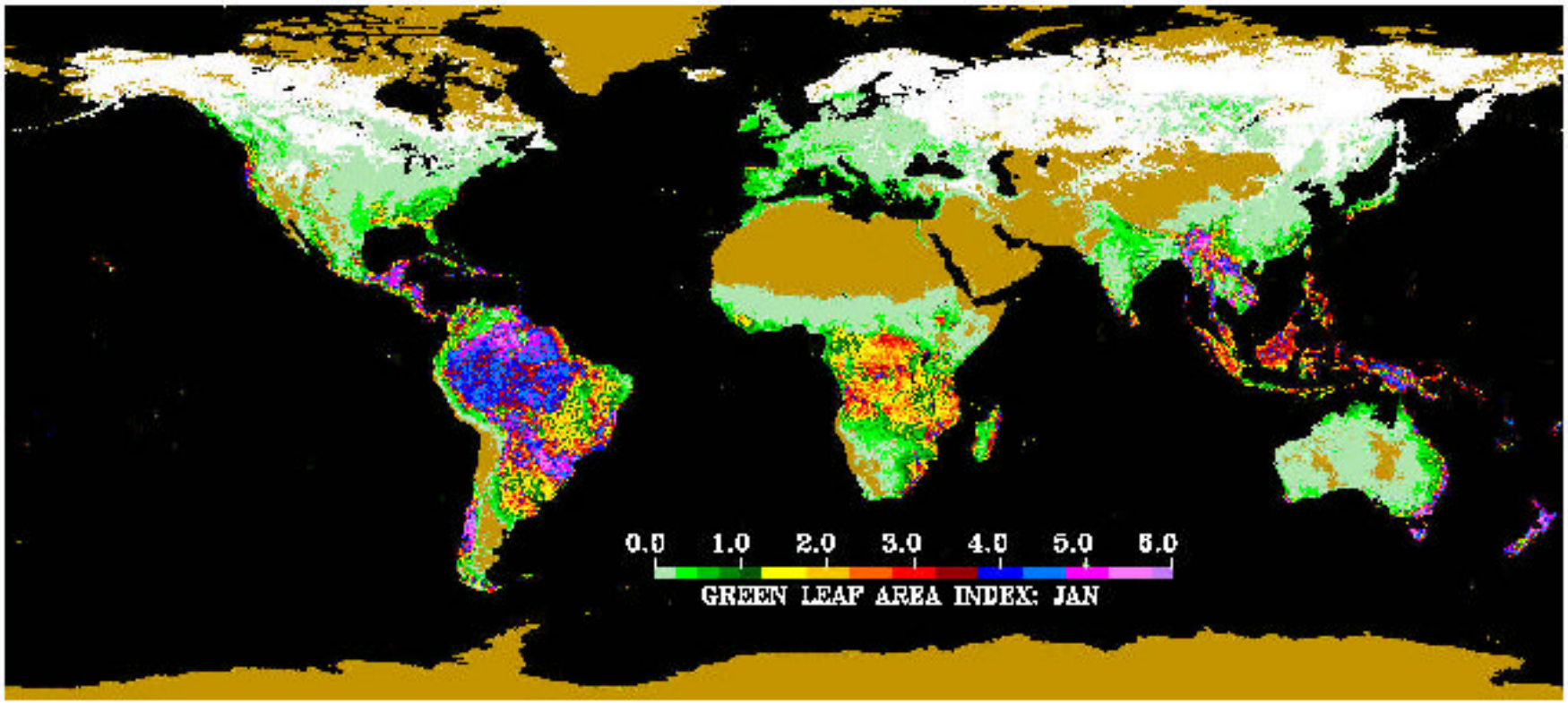
MODIS LAND ECOSYSTEM PRODUCTS

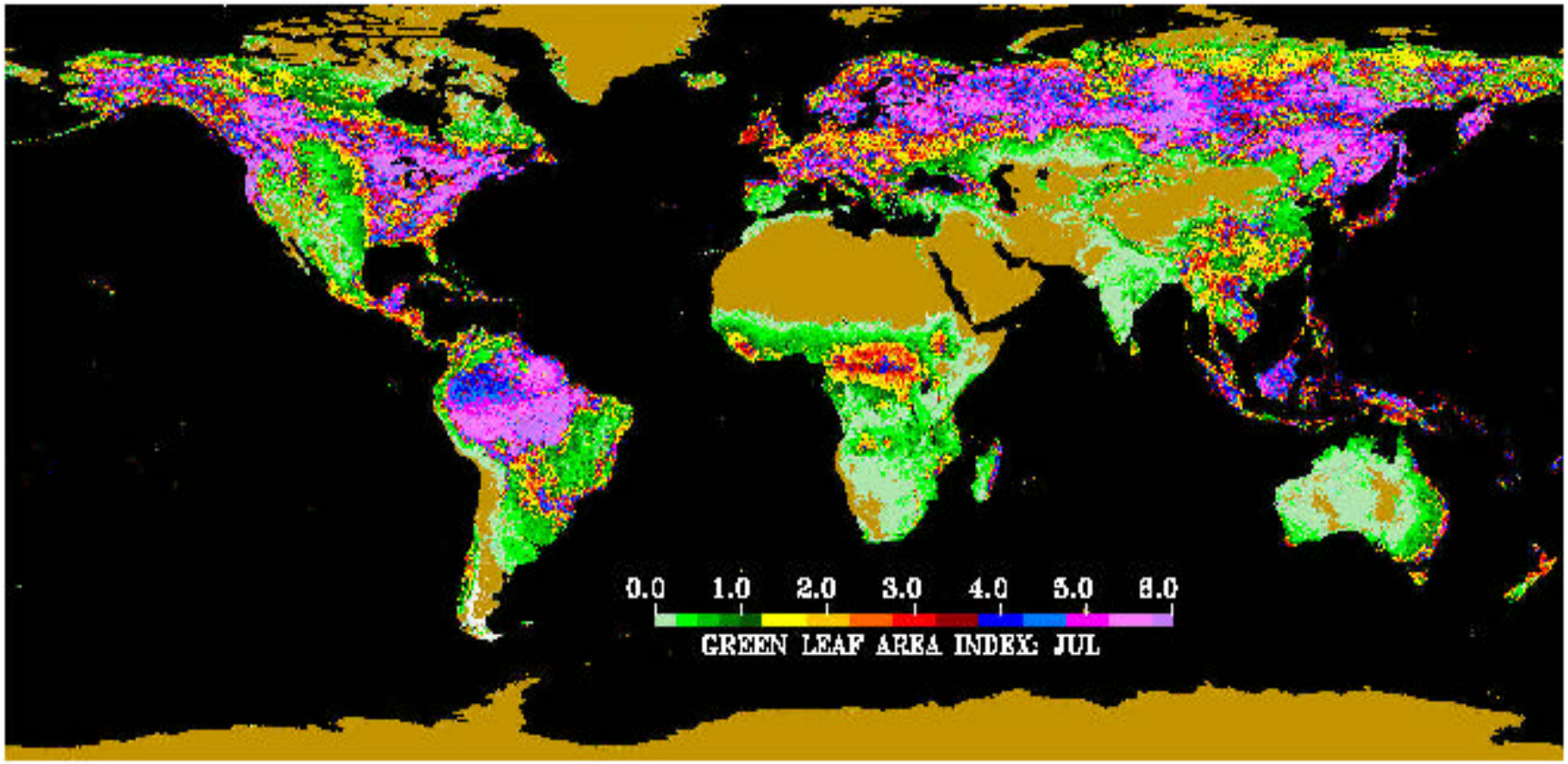
Steven W. Running,
with material from R. Myneni,
W.B.Cohen, and R.J.Olson

MODIS SCIENCE TEAM MEETING
DECEMBER 16, 1998

LAI (Leaf Area Index)

- LAI quantifies *vegetation canopy structure*, so changes weekly/seasonally
- Uses of LAI
  - GCMs for Land surface parameterization and energy partitioning
  - Hydrologic models as a scalar for evapotranspiration
  - Carbon cycle models to compute photosynthesis/respiration balances


0.0
1.0
2.0
3.0
4.0
5.0
6.0
GREEN LEAF AREA INDEX: JAN


0.0
1.0
2.0
3.0
4.0
5.0
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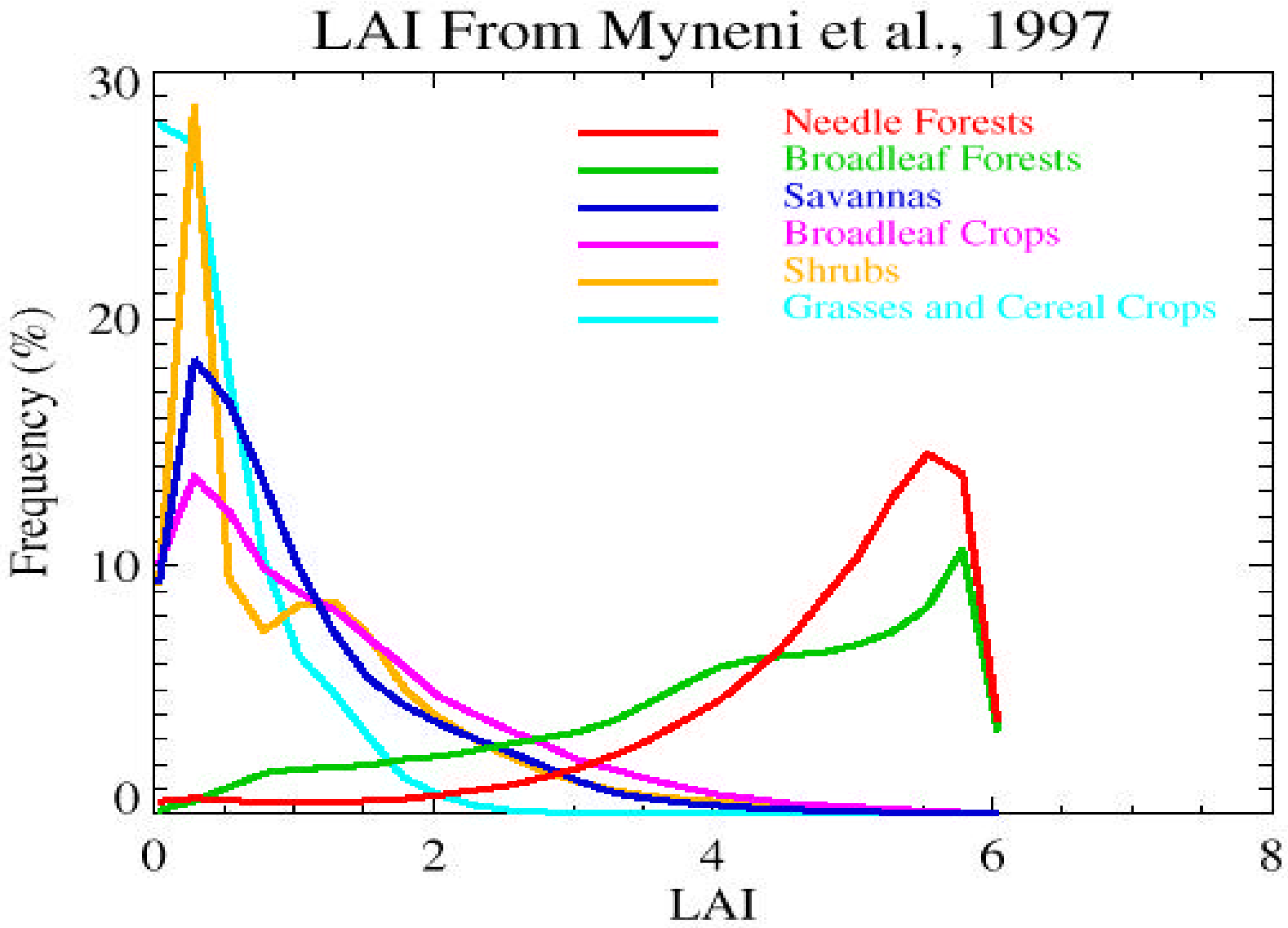
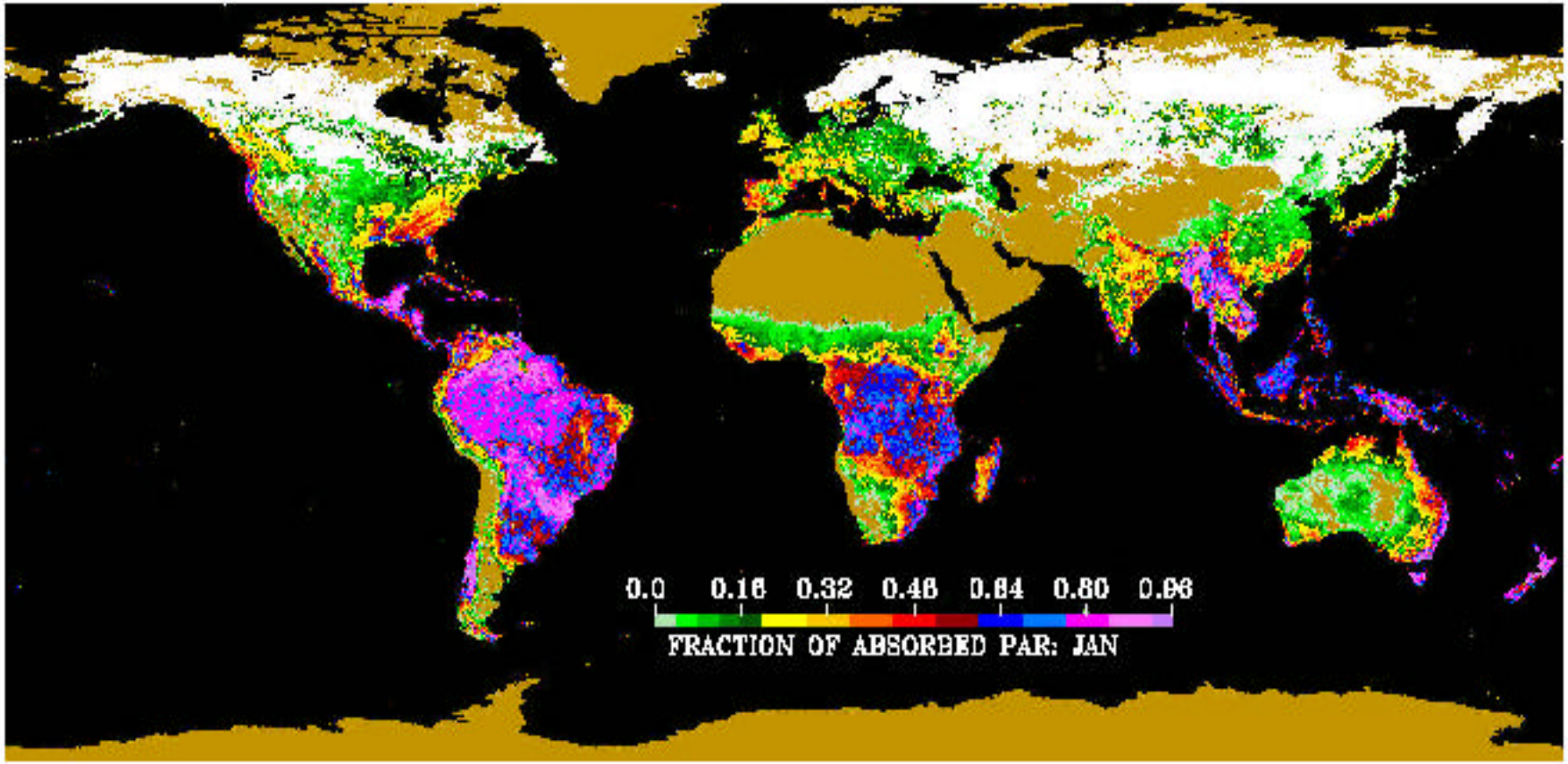
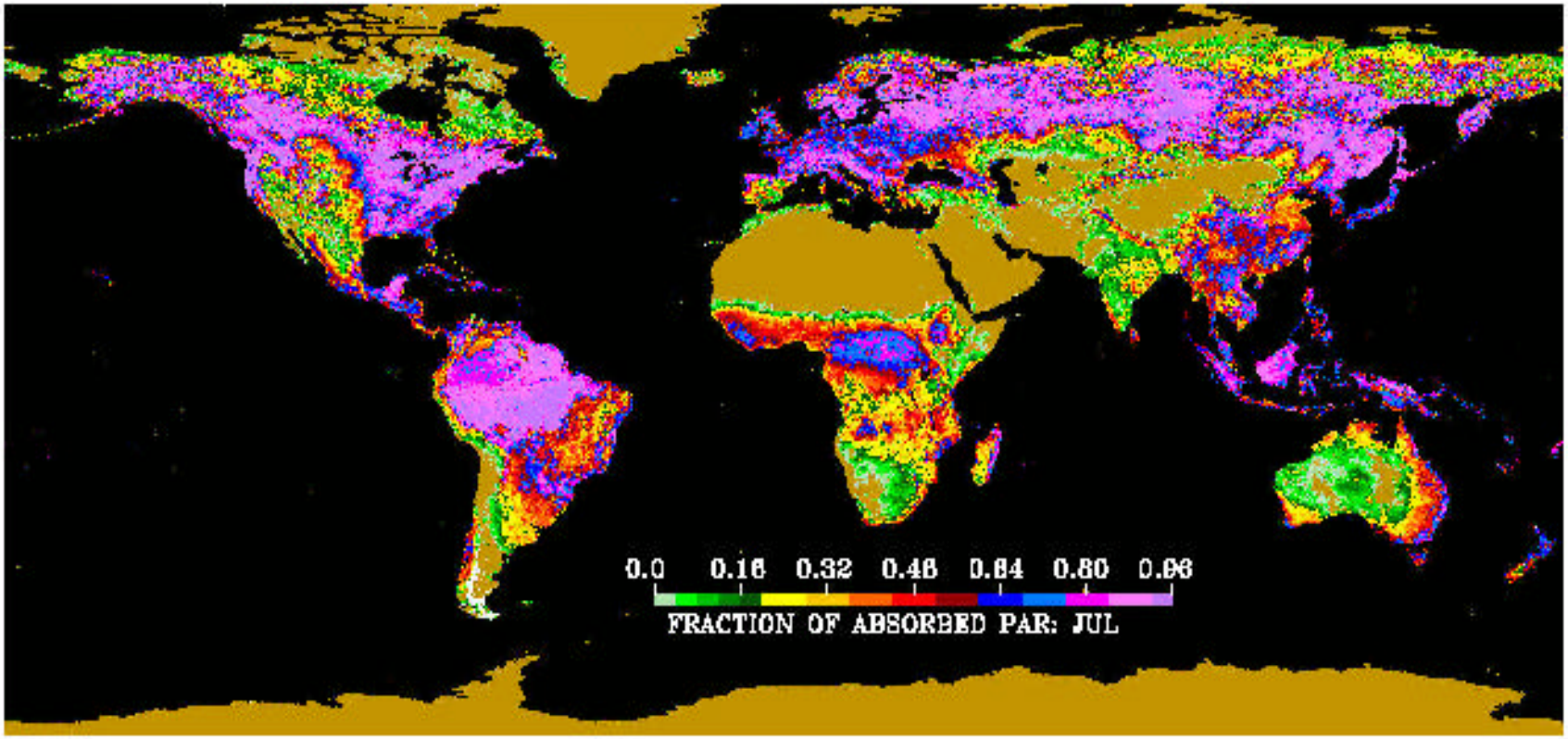
GREEN LEAF AREA INDEX: JUL

