Scaling carbon dioxide exchange from sites to regions

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Challenges in scaling terrestrial carbon fluxes

- A vast, complex system operating with poorly known feedbacks, periodic/stochastic behaviour...now in uncharted territory
- Eddy flux and biometric data – ‘effective samples?’
- Earth observations -‘shadows on the wall?’
- Modelling – ‘reality?’

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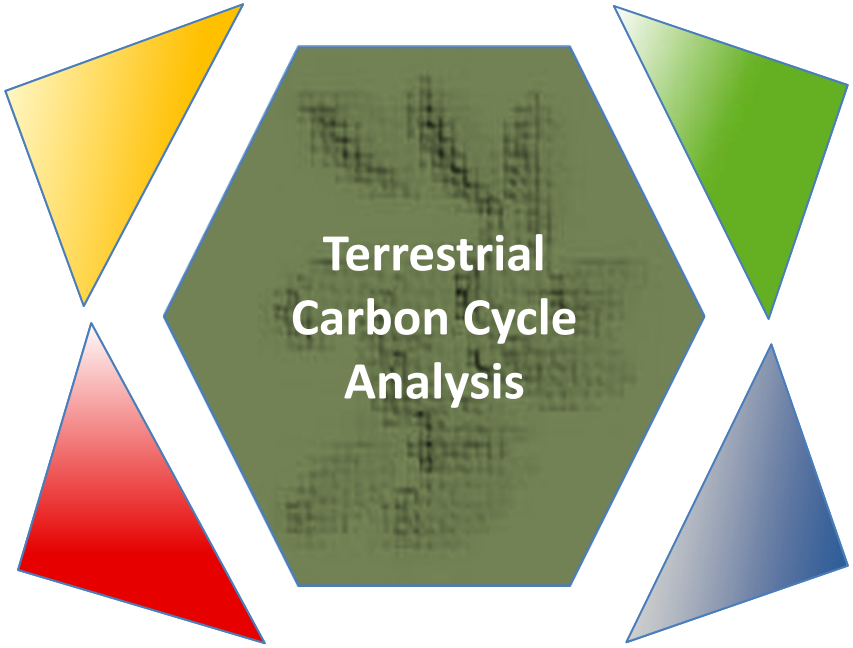
CARDAMOM - CARbon DAta MOdel fraMework

MODEL

DALEC: Data Assimilation Linked Ecosystem Carbon model

DRIVERS

Global ERA interim analyses



DATA

MODIS LAI time series, Biometric Satellite data, Eddy flux tower data, Plant trait data.

OPTIMIZATION

Metropolis-Hastings Markov Chain Monte Carlo Ecological & dynamic constraints

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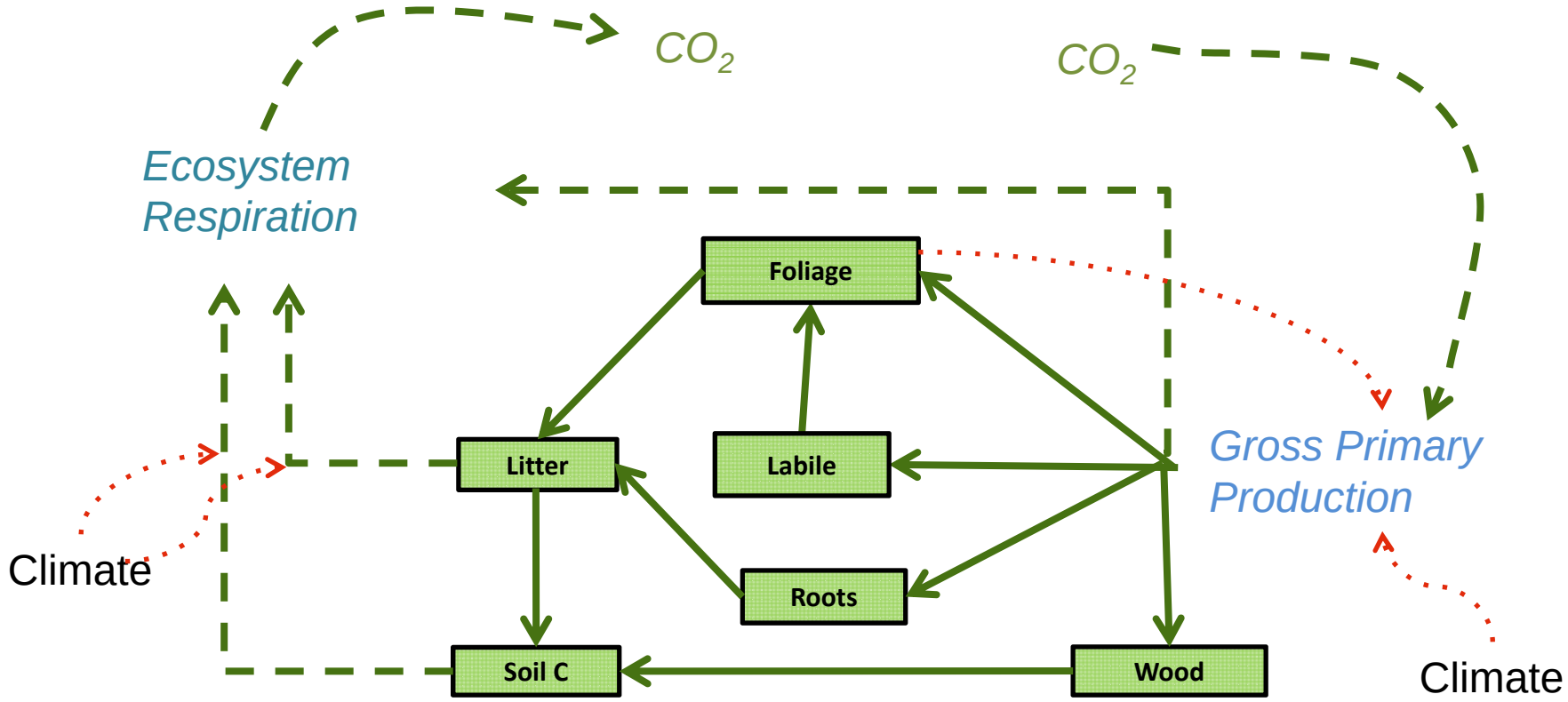
DALEC: Data Assimilation Linked Ecosystem Carbon model



