NSF SpecNet Proposal
"SpecNet: Proposal for an NCEAS Working Group"

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Summary

SpecNet (Spectral Network) is a network of terrestrial flux tower sites where 'near surface' remote sensing is being conducted to improve our understanding of controls on the biosphere-atmosphere carbon exchange. SpecNet sampling closely matches the spatial and temporal scale of flux measurements, allowing a direct comparison of remotely sensed signals to factors affecting fluxes. We propose a SpecNet Working Group that will examine the optical, thermal, and flux data emerging from these sites. A primary goal will be to standardize the remote sensing instrument, algorithms, data processing protocols, and data products for comparative analyses. The next step will be to compare results across ecosystems to reveal contrasting controls on carbon flux. This effort will help link remote sensing to fluxes, assist in validating satellite products (e.g. NPP derived from the MODIS sensor), and will provide an improved scientific foundation for emerging carbon policy.

Problem Statement

With the advent of new satellite sensors (e.g. MODIS sensors on the AQUA and TERRA platforms), we are now entering a new age of Earth System Science where daily whole-Earth observations of biospheric states and processes (e.g. carbon flux) are now possible. Increasingly, carbon cycle science is being asked to provide a basis for carbon policy (e.g. Kyoto Protocol). The new satellite sensors are beginning to provide the relevant datasets, including leaf area index (LAI), fractional light interception by green vegetation (FPAR), and net primary production (NPP). Yet, a recent review of the science from the MODIS sensor (e.g. MODIS meeting, Missoula MT, July 16-18, 2002) reveals that much work remains to validate and refine these products if they are to provide defensible estimates of biosphere-atmosphere carbon fluxes.

In principle, remote sensing can be linked to fluxes through the ground-based flux tower network (FLUXNET, Running et al. 1999). However, a fundamental challenge lies in the mismatch in temporal and spatial scales between satellites and ground-based measurements (Rahman et al., 2001). A combination of flux towers and scale-appropriate remote sensing is needed to address these challenges. Such systematic sampling across flux tower sites (SpecNet) has only begun in the last 2-3 years. The near-surface remote sensing within SpecNet resolves many of the technical issues associated with satellite sensing (e.g. perennial cloud cover in northern and tropical latitudes that obscures the surface, and large pixel sizes that blend functionally distinct landscape cover types into a single class). However, formidable technical issues remain in the analysis of these data, which cross multiple scales in spectral, spatial, and temporal domains. A synthesis of the early results from these sites is now needed.

See Field Sites for a list of current SpecNet locations.

Specific challenges at these sites include the characterization of *radiation-use efficiency*, *respiratory fluxes*, and vegetation "*functional types*." Promising directions for tackling each of these are further explained below.

Detecting radiation-use efficiency (RUE)

One way to view the photosynthetic uptake of carbon is through a light-use efficiency model, which depicts photosynthetic rate as a product of absorbed photosynthetically active radiation (APAR) and radiation-use efficiency (RUE) (Gamon and Qiu 1999). Similarly, net primary production (NPP) estimates can be derived from an integration of APAR and RUE over a growing season (Monteith 1977, Goward et al. 1985). Yet RUE is a spatially and temporally dynamic scalar that is not yet adequately characterized for all of the world's ecosystems due to lack of appropriate datasets (Gamon and Qiu 1999). Thus, a key challenge to current global photosynthetic and NPP estimates remains the estimate of RUE, which is typically derived from a combination of sources, including weather data (Running and Hunt, 1993) and biome-specific model constants (Ruimy 1994).

Recent studies have shown that hyperspectral (narrow-band) optical measurements can successfully track reductions in RUE during periods of stress. For example, reduced RUE due to temperature, water, or nutrient stress can be detected by the Photochemical Reflectance Index (PRI) (Gamon and Qiu 1999, Gamon et al. 2001). This index has successfully tracked RUE in boreal forest stands (Nichol et al. 2000, Rahman et al. 2001) and chaparral stands (Stylinski et al. 2002). Additional studies suggest that water absorption features (Penuelas et al. 1993, Sims and Gamon in review) or thermal bands (Nemani and Running, 1997), particularly when combined with other optical bands, may provide additional information on the degree of photosynthetic downregulation due to water stress. We now have a potent set of tools for directly assessing RUE with remote sensing, and we now need to validate this approach across multiple ecosystems with contrasting constraints.

Initial exploration of optical and flux data from existing SpecNet sites (Barrow, AK, and Sky Oaks, CA) reveal contrasting optical patterns reflecting different underlying controls on ecosystem carbon flux (figure 1). In the Arctic tundra, seasonally varying NDVI (landscape "greenness") was strongly correlated with photosynthetic flux, but PRI (RUE) was not. By contrast, in the evergreen chaparral, NDVI varied little, but PRI was strongly associated with seasonal changes in photosynthetic carbon flux and RUE. These results suggest that it is now possible to detect contrasting photosynthetic behavior and RUE using optical remote sensing, and provides an example of the kind of cross-site analyses to be conducted with a SpecNet working group.