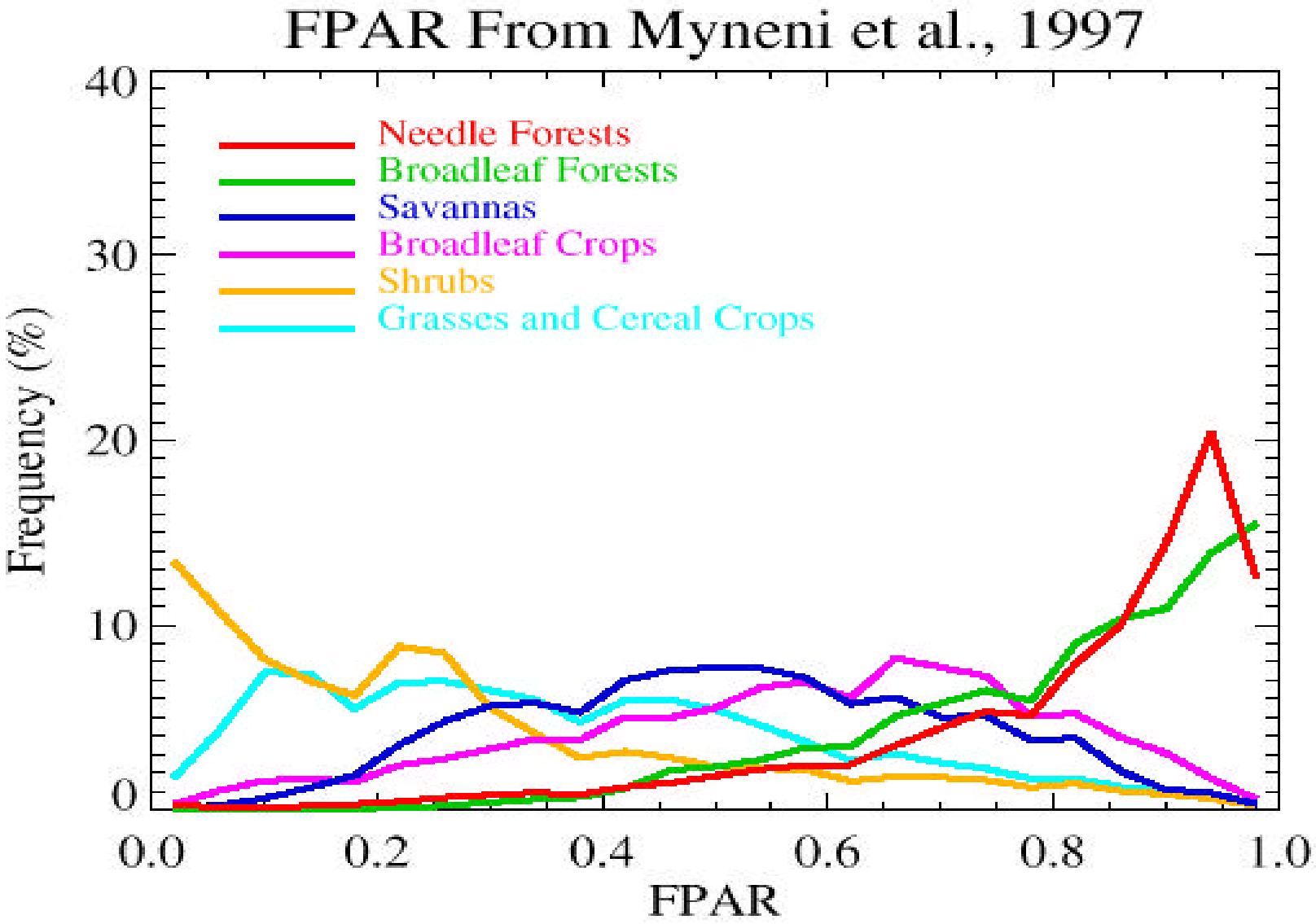

LAI From Myneni et al., 1997
Needle Forests
Broadleaf Forests
Savannas
Broadleaf Crops
Shrubs
Grasses and Cereal Crops
Frequency (%)
30
20
10
0
0
2
4
6
8
LAI

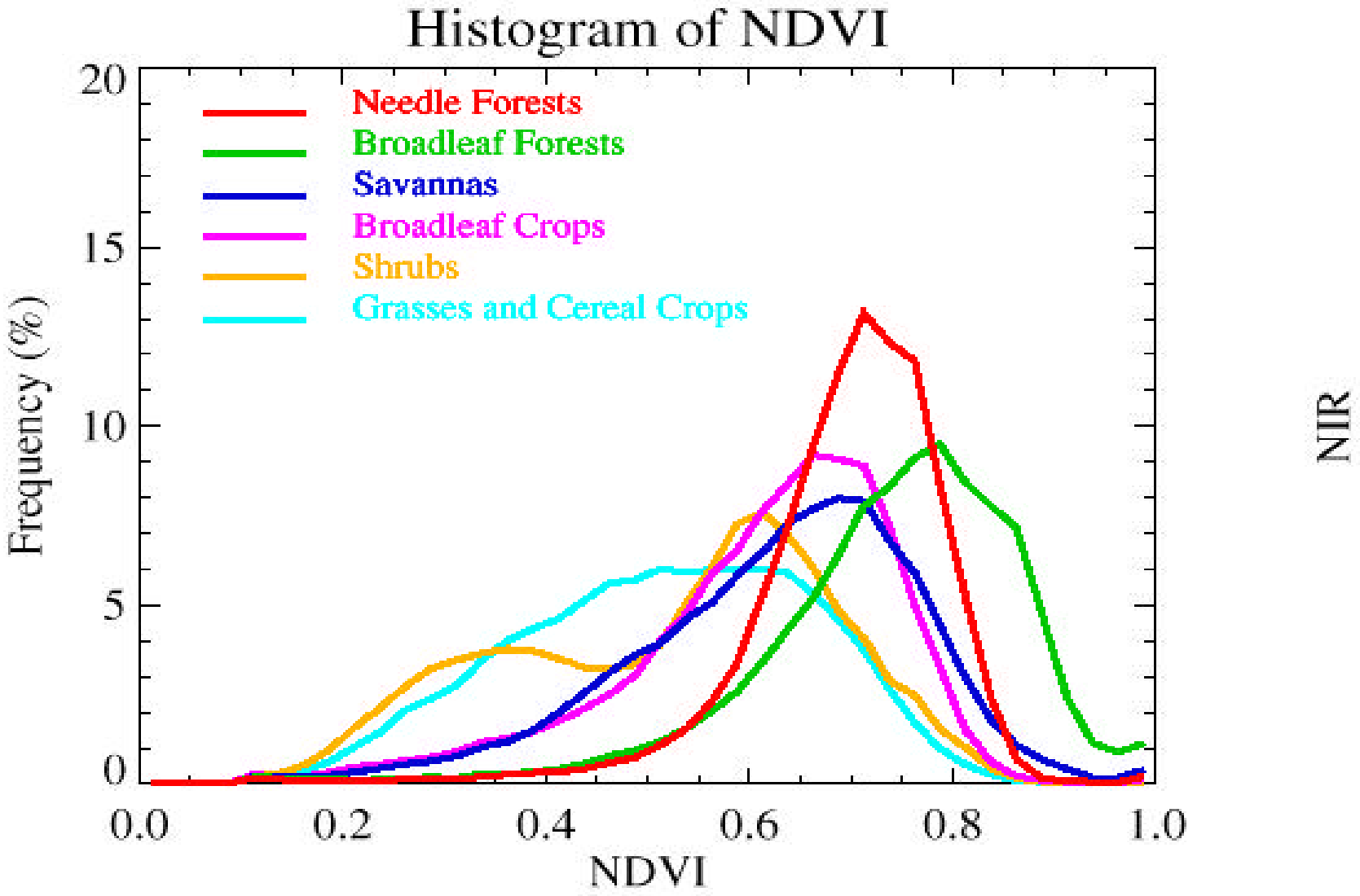
FPAR (Fraction Photosynthetically Active Radiation)

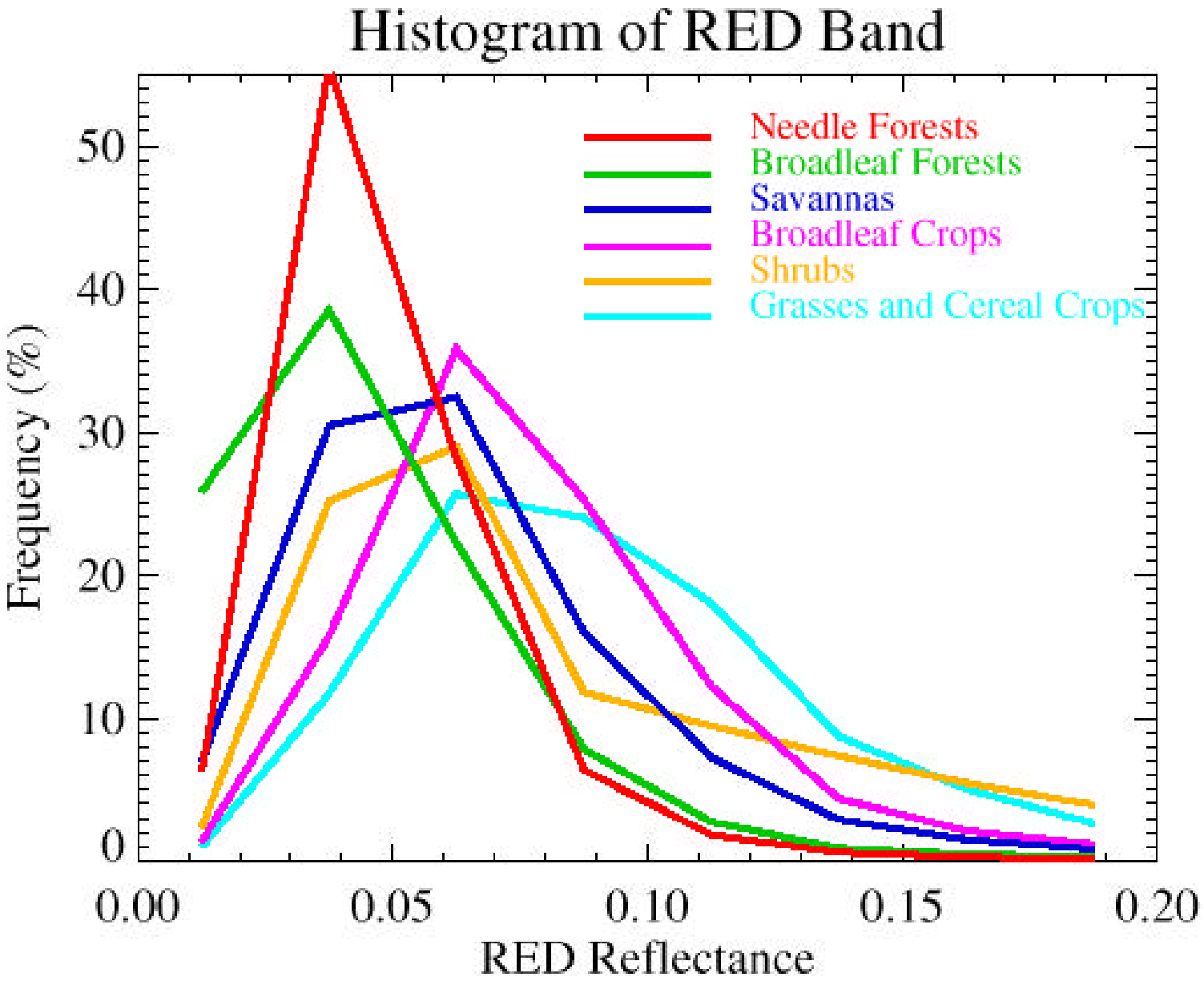
- FPAR *quantifies absorbed canopy radiation*, so changes daily
- conceptually related to NDVIs
- Use:
  - input to NPP algorithms