DALEC carbon pools and fluxes: 23 parameters describe pool allocation, phenology and turnover rates in ecosystem carbon cycling.

DALEC Parameter vector = [M_r, f_a, f_f, f_r, L_L, t_w, t_r, t_{lit}, t_{SOM} T_{rate}, C_{eff}, B_{day}, f_{lab}, R_r, F_{day}, R_f, LMA, C_{LA},C_{FO}, C_{RO}, C_{WO}, C_{LI}, C_{SO}]

C flux

CO_2 flux

influence

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Model Data Fusion (MDF)

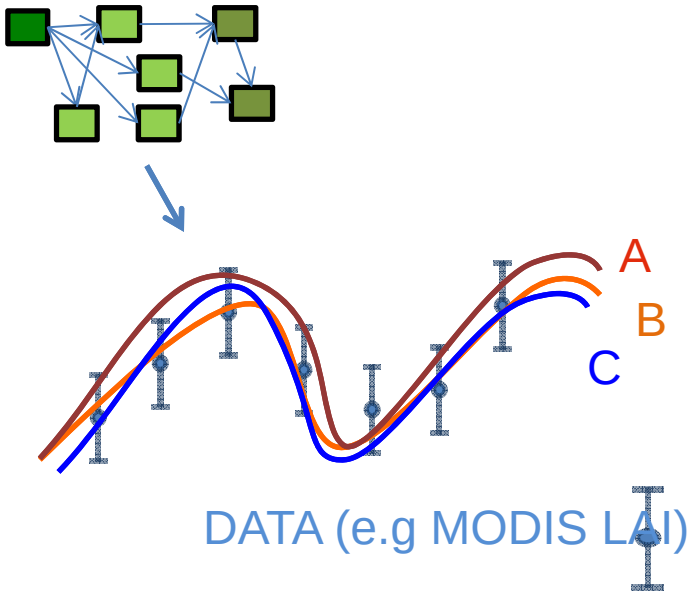
Random Sampling of DALEC parameters

A. p_1, p_2, …. , p_{23}

B. p_1, p_2, …. , p_{23}

C. p_1, p_2, …. , p_{23}

DALEC



Bayes' Theorem

$$p(x|c) \propto p(c|x)\, p(x)$$

Posterior parameter probability

Observation likelihood, given parameters

Prior Parameter Probability

Method = Metropolis Hastings MCMC

(1) Parameter value priors span across multiple orders of magnitude, BUT

(2) Only a subset of parameter space can be considered "ecologically consistent"

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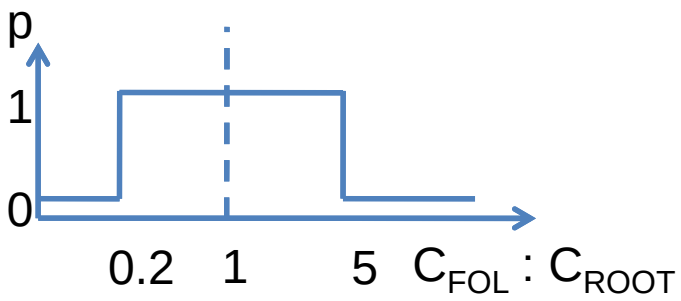
Ecological and Dynamic Constraints (EDCs)

DALEC Parameter vector = [M_r, f_a, f_f, f_r, L_L, t_w, t_r, t_{lit}, t_{SOM} T_{rate}, C_{eff}, B_{day}, f_{lab}, R_r, F_{day}, R_f, LMA, C_{LA},C_{FO}, C_{RO}, C_{WO}, C_{LI}, C_{SO}]

