An EOS-NASA Inter-disciplinary Science Team Progress Report

"Changes in Biogeochemical Cycles" 1998

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I. NATIONAL TO GLOBAL SCALES

A. Global Change: Continued Development and Application of Models

1. The Terrestrial Ecosystem Model (TEM).

During 1998, the IDS Team has been involved in numerous activities including the development of the Terrestrial Ecosystem Model (TEM); the application of TEM to explore the effects of increasing atmospheric CO_2 and climate variability on carbon storage in terrestrial ecosystems; participation in several model inter-comparisons; and the exploration of various model evaluation techniques.

Development of the Terrestrial Ecosystem Model

In conjunction with our work on the Electrical Power Research Institute's (EPRI) Carbon Cycle Model Linkage Project (CCMLP), we developed an initial transient version of TEM that incorporates the effects of land clearing, agriculture, and abandonment of agricultural fields on terrestrial carbon dynamics. Because of the importance and difficulty of transient calculations that address adequately succession as part of the transient, we are conducting a set of parallel studies on the coupling between modeling transient dynamics with succession and the contributions of remote sensing [including ESSP missions (i.e., canopy LIDAR)].

This set of topics will be more adequately addressed in the next Annual report (1999).

The model has been structured such that the carbon and nitrogen dynamics of agricultural crops may be simulated separately from the dynamics found in natural vegetation, but litter from vegetation in both natural and agricultural systems are added to a common soil organic carbon pool within a grid cell. As a result, the model can simulate the effects of land degradation, increases of atmospheric CO_2 and climate on the recovery of natural vegetation on a site after abandonment. Although agricultural productivity in this initial version of TEM is simulated as a simple proportion of the productivity of the potential vegetation in each grid cell across the globe, the model structure allows the eventual development of more sophisticated algorithms to simulate carbon, water and nitrogen dynamics in agricultural ecosystems. We are currently testing this version of TEM to see how well the model simulates the results of chronosequence studies.

Application of TEM and Comparison to Other Model Results

To understand how historical and projected increases in atmospheric CO_2 and climate variability affect terrestrial carbon storage, we have conducted a number of simulation studies with a transient version of TEM at both global (Xiao et al., 1998a; Kicklighter et al., 1999b; Prinn et al., 1999) and regional scales (Clein-Curley et al., 1999; Jenkins et al., 1999a; Tian et al., 1998a,b, 1999a,b). Two studies (Kicklighter et al., 1999b; Jenkins et al., 1999a) included the participation of other models such that the effects of different model assumptions and approaches on simulated carbon dynamics could be observed. In general, the response of terrestrial ecosystems to increasing CO_2 simulated by TEM is limited by nitrogen availability. In northern ecosystems, TEM estimates that global warming will cause more anthropogenic carbon to be stored in vegetation as a result of simulated increases in net nitrogen mineralization which partially alleviates nitrogen limitation in these ecosystems. Results from a transient version of TEM are also a part of the Vegetation/Ecosystem Modeling and Analysis Project (VEMAP) results being used in the National Assessment activities of the United States. In this connection it should be mentioned that:

- Co-I Jerry Melillo is serving as Co-Chair of the U.S. National Assessment of the potential consequences of climatic change;
- UNH (Moore and Rock) is serving as the coordinator of the New England Region in the U.S. National Assessment of the potential consequences of climatic change, and
- The IDS Team is supporting the data and information system for the U.S. National Assessment of the potential consequences of climatic change.
- The IDS grant continues to support development of the Global System Model which is the major modeling effort for the Joint Program of Science and Policy of Global Change, MIT, and includes economic models, atmospheric chemistry model, climate model, ocean model, and terrestrial ecosystem model. The Global System Model is used as a tool to help address science issues and policy issues in the context of climate change.

In addition to simulations of transient TEM, estimates of annual net primary productivity (NPP) and seasonal net ecosystem production (NEP) from an equilibrium version of TEM have also been compared with estimates of other models is other studies (Heimann et al., 1998; Pan et al., 1998; Xiao et al., 1998b; Bondeau et al., 1999; Cramer et al., 1999; Jenkins et al., 1999a,b; McGuire et al., 1999; Schloss et al., 1999). In addition, we are testing TEM against simple models developed by the IDS team in collaboration with other IDS investigations. For instance, over the past year we have completed an analysis that extends the work of Braswell et al (Science 1997), in cooperation with Vukicevic and Schimel from the Schimel IDS. We built a simple multicompartment model of the global terrestrial biosphere that simulates transient perturbations in response to variations in global temperature. Modeled effects on CO_2 exchange could result from both changes in carbon cycling rate, changes in pool sizes (due to direct effects of production and respiration, or indirect effects due to changing nitrogen mineralization rates. A model adjoint was constructed in order to evaluate model impulse-response characteristics and parameter sensitivities. Driven with observed temperature anomaly data found dCO_2/dt behavior consistent with observed atmospheric CO_2 growth rate. We found the nitrogen feedback significant, and there was evidence of 1-2 year time lags that is accentuated by the N feedback. A paper is in preparation for submission to Journal of Climate (Vukicevic, T., B.H. Braswell, and D.S. Schimel. Analysis of global terrestrial ecosystem CO_2 response to temperature anomalies using a simplified model).

Techniques of Model Evaluation

Although results from TEM have been useful for generating various hypotheses related to terrestrial carbon dynamics and the regulating roles of the nitrogen and water cycles, it is still desirable to determine how realistic the TEM estimates may be. To build confidence in TEM results, we have explored several evaluation techniques (beyond the previously mentioned inter-comparison activities). One important approach is to use seasonal estimates of NEP with an atmospheric transport model to estimate the how seasonal atmospheric CO_2 concentrations vary across the globe. These simulated atmospheric CO_2 concentrations are then compared to measurements of atmospheric CO_2 taken at an international network of CO_2 monitoring stations (Heimann et al., 1998). We have

- Examined how this approach can be used to test various assumptions about the role of snowpack on carbon fluxes from northern ecosystems (McGuire et al., 1999);
- Compared TEM estimates of NEP against eddy covariance measurements in the Amazon Basin (Tian et al., 1998);
- Examined the relationship of the NPP estimates of terrestrial biosphere models to NDVI (Bondeau et al., 1999; Schloss et al., 1999).
- Revisited how field estimates of NPP are derived in tropical forests and help to generate a consistent data base of field-derived NPP estimates that can be used for calibrating and evaluating future model results (Clark et al., 1999; Scurlock et al., 1999).

An important feature of 1999 will be the launch of EOS AM-1 and Ladsat-7. We are particularly interested in the potential contributions of MODIS and MISIR to model verification and validation studies. In this regards, see Section I. B. of this Report.

