January 6, 2016 @ Kyoto University
International Workshop on Vegetation Lidar and Application from Space

Terrestrial carbon modeling and Earth observation

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National Institute for Environmental Studies

Global Carbon Budget

(2005–2014 average)

33.0 ± 1.6 GtCO$_2$/yr 91%

Sources

3.4 ± 1.8 GtCO$_2$/yr 9%

16.0 ± 0.4 GtCO$_2$/yr
44%

Partitioning

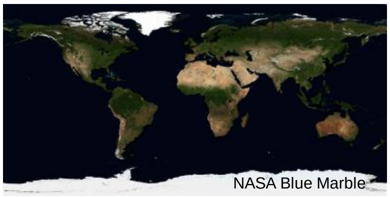
9.5 ± 2.9 GtCO$_2$/yr
30%
Calculated as the residual
of all other flux components

26%
10.9 ± 1.8 GtCO$_2$/yr

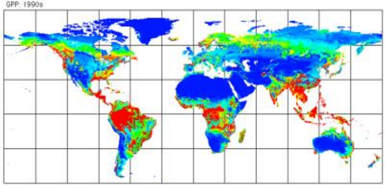
Source: CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2015; Global Carbon Budget 2015

Remote Sensing and Modeling

Remote Sensing


NASA Blue Marble

Modeling



	Remote Sensing	Modeling
👍	Global continuous monitoring Many spectral bands & variables Fine resolution (diagnostic)	Global simulation Many biogeochemical variables Future prediction (prognostic)
👎	Low frequency (except stationary ones) Cloud/aerosol/topography/ionosphere Short time coverage, drift, discontinuity No future prediction	Low–middle spatial resolution Estimation uncertainty Insufficient validation

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Modeling of Terrestrial Ecosystems

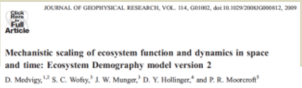
Terrestrial ecosystems (e.g., forest, grassland, shrub, desert etc.)
=> great diversity, heterogeneity, and complexity inc. human factors

Ecosystem modeling needs simplification (and assumptions) focusing on:
- structural aspects
  => height, volume, biomass, density, surface area, etc.
- functional aspects
  => productivity, gas exchange, resource use (efficiency) etc.

Many terrestrial ecosystem models have been developed:
- classic: mathematical models (e.g., logistic, Lotka-Volterra)
- modern: process-based (e.g., CASA, Biome-BGC)
- recent: dynamic / integrated (e.g., DGVMs, VISIT)
  => analysis, interpretation, prediction, application etc.

=> ESMs => management

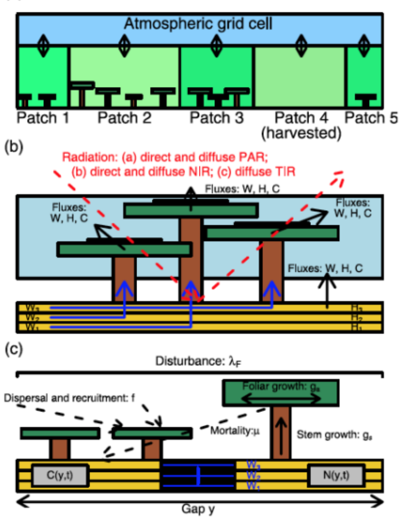
Structural Models


JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, G01002, doi:10.1029/2008JG000812, 2009

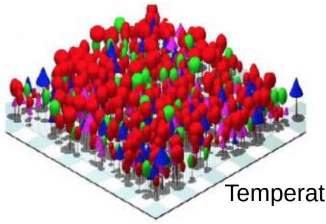
Mechanistic scaling of ecosystem function and dynamics in space and time: Ecosystem Demography model version 2

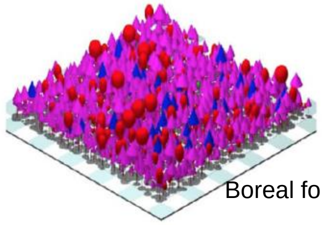
D. Medvigy,[1,2] S. C. Wofsy,[3] J. W. Munger,[3] D. Y. Hollinger,[4] and P. R. Moorcroft[5]

Ecosystem Demography version 2

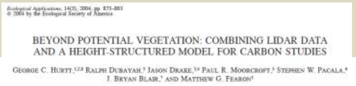


- Composition of plant functional types
- Vegetation canopy height
- Individual density and size distribution


Temperate forest

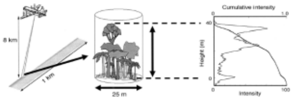

Boreal forest

Structural Models


Ecological Applications, 14(3), 2004, pp. S73–S83
© 2004 by the Ecological Society of America

