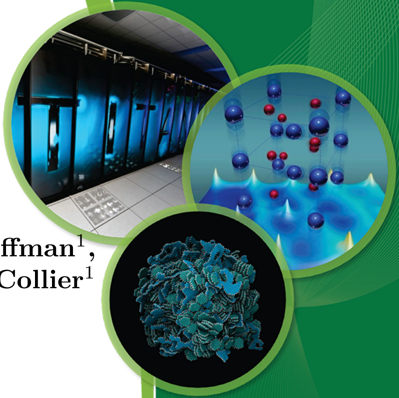
Understanding the Representativeness of FLUXNET for Upscaling Carbon Flux from Eddy Covariance Measurements



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Eddy Covariance Measurements

Eddy covariance data from regional flux networks are direct in situ measurement of carbon, water, and energy fluxes and are of vital importance for understanding the spatio-temporal dynamics of the the global carbon cycle.

Objective I

The EC method assumes the measurement site is located in flat terrain, experiences steady or stable atmospheric conditions, and is surrounded by uniform vegetation for an extended distance in the upwind direction – however, in practice they are often located in a non-ideal location.
Quantify how well sites represent larger landscape in space and time [representativeness].

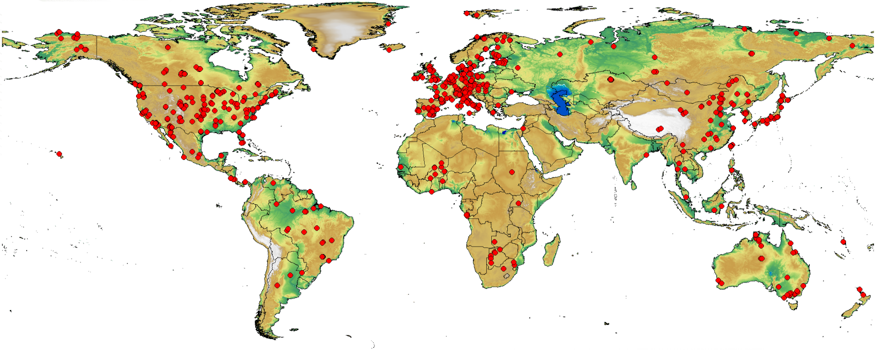
Objective II

Upscaling of the point measurements is required for landscape-scale interpretation of ecosystem processes, and constrain models.
Upscale the point EC flux measurements [GPP] from flux sites to global landscape, informed by representativeness [upscaling].

FLUXNET

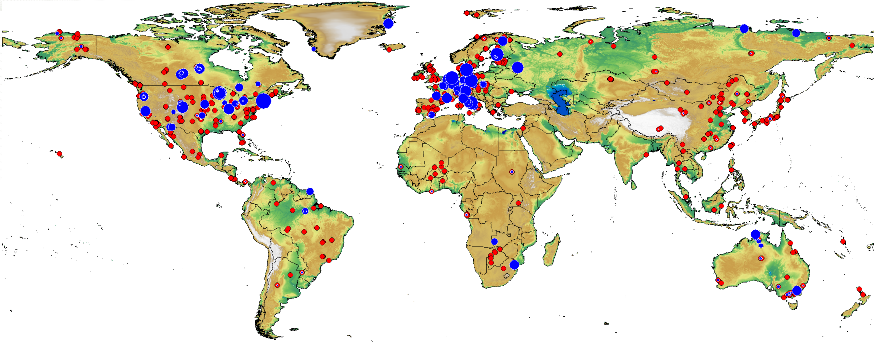
FLUXNET is a global network of micrometeorological flux measurement networks consisting of individual sites

