SMAP CalVal Workshop

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Summary of L4 Product Cal/Val Requirements

R. Reichle NASA/GSFC*
*J. Kimball** Univ. of MT*

** Email: Rolf.Reichle@nasa.gov Phone: 301-614-5693*
*** Email: johnk@flbs.umt.edu Phone: 406-982-3301 x230*

SMAP Level 4 soil moisture and carbon products

L4_SM Product:

Assimilating SMAP data into a land model driven with observation-based forcings yields:

– a root zone moisture product (reflecting SMAP data), and

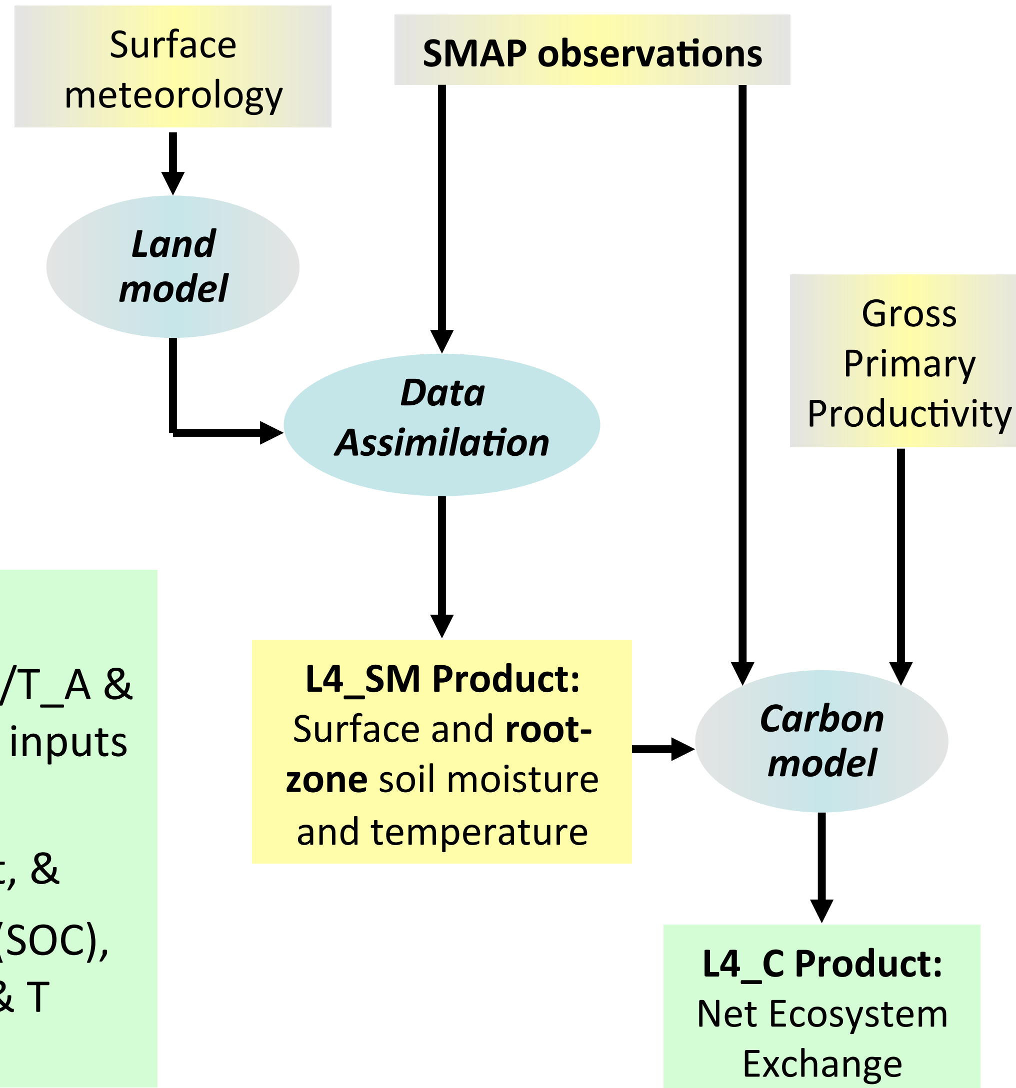
– a complete and consistent estimate of soil moisture & related fields.

