SMAP L4 Carbon Product Development

[1]John Kimball, [2]Rolf Reichle,
[3]Kyle McDonald, [2]Peggy O'Neill

[1]The University of Montana, [2]NASA GSFC,
[3]NASA JPL, Cal-Tech

SMAP Algorithms & Cal/Val Workshop, June 9-11 2009

SMAP L4 Carbon Motivation, Objectives

Motivation (NRC Decadal Survey 2007):

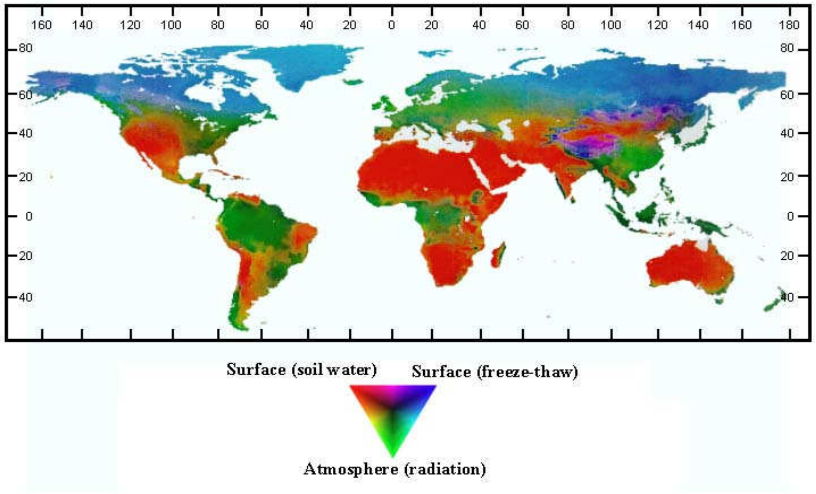
"*Soil moisture and its freeze-thaw state are key determinants of the global carbon cycle. Carbon uptake and release in boreal landscapes are a major source of uncertainty in assessing the carbon budget of the Earth system (the so-called missing carbon sink)* ".

"*A soil moisture mission will directly support science to reduce that major uncertainty*" (i.e. the missing carbon sink on land).

Science Objectives:

- Global, high-resolution mapping of soil moisture and its freeze/thaw state to:
  - *Link terrestrial water, energy and carbon cycle processes*
  - *Quantify net carbon flux in boreal landscapes*
  - *Reduce uncertainties about the "missing sink" for carbon (e.g. spatial pattern, seasonal-annual variability, sign/magnitude, biophysical controls).*

Soil Moisture and F/T state are primary environmental controls on boreal vegetation productivity and land-atmosphere CO_2 exchange