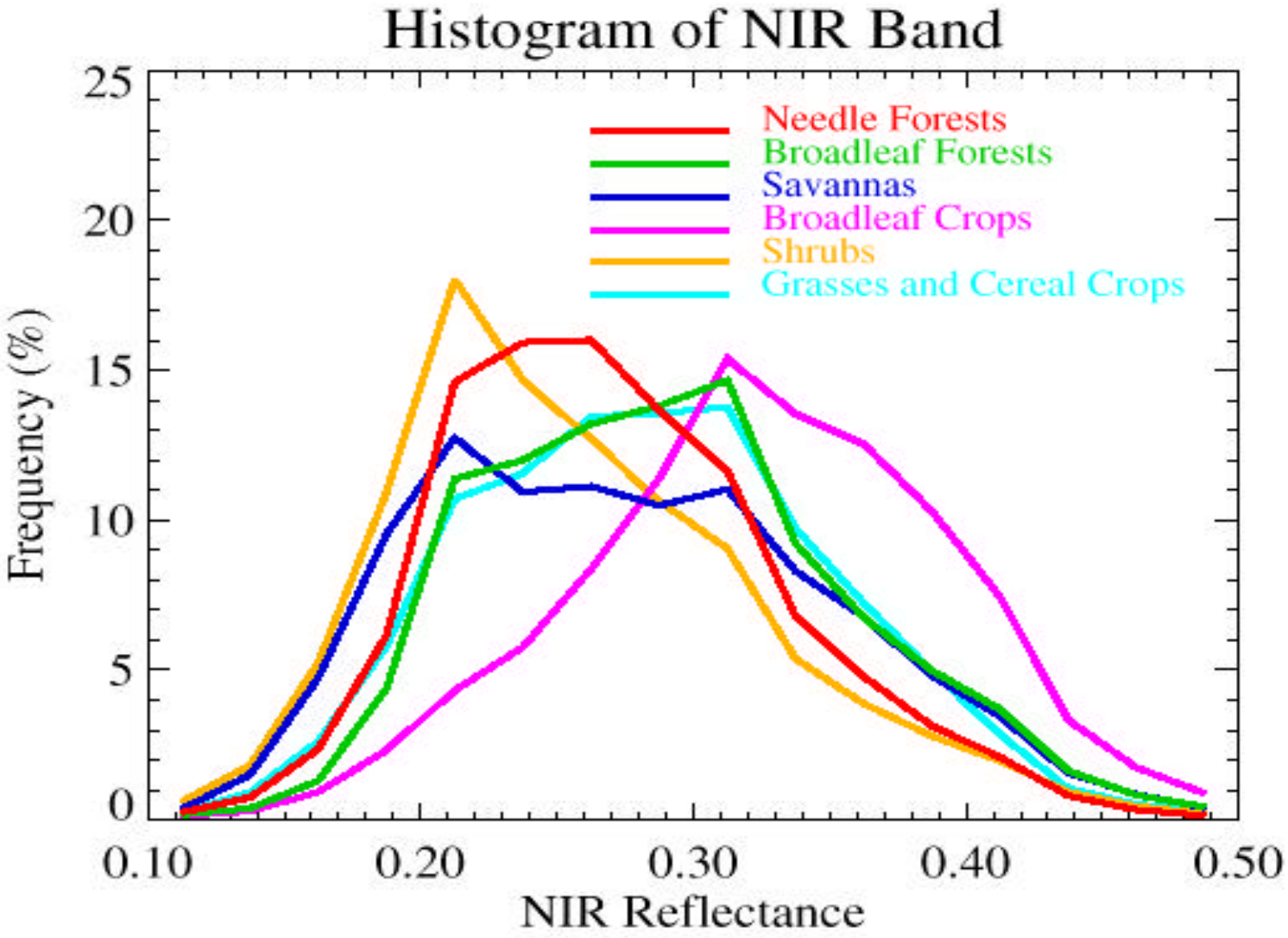

0.0 0.16 0.32 0.48 0.64 0.80 0.96
FRACTION OF ABSORBED PAR: JAN

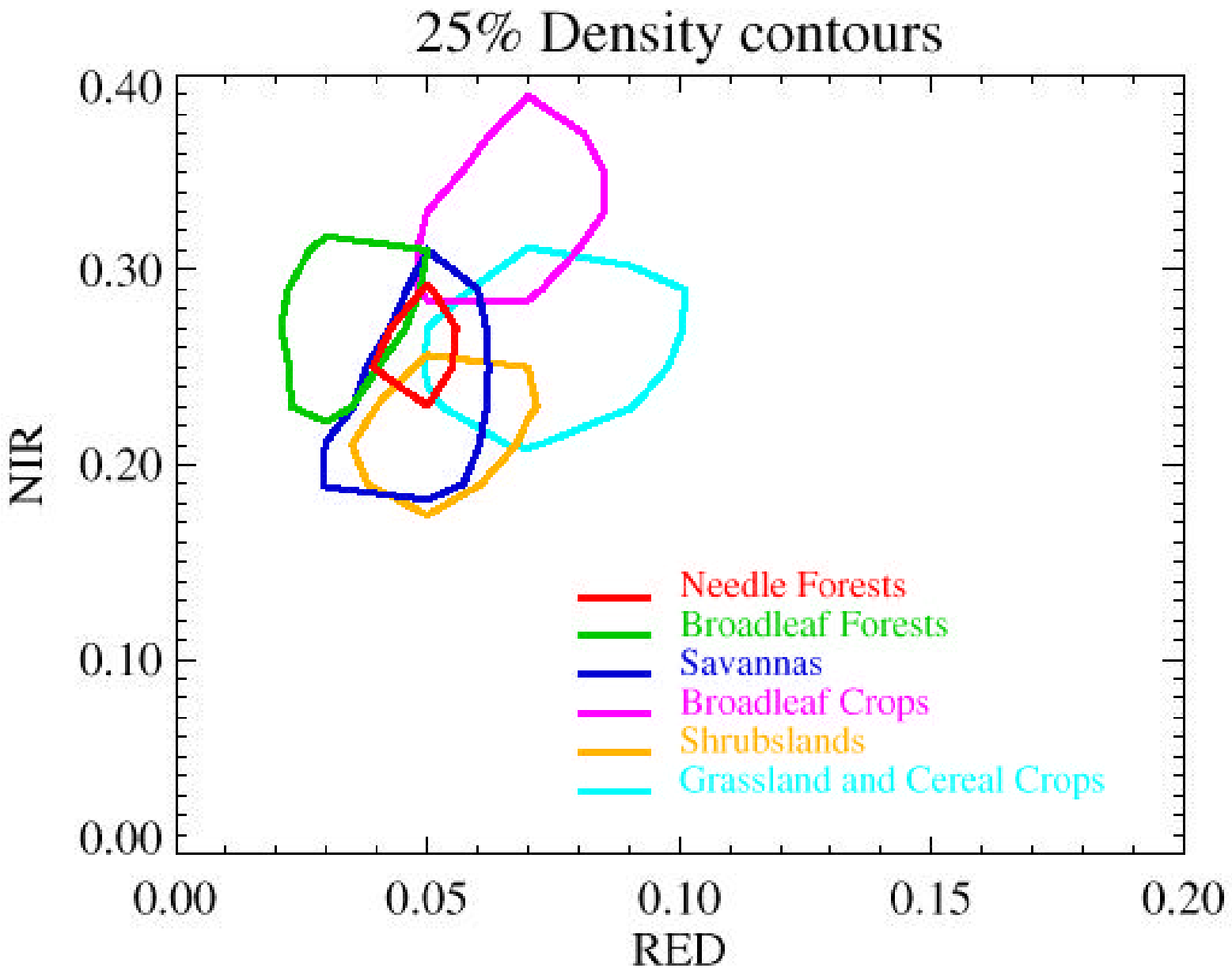

0.0 0.16 0.32 0.48 0.64 0.80 0.96
FRACTION OF ABSORBED PAR: JUL


FPAR From Myneni et al., 1997
Needle Forests
Broadleaf Forests
Savannas
Broadleaf Crops
Shrubs
Grasses and Cereal Crops
Frequency (%)
40
30
20
10
0
0.0
0.2
0.4
0.6
0.8
1.0
FPAR


Histogram of NDVI
Needle Forests
Broadleaf Forests
Savannas
Broadleaf Crops
Shrubs
Grasses and Cereal Crops
Frequency (%)
20
15
10
5
0
0.0
0.2
0.4
0.6
0.8
1.0
NDVI
NIR


Histogram of RED Band
Needle Forests
Broadleaf Forests
Savannas
Broadleaf Crops
Shrubs
Grasses and Cereal Crops
Frequency (%)
0
10
20
30
40
50
0.00
0.05
0.10
0.15
0.20
RED Reflectance

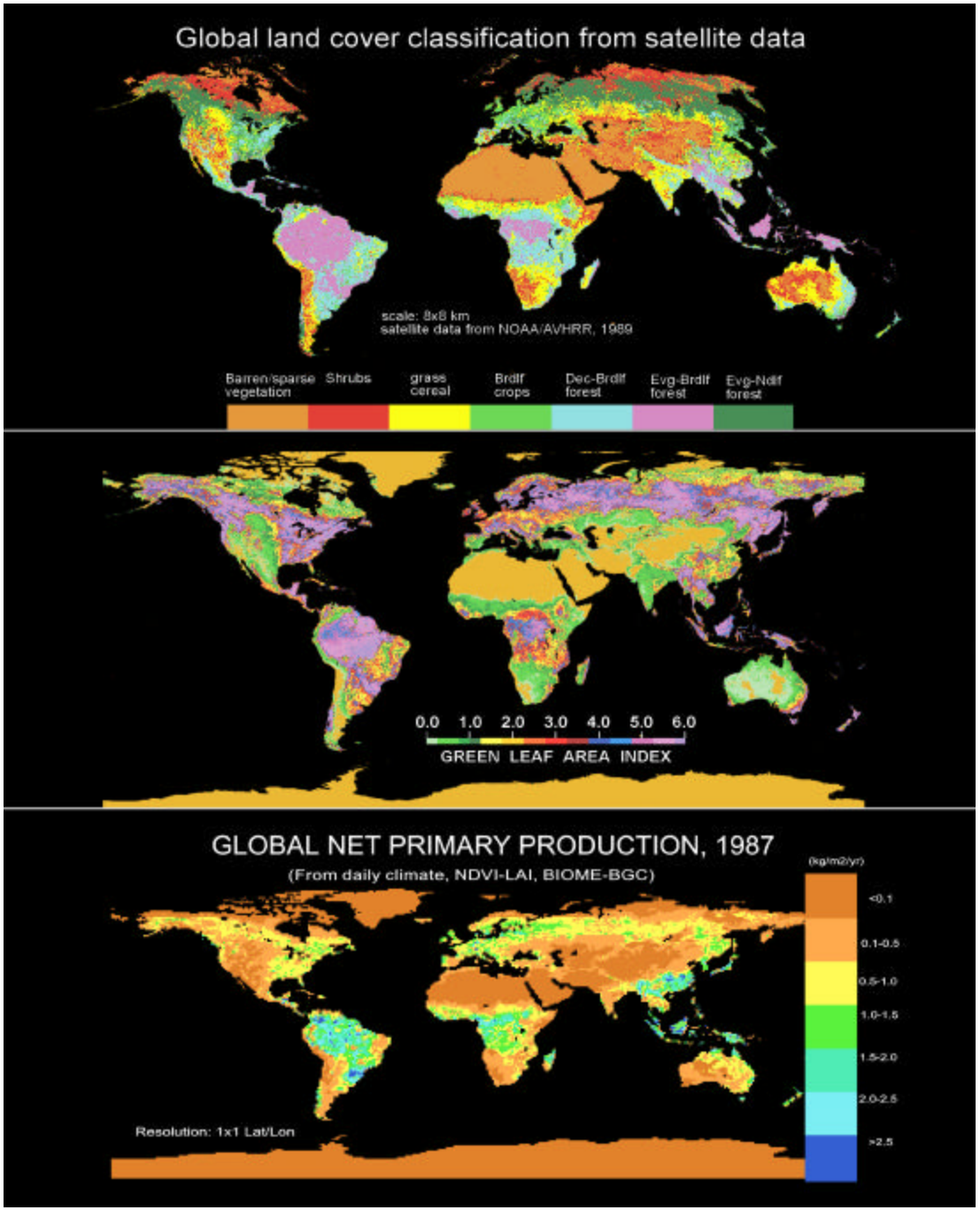

Histogram of NIR Band
Needle Forests
Broadleaf Forests
Savannas
Broadleaf Crops
Shrubs
Grasses and Cereal Crops
Frequency (%)
25
20
15
10
5
0
0.10
0.20
0.30
0.40
0.50
NIR Reflectance

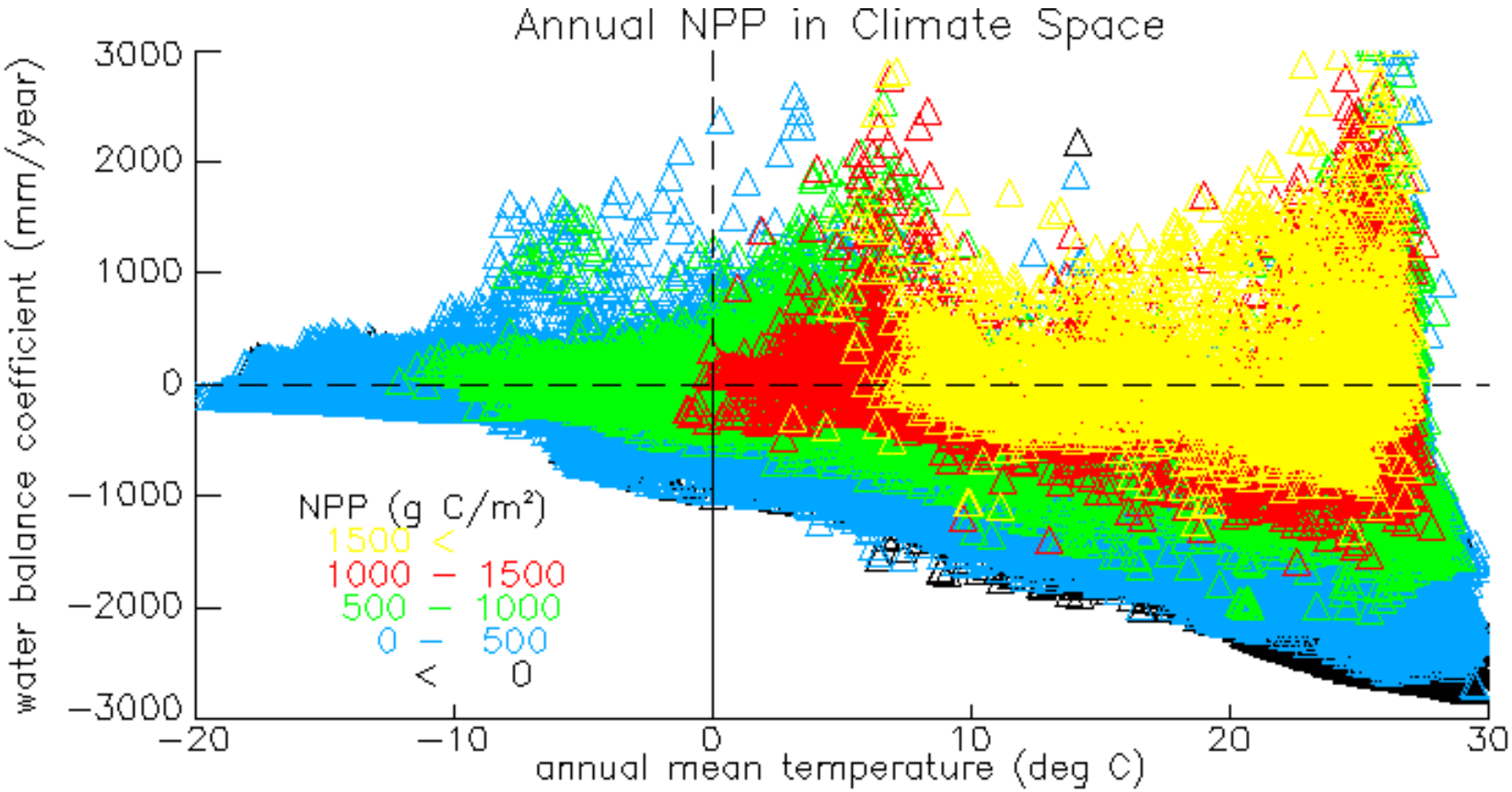

25% Density contours
0.40
0.30
0.20
0.10
0.00
NIR
0.00
0.05
0.10
0.15
0.20
RED
Needle Forests
Broadleaf Forests
Savannas
Broadleaf Crops
Shrubslands
Grassland and Cereal Crops

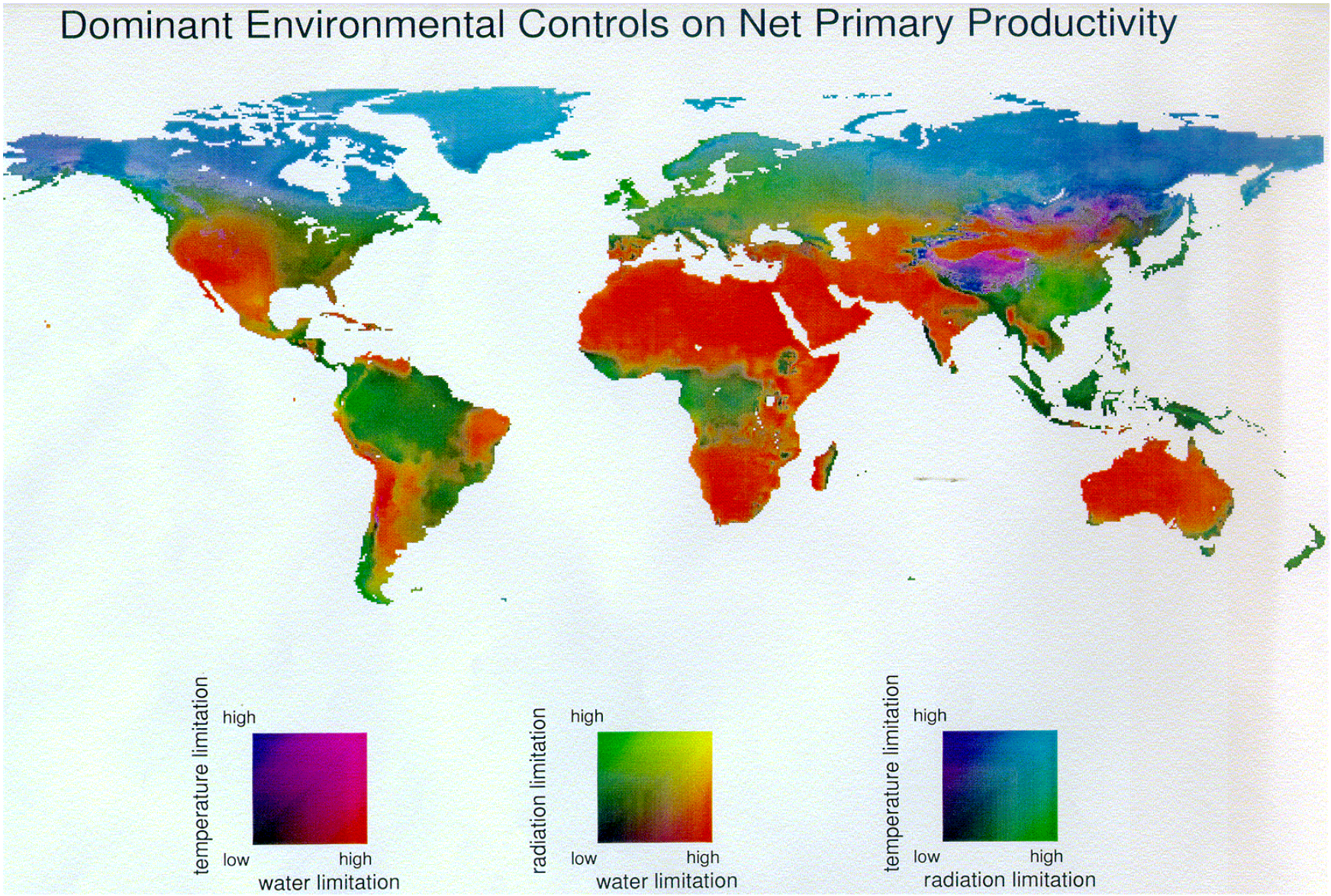
NPP (Net Primary Production)