L4_C Product:

Combining L4_SM (SM & T), high-res L3_F/T_A & ancillary Gross Primary Productivity (GPP) inputs within a C-model framework yields:

- a Net Ecosystem Exchange (NEE) product, &

- estimates of surface soil organic carbon (SOC), component C fluxes (R) & underlying SM & T controls.



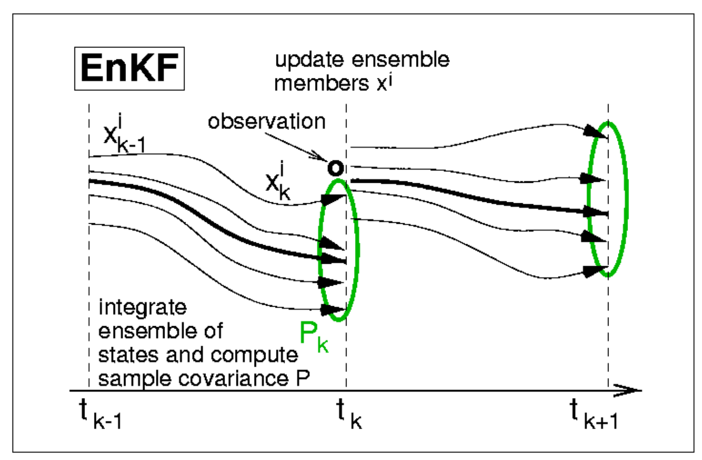
L4_SM baseline and option algorithms

Main objectives:

- Provide estimates of ***root zone*** soil moisture (top 1 m) based on SMAP obs.
- Provide ***global, 3-hourly, 9 km*** surface and root zone soil moisture.

Baseline algorithm:

- Customized version of existing NASA/GEOS-5 Land Data Assimilation System
  – 3d ensemble Kalman filter
  – Catchment land surface model



L4_SM inputs and outputs

SMAP inputs

Brightness temperature
(L1C_TB, 36 km)
Radar soil moisture
(L2_SM_A, 3 km)
Freeze-thaw state
(L3_F/T_A, 3 km)

L4_SM algorithm

Ancillary data inputs

Land model parameters

Surface meteorology (incl. observation-corrected precip)

Land assimilation parameters

L4_SM product

9 km, 3-hourly global output with 7-day latency

- **Surface soil moisture (≡ top 5 cm)**
- **Root zone soil moisture (≡ top 1 m)**

In units of m^3m^{-3} and percentiles

- **Research output**
  - surface and soil temperatures (**input to L4_C**)
  - sensible, latent, and ground heat flux
  - runoff, baseflow, snowmelt
  - surface meteorological forcings (air temperature, precipitation, …)
  - **error estimates** (generated by assimilation system)

L4_SM cal/val

Pre-launch

– Use L4_SM system with SMOS obs (also AMSR-E, Aquarius, …)

– Apply cal/val to the extent possible.

– Conduct OSSE's (calibration of assimilation parameters).

L4_SM cal/val

Post-launch

Calibration within 1st year:

Bias correction param's ("cdf matching"), assimilation param's (thru innovations).

Validation with in situ observations:

Surface soil moisture:

Apply L2_SM_A/P cal/val procedures.

Root-zone soil moisture:

In principle, cal/val is identical to surface soil moisture, but

- have fewer in situ obs. (e.g. from USDA/SCAN, NCDC/CRN)
- rarely/never have multiple in situ obs. within single grid cell

Requirement: Need as many **root-zone** soil moisture obs. as possible.

L4_SM cal/val

Post-launch

Additional evaluation:

– Examine “obs-minus-model” residuals for internal consistency of the L4_SM algorithm (Reichle et al. 2008; Crow and Reichle 2008).

– Evaluate with high-quality, independent precipitation obs (Crow 2007).

– Evaluate research product components (e.g. fluxes) to the extent possible.