- Includes: AmeriFlux, AfriFlux, AsiaFlux, CarboAfrica, CarboEuropeIP, CarboItaly, CarboMont, ChinaFlux, Fluxnet-Canada, GreenGrass, ICOS, KoFlux, LBA, NECC, OzFlux-TERN, TCOS-Siberia, and USCCC
- the locations of the sites in the network were not formally designed to uniformly and consistently observe global biomes and thus represent a sparse and spatially biased sampling of the global terrestrial ecosystem
- FLUXNET provides EC data from the sites in the network in a quality controlled and consistent format
- Latest FLUXNET2015: Realease 1 [Dec 2015], Release 2 [July 2016], Release 3 (final) [November 2016]



Red circles: Comprehensive list of EC Flux sites affiliated with FLUXNET [786]

Bakground map: SRTM Digital Elevation Map

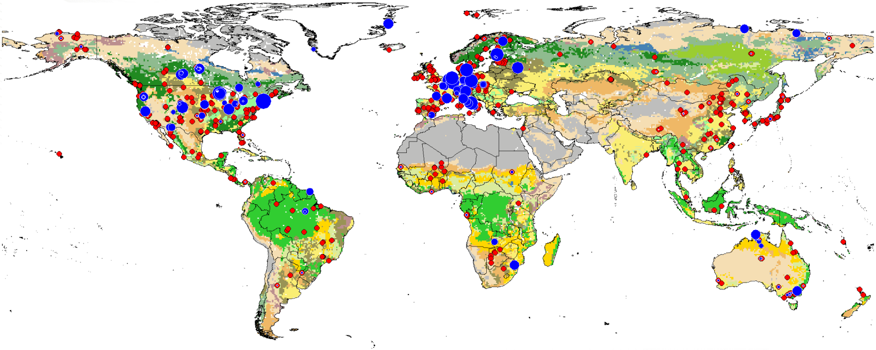


Red circles: Comprehensive list of EC Flux sites affiliated with FLUXNET [786]
Blue circles: Sites for which data is available in FLUXNET2015 (Nov 2016 release) [212]

Bakground map: SRTM Digital Elevation Map

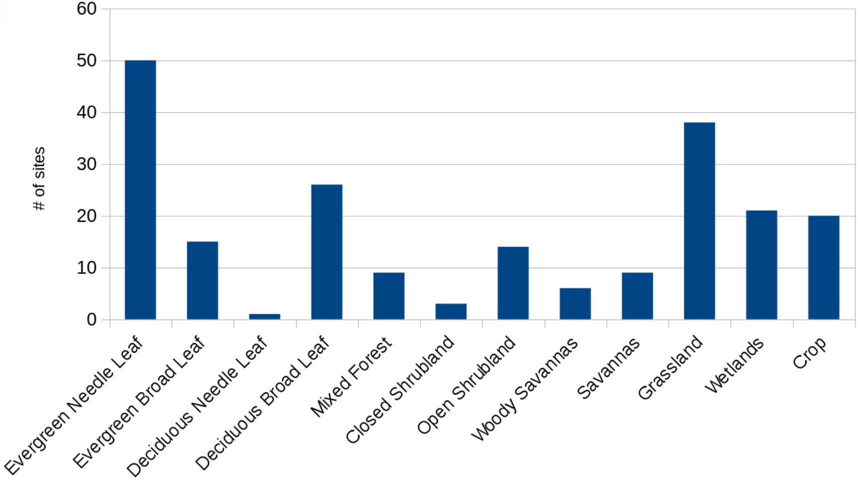
Distribution of FLUXNET sites: in space

Distribution of FLUXNET sites: in time



Distribution of FLUXNET sites across IGBP landcover types

Bakground map: IGBP Landcover Map



Global network of FLUXNET sites represents all IGBP landcover types. However, some biomes are better sampled than others.