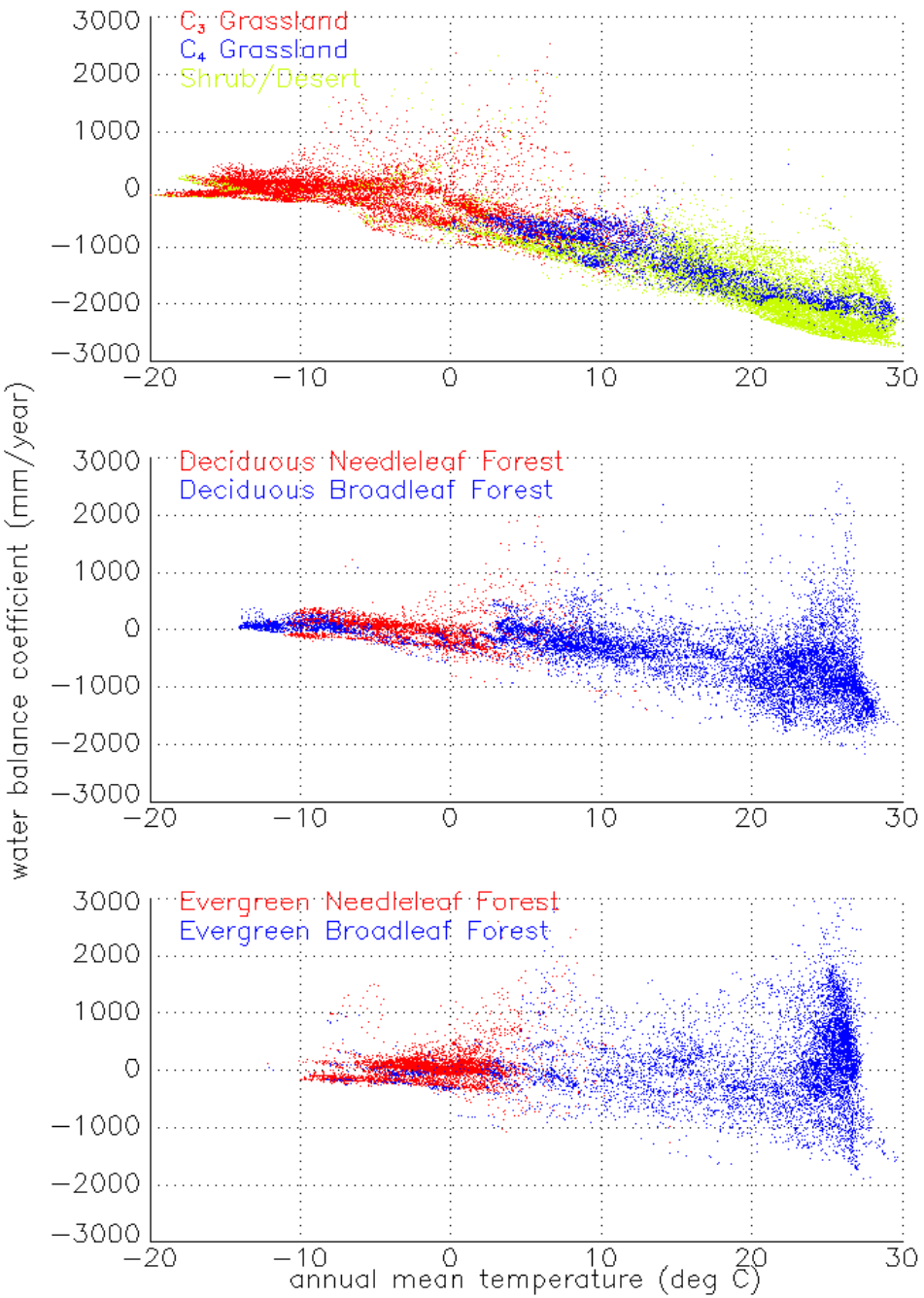
- Quantifies vegetation growth

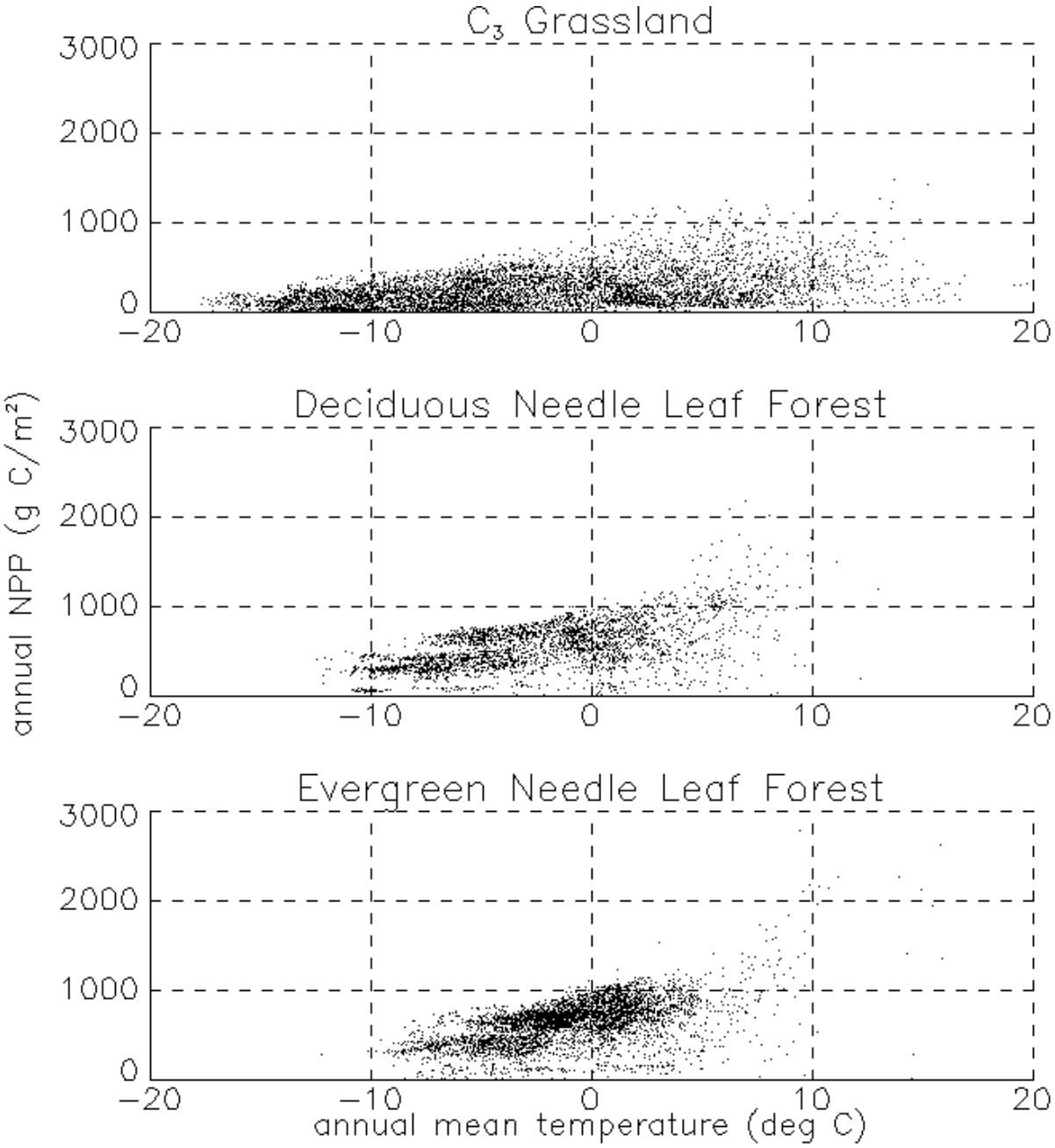
- Uses:
  - component of NEP for terrestrial carbon source/sink analyses [global interest]
  - practical measure of crop/range/forest growth [local interest]

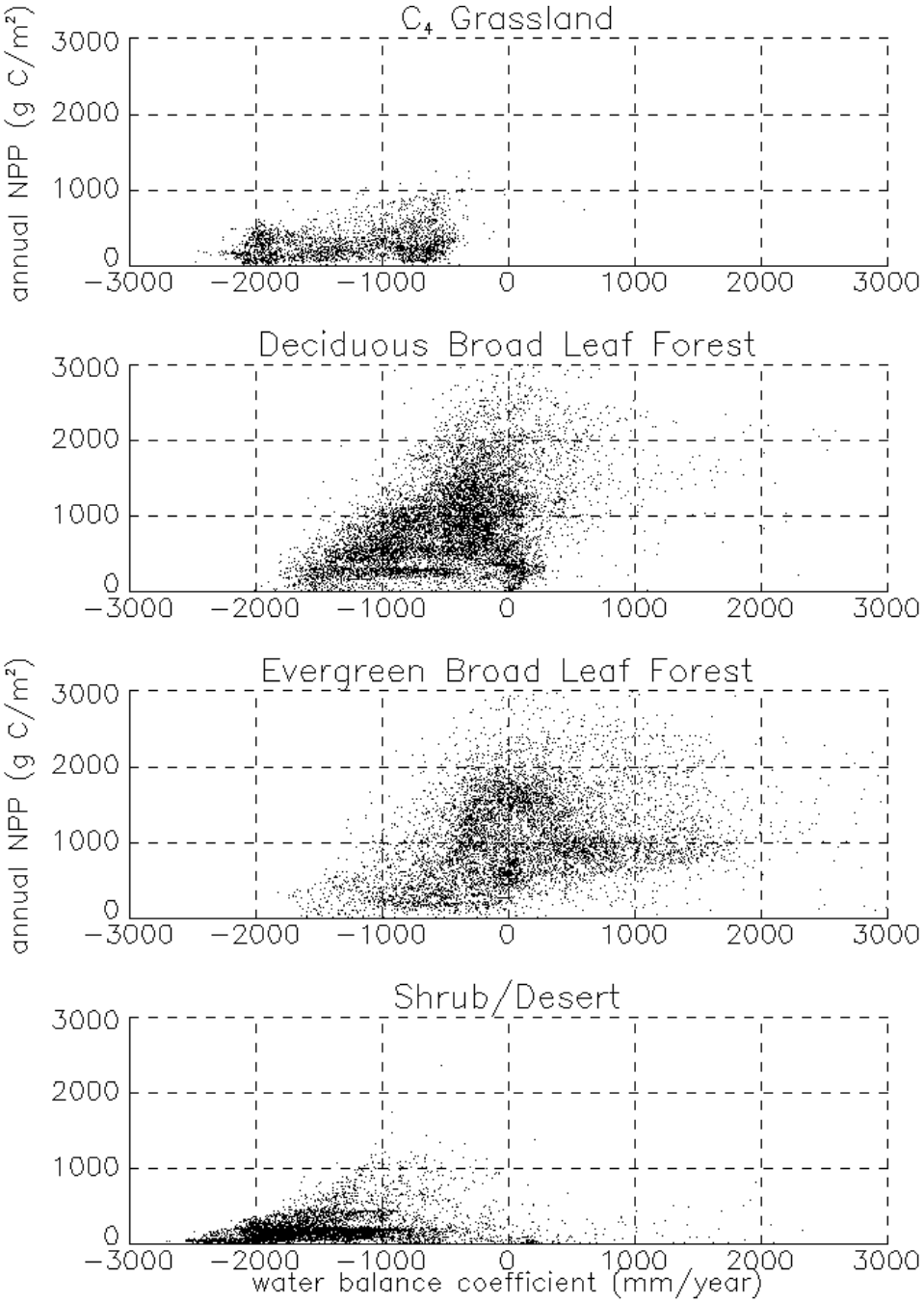

Global land cover classification from satellite data
scale: 8x8 km
satellite data from NOAA/AVHRR, 1989
Barren/sparse vegetation
Shrubs
grass cereal
Brdlf crops
Dec-Brdlf forest
Evg-Brdlf forest
Evg-Ndlf forest
0.0 1.0 2.0 3.0 4.0 5.0 6.0
GREEN LEAF AREA INDEX
GLOBAL NET PRIMARY PRODUCTION, 1987
(From daily climate, NDVI-LAI, BIOME-BGC)
(kg/m2/yr)
<0.1
0.1-0.5
0.5-1.0
1.0-1.5
1.5-2.0
2.0-2.5
>2.5
Resolution: 1x1 Lat/Lon


Annual NPP in Climate Space
water balance coefficient (mm/year)
3000
2000
1000
0
−1000
−2000
−3000
−20
−10
0
10
20
30
annual mean temperature (deg C)
NPP (g C/m²)
1500 <
1000 − 1500
500 − 1000
0 − 500
< 0


Dominant Environmental Controls on Net Primary Productivity
temperature limitation
high
low
high
water limitation
radiation limitation
high
low
high
water limitation
temperature limitation
high
low
high
radiation limitation


C3 Grassland
C4 Grassland
Shrub/Desert
Deciduous Needleleaf Forest
Deciduous Broadleaf Forest
Evergreen Needleleaf Forest
Evergreen Broadleaf Forest
water balance coefficient (mm/year)
annual mean temperature (deg C)
3000
2000
1000
0
−1000
−2000
−3000
−20
−10
0
10
20
30


C3 Grassland
Deciduous Needle Leaf Forest
Evergreen Needle Leaf Forest
annual NPP (g C/m²)
annual mean temperature (deg C)
3000
2000
1000
0
−20
−10
0
10
20


C4 Grassland
Deciduous Broad Leaf Forest
Evergreen Broad Leaf Forest
Shrub/Desert
annual NPP (g C/m²)
annual NPP (g C/m²)
3000
2000
1000
0
−3000
−2000
−1000
0
1000
2000
3000
water balance coefficient (mm/year)

MODIS Land Product Suites

Surface Radiation and Energy Budget Products

- **Surface Spectral Bidirectional Reflectances Corrected for Atmosphere**
- **Bidirectional Reflectance Distribution Function (BRDF)**
- **Albedo**
- **Land Surface Temperature (day & night)**
- **Snow and Ice**

Ecosystem Characterization Products

- **Spectral Vegetation Indices**
- **Fraction Absorbed Photosynthetically-Active Radiation (fAPAR)**
- **Leaf Area Index (LAI)**
- **Net Primary Production (NPP)**

Land Cover Products

- **Land Cover**
- **Land Cover Change**
- **Fire, Thermal Anomalies**
- **Burn Scars**

MODLAND Validation Approach

- Commitment to the EOS Land Validation Core Sites
- Product-specific sites, activities and validation protocols

  (primarily by MODLAND PIs)
- Close cooperation with EOS LandValidation and NASA R&A Program Investigators
- Establishing interaction with other AM instrument teams and international instruments

MODLAND Validation Approach (cont.)

- Participation in community field campaigns
  (LBA, SAFARI 2000, GCIP)
- Developing new validation instrumentation
  (e.g. MQUALs, CIMEL with BRDF)
- Collaboration with the data providers
  (PI's, DAACs, ESIPS, CRESS)

Validation Details:

http://modarch.gsfc.nasa.gov/MODIS/LAND/VAL

MODIS Validation site hierarchy

1. EOS Land ValidationCore Sites

Serving as a focus for satellite, aircraft, and ground data collection of land product validation, from which scientists can readily access in-situ and EOS instrument data

2. Product Specific Sites

Complementing the core sites, meeting the specific needs of individual MODIS products. Where possible, shared data with other instrument teams with similar products (e.g. Land Surface Temp. with ASTER team)

(Eventually other sites belonging to these networks can be used to ramp-up validation efforts, leveraging off of the infrastructure and protocols developed through the work done at initial core sites.)

Core Site Goals:

- Provide focused, cost effective opportunities for validating EOS Land Products
- Increase synergy within and between science teams for data collection and subsequent research
- Address science questions as appropriate
- Include Earth science networks in validation activities to provide *and* utilize EOS data.

Validation Test Sites Selection Criteria

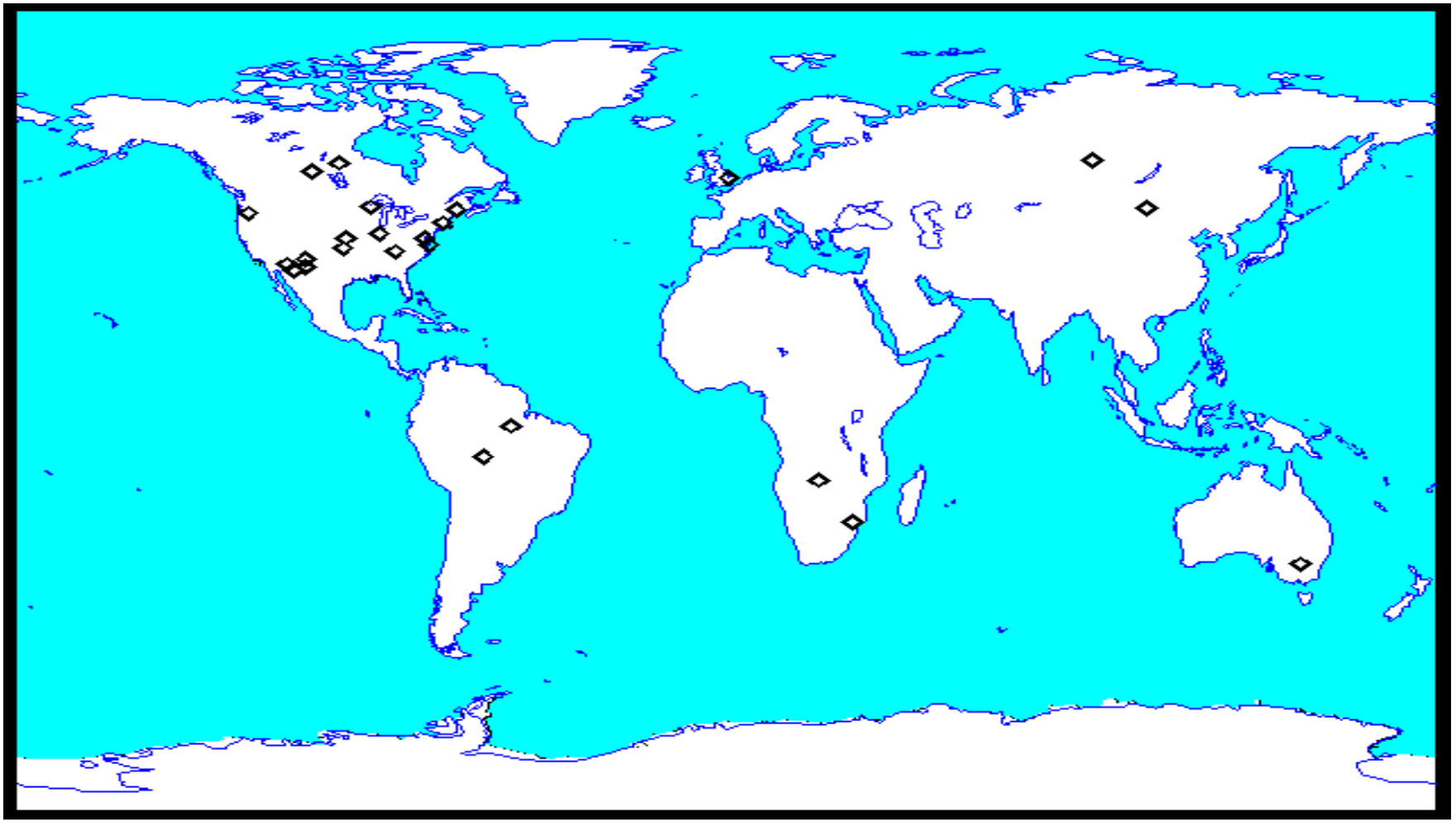
- Biome type
  - Productivity
  - Global spatial extent
- Accessibility
- Existing facilities

  (e.g. towers, laboratories, instrumentation)
- Heritage/long term commitment

Core Sites by MODLAND Biomes:

Grassland / Cereal Crop	**Shrubland / Woodland**	**Broadleaf Cropland**	**Broadleaf Forest**	**Needleleaf Forest**
ARM / CART OK	Jornada LTER NM	BARC MD	Harvard Forest LTER	Boreas NSA Canada
Konza LTER KS	Mongu Zambia	Barton Bendish UK	Ji Parana Brazil	Boreas SSA Canada
Mandalgobi Mongolia	SALSA AZ & Mexico	Bondville IL	Tapajos Brazil	Cascades, OR (H.J. Andrews LTER)
Sevilletta LTER NM	Skukuza South Africa	Maricopa Ag. Center, AZ	Walker Branch TN	Howland ME
Uardry Australia		VA Coastal Reserve LTER		Krasnoyarsk Russia
				Wisconsin LTER