2. The Global Hydrological Archive and Analysis System

We have continued our terrestrial water cycle work, pursuing which both modeling improvements and the generation & distribution of community-wide hydrometeorological products. As in previous reports, water budgeting and riverine transport analysis directly supports the TEM modeling effort. Specific focal points for our terrestrial water cycle research are given below:

Our water cycle analysis requires that temporally and spatially-distributed components of the terrestrial water balance be calculated. The Global Hydrological Archive and Analysis System (GHAAS) system is software code that serves as a hydrological GIS for multi-scale applications, funded in large measure through our IDS support. Over the last year the GHAAS has been used in numerous applications within our IDS team including: the intercomparison of evaporation functions for water balance and terrestrial NPP models, determination of US and global-scale water balances, global river network analysis, development of an improved water transport model, studies of anthropogenic effects on the water cycle of China, and pan-Arctic-region hydrological studies. The system has several components including: (1) a meta-database listing both internal and extramural biophysical data sets, (2) a data / model integration package, (3) several input/output functions to manipulate complex spatially-varying input/output fields, (4) resident water balance and fluvial transport models, (5) simulated river networks, and (6) an improved archive of monitoring data including UNESCO global river discharge (RivDIS v 1.1), R-ArcticNet and R-HydroNET (archives for the pan-Arctic and South America, Central America, and the Caribbean, respectively) and global river chemistry (GEMS/GLORI).

Simulated Global River Networks

Another major revision of the simulated network topology for world rivers at 30-minute spatial resolution (STN-30p v 5.12) took place in 1998. Full documentation can be found in a manuscript under review to Global Biogeochemical Cycles (Vörösmarty et al. 1999). We have quantitatively described the spatial organization of the global land mass using potential flow pathways across the entire non-glacierized surface of the Earth at 30-minute (longitude x latitude) spatial resolution. STN-30p has been verified against several independent sources that included map products and drainage basin statistics. A broad suite of diagnostics has been developed that quantitatively describes individual grid cells, river segments, and complete drainage systems for each of the six river and drainage basin orders. Continental and global-scale summaries of key STN-30p attributes are given. A total of 59,122 individual grid cells constitute the global non-glaciated land mass. The cells are organized into 33,251 distinct river segments which define 6,152 drainage basins. STN-30p flow paths and drainage basins are classified as order one through six using the ordering system of Strahler. A global total of 133.1 Mkm2 bear STN-30p flow paths with total length of 3.24 Mkm at 30-minute spatial resolution. A major finding is that the structure of STN-30p river systems is highly consistent with those of rivers analyzed at finer spatial scales as demonstrated by the numerical similarity of several geomorphometric indices.

The organization of global river networks can be shown to have an important role in linking the continental land mass to ocean, important for predicting both water and biogeochemical fluxes. From a continental perspective, low-order river segments (orders one to three) drain 90% of all land and thus constitute a primary source area for runoff and constituents. From an oceanic perspective, however, the small number (n=101) of large drainage systems (orders four to six) predominates, draining 65% of global land area and subsuming a large fraction of the otherwise spatially remote low-order rivers. The global mean distance to river mouths is 1050 km with individual continental values from 460 to 1340 km. The Mediterranean Sea and Arctic Ocean are the most land-dominated of all oceans with land:ocean area ratios of 4.4:1 and 1.2:1, respectively; remaining oceans show ratios from 0.55:1 to 0.13:1. Constituent monitoring data (annual means) from 475 individual stations have been geographically co-registered to STN-30 v 5.12 in preparation for nutrient flux analysis in collaboration with M. Meybeck of the University of Paris VI.

Terrestrial Water Balance Studies

The Water Balance Model forms the basis for the estimation of continental runoff and discharge in our global-scale drainage basin analysis. WBM is also a component of the MBL / UNH Terrestrial Ecosystem Model (TEM) and as such has contributed to our research exploring terrestrial carbon and nitrogen cycling (McGuire et al. 1997, 1993, 1992, Melillo et al. 1993), including the intercomparison of NPP models through the recent Potsdam and VEMAP exercises.

With the modeling protocols well-established at the global scale for several years, recent emphasis has been on identifying key uncertainties in model structure and / or biophysical inputs. We have continued to spend considerable effort in identifying, importing, error-checking, and distributing observed hydrographic data for model calibration and validation. Our recent series of tests using WBM to explore parameter sensitivity of several potential evaporation (Ep) methods have now been completed and published at both point (Federer et al. 1996) and continental scales (Vörösmarty et al. 1998a). Results of key water balance components will be made available for the conterminous US in support of the VEMAP exercise on our ESIP-WEBSTER WWWeb site. Ongoing work will complete the analysis at the global scale using well-documented river discharges for model performance evaluation. We are also exploring alternative model structures including the creation of multiple reservoir soils, use of non-stationary rainfall statistics to simulate daily events from monthly data, application of time-varying LAI, and modifications to our non-linear soil drying function. We also have developed a permafrost version of the WBM (Holden et al.1999). A permafrost Water Balance Model poises us for the potential use of space-borne radar remote sensing of northern landscape freezing and thawing, work that Steven Frolking is pursuing in collaboration with NASA, JPL, the University of Montana, and Bayreuth University.

We began in 1998 a data development effort uniting UNESCO and WMO hydrographic data sets through collaboration with the WMO-Global Runoff Data Center in Koblenz. A total of 668 individual gauging stations were identified and used to generate a climatology of runoff at the 30-minute spatial scale. From our calculations, 93 M km2 of the continental land surface actively discharges water. The portion of this data set represented by observed station data equals 72% of the global area that shows active runoff; the remainder is computed by the WBM / WTM. Runoff for individual cells of the STN-30, whole drainage basins, continents and the globe are currently being documented. We have also opened a dialogue with the WMO-Global Precipitation Climatology Project to apply spatially-distributed hydrographic fields that are constrained by the observational record to improve upon gridded precipitation estimates.

Of the several graduate students that have been supported by our NASA-EOS IDS team since 1989, three have focused on water-cycle related research (advised by Co-I Vörösmarty). These students employed both the models and GHAAS support software developed under NAGW-2669. On recent IDS-supported hydrology student completed his studies in 1997. Keshav Sharma, currently employed in the hydrometeorolgical service of Nepal, performed detailed studies of the Kosi Basin of the Himalayan region to identify the relative impact of climate vs land cover change on water balance and suspended sediment flux.

His studies are summarized in Sharma (1997) and a recently completed manuscripts (Sharma et al. 1999a,b). Another graduate student, Balazs Fekete, is performing the technical analysis in conjunction with the WMO-GRDC (described above) and is instituting a physically-based version of the original Water Transport Model.

Data Archive Contributions

A second version of the Global River Discharge Database (RivDIS v1.1) is now available at *http://www.csrc.sr.unh.edu/hydro/*. Time series data are presented on nearly 1000 rivers worldwide, providing important calibration / validation targets for the WBM and WTM. In 1998, the Oak Ridge National Laboratory DAAC began archiving and disseminating this information through a WWW server and CD-ROM. The National Snow and Ice Data Center DAAC is supporting the distribution of a pan-Arctic version of RivDIS v1.0 that will be supplemented with Russian State Hydrological Institute, USGS, and Environment Canada data (R-ArcticNET). The 3755-station database for the 22.4 M km2 Arctic Ocean watershed constitutes the single most comprehensive compendium of Arctic river discharge data now available. A WWWeb-based hydrometeorological archive, R-HydroNET, for South America, Central America, and the Caribbean is now fully operational and provides regional station data and gridded fields for both meteorological and hydrographic information. Co-I Vörösmarty served as an instructor in June 1998 for regional partners in R-HydroNET held in Panama City. RivDIS, R-ArcticNET, and R-HydroNET can be found at *http://www.csrc.sr.unh.edu/hydro/*.

