization prior to and during the field phase. The objectives of these six science groups for BOREAS-94 are summarized below, the names of individual principal investigators are listed in EXPLAN-94.

Airborne Fluxes and Meteorology (AFM): Four aircraft were used to measure turbulent fluxes; sounding lidars and radars were also deployed. Ten mesometeorological stations and a dense array of upper air radiosounding stations operated over the region during 1994. The Global Telecommunications System was used to transmit data from this network to operational meteorological centers for assimilation. Several investigators, including some with strong links to these centers, will use mesoscale and global scale atmospheric models in their studies of surface-atmosphere interactions.

Tower Fluxes (TF): Ten TF towers operated almost continuously during the growing season of 1994, measuring radiation, heat, water, CO_2 and in some cases CH_4 and other trace gas fluxes. Two of the sites, one in the NSA and one in the SSA operated more-or-less continuously from the fall of 1993 through the end of the 1994 growing season.

Terrestrial Ecology (TE): Over twenty teams are examining the biophysical controls on carbon, nutrient, water and energy fluxes for the major ecosystems in the boreal landscape and will develop models and algorithms to scale chamber measurements to stand, landscape, and regional scales. An important focus for the TE group is the measurement of components of the carbon cycle. A number of small towers were installed in the study areas to facilitate access to the vegetation canopy for chamber measurements and other in-situ work.

Trace Gas Biogeochemistry (TGB): Ten TGB teams use chamber measurements and other techniques to characterize the flux of trace gases between the soil and the atmosphere, including CO_2, CH_4 and non-methane hydrocarbons (NMHC's). The TGB group is also trying to quantify the long-term accumulation of carbon in boreal soils.

Hydrology (HYD): The HYD group has a focus on the measurement of snow hydrology components to support remote sensing algorithm development, and has also worked on catchment hydrological processes in the SSA and NSA using precipitation gage networks, stream gages and a rain radar (SSA only). One team operated a program of almost continuous soil moisture measurements at the TF sites during the 1994 growing season.

Remote Sensing Science (RSS): The RSS group is developing linkages between optical and microwave remote sensing observations and boreal zone biophysical parameters at leaf, canopy and regional scales using field, aircraft and satellite-borne sensors and a range of radiative transfer models.

The science teams were supported by a staff of scientists and support contractors from the National Aeronautics and Space Administration (NASA); Atmospheric Environment

Services (AES), Canada; the Canadian Center for Remote Sensing (CCRS), the School of Forestry, University of Wisconsin and the Canadian Forest Service. The BOREAS staff oversaw the components of the project that require significant logistical effort, extended and/or routine monitoring work, or work that requires the particular expertise and resources of one of the participating agencies. In particular, the staff dealt with the organization of the field logistics (tower construction, tower supplies, etc.) and the day-to-day management of field operations. The NASA staff also are responsible for implementing and operating the BOREAS Information System (BORIS) which will serve as a data organization, distribution and archiving center for the project.

Table 2 of Sellers et al. (1995) lists the eleven research aircraft committed to BOREAS-94 together with brief descriptions of their equipment. Note that the aircraft are divided into two groups; remote sensing (optical and microwave/gamma) and flux measurement.

Section 4 of Sellers et al. (1995) covers the details of the field operations conducted during BOREAS-94. All in all, the network of flux towers (TF sites) and surface meteorological stations functioned as well or better than expected. The airborne remote sensing and flux measurement operations went well except for IFC-2 when a combination of smoke and clouds prevented the acquisition of a complete remote sensing data set. A total of 350 airborne missions were flown in support of the BOREAS 1994 field campaigns. Tables 3, 4 and 5 in Sellers et al. (1995) summarize the work done during 1994.

1.4 Preliminary Science Results from BOREAS-94

Sections 5 and 6 of Sellers et al. (1995) cover some preliminary science results from BOREAS-94. These may be summarized as follows:

(i) The surface energy and heat balance: In terms of albedo, the boreal forest is one of the darkest ecosystems on Earth; the snow-free albedo of areas covered by coniferous species was observed to be less than 10% in BOREAS-94. This, combined with long daylengths during the growing season, ensures that a large amount of solar energy is absorbed by the surface when time-integrated over a day. However, a surprisingly small fraction of the intercepted energy is used to evaporate water from the system, as compared with the temperate forests and grasslands to the south. Results reproduced in sections 5.1 and 5.2 of Sellers et al. (1995) show that less than half of the available energy is typically used for evapotranspiration, which is estimated to average less than 2 mm/day over the area during the growing season. Because such a small fraction of the available energy is used in evapotranspiration, large sensible heat fluxes are generated which often lead to the development of very deep dry turbulent atmospheric boundary layers (ABL) over the region. From a preliminary inspection of the ECMWF and NMC forecasts provided to

BOREAS during 1994, it seems that these two numerical weather prediction models, thought to be the best of their kind in the world, are calculating excessive evapotranspiration rates for this region during the growing season, with subsequent overprediction of cloudiness and precipitation.

(ii) Physiological controls on the surface heat and carbon fluxes: During the early part of the growing season, the roots of many of the trees are frozen which inhibits photosynthesis and transpiration. Later in the growing season (at least, the 1994 growing season), the high daytime temperatures lead to large vapor pressure deficits which in turn initiate strong stomatal closure responses from all of the coniferous vegetation. This stomatal closure effect is so strong that for the bulk of the summer, the coniferous evapotranspiration rates appeared to be relatively insensitive to changes in radiation and other meteorological conditions.

Photosynthetic uptake was observed to continue at at least one TF site (NSA-OBS) long after the end of IFC-3, which ended in late September. Presumably, the soils and root systems remain warm for some time into the fall allowing active physiological processes to continue in the canopy. Similarly, significant CO_2 effluxes were measured throughout the winter. Other measurements and modeling studies indicate that the moss layer may also play a significant role in the carbon cycle of the region.

Why is the boreal vegetation so sparing with water which is so abundant in the region? (No direct soil water stress limitations on evapotranspiration were observed during the 1994 growing season if the effects of frozen roots are discounted). The obvious explanation is that the photosynthetic capacity of the vegetation is very low, presumably an adaptation to the nutrient-poor environment, leading directly to low transpiration rates. Still, it is puzzling why the stomatal response function seems tuned to such a low risk-low benefit strategy; one reason may be that 1994 was so warm and dry that we are seeing an atypical 'mean' growing season physiological response. During cooler, more humid years, the stomatal function may serve the vegetation more efficiently.

(iii) Remote sensing results: Preliminary results from the remote sensing component of BOREAS indicate that many of the hypotheses relating optical satellite data to surface conditions developed for other ecosystems, e.g. grasslands in FIFE, may transfer to the boreal forest, albeit with some significant additional effort. The first cut at doing this on a large scale is encouraging, see Sellers et al. (1995).

A number of BOREAS workshops have defined the initial interfaces required between regional-scale energy/water/carbon models and remote sensing parameters. These workshops have shown the need for parametrically homogeneous classes to initialize and evaluate the models.

In BOREAS, regional scale remote sensing will be used to map community composition, i.e., wetland conifer, upland conifer, deciduous, fens, conifer/deciduous mixed communities, and several classes of disturbance by approximate age. Within these classes, the models need other characteristics such as biomass density (for respiration loss), leaf area index (precipitation interception and roughness length), height and basal area fraction (roughness length) and the fraction of photosynthetically active radiation intercepted by the green portion of the canopy (FPAR) to compute transpiration and photosynthetic rates. Preliminary studies of the relationships between reflectance and the biophysical properties of boreal forest communities indicate that remote sensing can be used to map landcover characteristics. To obtain these regional-scale parameter maps, BOREAS investigators and staff will develop and apply optical and microwave algorithms to the aircraft and satellite data. The first versions of these maps, at the study area and regional scales, are now ready for evaluation in conjunction with the energy-water-carbon models.

Promising results are already available. AVHRR data have been used to develop a 1 km spatial resolution community composition map of the 1000x1000 km BOREAS regional study area. The technique used is very similar, if not identical, to that used on the 1 km AVHRR Pathfinder land cover data set. TM data have been used to develop a 30 m resolution map of the BOREAS Northern and Southern study areas. Both maps are of the model-required classes discussed above. The TM classifications show that the NSA and the SSA are similar in composition with respect to conifers, about 50% of both study areas, and mixed deciduous/conifers, roughly 20% in both areas, but somewhat different with respect to deciduous covers; 10% in the SSA and 4% in the NSA. Fens contribute only about 3 to 4% of each study area and open water about 10% of both areas. The remainder of the study areas are disturbed and regenerating in mixes of conifer and aspen (<30 yrs. old) comprising roughly 5% of the SSA and NSA.

Comparisons of the TM map to the 30 m auxiliary site data show an overall classification accuracy of about 80%. The TM and AVHRR maps have also been compared, showing 70 to 80% agreement between the 1km AVHRR and the 30m TM for aggregated classes such as conifer, mixed deciduous, regeneration and water. At the more detailed class breakout level, agreement decreases because of the difference in spatial resolution between TM and AVHRR. Other preliminary results from studies using optical and radar data indicate that biomass densities, LAI and FPAR can be estimated to about 5 levels, or roughly to 20% relative accuracy.

Microwave sensors on aircraft (DC-8, CV-580) and satellites (ERS-1) were used to monitor soil and canopy thaw, which relates to the start of photosynthesis. The ERS-1 C-band radar data showed an increase in backscatter between days 60 and 63, correlated to the soil thaw, and another increase around day 78 related to canopy thaw.

1.5 Shortcomings of the 1994 Data Set and Open Issues

The major shortcomings of the 1994 data set are as follows:

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

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

(iii) **Smoke in IFC-2**: Heavy smoke from forest fires alternating with patchy cloud cover severely reduced optical remote sensing opportunities in IFC-2, the mid-growing season field campaign. All of the airborne remote sensing data collection work was compromised to some extent: the C-130 (MAS, ASAS, TMS); the ER-2 (AVIRIS); the Chieftain (CASI) and the helicopter (SE-590, POLDER). Of the data gaps, perhaps the most serious is the suite of C-130 measurements, particularly the incomplete MAS and ASAS data acquisitions over the NSA. The result is that we do not have a complete remote sensing record of the growing season to match up with our surface flux observations and other data sets. This seriously compromises the development of algorithms for growing season (maximum) Fpar and LAI.

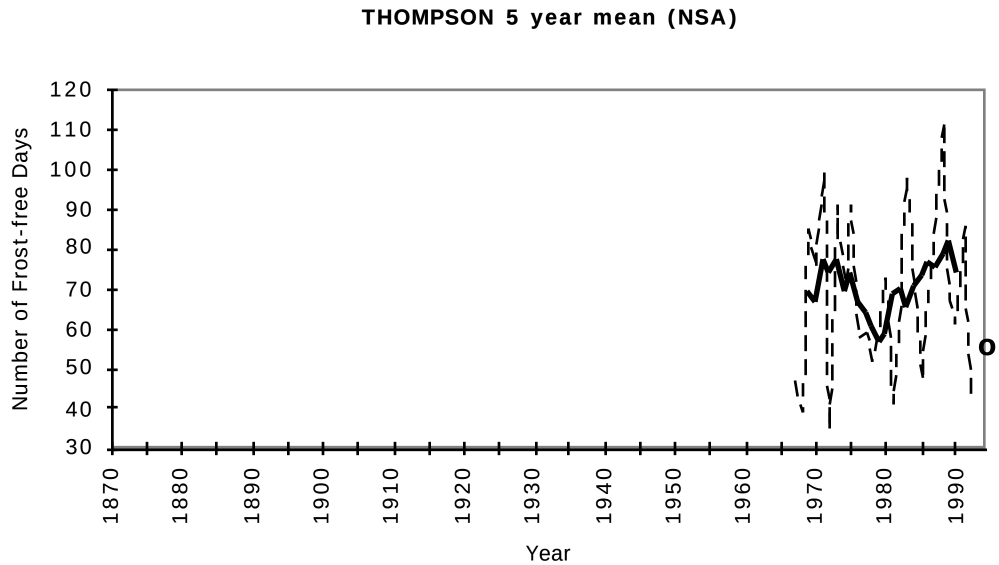
(iv) **Snow cover and the radiation balance**: Some preliminary modeling work indicates that the effects of the forest canopy on albedo may be highly significant in determining the winter climatology of the northern mid- and high-latitudes, see Bonan et al. (1992, 1995). This work suggests that replacement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

As yet, we have little useful surface and airborne data to help us understand how the snow-covered forest intercepts and reflects/emits incoming solar and longwave radiation. During the winter of 1993-1994, most of the forest appeared to be very dark, particularly at low view angles. This is true even for deciduous areas, where low solar angles in winter compensate for low stem densities with the result that the bulk of the solar radiation appears to be intercepted by stems and bare branches. By contrast, the agricultural areas to the south and the tundra to the north of the forest appeared to be almost completely snow-covered and were highly reflective. To what extent does the radiation balance of the surface correspond with this visual impression? Can we quantify them using satellite data? The radiation sensors on the Automatic Meteorological Stations (AMS) in BOREAS-94 were not equipped with snow blowers or alcohol sprayers so much of their data from early 1994 (the systems came on-line in March 1994) are suspect. The complete set of these anti-frost devices were only installed before the winter of 1994-1995. In addition, we do not have a complete optical remote sensing data set, consisting of surface (PARABOLA) and airborne (ASAS, CASI) data, over the snow-covered SSA radiative transfer test sites from the 1994 focused field campaigns. Compilation of this data set with supporting ground truth (snow depth, snow water equivalent) measurements would be a primary goal for a winter focused field campaign in 1996 to address the issues described above.

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

(v) **<u>1994: a record warm, dry year</u>**: 1994 was a record frost-free year for the SSA and the driest year on record in the NSA, see Figure 1.5. Since 1994 was characterized by high temperatures and high vapor pressure deficits, it may have provided us with an image of the transient behavior of the boreal forest with respect to global change rather than a representative baseline for the status quo. The representativeness of the 1994 field year would have been a discussion issue in any case, but the fact that 1994 was so exceptional leads us to suspect that we may be seeing something more relevant to the future of the system rather than obtaining a clear picture of its current functionality. The anomalous meteorological conditions of 1994 can be expected to influence many aspects of the BOREAS-94 data set in addition to vegetation responses; for example, the TGB group is expected to show some evidence that the long, warm growing season led to an unusual time-profile of soil/wetland CO_2 and CH_4 fluxes in the SSA.