BEYOND POTENTIAL VEGETATION: COMBINING LIDAR DATA AND A HEIGHT-STRUCTURED MODEL FOR CARBON STUDIES

George C. Hurtt,[1,2,8] Ralph Dubayah,[3] Jason Drake,[3,4] Paul R. Moorcroft,[5] Stephen W. Pacala,[6] J. Bryan Blair,[7] and Matthew G. Fearon[1]



Aircraft => DESDynI

(cancelled)

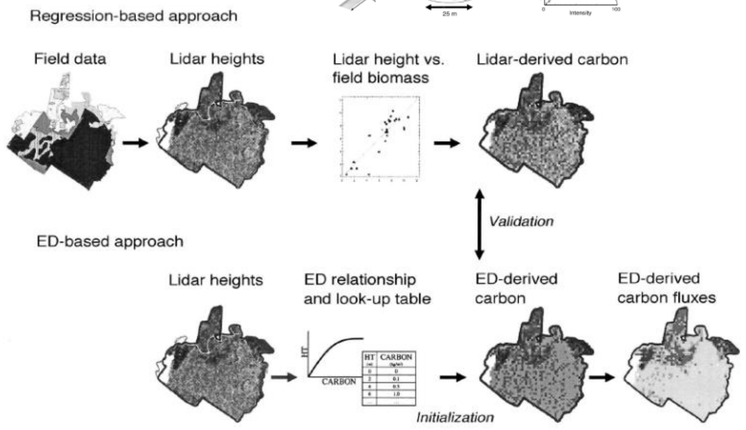


FIG. 4. Summary of the methodology for the regression-based and ED (ecosystem demography)-based approaches. The top row illustrates the regression-based approach in which field data and lidar data are statistically related and used to produce mapped estimates of carbon stocks. The bottom row illustrates the use of lidar data to initialize the ED model to produce mapped estimates of carbon stocks and net fluxes. Regression-based and ED-based estimates of carbon stocks are compared for validation.

(Hurtt et al. 2004)

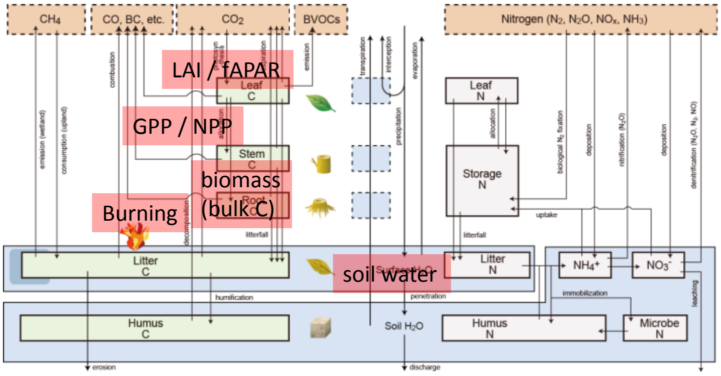
Functional Model

Vegetation Integrated SImulator for Trace gases

(Developed by NIES & JAMSTEC)

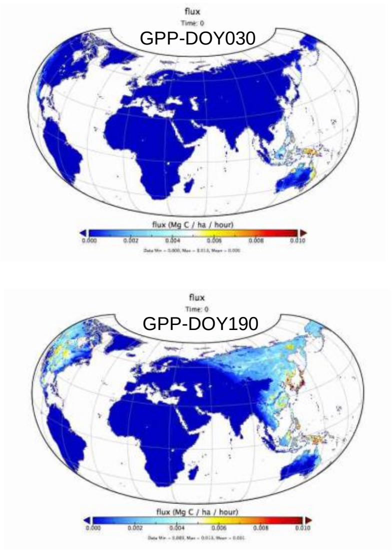
Objectives

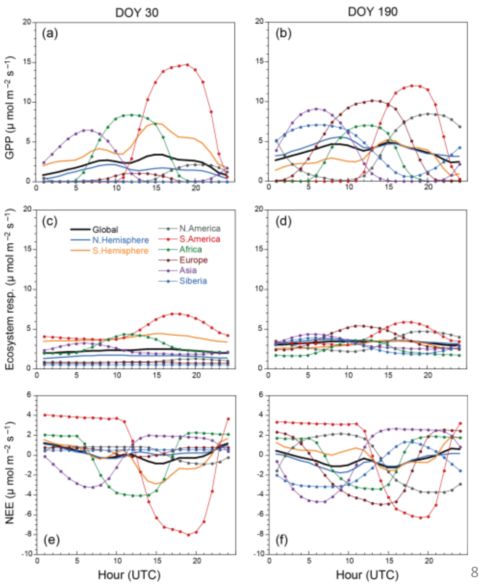
- Atmosphere-ecosystem biogeochemical interactions
- Assessment of climatic impacts and biotic feedbacks
- Ecosystem functions related to ecosystem services



