Satellite Remote Sensing of Pan-Arctic Vegetation Productivity, Soil Respiration and Net CO_2 Exchange Using MODIS and AMSR-E data

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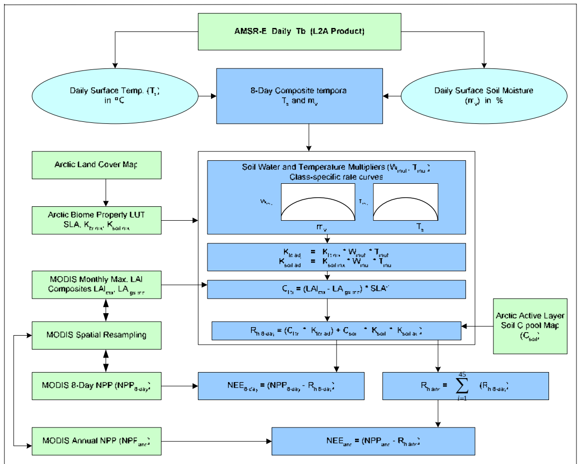
Abstract

We have developed a new satellite-based approach for regional assessment and monitoring of terrestrial net carbon exchange (NEE) for the pan-Arctic; NEE quantifies the magnitude and direction of land-atmosphere net CO_2 exchange and is a fundamental measure of the balance between carbon uptake by vegetation net primary production (NPP) and carbon loss through soil heterotrophic respiration (R_h). We extract surface soil wetness and temperature information from AMSR-E daily brightness temperature measurements at C- and X-band. These data are used as surrogates for soil active layer moisture and temperature controls on Arctic soil respiration. This information is used with regional land cover and soil carbon pool maps to compute relative magnitudes, spatial patterns and seasonality in R_h for the pan-Arctic. We combine AMSR-E based respiration information with other satellite-based measurements of vegetation structure (LAI) and productivity (GPP, NPP) from Aqua/Terra MODIS sensors to derive spatially explicit estimates of NEE for the pan-Arctic at weekly and annual intervals. Calibration and verification of these products involve multiscale comparisons with tundra chamber and eddy-flux tower CO_2 flux measurement networks, detailed hydroecological process model simulations and low altitude flux aircraft overflights along regional moisture and temperature gradients. This project will provide the first-ever operational satellite-based approach for regional assessment and monitoring of NEE, the primary measure of carbon exchange between the land and atmosphere. This study will also advance our understanding of the extent to which the Arctic is controlled by interactions among the cryosphere, climate, vegetation and hydrology; factors, which are interactive in complex ways and which are currently near critical thresholds, that can change rapidly as a result of small variations in climate, land cover and anthropogenic activity.

Introduction

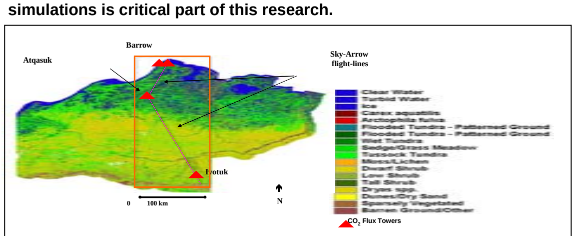
Net carbon exchange (NEE) is the residual difference between terrestrial sequestration and storage of atmospheric CO_2 by vegetation biomass net primary production (NPP) and terrestrial CO_2 loss through soil heterotropic respiration (Rh). NEE is a critical measure of the magnitude and direction of land-atmosphere carbon exchange integrating climate, hydrologic and ecological processes with atmospheric greenhouse gas concentrations and global change (Baldocchi et al. 2001). Seasonal and spatial variations in soil moisture and temperature correspond closely with regional patterns of land cover, topography and net CO_2 exchange. Local disturbances such as thermokarst related subsidence and drying of adjacent surface soil layers and variation in soil water content leads to increase the soil litter decomposition and respiration processes. This in turn alters the productivity, structure and species composition of local vegetation communities (Oechel et al. 1998). Tower CO_2 eddy-flux measurement networks provide detailed information regarding stand-level CO_2 surface-atmosphere exchange and associated biophysical processes, but they provide little information regarding spatial variability in these processes for larger regions (Running et al. 1999, Kimball et al. 2001).

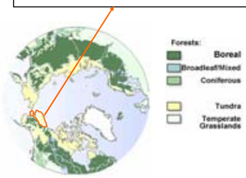
The focus of this research is to advance understanding of the Arctic carbon cycle and regional feedbacks to climate change and the global carbon cycle by developing improved techniques for regional assessment and monitoring of terrestrial carbon exchange from satellite biophysical remote sensing. This project will provide the first-ever operational satellite-based approach for regional assessments and monitoring of NEE, the primary measure of carbon exchange between the land and atmosphere. Our approach integrates MODIS land cover, vegetation structure (LAI) and productivity (NPP) data, with AMSR-E sensor-based characterization of surface soil moisture and temperature controls on R_h for regional assessment and monitoring of Arctic terrestrial Net CO_2 exchange.

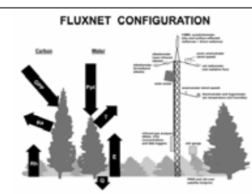


Satellite-based mapping and monitoring of Pan-Arctic R_h, NEE and surface soil temperature and moisture controls to CO2 respiration.