3. The Global Ecosystem Modeling and Analysis Suite (GEMAS).

Co-I Bill Emanuel has developed a global ecosystem modeling and analysis suite GEMAS that allows analysis of ecosystem responses to disturbances by human activities such as forest clearing and to natural events such as fire. The models explicitly treat the dependence of terrestrial biogeochemistry on environmental conditions including atmospheric CO_2 and climate. We are applying the GEMAS models to investigate the processes and disturbances that determine atmospheric CO_2 increase and responses to inter-annual climatic variability and to climatic change due to greenhouse gas increases.

During this phase of the project, University of Virginia investigators:

- Completed modifications to allow the specification of daily climatic variables and to compute daily solutions for all state variables,
- Extended an analysis of the sensitivity of leaf area to atmospheric CO_2 increase,
- Completed an analysis of the effects of changes in radiation regimes on terrestrial primary productivity, and
- Completed a comparison of stomatal conductance representations that are used in global models.

These contributions are discussed in more detail in Attachment One.

Four papers were submitted to major scientific journals and 1998 saw the final publication of two papers as well as a book synthesizing approaches to analyzing terrestrial ecosystem responses to global change. Project investigators participated in numerous meetings and workshops, presenting papers and posters. Emanuel also served as a member of the User Working Group for the ORNL Data Active Archive Center for terrestrial biogeochemistry.

B. Global Change: The Role of Remote Sensing at Global Scales.

1. MODIS/MISR: Inversion Algorithm Development

We continued development of our algorithm for retrieval of biophysical and ecological parameters from satellite bidirectional reflectance observations. The project continues to be a cooperative effort between the Moore and Schimel IDS teams. We have generalized the prototype AVHRR-based algorithm (Braswell et al JGR 1996) to accept reflectance and geometrical observations from multiple and arbitrary reflectance bands. We plan to use the algorithm with simultaneous MODIS / MISR data. Our goal is to quantify regional-to-global scale structural and functional attributes of ecosystems (e.g., LAI, fAPAR, albedo) using maximal information from the satellite instrument. Our method has an important tie to field investigations in that the inversion is constrained by field observations of leaf optics and by structural types keyed to a land-cover database.

Current plans for the upcoming year include:

- Evaluation with AVHRR time series, now that computational resources are available, and

- Acquisition of VEGETATION (from European colleagues) data for detailed testing and analysis.

The purpose of the AVHRR effort will be to evaluate further interannual variability of the biosphere, accounting for local and large-scale geometrical biases that are introduced by scan angle and instrument drift, respectively. The need for data like that available from VEGETATION arises from a need for *in situ* evaluation of the satellite-based estimates and because its characteristics closely resemble those of MODIS. VEGETATION data include aerosol (it observes reflectance in blue wavelengths) and water vapor corrections, and so spatial variations are more likely to carry information about vegetation BRDF, and thus canopy structure. Also, its current availability will allow us to evaluate our methodology prior to AM-1 launch. We will focus initially on structurally extensive, homogeneous canopies (i.e., wheat agriculture in northern China). We also plan to cooperate with Greg Asner (from the Sellers and Schimel IDS teams) to include spectral unmixing to enable evaluation of the inverse-model approach across a long transect in the spatially heterogeneous central US.

2. Land-use and Land-cover Change

In 1998, Co-I X. Xiao has begun to initialize the research effort for modeling land-use and land-cover change at continental to global scales through an exploratory analysis of cropland distribution across the globe. The 1-km global land cover classification provided by the IGBP-DIS (DIScover database from EROS Data Center) was used. The original 1-km global land cover data in Goode projection was first re-projected to 30 arc second and then aggregated to 0.5^{o} (longitude and latitude) resolution grid. He also organized global data of world population, human settlement (nighttime lit area from DMSP), terrestrial ecosystem characteristics (e.g., net primary production, estimated evapotranspiration).

We have compared the AVHRR-derived cropland classification of China with the agricultural census data in 1990. There is large discrepancy between these two data sets across the scales of county, province and country. It highlights the under-reporting issue of cropland area in the agricultural census data of 1990. A paper "Agricultural land use in China: a comparison of area estimates from ground-based census and satellite-borne remote sensing" has been submitted for publication. At finer spatial scales and in collaboration with Dennis Ojima (David Schimel's IDS team), we are examining the impacts of livestock grazing intensity, land conversion for croplands and hay-mowing pasture on grassland vegetation in Xilin river basin, Inner Mongolia, China, using Landsat TM data on 7/31/1987, 8/11/1991, 8/x/1997.

In collaboration with the new TECO/Rice project, Xiao am leading the remote sensing component for (1) identifying and mapping paddy rice across China, (2) monitoring rice growing condition (LAI, biomass). We have preliminarily selected four landscape sites (100 km by 100 km) across South China, two of which are the long-term agro-ecosystem research stations of the Chinese Ecological Research Network (CERN). We are currently contacting local researchers to design implementation plans for fieldwork related to remote sensing at the site and landscape scales.

Frolking has been developing estimates of nitrous oxide emissions from agriculture in China. This builds upon his work on this issue as part of the US Trace Gas Network (TRAGNET) project. A TRAGNET manuscript has been published (and a related talked presented as an invited contribution at the fall 1998 AGU meeting). In addition, Frolking served as a co-editor of a special issue of *Nutrient Cycling in Agroecosystems*, and with Xiao has submitted a manuscript (mentioned above) comparing remote sensing based and ground census based agricultural land use in China. A Poster was presented at the fall 1998 AGU on the preliminary analysis of our trace gas

More generally, we are developing a close working relation China. We recently contacted the Sub-Center of Atmospheric Sciences (SCAS) of Chinese Ecological Research Network for specifying the collaboration in rice paddy trace gas studies. They have agreed to a long-term collaboration in developing biogeochemical methodologies and regional assessments. SCAS is physically located in and institutionally affiliated to the Institute of Atmospheric Physics, Chinese Academy of Sciences (CAS). We attach (Attachment Two) a

DRAFT Agreement outlining this collaboration. This builds upon a similar and parallel development with the Chinese Academy of Meteorological Sciences.

The IDS also contributes to a close working relationship with Brazil through the NASA LBA project. The IDS grant expands upon the LBA support both in terms of model development and application as well as in developing remote sensed databases.

