National Aeronautics and Space Administration

NASA Carbon Monitoring System

NASA Carbon Monitoring System Overview

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http://carbon.nasa.gov

nasa.carbon

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Congressional Direction (Summary)

Congressional Direction in 2010:

Also included within the funds provided for other mission and data analysis, the conference agreement provides $6,000,000 for pre-phase A and pilot initiatives for the development of a carbon monitoring system. Any pilot developed shall replicate state and national carbon and bio…

…"pilot initiatives for the development of a carbon monitoring system…"

…"replicate state and national carbon and biomass inventory processes that provide statistical precision and accuracy with geospatially explicit associated attribute data…"

…"development of a prototype Monitoring Reporting and Verification (MRV) system which can provide transparent data products achieving levels of precision and accuracy required by current carbon trading protocols…."

…"[development of] a plan…incorporating such a [MRV] system into its operating plan and long-term budget projection…"

sampling, quantification, and development of a prototype Monitoring Reporting and Verification [MRV] system which can provide transparent data products achieving levels of precision and accuracy required by current carbon trading protocols. The Committee is concerned that NASA has not established a program of record around the development of MRV system, and therefore expects a plan from NASA not later than 90 days after enactment of this act incorporating such a system into its operating plan and long-term budget projection. The Committee recognizes that the current orbital and suborbital platforms are insufficient to meet these objectives. Therefore, the use of commercial off-the-shelf technologies is recommended as these products could provide robust calibration validation datasets for future NASA missions.

NASA-CMS Phase 1

Biomass Pilot. *The goals of the Biomass Pilot are to:*

- Utilize satellite and in situ data to produce quantitative estimates (and uncertainties) of aboveground terrestrial vegetation biomass on a national and local scale.
- Assess the ability of these results to meet the nations need for monitoring carbon storage/sequestration.

Flux Pilot. *The objectives of the Flux Pilot are to:*

- Combine satellite data with modeled atmospheric transport initiated by observationally-constrained terrestrial and oceanic models to tie the atmospheric observations to surface exchange processes.
- Estimate the atmosphere-biosphere CO_2 exchange.

Scoping Efforts. *The objectives of the Scoping Efforts are to:*

- Identify research, products, and analysis system evolutions required to support carbon policy and management as global observing capability increases.

CMS Award year: # of projects (decision support - MRV)

2012: 20
2013: 17
2014: 15
2015: 15
2016: 14

Global Surface-Atmosphere Flux

2012: 2
2014: 3 (2)
2015: 1 (1)
2016: 2

Land-Atmosphere Flux

2012: 6 (5)
2013: 8 (6)
2014: 2 (2)
2015: 10 (10)
2016: 8 (4)

Ocean-Atmosphere Flux

2012: 1
2016: 1

Ocean Biomass

2012: 3
2016: 1

Land-Ocean Flux

2012: 1
2014: 1 (1)

Land Biomass

2012: 7 (5)
2013: 9 (9)
2014: 9 (7)
2015: 8 (8)
2016: 7 (5)

Award Year and Themes Addressed

Year	Land Biomass	Ocean Biomass	Land-Atmos Flux	Ocean-Atmos Flux	Land-Ocean Flux	Global Flux	Decision Support	MRV	Atmos Transport
2010	20%	20%	20%	40%	40%	20%	0%	0%	0%
2012	45%	15%	55%	30%	5%	10%	35%	15%	15%
2013	76%	0%	71%	0%	0%	0%	18%	82%	12%
2014	67%	0%	80%	27%	20%	20%	60%	80%	27%
2016	53%	0%	73%	0%	0%	7%	20%	100%	13%
Trend									

Participants by Organization Type and Country

TYPE (# unique)	US	Can	UK/EU	Brazil	Mexico	Gabon	Indonesia	Total
University (43)	82	1	3	1	3		1	91
National (19)	102		2	2	1	1		108
State (2)	3							3
Private (11)	16		1					17
NGO (7)	10			1	2			14
Total	**213**	**1**	**7**	**3**	**7**	**1**	**1**	**233**