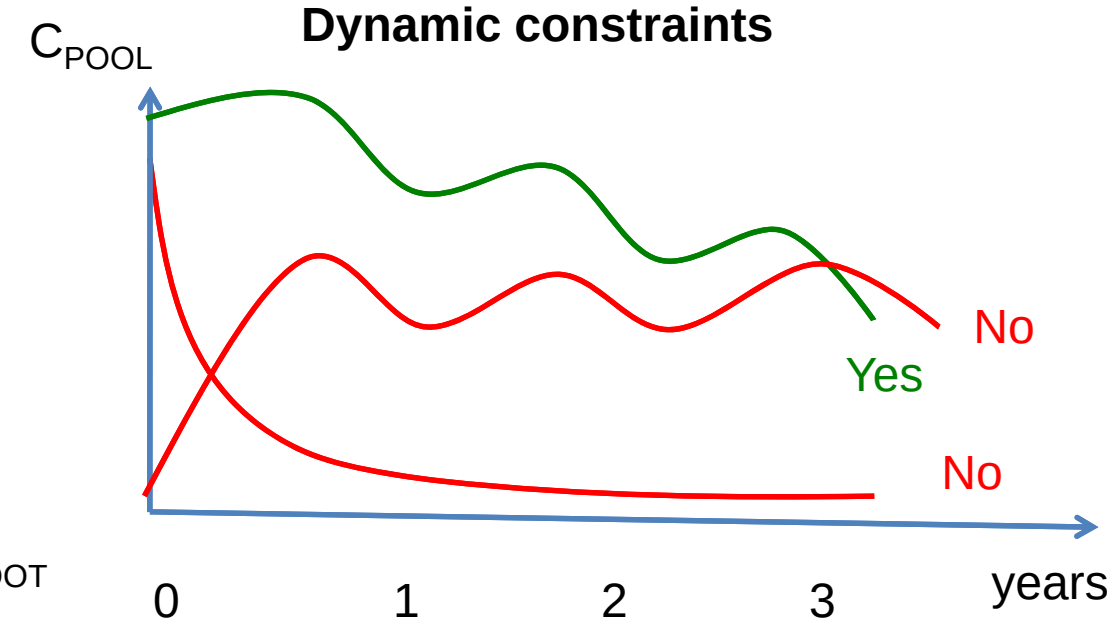
Turnover constraints

$t_{SOM} < t_{litter}$ & $t_{wood} < t_{foliar}$

C_{root}: C_{fol} ratio

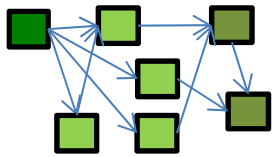


Dynamic constraints



Analytical dynamic constraints

order of magnitude constraint on proximity of steady state C pool to initial value (wood, roots, litter, SOM)



In total: 12 checks

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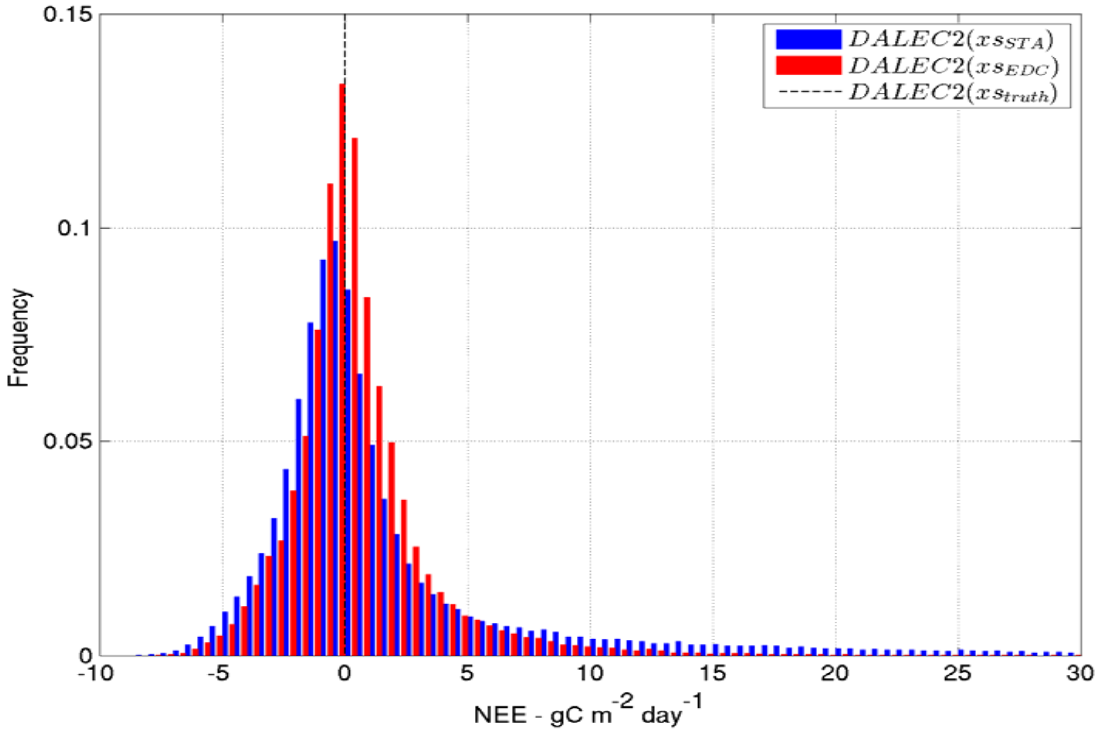
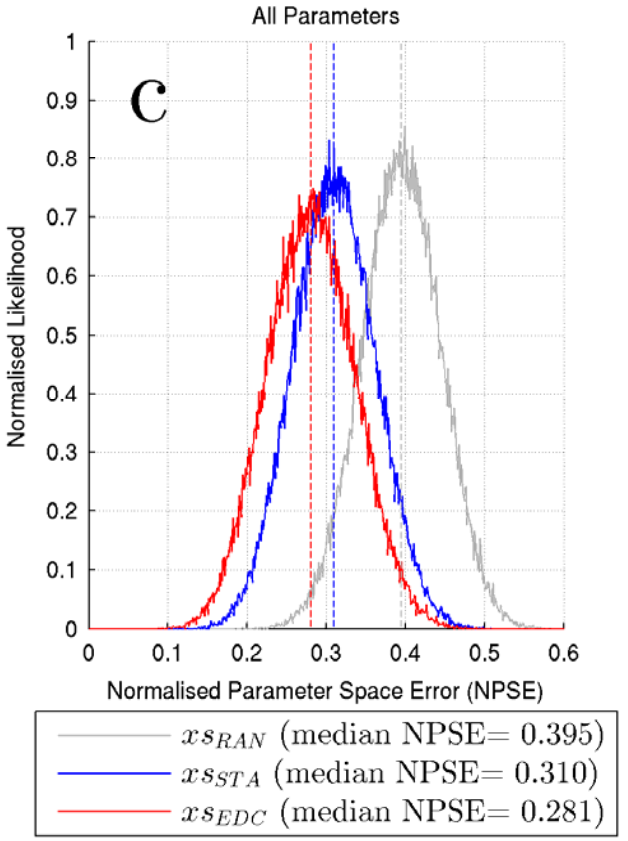
EDCs reduce flux bias and assist parameter constraint