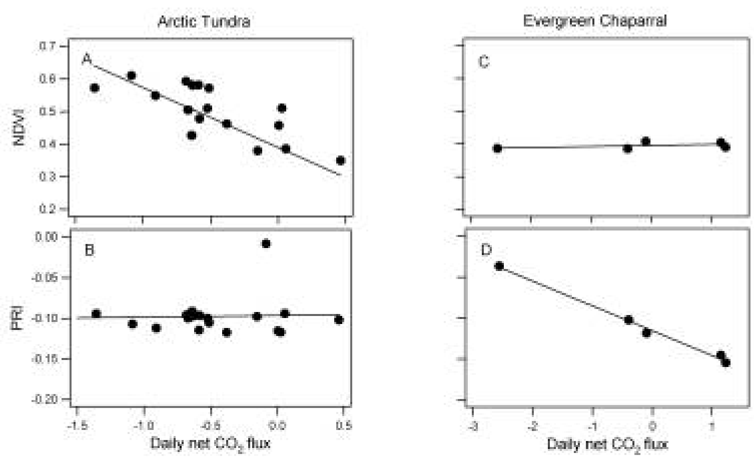

Figure 1 - Optical indices (NDVI or PRI) plotted against daily net CO2 flux (gC m-2 d-1, with negative flux indicating photosynthetic carbon uptake) for Arctic tundra (Barrow, AK, left) and evergreen chaparral (Sky Oaks, CA, right). Data obtained by 100 m tram sampling within the flux tower footprint. Note the complementary behavior of NDVI and PRI in these ecosystems, indicating contrasting patterns of phenology and RUE. (Gamon et al. in prep.)

Understanding controls on respiratory fluxes

Most global analyses model soil or ecosystem respiration as an exponential function of temperature. However, analysis at one of the SpecNet sites (Sky Oaks CA) illustrates how the temperature control can be "overridden" by moisture controls, and this can be detected with the 970 nm Water Band Index (figure 2). Given the importance of clearly defining respiration controls for cross-site analyses of carbon flux (Valentini 2000), another goal of a SpecNet working group would be to further explore optical and thermal indicators of respiratory carbon flux across sites. These indicators would include surface temperature, moisture content, vegetation type, and standing biomass.

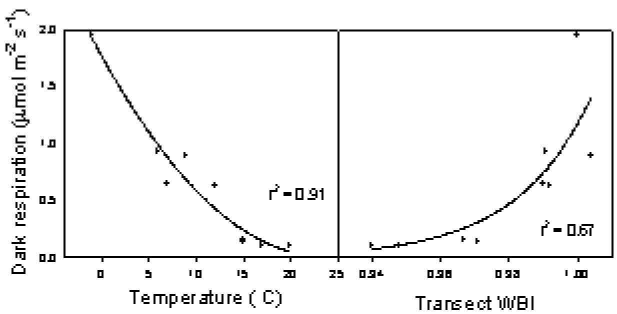

Figure 2 - Ecosystem dark respiration in evergreen chaparral (Sky Oaks, San Diego County, USA) as a function of nighttime air temperature and ecosystem water status (water status sampled during daylight hours using the water band index, WBI). WBI is an optical index of vegetation water status derived from the water absorption feature at 970 nm. The surprising negative relation between temperature and respiration across multiple dates (2001) is due to the overriding influence of drought at this water-limited site. (Sims et al. in prep.)

<u>Distinguishing functional types</u>

A key to understanding biospheric flux at the global scale lies in proper characterization of vegetation cover types (DeFries and Townshend 1994). Hyperspectral (Fuentes et al. 2001) or thermal (Nemani and Running 1997) sensors provide new ways for distinguishing functionally distinct cover types. Furthermore, because these sensors provide a number of functionally significant bands and vegetation indices, it is now possible to design increasingly "intelligent" (i.e. physiologically-based) approach to classifying vegetation cover (Gamon and Qiu 1999, Fuentes et al. 2001). Work at existing SpecNet sites is now revealing new ways to distinguish key cover types remotely (figure 3). A key goal of a SpecNet working group will be to systematically explore these approaches across contrasting SpecNet sites, and to link these cover types to fluxes.

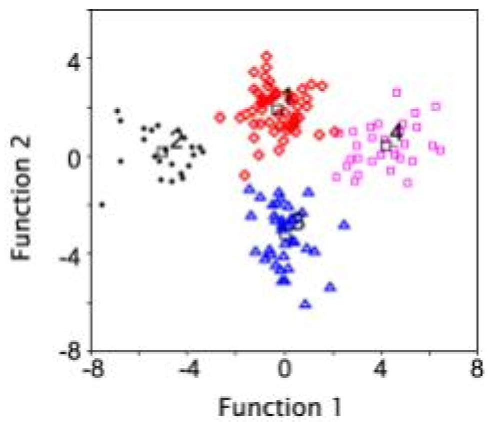

Figure 3 - Results of discriminant analysis, illustrating the ability to distinguish vegetation functional types in Arctic tundra (Barrow, Alaska) using hyperspectral reflectance. Inputs to the discriminant analysis were based on reflectance spectra (400-1000 nm) of individual cover types (approx. 10 cm diameter) taken at mid-season. Black squares indicate group centroids for 1) graminoid vascular plants, 2) broadleaf vascular plants, 3) lichens, and 4) mosses. One goal of SpecNet will be to develop a unified approach to classifying functional types across sites based on optical and thermal signals. (S. Houston et al. in prep.)

