Future Monitoring of Northern Carbon Cycle Dynamics from SMAP

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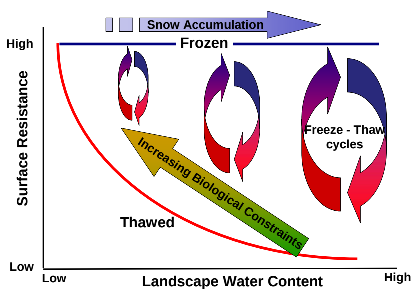
Introduction

A major goal of the Soil Moisture Active Passive (SMAP) mission as directed by the recent NRC Decadal Survey is to reduce uncertainty regarding the boreal carbon sink for atmospheric CO_2. The planned freeze/thaw (F/T) state measurement from SMAP will provide a surrogate measure of seasonal frozen and non-frozen conditions that define the potential growing season for northern ecosystems. The F/T variable also provides a measure of cold temperature constraints to plant growth and sequestration of atmospheric CO_2. The SMAP mission will provide F/T and soil moisture information with much improved spatial resolution and sensitivity over current satellite microwave remote sensing observations, and will quantify the primary environmental (temperature and moisture) controls on land-atmosphere CO_2 exchange. New algorithms are being developed to combine future SMAP soil temperature and moisture retrievals with vegetation gross primary production (GPP) information from optical/IR sensors such as MODIS to estimate surface soil organic carbon stocks, ecosystem respiration and net ecosystem exchange (NEE) of CO_2 with the atmosphere. Initial testing of these algorithms using AMSR-E microwave remote sensing inputs indicate RMSE accuracies within the uncertainty of tower CO_2 flux measurements, while model sensitivity studies predict >2-fold accuracy improvement from SMAP over AMSR-E. This information will provide improved mapping and prediction of northern CO_2 source-sink activity, component fluxes (GPP, ecosystem respiration) and associated environmental controls on these processes, and a direct path to reducing uncertainty regarding the boreal carbon sink for atmospheric CO_2. *Portions of this research were carried out at the Ames Research Center and Jet Propulsion Laboratory, California Institute of Technology under contract to the National Aeronautics and Space Administration.*

SMAP Measurements and Environmental Controls on Water, Energy and Carbon Fluxes



SMAP measurements of soil moisture and freeze-thaw cycles will provide an integrated measure of critical controls on surface water mobility and associated constraints to ecosystem processes. Decreasing water content imposes increasing constraints to CO_2 exchange, as do seasonal and episodic freezing. These temperature and moisture controls regulate land-atmosphere energy and water exchange, vegetation productivity, and sequestration of atmospheric CO_2 .

References

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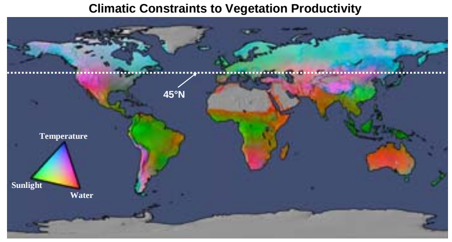
Motivation and Objectives for Carbon Cycle Science

Climatic Constraints to Vegetation Productivity

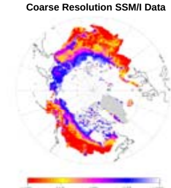


The primary motivation for SMAP carbon measurements come from the recent NRC Decadal Survey (**1**), which states that "*Soil moisture and its freeze-thaw state are key determinants of the global carbon cycle. Carbon uptake and release in boreal landscapes are a major source of uncertainty in assessing the carbon budget of the Earth system (the so-called missing carbon sink)* ", and that "*A soil moisture mission will directly support science to reduce that major uncertainty*" (i.e. the missing carbon sink on land). The SMAP mission will provide global, high-resolution mapping of soil moisture and its freeze/thaw state to: 1) Link terrestrial water, energy and carbon cycle processes; 2) Quantify net carbon flux in boreal landscapes, and 3) Reduce uncertainties regarding the "missing sink" for carbon. The primary domain for SMAP carbon cycle objectives includes northern (>45°N) boreal-Arctic land areas considered a major sink for atmospheric CO_2, where cold temperatures are limiting to vegetation net primary production (above, **2**) and associated biological processes.