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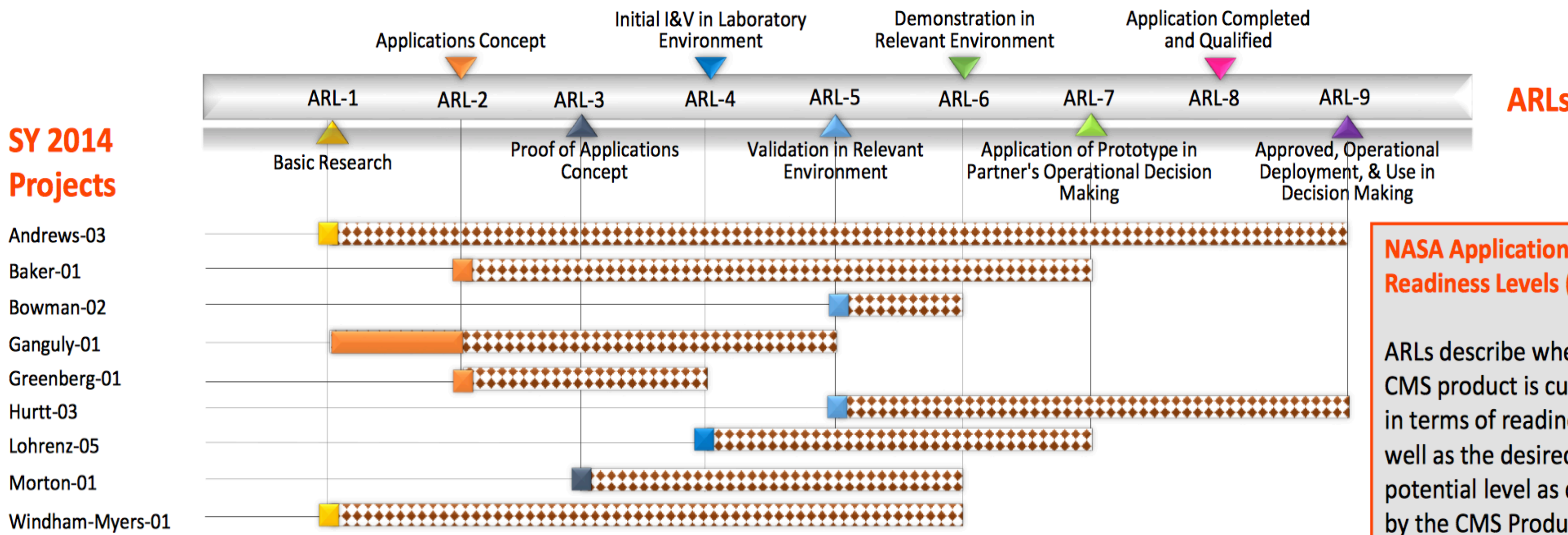
CMS Application Readiness Levels (ARLs)



Fatoyinbo-01
Hudak-01
Jacob-02
Ott-01
Walker-W-01
Williams-C-01

Different ARLs are provided for the products in these projects. Refer to individual corresponding charts describing the product ARLs.

NASA Application Readiness Levels (ARLs)

ARLs describe where the CMS product is currently in terms of readiness, as well as the desired and potential level as defined by the CMS Product Scientist.

The ARLs were provided by the CMS Product Scientist and represent the most accurate representation of the state of each product.

Products can start at any level. It is not expected they will start at ARL1 and end at ARL9.

Project ID
PI-Project # (Andrews-02)-Each CMS Project is represented by its color and identified by the PI on the project

Solid color: each solid bar is indicative of where the PI feels their project is NOW in terms of application readiness.

Pattern fill: indicates the level each PI is striving for and the application readiness level they feel their project can ultimately satisfy.

Gradient fill: indicates current level has not been reached fully.