Source: Nemani et al. 2003. Science 300

L4_C Algorithm summary

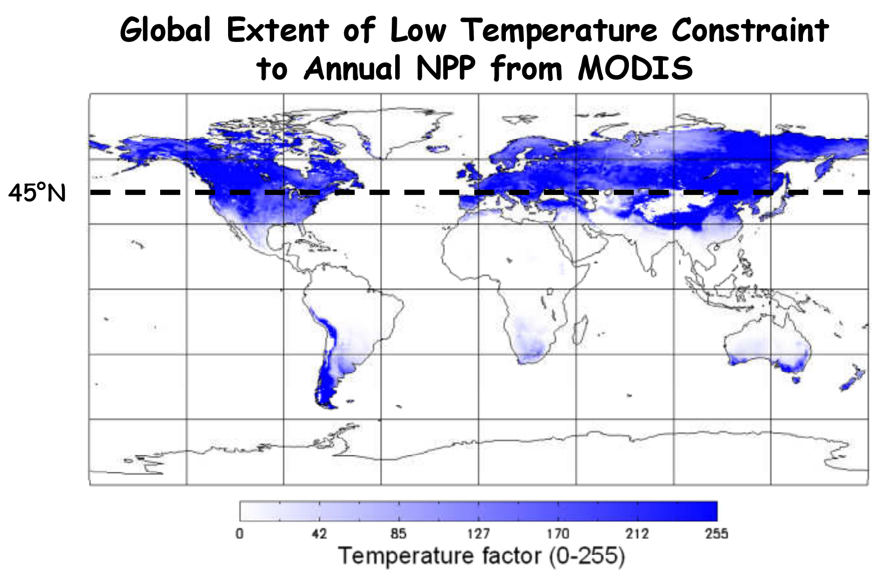
Baseline: Land-atmosphere CO_2 exchange

- **Motivation/Objectives**: Quantify net C flux in boreal landscapes; reduce uncertainty regarding missing C sink on land;
- **Approach**: Apply a soil decomposition algorithm driven by SMAP L4_SM and GPP inputs to compute land-atmosphere CO_2 exchange (NEE);
- **Inputs**: Daily surface (<5cm) soil moisture & T (L4_SM) & GPP (MODIS/NPP);
- **Outputs**: NEE (primary/validated); R_{eco} & SOC (research/optional);
- **Domain**: Vegetated areas encompassing boreal/arctic latitudes (≥45°N);
- **Resolution**: 10x10 km (9x9 km earth grid);
- **Temporal fidelity**: Daily ($g\ C\ m^{-2}\ d^{-1}$);
- **Latency**: Initial posting 12 months post-launch, followed by 14-day latency;
- **Accuracy**: Commensurate with tower based CO_2 Obs. (RMSE ≤ 30 $g\ C\ m^{-2}\ yr^{-1}$).

L4_C Product Domain

Land areas where low temperatures are a major constraint to land-atmosphere CO_2 exchange.

- All Vegetated land areas above 45°N latitude.
  - Encompasses boreal-arctic areas considered a major sink for global CO_2 emissions;
  - T is a primary constraint on ecosystem processes (GPP, R, NEE);
  - NEE is a dominant influence on northern atmospheric CO_2 variability;
  - Minimal effects of tropical biomass burning and fossil fuel emissions on CO_2 patterns;

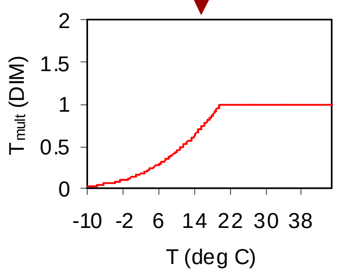


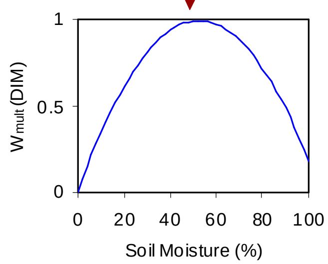
Prototype L4_C Algorithm

(SMAP L4_SM inputs)

F/T, [1]Surface T_{soil}

[1]Surface SM





T_{mult} Scalar Multipliers (DIM) W_{mult}

(Optical-IR RS inputs)

Land cover (BPLUT)

GPP

C_{fract}
CUE

$NPP = GPP * (1-CUE)$
$R_{aut} = GPP - NPP$

C Substrate Pools (kg C m^{-2})

$C_{met} = C_{fract} * NPP$
$C_{str} = (1-C_{fract}) * NPP$
$C_{rec} = 0.7 * C_{str}$

Decomp. Rates (d^{-1})

$K_{met} = (K_{mx} * T_{mult} * W_{mult})$
$K_{str} = 0.4 * K_{met}$
$K_{rec} = 0.01 * K_{met}$

Flux Calc. (kg C m^{-2}):