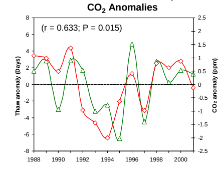
Ecological Significance of Future SMAP Measurements

Potential SMAP products having ecological significance include land surface freeze/thaw (F/T) status. The F/T signal from satellite microwave remote sensing coincides with arrival of seasonal snow cover in the fall; seasonal snowmelt and the new release of water in the landscape in the spring and the onset and duration of annual growing seasons. The Figure below (left) shows the mean growing season onset for the pan-Arctic basin and Alaska (excluding non-vegetated areas in grey) as derived from relatively coarse (~25-km) resolution SSM/I data. The annual thaw signal is strongly correlated with the spring drawdown and annual minimum of atmospheric CO_2 as reported by northern (>50°N) CO_2 monitoring stations (below right, **3**), where negative anomalies denote both earlier thaws and stronger net annual uptake of atmospheric CO_2. Strong influence of growing season onset on northern vegetation productivity is also indicated by the correspondence between SSM/I based spring thaw timing and mean annual NPP (bottom left) and maximum annual LAI (bottom right) derived from the NOAA AVHRR record for Alaska (**4**). SMAP will provide improved resolution and enhanced L-band sensitivity to F/T and the environmental processes controlling land-atmosphere carbon source/sink dynamics.

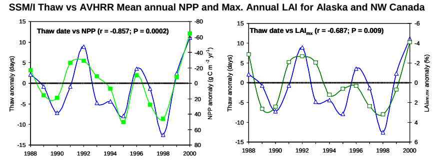
Mean (1988 – 2002) Growing Season Onset Derived From Coarse Resolution SSM/I Data



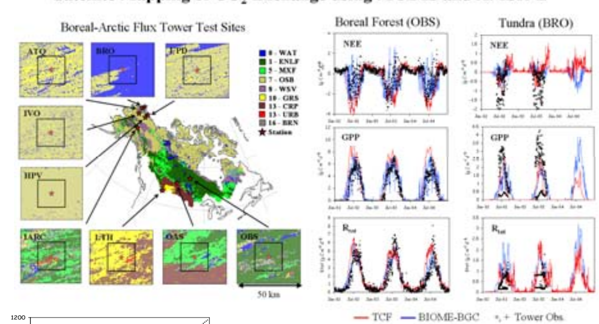
SSM/I Thaw Date vs Atmosphere CO_2 Anomalies

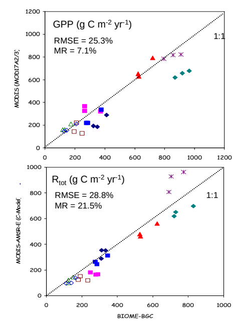


SSM/I Thaw vs AVHRR Mean annual NPP and Max. Annual LAI for Alaska and NW Canada



Prototype SMAP L4 Carbon Algorithm Performance over Northern Test Sites

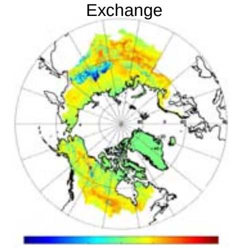




SMAP will provide measurements of surface moisture and temperature that define primary environmental controls to ecosystem respiration and land-atmosphere CO_2 exchange over northern land areas. Application of a prototype SMAP L4 Carbon algorithm using MODIS (MOD17A2) GPP and AMSR-E derived soil moisture and temperature inputs over boreal-Arctic tower test sites indicates RMSE accuracies sufficient to determine the net ecosystem-atmosphere exchange (NEE) of CO_2 to within 31 g C m^{-2} yr^{-1}, which is within estimated (30-100 g C m^{-2} yr^{-1}) tower measurement accuracies (**5, 6**). Algorithm sensitivity studies indicate that the soil moisture and temperature information from SMAP will resolve NEE to within 13 g C m^{-2} yr^{-1} (RMSE), a more than two-fold increase in precision over current methods.

Observations to Applications: Quantify Carbon Source-Sink Activity in Boreal Landscapes

Mean Daily net CO_2 Exchange



NEE (g C m^{-2}) DOY 177, 2004

Future SMAP products include daily maps of net ecosystem CO_2 exchange (NEE). A prototype SMAP L4 NEE product (left) is derived from MODIS GPP (MOD17A2) inputs with AMSR-E 6.9GHz derived surface moisture and temperature controls to soil respiration (**5**). These products can be used within a carbon data assimilation framework such as the NOAA CarbonTracker (**7**) to quantify regional C budgets and C source/sink activity. SMAP will provide new observations of land surface processes controlling carbon source/sink dynamics with increased (>11-fold) spatial resolution over current inputs from relatively coarse scale land surface models.