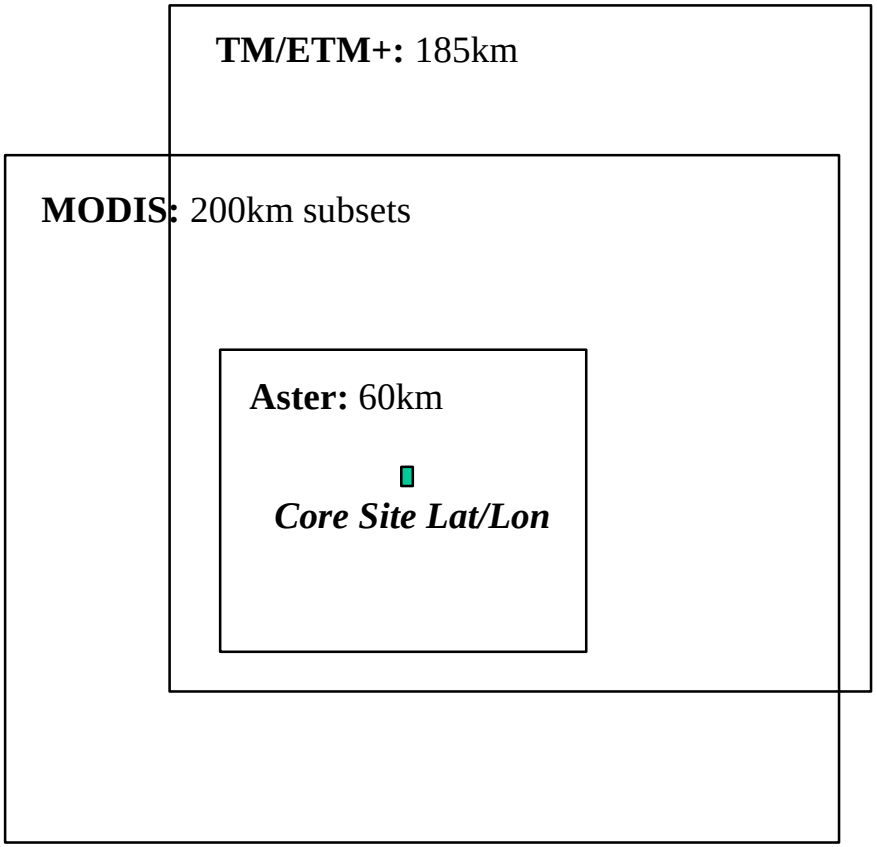
EOS Core Site Map



Core Site activities:

- Characterize site properties
- Develop validation schedule
- Create individual web pages for validation data
- Help develop centralized web access and archive system for Core Site data
- Help develop acquisition plan for L7, ASTER and other EOS sensors data
- Develop MODIS subsetting capability
- Plan and acquire MQUALS and other Airborne data
- Ensure deployment of sunphotometers
- Negotiate access to historical data

Data for EOS Land Validation Core site



Imagery expected at EDC:
- ASTER (60km)
- TM/ETM+ (185km)
- MODIS (subset)

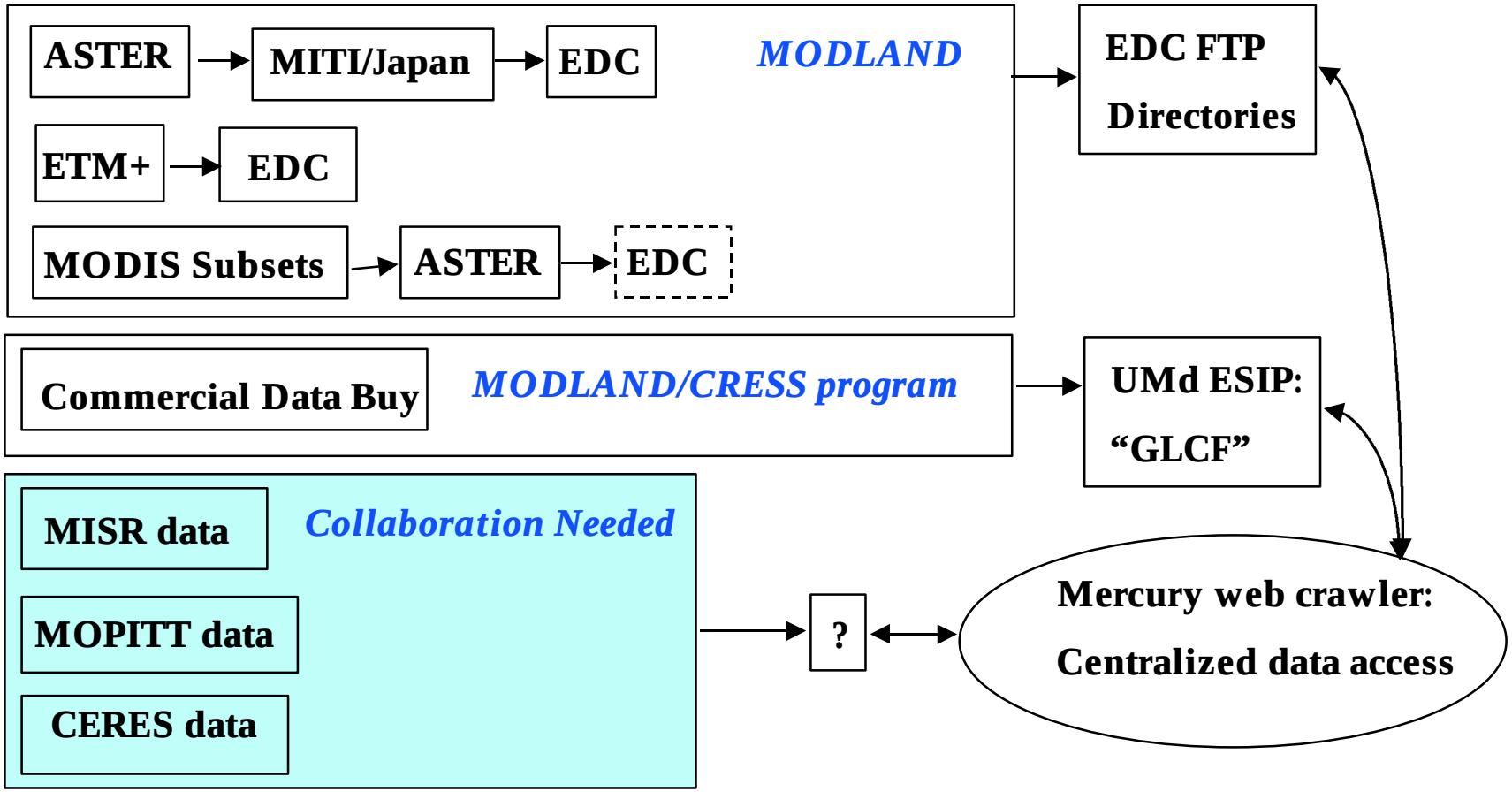
TBD:
- MISR (360km)
- CERES(subset)
- MOPITT (subset)

Possible Other Satellite Data for comparison:
- SeaWiFS
- AVHRR 1km
- High Res. Commercial data products

Ancillary Data:
- DEMs
- Land Cover
- Soils

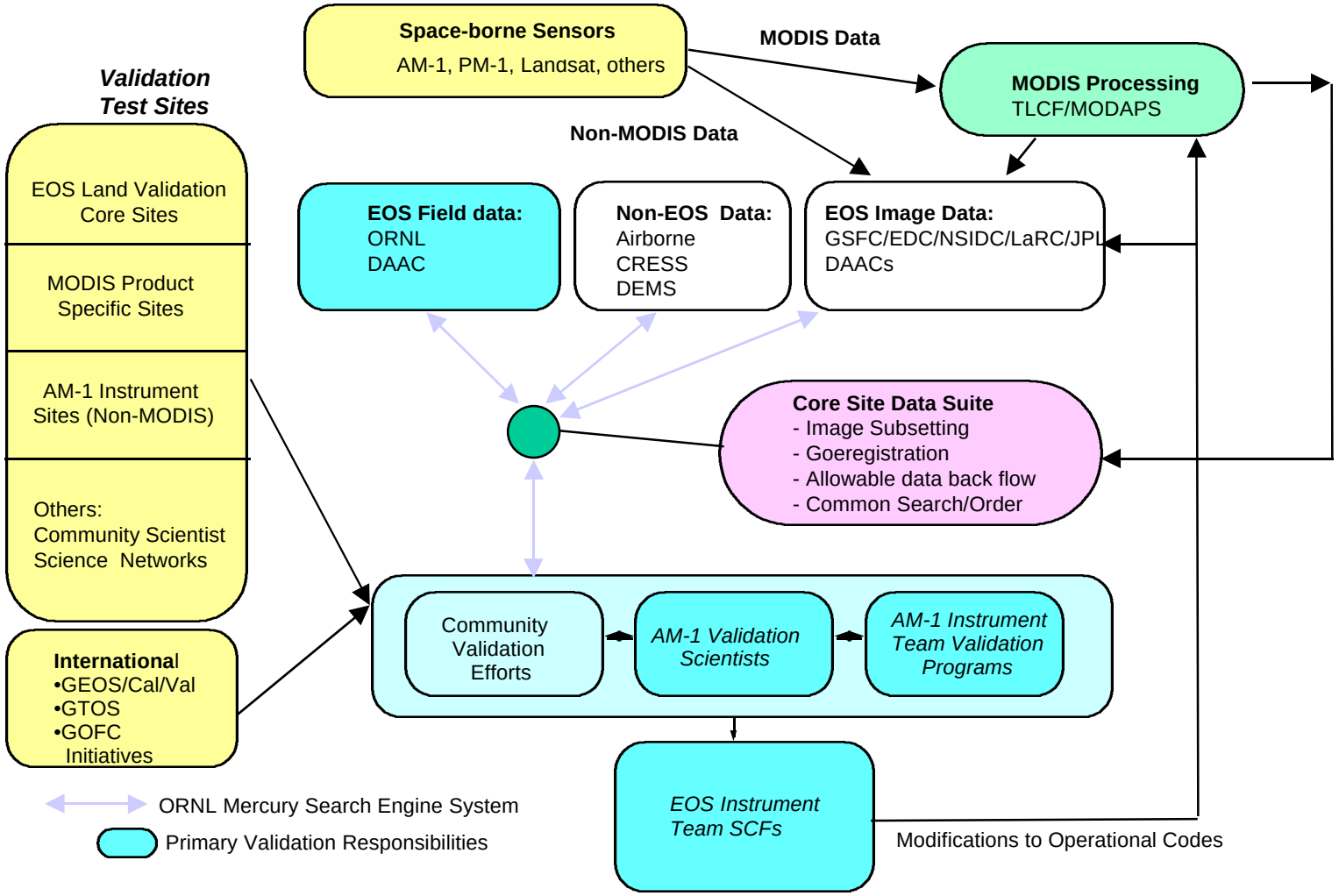
Field data:
through ORLN's Mercury

Core Site image data



CRESS = Commerial Remote Sensing for Earth System Science

Data flow


Space-borne Sensors
AM-1, PM-1, Landsat, others
MODIS Data
MODIS Processing
TLCF/MODAPS
Non-MODIS Data
Validation Test Sites
EOS Land Validation Core Sites
MODIS Product Specific Sites
AM-1 Instrument Sites (Non-MODIS)
Others:
Community Scientist
Science Networks
EOS Field data:
ORNL
DAAC
Non-EOS Data:
Airborne
CRESS
DEMS
EOS Image Data:
GSFC/EDC/NSIDC/LaRC/JPL
DAACs
Core Site Data Suite
- Image Subsetting
- Goeregistration
- Allowable data back flow
- Common Search/Order
International
•GEOS/Cal/Val
•GTOS
•GOFC
Initiatives
Community Validation Efforts
AM-1 Validation Scientists
AM-1 Instrument Team Validation Programs
EOS Instrument Team SCFs
Modifications to Operational Codes
ORNL Mercury Search Engine System
Primary Validation Responsibilities

Developmental Activities

- MQUALs *http://gaia.fcr.arizona.edu/MQUALS.html*

  "MODIS Quick Airborne Looks" airborne radiometric system for rapid and low cost product validation.

  Multispectral digital camera, albedometer, 4-band radiometer, and GPS.

  Will use light aircraft operators local to each site.

- CIMEL with BRDF

  Modified sun photometer, reconfigured to collect directional surface radiances as required for validation of atm. correction, vegetation indices, and BRDF.

MQUALS initial site priorities

Top priority:

ARM/CART

Cascades/HJA

Bondville *

Harvard Forest *

Konza *

Maricopa

Wisconsin, Park Falls

Second priority:

BARC

Jornada

Walker Branch

International Sites

BOREAS NSA *

LBA

SAVE / SAFARI-2000

*** = Bigfoot site**

Priority based on field work activity planned for 1999, potential network interest, and multiple MODLAND products and EOS investigators utilizing the site.

Cooperation with EOS Validation Investigators

14 EOS Validation Investigations evaluating MODLAND Products

- **Baldocchi**
- **Fowler**
- **Gower**
- **Hook**
- **Li**
- **Liang**
- **Meyer**
- **Nolin**
- **Olson**
- **Privette**
- **Schowengerdt**
- **Shi**
- **Teillet**
- **Thome**
- **Ward**

http://modarch.gsfc.nasa.gov/MODIS/LAND/VAL/am1/abstract.html

MODLAND
Validation Web Links

- MODLAND Validation

  http://modarch.gsfc.nasa.gov/MODIS/LAND/VAL
- Land Cover at BU: Validation and Test Sites (VATS - STEP)

  http://crs-www.bu.edu/~jcfh/step.html
- Land Cover Change at UMD

  http://www.geog.umd.edu/landcover/modis/MOD44_valplan.pdf
- LAI/FPAR/NPP Protocol

  http://modarch.gsfc.nasa.gov/MODIS/LAND/VAL/lai_meeting.html
- LAI/FPAR/NPP Validation activity at BU

  http://cybele.bu.edu/research/modismisr/validation.html

Collaborations with Science Networks

- AERONET *http://aeronet.gsfc.nasa.gov:8080/*

  CIMEL Sun Photometers, several with BRDF capability. Currently being redeployed around validation network.

- Fluxnet *http://daacl.esd.ornl.gov/FLUXNET/*

  Global Array of Tower Flux Networks. Used in part to validate EOS Terrestrial Carbon, Water and Energy Budgets

- BIGFOOT *http://www.fsl.orst.edu/spacers/bigfoot/plan.html*

  Scaling and NPP studies at 4 Land Validation Core sites

- IGBP *http://rsrunt.geog.ucsb.edu/igbp.html*

  Land Cover Validation Activity

- Global Land Cover Test Sites *http://glcts.maxey.dri.edu/glcts/*

  Archiving of AVHRR and Landsat imagery for 9 of 23 EOS Land Validation Core sites

- LTER *http://www.lternet.edu/*

  Ongoing field and remote sensing measurements, 7 of 23 EOS Land Validation Core Sites

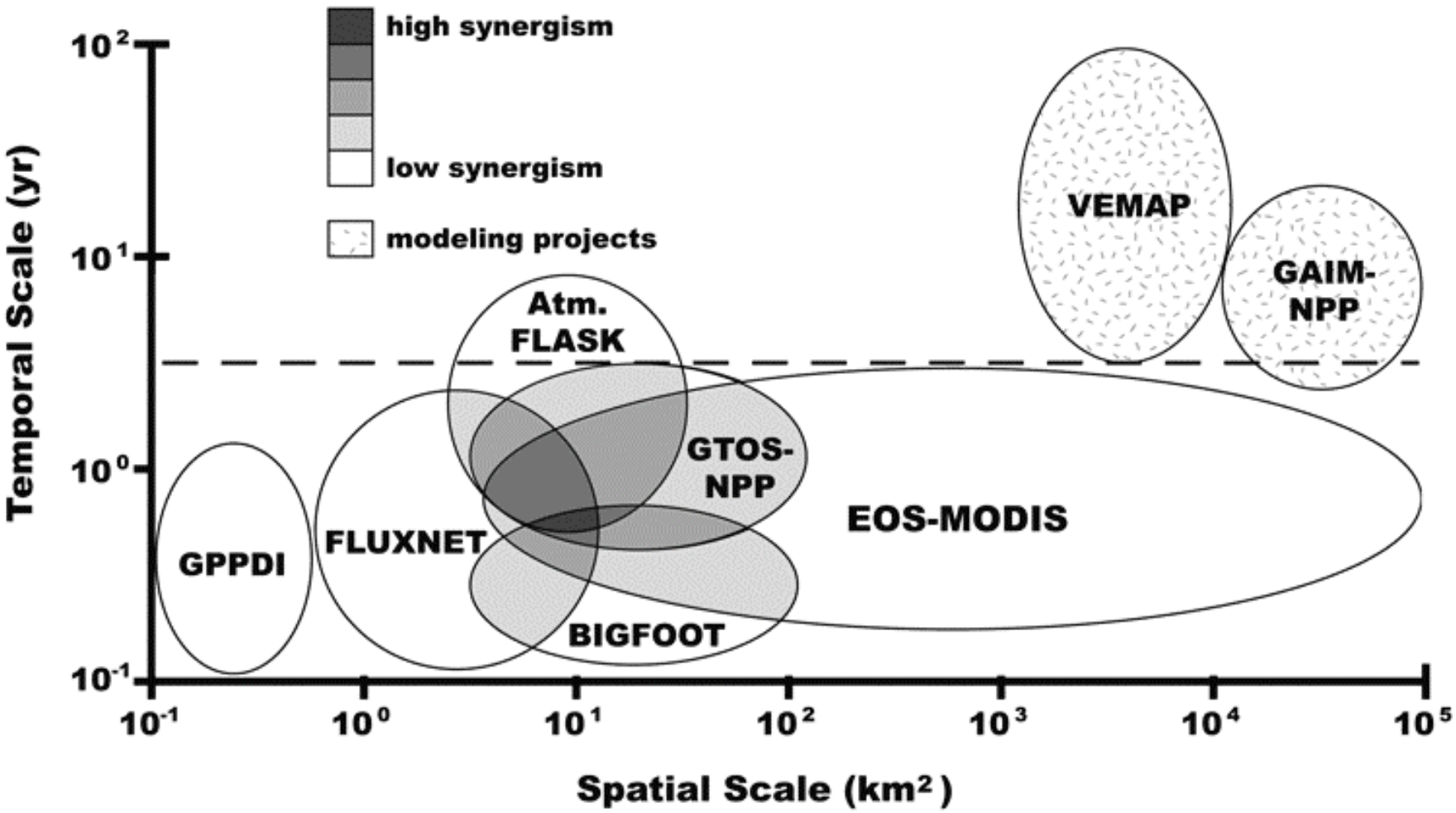
Sources of LAI/FPAR and NPP Variability

- Spatial
  - biome type
  - climate gradients, (water and temperature)
- Temporal
  - phenology and growing season