CMS Products and Policy Support Examples

CMS PI and Product	Organization & POC	Policy of Interest
Fatoyinbo-01 Mangrove canopy height	**USDA Forest Service**, Carl Trettin	REDD+, Le Gabon Emergent, Gabon Forest Carbon Assessment, Silvacarbon, GEO-FCT
Hudak-01 Aboveground biomass maps	**Northwest Management, Inc.**, Mark Corrao	Forest Vegetation Simulator (FVS), SilvaCarbon, REDD+, NACP, IPCC
Hurtt-03 Aboveground biomass maps, canopy height and forest/non-forest maps, land cover maps	**Maryland Department of Natural Resources**, Christine Conn and Rob Feldt	FIA, Federal Land Policy and Management Act (FLPMA), Maryland Greenhouse Gas Emissions Reduction Act Plan, Maryland Climate Action Plan, Chesapeake Bay TMDL, Maryland Forest Preservation Act, Maryland No Net Forest Loss Act, Climate Framework for Delaware, Forest Legacy Program, Pennsylvania Climate Change Act, TreeVitalize Program
Jacob-02 Gridded inventory of North American methane emissions	**U.S. EPA**, Bill Irving	Global Climate Change and Clean Air Initiative of the US State Department, Global Methane Initiative of the US EPA, CAA, NGHGI, President Obama's Climate Action Plan (CAP), NALS, national methane inventory reports to UNFCCC
Windham-Myers-01 Maps of coastal wetland carbon stocks	**U.S. EPA**, Tom Wirth	REDD+, NGHGI, Global Methane Initiative of the US EPA, Blue Carbon Initiative, Coastal Wetland Planning, Protection, and Restoration Act, NOAA Habitat Restoration Monitoring

CMS Products and Policy Support Examples Con't

CMS PI and Product	Organization & POC	Policy of Interest
Cochrane-01 Estimates of burned area, land cover changes, peat fire-related emissions, timing of fire activity	**Indonesia Ministry of Environment and Forestry**, Israr Albar	REDD+, Indonesian National Carbon Accounting System (INCAS), Mega Rice Project (MRP), NFMS, US-Indonesia Partnership, Indonesia-Australia Forest Carbon Partnership, Doha/Kyoto
Dubayah-04 Canopy height and forest/non-forest maps for Sonoma County	**Sonoma County Agriculture & Open Space Preservation District**, Tom Robinson and Karen Gaffney	REDD+, Sonoma County initiatives, California Assembly Bill 32: Global Warming Solutions Act (CA-AB32), CAP
Duren-01 Carbon Mapper and white papers	**California Air Resources Board**, Bart Croes **U.S. Department of State**, David Reidmiller	Many (multi- and bi-lateral international agreements; domestic regulation and voluntary programs; sub-national federations; private markets)
Morton-02 & Cook-03 Maps of carbon stocks with pixel-level carbon estimates	**USDA Forest Service**, Hans Andersen	FIA, FLPMA
Nehrkorn-01 DARTE Annual On-road CO2 Emissions on a 1-km Grid	**Providence City Hall**, Leah Bamberger	City emissions inventories, RGGI, C40 Cities Climate Leadership Group, ICLEI Local Governments for Sustainability, FLPMA, CAA

- 343 unique publications (papers, book chapters)
  - 25 publications in Nature, Science and PNAS including eight currently on the NACP Citations Classics list with over 100 citations

- Baccini, A., Walker, W., Carvalho, L., Farina, M., Sulla-Menashe, D., Houghton, R. A. **2017**. Tropical forests are a net carbon source based on aboveground measurements of gain and loss. Science. 358(6360), 230-234. doi: 10.1126/science.aam5962 *(Baccini (CMS 2015) Walker (CMS 2014))*
- Bond-Lamberty, B., Bailey, V. L., Chen, M., Gough, C. M., Vargas, R. **2018**. Globally rising soil heterotrophic respiration over recent decades. Nature. 560(7716), 80-83. doi: 10.1038/s41586-018-0358-x *(Vargas (CMS 2016))*
- Hengl, T., Mendes de Jesus, J., Heuvelink, G. B. M., Ruiperez Gonzalez, M., Kilibarda, M., Blagotic, A., Shangguan, W., Wright, M. N., Geng, X., Bauer-Marschallinger, B., Guevara, M. A., Vargas, R., MacMillan, R. A., Batjes, N. H., Leenaars, J. G. B., Ribeiro, E., Wheeler, I., Mantel, S., Kempen, B. **2017**. SoilGrids250m: Global gridded soil information based on machine learning. PLOS ONE. 12(2), e0169748. doi: 10.1371/journal.pone.0169748 *(Vargas (CMS 2013)*, **)** NACP Citation Classic with 141 Citations
- Houghton, R. A., House, J. I., Pongratz, J., van der Werf, G. R., DeFries, R. S., Hansen, M. C., Le Quere, C., Ramankutty, N. **2012**. Carbon emissions from land use and land-cover change. Biogeosciences. 9(12), 5125-5142. doi: 10.5194/bg-9-5125-2012 *(Houghton (CMS 2011)*, NACP Citation Classic with 315 Citations
- Sargent, M., Barrera, Y., Nehrkorn, T., Hutyra, L. R., Gately, C. K., Jones, T., McKain, K., Sweeney, C., Hegarty, J., Hardiman, B., Wofsy, S. C. **2018**. Anthropogenic and biogenic CO2fluxes in the Boston urban region. Proceedings of the National Academy of Sciences. 115(29), 7491-7496. doi: 10.1073/pnas.1803715115 *(Nehrkorn (CMS 2015))*
- Olofsson, P., Foody, G. M., Herold, M., Stehman, S. V., Woodcock, C. E., Wulder, M. A. **2014**. Good practices for estimating area and assessing accuracy of land change. Remote Sensing of Environment. 148, 42-57. doi: 10.1016/j.rse.2014.02.015 *(Stehman (CMS 2013)*, NACP Citation Classic with 372 Citations