Carbon-cycle *Water-cycle* *Nitrogen-cycle*

Simulation of Ecosystem Functions

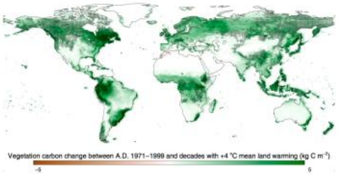




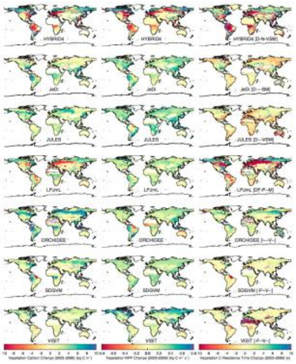
(Ito, Hikosaka, Patra, in revision)

Uncertainty

Carbon residence time dominates uncertainty in terrestrial vegetation responses to future climate and atmospheric CO_2

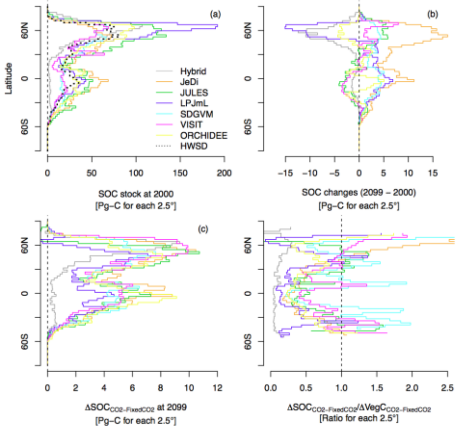


Different types of models



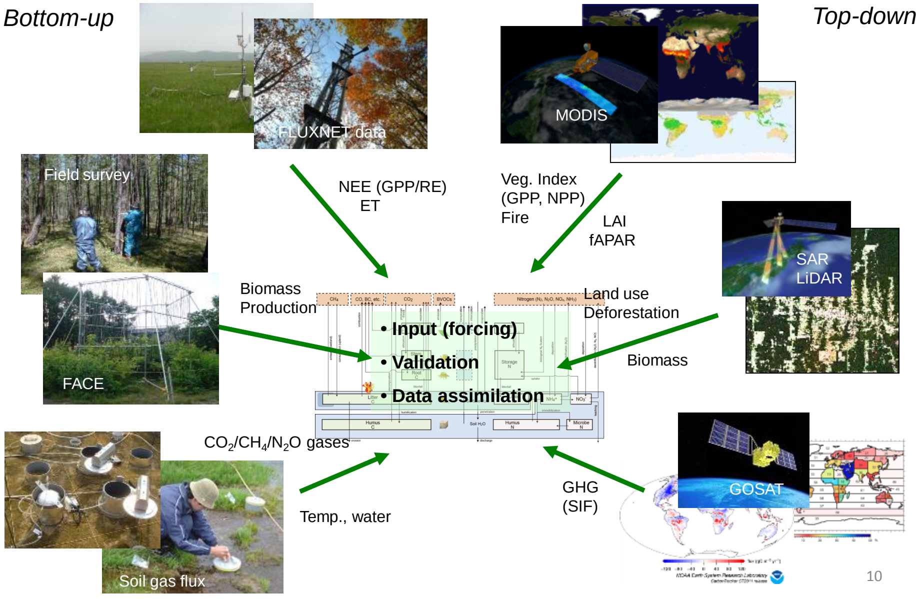
Earth System Dynamics

Quantifying uncertainties in soil carbon responses to changes in global mean temperature and precipitation



Friend, A. D., et al. (2014), Carbon residence time dominates uncertainty in terrestrial vegetation responses to future climate and atmospheric CO_2, *Proceedings of the National Academy of Science U.S.A.*, *111*(9), 3280–3285, doi:10.1073/pnas.1222477110.
Nishina, K., et al. (2014), Quantifying uncertainties in soil carbon responses to changes in global mean temperature and precipitation, *Earth System Dynamics*, *5*, 197–209, doi:10.5194/esd-5-197-2014.

Data–Model Fusion



Bottom-up

Top-down

FLUXNET data

MODIS

Field survey

NEE (GPP/RE)
ET

Veg. Index
(GPP, NPP)
Fire

LAI
fAPAR

SAR
LiDAR

Biomass
Production

Land use
Deforestation

- **Input (forcing)**
- **Validation**
- **Data assimilation**

FACE

Biomass

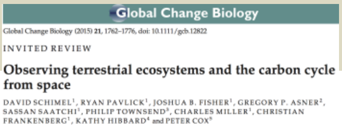
$CO_2/CH_4/N_2O$ gases

Temp., water

GHG
(SIF)