CALIBRATION AND VALIDATION ACTIVITY

- BIGFOOT
- FLUXNET
- GTOS
- ORNL DAAC
- IGBP-DIS

Terrestrial Validation Synergism



Components of Global/Regional Flux Networks

Global Network

- infrastructure for flux data collection and synthesis
- inter-network calibration
- value-added products
- consistent database for distribution and archive

Regional Networks

- science plans
- data plans
- cross-site calibration
- regional databases

Tower sites

- science
- store raw data
- perform QA
- compute 1/2-1 hour values
- document data

FLUXNET

Science Component:

Steering Committee, algorithm development, synthesis

Data Information System Component:

Steering Committee, monthly/annual flux* and ecological site data, standard format, modeling/satellite links

(Typical regional networks)

AmeriFlux

Flux*, meteorological and ecological site data; QA/QC, documentation, and distribution according to the AmeriFlux Science Plan

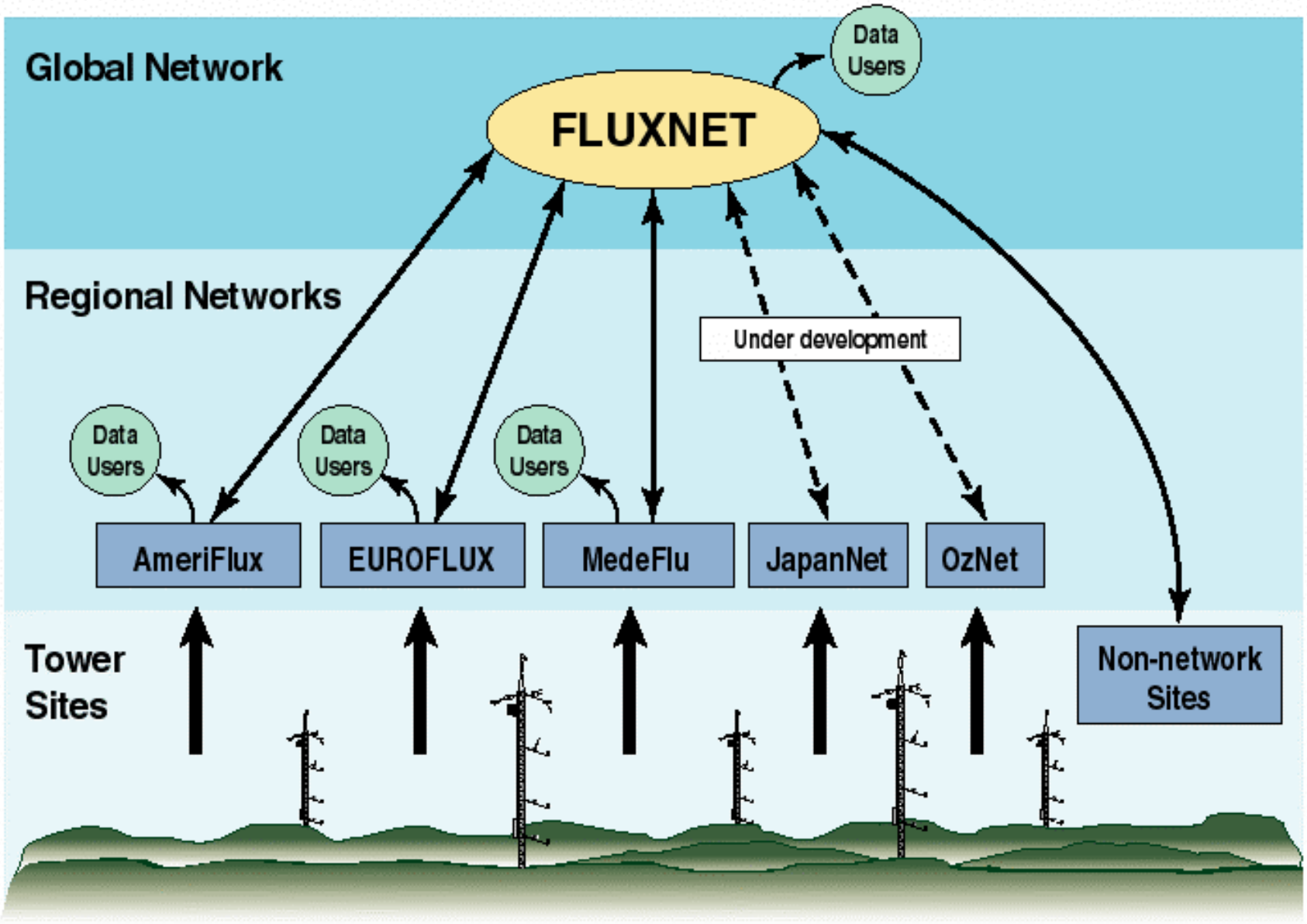
EUROFLUX

Flux*, meteorological and ecological site data; relational database; data distribution; QA/QC, Methodology Working Groups

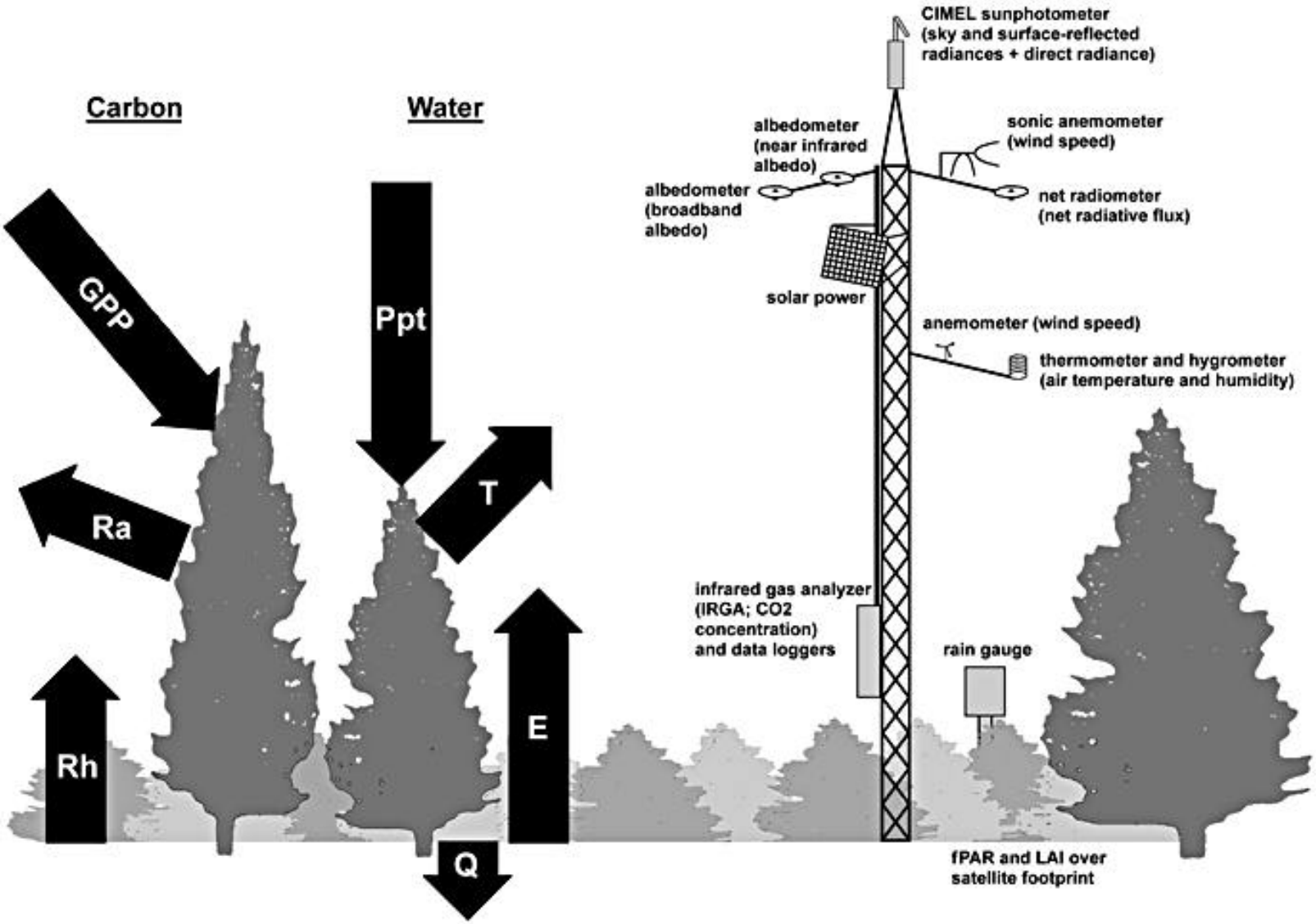
**Flux data includes carbon, water vapor and energy fluxes aggregated to 1/2-1 hour time steps*

ORNL 98-914/lmh

Architecture of Global/Regional Flux Networks

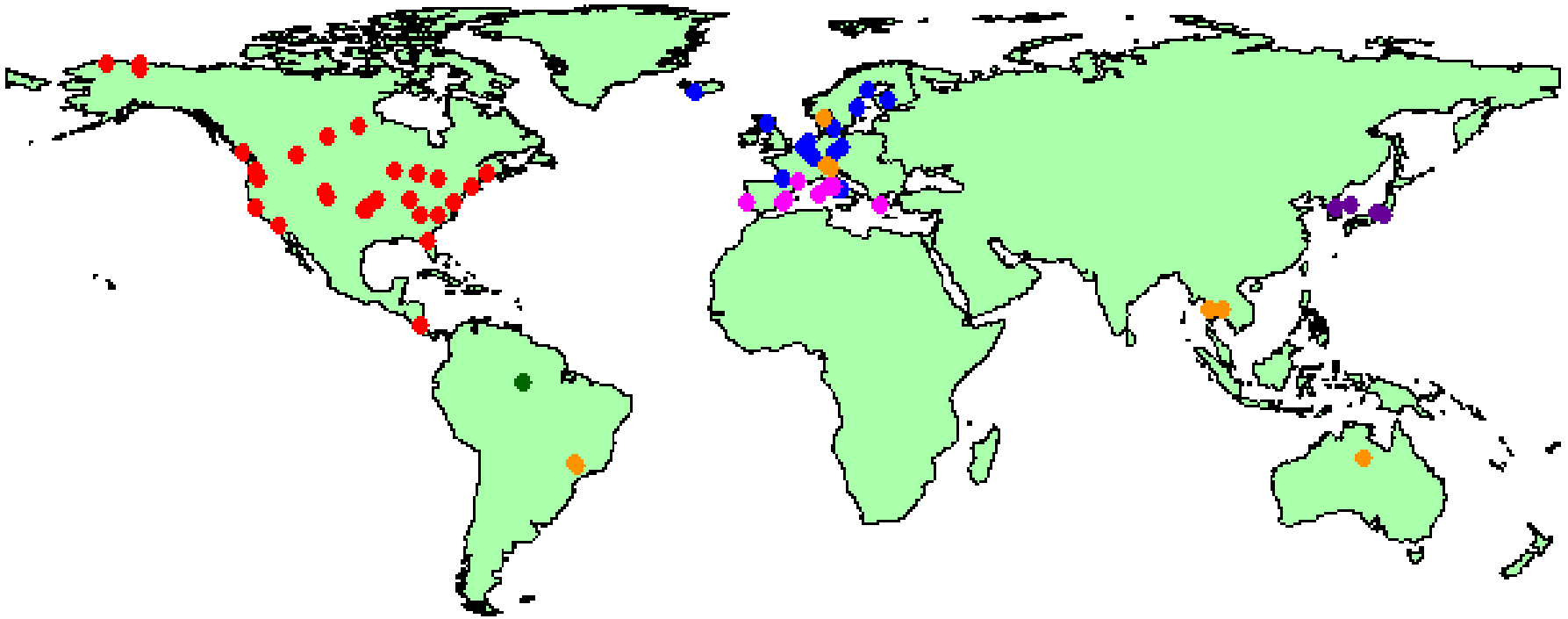


FLUXNET CONFIGURATION

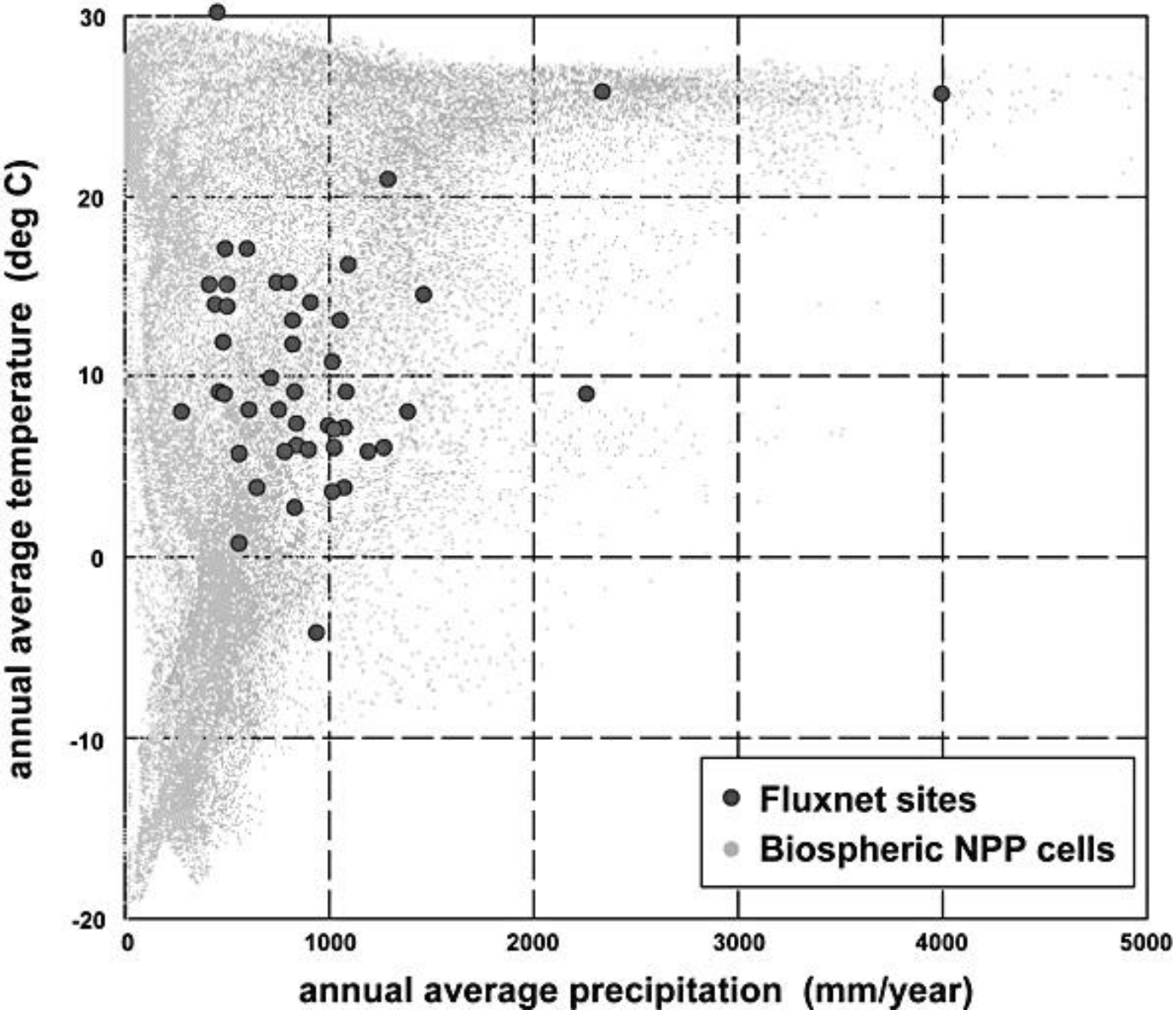


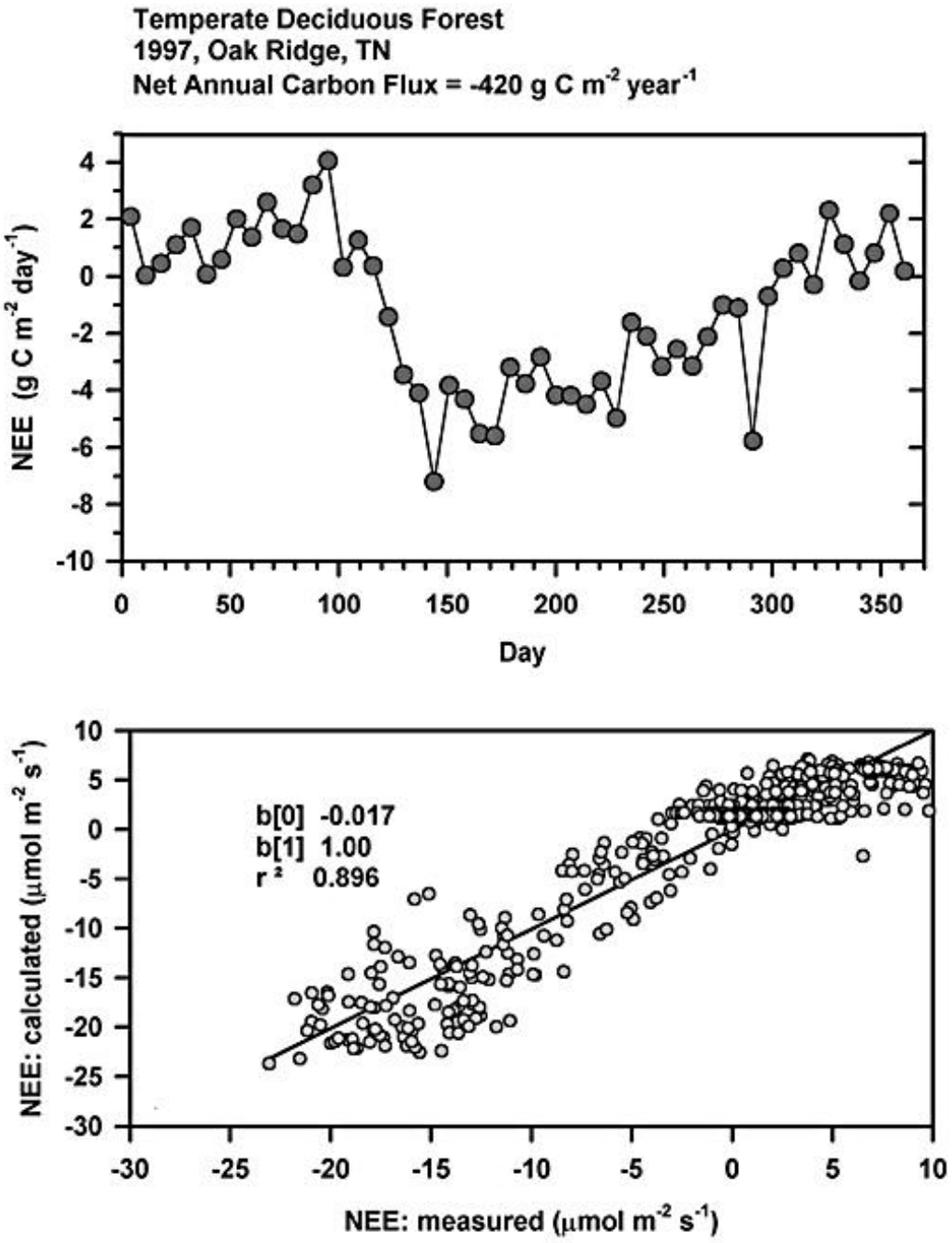
FLUXNET Sites

AmeriFlux(•), EUROFLUX(•), Medeflu(•), JapanNet(•), LBA(•), others(•)

