Regional Assessment Of Arctic Vegetation Productivity And Soil Respiration Environmental Controls Using MODIS And AMSR-E: A New Approach For Satellite Monitoring Of Pan-Arctic Terrestrial Net CO_2 Exchange

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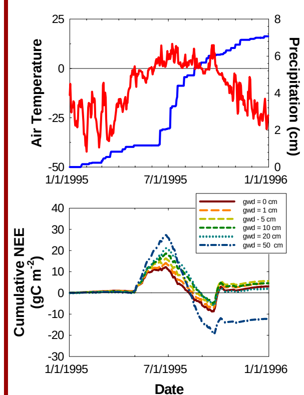
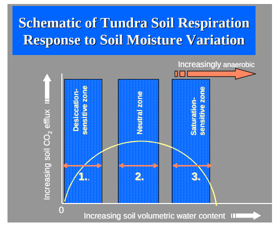
Abstract

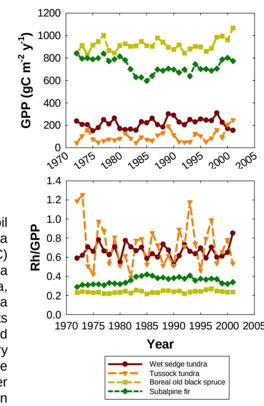
We are developing a new satellite-based approach for regional assessment and monitoring of terrestrial net carbon exchange (NEE) for the pan-Arctic; NEE quantifies the magnitude and direction of land-atmosphere net CO_2 exchange and is a fundamental measure of the balance between carbon uptake by vegetation 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-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, FPAR) 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.

Variability in GPP and Respiration Components of Net CO_2 Exchange

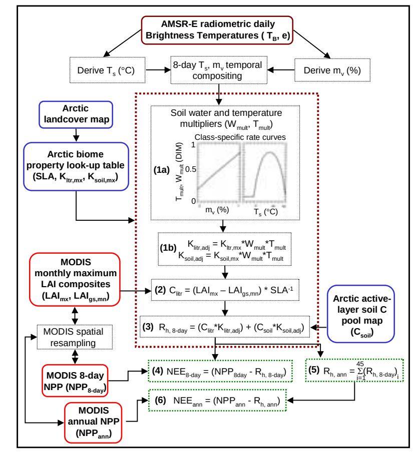




The graphs at right show annual GPP and it's relationship to soil heterotrophic respiration (Rh) as simulated for four sites along a latitudinal transect using an ecosystem process model (Biome-BGC) and long-term daily meteorological inputs for wet sedge tundra (Barrow, AK), tussock tundra (Atqasuk, AK), boreal (Manitoba, Canada), and subalpine (Niwot Ridge, CO) evergreen forests. Tundra vegetation productivity (GPP) is relatively small, while Rh represents a majority of net CO_2 exchange (NEE) relative to boreal and subalpine forests. Soil moisture and temperature are the primary controls to Rh and NEE in the Arctic (1,4). The illustration above shows the non-linear parabolic response of Rh to soil water variability, which yields complex spatial and temporal patterns in NEE. Daily meteorological conditions and associated seasonal NEE simulations under different ground water depths for a tundra site near Barrow Alaska show that moderate decreases in groundwater depth (gwd) yield dramatic changes in NEE and relative source-sink strength for atmospheric CO_2.

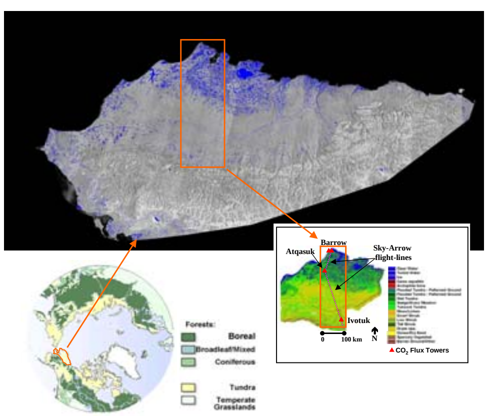


Deriving Arctic Net CO_2 Exchange from Satellite Remote Sensing



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. The diagram above illustrates an approach for remote sensing based derivation of weekly and annual NEE. We exploit AMSR-E daily mapping capabilities and C-band passive microwave sensitivity to surface soil moisture and temperature (5, 6) for quantifying controls to soil respiration within major Arctic vegetation communities as defined from regional land cover maps. We use this information and soil active layer carbon pools derived from long-term climatologies and soil inventory network measurements to quantify spatial and temporal variations in Rh. This information is combined with corresponding MODIS 8-day and annual NPP measurements to derive NEE at weekly and annual time steps.

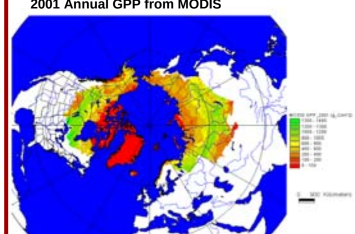
Multiscale Assessment and Verification of Arctic NEE



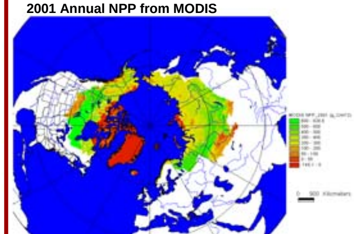
We use a multiscale approach for calibration and verification of satellite remote sensing based NEE calculations, involving comparisons with: 1) eddy-flux and chamber CO_2 measurements from existing Arctic tower networks; 2) stand-level ecosystem process model simulations of soil hydrologic and carbon cycle dynamics at tower site locations; 3) spatially explicit hydro-ecological process model simulations within nested Arctic subregions; 4) relatively high resolution surface soil moisture information for Arctic subregions derived from airborne and satellite Radar remote sensing data, and 5) low-altitude aircraft measurements of CO_2 fluxes, spectral reflectance and surface temperature along regional land cover, moisture and temperature transects. The Alaska North Slope study region (above) encompasses more than 7.6 million km^2 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.

Monitoring Pan-Arctic Vegetation Productivity from MODIS

2001 Annual GPP from MODIS



2001 Annual NPP from MODIS



Annual GPP and NPP for the Pan-Arctic basin and Alaska as derived from the MODerate resolution Imaging Spectroradiometer (MODIS) onboard the NASA Terra satellite (at left). MODIS provides global estimates of vegetation productivity at 8-day to annual intervals and relatively fine (1km) spatial scales (2). Arctic tundra represents approximately 30% of the vegetated area and has the lowest productivity relative to boreal and temperate forested regions. Vegetation productivity for most of the region is temperature limited, while southerly margins of the basin and are also influenced by soil moisture deficits during the growing season (3). Global observations of vegetation productivity from MODIS provide the means for quantifying net assimilation and storage of atmospheric CO_2 in vegetation biomass. However, these methods still provide an incomplete picture of ecosystem carbon cycle dynamics and terrestrial feedbacks to the atmosphere because of a lack of information regarding soil heterotrophic respiration (Rh) and the balance between terrestrial uptake and emission of CO_2. This lack of information is especially acute for the Arctic due to the large role that Rh has in the regional carbon budget and the enormous potential for Arctic regional feedbacks to climate change and the global carbon cycle (4).

References

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