(vi) **<u>Positive surface-atmospheric boundary layer drying feedback</u>**: The development of deep dry boundary layers suggests that a positive drying feedback may be at work in this region at the beginning of the growing season when the soils are still partially frozen (see Betts et al.; in press) and also during warmer periods when the vapor pressure deficit feedback effect becomes important. We believe that we have the data from BOREAS-94 to make some headway on determining if this model holds up for the warm, dry conditions of 1994. If this turns out to be true or partially true for 1994, which is likely, to what extent would it hold for more 'normal' conditions? If this feedback system is the norm, it implies that the result of the vegetation's conservative water-stress avoidance strategy in the region is to exacerbate the degree of external stress. Teleologists would propose that this implies that the ecosystem is out of sync with its climate while strict Darwinists (Dawkins faction) might argue that this apparent reduction in ecosystem efficiency is to be expected from game theory. More data for a different kind of year would help to resolve some of these issues.



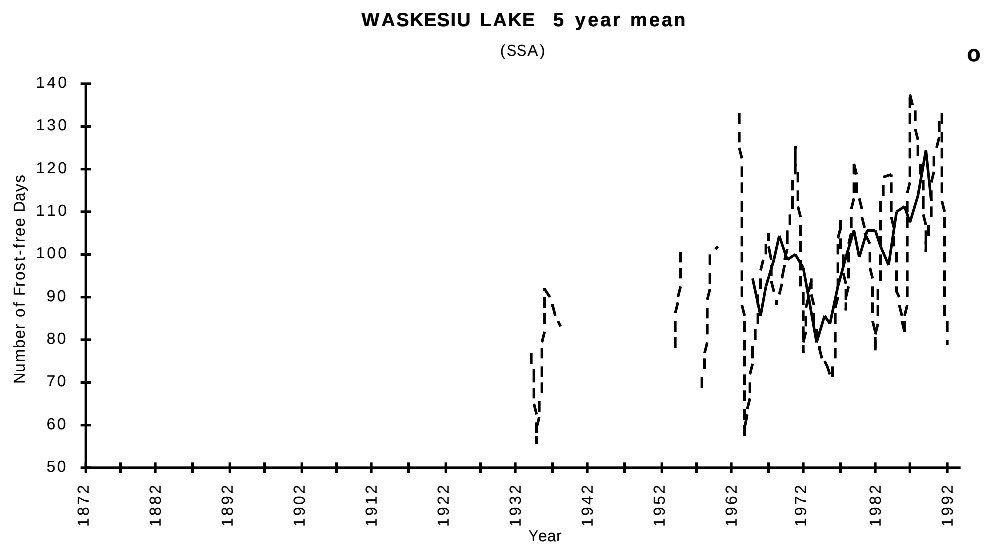
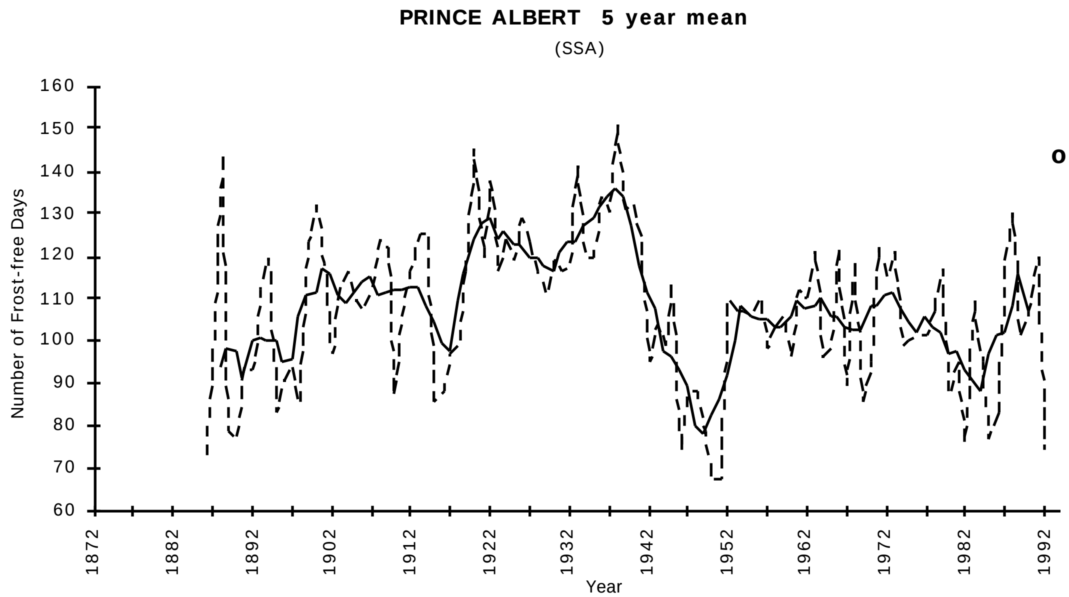
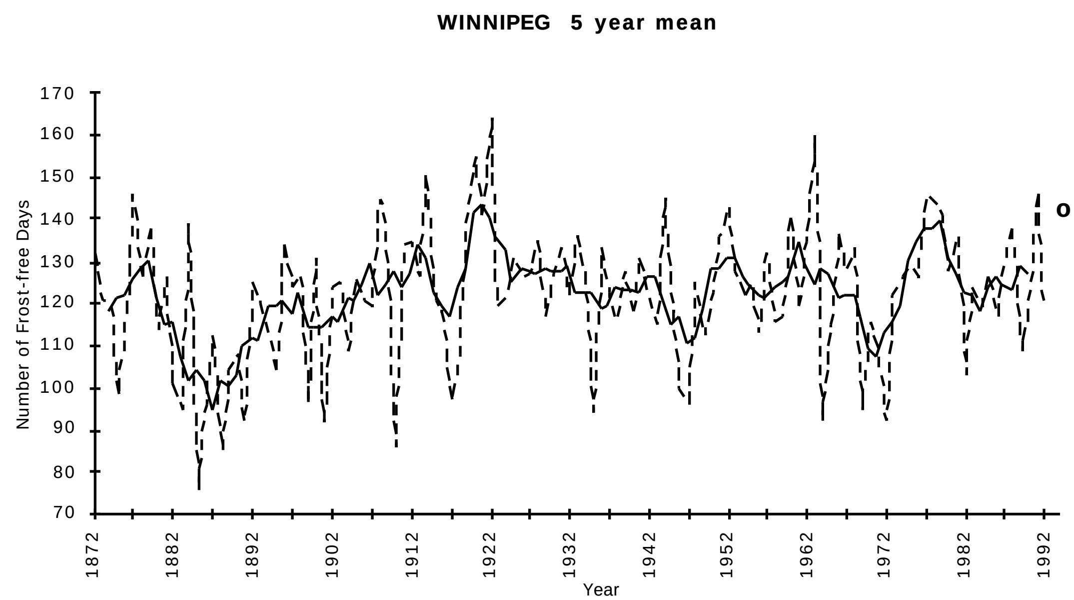


Figure 1.5a Record of frost-free days by year for sites in and near the BOREAS region. The heavy lines are five-year running means and the solid black circles are the reported 1994 values.





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2. ANALYSES AND PLANNING ACTIVITIES: 1994-1995

2.1 White Papers and Workshops

Since the end of the BOREAS-94 field season, there have been three BOREAS Science Workshops.

December 1994, Williamsburg. The BOREAS Science Team met for three days to review preliminary results from the 1994 field season. Some activities for 1995 were scoped out. These were not supported by the funding agencies who requested a year of analysis and planning prior to a significant return to the field.

March 1995, Turf Valley. A large subset of BOREAS investigators met to review outstanding science issues and formulate preliminary plans for 1996. Three White Papers were written up after this workshop.

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

October 1995, Patuxent Wildlife Center, Beltsville. Almost the entire BOREAS team gathered to review all aspects of ongoing and planned activities in BOREAS. The White Papers were presented and subsequently revised; they are now available from the US Project Office on request.

The science issues in the White Papers were translated into activities to be executed in BOREAS-96. This document, EXPLAN-96, describes the science investigations for BOREAS-96 as well as the supporting staff activities.

2.2 Objectives of BOREAS-96

The objectives for BOREAS-96 are drawn directly from the BOREAS White Papers. The next three subsections reproduce excerpts from the White Papers which summarize the goals and methodologies for BOREAS-96.

2.2.1 Fluxes and Processes at the Stand Level

The main goal of the proposed in situ stand level work is to develop an integrated approach to understanding fluxes and processes at the stand scale, specifically the roles of different components; canopy, understory, moss, soils, in contributing to the total fluxes of energy, water and carbon. Some TF measurements and associated in situ observations should extend from before until after the end of the 1996 growing season, i.e. from March through November. This should be augmented by a summer IFC designed to perform a well-coordinated three to four week experiment that will provide data from several key sites to test our physiological, NEE exchange and canopy-ABL feedback models.

The work will require continuous measurement of CO_2 and H_2O fluxes above stands at selected forest sites and concurrent eddy-covariance measurements of CO_2 and H_2O below the forest canopy. Chamber measurements of CO_2 (and other trace gas) fluxes from the forest floor will be made during daytime and night-time throughout the IFC. Chambers will be used to measure moss photosynthesis and respiration and tree bole respiration. These measurements are necessary to help resolve the difficult issue of estimating accurately the night-time net CO_2 efflux from the forest. Leaf or branch chambers should be operated and should be complemented with porometry measurements for stomatal conductance at 3 or more levels in the overstory and at least one level in the understory and moss layers. Heat balance or heat pulse techniques should be used to provide an independent measurement of tree transpiration. Chambers and lysimeters should be used to measure moss transpiration and forest floor evaporation (a comprehensive list of measurements is given in section 3.5).

Radiosonde and tethersonde ascents are important for the testing of ABL-mixed layer models of canopy evaporation and CO_2 exchange and to establish the role of negative feedback between the ABL and the stomatal conductance of the forest. Remote sensing indices, including NDVI, the simple ratio, bi-directional reflectance (PARABOLA) must be obtained together with canopy leaf area index and structure (LI-COR LAI 2000 and TRAC). Finally, high-quality supplementary measurements of climate (radiation fluxes, etc. from the AFM-7 Mesonetwork) and soil moisture (HYD groups) data must be maintained.

The specific measurement objectives for the 'ground' science teams working at or near Tower Flux (TF) sites are as follows:

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

(b) To determine closed C, water and trace gas budgets for the stands over a year by measuring their fluxes during spring and fall IFCs. During a summer IFC, focused experiments to establish the validity of measurements of night-time CO_2 effluxes should be done.

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

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

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

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

2.2.2 **Surface and Atmospheric Boundary Layer Studies**

The goal of the continued collection of surface, atmospheric boundary layer (ABL) and upper air data in BOREAS-96 is:

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

BOREAS-96 is driven by the need to get a complete seasonal cycle to address the annual carbon balance, and the desire to understand better the component fluxes, and the contributions by the understory (especially the moss layer, see paper I). The 1994 measurement campaigns did not adequately sample the transitional seasons of spring and fall, nor provide adequate measurements of the understory except at the Old Aspen site.

The ABL measurements are largely in support of the tower flux measurements, as well as modeling studies. In 1994, the continuous surface flux and meteorological measurements and the more detailed ABL measurements by aircraft, rawinsondes, a wind profiler, cloud radar, lidar ceilometer and a cloud camera provided a detailed data set to analyze the interactions between the surface and the overlying atmosphere. Much of this analysis is still in progress. The 1994 campaign confirmed the importance of the feedbacks between deep dry ABL's, which produce large vapor pressure deficits at the surface, which reduce evapotranspiration though stomatal closure. In addition, studies at the NSA OJP site by TF-8 suggest the need for further studies of the links between cloud cover, and stomatal controls. The 1994 measurements were however probably not adequate to address the diurnal cycle of CO_2: there is a large storage component at night in the shallow nocturnal ABL, which is vented as the daytime ABL grows (on most but not all days). There were some deficiencies in the aircraft flux measurement program; the fluxes of energy and CO_2 from the lakes were not measured in autumn when the lakes are warm and fluxes are thought to be high. In addition, the 1994 aircraft measurements of absolute carbon dioxide concentration were not accurate enough to assess spatial variability above different land-cover elements or to be of much use to atmospheric tracer modeling studies.

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

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

The specific objectives for the BOREAS-96 ABL measurements are as follows:

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

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

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

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

2.2.3 **Remote Sensing Science**

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

The measurement goals for RSS for BOREAS-96 are as follows:

<u>Airborne/Satellite Observations</u>

(a) Obtain growing season airborne data required by the BOREAS MODLAND Team to develop algorithms applicable to EOS MODIS, i.e. where necessary, use AVIRIS as a MAS substitute, and ASAS for angular characterization. MODLAND representatives indicate that continuing the MAS/AVIRIS flights over the next two years is critical to preparations for the MODIS launch. MODIS data simulation for BOREAS can also be achieved using a combination of AVIRIS and TIMS. ASAS and PARABOLA data (with as much data as possible collected concurrently) are needed to better characterize and upscale spectral albedo, and FPAR and LAI at the TF sites during the growing season. AVIRIS imagery over the NSA and the SSA during winter/early thaw with continuous snow cover, and later during the thaw with partial snow cover to measure snow extent are also desirable. This is important to test the repeatability of mapping snow in discontinuous canopies and to link these products to models. Moreover, this product should provide a suitable reference against which to test other sensor algorithms (e.g. MODIS, SAR, Landsat TM).

(b) Basic (ASAS) bidirectional reflectance measurements over forest stands with a snow background must be acquired, since these measurements (missing from 1994) are necessary to characterize the wintertime radiation balance of boreal forests.

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

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

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

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

Surface Observations

(g) Obtain surface bidirectional reflectance and emission measurements within conifer and deciduous canopies in winter and during the growing season over visible, shortwave infrared and thermal infrared wavelengths, including the moss layer (e.g. PARABOLA-III). These observations will support ASAS/AVIRIS/MAS acquisitions.