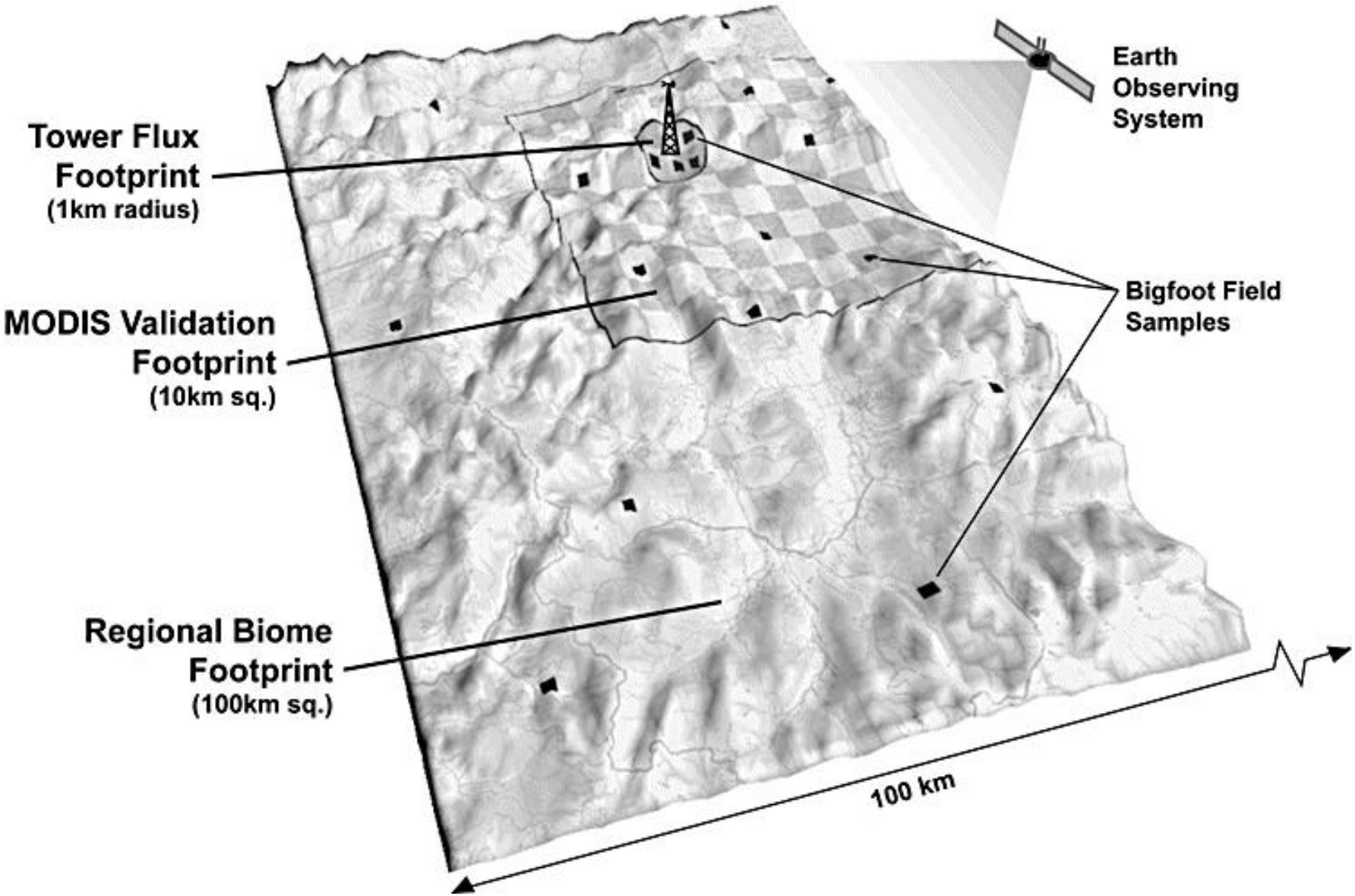


Climate Space of Global Vegetation




Temperate Deciduous Forest
1997, Oak Ridge, TN
Net Annual Carbon Flux = -420 g C m-2 year-1
NEE (g C m-2 day-1)
Day
b[0] -0.017
b[1] 1.00
r ² 0.896
NEE: calculated (μmol m-2 s-1)
NEE: measured (μmol m-2 s-1)

Multi-scale Measurement Strategy



Characterizing the Land Surface in Support of MODIS Product Validation

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Warren B. Cohen, USFS PNW Research Station

Stith T. Gower, University of Wisconsin

David P. Turner, Oregon State University

Peter B. Reich, University of Minnesota

& host of collaborators

Objectives

Science:

• Develop understanding of the climatic and ecological controls on total net primary production and carbon allocation within and among biomes

• Learn how flux tower-measured NEE and field-measured NPP co-vary & how to translate between them using ecological models

• Determine how basic scaling tools (e.g., remote sensing, ecological models, generalization) contribute to errors in global characterizations of net primary production

Methodological:

• At a given site, measure/observe land cover, LAI/f_{APAR}, and NPP (above- & belowground components) across a 5-by-5 km area

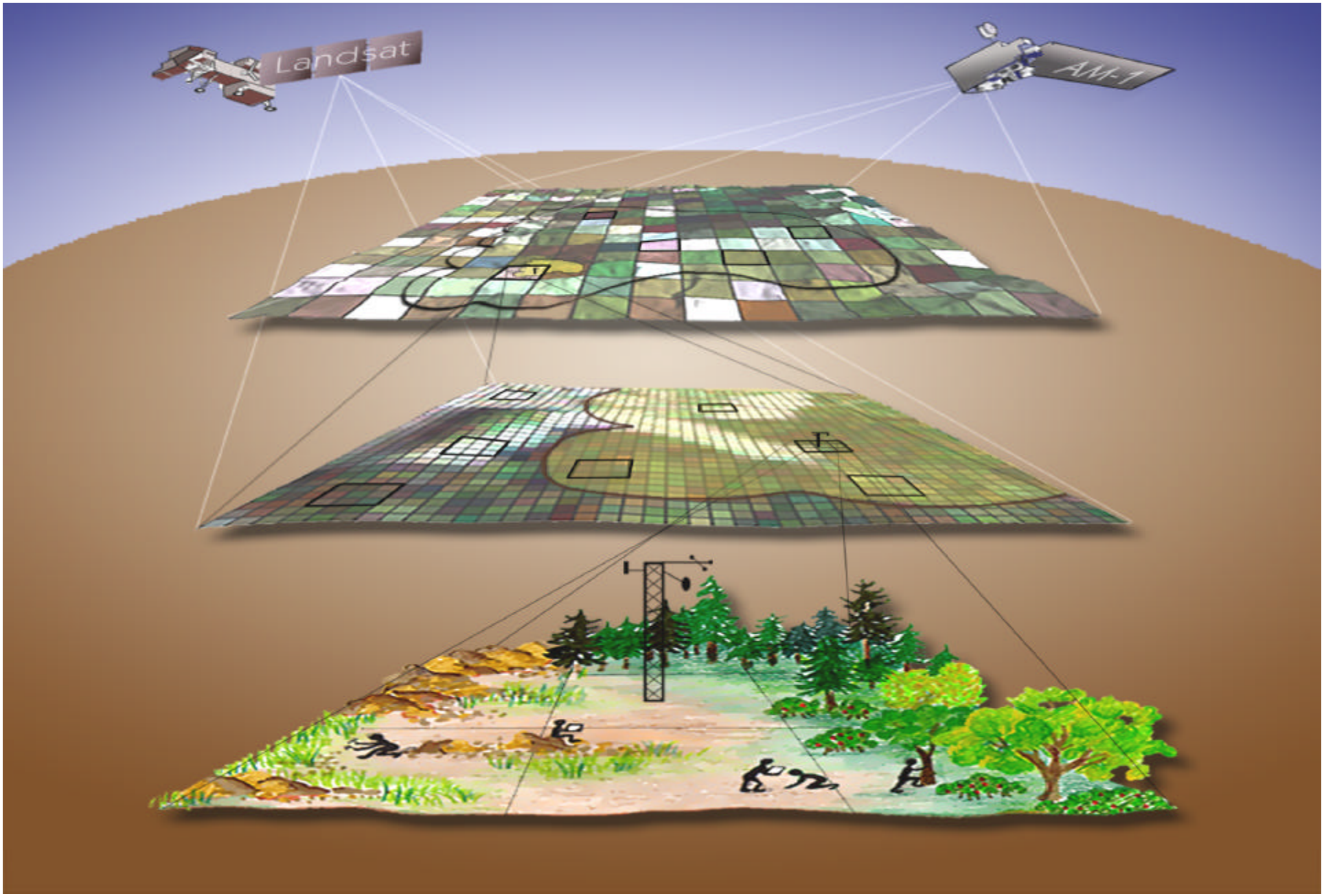
• Extrapolate field measurements to high resolution grids (cover, LAI /f_{APAR}, aNPP) using Landsat imagery and statistical & ecological models

• Characterize errors in these grids using independent field observations

• Compare field-verified high resolution grids to MODIS product grids

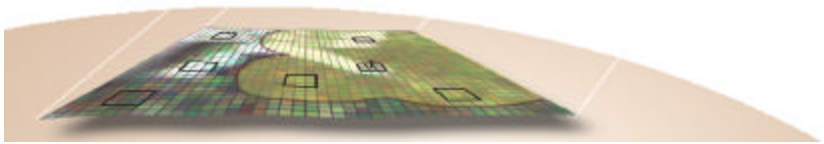
• Isolate effects of land cover generalization, image grain size, and ecological modeling parameters on MODIS NPP estimates

• In the field, examine spatial autocorrelation of cover, LAI /f_{APAR}, and NPP , use this information to guide interpretations


Landsat
AM-1

LAI /f_{APAR} Mapping

- Develop site-specific SVI-LAI /f_{APAR} relationships
- Seasonal snapshots to characterize phenological development for two or three consecutive years
- If needed, simply “paint-by-numbers”



Land Cover Mapping

• Site-specific information; functionally meaningful at a local level (e.g., forest age, specific crop type)

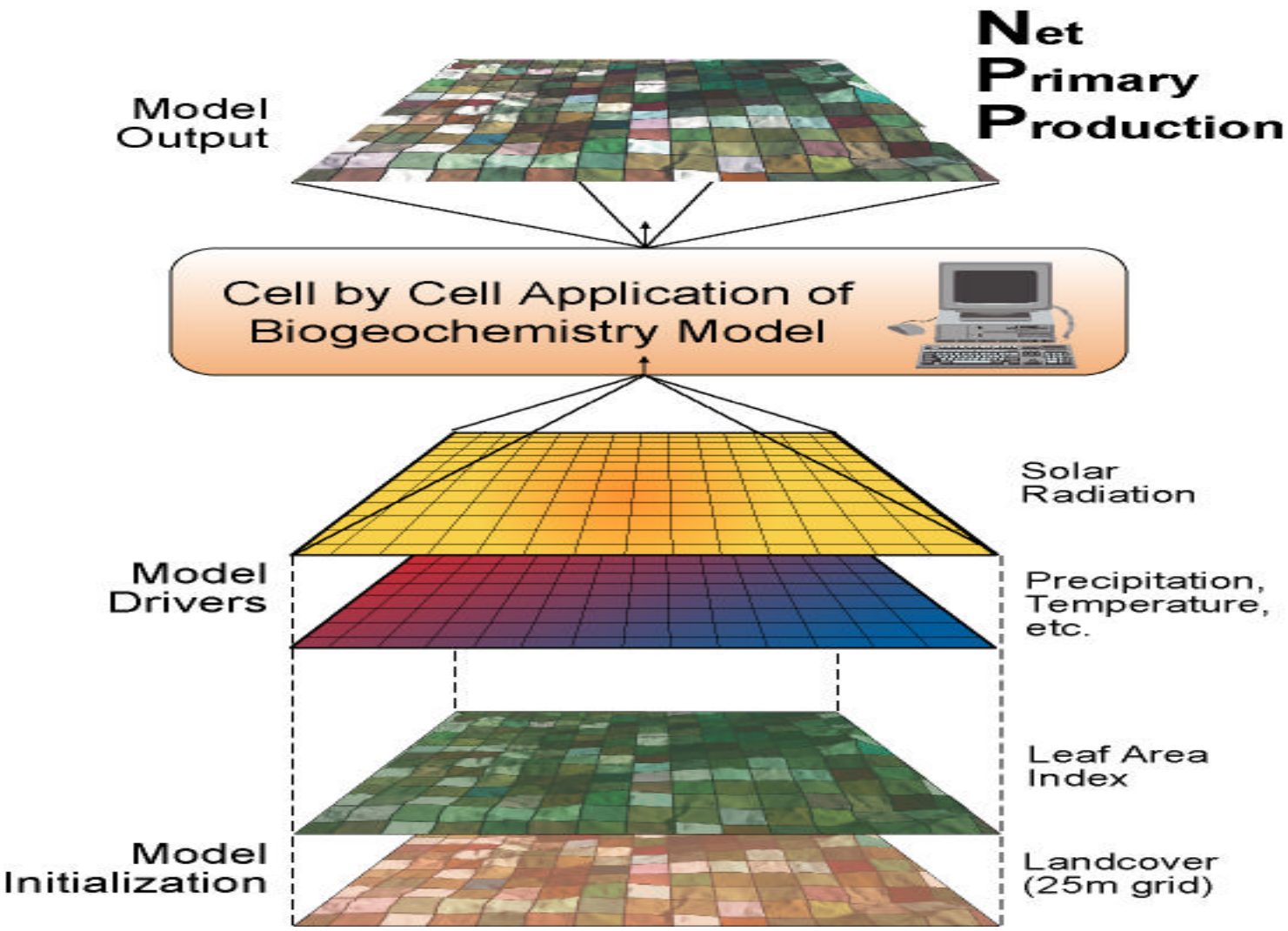
• To the extent possible, continuous information; e.g., percent green vegetation cover, conifer-hardwood proportions

• Seasonal snapshots for two or three consecutive years to help assign land cover labels

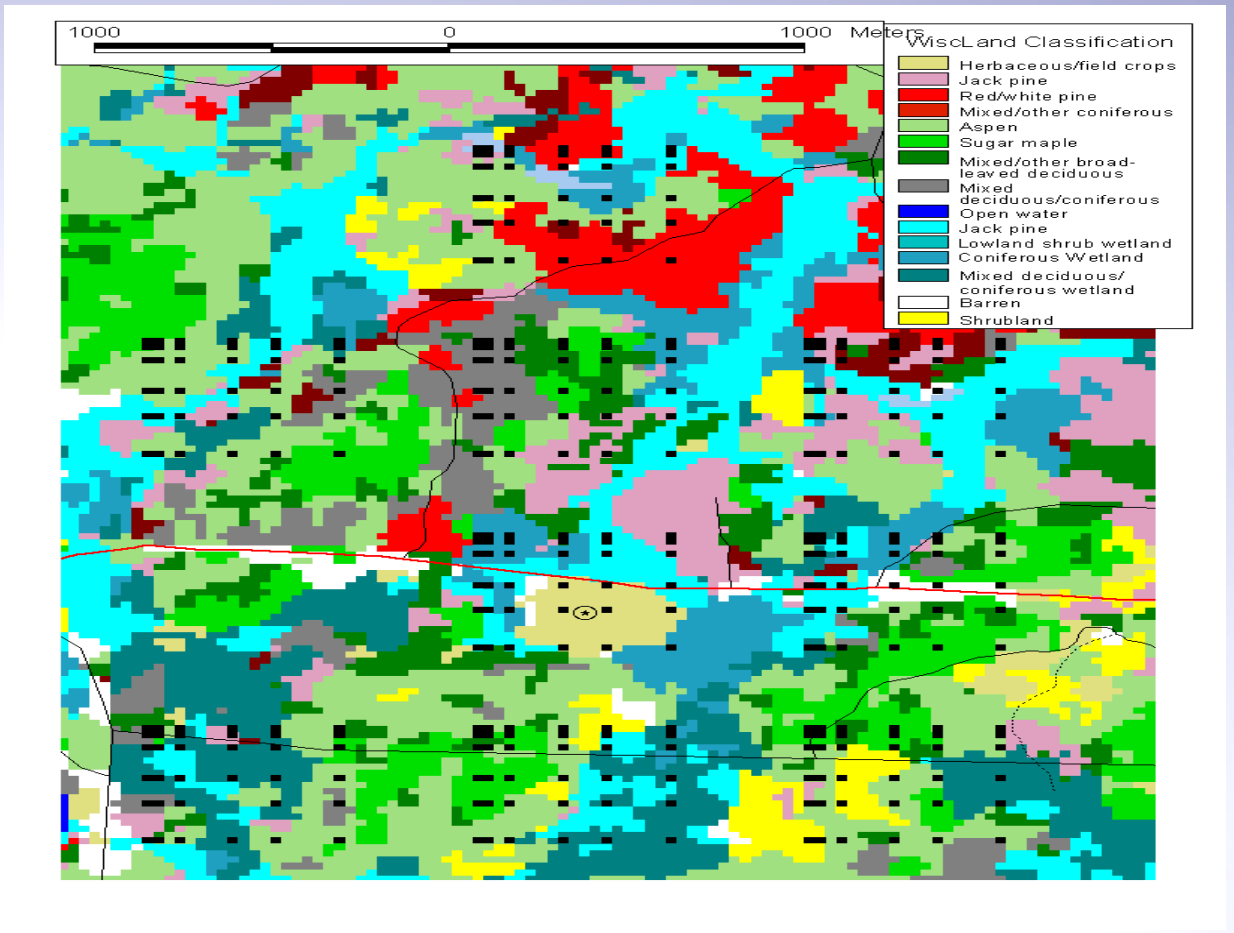
• Unsupervised classification, regression modeling, and decision-tree/rule-induction approach to land cover mapping

