Challenges in Monitoring the Global Terrestrial Biosphere

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Divecha Climate Change Center
Indian Institute of Science

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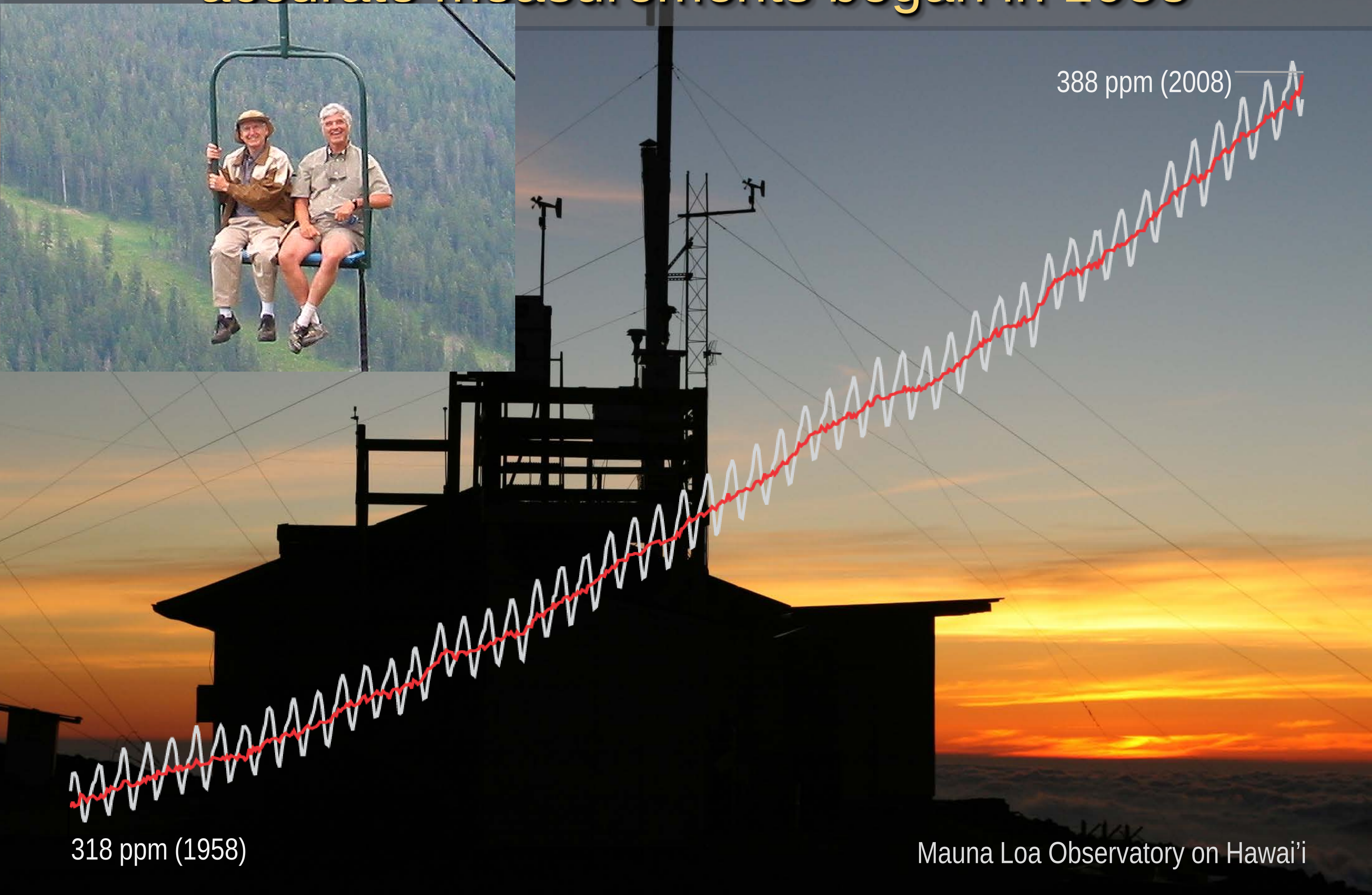
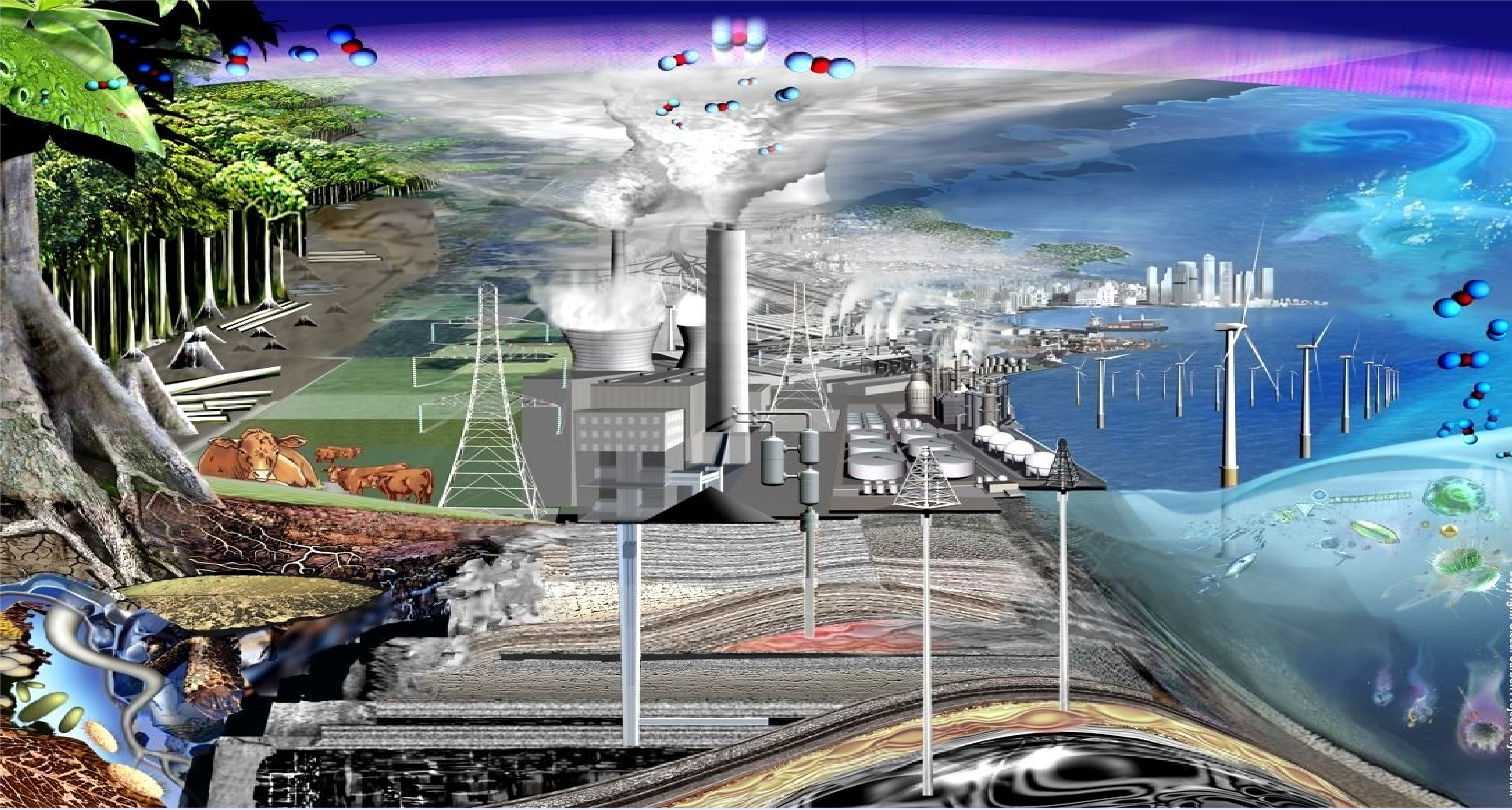
Carbon dioxide has risen by 36% since accurate measurements began in 1958