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

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

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

Snow cover data (depth, water equivalent, density) were acquired at NSA and SSA snow courses throughout the winter of 1994/95 (first and fifteenth of each month). This measurement program is planned to be repeated during the 1996 winter before 3/1/96. These measurements represent a core BOREAS snow cover data set which can support remote sensing algorithm development and hydrological modeling efforts as well as other BOREAS science investigations. HYD-4 is responsible for coordinating this measurement program and providing the data to BORIS.

3.0 BOREAS-96 FIELD ACTIVITIES

3.1 Overview

The scientific objectives discussed in Chapter 2 have been matched against team capabilities and project resources to formulate a plan for BOREAS-96. This plan is discussed in detail in this and subsequent chapters.

Figure 3.1 shows the main components of BOREAS-96. These are blocked out by heavy dashed lines and are discussed in the subsections below. In summary:

(i) **Monitoring**: Continuing automatic meteorological station measurements, hydrological measurements and satellite/sunphotometer observations. (3.2)

(ii) **Winter RSS Campaign**: Airborne and in situ observations of the radiation field above and within winter forest canopies; follow-up on the remote sensing of winter albedos. (3.3)

(iii) **NSA Growing Season Studies**: Surface studies involving TF measurements at at least three sites (NSA-OBS, NSA-OJP, NSA-Fen and possibly NSA-YJP) will take place from April through November 1996. Three small IFCs, which will incorporate the bulk of the supporting TE work, will take place in the thaw, summer and fall timeframes (represented by raised shaded areas in figure 3.1). There will also be some TGB work (3.4).

(iv) **SSA Growing Season Studies**: Surface, principally TF, TE and HYD measurements, will take place within the SSA from March through November. SSA-OA and SSA-OBS will be the foci of most of this work. In parallel with the NSA schedule, there will be three small IFCs which will incorporate most of the coordinated TF and TE work (3.5).

(v) **Growing Season RSS and AFM activities**: There will be some airborne and surface RSS work during the summer IFC. Radiosoundings and airborne flux measurements will be conducted during the summer and fall IFCs. (3.6)

3.2 Monitoring

3.2.1 Automatic Meteorological Stations (AMS)

All of the 10 AMS sites will continue in operation through at least November of 1996; after that, they may be reduced to a subset which will likely include the sites at SSA-OA, SSA-OJP, NSA-OJP/Fen, NSA-YTH (Airport). The

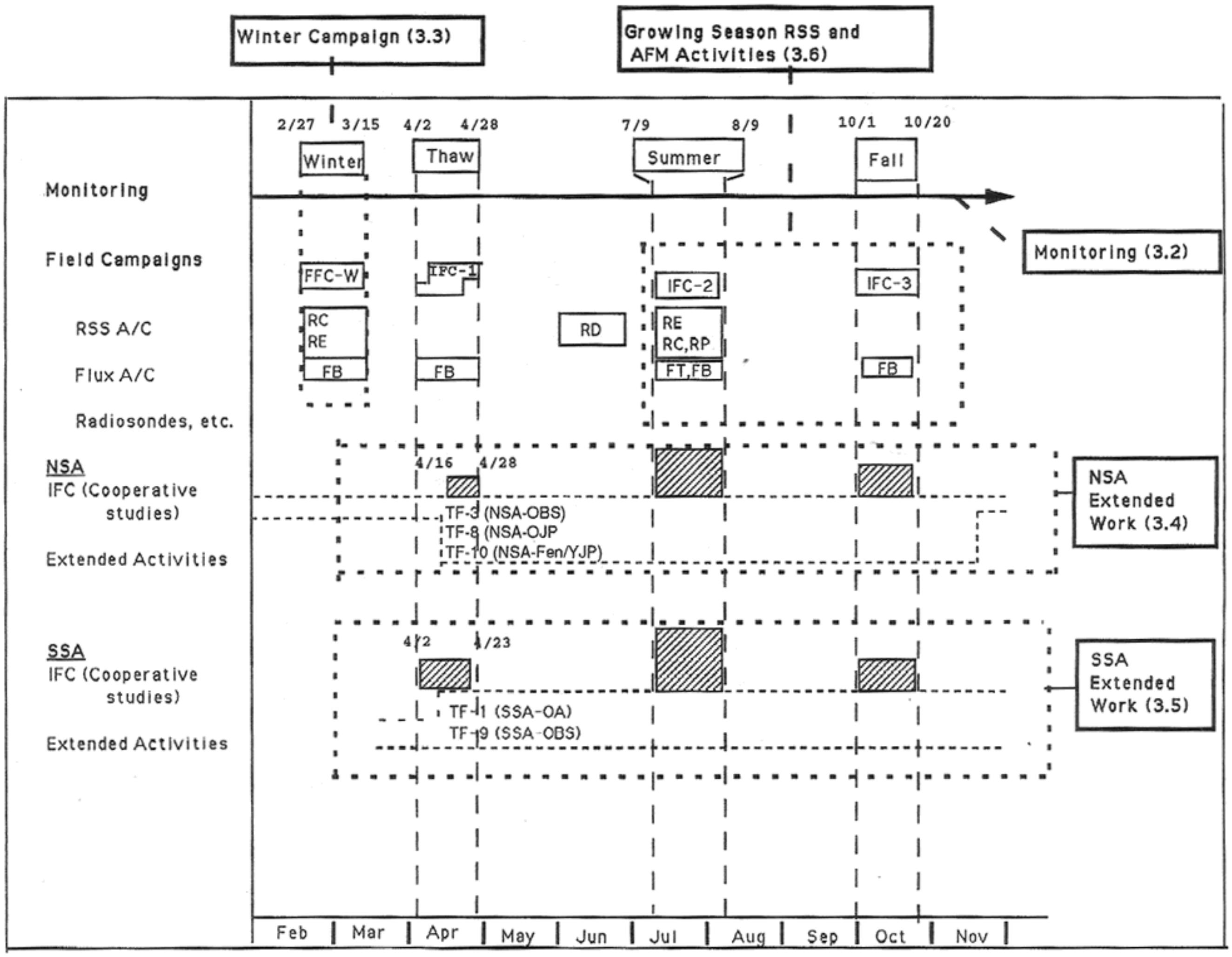

Figure 3.1 Overview of schedule for BOREAS-96 activities. The activities bounded by heavy dashed lines make up the major subcomponents: monitoring, winter RSS campaign, NSA growing season work, SSA growing season work, and growing season RSS and AFM activities. The raised hatched areas represent IFCs.

Table 3.2.1
Parameters to be Measured by the BOREAS AMS Network (AFM-7)

Parameters measured	Resolution	Accuracy	Typical sensor/supplier
Sensor suite A			
Above-canopy temperature	0.1deg C	+/- 0.4deg C	Vaisala HMP35C
Within-canopy temperature	0.1deg C	+/-0.25degC	Campbell 107F
Soil moisture H20 potent. RF			Campbell scientific/matrix
Air Pressure	0.01kPa	+/-0.05kPa	Setra SB270
Humidity	1 percent	+/-3 percent	Vaisala HMP35C (same as air temperature)
Wind speed	.1m/s,1deg	5percent,2deg	RM Young Wind Monitor 05103-10
Precipitation *	1mm	5percent	AES Tipping Bucket Rain Gauge, Belfort Gauge
Snow depth	0.5cm	+/-1.0cm	Campbell Scien. UDG 1 ultrasonic depth sensor
Incident Shortwave	1percent	5percent	Eppley (PSP)
Incident PAR	1percent	2percent	Skye-Probetech (SKE510) PAR sensor
Reflected Shortwave	1percent	2percent	Eppley (PSP)
Net radiation	1percent	5percent	Fritschen type net radiometer
TIR Surface Temp	<1degC	+/-0.5˚C	Everest (4000 AL)
Soil temperature	0.1degC	+/-0.4˚C	Campbell scientific 107 BAM
Sensor suite B			
Diffuse Shortwave down	1percent	1percent	Eppley (PSP) plus shadow band
Longwave down	1percent	2percent	Eppley (PIR) plus shadow band

*The Belfort-type precipitation gauge are located in clearings within cable distance of the station. The field of view from the top of the gauge to the nearest obstruction should not be greater than 45 degrees.

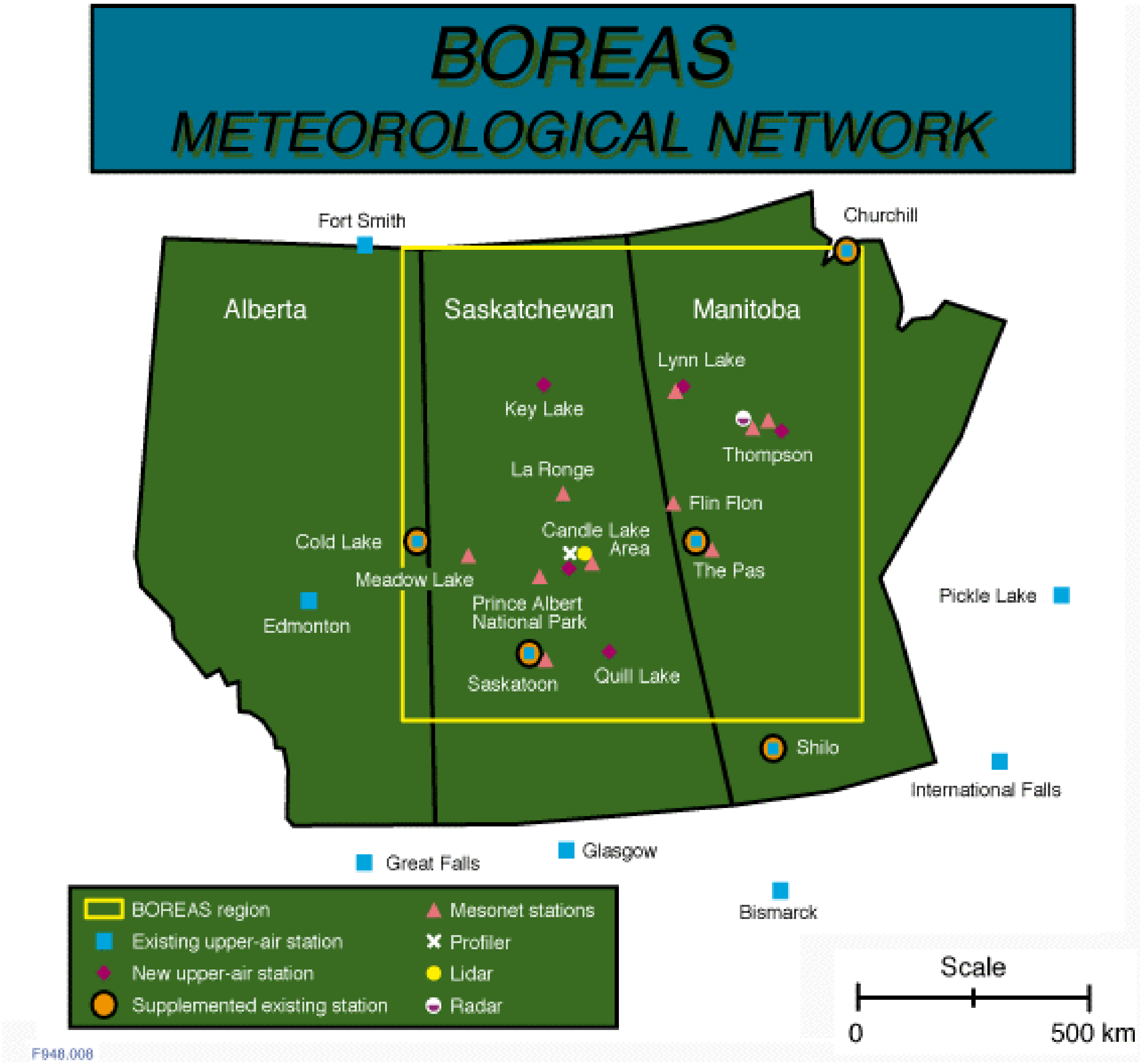

Figure 3.2.1a The mesoscale meteorological network and upper-air meteorological network.

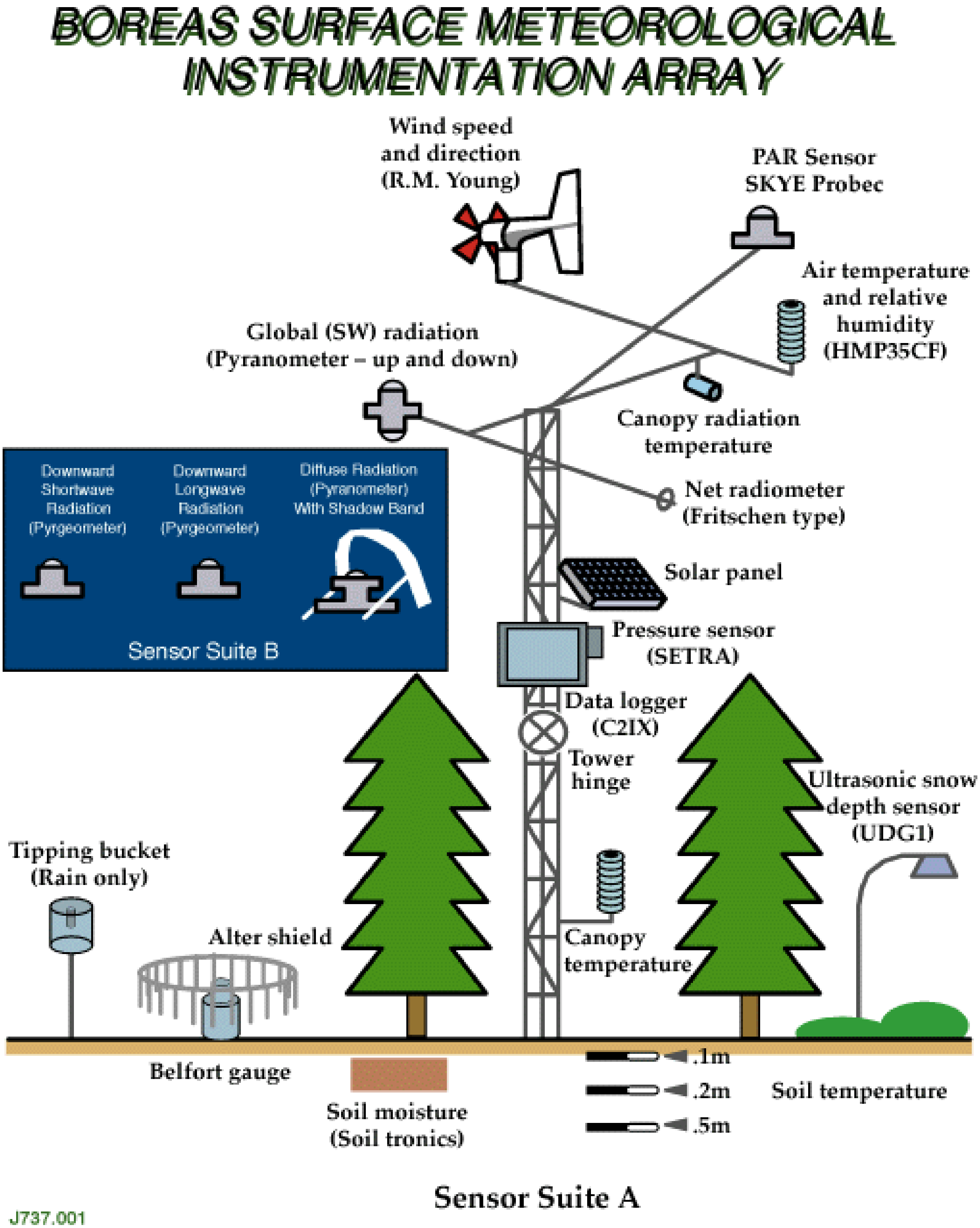

Figure 3.2.1.b Schematic of AMS Sensor Suites corresponding to Table 3.2.1.

measurements taken at the sites are summarized in table 3.2.1, and the distribution of sites is shown in figure 3.2.1a. A schematic of an AMS site is shown in figure 3.2.1b.