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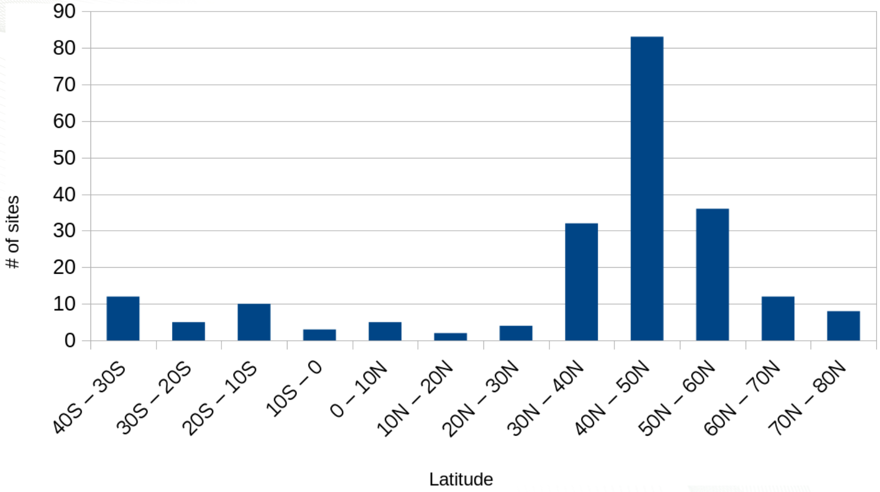


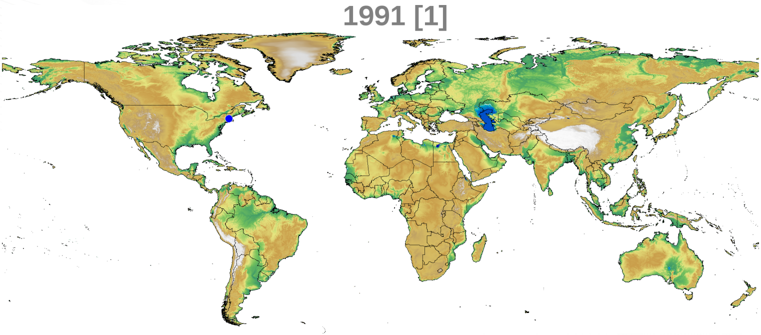
Strong northern mid-latitude sampling bias, while a large part of the globe is sparsely or unsampled.

Evaluating FLUXNET network

Distribution of FLUXNET sites: in space

Distribution of FLUXNET sites: in time

FLUXNET in time



Sites in the network have different start/end of operations, thus, available network is always changing

- FLUXNET observations are sparse in space, and sparse in time
- Synthesis of FLUXNET EC measurement must consider that variability
- Changing data availability thru space and time would [should] be reflected in the accuracy of the upscaled data products

Methodology

1. Quantify representativeness of FLUXNET sites in multi-dimensional environmental data space [Euclidean distance].
    - Dimensionless metric
    - Of interest are relative (not absolute) values
2. Develop ecoregions using multi-dimensional data set
3. For every gridcell in space and time, identify the observations from similar environment
    - Spatial resolution: 4 km Temporal resolution: monthly
    - Use data from a given time only (NOT the time series)
4. Fit a fairy simple *Inverse Distance Weighted Mean* algorithm at every grid cell, every month. Weights used are represenativeness calculated in multi-dimensional data space
    - Sites farther away in multi-dimensional data space are more dissimilar and thus lower weight
    - Good news: there's always a neighbor, Bad news: there's always a neighbor

Table: Environmental variables used for ecoregion delineation, representativeness analysis and upscaling. These data are in the form of ∼4 km raster grids.

