Derivation of Pan-Arctic Soil Decomposition, Heterotrophic Respiration and Net Ecosystem Carbon Exchange Using AMSR-E and MODIS Data

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Abstract

We have developed an approach for regional assessment and monitoring of land-atmosphere carbon dioxide (CO_2) exchange (NEE) and soil heterotrophic respiration (R_h) for boreal forest and arctic tundra biomes using synergistic satellite remote sensing information from MODIS and AMSR-E. We use C- and X- band brightness temperatures from AMSR-E to extract surface wetness and temperature, and MODIS land cover, Leaf Area Index (LAI) and Gross Primary Production (GPP) information to represent vegetation structure and productivity. Calibration and validation activities involve comparisons between satellite remote sensing data and boreal-arctic CO_2 eddy flux tower and biophysical measurement networks and hydro-ecological process model simulations. We analyze spatial and temporal anomalies and environmental drivers of NEE at daily, weekly and annual time steps. We find strong linear correspondence between AMSR-E surface emissivities and surface temperatures at 6.9 and 36.5 GHz horizontal and vertical polarizations. Preliminary results indicate that the 36.5 GHz channel yields better surface temperature performance, while 6.9 GHZ channel yields unambiguous identification of RFI. We integrated existing satellite–based measurements of vegetation structure (LAI) and productivity (GPP) from MODIS with AMSR-E derived land surface temperature and moisture fields within a simple physically based carbon algorithm to derive spatially explicit estimates of Rh and NEE for the pan-arctic basin and Alaska at daily, weekly and annual intervals. We compared satellite data derived NEE with site based measurements and BIOME-BGC process model simulations at boreal and Arctic CO_2 eddy-flux tower sites. These results show generally good agreement between satellite based results and site network measurements and ecosystem process model simulations of Rh and NEE spatial and temporal dynamics. While the satellite based results capture regional patterns in Rh and NEE, our ability to represent sub-grid scale surface heterogeneity is limited by the coarse (25-60km) spatial resolution of the AMSR-E footprint. Our results also indicate that carbon cycle response to climate change is non-linear and strongly coupled to arctic surface hydrology.

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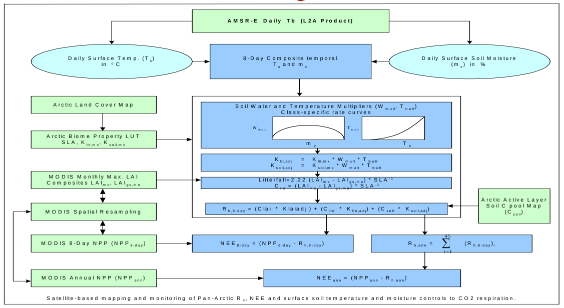
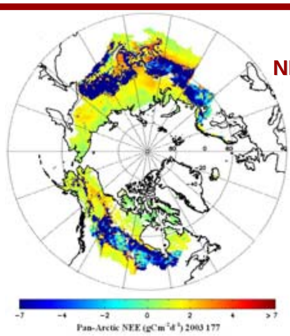
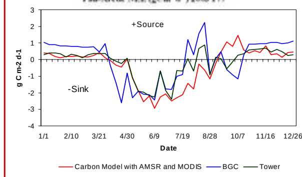
Model Logic



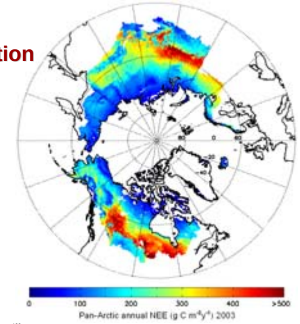
Synergistic information from MODIS and AMSR-E sensors offer the potential for regional mapping and monitoring of land-atmosphere net CO_2 exchange for the pan-Arctic. The diagram above illustrates an approach for remote sensing-based derivation of weekly and annual Rh and NEE. We exploit AMSR-E daily mapping capabilities and X- and C-band passive microwave sensitivity to surface moisture and temperature (1, 2) for quantifying the primary environmental controls to soil respiration within major boreal and 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 R_h. This information is combined with corresponding MODIS 8-day and annual GPP and NPP measurements to derive NEE at daily, weekly and annual time steps.