SMAP L4_SM validation approach

Methodology	Data	Importance	Metric
Core Sites	Observed grid cell average values (time-continuous)	Primary	Anomaly correlation, *RMSE, bias*
Sparse Networks	Observed values (time-continuous)	Primary	Anomaly correlation
Satellite Products	Orbit-based match-ups (SMOS, ASCAT, …)	Secondary: Pending continued operation	Anomaly correlation, *RMSE, bias*
Model Products	Global modeling and assimilation systems (ECMWF, NCEP, …)	Primary	Anom. correlation, assim. diagnostics, *RMSE, bias*
Field Experiments	Detailed estimates for a very limited set of conditions	Secondary	Anomaly correlation, *RMSE, bias*

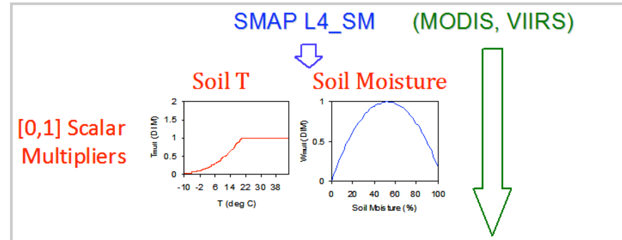
Synergies with L4_SM development: Cal/val based on land modeling and assimilation

- ***Algorithm Testbed***
    - GMAO Nature Run
- ***Supplemental and complementary*** validation approaches:
    - Include:
        - Triple collocation (L2_SM)
        - Consistency of assim. increments with independent precipitation obs. (L2_SM, L4_SM)
        - Consistency of assim. system diagnostics (e.g., statistics of "obs.-minus-forecast" residuals) (L4_SM)
    - Enable scaling from point-scale obs. to satellite-scale estimate
    - Are independent of scheduling risk associated with field campaigns

L4_C baseline algorithm

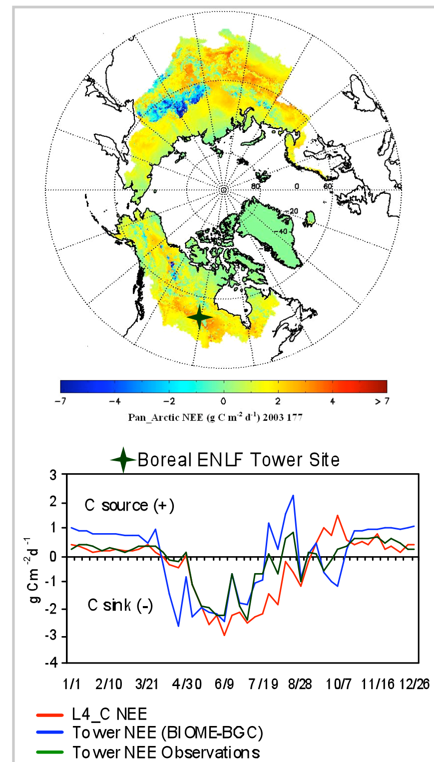
Product: Net Ecosystem CO_2 exchange (NEE = GPP – R_{eco})

- **Motivation/Objectives**: Quantify net C flux in boreal landscapes; reduce uncertainty regarding missing C sink on land (NRC Decadal Survey);
- **Approach**: Apply a soil decomposition model driven by SMAP L4_SM & ancillary (LC, GPP) inputs to compute NEE;
- **Inputs**: Daily surface (<10cm) SM & T (L4_SM), LC & GPP (MODIS, VIIRS);
- **Outputs**: NEE (primary/validated); R_{eco} & SOC (research);
- **Domain**: Vegetated areas encompassing boreal/arctic latitudes (≥45 N);
- **Resolution**: 9x9 km;
- **Temporal fidelity**: Daily (g C m^{-2} d^{-1});
- **Latency**: 14-day;
- **Accuracy**: Commensurate with tower based CO_2 Obs. (RMSE ≤ 30 g C m^{-2} yr^{-1} and 1.6 g C m^{-2} d^{-1}).



$$NEE = k_{opt} * Temp * Moist * \hat{C} - GPP * (1 - f_{aut})$$

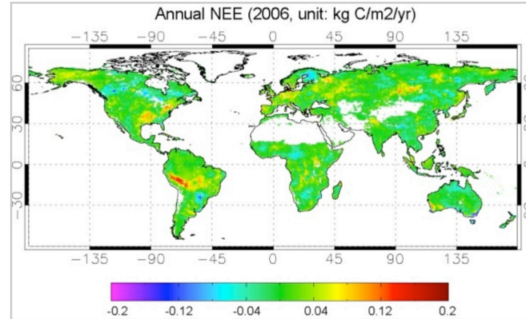
$$\hat{C} = \sum_{i=0}^{3} k_i C_i \quad [\text{g C m}^{-2}]$$