Variable Description	Units	Source
Bioclimatic Variables		
Annual mean temperature	°C	Hijmans et al. (2005)
Mean diurnal range	°C	Hijmans et al. (2005)
Isothermality	–	Hijmans et al. (2005)
Temperature seasonality	°C	Hijmans et al. (2005)
Temperature annual range	°C	Hijmans et al. (2005)
Mean temperature of wettest quarter	°C	Hijmans et al. (2005)
Mean temperature of driest quarter	°C	Hijmans et al. (2005)
Mean temperature of warmest quarter	°C	Hijmans et al. (2005)
Mean temperature of coldest quarter	°C	Hijmans et al. (2005)
Annual precipitation	mm	Hijmans et al. (2005)
Precipitation during the wettest quarter	mm	Hijmans et al. (2005)
Precipitation during the driest quarter	mm	Hijmans et al. (2005)
Precipitation during the warmest quarter	mm	Hijmans et al. (2005)
Precipitation during the coldest quarter	mm	Hijmans et al. (2005)
Edaphic Variables		
Available water holding capacity of soil	mm	Global Soil Data Task Group (2000); Sax
Bulk density of soil	g/cm^3	Global Soil Data Task Group (2000); Sax
Soil carbon density	g/m^2	Global Soil Data Task Group (2000); Sax
Total nitrogen density	g/m^2	Global Soil Data Task Group (2000); Sax
Topographic Variables		
Compound topographic index (relative wetness)	–	Saxon et al. (2005)

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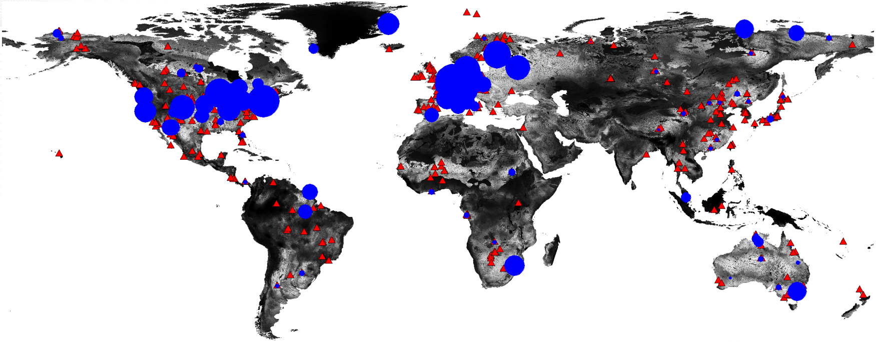
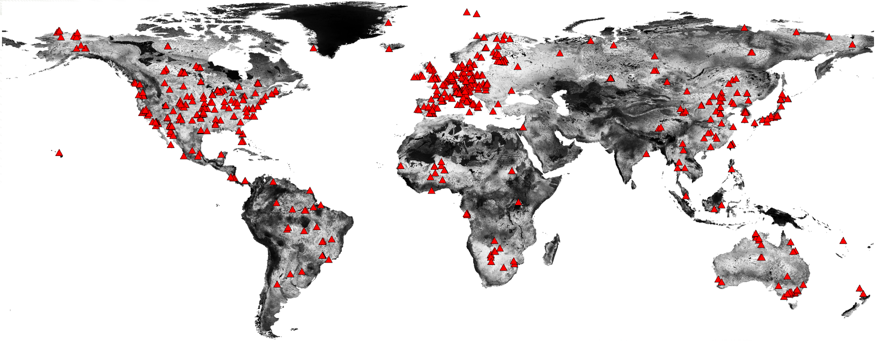


Spatial representativeness of FLUXNET2015 [212 sites] [ACTUAL]. Light regions are well represented by this collection of sites, while dark regions are poorly represented.



Spatial representativeness of larger FLUXNET network [786 sites]
[POTENTIAL]