Synthetic studies – 40 synthetic deciduous forests
Assimilate: LAI time series, single soil carbon estimate

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Independent tests at flux sites indicate value of EDCs

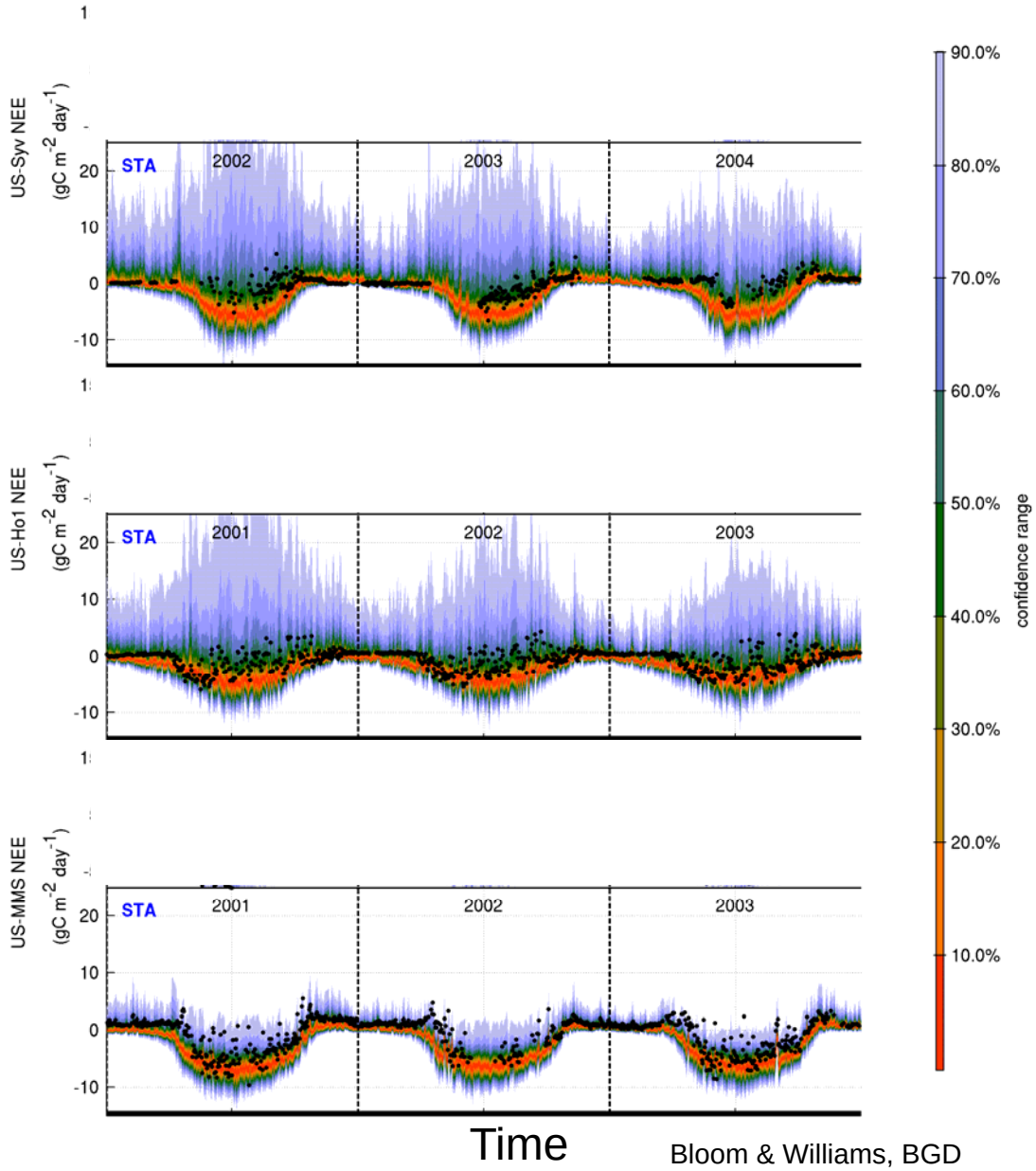
Assimilate MODIS LAI, HWSD soil C

Sylvania
(Mixed forest)

Howland
(Evergreen forest)

Morgan Monroe
(Decid. Broadleaf)

Ameriflux data