$R_h = (K_{met} * C_{met} + K_{str} + C_{str} + K_{rec} * C_{rec})$

$SOC = (C_{met} + C_{str} + C_{rec}) - R_h$

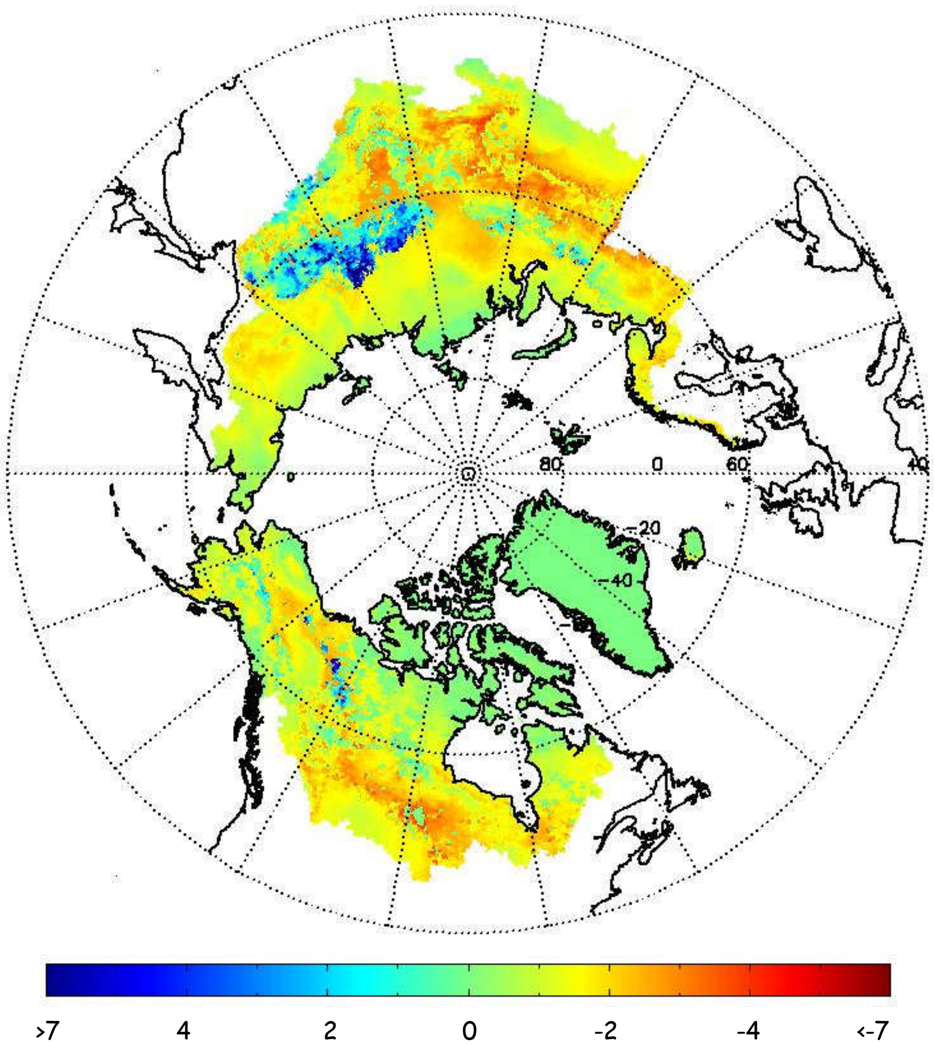
$NEE = (R_h + R_{aut}) – GPP$

[1] <5cm depth
Source: Kimball et al. 09. *TGARS* 47(2).

Primary Output: NEE (g C m^{-2} d^{-1}); Optional: SOC (≤5cm depth, kg C m^{-2}); R_{eco} (g C m^{-2} d^{-1})

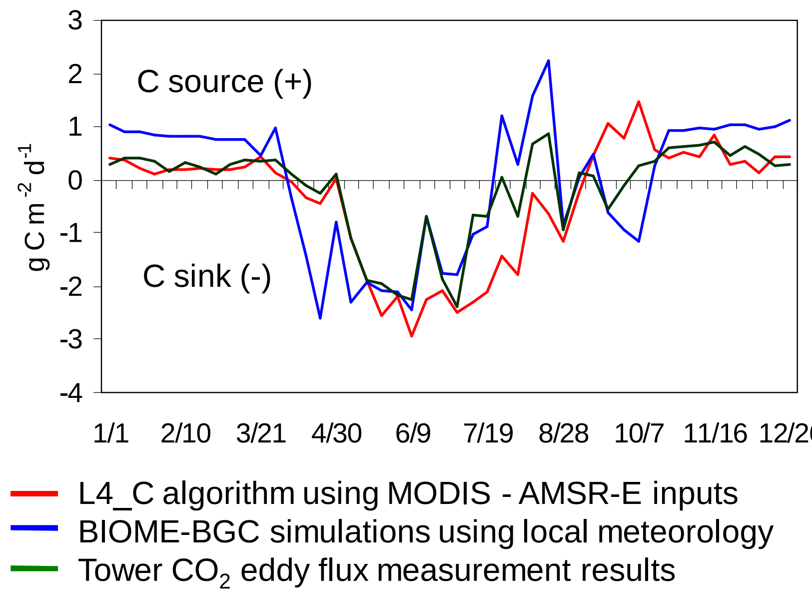
Prototype L4_C Product Example

Mean Daily net CO_2 Exchange (NEE)