GOSAT

Soil gas flux



Global Change Biology

Global Change Biology (2015) 21, 1762–1776, doi: 10.1111/gcb.12822

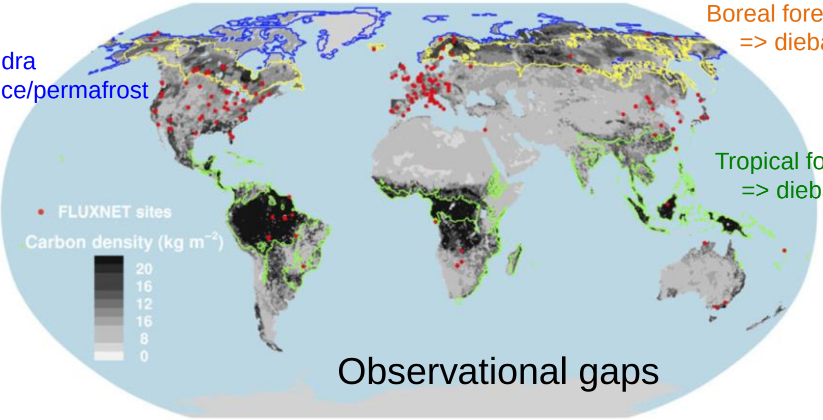
INVITED REVIEW

Observing terrestrial ecosystems and the carbon cycle from space

DAVID SCHIMEL[1], RYAN PAVLICK[1], JOSHUA B. FISHER[1], GREGORY P. ASNER[2], SASSAN SAATCHI[1], PHILIP TOWNSEND[3], CHARLES MILLER[1], CHRISTIAN FRANKENBERG[1], KATHY HIBBARD[4] and PETER COX[5]

Focal Area: Tipping Elements

Tipping elements: large-scale irreversible change
=> future risk and feedback



Tundra
=> ice/permafrost

Boreal forest
=> dieback

Tropical forest
=> dieback

Observational gaps

(Schimel et al., 2015)

Global Change Biology

Global Change Biology (2015) 21, 1762–1776, doi: 10.1111/gcb.12822

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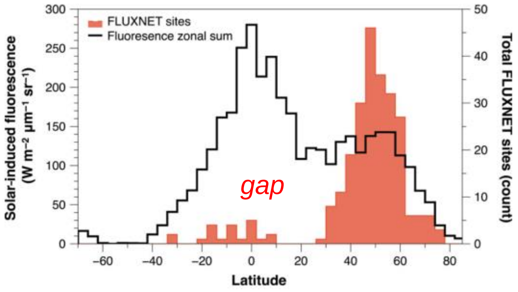
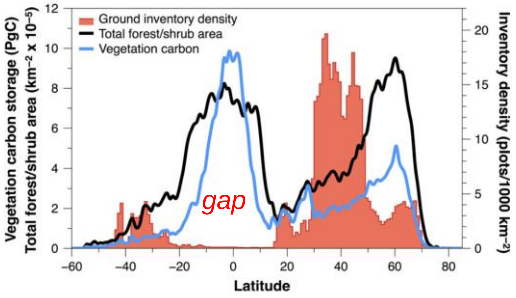
Gaps in Field Observations

Productivity
(function)



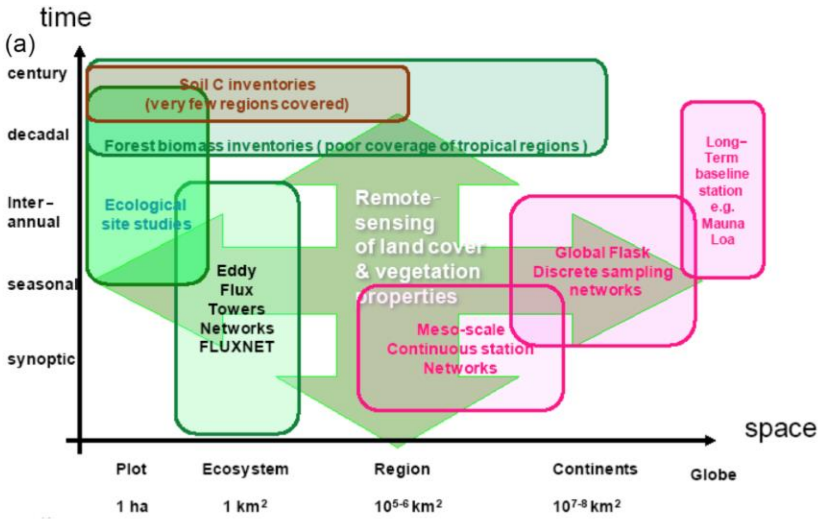
Biomass
(structure)



(Schimel et al., 2015)

Earth Observations


Current systematic carbon-cycle observations and the need for implementing a policy-relevant carbon observing system



(Ciais et al., 2014)