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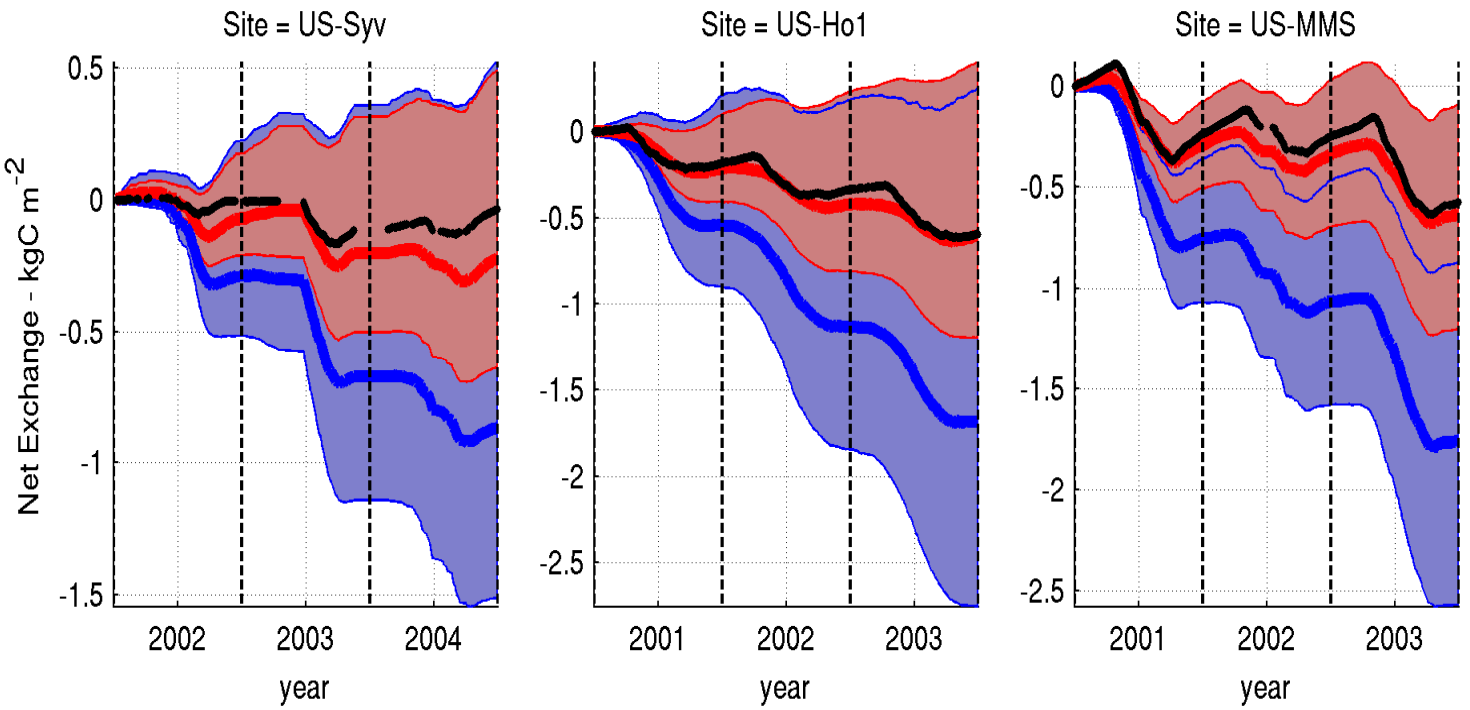
Independent tests of cumulative NEE at Ameriflux sites

EDC median
EDC 50% C.R.
STA median
STA 50% C.R.
AMERIFLUX



Ameriflux data

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Terrestrial ecosystem carbon cycle analysis

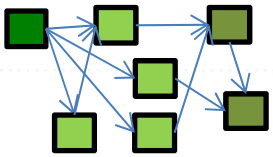
Posterior DALEC Parameter Probability
1° x 1° Pixel scale parameter, flux & carbon pool estimates