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

NEE for NSA-OBS Ameriflux Site

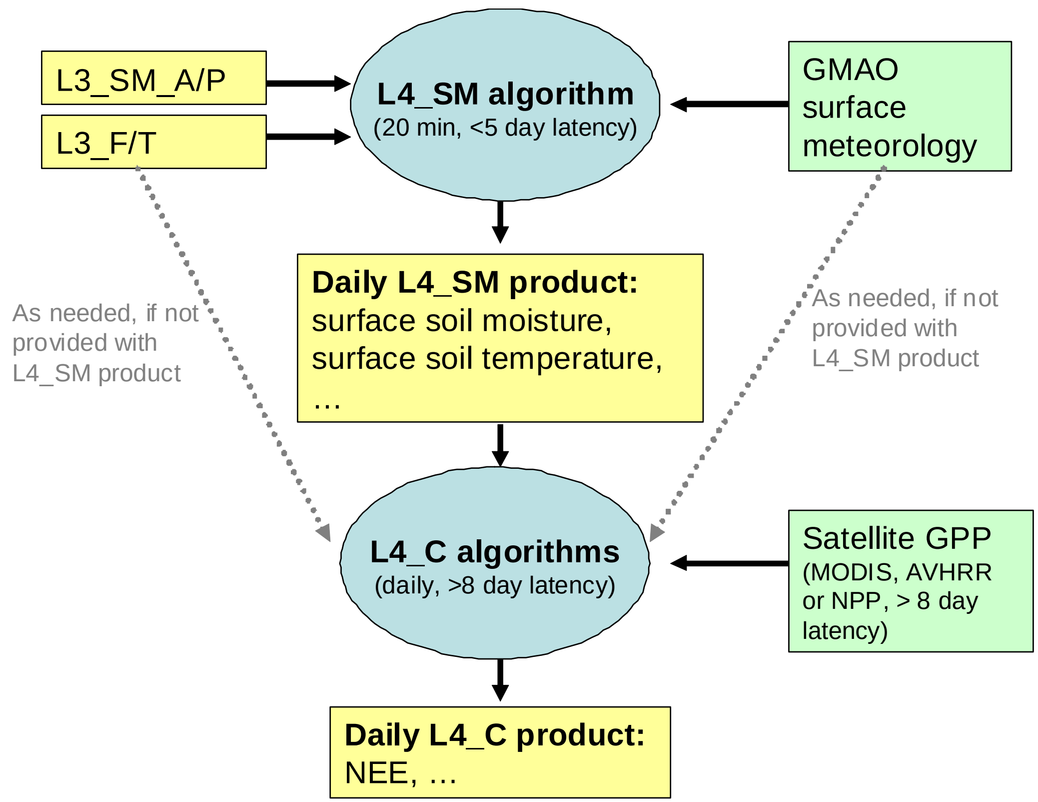


Pan-arctic NEE (**left**) produced using L4_C algorithms with MODIS GPP (MOD17) & AMSR-E (6.9GHz) SM and T inputs. The graph (**above**) shows the 2004 seasonal pattern of daily NEE for a mature boreal conifer stand as depicted by the L4_C algorithm, BIOME-BGC model and tower CO_2 flux measurements. *SMAP L4_C resolution/sampling will allow characterization of surface processes commensurate with the measurement footprint & accuracy of tower flux measurements: ~10km spatial resolution, daily temporal fidelity, NEE ≤ 30 g C m^{-2} yr^{-1} RMSE.*

L4_C Implementation Options

Options:

- Compute NEE using SMAP (L3_SM_A/P, L3_F/T), [1]GMAO (T) and MODIS GPP inputs directly;
- Compute NEE using L4_SM (T, SM) and satellite based GPP inputs;
- Implement enhanced GPP using model assimilation of MODIS GPP.
- Include L4_C intermediate variables as additional products (SOC, R components).



[1]NASA Global Modeling and Assimilation Office

Ancillary data needs

Static:

- Land cover classification (minimum 5-classes distinguishing major boreal/arctic biomes);

- Mask (ID land-ocean boundaries, open water bodies & areas where L4_C accuracy requirements can be met);

Dynamic:

- Surface (≤5cm depth) soil moisture (daily); Source: L4_SM;

- Surface soil temperature (daily); Source: L4_SM;

- GPP (8-16 day; g C m^{-2} d^{-1}); Optional sources: MODIS (MOD17), AVHRR, NPP/NPOESS; model assimilation.