NASA's Approach to CMS/MRV

- Recognizes that a sustained, observationally-driven carbon monitoring system using remote sensing data has the potential to significantly improve the relevant information base for the U.S. and world;
- Recognizes multiple users, multiple scales, multiple quantities, and multiple frameworks for MRV (e.g. International, national and subnational, markets);
- Regonizes the importance of user engagement to be responsive to stakeholder needs;

The goal for NASA's CMS project is to prototype the development of carbon monitoring capabilities needed to support stakeholder needs for MRV.

*NASA-CMS (2014) Progress Report

Lidar Facilitates Aboveground Biomass Carbon (AGBC) Estimation Across Space And Time

P. Fekety, M. Falkowski, A. Hudak (PI) (Project: 14-CMS14-0026; Award: NNH15AZ06I)

Background:

Regional forest planning is challenging for USFS managers faced with budget constraints.

Analysis:

Evaluated transferability of lidar-derived AGBC estimates from models trained with plot data that were collected neither locally (Fig. 1) nor contemporaneously (Fig. 2).

Findings:

Losses in accuracy and precision from AGBC models based on spatially or temporally disjunct observations are acceptable.

Significance:

Given consistently processed lidar collections, inventory plot data can be leveraged broadly in space and time to more efficiently manage regional forest AGBC sequestration.

Fig. 1. Six spatially disjunct project areas with lidar and forest inventory plot data.