This diagram illustrates an approach to derive weekly and annual NEE using AMSR-E surface soil moisture and temperature (Njoku et al. 2003) and MODIS NPP, LAI for quantifying controls to soil respiration within major Arctic vegetation types as defined from regional land cover maps. We also use soil active layer carbon pools derived from long-term climatology and soil inventory network measurements to quantify spatial and temporal variations in R_h. This synergistic information from MODIS and AMSR-E sensors offer the potential for regional mapping and monitoring of land-atmosphere net CO_2 exchange for the Pan-Arctic. Validation of the results using tower CO_2 eddy-flux network, regional aircraft measurements and site network hydro-ecological model simulations is critical part of this research.







The Alaska North Slope study region (above) encompasses more than 7.6 million km² and includes an intensive study area encompassing chamber and eddy covariance tower CO_2 monitoring sites and Sky-Arrow based flight transects spanning major Arctic land cover, thermal and moisture gradients. This figure shows the eddy-flux tower and CO_2 measurement from existing Arctic tower networks and stand-level ecosystem process model of soil hydrologic and carbon cycle dynamics at tower site locations.

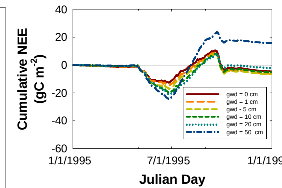
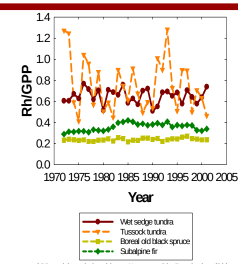
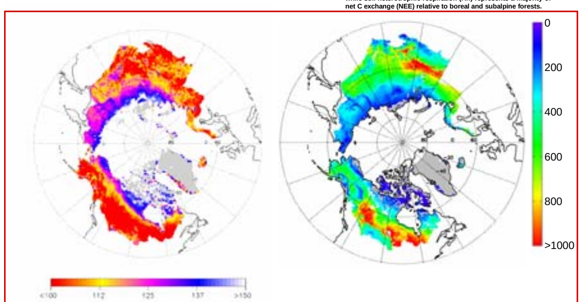


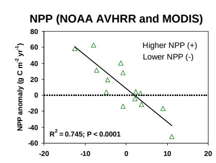
Figure above shows simulated variations in seasonal net CO_2 accumulation (NEE) under different ground water depths (gwd) at Barrow, AK; Moderate decreases in groundwater depth enhance both NPP and respiration rates. This alters the carbon balance at the site, as it moves from a net sink to a net source of carbon.

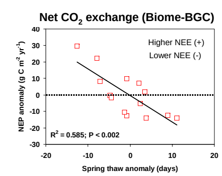


GPP and its relationship to Heterotrophic Respiration (Rh) are simulated for four sites along a latitudinal transect using Biome-BGC and 50-year site daily meteorological inputs: wet sedge tundra (Barrow, AK), tussock tundra (Atqasuk, AK), boreal old black spruce (Manitoba, Canada), and subalpine fir (Niwot Ridge, CO). Tundra vegetation productivity (GPP) is relatively small, while soil heterotrophic respiration (Rh) represents a majority of net C exchange (NEE) relative to boreal and subalpine forests.

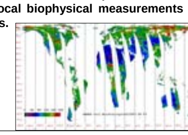


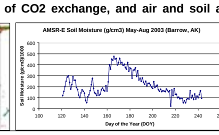
The figure above (left) shows the mean primary thaw day (day of year) for the pan-arctic basin and Alaska as derived from SSM/I satellite data from 1988-2002 (Kimball et al.2004). The Figure above (right) shows the 2003 MODIS production efficiency model (MOD17 PEM) derived GPP(gCm-2yr-1) for the domain. The graphs below show the close correspondence between the SSM/I derived spring thaw and annual C cycle anomalies (1988-2001) depicted by NOAA AVHRR PEM derived NPP (lower left) and regional ecosystem process model simulations of NEE (lower right) for the Alaska portion of the domain.

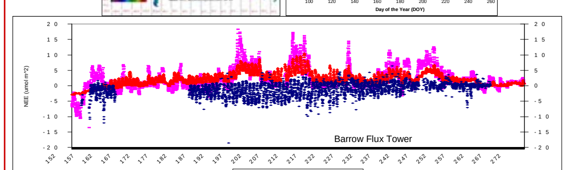


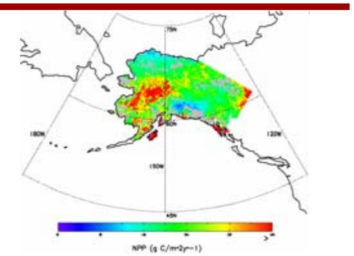


The Figure below shows the AMSR-E derived soil moisture for the pan-Arctic domain and a comparison of the seasonal pattern of AMSR-E derived soil moisture over Barrow Alaska relative to local biophysical measurements of CO2 exchange, and air and soil active layer temperatures.

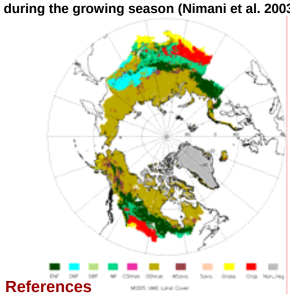








NPP trend for Alaska and Pan-Arctic region derived from AVHRR (1982-2000) is shown in figure above. Vegetation productivity for the most of the region is temperature limited, while southern margin of the basin are also influenced by soil moisture deficits during the growing season (Nimani et al. 2003).



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