SMAP L4_C Error Budget

Estimated uncertainty (RMSE) for SMAP L4_C based NEE

Type of Error	Error Source	Source Units	Range	Value	NEE Contribution ($g\ C\ m^{-2}\ y^{-1}$)
Input Data	Temperature	°C	1.5-4	3.5	2.1
	Moisture	vol. $cm^3\ cm^{-3}$	0.04-0.10	0.05	1.9
	GPP	$g\ C\ m^{-2}\ d^{-1}$	1.0-2.0	1.5	4.4
Model Parameterization	Optimal Decomp. Rates/Response Curves	d^{-1}	0.001-0.01	0.0015	0.2
	Pool Representation/Steady State	$g\ m^{-2}$	100-1000	500	12.0
	Autotrophic Respiration fraction	dim.	0.05-0.15	0.1	1.5
Heterogeniety	Land Cover Heterogeniety (Soil Respiration)	$g\ C\ m^{-2}\ yr^{-1}$	10-95	95	25.0
Total NEE Error	Inputs Only	$g\ C\ m^{-2}\ yr^{-1}$			5.2
	Model Only	$g\ C\ m^{-2}\ yr^{-1}$			12.1
	Inputs + Model	$g\ C\ m^{-2}\ yr^{-1}$			13.2
	Inputs + Model + Het.	$g\ C\ m^{-2}\ yr^{-1}$			28.7

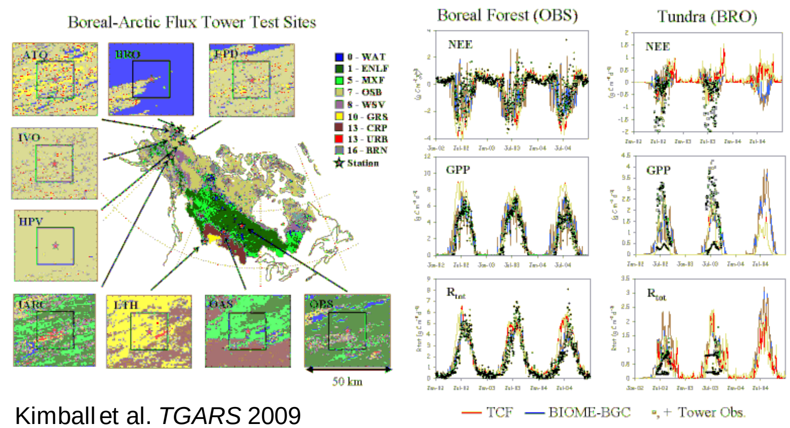
Target accuracy: NEE RMSE ≤30 $g\ C\ m^{-2}\ yr^{-1}$

Planned L4_C calibration and validation

Pre-launch:

- Assess accuracy of SM & T inputs (from L4_SM product) over L4_C northern (≥ 45°N) domain;
- Algorithm sensitivity studies using available GPP (MODIS, model assimilation), SM & T (GMAO, AMSR-E, SMOS, PALSAR) inputs;
- Initialization/calibration/optimization of L4_C algorithm parameters (e.g. BPLUT, SOC pools);

L4_C Test using MODIS & AMSR-E Inputs

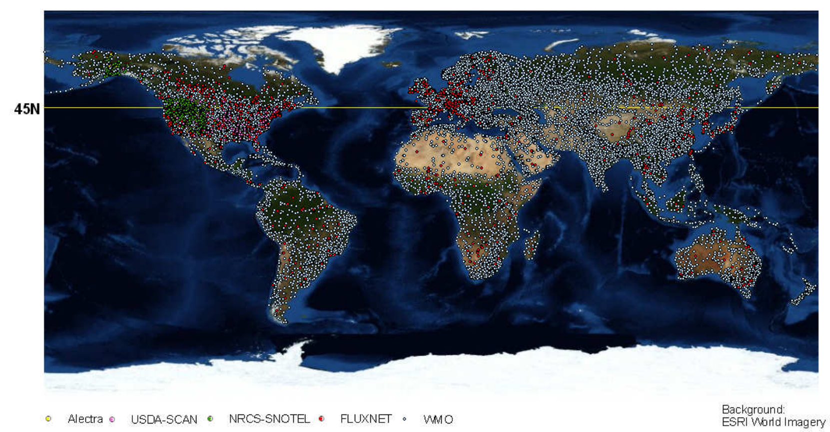


Kimball et al. *TGARS* 2009

Post-launch:

- Verify SMAP L4_C NEE accuracy using CO_2 data from northern FLUXNET sites;
- Model assimilation studies through GMAO-LIS & application community (NASA-TOPS, NOAA-CarbonTracker);