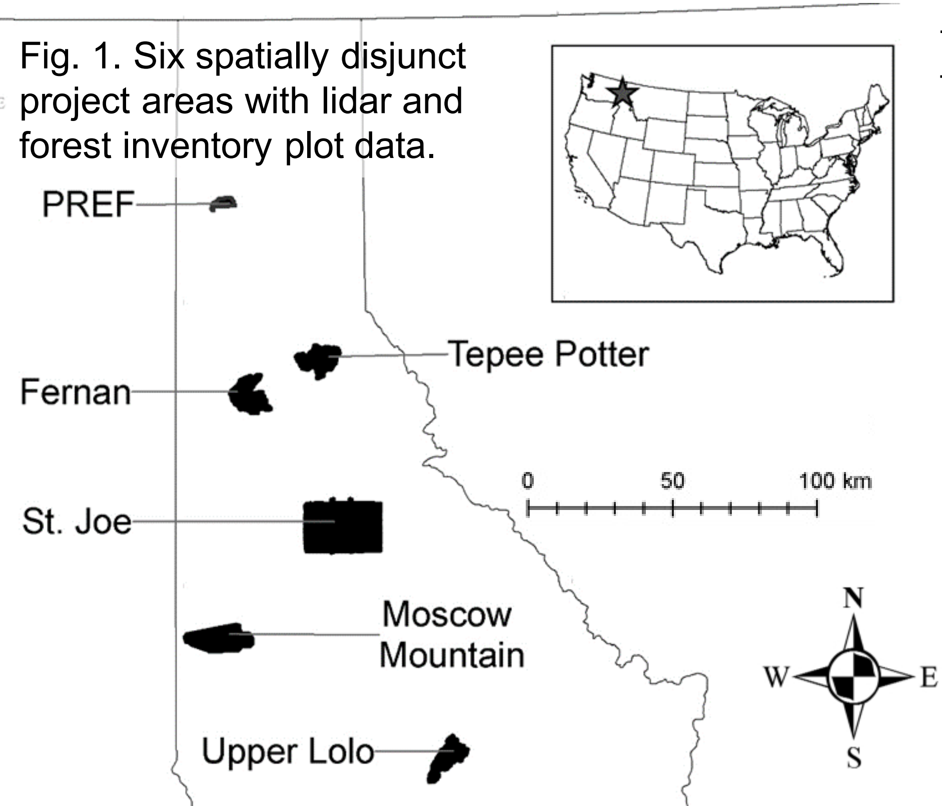
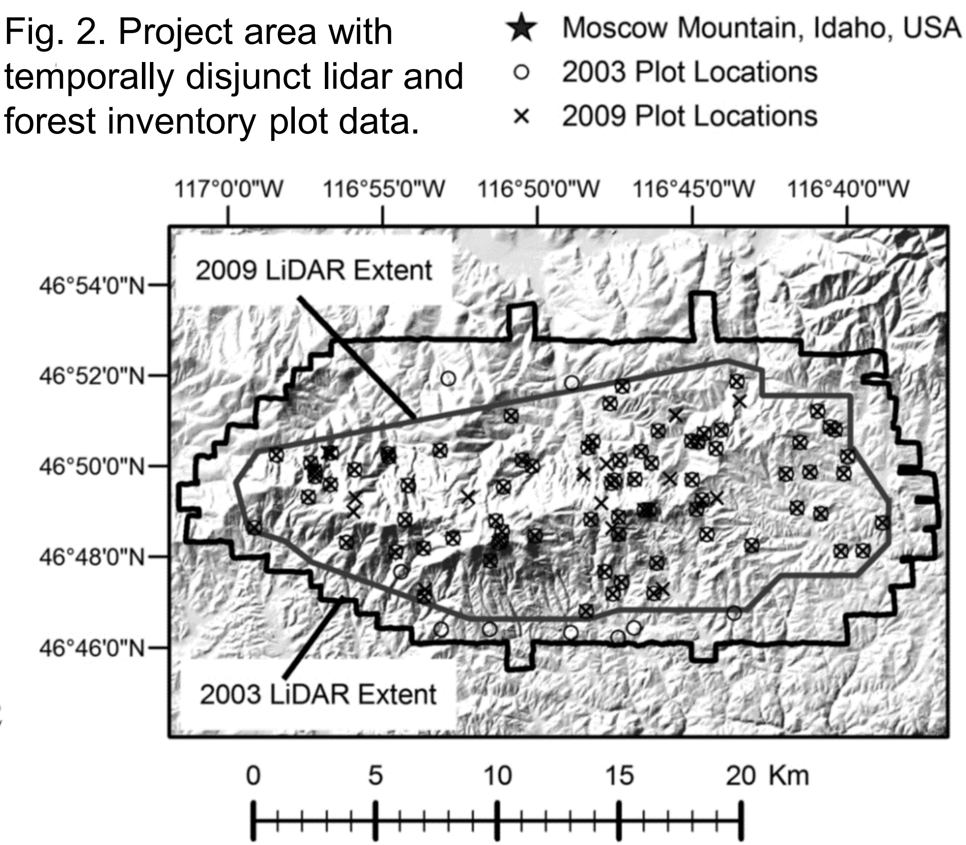


Fig. 2. Project area with temporally disjunct lidar and forest inventory plot data.



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UNIVERSITY OF MARYLAND

Beyond MRV: High-resolution forest carbon modeling for climate mitigation planning over Maryland, USA

Hurtt, G., Zhao, M., Sahajpal, R., Armstrong, A., Birdsey, R., Campbell, E., Dolan, K.A., Dubayah, R., Fisk, J.P., Flanagan, S.A., Huang, C., Huang, W., Johnson, K., Lamb, R., Ma, L., Marks, R., O'Leary, D., O'Neil-Dunne, J., Swatantran, A., Tang, H., 2019. *Environmental Research Letters*.
https://doi.org/10.1088/1748-9326/ab0bbe

Science Questions

- How can we accurately monitor current forest cover and carbon stocks to aid policy efforts aimed at reducing deforestation and degradation as well as increasing afforestation and reforestation for climate mitigation?
- How can ecological modeling quantitatively estimate future carbon sequestration potential in response to land-use and management decisions?