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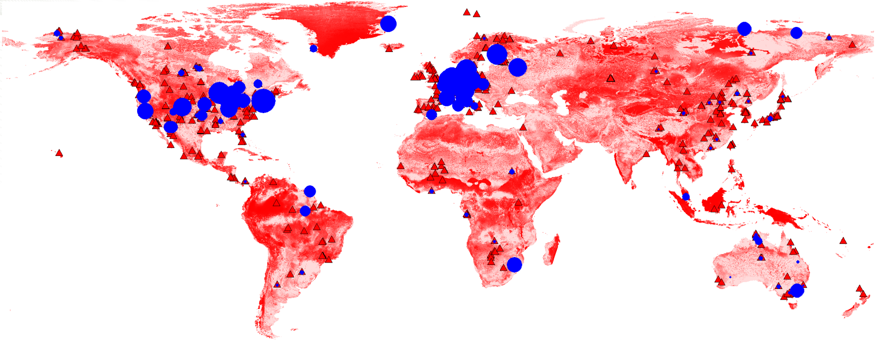
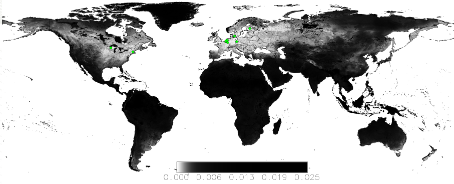
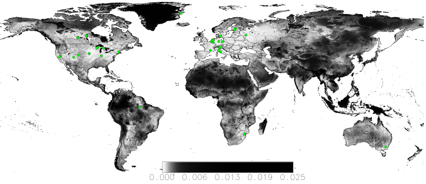


Lost/missing information = Potential - Actual
to Lost opportunity/knowledge due lack of data sharing

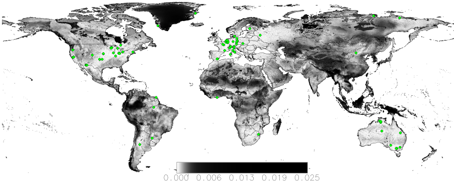
FLUXNET representativeness thru time



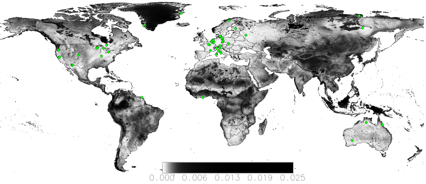
(a) 1996



(b) 2001



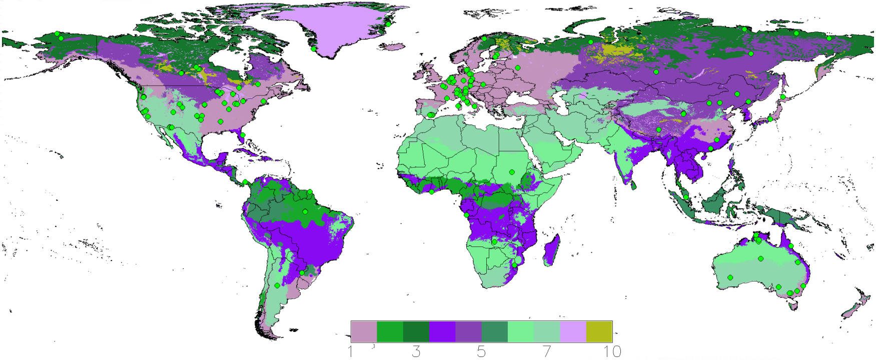
(c) 2011



(d) 2014

Representativeness has gradually improved over time.

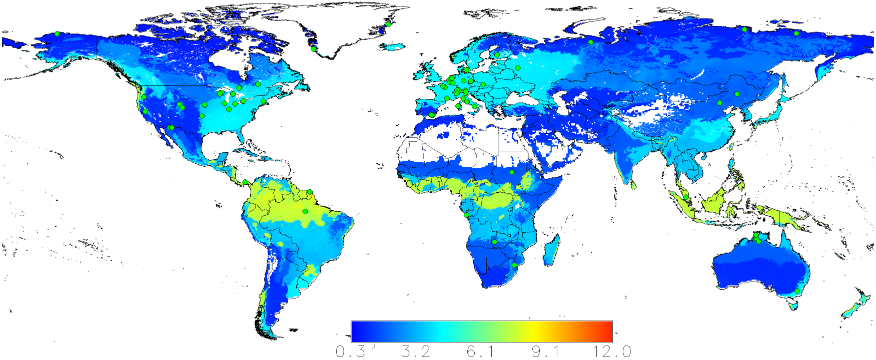
Ecoregions to delineate the environmental data space