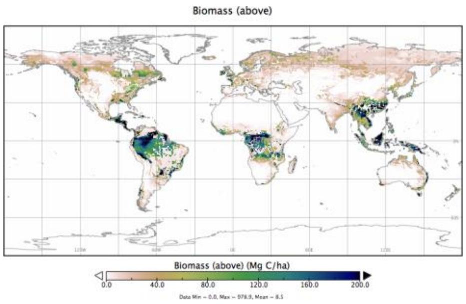
Estimated Biomass Distribution

VISIT

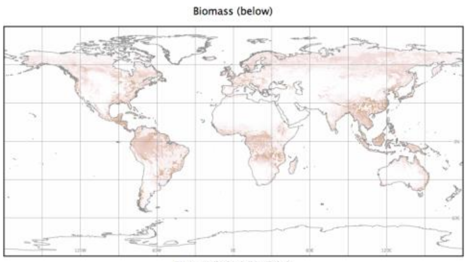
Model estimation based on mass-balance (or growth)
∆Biomass = Photosynthesis – Respiration – Litterfall – (Burning + Harvest)

=> Forest degradation could be underestimated
=> Need more validation for both stocks and flows

Aboveground (leaf+stem): 454 Pg C (85.4%)



Belowground (root): 78 Pg C (14.6%)



Validation data

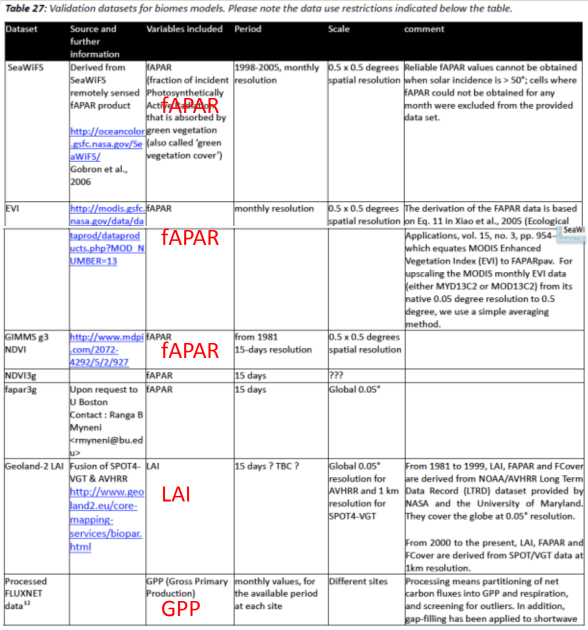
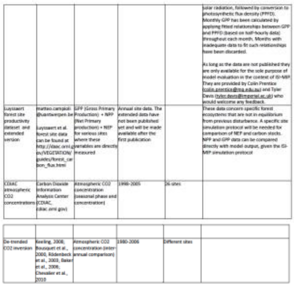


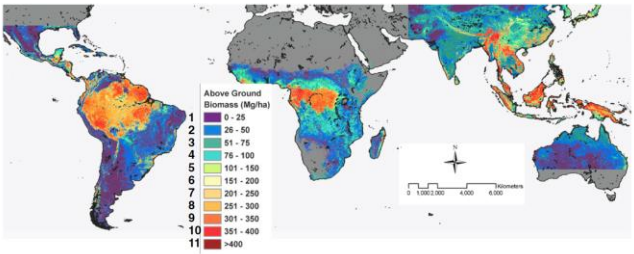
Table 27: Validation datasets for biomes models. Please note the data use restrictions indicated below the table.

Dataset	Source and further information	Variables included	Period	Scale	comment
SeaWiFS	Derived from SeaWiFS remotely sensed fAPAR product http://oceancolor.gsfc.nasa.gov/SeaWiFS/ Gobron et al., 2006	fAPAR (fraction of incident Photosynthetically Active Radiation that is absorbed by green vegetation (also called 'green vegetation cover') fAPAR	1998-2005, monthly resolution	0.5 x 0.5 degrees spatial resolution	Reliable fAPAR values cannot be obtained when solar incidence is > 50°; cells where fAPAR could not be obtained for any month were excluded from the provided data set.
EVI	http://modis.gsfc.nasa.gov/data/dataprod/dataproducts.php?MOD_NUMBER=13	fAPAR fAPAR	monthly resolution	0.5 x 0.5 degrees spatial resolution	The derivation of the FAPAR data is based on Eq. 11 in Xiao et al., 2005 (Ecological Applications, vol. 15, no. 3, pp. 954– which equates MODIS Enhanced Vegetation Index (EVI) to FAPARpav. For upscaling the MODIS monthly EVI data (either MYD13C2 or MOD13C2) from its native 0.05 degree resolution to 0.5 degree, we use a simple averaging method.
GIMMS g3 NDVI	http://www.mdpi.com/2072-4292/5/2/927	fAPAR fAPAR	from 1981 15-days resolution	0.5 x 0.5 degrees spatial resolution	
NDVI3g		fAPAR	15 days	???	
fapar3g	Upon request to U Boston Contact : Ranga B Myneni <rmyneni@bu.edu>	fAPAR	15 days	Global 0.05°	
Geoland-2 LAI	Fusion of SPOT4-VGT & AVHRR http://www.geoland2.eu/core-mapping-services/biopar.html	LAI LAI	15 days ? TBC ?	Global 0.05° resolution for AVHRR and 1 km resolution for SPOT4-VGT	From 1981 to 1999, LAI, FAPAR and FCover are derived from NOAA/AVHRR Long Term Data Record (LTRD) dataset provided by NASA and the University of Maryland. They cover the globe at 0.05° resolution. From 2000 to the present, LAI, FAPAR and FCover are derived from SPOT/VGT data at 1km resolution.
Processed FLUXNET data[12]		GPP (Gross Primary Production) GPP	monthly values, for the available period at each site	Different sites	Processing means partitioning of net carbon fluxes into GPP and respiration, and screening for outliers. In addition, gap-filling has been applied to shortwave