Analysis

The study presents a new forest carbon monitoring and modeling system that combines high-resolution remote sensing of forest height, field data, optical remote sensing and ecological modeling (Ecosystem Demography model). We estimate contemporary above-ground forest carbon stocks, and project future forest carbon sequestration potential for the state of Maryland at 90 m resolution, over approximately 3.2 million grid cells. This is nearly 100,000 times the resolution at which global carbon models are run.

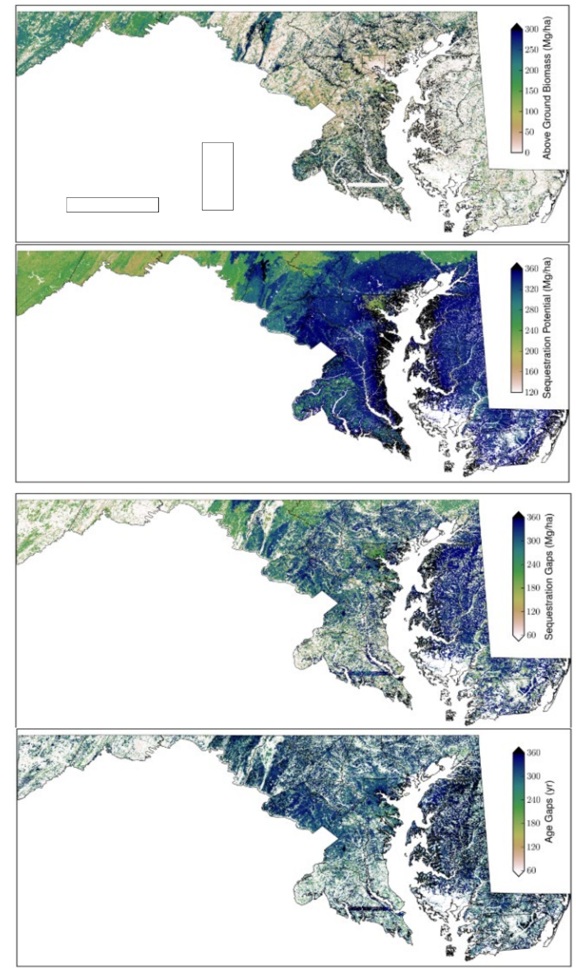
Results

In Maryland, the contemporary above-ground carbon stock was estimated to be 110.8 Tg C (100.3-125.8 Tg C). The forest above-ground carbon sequestration potential for the state was estimated to be much larger at 314.8 Tg C, and the forest above-ground carbon sequestration potential gap was estimated to be 204.1 Tg C, nearly double the current stock. The time needed to reach this potential, or carbon sequestration potential time gap was estimated to be 228 years statewide, with 50% of the gap being realized in 80 years. These results imply a large statewide potential for future carbon sequestration from afforestation and reforestation activities.

Significance

With this approach, it is now possible to quantify both the forest carbon stock and future carbon sequestration potential over large policy relevant areas with sufficient accuracy and spatial resolution to significantly advance planning. These data products are now being used by the state of Maryland to plan for the Greenhouse Gas Reduction Act (GGRA). With the launch of NASA-GEDI mission, these analyses can be scaled to national, continental and global domains.

(a)
(b)
(c)
(d)