3.2.2 Hydrological measurements

The BOREAS-96 work plan will involve activities similar to those in 1994 and 1995. All five stream flow and 22 precipitation gauges in the NSA and SSA will be reactivated in April 1996. The sites will be visited once every 3-4 weeks by University of Waterloo personnel (HYD-9) until November 1996. The catchments are:

SSA

White Gull Creek, gauged above Highway 106 and at Harding Road.

NSA

NW1 Basin, gauged on the Sapochi River at the Highway 391 bridge.
NW2 and NW3: two small watersheds which straddle route 391.

Locations of the gauges and details about the measurements can be found in EXPLAN-94, section 3.2.2.

3.2.3 Satellite observations

A program of satellite data acquisitions will be coordinated during the 1996 field year; satellite instrument attributes are shown in Table 3.2.3. Sunphotometer data will be acquired by RSS-11 using the automatic network in place.

GOES data will be acquired continuously be RSS-14 and processed into a series of surface radiation budget products: S↓, S↑, PAR↓, PAR↑, albedo, L↓, L↑, R_n. The GOES data will be acquired from the beginning of FFC-W through the end of IFC-3.

A full tabulation of satellite overpasses and geometry is given in Appendix E with summaries for SPOTand Landsat shown in Chapter 6. These tables show the theoretical maximum number of scenes. The actual number received is subject to satellite performance as well as ground station constraints and, in the case of SPOT-HRV, constraints due to scheduling off-nadir takes for non-BOREAS users. There are limited opportunities for acquiring imagery for these three instruments because of orbital and instrument configurations. Figure 3.2.3 shows the locations of image frames for Landsat and SPOT over the SAs and the transect.

Landsat: Four Landsat scenes are located within the BOREAS region; Southern Study Area (SSA), Transect West (TW), Transect East (TE) and Northern Study Area (NSA). Two of these scenes require that the scene center be shifted for a good transect coverage.

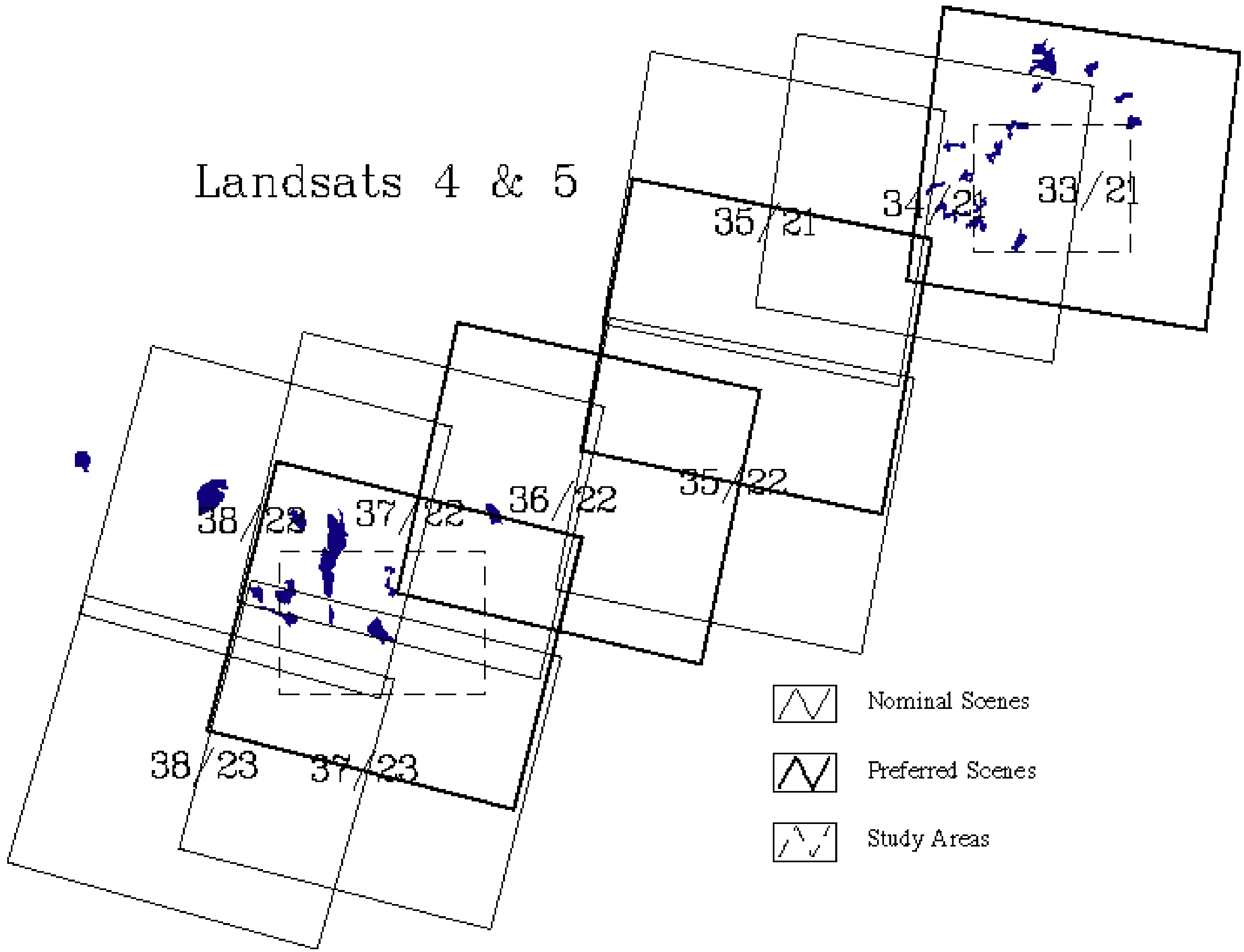

Figure 3.2.3: Arrangement of Landsat and SPOT scenes in the BOREAS Region

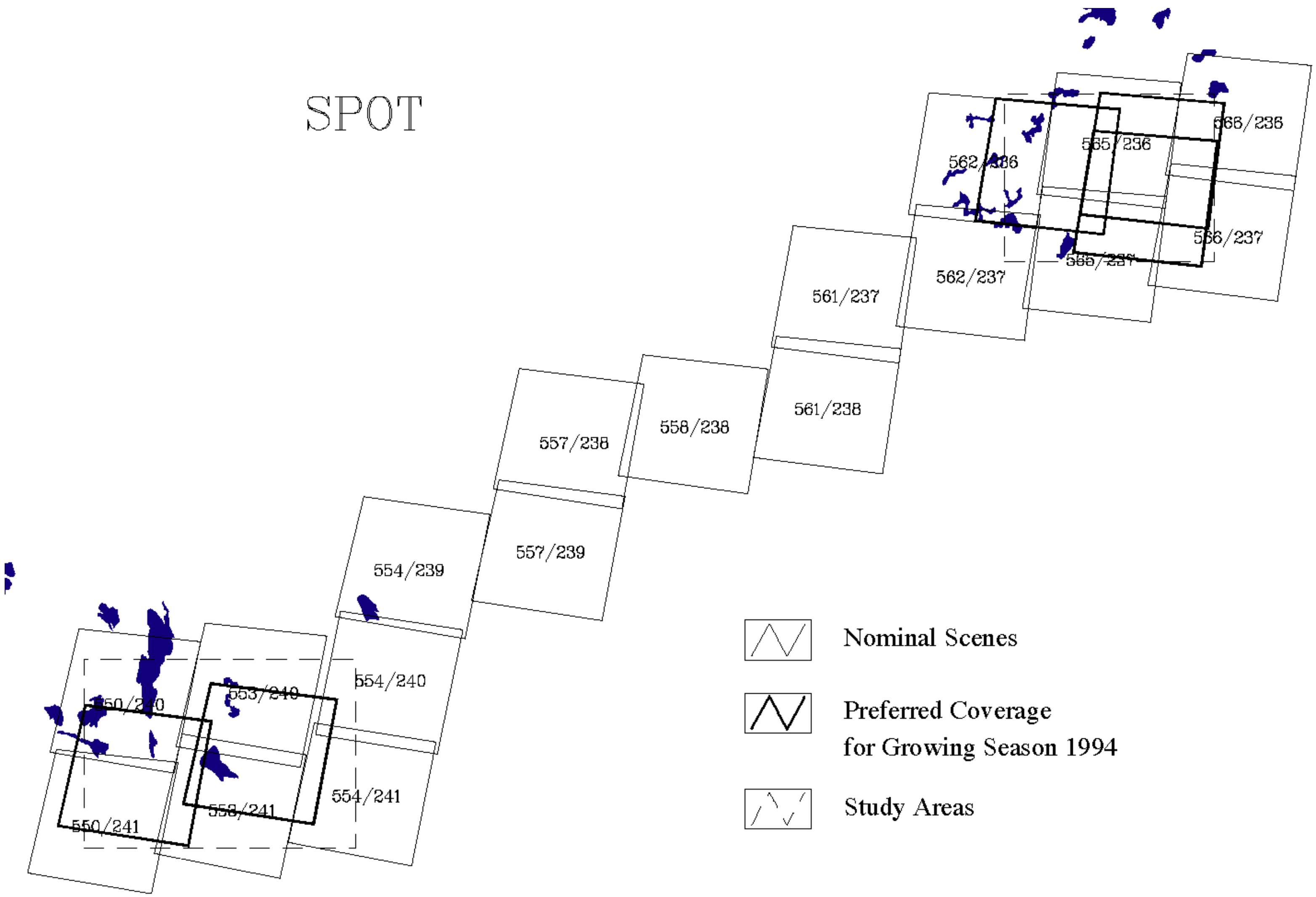

Figure 32.3: Arrangement of Landsat and SPOT scenes in the BOREAS Region (cont)

Table 3.2.3 Satellite Instrument Attributes

Satellite	Bandpass Instrument/Band	(50% RSR)(μm)	Spatial Resolution	Repeat/Time
ERS-1	C-band (23° incidence)	NA	30 m (high)	Monthly
	VV polarization		100 m (low)	Weekly
GOES	Visible	0.52 - 0.72	1 km	48 per day
	Infrared	16.47 - 7.0	4 km	48 per day
	Water vapor	20.2 - 11.2	8 km	24 per day
Landsat-5	MSS/1	0.497 - 0.607	78 m	1 per 10 days
	MSS/2	0.603 - 0.615	78 m	
	MSS/3	0.704 - 0.814	78 m	
	MSS/4	0.809 - 1.036	78 m	
	TM/1	0.451 - 0.521	30 m	
	TM/2	0.526 - 0.615	30 m	
	TM/3	0.622 - 0.699	30 m	
	TM/4	0.771 - 0.905	30 m	
	TM/5	1.564 - 1.790	30 m	
	TM/6	10.45 - 12.46	120 m	
	TM/7	2.083 - 2.351	30 m	
NOAA-12	AVHRR/1	0.570 - 0.699	1.1 km	2 per day
	AVHRR/2	0.714 - 0.983	1.1 km	
	AVHRR/3	3.525 - 3.931	1.1 km	
	AVHRR/4	10.33 - 11.25	1.1 km	
	AVHRR/5	11.39 - 12.34	1.1 km	
NOAA-14	AVHRR/1	0.570 - 0.699	1.1 km	2 per day
	AVHRR/2	0.714 - 0.983	1.1 km	
	AVHRR/3	3.525 - 3.931	1.1 km	
	AVHRR/4	10.33 - 11.25	1.1 km	
	AVHRR/5	11.39 - 12.34	1.1 km	
SPOT-2	HRV/1	0.506 - 0.591	20 m	1 per 3 to 5 days
	HRV/2	0.627 - 0.670	20 m	
	HRV/3	0.792 - 0.884	20 m	
	HRV/PAN	0.525 - 0.706	10 m	
SPOT-3	HRV/1	0.506 - 0.591	20 m	1 per 3 to 5 days
	HRV/2	0.627 - 0.670	20 m	
	HRV/3	0.792 - 0.884	20 m	
	HRV/PAN	0.525 - 0.706	10 m	

SPOT: There are two SPOT satellites in operation, each equipped with two pointable instruments. However, the instruments cannot acquire one site (say SSA) and then slew round to acquire the other (NSA) on the same orbit. It also requires two SPOT scenes to cover the SSA. Sometimes, images may be acquired for both sites on the same day when both SPOT satellites are in range.