Global Biophysical Station Networks



Calibration of L4_C parameters using FLUXNET

- Baseline L4_C algorithm parameterized for general biomes and assumptions of dynamic equilibrium between GPP and R under average climate conditions*, but succession and disturbance can push ecosystem from steady-state;*

- Parameterization error contributes ~30% of total L4_C uncertainty;

- *CO_2 measurements from global observation networks (FLUXNET) can be used for model calibration and to account for non steady-state conditions;*

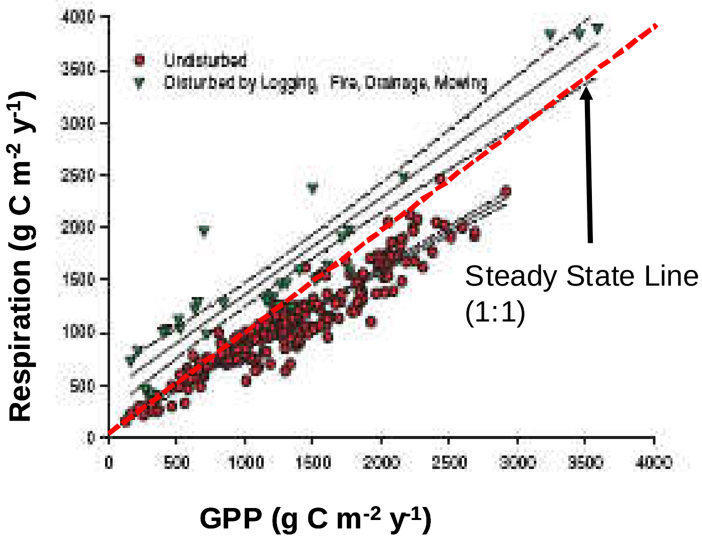
- *Without model-tower calibration, baseline L4_C algorithm is still within targeted accuracy requirements (≤30 g C m^{-2} yr^{-1}).*

Table 2. General Biome Properties Look-up Table (BPLUT) describing ecophysiological parameters for L4_C model calculations.

[A]Land cover	[B]C_{fract} (DIM)	[C]CUE (DIM)	[C]R_a:GPP (DIM)
Tundra (OSB)	0.72	0.54	0.46
Evergreen forest	0.49	0.54	0.46
Mixed Forest	0.59	0.54	0.46
Grassland	0.76	0.6	0.6

[A] MODIS IGBP global land cover classification (Friedl et al. 2002) for dominant boreal/tundra vegetation classes: Tundra or open shrubland (OSB); Grassland; Evergreen needleleaf coniferous forest; Mixed broadleaf deciduous and evergreen needleleaf coniferous forest types;
[B] Proportional NPP allocation to metabolic and structural (1-C_{fract}) SOC pools from Potter et al. (1993) and Ise and Moorcroft (2006);
[C] Carbon Use Efficiencies (NPP:GPP) and corresponding R_a:GPP ratios for representative boreal and grassland ecosystems from Gifford et al. (2003).

[1]Succession/Disturbance Effects on Tower CO_2 Fluxes



[1] Baldocchi, 2008. *Australian J. Bot*.

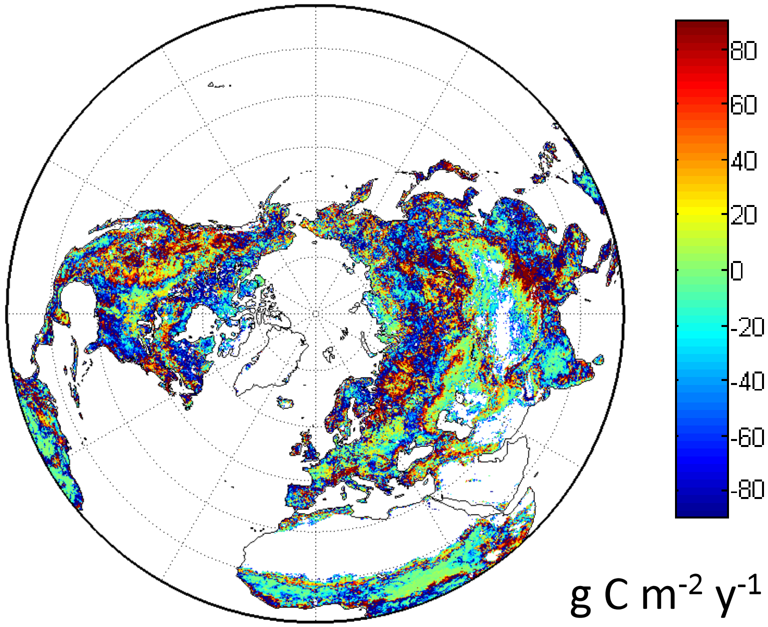
Heterogeneity contribution to L4_C uncertainty

- Land cover (LC) heterogeneity contributes more than half of total L4_C uncertainty.