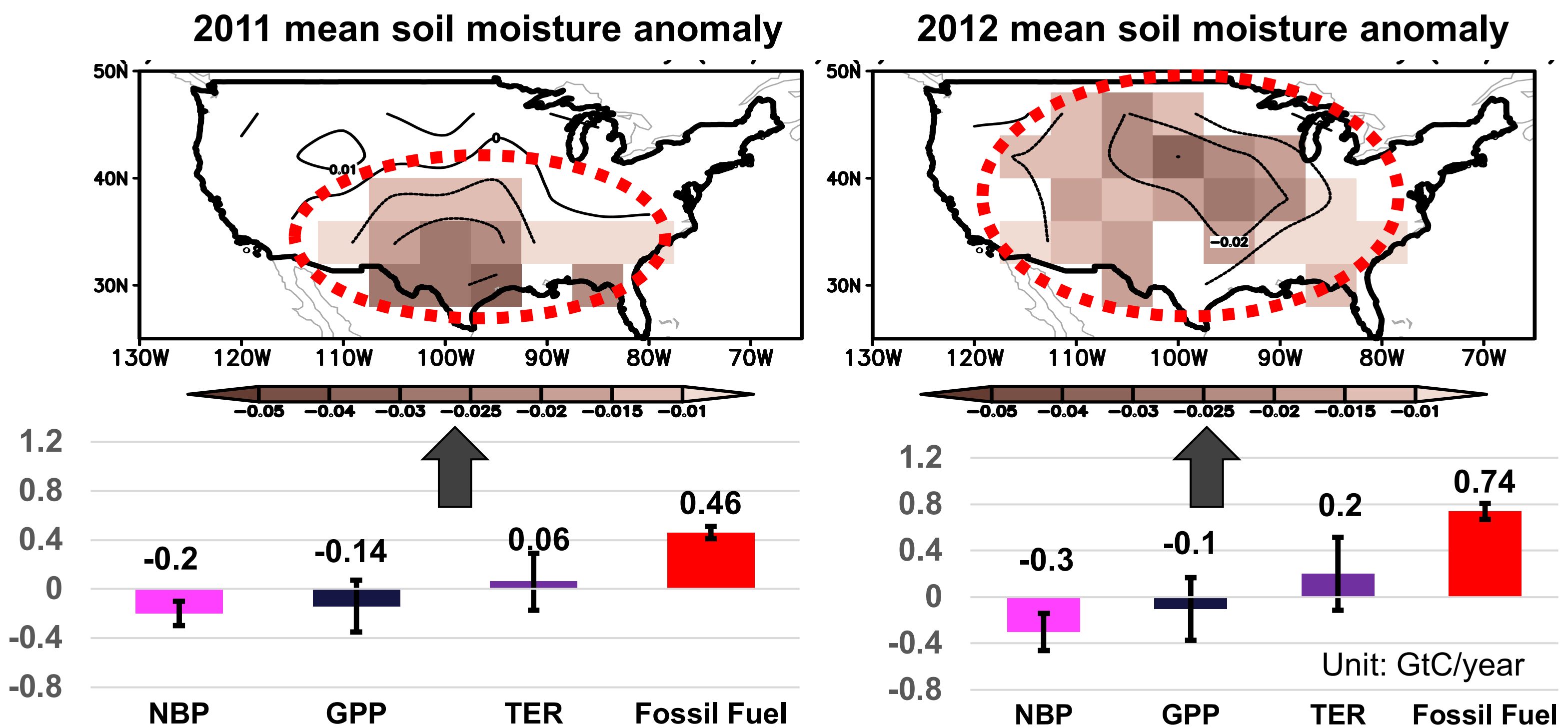


a) AGB Spatial pattern of 90-m biomass estimated by Lidar-initialized ED
b) CSP Map of carbon sequestration potential estimated by Lidar-initialized ED
c) CSPG Map of gap to carbon sequestration potential estimated by Lidar-initialized ED
d) CSPTG Map of carbon sequestration potential time gap estimated by Lidar-initialized ED

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Detecting drought impact on terrestrial biosphere carbon fluxes over contiguous US with satellite observations

Liu, J. et al. (2018), Environ. Res. Lett., Vol 3



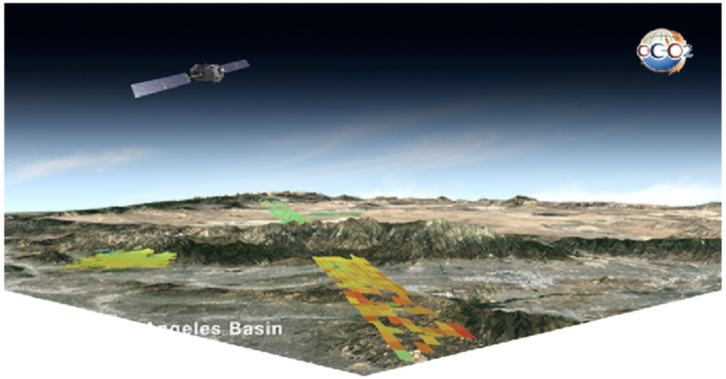
Brown color indicates drought impacted region.