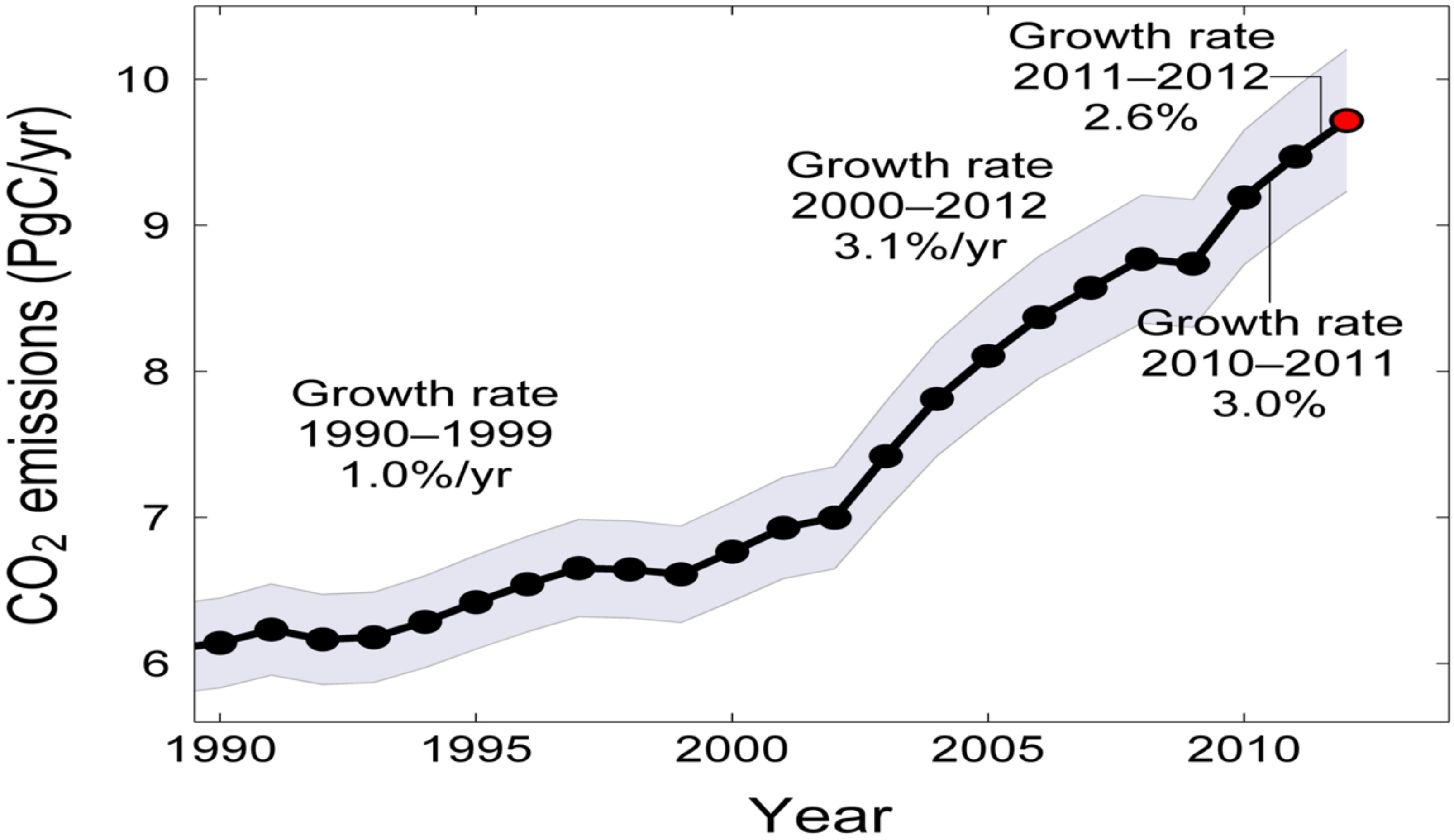
“The rise in CO_2 is proceeding so slowly that most of us today will, very likely, live out our lives without perceiving that a problem may exist”