ERS-1: The ERS-1 C-VV SAR operates at a fixed incidence angle of 23°. The ERS-1 orbit is periodically changed by ESA which results in varying coverage of the BOREAS region. For example, complete coverage was provided by a 35-day repeat until December 15, 1993, a 3-day repeat until March 15, 1994 and a 176-day repeat from then on. During the 35- and 176- day repeat, the 1000 x 1000 km site is mapped every 17-days, and the instrument therefore collects data at weekly intervals, day and night, over the BOREAS region.

3.3 Winter RSS Campaign

The justification for the Winter RSS work is given in the BOREAS Science White paper III, section 2.1.

Figure 3.3 outlines the principal activities for FFC-W, planned to run 2/27/96 through 3/15/96. The main elements are summarized below.

3.3.1 Airborne data acquisition

RSS-2: Multi-angle (BRDF) observations: The NASA C-130Q(RC), equipped with ASAS will be used to fly a series of RC-TS/RC-SS missions over the TF sites in the SSA where the PARABOLA (RSS-1) will be working, and some other targets of low surface roughness. The first priority targets are:

SSA-OA
SSA-OBS
SSA-OJP
Frozen lake (Namekus)
Agricultural site

As a second priority, data will be collected over the SSA-Fen and SSA-YJP sites.

During the FFC-W repeat flights may be made over some of the high priority sites if conditions change (e.g. a fresh snowfall), or RSS-1 has moved and is taking data at a new site.

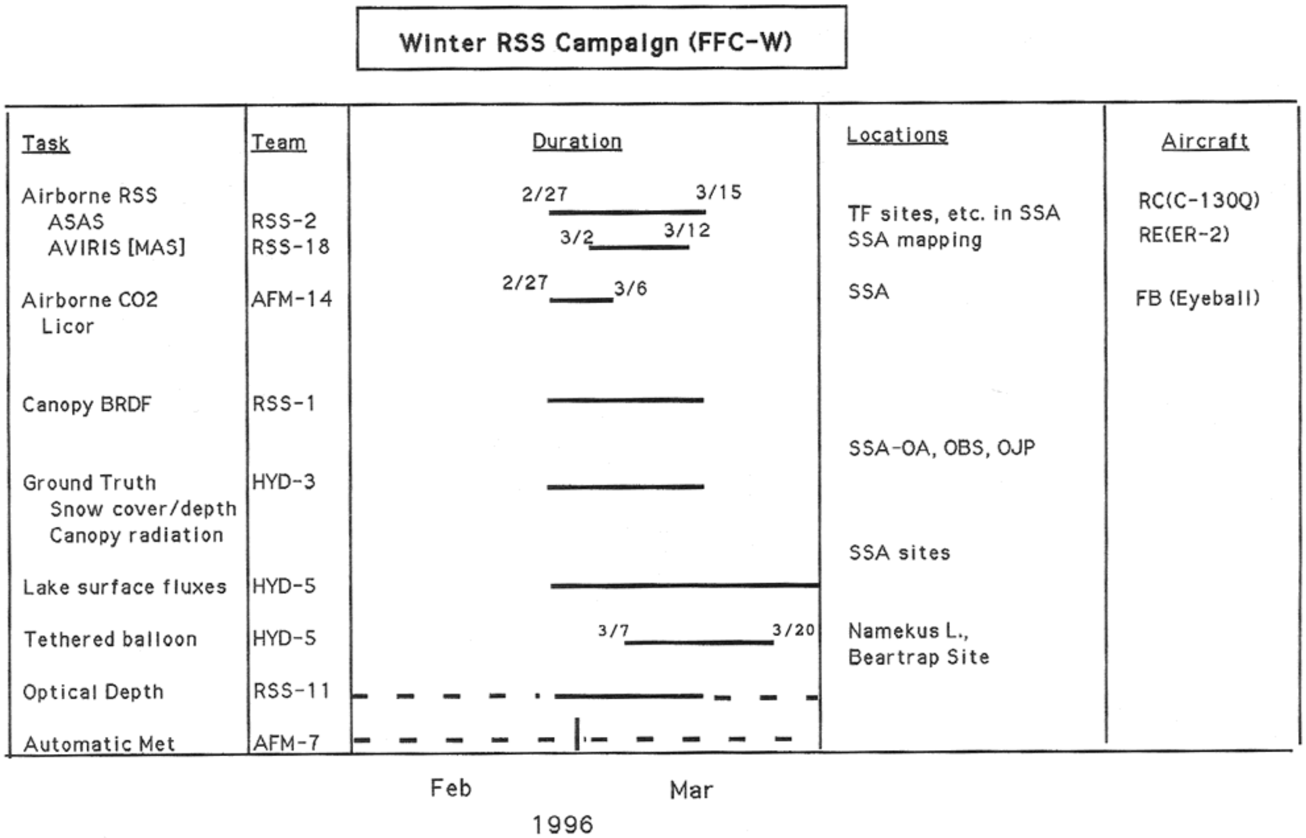

Figure 3.3 Schedule of activities for Winter RSS Campaign (FFC-W '96) in BOREAS-96. Solid line indicates presence on site; dashed line indicates automatic data acquisition.

As a last priority, data will be collected over the NSA TF sites: NSA-OBS, NSA-OJP, NSA-Fen, NSA-YJP, NSA-OA (TE); and over the transect between the study areas (RC-RT). This will only be done if flight hours are available.

RSS-18: AVIRIS data acquisition: The NASA ER-2 (RE) will fly a mapping mission over the SSA (RE-MS), including lines B, C, D, G, H, I, J, K (i.e. lines A, E and F can be dropped in RE-MS). Lines I and J are to be extended 15km southwards to cover the agricultural site. The AVIRIS data will be analyzed to produce analogs of the MAS bands out to 2.5 microns, using the convolution algorithm developed by RSS-18.

AFM-14: Airborne CO_2 concentration measurements: The Eyeball (FB) aircraft will be equipped with a Licor CO_2 analyzer and will be used to perform a series of soundings and transects over the SSA (FB-VS). It will also fly birddog missions (WX recce) for the C-130 as necessary (FB-ES).

3.3.2 Surface measurements

RSS-1: PARABOLA data will be acquired at SSA-OBS, SSA-OA, and SSA-OJP in that order. These may be followed by measurements at the agricultural site and Namekus Lake (see 5.2.1.1b). Measurements will be done in collaboration with HYD-3. On 2/26, RSS-1 will set up for calibration tests at Paddockwood School; on 2/27 they will set up for data acquisition at SSA-OBS. Calibration with the aircraft hemisphere (RC) will be done in the Athabaska hangar if necessary.

RSS-11: Two CIMEL photometers will be set up in the SSA; one at Paddockwood and one outside SSA-Ops. A handheld instrument will operate at SSA-OBS and other TF sites where RSS-1 is working.

HYD-3: HYD-3 will support the RSS-1 measurements by characterizing snow properties at the three TF sites equipped with PARABOLA. If time allows, HYD-3 should also characterize the agricultural and frozen lake (Namekus) sites. A radiation array will be set out below the canopy and some tree holography will be attempted.

HYD-5: HYD-5 will measure fluxes (eddy correlation) and meteorological variables over Namekus Lake using 3m towers, from 2/25 through 3/24. A tethered balloon system will be operated from 3/7-20/96. Flux measurements may be taken at the Bear trap site near Waskesiu.

AFM-7: Maintenance will be enhanced during FFC-W at the SSA-OA and SSA-OJP sites.

If the C-130 does NSA missions, Jo Lutley will be contacted by SSA-Ops to take handheld measurements at the time of the overflight.

3.4 NSA Growing Season

3.4.1 Overview, rationale

Figure 3.4 summarizes the proposed work at the NSA for BOREAS-96. Several data gaps were identified in White Paper I on stand level measurements; primarily, carbon flux, evapotranspiration, and canopy physiological measurements during the spring thaw and autumn freeze-up transition seasons are missing. In addition, information about the controls over fluxes from the moss layer are critically needed because of the possibly important role of moss in the carbon and water fluxes, and in water storage. Analysis of observations from the continuously operating flux system at NSA-OBS has shown that respiration in autumn may counter a significant fraction of the summer carbon uptake. Therefore, the focus for the autumn measurements is to quantify soil/moss fluxes in the transition period, and determine what triggers overstory shutdown and controls soil/moss carbon fluxes. Model studies have pointed to the need for more "component" based observations of the contributors to the carbon budget, particularly separating the components of moss/soil carbon fluxes. To better test models, the modeling groups expressed a desire for longer, continuous time-series of data. Finally, interesting atmosphere-vegetation feedbacks (humidity-transpiration) were observed in 1994, but were not fully explored.

3.4.2 Measurement tasks

The plan for NSA BOREAS-96 observations is summarized in figure 3.4. It includes:

* A program of limited above-canopy flux measurements from April 16 to November 15 at the NSA tower sites that operated only during the 1994 growing season (NSA-OJP, Fen and possibly YJP). This will complement the ongoing work at NSA-OBS. It is critical to know the stage in a draw-down cycle that physiological measurements are made. A concurrent program of continuous soil moisture observations, using both TDR and neutron probe measurements at the NSA forest tower sites will support these observations. At the NSA-Fen, continuous measurement of water level is proposed by TF-10.

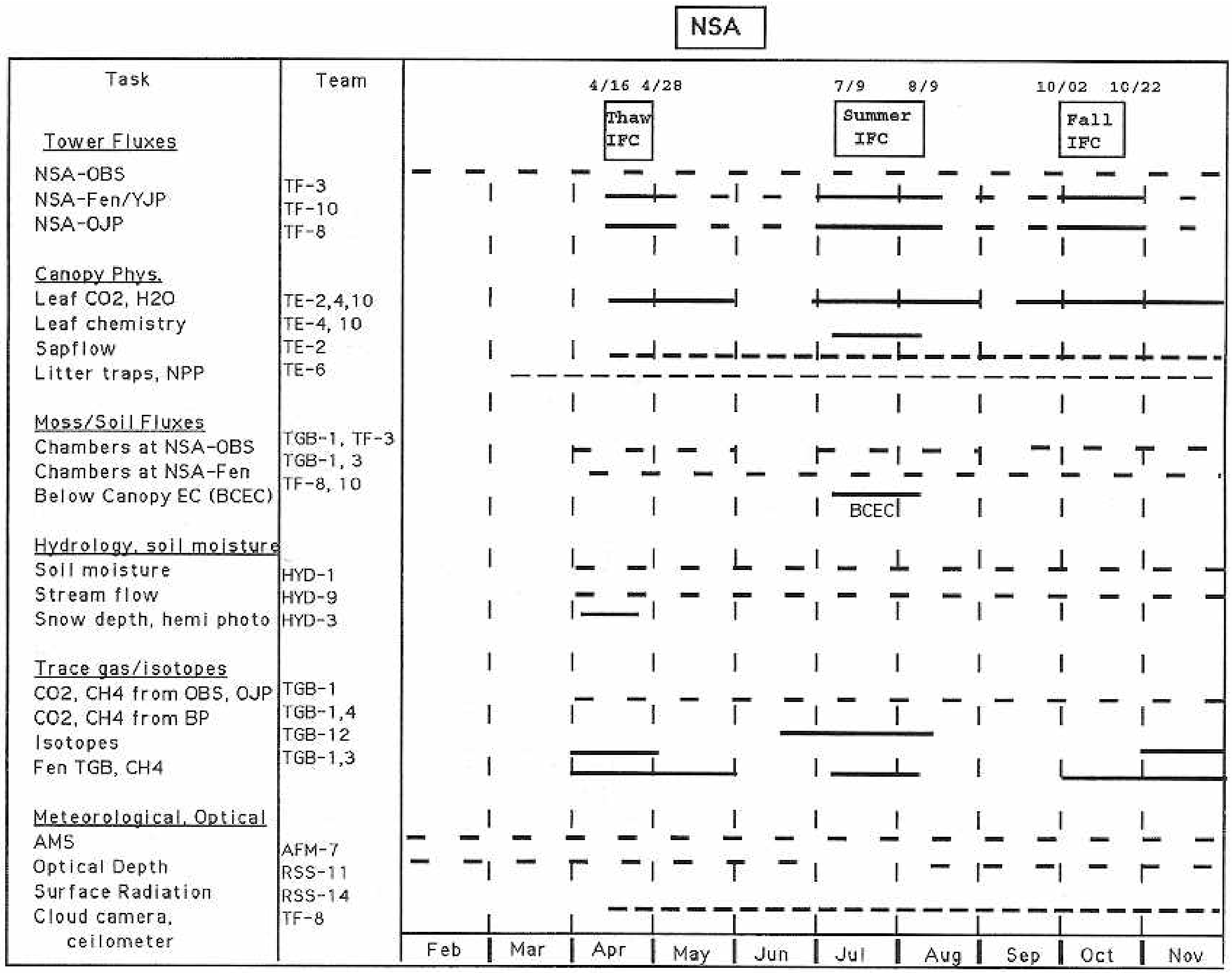

Figure 3.4 Breakdown of NSA Growing Season Studies. Solid lines indicate intensive work, with investigators on site; dashed lines denote monitoring-type measurements, where investigators may only make occasional visits to the sites.

*	Focused ecophysiological (TE) and biogeochemical (TGB) studies during spring, thaw and in the autumn at the NSA-Fen, OBS, OJP, and possibly the YJP sites, see Table 3.4.3. The chronology of photosynthesis initiation and the relative importance of surface, subcanopy and canopy processes to C uptake will be documented. These efforts include chamber CO_2 flux (soil/moss surface) sap flow measurements, and canopy photosynthesis profiles. Especially at the Fen, we propose a measurement program aimed at identifying the sequence of different plant communities that dominate the C budget during the transition seasons. This will complement the work done in the summer of 1994.

*	A summer intensive field period, primarily focused on a comparative study of the jack pine sites. Additional TF subcanopy eddy flux measurements will be used in concert with TE sap flow and leaf-level physiological measurements, and TGB measurements of soil CO_2 flux. The context for these intensive observations will be provided by the ongoing meteorological measurements and the continuous soil moisture measurements. We propose to follow the response of the jack pine to a dry period following rain.

*	Litterfall measurements may be made twice in 1996 at the TF sites and perhaps some auxiliary sites. End-of-season NPP measurements will be made at the same places.