- *Significant (up to ~50%) error reduction could be achieved by implementing L4_C algorithms at finer spatial scale (e.g. up to 1-km based on LC, L3_F/T and MODIS GPP inputs).*

- *Baseline 10-km L4_C algorithm resolution still within targeted accuracy requirements (≤30 g C m^{-2} yr^{-1}).*

LC Weighted – LC Dominant R flux



Land Cover (MODIS) Heterogeneity Contribution to NEE (RMSE)

Dom. LC > (%)	Area (%)	Value (RMSE) (g C m^{-2} y^{-1})	NEE Contrib. (g C m^{-2} y^{-1})	NEE total (g C m^{-2} y^{-1})
30	96.7	95	25	28.7
50	66.9	69	19	22.3
70	34.7	41	11	17.2
90	12.3	17	4.6	13.9

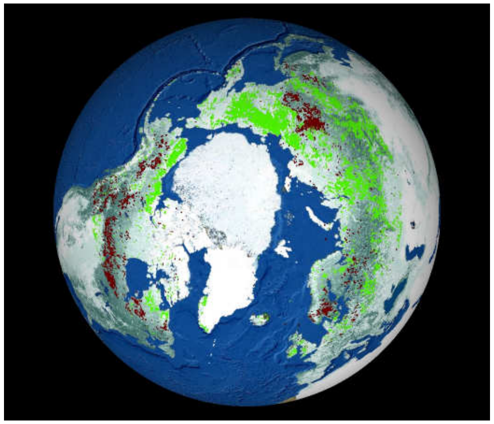
Potential Applications of L4_C Results

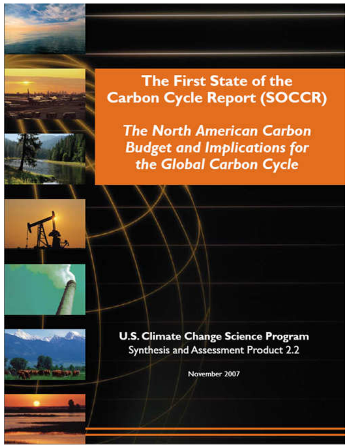
Climate Change:
Monitoring of patterns, variations & anomalies in CO_2 source/sink activity; vegetation, moisture & temperature effects on carbon uptake and release.

Forestry and Agriculture:
Carbon sequestration assessment and monitoring; net productivity; drought impacts, disturbance & recovery; Spatial-temporal extrapolation of in situ observations.

Environmental Policy:
Regional carbon budgets; carbon accounting and vulnerability assessments.

SMAP ApWG: http://smap.jpl.nasa.gov/science/applicWG/



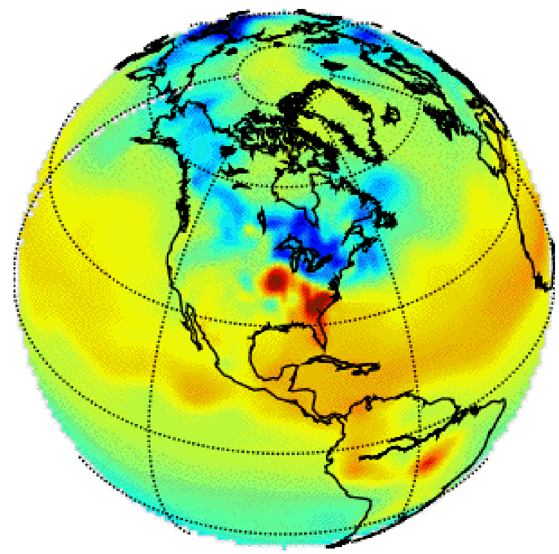


Observations to Applications: Quantify Carbon source-sink activity in Boreal Landscapes

Post-launch: L4_C model assimilation to quantify boreal C source-sink activity

- Apply L4_C products within carbon data assimilation system for tracking global CO_2 exchange and net C source/sink activity;
- Atmospheric perspective based on atmospheric transport model (TM3) constrained by satellite remote sensing and sparse surface observations;
- Accounts for fossil-fuel and fire related CO_2 emissions;
- Currently uses 1-degree CASA land model to define land-atmosphere C exchange (NEE);
- Provides means to quantify boreal Carbon source/sink activity (SMAP Decadal Survey objective);