In addition to the three issues discussed above, the SpecNet Working Group will also address the following questions:

1) Can we use scale-appropriate remote sensing to characterize complex spatial and temporal patterns during key transitional phases (e.g. snowmelt, greenup, rehydration after rain, etc.)? Note that non-linear effects may predominate at these times. For example, during snowmelt, remaining snow patches will "contaminate" estimation of whole-ecosystem NDVI (greenness), and thus lead to false estimates of FPAR. Current maximum value compositing techniques used to analyze satellite data can exacerbate this problem.

2) Can we identify robust links between optical/thermal signals and factors controlling ecosystem carbon and water vapor fluxes? Furthermore, will these signals apply across all sites?

3) Can we come up with accurate estimates of component fluxes (i.e. respiratory and gross photosynthetic fluxes, and contributions from multiple canopy or landscape components) using scale-appropriate remote sensing alone?

4) Can we identify suitable sampling methods for technically challenging sites (e.g. arctic tundra, tropical forests, or sites with complex topography)?

5) Can we define standard protocols for blending complex datasets in multiple domains (e.g. fluxes in time and optical patterns in space)?

6) Can we identify "scaling protocols" for relating multiple observations and datasets collected at multiple spatial, temporal, and spectral scales?

Rationale for NCEAS support

This is an integrative exercise, combining existing flux and meteorological data (AMERIFLUX/FLUXNET, supported by DOE) with optical and thermal data (SPECNET, currently a "volunteer" organization of cooperating investigators with separate sources of support

- see http://vcsars.calstatela.edu). This validation is not likely to be best supported by NASA, which remains primarily a space-science agency with an agenda of developing satellite platforms. In the past, DOE has been primarily interested in supporting direct flux measurements and their validation, but has not always supported ancillary remote sensing across flux tower sites. Consequently there is a need for agencies such as NSF to support data validation, integration and analysis.

Current SpecNet work is being conducted by several investigators in multiple ecosystems. The proposed Working Group includes representatives from each SpecNet site (Table 1), modelers and geographers for addressing scaling issues, scientists experienced in programming and managing large datasets, and additional members planning to extend this network to new sites. By convening an NCEAS working group, we hope to explore the new datasets emerging from current SpecNet sites, with the goal of specifically addressing radiation-use efficiency, respiratory controls, and functional vegetation types. Technical issues of bridging multiple spatial and temporal scales must also be addressed. There is a need for standardization and archiving of existing data so that cross-site analysis can proceed, and NCEAS is ideally suited to these functions. This standardization will also provide a foundation for others wishing to add sites to the network, and will provide a stronger basis for validating models and satellite products.

Proposed Activities and Timetable

We plan a 2-year Working Group, beginning in October, 2002. In the first year, we plan to hold two weeklong meetings (tentatively scheduled for January and July 2002), primarily focused on data standardization, integration and analysis. In year two (October 2002-Sept 2003), we plan to hold a final meeting to prepare publications contrasting optical and flux behavior across sites.

Table 2 - Schedule of SpecNet Activities

Tentative Date(s)	**Activities**
October 2002	Begin project, establish rules for data sharing, and begin initial data collection/analysis
January 2003	First NCEAS meeting, present initial data and analyses, discuss standard protocols
July 2003	Second NCEAS meeting, re-examine progress, and plan publications
January 2004	Meet to discuss final results prior to publication

Anticipated results

Results will be made available through the SpecNet website (a preliminary view is available at http://vcsars.calstatela.edu), NCEAS, and journal publications, and will include:

1) Development of standard sampling, processing and analytical tools and protocols, including:

   a) Spectral indices (e.g. vegetation indices such as NDVI, SAVI, EVI, or "stress" indices such as the water band indices and PRI),

   b) components of flux models (e.g. RUE, FPAR and respiration),

   c) scalable protocols for validation of satellite products,

   d) methods for interpolation of flux data (e.g. using optically derived methods for difficult sites or when flux towers fail),

   e) current models (e.g. radiative transfer models and other light-use-efficiency-based models),

   f) optical instruments, data processing protocols and software.

2) Improved methods for assessing complex sites (e.g. sites with complex terrain, mixed pixels, or chronic cloudcover), transitional phases (e.g. seasonal changes or weather events).

3) Clarification of the contrasting controls on photosynthetic and respiratory processes contributing to biosphere-atmosphere carbon exchange.

<u>Beneficiaries</u> will include Earth System Scientists using flux towers and remote sensing tools for the analysis of the terrestrial carbon budget. Once tools and protocols for cross-site analysis are in place, we anticipate that SpecNet will provide a means to independently validate satellite products. In the long run, an improved understanding of the terrestrial carbon budget will provide a stronger basis for intelligent carbon cycle policy.

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