These studies are designed to be coordinated with the boundary layer observations proposed as part of AFM, see section 3.6. In particular we wish to document the time relationship between ET, boundary layer moistening over a period of days, and the appearance of shallow, convective clouds forced by surface heat and water vapor fluxes.

The group supports the use of a CO_2 concentration system (like a Licor) be installed on a light aircraft, such as Eyeball (FB), see 3.6. This would allow the measurement of time sequences of the CO_2 profile over several days during the "recovery" periods of soil moisture draw-down. Such a measurement, coupled with the JP site-specific detailed physiology and site-wide flux measurements, and cloud observations, would use the convective boundary layer as a tool for spatial integration of surface fluxes of water vapor, heat, and CO_2.

3.4.3 Team Task Summary

The timelines for each science team are laid out in figure 3.4. Team activities are summarized below.

Tower flux

TF-3:	Ongoing continuous flux operation at NSA-OBS

TF-8: April 16 - Nov. 1 "minimal operations"; July 9 - Aug. 9 summer IFC, at NSA-OJP and supporting other sites. (See also meteorological/optical work below).

TF-10: April 16 - Nov. 1 "minimal operations"; July 9 - Aug. 9 summer IFC at NSA-Fen and NSA-YJP. Support to other NSA TF work.

Canopy

TE-2: Sap flow, leaf CO_2, H_2O [thaw, IFC, autumn]

TE-4: Leaf CO_2, H_2O; branch bag CO_2, H_2O in IFC-2; Collection of samples for biochemical analyses in collaboration with TE-10

Moss/Soil Fluxes

TGB-1: Automatic CO_2, CH_4 chambers at NSA-OBS

TF-3, 8, 10: Below canopy EC (H_2O, CO_2) at NSA-OJP, NSA-OBS

Hydrology/soil moisture

TGB-4: Soil moisture TDR at NSA-OBS

HYD-1: Soil moisture TDR and/or neutron probes at NSA-OJP, OBS, YJP.

- OBS: Automated TDR at 5 depths.
- OJP: Automatic TDR's at 4 depths and 2 locations; Neutron probe transect of 5 rods/TDR; manual operation every other day in IFC-2.
- YJP: Same as OJP.

HYD-3: Snow measurements, hemispherical photography

HYD-9: Ongoing stream flow (see 3.2.2).

Trace gas/isotopes

TGB-1, 3: CO_2, CH_4 from NSA-Fen (chambers)

TGB-3: CO_2 from Beaver Pond

TGB-4: CO_2, CH_4 from Beaver Pond

TGB-12: Isotopes from NSA-TF sites

Meteorological, optical

AFM-5: Automatic Meteorological Stations.

TF-8: Cloud camera, ceilometer at OJP.

RSS-11: Optical depth from automatic sunphotometers

RSS-14: Provision of 3-hourly surface radiation budget terms from GOES (see 3.2.3).

Further details on the timing of the ecophysiological measurements may be found in Table 3.4.3.

3.4.4 Operational considerations

3.4.4.1 TF Operations for NSA in 1996:

All NSA TF towers should operate from April through November with a minimal suite of flux measurements and supporting meteorological data at one height above the canopy. Included are heat, water vapor, CO_2, and net radiative fluxes via the eddy correlation method; air temperature, and relative humidity. In the soil, a minimum of three levels of temperature will be measured. Stem temperature at one or more sites as well as subcanopy temperature and humidity complete the minimal tower data set.

The collection of selected long-term data series that span the growing season and its transition seasons on all sites was preferred to the strategy of dropping towers to enable more measurements at the remaining site(s). By maintaining basic measurements at all the sites, the NSA team will provide a stronger data base for use in scaling to the region and to understand better species-specific carbon, water, and energy budgets.

To achieve this "minimalist" approach, the TF teams will share personnel, resources and equipment. Having fewer people in the field results in considerable financial savings. Also, to the greatest extent feasible, all sites will be automated. OBS is already running continuously. The people for servicing OJP, YJP, and Fen towers will be provided by TF-10 and TF-8. When necessary, people in the field will also help TF-3 with equipment replacement; that group already covers routine data maintenance. More robust sonic anemometers of the same type as that already in use at OBS and OJP will enable the Fen and YJP sites to operate automatically and facilitate repairs at any of the sites. Spare parts will be interchangeable among the groups, who will cooperate for tower equipment replacement and servicing. To address scientific questions of carbon component behavior and understory fluxes, intensive field campaigns are planned. During the IFCs, not all towers will be operating at maximum capacity. Rather, many specific problems will be addressed. In the spring and autumn, carbon component measurements at the fen, OBS, YJP, and OJP will be conducted with no additional TF measurements.

In the summer, the focus will shift to the OJP and YJP sites, with emphasis being placed on relating heat and vapor fluxes to canopy physiology (see below). Understory fluxes will be measured with several below-canopy eddy correlation (BCEC) units, self-contained eddy correlation systems employing Campbell

Table 3.4.3 Ecophysiological measurements in NSA

Task	Timing	Sites				
		OBS	OJP	YJP	Fen	OA (TE)
Xylem flow	IFC-1 IFC-2 IFC-3	--- TE-2 TE-2	-- TE-2 TE-2	-- TE-2 TE-2	- - -	- - -
Branch bag A_n, g_s	IFC-1 IFC-2 IFC-3	-- TE-4 --	-- TE-4 --	-- TE-4 --	- - -	- - -
Canopy leaf A_n, g_s	IFC-1 IFC-2 IFC-3	-- TE-2, 4 ?	-- TE-2, 4 ?	-- TE-2, 4 TF-10	- TE-4 -	- TE-4 -
Canopy Chemistry	IFC-1 IFC-2 IFC-3	-- TE-4,10 --	-- TE-4,10 --	-- TE-4,10 --	-- TE-4,10 --	-- TE-4,10 --
Understory A_n, g_s	IFC-1 IFC-2 IFC-3	- TE-4 -	- - -	- - -	- - -	- - -
Moss; soil A_n, $resp^n$	IFC-1 IFC-2 IFC-3	-- TGB-1 TGB-1	- TGB-1,3 TGB-1,3 -	- TGB-1,3 TGB-1,3	TGB-1,3 TGB-1,3 TGB-1,3	- - -
Isotopes	IFC-1 IFC-2 IFC-3	TGB-12 - TGB-12	TGB-12 - TGB-12	TGB-12 - TGB-12	TGB-12 - TGB-12	TGB-12 - TGB-12
Litterfall, NPP, NEP	IFC-1 IFC-2 IFC-3	-- TE-6 --	-- TE-6 --	-- TE-6 --	TGB-1 TGB-1 TGB-1	-- TE-6 --

single-axis sonic anemometers that TF-10 and TF-8 already have. Replication is desirable when using the eddy correlation technique in the heterogeneous subcanopy environment. We anticipate taking the summer data during one or more dry-down sequences at OJP and YJP, thus being able to evaluate surface stress changes as well as the controls exerted by the changing humidity status of the boundary layer. It is planned to set-up arrays of these BCEC rigs for around two weeks at a time at the OBS, OJP and YJP sites. Because of the importance of placing these measurements in the context of the seasonal tower fluxes, and the importance of soil water in altering leaf physiology, continuous soil moisture observation from TDR and neutron probes is important to these studies. At YJP and Fen, TF-10 proposes stomatal conductance measurements to complement work by the TE groups see also table 3.4.3.

3.4.4.2 Transition season observations:

The annual carbon balance of the boreal forest is believed to be very sensitive to the timing of the startup of photosynthesis in the spring. We know very little about what controls the start of spruce and moss photosynthesis. Is the onset time controlled primarily by air temperature, soil temperature, or by some physiological regulation? Do moss and spruce start at the same time?

A number of canopy ecophysiological studies will be performed in the NSA, see Table 3.4.3.

We propose continuous measurement of moss surface CO_2 exchange by automated chambers, continuous measurements of whole forest exchange by eddy correlation, continuous measurements of transpiration by sap flow, and a set of intensive spruce needle and moss physiological measurements. This work will be led by TGB-1 in the NSA using a set of autoatic chambers at NSA-OBS and manually operated chambers at NSA-OJP, Fen and YJP. Collars are in place at OBS, OJP, and Fen; some new ones will have to be installed at YJP. Temperatures will be measured in the moss layer and the base of the moss layer; the exact depths of these temperatures are to be finalized with TE-6 (who will lead similar work in the SSA) to maintain a uniform methodology across the project. Intensive physiological measurements should run from April 15 to May 30 with a focus at the NSA OBS site. The work at the other sites, will proceed at a lower intensity; for example, soil/moss CO_2 measurements will be done at NSA-OJP every other week. Measurements should include environmental response curves and in situ measurements along with a characterization of soil temperature and water status.

Chamber measurements will be used to estimate soil and moss respiration. Total carbon losses from the soil are comprised of metabolic respiration of roots and mosses (2/3?) and decomposition of dead organic matter. Relative contributions vary from spring to fall and respond differently to moisture, temperature, etc. Three methods were proposed to separate these components:

1. Stable isotopes in respired CO_2. Mosses are more depleted in ^{13}C than trees or soil organic matter; ^{18}O may also be a useful measurement.

2. Effective diffusivity combined with CO_2 profiles in moss will allow calculation of CO_2 production with depth. [Diffusivity can be estimated by tracking SF_6/Rn].

3. ^{14}C in CO_2 separates contributions from fast-cycling organic and metabolic respiration and old decomposing organics.

Isotopic Measurements will be made by TGB-12 at OBS, OJP, YJP, Fen to address these issues: the measurements will consist of 1-2 profiles with fluxes in spring summer, fall.

The same questions are raised regarding what controls the shutdown of photosynthesis at the end of the growing season, i.e. air and soil temperatures, or a major event like a single hard frost. A similar series of measurements to those proposed for spring (moss and branches) is recommended for autumn for the TF sites.

3.4.4.3 Wetland ecosystems

3.4.4.3.1 Fens

1. Fens are regionally extensive and they sequester more carbon than any other ecosystem. Thus, potential for carbon loss (especially with permafrost degradation) is great.

2. Fens are not forests--they behave differently, since the moss <is> the soil. In the models, the fens are the least understood.

3. As noted above, observations of carbon budget components are missing in the spring and fall.

4. Fens are heterogeneous. Different components of the fen ecosystem have different start-up and turn-off times in terms of carbon uptake, resulting in different seasonal patterns between the larger fen complex and individual plant communities (e.g., sedge, shrub, sphagnum-dominated). Also, mosses and vascular plants have different seasonal patterns in terms of NPP. Moss NPP is greatest in early-mid summer. Understanding the carbon balance of the entire fen complex requires an understanding of the thaw and freeze-up periods for each of the component ecosystems.

3.4.4.3.2 Beaver Ponds

Beaver ponds also play an important role in the carbon budget of the boreal landscape. Observations in 1994 (TGB-4, TGB-1) indicated that beaver ponds are always a source of atmospheric CO_2. The ponds from the BOREAS-94 regional survey will be revisited and surface water concentrations of CO_2 and CH_4 will be determined. Subject to support, TGB-4 will return to the NSA 1994 beaver pond site, to continue the CO_2 flux studies. As with the fen, the emphasis would be on the May thaw and autumn freeze periods. Observations proposed for the beaver ponds (TGB-4, TGB-1) include:

- CO_2/CH_4 in surface water; revisit regional BP survey sites, variability
- Thaw-May, IFC-2, Sept.-freeze 1996
- At least twice during each IFC [TGB-1, TGB-4]

3.5 SSA Growing Season Studies

Figure 3.5 summarizes the proposed work at the SSA for BOREAS-96. Table 3.5.2 provides more details on the ecophysiological (TE) and biogeochemical (TGB) work.

3.5.1 Overview, rationale

The areas of proposed BOREAS-96 SSA work can be summarized as follows:

- The aim is to establish annual carbon and H_2O balances but currently we lack data during thaw and fall periods.

- We need to understand the environmental controls on fluxes throughout the year to enable them to be modeled.

- The aim is to establish closed carbon and H_2O budgets for the stands but currently we lack data on the understory and moss layers.

- Data are needed from which to derive parameters for modeling throughout the year.

- Nighttime CO_2 effluxes need to be better characterized and possible losses explored.

- Links with ABL processes need to be developed.

3.5.2 Measurement Tasks

3.5.2.1 Stand Scale Processes

The OA (TF-1) and OBS (TF-9) flux sites will operate continuously from the thaw in the spring through to the freeze-up in the fall. Proposed start dates are 4/15/96 and 3/23/96, respectively, and measurements will continue until approximately the end of November.

At both sites there will be:

- eddy covariance measurements of fluxes of momentum, sensible heat, H_2O and CO_2 above the canopy (top priority for continuous operation)

- similar eddy covariance flux measurements in the trunk space

- a fully instrumented weather station above the canopy and in the trunk space, and some additional measurements at and close to the soil/moss surface (air and surface temperature, wetness, PAR, humidity, windspeed) especially at OBS

- profiles of atmospheric CO_2 concentration and air temperature

- profiles of soil temperature (to start as soon as possible to run through the winter)

- sapflow estimates of tree transpiration for comparison with eddy fluxes (TE-7 at OA), throughout the entire period.

3.5.2.2 Canopy Processes

The overstory of both OBS and OA was characterized during mid season in 1994. However, our knowledge is still incomplete regarding early/late season physiology and scaling of fluxes from individual canopy components to canopy level, especially at OBS. No studies were made of the physiological responses of black spruce to freezing temperatures which regulate the beginning and end of canopy activity. Studies in 1994 showed that leaf fluorescence measurements are ideally suited for assessing the integrity of photosynthetic processes. Measurements of stomatal conductance, net CO_2 uptake and sapflow will supplement these observations. These measurements will be made by TE-4 starting early during the thaw (3/23/96) and carried through until full activity is attained (probably in early May). It will also be important to determine if acclimation of needles to low temperature significantly alter their performance relative to that expected from physiological studies of mid season foliage. Other TE teams may be available for photosynthetic measurements at OBS during the new needle flush (e.g., TE-10, TE-11 during early June).