Ecoregions defined using multi-variate k-means cluster analysis (k=10)

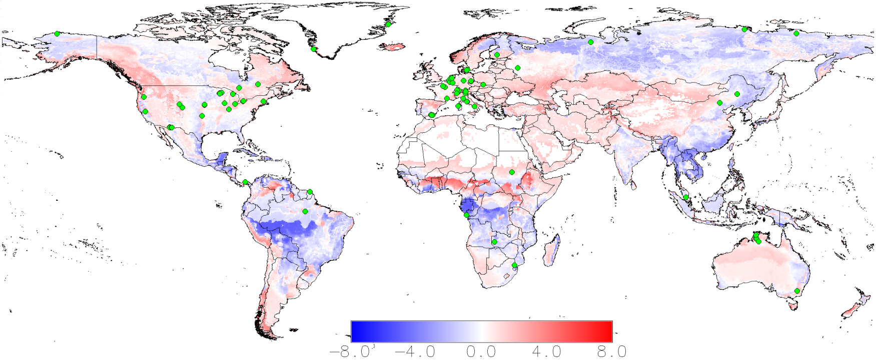
Year	Total	Ecoregions									
		1	2	3	4	5	6	7	8	9	10
		14.27%	4.19%	14.65%	12.19%	17.84%	3.12%	12.21%	14.82%	5.45%	1.25%
1991	1	1	0	0	0	0	0	0	0	0	0
1992	1	1	0	0	0	0	0	0	0	0	0
1993	1	1	0	0	0	0	0	0	0	0	0
1994	2	1	0	0	0	0	0	0	0	0	1
1995	3	2	0	0	0	0	0	0	0	0	1
1996	13	11	0	1	0	0	0	0	0	0	1
1997	17	13	1	1	0	1	0	0	0	0	0
1998	20	16	1	1	0	1	0	0	0	0	1
1999	24	19	1	1	1	1	0	0	0	0	1
2000	36	27	2	2	2	1	0	0	1	0	1
2001	52	32	2	5	4	1	0	0	3	0	6
2002	73	43	3	6	4	5	0	0	3	1	8
2003	86	45	3	9	7	8	1	0	3	1	9
2004	104	58	4	10	7	8	1	0	6	1	9
2005	106	62	3	10	7	5	1	1	7	1	9
2006	95	62	3	8	7	3	1	1	7	1	2
2007	99	62	5	7	7	4	1	1	9	1	2
2008	104	64	4	7	8	4	1	3	10	1	2
2009	103	63	4	6	8	3	1	3	14	1	1
2010	101	63	2	8	4	4	0	3	16	1	0
2011	109	68	3	6	4	2	0	5	19	2	0
2012	113	69	2	6	4	3	0	5	21	3	0
2013	99	59	2	6	4	2	0	5	18	3	0
2014	84	50	2	6	2	2	0	2	18	2	0

Data product: Time integrated annual mean GPP



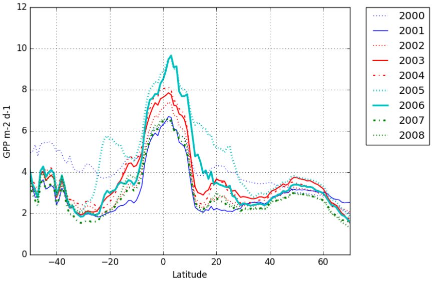
Global gridded upscaled GPP for year 2008