II. REGIONAL TO NATIONAL SCALES

A. Global Change: Effects on Forest Ecosystems

1. The MAP-BGC Project - Combining High and Moderate Resolution Remote Sensing with Field and Modeling Data to Map Forest Production and Nitrogen Cycling

Our EOS-IDS project is almost unique in the development and application of hyperspectral resolution remote sensing for land applications. With past support, and in conjunction with the Harvard Forest site within NSF's Long-Term Ecological Research (LTER) Program, we have demonstrated the potential for measurement and mapping of foliar chemical constituents such as nitrogen, lignin and cellulose which control both carbon gain in forest ecosystems through photosynthesis and carbon loss through decomposition (Martin and Aber 1997). Using the AVIRIS instrument, we have also developed methods for greatly increasing the accuracy species occurrence mapping within forested stands (Martin et al. 1998).

With additional support from NASA through the TECO program, we have now undertaken an ambitious extension of hyperspectral applications from the stand to the subregional level. The MAP-BGC project (Mapping and Analysis of Productivity and BioGeoChemistry) is a combination of remote sensing and field data collections encompassing the entire White Mountain National Forest area in New Hampshire and Maine (Ollinger et al. submitted). AVIRIS data have been collected for over 80 contiguous scenes covering 8000 km2. An intensive field site, the Bartlett Experimental Forest, is being used to develop relationships between foliar N and lignin, and rates of N cycling and forest production. An additional set of study sites have been collocated with USFS Forest Inventory and Analysis (FIA) sites spread throughout the White Mountains. Existing data from these sites allow the estimation of NPP. Relationships between foliar chemistry and site processes developed at Bartlett will be tested using data from the FIA sites. If validated, these relationships will be used to map N cycling and forest production throughout the White Mountains region. Preliminary results of this new initiative were presented as a special session (8 posters) at the meetings of the Ecological Society of America this year (Attachment Three).

2. Estimating Effects of Global Change on Forest Production, Carbon Balance and Water Yield - the Eastwide Assessment Project

Previous support through EOS-IDS has fostered the development of the PnET model of carbon, water and nitrogen cycling in forest ecosystems. This model has been used to map:

- current rates of forest production and water yield for the northeastern US; and

- predicted responses to changes in climate and atmospheric CO_2 (Aber et al. 1995).

It has also been used to predict regional patterns in steady-state N cycling (Aber et al. 1997), and effects of ambient tropospheric O_3 on forest production (Ollinger et al. 1997).

In the past year, we have completed three major additional steps in the rigorous application of this model to the regional prediction of forest responses to global change in the eastern US. The are:

A major regional-scale validation of PnET against all available data on forest production and water yield. PnET was run at 1 km resolution (~300,000 land pixels) for the New England/Eastern New York region. Productivity data were compared with measured values at several sites within the region. Mean error of the estimate for these predictions, which covered both deciduous and coniferous forest types ranging from low elevation to near treeline, was 5.2%. Spatial estimates of water yield (runoff) were compared against a digital regional map extrapolated from USGS gauging station data. Errors in estimation of total annual runoff averaged 8.4% (Ollinger et al. 1998, Bishop et al. 1998).

Extension to PnET to all forests in the Eastern US. In conjunction with the USFS Northern and Southern Global Change Programs, we have begun adapting VEMAP and USFS Forest Inventory and Analysis (FIA) data sets to provide both input data planes and spatial validation data. Beginning with the VEMAP 0.5° resolution, we are assessing which relationships in PnET that were appropriate at the smaller scale of the northeastern work need to be altered for this larger region. In addition we are: a) comparing data from existing ground-based phenological studies with long-term NDVI and transient climate datasets for predicting the controls on seasonal canopy phenology (leafout/leafoff), b) compiling ground-based measurements of solar radiation received at the surface throughout the Eastern US in order to correct the radiation data plane in VEMAP-I as we have done for the northeast, and c) accessing FIA data to provide input information on the distribution of forest types through the Eastern US, and also to provide a very large number of ground-based estimates of forest NPP for comparison with PnET predictions (validations). In regards to a), Aber, Braswell, and Frolking are serving as advisors to a graduate student (Julian Jenkins), who is working on using interannual AVHRR-NDVI and VEMAP II data to investigate climate controls on phenology in the US at 0.5° spatial scales. Whether there is information on interannual time scales is still not known, but some consistent behavior has emerged suggesting growing degree-day controls. These results thus far appear novel and differ from other recent papers. The work is continuing using LTER and botanical observations to validate the approach.

Estimation of Increased C storage due to N deposition. Part of the large C sink linked to northern temperate forests has been attributed to the fertilization effects of N deposition. To examine this question at Hubbard Brook, one of the best-studied long-tern ecological research sites in the north temperate zone, we applied the CN version of PnET to this site. Realizing, however, that previous land use events, dating back even a century or more, can alter current forest status and response to perturbations, we also used data from the several land use treatment experiments at Hubbard Brook to further validate the models basic C and N responses. The model predicted changes in nitrate losses to streams in response to these treatments very well. Results of runs with and without historical increases in N deposition suggest that 978 to 1469 g $C.m^{-2}$ have been added to these systems by the fertilization effect (Aber and Driscoll 1998). The range of responses shows the importance that previous land use history and changes in vegetation type have in modifying ecosystem response to environmental perturbations.

3. Monitoring Initial Stages of Forest Recovery in the Krusne Hory, Czech Republic

The focus of this component of the EOS IDS effort has been on the development of the most effective remote sensing methodology for assessing accurately forest state-of-health associated with poor air quality. In a sense, the Krusne Hory area is an end-member with extremely poor air quality; however, as an end-member the results here are useful in other regions with less extreme degradation in air quality.

This work has led to the development of a large number of study sites located along a pollution gradient in the Krusne hory mountains in northwestern Bohemia, in the Czech Republic (Entcheva, et al., 1997, 1998a,b). Using Landsat Thematic Mapper (TM) data and a logit regression approach to classification of forest damage, we are able to discriminate only three damage categories (light, moderate, and heavy), while Czech foresters on the ground visually recognize at least five damage classes in the Norway spruce stands at these sites (Lambert, et al., 1995; Ardo, et al., 1997). Our overall goal is to determine if hyperspectral data provide additional damage assessment capabilities, especially as related to the detection of initial stages of damage.

This research project, centered on the remote sensing-based monitoring of the health (and damage) in Czech forests, began in 1989. Co-I. Barry Rock's first major field work in the Krkonose, Krusne hory and Sumava began in July, 1991, and documented the severity of damage in Norway spruce stands in these mountain regions. The work in 1991 centered on spectral characterization of spruce foliage as well as the needle cellular condition (anatomy). The forest conditions were very damaged when needle (foliar) assessment was conducted in 1991 using field-made spectral reflectance data. By 1995, an improvement in the apparent amount of chlorophyll was seen in the spectral data for the same area, and the improvement has been further documented with fieldwork conducted in the summer of 1997, with both spectral and anatomical assessments, as well as chlorophyll analyses conducted by Dr. Jana Albrechtova and her students from the Faculty of Science, Charles University, Prague.