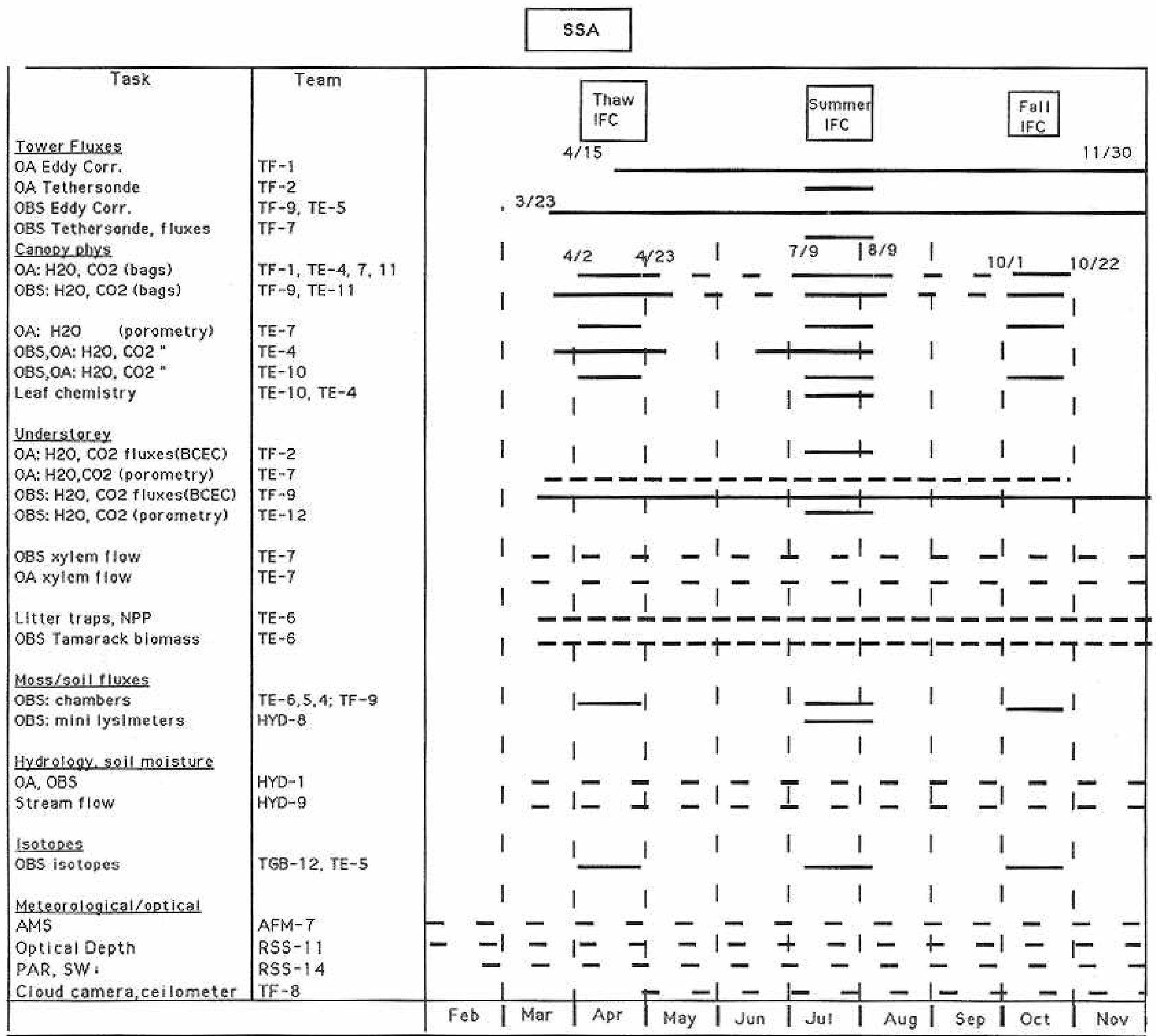

Figure 3.5 Breakdown of SSA Growing Season Studies. Solid lines indicate intensive work, with investigators on site; dashed lines denote monitoring-type measurements, where investigators may only make occasional visits to the sites.

Table 3.5.2 Ecophysiological Measurements in SSA

Task	Timing	Sites	
		OBS	OA
Xylem flow	IFC-1 IFC-2 IFC-3	TE-7 TE-7 TE-7	TE-7 TE-7 TE-7
Branch bag A_n, g_s	IFC-1 IFC-2 IFC-3	TF-9, TE-11 TF-9, TE-11 TF-9, TE-11	TE-4, 7, 11; TF-1 TE-4, 7, 11; TF-1 TE-4, 7, 11; TF-1
Canopy leaf A_n, g_s	IFC-1 IFC-2 IFC-3	TE-4 TE-10 TE-4	- TE-4, 7, 10 -
Understory A_n, g_s	IFC-1 IFC-2 IFC-3	- TE-12 -	- TE-7, TF-1 -
Moss; soil A_n, $resp^n$	IFC-1 IFC-2 IFC-3	- TE-6, 5, 4 -	TE-7 TE-7 TE-7
Canopy Chemistry	IFC-1 IFC-2 IFC-3	- TE-10, 4 -	- TE-10, 4 -
Undercanopy radiation, T_s	IFC-1 IFC-2 IFC-3	- TE-5, 6 HYD-8 -	- - -
Isotopes	IFC-1 IFC-2 IFC-3	TGB-12 TE-5 TGB-12	TGB-12 - TGB-12
Litterfall, NPP	IFC-1 IFC-2 IFC-3	TE-6 TE-6 TE-6	TE-6 TE-6 TE-6

A mid season intensive campaign will focus on making the link between leaf physiology and canopy fluxes. This will involve measurements of the vertical profiles of photosynthesis and stomatal conductance, augmented by leaf water potential and leaf chemistry measurements (chlorophyll, nitrogen etc.). TE-10 will collect leaf samples in SSA; TE-4 will collect them in the NSA, and both will do the biochemical analyses. Additionally, branch bag studies in 1994 (TE-11 and TF-9) demonstrated that these provide a very useful intermediate step in scaling from the leaf to the canopy. Notably these measurements are free of large substrate respiratory fluxes of CO_2 that complicate interpolation of the site measurements. Therefore, they are a much better test of shoot-level photosynthetic models. Branch bags will be installed; two at OA, four at OBS. At OA these will be installed in the aspen overstory. At the OBS, bags will be installed in the upper and lower branches. Continuous measurements of photosynthesis (A_n) and conductance (g_s) by these setups, added to moss, soil and understory contributions can be compared to the observed tower fluxes.

These studies will be conducted by TF-9 at OBS; and TF-1, TE-7, 11 at OA.

In addition, branch level conductance from branch bag studies will be compared with sap flow measurements at OA and OBS (TE-7). Other tree measurements are also planned by various groups. Leaf and shoot water potential measurements will be made at both sites by TE-7 (OA) and TE-12 and TF-9 (OBS).

The overstory effort requires two canopy access towers per site (OA and OBS), one each with access to power for the branch bags. IRGAs and computers (or CR 10 or CR-21X data loggers) will be used to operate the branch bags. Vertical and horizontal APAR distributions at the two sites are essential.

3.5.2.3 Understory

The understory was a major focus of the work done in BOREAS-94 at the OA site but it received little attention at OBS. Biometry studies indicate that the understory accounts for a significant fraction (10-20%) of the net stemwood production at the OBS. Vertical profiles (TE-4, TF-9) at the OBS indicate that the understory does not exhibit midday stomatal closure during hot dry days and may contribute a large part of the total CO_2 flux on these days. An effort will be mounted in BOREAS-96 to characterize better this component of the OBS system and will include the following:

(a) Determination of physiological characteristics of representative leaves of the sub canopy and calibration of a physiological model to simulate these responses;

(b) Observations of net CO_2 uptake and stomatal conductance and of the necessary driving variables, quantum flux, leaf temperature, saturation deficit and u_*, made under ambient conditions, which will be used to test the model.

(c) Comparison of the responses of the understory and the upper canopy on days when significant stress occurs - low temperature, water stress and hot dry mid-summer days - with special regard to the significance of mid-day stomatal closure.

(d) Address the spatial scaling issue across the site, which will require characterization of LAI, FPAR and cover fraction, and may involve destructive sampling, light measurements and assistance from Remote Sensing Science teams or BOREAS staff.

These studies will be conducted primarily by TE-12 at SSA-OBS. At SSA-OA, TF-1 and TE-7 will be responsible for acquiring the appropriate data to characterize the understory.

3.5.2.4 <u>Moss/Soil Processes</u>

During BOREAS-94 very little work was done on the role of the moss layer that very largely comprises the ground vegetation at coniferous sites. However, remote sensing data and models suggest that the moss may contribute substantially (up to 30%) to the total flux. These issues are outlined and addressed below.

3.5.2.4.1 Contribution of the moss/soil system to total fluxes

The contribution of the moss/soil system at the SSA-OBS to the total ecosystem CO_2 and evaporative fluxes will be investigated. The investigation will focus on the environmental controls exerted by the following factors.

a) temporal variation associated with temperature and moisture content of moss;

b) spatial variation associate with hummocks, hollows and with environmental gradients; and

c) how is it affected by low windspeeds and temperature increases at night?

The sampling procedures for CO_2 and H_2O flux from moss/soil will include:

- continuous automatic sampling of chambers at OBS (TE-6);

- repeated sampling of small plots (collars) using a Li Cor 6200 system with large chambers at OBS (TE-5);

- experiments to wet up moss and follow fluxes during dry down at OBS (TE-5, TE-6);

- semi-continuous soil (and stem) CO_2 efflux measurements at both SSA-OA (TF-1 and TE-2) and SSA-OBS (TF-9) using chambers over extended periods, especially at night, to quantify the contribution of soil and foliage CO_2 efflux to the carbon balance; and

- continuous lysimeter measurements below the moss by HYD-8 (Band).

Collars will be placed to include hummock/hollow variation and along environmental gradients of water content. Temperature measurements will be made at different depths in the moss/soil layer at depths jointly defined by TE-6 and TGB-1.

All chamber measurements will be made in association with measurements of PAR, moss temperature, air temperature, RH, moss water content etc.

3.5.2.4.2 Contribution of moss respiration to moss/soil respiration CO_2 fluxes.

Separation will be attempted by TE-5 using differences in $d^{13}C$ between moss $d^{13}C$ (32%) and other system components (tree leaf $d^{13}C$ = 26%; tree roots $d^{13}C$ = 26%; and soil organic matter $d^{13}C$ = 26%).

Sampling procedures will include:

- total system $d^{13}C$ of respired CO_2 from tower flask sampling;

- moss/soil contribution from chamber measurement of $d^{13}C$ of respired CO_2;

- $d^{13}C$ of CO_2 sampled from (i) within moss; (ii) within soil, and of soil organic matter in collaboration with TGB-12;

- $d^{13}C$ of CO_2 released from moss respiration in lab experiments.

To assist with the interpretation and scaling up of the chamber measurements, TF-9 and TE-5 will measure eddy fluxes in the trunk space to obtain the spatially integrated fluxes of CO_2 and H_2O from the ground vegetation.

In addition, TF-9 will install a weather station in the trunk space with soil measurements of the moss surface (temperature, wetness, windspeed and humidity). The spatial distribution of PAR at the ground surface will also be measured with a number of sensors and net radiation at a few points.

3.5.2.5 Stable Isotopes of CO_2

Stable isotope techniques have contributed greatly to global studies of CO_2 partitioning between the ocean and the terrestrial biosphere. Important parameters that influence the quantitative outcome of global studies of CO_2 partitioning using ^{13}C are: (1) discrimination during photosynthetic gas exchange; and (2) isotopic disequilibrium between CO_2 released during ecosystem respiration and atmospheric CO_2. The first of these parameters is quite well understood, but there are virtually no measurements of the second parameter. In addition, it may be possible in the near future to partition global CO_2 using ^{18}O in CO_2. Since the processes controlling the ^{18}O composition of atmospheric CO_2 are completely independent from ^{13}C , the ^{18}O data can provide important checks on the results of the ^{13}C studies.

We have been actively involved in studying the factors affecting ^{13}C and ^{18}O fractionation during leaf and ecosystem level CO_2 exchange. In Black Spruce forests the moss layer appears to have a very significant influence on ^{18}O exchange processes, and as a consequence these forests have a very different influence on the ^{18}O content of the atmosphere than do Jack pine or broad leaf forests in northern regions.

TE-5, in collaboration with TGB-12, proposes to make the following measurements at OBS at intervals during May - November 1996:

(a) ^{13}C , ^{18}O content of CO_2 from flask samples collected within the forest boundary layer from tower or balloon platforms.

(b) ^{13}C , ^{18}O content of CO_2 collected at different depths within the overstory and understory canopies, moss and soil and of soil organic matter.

3.5.3 Team Task Summary

The time-lines for team activities are set out in figure 3.5 and Table 3.5.2; the individual tasks are summarized below.

Tower Fluxes

TF-1: Fluxes will be measured at the SSA-OA (4/15 - 11/30/96).
TF-2: Tethersonde for nocturnal CO_2 at SSA-OA.

TF-9: Flux measurement work at SSA-OBS (3/23-11/30/96).
TE-5/TF-7: Supporting flux measurements at SSA-OBS; balloon-mounted CO_2 sampling.

Canopy Physiology

TF-1: Leaf porometry at SSA-OA for H_2O and CO_2 conductances-photosynthesis.
TF-9: Leaf porometry/branch bags at SSA-OBS for H_2O and CO_2 conductances-photosynthesis.
TE-4: Leaf porometry at SSA-OBS, SSA-OA; leaf chemistry analyses.
TE-5: Xylem flux, heat-pulse at OBS.
TE-6: Litter traps and NPP; SSA-OBS tamarack biomass destructive sampling; sub-canopy radiation train-track.
TE-7: Sap flow at SSA-OBS, SSA-OA.
TE-10: Leaf porometry at SSA-OBS, SSA-OA; leaf chemistry profiles.
TE-11: Branch bags supplied to SSA-OA, SSA-OBS teams; visits.
TE-12: Leaf porometry at SSA-OBS, understory.

Understory Physiology/Fluxes

TF-2: Understorey eddy correlation at SSA-OA.
TE-7: Understorey leaf porometry at SSA-OA.
TF-9: Understorey eddy correlation at SSA-OBS.
TE-12: Understorey leaf porometry aat SSA-OBS (IFC-2 only).