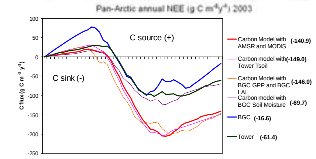
NEE Results and Validation





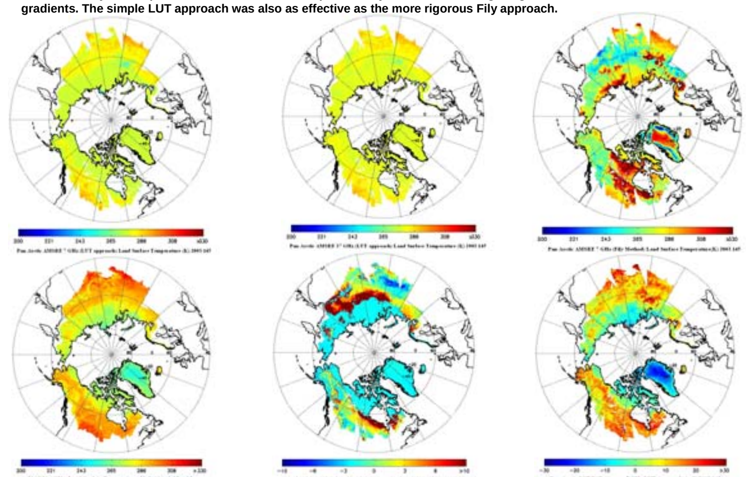
Daily surface moisture and temperature fields derived from AMSR-E are used with MODIS LAI and GPP information to compute R_h and NEE at 8-day and annual time steps. These results are evaluated using regional flux tower site data and site-based ecosystem process model (BIOME-BGC) simulations. The map on the left shows pan-Arctic daily NEE on June 26, 2003, while the map on the right shows the MODIS-AMSRE based annual NEE for 2003. The plot on the left shows the comparative seasonal NEE patterns from MODS-AMSRE results, tower CO2 measurement based calculations and BIOME-BGC model simulations using local meteorology at the NSA-OBS (NOBS) Ameriflux tower. The plot on the right shows the NOBS cumulative NEE pattern derived from these approaches over the 2003 period.



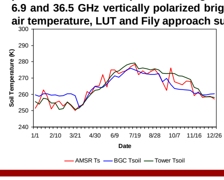


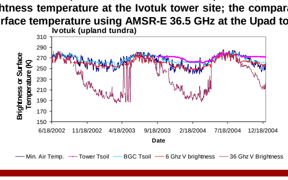
AMSRE Surface Temperature Derivation and Validation

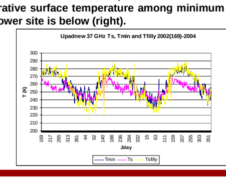
Land surface temperatures are derived using 2 approaches: a simple landcover based LUT and a more process oriented approach using H and V polarization microwave emissions (at 6.9 and 36.5 GHz bands Fily (5)). We also compare differences among these approaches and channels with the MODIS Aqua LST product, as shown below. Atmospheric effects, such as clouds and water vapor, and the effect of surface conditions (e.g., terrain, vegetation biomass, open water) on microwave emissivity vary depending on the channel characteristics. The AMSR-E 6.9 and 36.6 GHz channels were found to be sensitive to minimum daily air temperature and surface soil temperature dynamics across large vegetation biomass, thermal and moisture gradients. The simple LUT approach was also as effective as the more rigorous Fily approach.



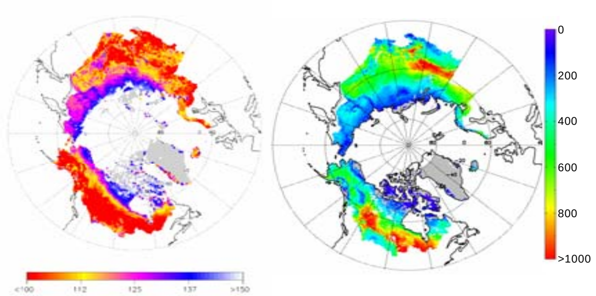
The plot below (left) shows the soil temperature comparison at the Barrow (Fily approach, AMSRE 6.9 GHz, 2003, 8-day average); the middle plot illustrates the comparison among minimum air temperature, tower site soil temperature, BIOME-BGC model soil temperature and AMSRE 6.9 and 36.5 GHz vertically polarized brightness temperature at the Ivotuk tower site; the comparative surface temperature among minimum air temperature, LUT and Fily approach surface temperature using AMSR-E 36.5 GHz at the Upad tower site is below (right).