Concurrent with the fieldwork in 1991, a parallel analysis of Landsat data from 1972, 1975, 1978, 1985 and 1989, was conducted, with the goal of determining to what extent satellite data can be used to detect, monitor and map both the level of forest damage and the areal extent of the damage. This work confirmed that only three (3) levels of damage could by accurately identified using Landsat Thematic Mapper (TM) data: low damage (healthy forests), moderate damage (40-50% foliar loss), and heavy damage (80% or more foliar loss). The Landsat data were not able to detect the initial stages of damage recognized by foresters on the ground (Lambert, et al., 1995; Ardo, et al., 1997; Entcheva, et al., 1997).

This year (1998) has seen the use of airborne hyperspectral sensors to evaluate and document this improvement for larger areas in the Krusne hory. We are using the Sumava airborne data as a healthy "control" and will be comparing two different types of damage (air pollution damage in the Krusne hory; bark beetle damage in the Sumava), and thus will compare the hyperspectral differences between damage types.[1] In addition, we hope to be able to use the hyperspectral sensors to detect the initial stages of damage not detected using Landsat satellite data (Entcheva, et al., 1998a,b).

In sum, the primary objectives of the IDS-related activities during 1998 in the Krusne hory and Sumava Mountains of the Czech Republic were:

- To acquire airborne narrow-band video (RDACS) and hyperspectral (ASAS) imagery for the study areas;
- To collect supporting field forest stand data, Norway spruce foliar samples for determination of state-of-health and physiological conditions, standardized field narrow-band video camera and spectrometer data;
- To develop algorithms for use in the classification of the airborne imagery data into stand damage classes; and
- To document the initial stages of recovery at the Krusne hory site.

These objectives were accomplished, but the effort was considerable. We attach (Attachment Four) a sketch of the actions needed to conduct a successful field and validation campaign. This Attachment is included as a guide or example to other teams of the commitments necessary to obtain adequate field data; in the EOS AM-1 and Landsat-7 era, we must consider carefully and coordinate well all field campaigns to achieve maximum benefit. The Attachment also contains details of the scientific investigation.

4. Outreach Activities

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[1] We recognize that the spruce bark beetle damage has been extensive in the Sumava in recent years (especially 1997 and 1998), resulting in less than healthy conditions.

4.1 Climate Change Initiatives

During the Fall, 1998, several major initiatives were developed to provide the science behind current climate change studies to a broad audience beyond the research communities. These initiatives included the following activities:

AAPG Lectures on Climate Change - For two weeks in October, Barry Rock presented a total of 14 lectures to members of the American Association of Petroleum Geologists (AAPG), as part of an AAPG Distinguished Lecturer series. His topic, Global Warming - Fact or Fantasy: the Science behind Climate Change, was delivered to approximately 1700 oil and gas industry stakeholders. His presentations centered on what scientists know, and don't know, about climate change, both past and present. His tour included AAPG Clubs in 12 western states, and served as a means of opening a meaningful and scientific dialogue with this important segment of greenhouse gas producers.

Sigma Xi Fall Lecture - On November 12, 1998, a Sigma Xi Fall Lecture Series presented a panel discussion entitled: Climate Change and its Potential Impacts on New Hampshire. Panelists were B. Rock, Barry Keim (NH State Meteorologist), and Don LaTourette (NH Department of Environmental Services, and State Climate Change Specialist). Approximately 75 members of the UNH academic community and the town of Durham attended this informational meeting.

Forest Watch Teacher Training Session on Climate Change Issues - At the December Forest Watch Teacher's Workshop a series of presentations were made to promote and develop a series of climate change activities, for use in the New England-wide Forest Watch Program. At present, over 200 schools are involved in the Forest Watch Program, which has as its focus, the study of air quality (chemical climate) impacts on a sensitive bioindicator species (white pine) across New England.

4.2 K-12 Outreach Activities

As in past years, K-12 outreach activities have been a significant part of the UNH EOS/IDS effort (Lawless and Rock, 1998; Spencer et al., 1998a,b). Specific Teacher Support Materials focused on the scientific capabilities of the sensors onboard the EOS AM-1 platform have been developed, for use in GLOBE, Forest Watch, and Boreal Forest Watch. Each set of materials have focused on specific aspects unique to each outreach program: land cover mapping using MODIS data for GLOBE, forest damage assessment with Landsat 7 for Forest Watch, and the use of Canadian radar data (RadarSAT) for boreal forest assessment in Boreal Forest Watch.

In addition, a Czech version of Forest Watch has been developed, in conjunction with Dr. Jana Albrechtova, Charles University, Prague. Dr. Albrechtova and her students have trained Czech teachers from a total of 30 high schools, most of them located either in the Krusne hory or the Sumava Mountains. The Program, known locally by the Czech name for Spruce Watch (literally "How Are

Spruces?"), trains teachers to train their students to monitor key symptoms of forest decline exhibited by Norway Spruce in the Czech Republic. All of the symptoms (chlorotic flecking, needle burn, bud abortion, and age classes of needles retained) are characterized by the students, for Norway spruce trees found near their schools. 1999 will provide the first sets of student-made measurements.

Late 1997 through 1998

Refereed Publications
and
Conference Contributions
(Partial listing of latter)

Aber, J.D., S.V. Ollinger, C.A. Federer and C. Driscoll. 1997. Modeling nitrogen saturation in forest ecosystems in response to land use and atmospheric deposition. Ecological Modelling 101:61-78

Aber, J.D. and C.T. Driscoll. 1997. Effects of land use, climate variation and n deposition on N cycling and C storage in northern hardwood forests. Global Biogeochemical Cycles 11:639-648

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Asner, G.P., B.H. Braswell, D.S. Schimel, and C.A. Wessman. 1998. Ecological research needs from multi-angle remote sensing data. Remote Sensing of Environment, 63:155-165.

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Braswell, B.H., D.S. Schimel, and G.P. Asner. Toward global retrieval of land surface parameters from EOS data using inverse radiative transfer modeling (poster). Workshop on Inverse Methods in Global Biogeochemical Cycles. March 1998; Heraklion, Greece.

Braswell, B.H., Interannual Variability of Climate-Carbon Cycle Interactions. University of Texas Department of Geology, Invited lecture. November, 1998; Austin Texas.

Braswell, B.H., Indirect biogeochemical controls on the growth rate of atmospheric CO2. University of Rhode Island Institute of Oceanography, Invited lecture. May 1998; Narragansett, Rhode Island.

Bubier, J. L., S. Frolking, P. Crill, E. Linder. 1998-in review. Net ecosystem productivity and its uncertainty in a diverse boreal peatland using CO_2 exchange measurements, *Submitted: J. Geophys. Res.*

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ATTACHMENT ONE

Global Biogeochemical Implications of Terrestrial Ecosystem Responses to Environmental Change

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This Attachment provides details on progress of the project "Global Biogeochemical Implications of Terrestrial Ecosystem Responses to Environmental Change" during the period January 1 through December 31, 1998. During 1998, NASA modified the funding year for this project to May 1, 1998 through April 30, 1999. In response to this change, we rescheduled tasks, particularly those involving graduate students and post-doctoral research staff. Thus, to some extent, this progress report precedes the completion of the current year's research.