Moss/soil fluxes

TF-1: Manual chamber measurementsof H_2O, CO_2 in IFC-2, SSA-OBS.
TF-9: Manual chamber measurements of H_2O, CO_2 at SSA-OBS.
TE-5: Multiple collars for spatial variability of H_2O, CO_2 at SSA-OBS.
TE-6: Automatic collar measurements of H_2O, CO_2 at SSA-OBS.
TE-7: Soil CO_2 fluxes at SSA-OA.

Hydrology/soil moisture

HYD-1: Automated TDR, transect, 5 depths at SSA-OA by 3/25/96. Manual TDR, transect of 5 rods at SSA-OBS. May put in 2 40m/5 depth transects in to be read in IFC-2 only but equipment left in place for TF-9 to operate.
HYD-8: Mini lysimeters on moss/soil layers at SSA-OBS; sub-canopy precipitation. (IFC-2 only).
HYD-9: Stream flow at White Gull gages in SSA, see section 3.2.2.

Isotopes

TE-5: Isotopic samples from SSA-OBS during IFC's.
TGB-12: Isotope samples taken from SSA-OBS probes at beginning and end of season.

Meteorology/Optical

AFM-7: Automatic met stations at SSA-OA, SSA-OJP.
TF-9: Cloud camera at SSA-OBS; to be set up by TF-8 in 5/96. also ceilometer (Staff).
RSS-11: Automatic sun photometry at PANP and SSA-YJP.
RSS-14: Calculation of surface radiation fluxes from GOES, see 3.2.3..

3.6 Growing Season RSS and AFM Activities

Figure 3.1 shows that the summer and fall IFCs in BOREAS-96 will be small-scale equivalents to IFC-2 and IFC-3 of BOREAS-94 in that they will include coordinated remote sensing and atmospheric boundary layer/tropospheric measurements as well as surface measurements. Operational planning and management of these activities will continue much along the same lines as was done in BOREAS-94.

3.6.1 AFM Activities

Figure 3.6.1 shows the schedule of AFM activities for BOREAS-96.

Flux aircraft

AFM-4: The NRC Twin Otter (FT) will only deploy in IFC-2 but will take measurements over both the SSA and NSA. The aircraft will measure momentum, H, H_2O and CO_2 fluxes, and NO_x concentrations. CH_4 will not be measured. It is planned to fly FT-TS, FL-CS and FL-ZS lines routinely in the SSA. The FT-RT run will be completed on SSA-NSA transits.

FT should occasionally be used in a profiling mode to (i) gather statistics on turbulent components (TKE and u', v', w') under various cloud cover conditions and (ii) to obtain daytime CO_2 profiles through the ABL (FT-VS).

AFM-14: The Eyeball (FB) aircraft will be equipped with a CO_2 analyzer, logger and pressure/temperature/humidity sensing equipment. Soundings (FB-VS) will be made routinely; as part of regular Eyeball operations (site inspections, WX recce, SSA-NSA transits

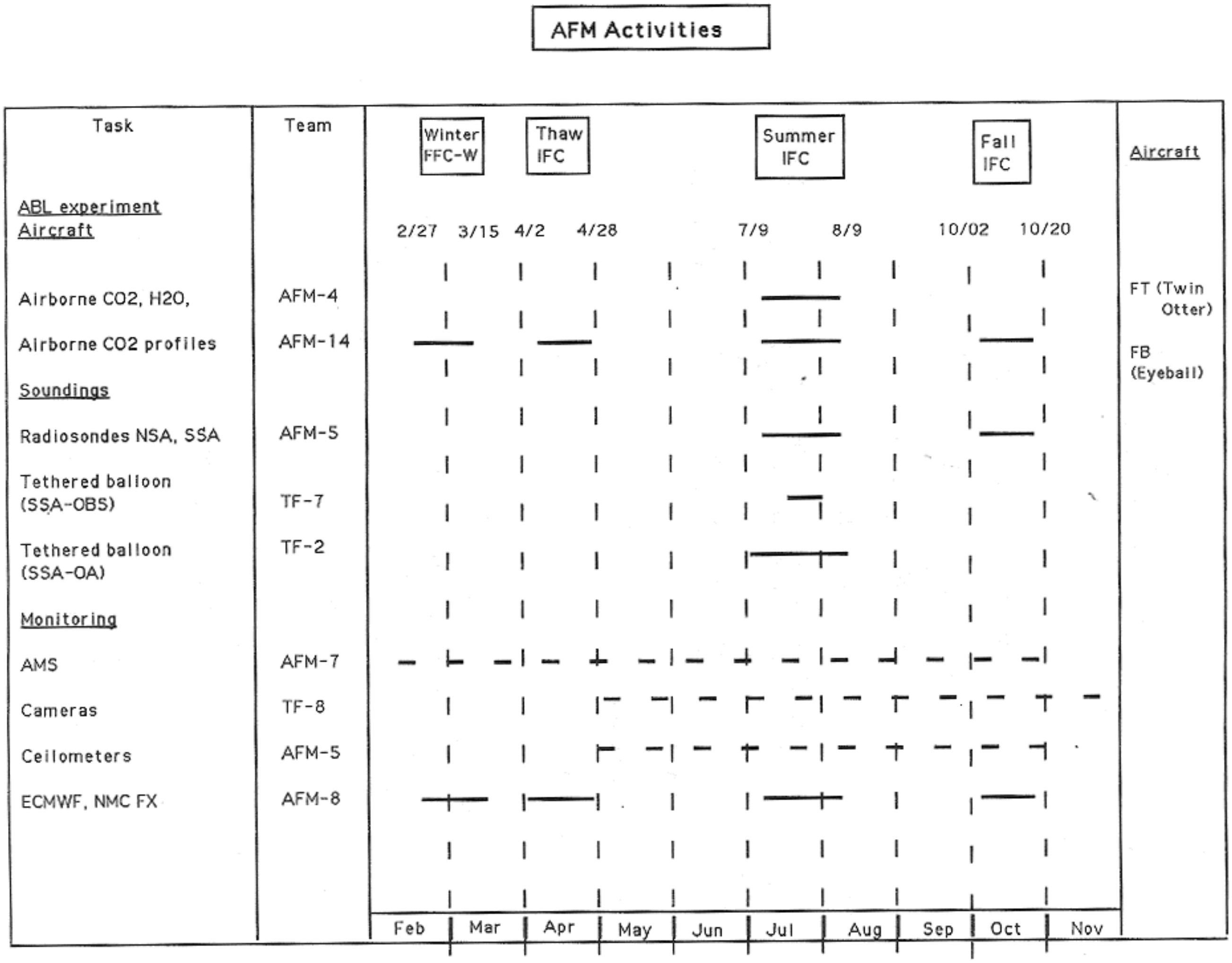

Figure 3.6.1 AFM Activities in BOREAS-96

and forward air traffic control/bird-dog operations: FB-ES); and as opportunities permit.

The intention is to obtain midday profiles of CO_2 up through to ABL cloud layer, for use by tracer modelers.

Soundings

AFM-5: Radiosondes will be operated out of the SSA (HQ Operations) and NSA (Thompson Zoo) launch sites. The total supply of sondes runs to 400-500. It is proposed that 6 sondes are launched per day on good-weather days at both study areas. The times are: 1115, 1515, 1715, 1915, 2115, 2315 Zulu at Candle Lake and Thompson. The sondes at 1515, 1915, and 2115 will be dropped on days that are rainy at 1430 Zulu in the morning. Two sondes per day at synoptic times at nominally 1200 and 2400 Zulu are launched operationally from Saskatoon, The Pas and Churchill.

TF-7: A tethered balloon may be operated in IFC-2 at SSA-OBS. This would allow for nocturnal and early morning profiling of CO_2 , for flux calculations, and some daytime profiling work for linkage to the airborne EC measurements.

Monitoring

AFM-7: The AMS network will continue operations until 11/30/96. Thereafter, we can recommend that 4-5 BOREAS AMS sites be continued, and the rest decommissioned. The candidate sites for post-BOREAS are:

SSA

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

NSA

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

We will also request SRC to continue to supply the data from their permanent site in Saskatoon.

TE-8: Cloud cameras will be installed at NSA-OJP and SSA-OBS in 05/96, to run through 11/96.

AFM-8: BOREAS Ops will have access to the ECMWF and NMC forecasts for BOREAS for all intensive field operations, see figure 3.6.1. Environment Canada will also be providing forecast support from the Saskatoon office, see 4.1.3.9.

Staff: Ceilometers should be installed at NSA-OJP and SSA-OA for the growing season.

3.6.2 RSS Growing Season Activities

Figure 3.6.2 shows the planned RSS activities for BOREAS-96. These will be concentrated in IFC-2. (ASAS and AVIRIS data will also be acquired over the SSA in FFC-W, see 3.2).

Airborne measurements

RSS-2: The NASA C-130Q (RC), equipped with ASAS will conduct RC-TS and RC-TN measurements in IFC-2. The agricultural site in the SSA, will also be given the RC-TS treatment.

RSS-18: The NASA ER-2 (RE) will fly RE-MS, and RE-MN plus RE-RT missions with AVIRIS, and MAS instrument in IFC-2. The AVIRIS data will be convoluted to simulate MODIS bands and these along with the MAS data will be passed to the MODLAND team.

Both aircraft will have air photo equipment.

RSS-19: The Chieftain (RP), equipped with CASI, will conduct RP-TS, RP-TN flights, coordinated with RC and RSS-1. Also transect flights, RP-RT and a transect line into the tundra (RP-XB).

RSS-15; There is a chance that the NASA DC-8 (RD) will fly radar surveys over the SSA in June; RD-MS, BS, FS.

Supporting measurements

TE-23: A team will characterize FPAR/LAI at the TF sites (Category I) and other selected auxiliary sites (Category II and III) sites throughout SSA and NSA.

RSS-1: PARABOLA measurements will be made at SSA-OBS, SSA-OA and SSA-OJP, coincident with the RC-TS missions and other periods of good weather in IFC-2.

RSS-7: LAI-2000 and TRAC measurements of FPAR/LAI; supporting CASI in the NSA and along the tundra transect.

RSS-11: Optical depth will be measured by the automatic sun photometry network.

RSS-19: Understorey reflectance measurements in IFC-2.

<u>Surface validation (radar)</u>

RSS-15: Field checks of radar images in SSA and perhaps NSA (8/1-8/96). Also, tree geometry/dialectric measurements in SSA, (8/10-17/96).

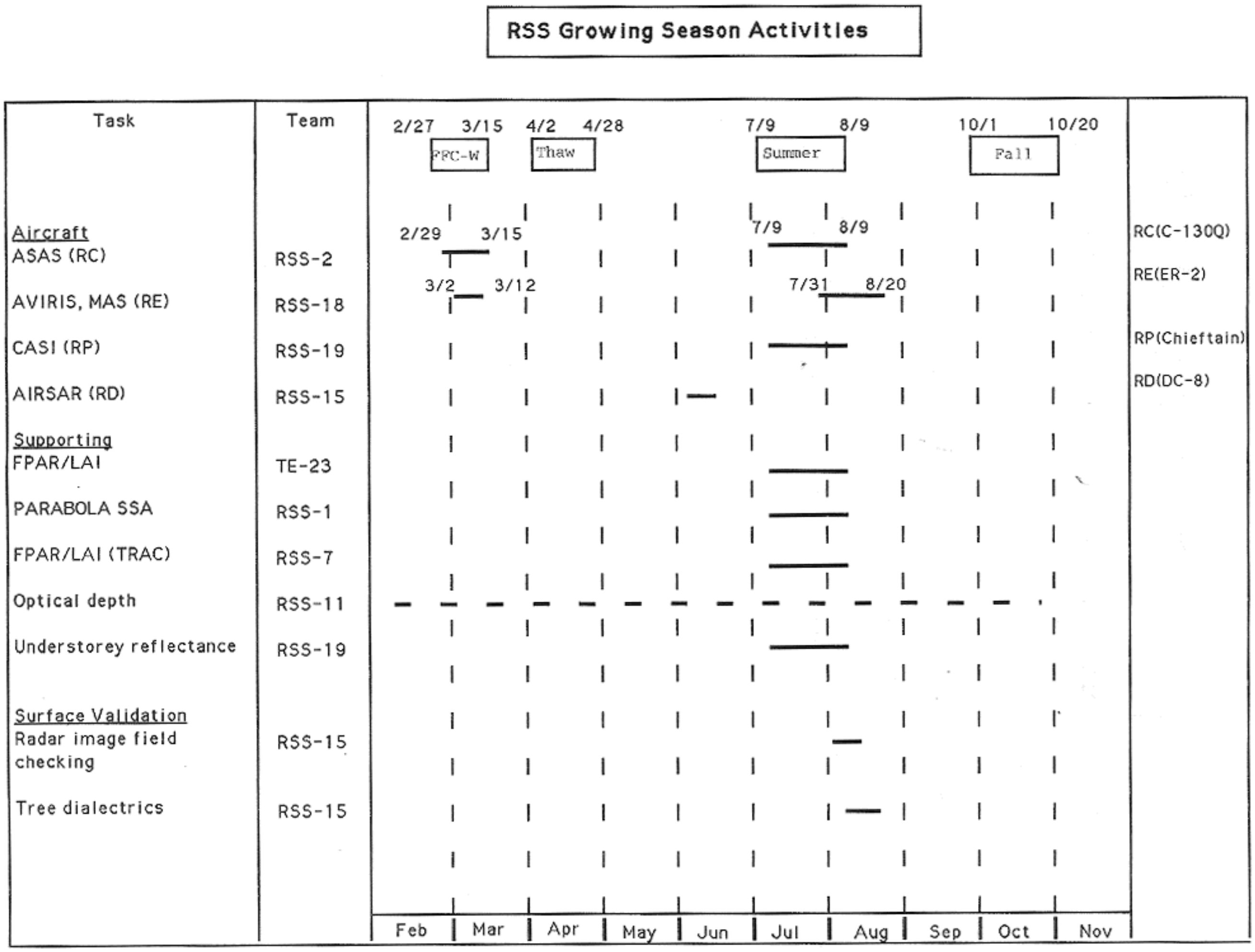

Figure 3.6.2 RSS ACtivities in BOREAS-96