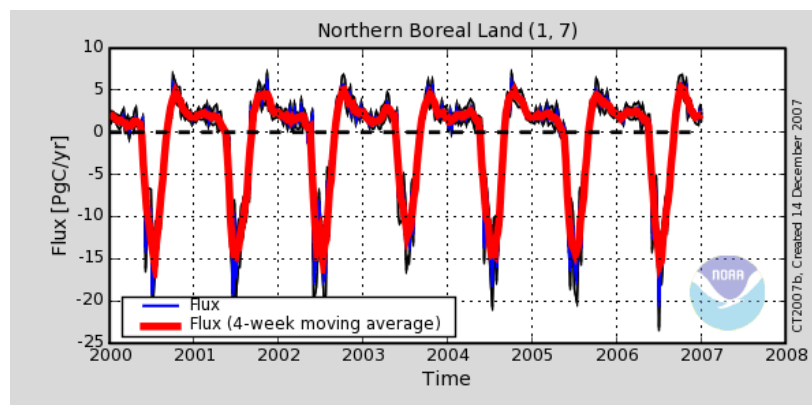
NOAA CarbonTracker



Annual C balance

Results Summary (all units PgC/yr)

Year	First Guess	Estimate	Fire Emission	Fossil Emission	Total Flux
2000	-0.30 ± 1.67	-1.37 ± 1.35	0.15	0.11	-1.11 ± 1.35
2001	-0.25 ± 1.67	-1.18 ± 1.33	0.11	0.11	-0.96 ± 1.33
2002	-0.24 ± 1.80	-1.25 ± 1.38	0.25	0.11	-0.89 ± 1.38
2003	0.02 ± 1.61	-0.86 ± 1.25	0.38	0.11	-0.37 ± 1.25
2004	0.01 ± 1.69	-1.07 ± 1.32	0.15	0.12	-0.80 ± 1.32
2005	-0.03 ± 1.57	-1.12 ± 1.25	0.11	0.12	-0.89 ± 1.25
2006	-0.16 ± 1.72	-0.98 ± 1.21	0.14	0.12	-0.71 ± 1.21



http://www.esrl.noaa.gov/gmd/ccgg/carbontracker/index.html

Issues

Planning for SMAP field campaigns to address L4_C issues:

- Focus on Northern (>45°N) land areas;
- Resource availability, including field, airborne, satellite and model components;
- Objectives (SM & T scaling properties; L4_SM accuracy; LC/terrain/open water heterogeneity & biomass effects on L4_SM & L4_C uncertainty);
- Canadian (CSA led) participation;
- Coordination with other missions (DESDynI, SMOS) and field campaigns (VuRSAL).

Pre-launch data assembly for L4_C development, testing & evaluation:

- L4_C inputs: SM & T (GMAO-LIS), GPP (MODIS), Ancillary (e.g. LC, mask definition to define areas where accuracy reqs. can be met);
- In situ biophysical & surface meteorology data (e.g. FLUXNET, WMO)
- Algorithm test-bed software and database development at JPL

Implementation options for L4_C algorithms:

- Continuity of EOS Terra/Aqua MODIS MOD17 GPP vs alternative sources (NPP, AVHRR, model assimilation);

Spatial resolution and gridding:

- Finer spatial scale implementation to improve L4_C accuracy;
- Consistent projections for SMAP products & ancillary data (e.g. polar vs global; projection options: EASE-grid, etc..).

Next steps and timeline

Pre-launch L4_C algorithm development (2009-13):

- Draft L4_C ATBD development (Jan 09);
- ATBD external review (May/Jun 09);
- Final ATBD describing L4_C algorithms; (early 2010)
- L4_C sensitivity and Cal/Val studies;
- Production & operational implementation of L4_C science code;
- Initialization of L4_C algorithms;

Post-launch L4_C implementation and operations (2013-2015):

- Re-initialization, calibration and refinement of algorithms using SMAP inputs;
- Validation/documentation of L4_SM inputs to L4_C algorithms for northern (≥45°N) test sites;
- Operational production of L4_SM and L4_C products;
- Validation/documentation of L4_C accuracy in relation to mission requirements;
- Refinement and reanalysis of L4_C product stream;