Daily Climate Drivers. Most global analyses of terrestrial biogeochemistry have specified monthly values of climatic variables. This is because daily data are not readily available, and the implementations of a number of models do not accept daily data or solve model equations with daily resolution. But using the ISLSCP climate data to specify daily rather than monthly climatic variables substantially improves the accuracy and realism of our simulations. As expected, this is true particularly for variables such as evapotranspiration and soil moisture that are sensitive to temporal patterns in precipitation.

Thus, the University of Virginia group continued to modify its ecosystem modeling suite toward a completely explicit daily implementation. In completing these modifications, we developed an interface into NetCDF files for both model input and output. This interface provides compatibility with data sets assembled by the VEMAP II EOS initiative, and straightforward conversion to HDF files allows coupling to EOS remote sensing products.

The overall significance of temporal resolution in the accuracy of terrestrial biogeochemistry analyses remains unclear. As we incorporate daily resolution into our models to improve accuracy and provide compatibility with the EOS land products, tests of our models at sites collecting continuous observations of net ecosystem exchange by eddy covariance methods indicate that resolution of the diurnal cycle also can be significant in the simulation of carbon uptake and loss over annual and longer periods (Gu et al. 1998). Since these flux measurements will be an important basis for validating EOS land products, the issue of temporal resolution in representing terrestrial ecosystem processes requires further investigation. We continue to work closely with the MODIS instrument team and land validation projects to address this issue and are completing a paper summarizing our model analyses of temporal resolution.

Sensitivity of leaf area to atmospheric CO_2 increase. Increased primary productivity in response to atmospheric CO_2 increase continues to be viewed as a likely mechanism for increasing terrestrial carbon storage. We extended our analysis of leaf-area sensitivity to CO_2 increase to include the sensitivity of a fundamental relationship between moisture loss and photosynthetic capacity. In many regions, moisture constrains leaf area and thus the structure of vegetation and carbon storage in biomass (Woodward et al. 1995). Our analysis of the sensitivity of the leaf-area distribution across the U.S. to atmospheric CO_2 increase generally indicates higher leaf area at 560 ppmv, twice the preindustrial concentration, than at the contemporary concentration of 360 ppmv (Emanuel and Woodward 1998).

From the standpoint of carbon uptake and storage, the most significant increases are across the Midwest where moisture constrains leaf area to values intermediate between those of open woodlands or savanna and closed canopy forests. At elevated CO_2 leaf areas typical of forests are simulated across the region. But overall, the sensitivity of leaf area to a doubling of atmospheric CO_2 is not large, especially in the more arid west --- the leaf-area increase would be difficult to detect by remote sensing. Our extended analysis indicates that this may be due to the conservative nature of relationships between ecosystem processes of productivity and moisture loss.

Responses of both photosynthetic capacity and evapotranspiration affect the sensitivity of primary productivity to atmospheric CO_2 increase. Using observations collected at about 10 field sites, Baldocchi and Meyers (1998) demonstrate a relationship between these processes in the partitioning of energy into latent heat of evaporation. As canopy photosynthetic capacity increases, the ratio of the latent heat of evaporation to its equilibrium value converges to 1.2, the widely observed value of the Priestly-Taylor coefficient. We verified that our model maintains this relationship when evaluated at each point within the U.S. characterized by the VEMAP data. This form of model validation may prove very useful in assessing the accuracy of EOS land products. We found that although both photosynthetic capacity and evapotranspiration are larger at elevated CO_2, the fundamental relationship between these variables is not affected. In addition to submitting a paper for journal publication, we are interacting with investigators to incorporate these results into the U.S. National Assessment of the potential consequences of climatic change.

Effects of changes in radiation regimes on terrestrial primary productivity. Radiation regimes are among the most important factors determining primary productivity, and inter-annual variations in radiation appear to be evident in continuous records of net ecosystem productivity. Cloudiness and aerosols affect the relative magnitudes of diffuse and direct radiation available to ecosystems. We analyzed the influence of this effect on primary productivity using a model that incorporates a detailed description of radiative transfer into representations of leaf conductance and photosynthesis similar to those of our global model. The analysis indicates that increased cloudiness and aerosol loading of the atmosphere can present a higher ratio of diffuse to direct radiation that is more favorable to primary productivity. We have submitted papers describing this analysis to Nature and to Global Change Biology (Gu and Shugart 1998, Gu et al. 1998). The effect of changes in radiation regime may be apparent in remote sensing data, for example in the analysis reported by Myneni et al. (1997), and we are interacting with the Boston University EOS project to investigate this.

A comparison of stomatal conductance representations. Large-scale patterns of simulated leaf area and primary productivity are very sensitive to the representation of stomatal conductance and its dependence on environmental conditions. However, the accuracy of stomatal conductance representations has been debated in the literature without resolution (Montieth 1995), particularly regarding the influences of humidity, and it is difficult to discriminate between representations based on data collected in controlled experiments, much less in the context of global simulations.

In order to clarify the influences of different stomatal conductance functions on simulated large-scale patterns in primary productivity, we compared simulations along the Kalahari Transect in Southern Africa with three stomatal conductance modules incorporated consistently into our full terrestrial ecosystem model. The models included a typical multiplicative response module in which stomatal conductance is a maximum value multiplied by the product of response functions for each environmental variable considered, a semi-empirical function that function that maximizes productivity and considers nitrogen allocation.

The Kalahari Transect provides a moisture gradient from desert to tropical forest. This comparison identified substantial differences between the models that were particularly evident as differences in the locations along the transect at which major shifts in simulated productivity and water-use efficiency occur in response to changes in the moisture regime. This pattern of productivity along the Kalahari Transect should be observable in remote sensing data, and we are examining this in AVHRR data from the region.

This comparison of stomatal conductance representations was reported as part of an University of Virginia Ph.D. dissertation defended successively in December, 1998. The dissertation material is being revised and will be submitted to a journal for publication early in 1999.

ADDITIONAL REFERENCES

Monteith, J. L. 1995. A reinterpretation of stomatal responses to humidity. Plant, Cell and Environment 18:357--364.

Myneni, R. B., C. D. Keeling, C. J. Tucker, G. Asrar, and R. R. Nemani. 1997. Increased plant growth in the northern high latitudes from 1981 to 1991. Nature 386:698--702.

Woodward, F. I., T. M. Smith, and W. R. Emanuel. 1995. A global primary productivity and phytogeography model. Global Biogeochemical Cycles.