Difference vs FLUXNET-MTE

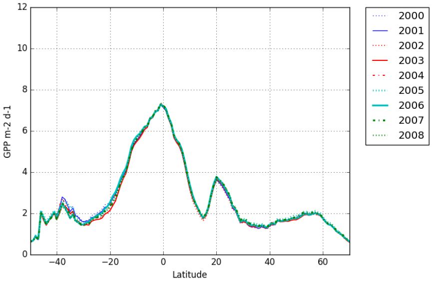


Comparison with FLUXNET-MTE GPP for year 2008

Inter-annual variability in GPP



(e) Upscaled GPP



(f) FLUXNET-MTE GPP

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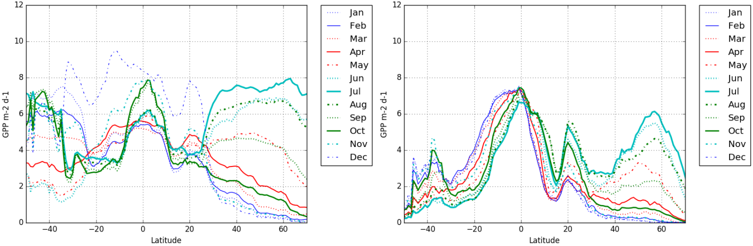
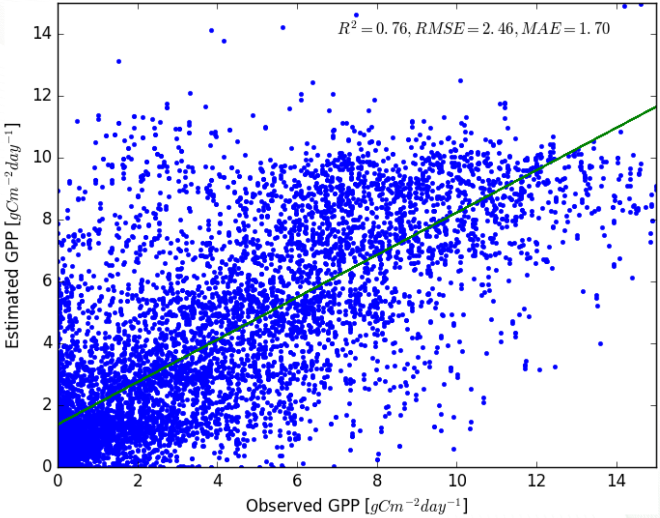
Intra-annual variability in GPP



(g) Upscaled GPP (h) FLUXNET-MTE GPP

We built the model using observations only from same time, not the time series thus no smoothing was applied and data product is direct reflection of observations (and any associated potential bias).

Boot strap validation



10 ensembles were perfermed by holding back 10% of data each year for validation.

Summary

Strengths:

- High spatial resolution global data product
- Captures the spatio-temporal variability observed at flux towers
- Quantify the representativeness of FLUXNET network of sites. They provide a confidence bound on the upscaled/estimated data products, variable in space and time
- Simple and efficient workflow to develop gridded product as more data sets become available
- Help strategically identify areas of critical data need

Limitations:

- Observations from limited numbers of flux sites
- High uncertainty in carbon rich tropical region due to extremely limited flux observations
- Sensitive to any fluctuation in observed fluxes
- Accuracy vary thru space and time
- Not many good validation data sets available

What's next..

- Currently our underlying data is based on long term climatology, but using remote sensing we can employ monthly time series and capture the temporal variation in environmental conditions.
- Incorporate the uncertainties in flux estimates to better quantify the uncertainties associated with the upscaled products.
- Bring together data from other networks/sites that are not part of FLUXNET (data inconsistency requires care!).

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This work used eddy covariance data acquired and shared by the FLUXNET community, including these networks: AmeriFlux, AfriFlux, AsiaFlux, CarboAfrica, CarboEuropeIP, CarboItaly, CarboMont, ChinaFlux, Fluxnet-Canada, GreenGrass, ICOS, KoFlux, LBA, NECC, OzFlux-TERN, TCOS-Siberia, and USCCC. The FLUXNET eddy covariance data processing and harmonization was carried out by the ICOS Ecosystem Thematic Center, AmeriFlux Management Project and Fluxdata project of FLUXNET, with the support of CDIAC, and the OzFlux, ChinaFlux and AsiaFlux offices.

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