C state likelihood function = observation likelihood & parameter priors
No spin-up
No PFTs
No Steady state

Drivers:

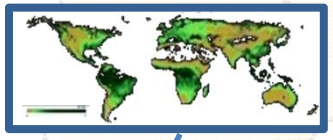
ERA-interim 1° x 1° resolution 8-day time-step 2001-2010

DALEC

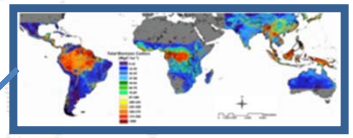


Biometric Data Constraints

MODIS LAI

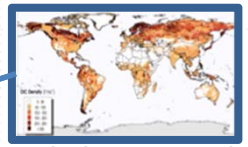


Pan-Tropical Biomass



Saatchi et al. 2011

HWSD Soil Organic C



Hiederer & Köchy, 2012

$$p(x|c) \propto p(c|x)\, p(x)$$

Parameter probability **p(x|c)** at each pixel derived using a Metropolis-Hastings MCMC algorithm

C_{eff} constraint: 100 Gt/yr < Global GPP <150 Gt/yr

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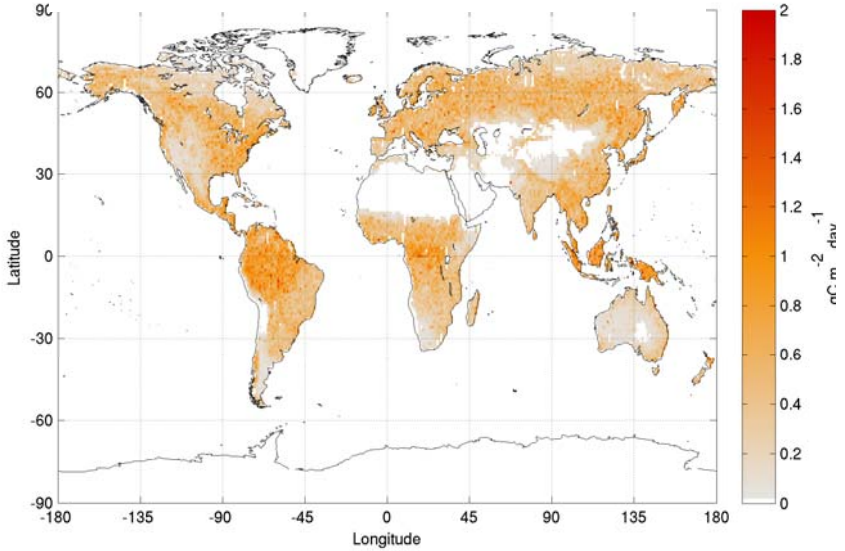
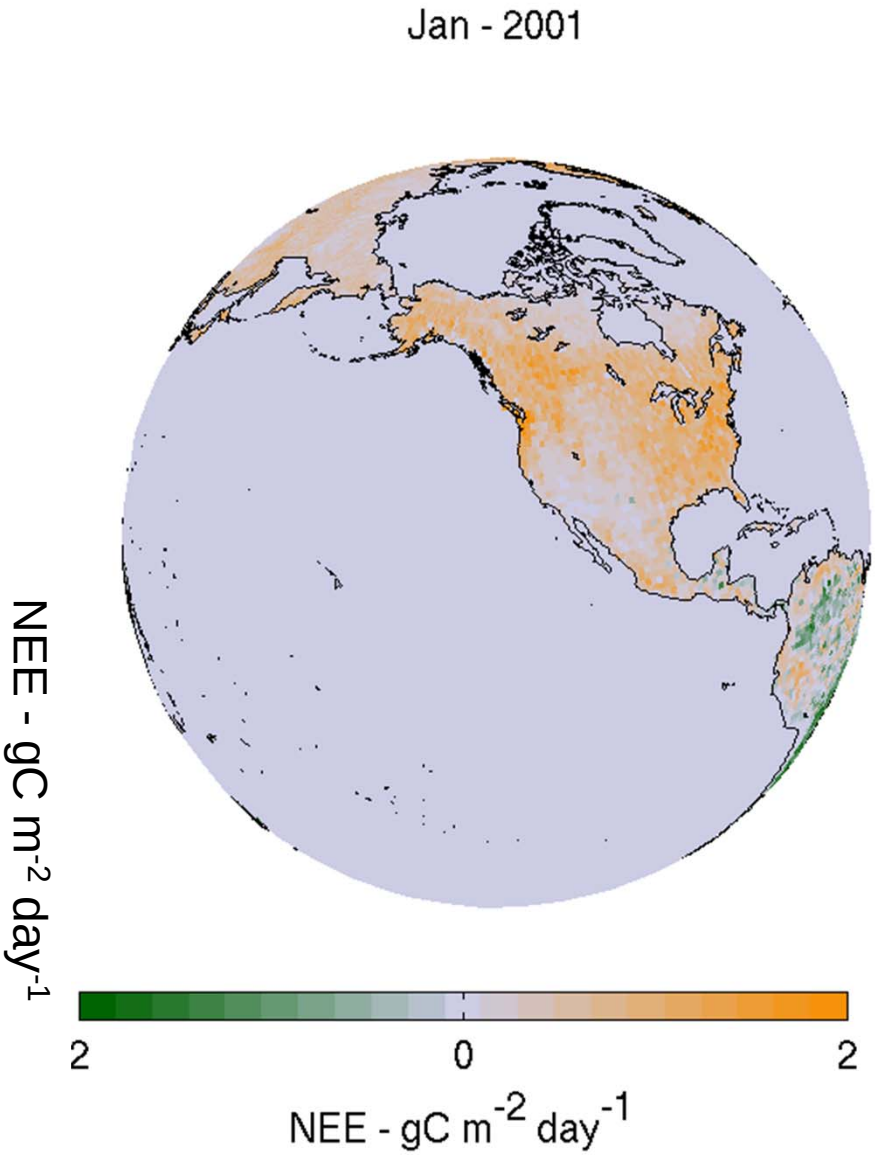
Mean monthly NEE at 1° x 1°