ATTACHMENT TWO

DRAFT
MEMORANDUM OF UNDERSTANDING

Sub-Center of Atmospheric Sciences
Chinese Ecosystem Research Network
Institute of Atmospheric Physics
Chinese Academy of Sciences
Beijing, People's Republic of China

Institute for the Study of Earth, Oceans, and Space
University of New Hampshire
Durham, New Hampshire
United States of America

The Sub-Center of Atmospheric Sciences (SCAS) is one of the laboratories of Chinese Ecosystem Research Network (CERN). SCAS affiliates to Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences. Institute for the Study of Earth, Oceans , and Space (EOS) is one of research divisions of University of New Hampshire. SCAS and EOS share many scientific interests in the fields of biogeochemistry and atmospheric chemistry. Recognizing the potential for mutual scientific benefit, this agreement establishes a broad framework for research and cooperation between the SCAS and EOS.

1. This agreement is intended to foster and facilitate scientific collaboration. It establishes a relationship between scientists in a non-binding agreement that is subject to all rules and regulations of our respective agencies and countries.

2. This agreement fosters a reciprocal research program in the fields of biogeochemistry and atmospheric chemistry with the two research groups acting as equal partners.

3. The types of scientific collaboration envisioned include scientific visitor appointments, exchange of existing scientific data, joint field research, scientific workshops, and the sharing of numerical modeling and instrumental techniques.

4. Both groups will facilitate collaborative research programs and related logistics.

5. The results of this collaborative research, including scientific data, instrument development, numerical models, and regional inventory / assessment will be shared and jointly published.

6. This agreement is to remain in effect for five years from its signing with the expectation of renewal at that time.

This understanding does not commit either groups or their affiliations to obligate funds or personnel. Any binding obligations desired between the parties will be formally established through joint proposals and will not become binding unless funding is established and implementing contracts are executed.

____________________	____________________
Yuesi Wang Director, SCAS	Changsheng Li Research Professor, EOS
Date signed	Date signed
____________________	____________________
Beijing, P. R. China	Durham, New Hampshire, USA
Approval by	Approval by
____________________	____________________
Mingxing Wang Director, IAP	Berrien Moore III Director, EOS
Date signed	Date signed
____________________	____________________
Beijing, P. R. China	Durham, New Hampshire, USA

ATTACHMENT THREE

White Mountain MAPBGC project posters

presented at

the Ecological Society of America Meeting

Summer 1998

ATTACHMENT FOUR

Monitoring Initial Stages of Forest Recovery:
Krusne Hory, Czech Republic
The Field Effort.

A Background Sketch
and
Scientific Accomplishments

Barry Rock
Institute for the Study of
Earth, Ocean, and Space
University of New Hampshire

1. <u>Preliminary work</u> – Organization of the summer campaign involved planning for the flights, planning field effort and sample collections, and laboratory analyses of the samples collected. The project had initially planned to make use of space-borne Lewis hyperspectral and air-borne narrow-band imagery. Due to the launch failure of Lewis, we were forced to plan on airborne involving the acquisition of both hyperspectral and narrow-band imagery.

January 1998 - UNH visit to GSFC: Doctoral Candidate Petya Entcheva presented a seminar highlighting past research and expressing the need for overflights of Czech study sites using an imaging spectrometer. At a meeting with Jim Irons, Carol Russell, Phil Dobney and others at Goddard, discussion of the specifications of the Airborne Solid State Array Spectrometer (ASAS) were held, the instrument schedule/availability for the field season 1998, was discussed, and arrangements made for August overflights of the Krusne hory and Sumava study sites. At the same time, arrangements were made to have ASAS overflights of selected ice storm damage sites in the White Mountains in New Hampshire.

February 1998 – UNH visit to Stennins Space Center: meetings Greg Carter, Bruce Spearing, Kenneth Kopenhaver, Chiang Hieng Mao involved discussion of the need to use a narrow-band airborne imaging camera system in the project. Meetings at the SSC remote sensing division and discussion of the characteristics and availability of their Real-time-display Digital Airborne Camera System (RDACS) led to a decision to conduct coordinated overflights using both ASAS and RDACS systems in August.

March 1998 – UNH visit to NASA headquarters, with detailed discussions and approval of the use of ASAS for the Czech project.

April 1998 – A combined team from GSFC and UNH visited the Czech Republic, for the purpose of selecting private aerial survey companies to fly ASAS and RDACS. Meetings were held at the Czech Forest service and Nature Conservancy agencies with V. Henzlik and J. Rejl, expressing the need for appropriate aircraft and experienced personnel, skilled in aerial imagery acquisition. Based on Czech colleagues suggestions, and after visiting a number of airline companies, airfields and evaluating the capabilities of a number of aircraft, we selected and contracted for the 1998 effort an Antonov 2 aircraft, operated by the FLYMA company for ASAS, and a Cessna 26 aircraft, operated by the ARGUS company, for RDACS.

May-June1998 – UNH on-going analysis of topographical maps, CIR photography and LandsatTM imagery , determining the optimal areas for additional study sites (a total 224 sites, 60 of which were intensive study sites representing the full range of damage conditions), flightlines and aircraft coordination, preparation of field equipment and classification manuals for forestry surveying and sampling, preparation of LandsatTM imagery and aerial photography of the study sites for use in the field.

2. Field campaign 1998:

July 22 - Aug. 11 – Establishing of research sites based on the Landsat TM data, aerial photography, forestry maps and the summer 1997 field visits. The study areas were classified into 5 damage classes, based on field observations made from 7/23 - 8/11. The task was performed by 2 teams from UNH with the help of Czech students. The study areas in Krusne hory and Sumava mountain were visited, evaluated on the ground and the health condition of the forest at 60 intensive research plots were established (48 in Krusne hory and 12 in the Sumava). Within a 30x30m sampling plot the team characterized stand structure, estimated the damage class of selected trees, geo-referenced the plot, and recorded ancillary data.

August 14 – An organizational meeting of all the overflight campaign participants was held at Charles University, in Prague. The UNH team (8 people), the ASAS and RDACS engineers, the collaborating colleagues from SSC (Dr. Rick Miller), Charles university Prague (Dr. Jana Albrechtova), the Czech Forest service (Vladimir Henzlik) and Nature conservancy agencies (Jindra Rejl), representatives of the Czech press (3 News papers, 2 TV networks) met and presented the goals of the effort, as well as the experimental design and the field strategy. Details of procedures for maintaining daily communications, decision chain-of-command, and coordination of the overflights and ground calibration activities were also developed. It is important to note that in-country phone communications are often unreliable in the Czech Republic, thus requiring the use of mobile phones for day-to-day coordination. Although use of the mobile phones was limited in mountainous regions, they did allow for effective coordination of activities.

August 15 – September 3 – Ground sample collections were performed by a team from UNH, SSC and collaborating Czech colleagues from Charles University. At each plot foliar samples for narrow band imaging and spectrometry, chlorophyll and detailed histochemical and quantitative anatomical analyses were collected. Branch samples were collected from the top, most active portion of the tree crown. Spectral reflectance data for the some samples were measured using a GER 2600 Visible Infrared Intelligent Spectrometer (VIRIS). The narrow band imaging digital video camera system developed at SSC was used to acquire images of branch segments at selected narrow-band spectral regions (using 10nm interference band-pass filters. All sampling plots were precisely located, using a GPS unit.