Example of ISI-MIP

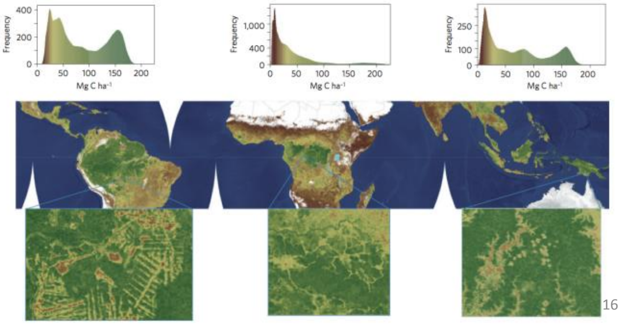


LiDAR-observed Biomass



(Saatchi et al. 2011, PNAS)
AGB 193 Pg C
BGB 54 Pg C

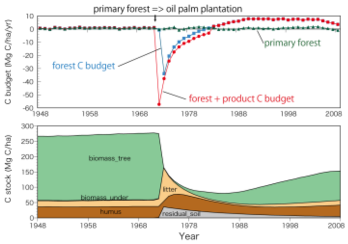
- MODIS 500m imagery
- GLAS LiDAR
- SRTM



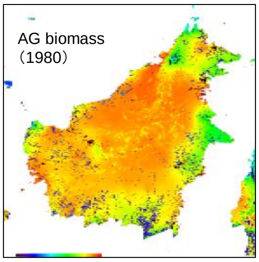
(Baccini et al. 2012, NCC)
AGB 228.7 Pg C

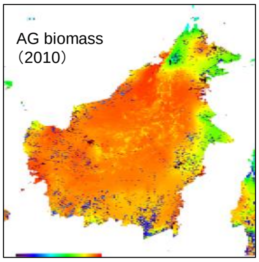
- MODIS 500m imagery
- GLAS LiDAR
- SRTM

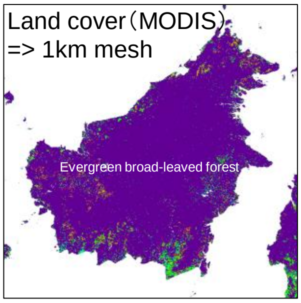
Scale-gap can be reduced by fine-resolution



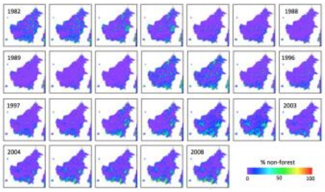
Model estimation

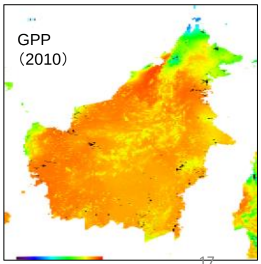

AG biomass
（1980）


AG biomass
（2010）


Land cover（MODIS）
=> 1km mesh

forest cover map (1981-2008)




GPP
（2010）

(Adachi et al., unpublished)

RS of Biodiversity


Contents lists available at ScienceDirect

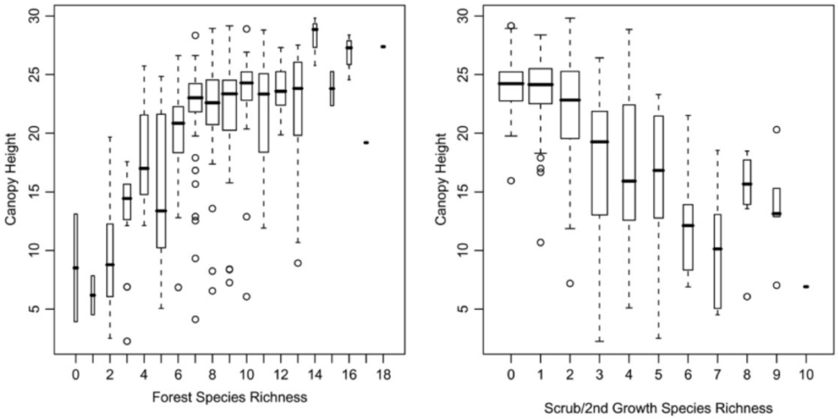
Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Characterizing 3D vegetation structure from space: Mission requirements