2001-2010: global terrestrial carbon cycle analysis.

NEE UNCERTAINTY



Bloom & Williams, in prep.



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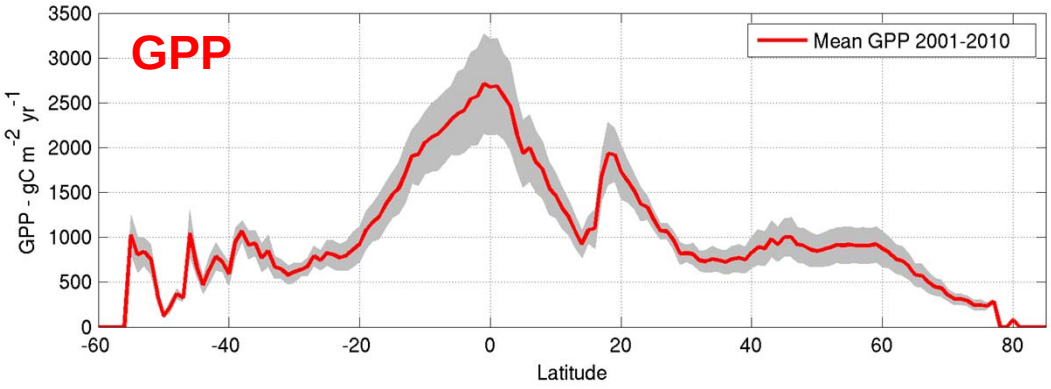
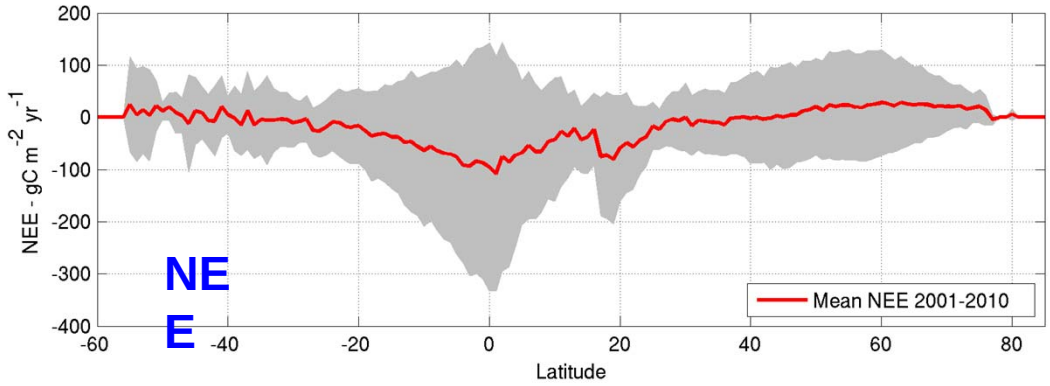
CARDAMOM fluxes 2001-2010: key results