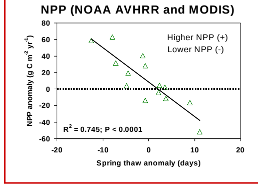


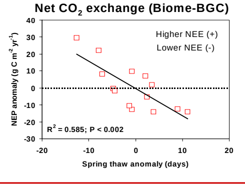


Cold Temperature Controls on Pan-Arctic Carbon Cycle



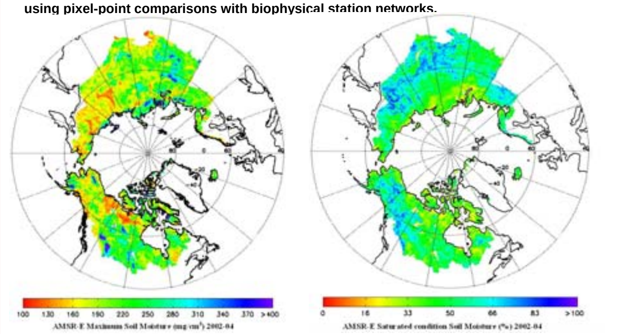
The figure above (left) shows the mean primary thaw day (day of year) for the pan-Arctic basin and Alaska as derived from SSM/I satellite data from 1988–2002 (3,4). The figure above (right) shows the 2003 MODIS production efficiency model- (MOD17 PEM) derived GPP($gCm^{-2}yr^{-1}$) for the domain. The graphs below show the close correspondence between the SSM/I-derived timing of spring thaw and annual C cycle anomalies (1988–2001) depicted by the NOAA AVHRR Pathfinder derived NPP (lower left) and regional ecosystem process model simulations of NEE (lower right) for the Alaska portion of the domain.

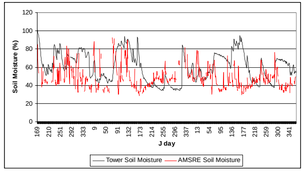


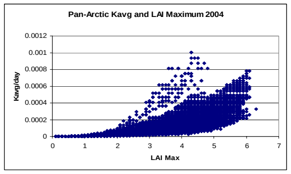


AMSR-E Surface Moisture and Soil Respiration Controls

The map below (left) shows maximum surface moisture during 2002–04, and the map below (right) shows mean saturated surface moisture during the same period for the pan-Arctic domain, as derived from AMSR-E L3 daily C- and X-band data (2). The plot below (right) shows the relationship between annual maximum LAI and the estimated average 2004 soil litter decomposition rate constant; this is used with AMSR-E temperature and moisture scalars to estimate soil respiration R_h. The plot below (left) shows comparative soil moisture at the Lethbridge tower site during 2002–04. Spatial heterogeneity in surface moisture can be much greater than seasonal variability posing a significant challenge for rigorous validation using pixel-point comparisons with biophysical station networks.







References

(1) Njoku, E.G., 1994. Surface temperature estimation over land using satellite microwave radiometry, pp. 509-530. IN: B.J. Choudhury, Y.H. Kerr, E.G. Njoku and P. Pampaloni (eds.) Passive Microwave Remote Sensing of Land-Atmosphere Interactions. VSP Publishers, Utrecht, The Netherlands.
(2) Njoku, E.G., T.J. Jackson, et al., 2003. Soil moisture retrieval from AMSR-E. *IEEE Transactions on Geoscience and Remote Sensing* (In press).
(3) McDonald, K.C., J.S. Kimball, E. Njoku, R. Zimmermann and M. Zhao, 2004. Variability in springtime thaw in the terrestrial high latitudes: Monitoring a major control on the biospheric assimilation of atmospheric CO2 with spaceborne microwave remtoe sensing. *Earth Interactions*, 8(20), 1-23.
(4) Kimball, J.S., K.C. McDonald and M. Zhao, 2005. Spring thaw and its effect on northern terrestrial vegetation productivity observed from satellite microwave and optical remote sensing. *Earth Interactions* (In-review).
(5) Fily, M, A Royer, K Goita, C Prigent. 2003. A simple retrieval method for land surface temperature and fraction of water surface determination from satellite microwave brightness temperatures in sub-arctic areas. *Remote Sensing of Environment* 85: 328-38.