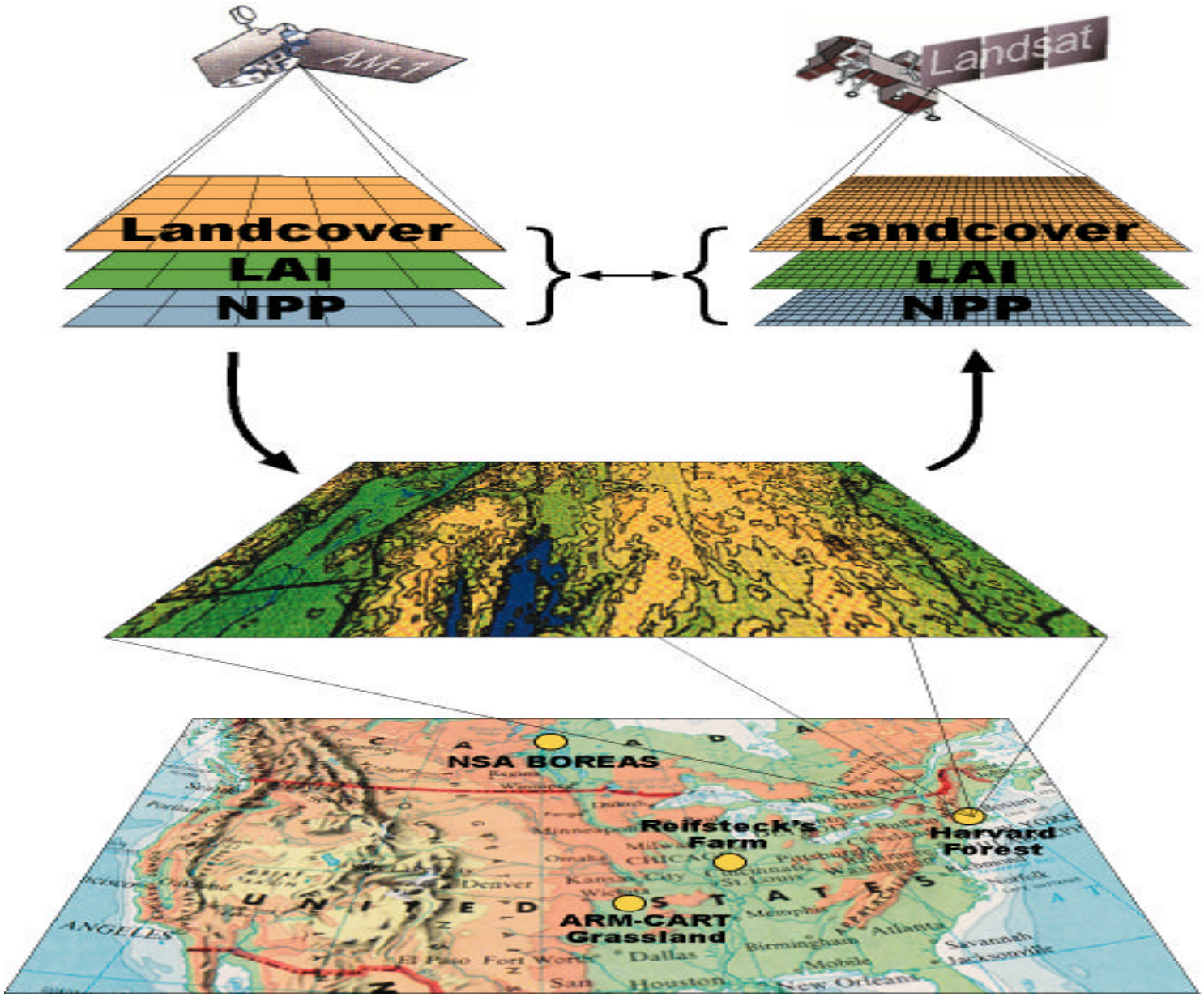
• Also map directly into MODIS generalized cover classes at fine grain

BigFoot


Net
Primary
Production
Model
Output
Cell by Cell Application of
Biogeochemistry Model
Solar
Radiation
Model
Drivers
Precipitation,
Temperature,
etc.
Leaf Area
Index
Model
Initialization
Landcover
(25m grid)

Conceptual Design for Field Sampling




AM-1
Landsat
Landcover
LAI
NPP
Landcover
LAI
NPP
NSA BOREAS
Reifsteck's Farm
Harvard Forest
ARM-CART Grassland
UNITED STATES
CANADA
Denver
Dallas
Houston
Atlanta
New Orleans
Minneapolis
Omaha
Kansas City
St. Louis
Memphis
Birmingham
Mobile
Jacksonville
Savannah
El Paso
Fort Worth
San
ANGELES

Representative values for leaf area index and net primary production for the study sites--what we know now.

Site Location, Primary Collab.	Vegetation Cover	LAI Minimum	LAI Maximum	LAI Avg.	ANPP (t/ha) Minimum	 Maximum	 Avg.	BNPP (t/ha)	Total NPP (t/ha)
BOREAS NSA	black spruce-feathermoss	3.8	4.8	4.3	2.2	2.6	2.4	2	4.4
Manitoba, Goulden	black spruce-sphagnum	..	..	..	..	..	..	..	..
	fen	..	..	..	..	..	..	..	..
Harvard Forest	northern hardwoods	4	5.5	4.7		6	3		
Massachusetts, Wofsy	pine	4.8	6	5.4		5.5	2.7		
ARM-CART grassland	tallgrass prairie	..	..	2.9	5.2	7	6.1	..	
Oklahoma, Verma									..
Reifsteck's Farm	corn/soybean	0	3.8	..	19	21.6	20.7	3.7	24.4
Illinois, Meyers									

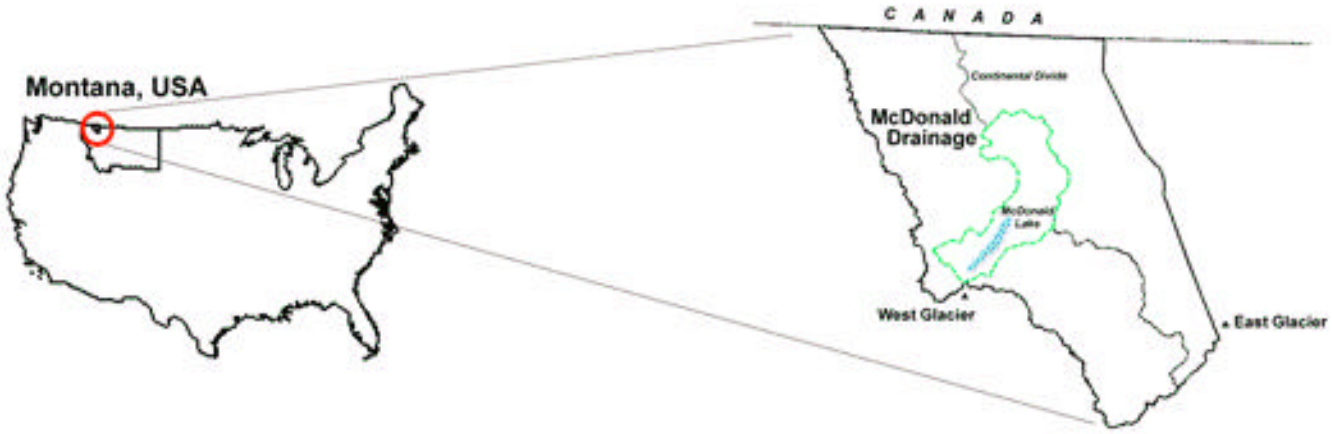
Study sites, location and proposed sampling intensity and measurement approaches for estimating vegetation cover, leaf area index (LAI) and net primary production (NPP).

Site	Location	# of Veg. cover & & LAI plots	# of NPP plots	Vegetation cover	Methods for field LAI	LAI phenology #/yr, yrs	Method for ANPP	Method for BNPP
BOREAS NSA-BS	Thompson, Man.	100	40	black spruce-feathermoss	AL,L,MVI	3, 2	AL, M	MR
	Canada			black spruce-sphagnum	AL,L,MVI	3, 2	AL,CW	MR
				fen	L	3, 2	AL, CW	MR
Harvard Forest	Harvard Forest, MA	100	40	northern hardwoods	AL,L,MVI	3, 2	AL,CW	MR
Osage Prairie	Osage Co. OK	100	40	tallgrass prairie	CP,L, MVI	10-12, 2	CP	MR, IGC
Crop	Urbana, IL	100	40	corn/soybean	CP,L,MVI	10-12, 2	CP	MR, IGC

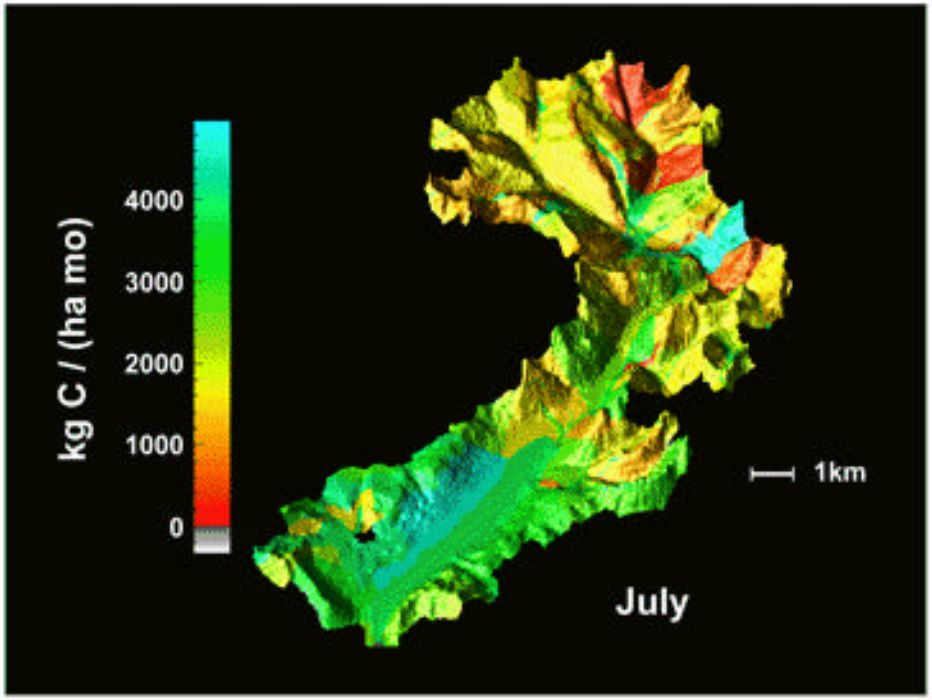
AL=ALLOMETRY, L= Li-Cor LAI-2000 Plant Canopy Analayzer, MVI= Multi-band Vegetation Imager, CP = clipped plots

M = Mesh ingrowth plots, CW = crank wires, MR = MiniRhizotrons, IGC = InGrowth Cores

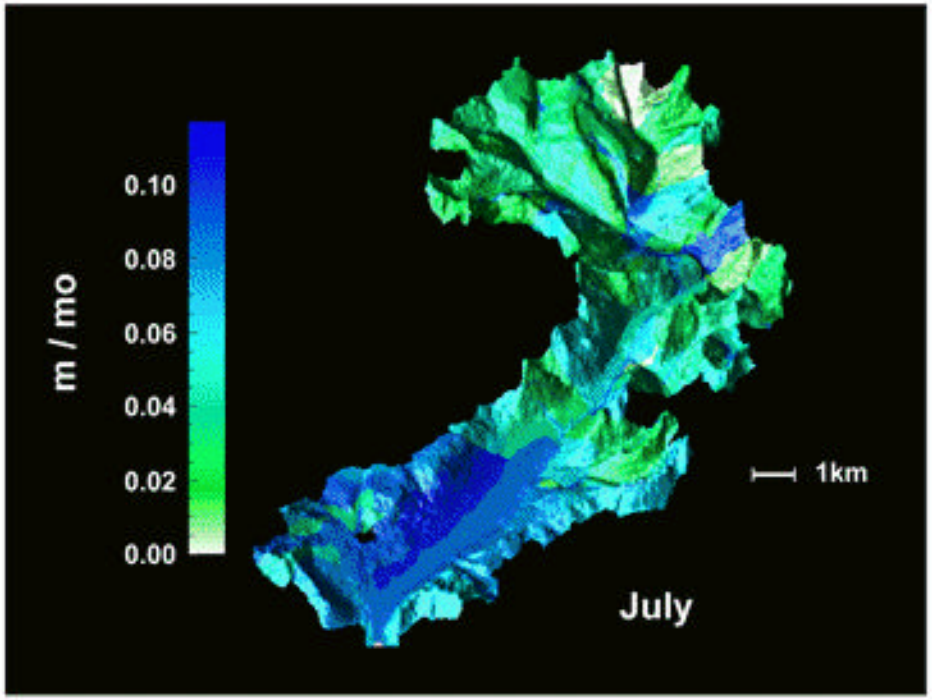
Lake McDonald watershed, Glacier National Park



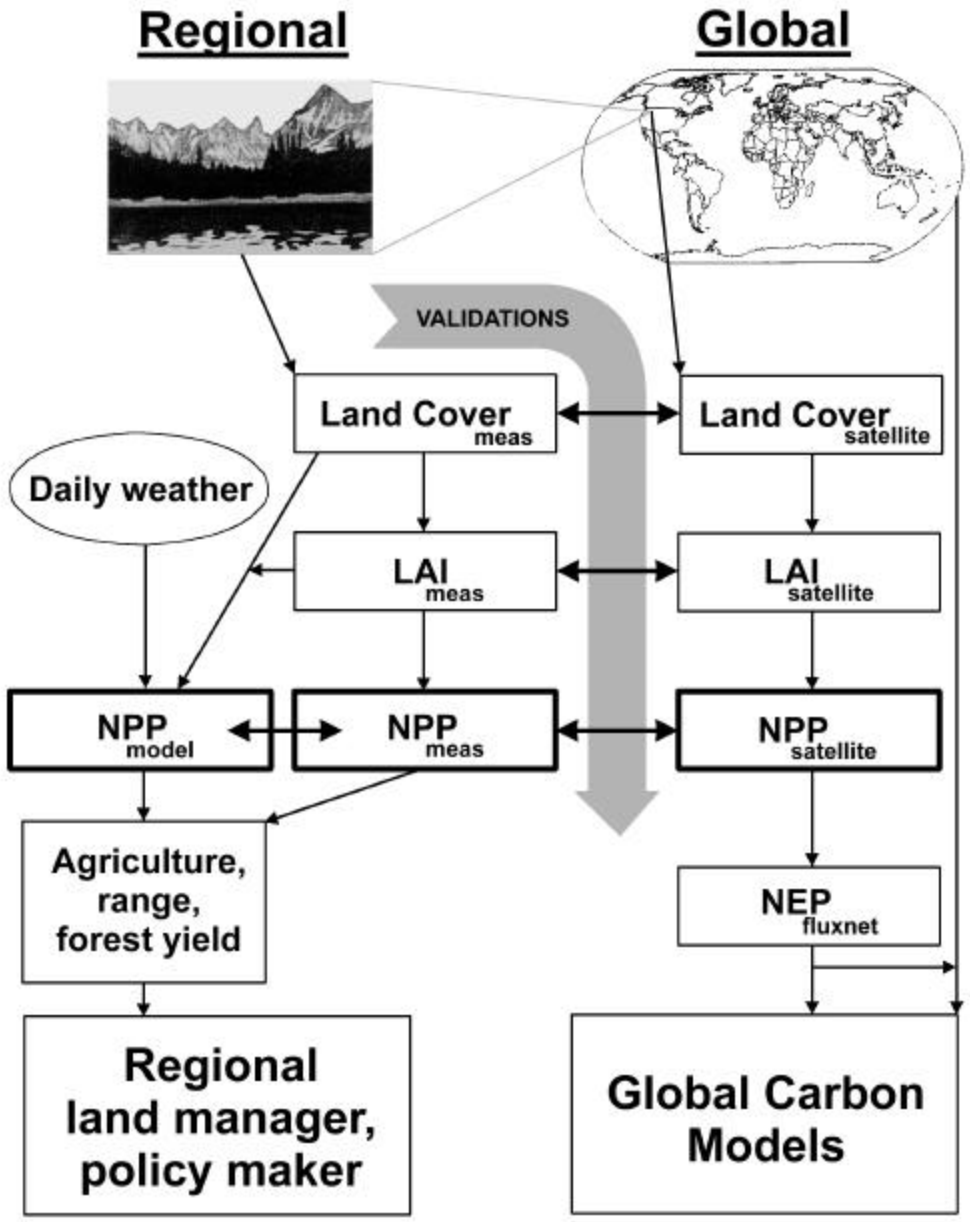
Photosynthesis



Transpiration



GTOS - NPP


Regional
Global
VALIDATIONS
Land Cover meas
Land Cover satellite
Daily weather
LAI meas
LAI satellite
NPP model
NPP meas
NPP satellite
Agriculture, range, forest yield
NEP fluxnet
Regional land manager, policy maker
Global Carbon Models