(A) Global carbon flux estimates





Gross Primary Production

$GPP_{01\text{-}10}$ = 123.2 ± 7.5 PgC yr^{-1}

Net Ecosystem Exchange

$NEE_{01\text{-}10}$ = -1.8 ± 2.7 PgC yr^{-1}

Global carbon pool totals

Labile = 4 ± 2 Pg C

Foliar = 11 ± 7 Pg C

Fine Roots = 16 ± 12 Pg C

Wood = 535 ± 298 Pg C

Litter = 17 ± 14 Pg C

SOM = 1415 ± 735 Pg C

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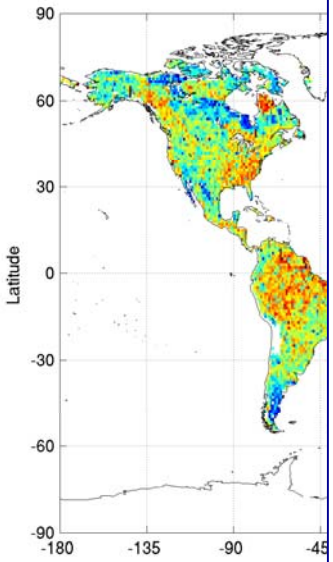
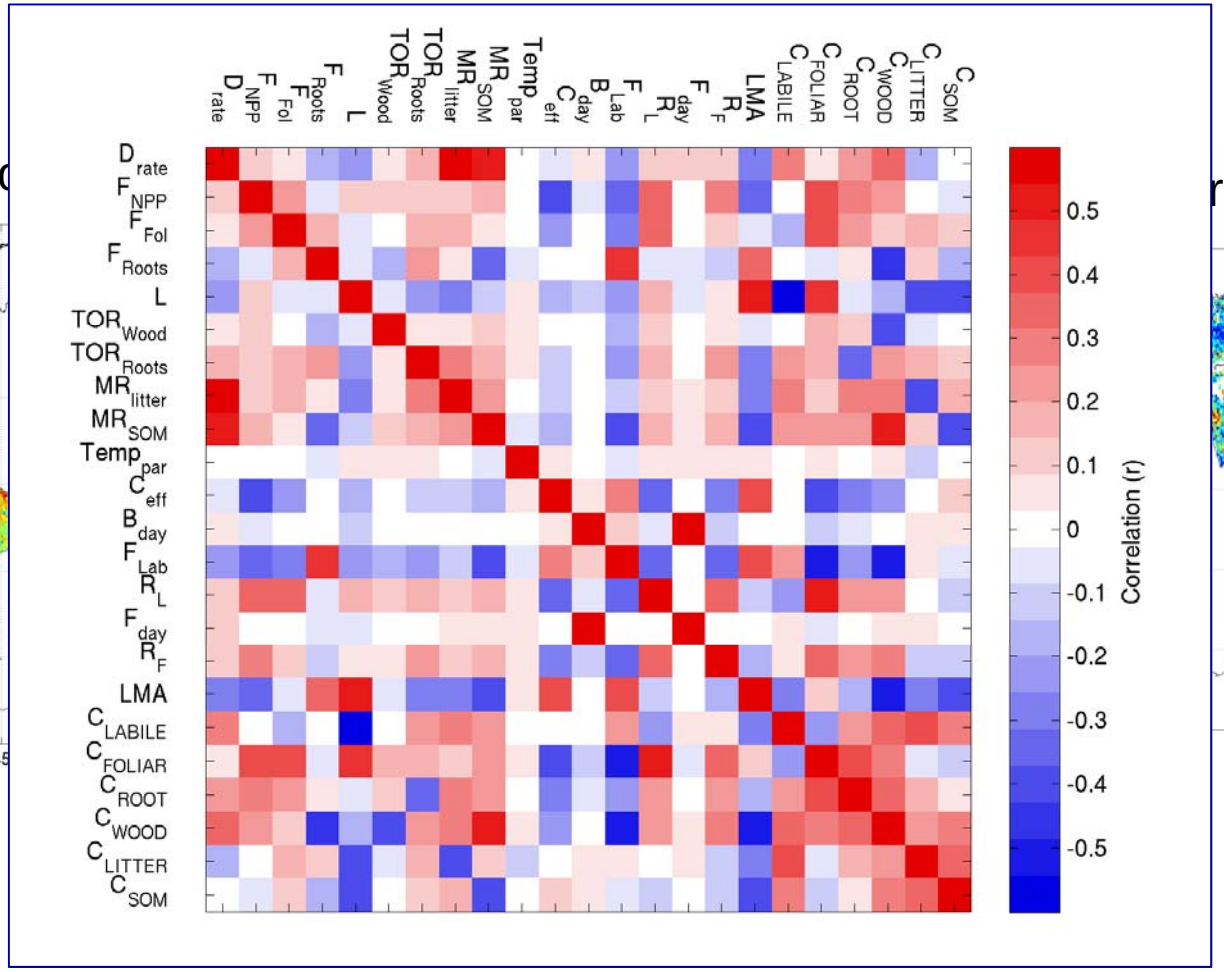
CARDAMOM DALEC – Posterior parameters

Soil turnc





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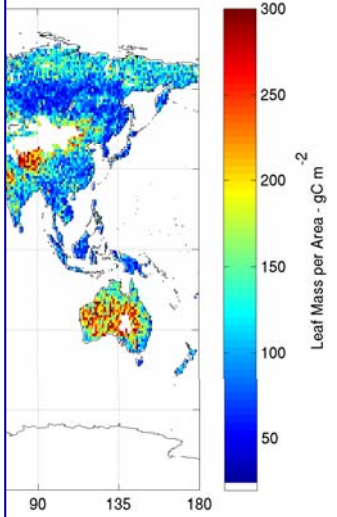

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Next steps – perturbed systems

- Assimilating burned area data (MODIS) and deforestation time series (LandSat...)
- Assimilating sequential biomass maps (ALOS, BIOMASS...)
- Including croplands and other human managed systems

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Conclusions

- CARDAMOM provides a data-consistent approach to terrestrial C analysis across scales
- Multiple data-streams combined with constrained mass balance modelling allow estimation of C dynamics from local to global
- Coupling to N and water cycles – to allows link to further EO/field data constraints and process interaction

Acknowledgements:

Ameriflux PIs, NASA MODIS team, Saatchi et al. biomass team, HWSD team, TRY team, FLUXCOM partners

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