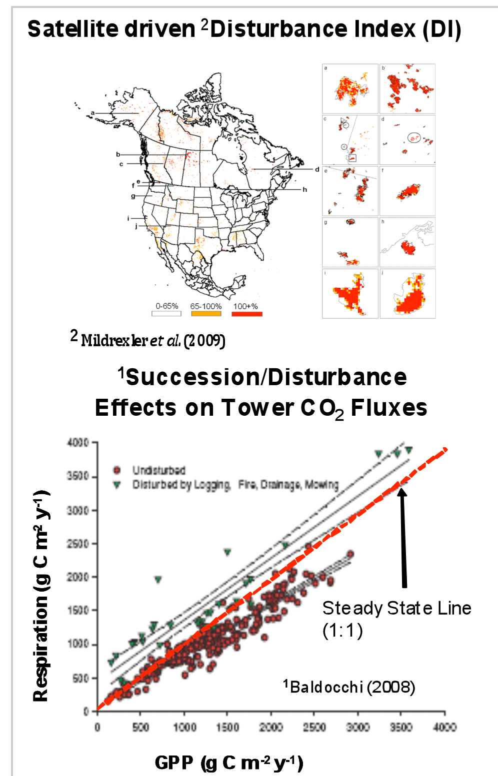


L4_C algorithm options

Several L4_C options are being evaluated based on recommendations from an earlier ATBD peer-review; options designed to enhance product accuracy & utility include:

- Global domain encompassing all vegetated land areas;
- Internal GPP calculations using SMAP L4_SM, L3_FT & ancillary land cover (LC) & VI (e.g. NDVI from MODIS, VIIRS) inputs;
- Represent finer scale (<9km) spatial heterogeneity consistent with available LC inputs;
- Explicit representation of LC disturbance (fire) and recovery impacts;
- Algorithm calibration using available observation data (FLUXNET, soil inventories).





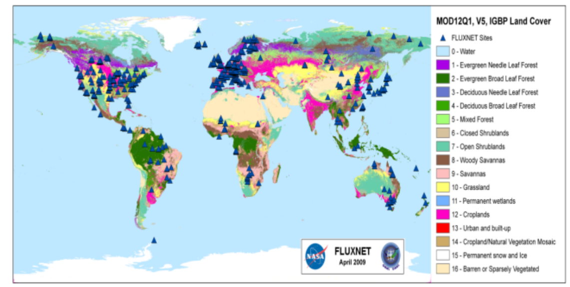
L4_C cal/val

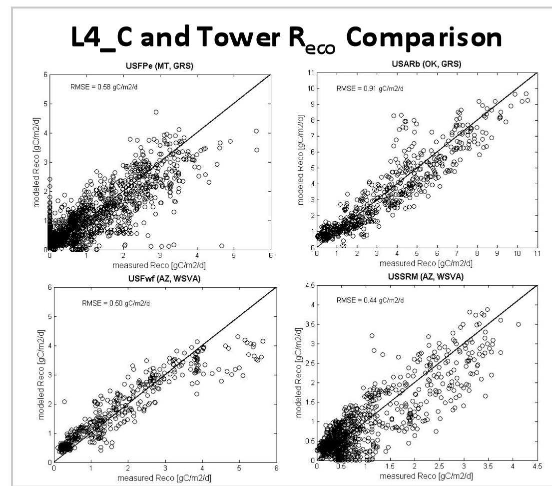
Pre-launch:

- L4_C development & testing using available inputs: LC, NDVI, GPP (MODIS); SM & T (MERRA); FT (SSM/I, AMSR-E, SMOS);
- Calibration/optimization and initialization of L4_C algorithm parameters (e.g. BPLUT, SOC pools, disturbance history);

Post-launch:

- Re-calibration & re-initialization of L4_C parameters using SMAP L4_SM inputs;
- Verify SMAP L4_C NEE accuracy:
  - Tower site comparisons using CO_2 Obs; stand-level C-model simulations & sensitivity studies;
  - Comparisons with available soil inventories;
  - Field campaigns using nested in situ, airborne (CARVE, AirMOSS) & satellite data;
  - Atm. model inversions of L4_C outputs & comparisions of resulting C source/sink activity against available observations (CO_2 flask network, GOSAT, OCO-2).