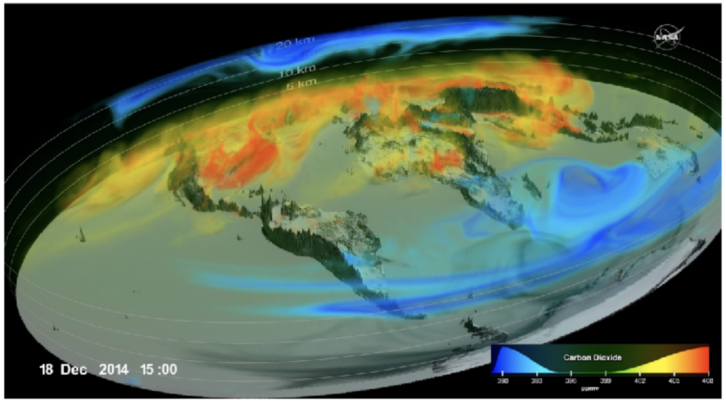
Biosphere carbon flux anomalies from drought in comparison to regional fossil fuel emissions.

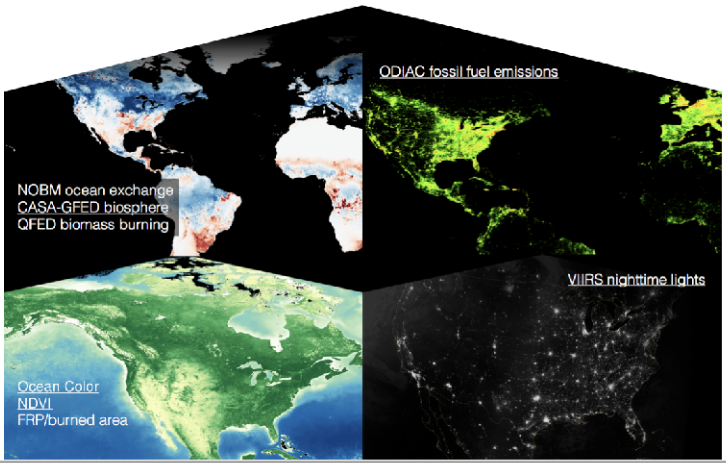
Science Question: The 2011 dry spell in Texas was the worst one-year period of drought since 1895, and the area span of 2012 summer drought was comparable to the dust bowl era. Liu et al addressed the following questions: 1) What are the impacts of these two severe droughts on terrestrial biosphere net biosphere production (NBP)? 2) what are the driving processes (growth vs. decomposition)? 3) How significant of the biosphere flux anomaly relative to regional fossil fuel emissions?

Data and Results: We used NASA CMS-Flux inversion system to infer monthly NBP and GPP from GOSAT B7.3 xCO2 and Solar induced fluorescence (SIF) over 2010-2015, calculating TER as a residual. Over the drought impacted region, the annual NBP decreased by 0.2 ± 0.1 GtC and 0.3 ± 0.16 GtC respectively in 2011 and 2012, equal to 40% of the mean fossil fuel emission over these regions. About half of the NBP reduction was due to a decrease of GPP, and the other half was due to an increase of respiration.

Significance: The large magnitude of natural biosphere carbon flux anomalies relative to regional fossil fuel emissions indicate that any mitigation policy to reduce regional contributions to atmospheric CO_2 growth needs to consider the interannual variability and long-term trend of the natural carbon cycle.







Integrating Top-Down and Bottom-Up Estimates of Carbon Flux

- Satellite observations provide important constraints on carbon flux estimates which is critically needed to improve climate models and inform policymakers.
- Ocean color and NDVI information inform model-based estimates of ocean and land productivity while observations of fire radiative power, burned area, and nighttime lights support high-resolution fire and fossil fuel emission inventories (bottom)
- Satellite carbon dioxide measurements provide a new tool for estimating total fluxes (top). Atmospheric observations are assimilated into a transport model, which also leverages millions of daily weather observations. These data correct errors in the initial flux estimates to create a 'top-down' flux estimate.
- Since 2010, NASA's Carbon Monitoring System has helped to advance the quality of global flux data products, providing a new set of tools for scientists and stakeholders.