Forrest G. Hall a,*, Kathleen Bergen b, James B. Blair c, Ralph Dubayah d, Richard Houghton f, George Hurtt g, Josef Kellndorfer f, Michael Lefsky i, Jon Ranson c, Sasan Saatchi h, H.H. Shugart i, Diane Wickland e

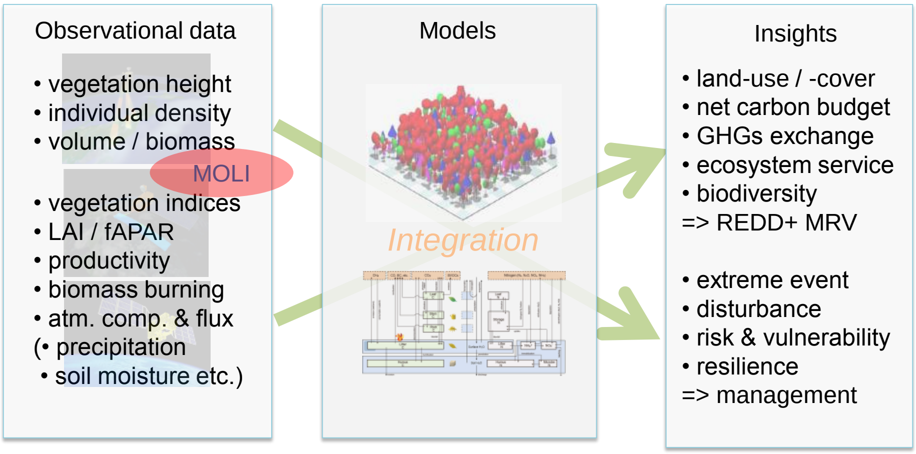
Canopy height



Biodiversity (bird)

(Hall et al., 2011)

Concluding remarks



Observational data

- vegetation height
- individual density
- volume / biomass

- vegetation indices
- LAI / fAPAR
- productivity
- biomass burning
- atm. comp. & flux

(• precipitation
 • soil moisture etc.)

Models

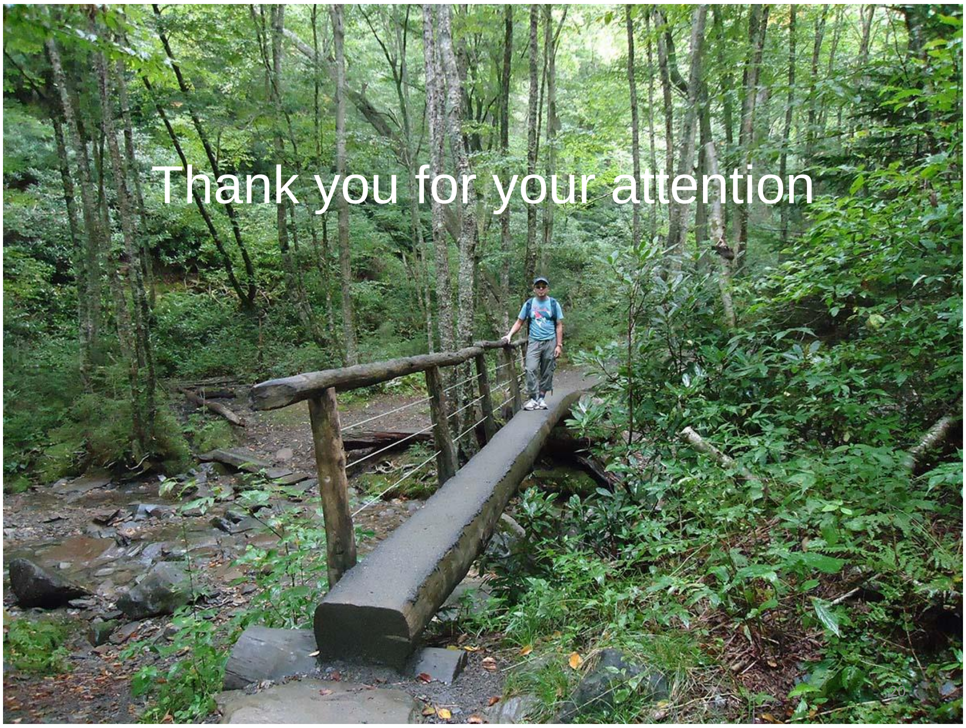
Insights

- land-use / -cover
- net carbon budget
- GHGs exchange
- ecosystem service
- biodiversity