SMAP L4_C validation approach

Methodology	Data	Importance	Metric
Core Sites	Observed grid cell average values (time-continuous)	Primary	Correlations, *RMSE, bias*
Sparse Networks	Observed values (time-continuous)	Primary	Correlations, RMSE, bias
Satellite Products	Orbit-based match-ups (SMOS, PALSAR, …)	Secondary	Anomaly correlation, *RMSE, bias*
Model Products	Site & Global modeling systems, model inversions (Carbontracker)	Primary	Sensitivity diagnostics, correlation, *RMSE, bias*
Field Experiments	Detailed estimates for a very limited set of conditions	Secondary	correlations, *RMSE, bias*

Optimal L4_C validation site design

- **Characterize major biomes within northern land areas (baseline)**
  - Boreal ENLF, tundra, grassland, mixed forest (DBLF, ENLF), & DNLF types;
  - Disturbance history & stand succession impacts;

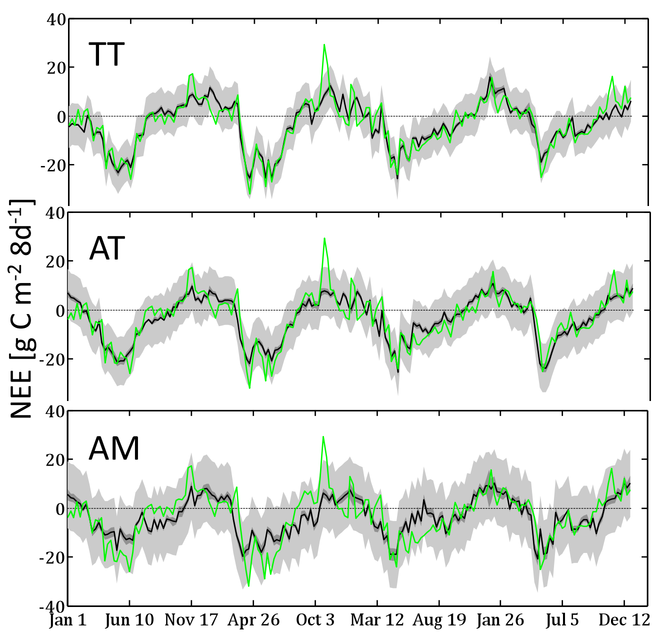
- **Representative conditions within regional (~10x10 km) window**
  - Select sites with relatively homogeneous land cover & terrain conditions;
  - Continuous measurements to characterize daily variability & cumulative annual C fluxes;

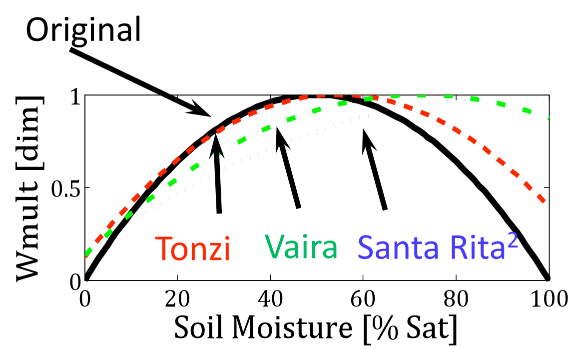
- **Documented uncertainty (systematic & random error) in C flux measurements**
  - Established and well defined protocols for correction & gap filling to establish complete annual C flux time series;
  - Multi-year time series to establish average conditions & year-to-year variability;

- **Coincident measurements of surface meteorology, H_20 & CO_2 fluxes**
  - Enable analysis of water, energy & carbon cycle linkages;
  - Measurements of component C fluxes (GPP, R_{eco}, NEE) & environmental controls (SM and soil T, surface SOC).