3. Data processing, analyses and preliminary results:

3.1. Remote sensing:

Airborne Hyperspectral and Narrow-band Imagery - Imagery were acquired using the ASAS hyperspectral sensor and the RDACS narrow-band video system for all sites in the Krusne hory and Sumava Mountains. The weather conditions during the data acquisitions were unstable and during the overflights cumulous clouds developed. Our expectation is that some of the imagery will have clouds and shadow effects, which will create difficulties for the analyses. Based on a recent visit to Goddard (November 2-6, 1998) and a planned visit to Stennis (January, 1999), selected segments of common ASAS and RDACS flight lines will be identified which include ground calibration targets, a range of forest stand damage classes and a range of land cover types will be identified and used to compare the relative capabilities of each system.

Currently the imagery is being calibrated and atmospheric corrections and calibration to ground reflectance spectra of targets will be completed.

Field Spectrometry - Based on field spectrometer (VIRIS) measurements made under laboratory conditions, and narrow band imaging digital camera (NBC) in laboratory conditions:

- Initial results suggest little variation in red edge parameters (REIP, RARS ratio, RE3/2, etc.) characterizes 1st-, 2nd-, and 3rd-year needles collected from trees in different damage classes, supporting the hypothesis that all trees are undergoing a recovery;
- Very strong correlations are seen between the VIRIS and NBC methods of characterizing red edge properties of the needle samples collected, indicating that the airborne systems (ASAS and RDACS) may provide similar correlations of ground spectral properties;
- Current activities are centered on comparison of ASAS and RDACS data for common ground control points (ground calibration targets, the same land cover types, and field study sites).

Narrow-band imaging – Image acquisition, data capture and processing steps include the following:

- Digital images from all foliar samples were acquired under standardized conditions at 550 , 675, 700 and 800 nm (+/- 5nm) wave bands, using a standard hemispheric light source and a gray scale panel .
- Using the gray scale, conversion of the digital brightness values to reflectance.

Expected results from comparisons between VIRIS and NBI Camera data, based on 1997 results: A comparison done in 1997, of average percent reflectance values recorded by the VIRIS and estimated percent reflectance derived from video images at 670, 700 and 720nm for the same branch segment samples in the laboratory shows a highly significant relationship ($p<0.01$, $r^2=0.91$). These results suggest that the NBC system provides imaging and modeling at selected red edge narrow bands with high confidence (90%). A comparison among spectral data derived using field spectrometer, and narrow band video camera data from tower and from needle samples supports the hypotheses that:

- narrow band imaging in selected wavelength regions will provide reliable radiometric data;
- Detection of the early stages of forest decline may be possible based on narrow band (10nm wide bands) spectral data;
- The optimal bands for stress detection are located along the red-edge shift region – 675nm, 698nm, 720nm, other bands of interest for developing ratios are 550nm, 800nm.

Further analyses of the data collected during 1998 are in progress and will evaluate the strength of the relationship between chlorophyll levels and reflectance values, REIP and calculated ratios and build algorithms describing the relationships for the different damage classes. All of these activities investigate the relationship between field variables, forest stand characteristics and reflectance and anatomy data.

3.2. Pigment Analyses

Chlorophylls. Chlorophyll pigment extraction methods were employed during the 1998 fieldwork. Total chlorophyll, chlorophylls a and b, and total carotenoids were measured and evaluated by research personnel at Charles University, in Prague. Preliminary results indicate little or no variation in key chlorophyll values either between damage classes of individual trees, or across age-classes of needles. These results:

- correspond very well with field spectral measurements of red edge parameters;
- support the hypothesis that recovery is occurring in trees of all damage classes in the Krusne hory;
- and suggest similar state-of-health at both the Krusne hory and Sumava study sites.

Polyphenolics. In addition to the extraction of chlorophyll and carotenoid pigments from needle samples from all trees included in the present study, selected trees were analyzed to a range of histochemical properties, including the amount and frequency of occurrence of the polyphenolic compounds lignin and tannins. Both of these phenoloc compounds are implicated in changes of state-of-health and the development of damage in conifers. Preliminary results indicate:

- Levels of tannins are similar across damage classes, although a "normal" increase is seen in 1st-, 2nd-, and 3rd-year needles. These results support the hypothesis that recovery is occurring in trees in the Krusne hory;
- Levels of lignin in foliage decreases as damage increases for trees in the Krusne hory.

3.3 Dendrocronology

Tree increment cores were collected from all five trees within a sample plot. From some trees it was necessary to collect multiple cores. The total number of tree increment cores collected during 1998 is 300. Ring widths are currently being measured using a digital computerized measuring system. Jennifer Supple, a new Doctoral student in CSRC, is doing this work.

Preliminary findings from 1997 effort: To evaluate growth trends by damage class, ring-width series were first separated into age and damage classes and then averaged. In addition, non-parametric bootstrap 95% confidence intervals were developed for the mean ring-width chronologies. Our findings suggest that the pattern of decline began between 1945 and 1949. In the period 1970 - 1984, tree growth was most impaired and an apparent recovery began after 1985 and continues to the present. Regional climate data, covering the period from 1963 till 1990 (Climate station at Fichtelberg) was used for assessing the effect of precipitation and temperature on tree growth. The effect of temperature on tree growth was found not to be significant for both healthy and decline sites ($p>0.05$, $R^2=0.01$). Multiple regression analysis suggests that precipitation had a significant effect ($p<0.05$) on the healthy trees (DM0) and did not cause a significant effect ($p>0.05$, $R^2=0.06$).) on the tree growth of the damaged trees (DM1, DM2 and DM3). The results suggest for the healthy trees (DM0) a strong dependence of tree growth on precipitation and for the damaged trees (DM1-DM3) a decoupling of growth rate and the limiting ecological factor for the region - precipitation. Our dendrocronology analyses provide the evidence for forest recovery in the area of Krusne hory.

Expected Results: The analyses of the 1998 tree core samples are expected to provide the necessary sample size and spatial extend to support conclusions at a landscape level. Further analyses are needed to document the process and compare the growth trends for the forests from Krusne hory and the control areas in the Sumava mountains.

3.4. Digital data base and mapping of the study areas:

All sites (total of 225) were geo-referenced, recorded were also the GPS coordinates of an important for recognition land features and marks. Currently are being created Polygon attribute tables, for each study site. They will be connected with the GPS points and merged with the digital database of the study areas created during 1997. The digital database will be used in the imagery geo-referencing, interpretation and classification.

3.5. Lignin, cellulose and nitrogen

During the 1998 effort 900 sets of samples (1st-, 2nd-, and 3rd-year needles) were collected from trees at the 60 intensive sites. The samples were air-dried for one week at 70° C and stored into special containers. Further processing of the samples is scheduled and currently being conducted at the research laboratory of John Aber. Of particular interest will be the comparison of histochemical studies focused on lignin and tannins with the results from these spectral characterizations using the IR methods.