=> REDD+ MRV

- extreme event
- disturbance
- risk & vulnerability
- resilience

=> management



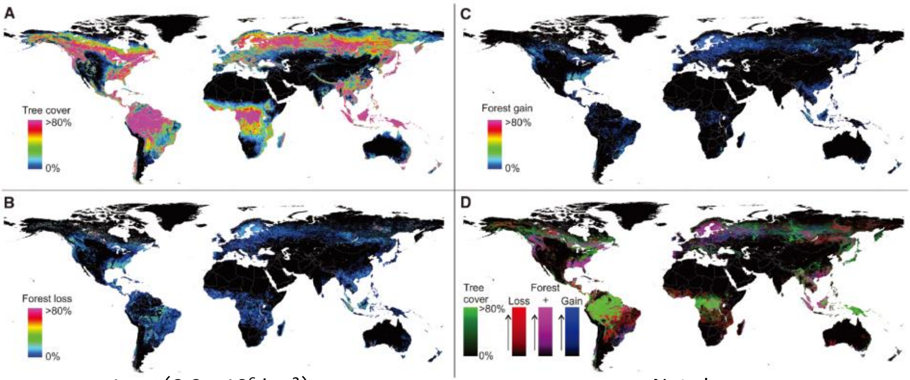
Thank you for your attention

Land-cover change

2000–2012 Landsat data + Google Earth Engine

Forest cover

Gain（0.8 x 10^6 km^2）

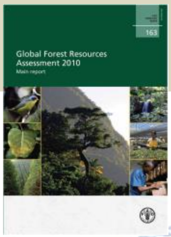


Loss（2.3 x 10^6 km^2）

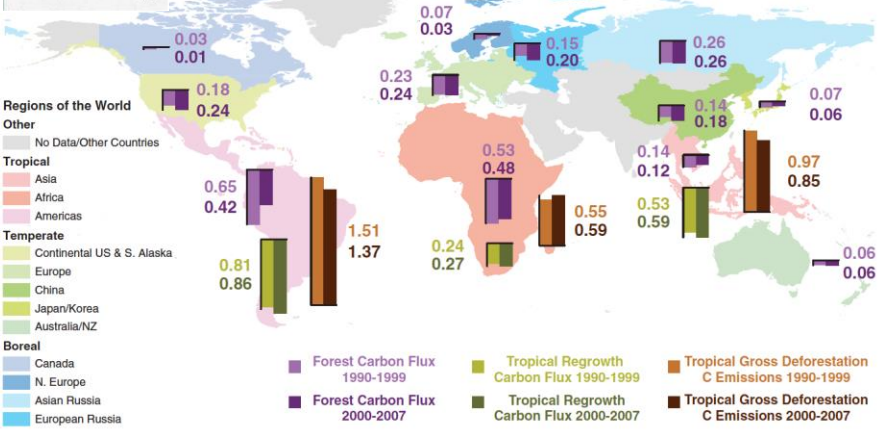
Net change

(Hansen et al. 2013, Science)

Forest Inventory

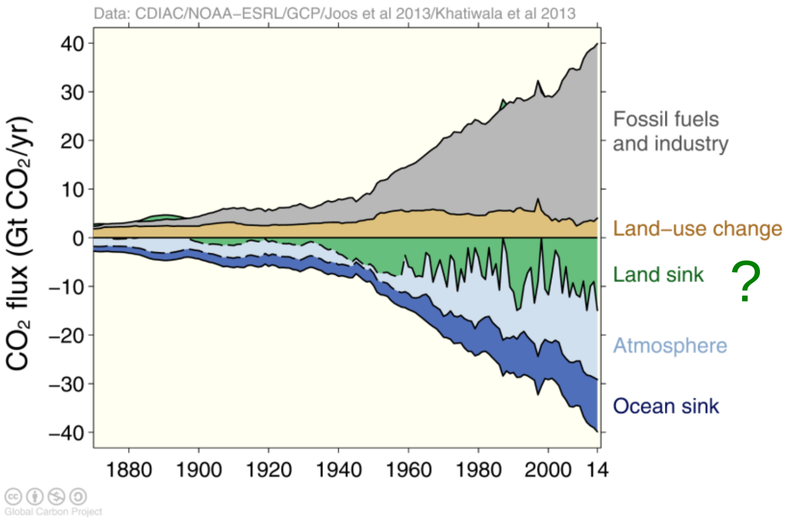


Global Forest Resources Assessment 2010
Main report



(Pan et al. 2011, Science)

Global Carbon Budget



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