L4_C Cal/Val using Tower Site Data

Woody Savannah (Tonzi Ranch, CA[1])



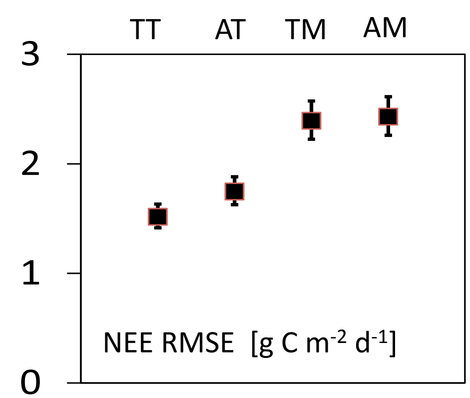


TT : Tower Met. + Tower GPP

AT : AMSR-E Met. + Tower GPP

TM: Tower Met. + MODIS GPP

AM: AMSR-E Met. + MODIS GPP



Tower CO_2 flux data (FLUXNET) is used for L4_C calibration & validation (e.g. **left**). Baseline model performance is evaluated for expected accuracy (NEE RMSE<30 g C m^{-2} yr^{-1} or 1.6 g C m^{-2} d^{-1}). A Markov Chain Monte Carlo (MCMC) optimization is applied to minimize an objective function by adjusting biome-specific model parameters to representative tower data, including calibrating soil moisture response curves (**center**) for better accuracy. Uncalibrated model runs (**right**) using alternative remote sensing & tower inputs are also used to clarify error propagation & uncertainty sources. Available FLUXNET data includes >400 site year measurements & represent most global biome types.

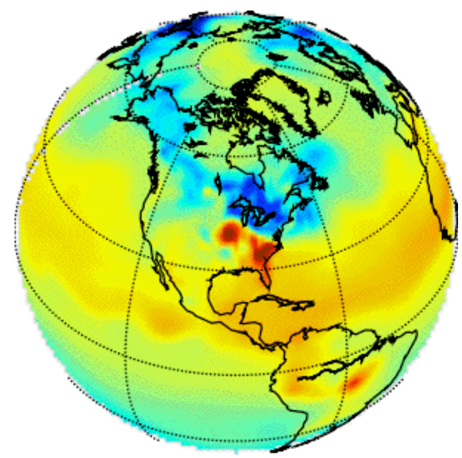
[1]D. Baldocchi is PI of Tonzi and Vaira FLUXNET tower sites; [2]R. Scott is PI of Santa Rita Site

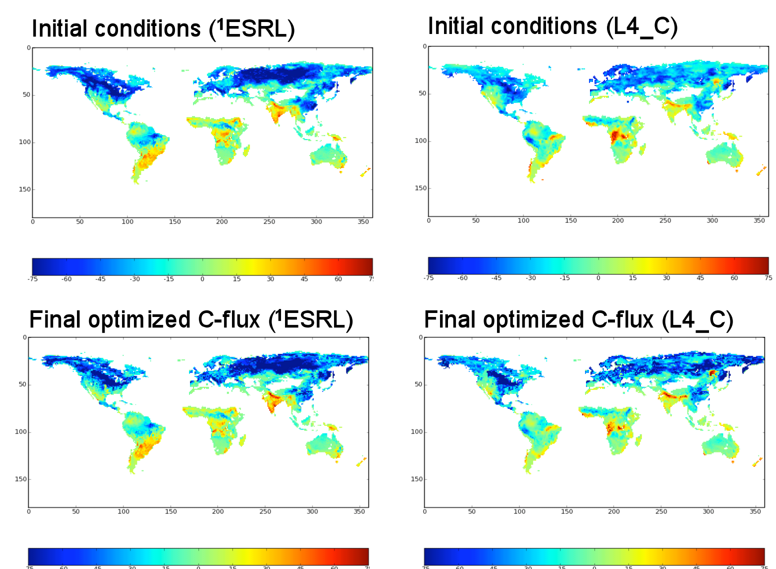
SMAP Science Objective: Quantify C source-sink activity

<u>Post-launch</u>: L4_C model assimilation to quantify net CO_2 source-sink activity

- Apply L4_C products within carbon data assimilation system for tracking net CO_2 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;
- L4_C based NEE provides land surface initial conditions;
- Provides for rigorous validation using synergistic C observations (CO_2 flask network, GOSAT, OCO-2);
- Provides means to quantify C source/sink activity (SMAP Decadal Survey objective);

[1]NOAA CarbonTracker





[1]http://www.esrl.noaa.gov/gmd/ccgg/carbontracker2