Keeling CD, Harris TB, Wilkins EM, 1968. Concentration of atmospheric carbon dioxide at 500 and 700 millibars. J. Geophys. Res. 73:4511-28

Fossil and Cement Emissions

Global fossil and cement emissions: 9.5±0.5PgC in 2011, 54% over 1990

Projection for 2012: 9.7±0.5PgC, 58% over 1990

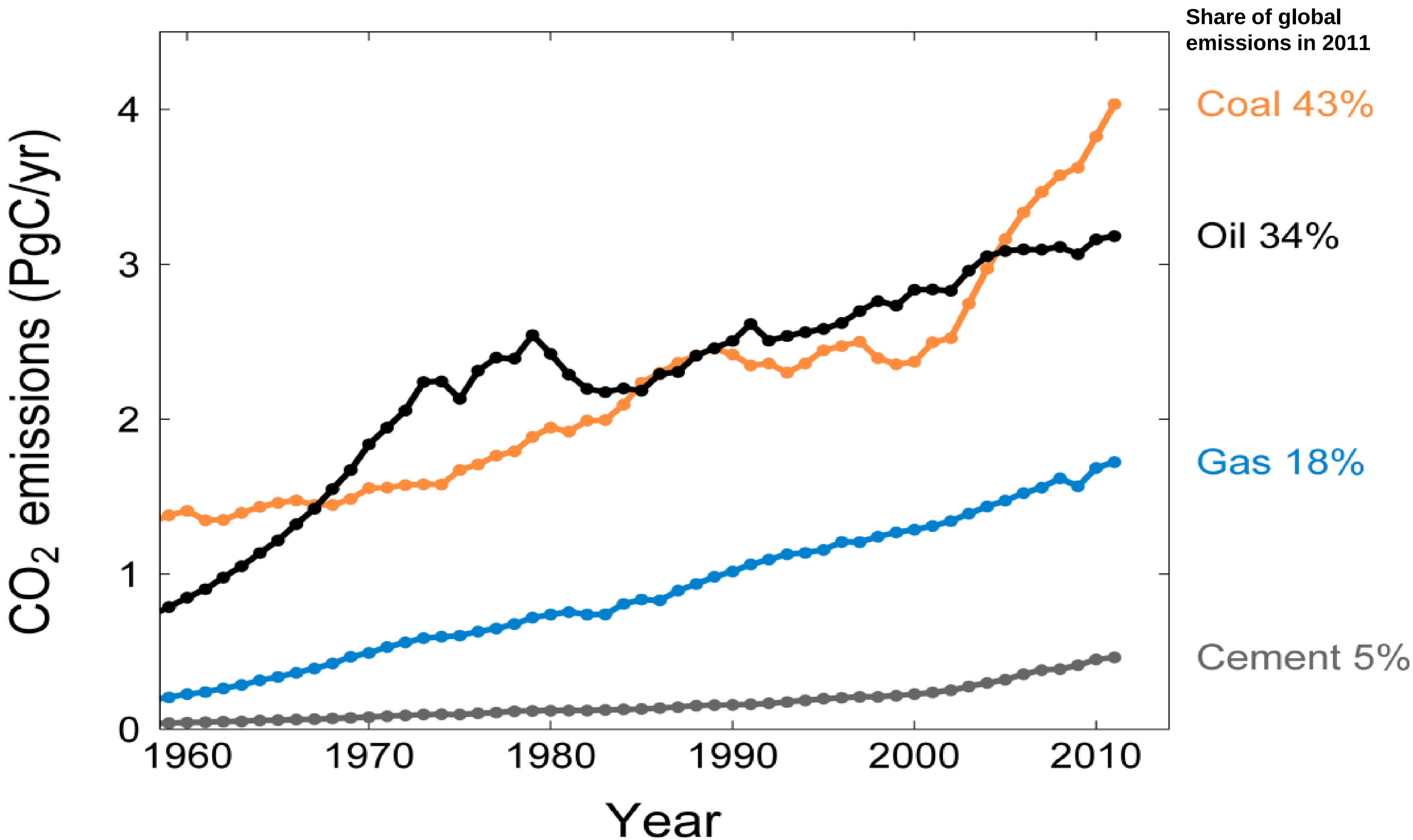


Uncertainty is ±5% for one standard deviation (IPCC "likely" range)

Source: Peters et al. 2012a; Le Quéré et al. 2012; CDIAC Data; Global Carbon Project 2012

Emissions from coal, oil, gas, cement

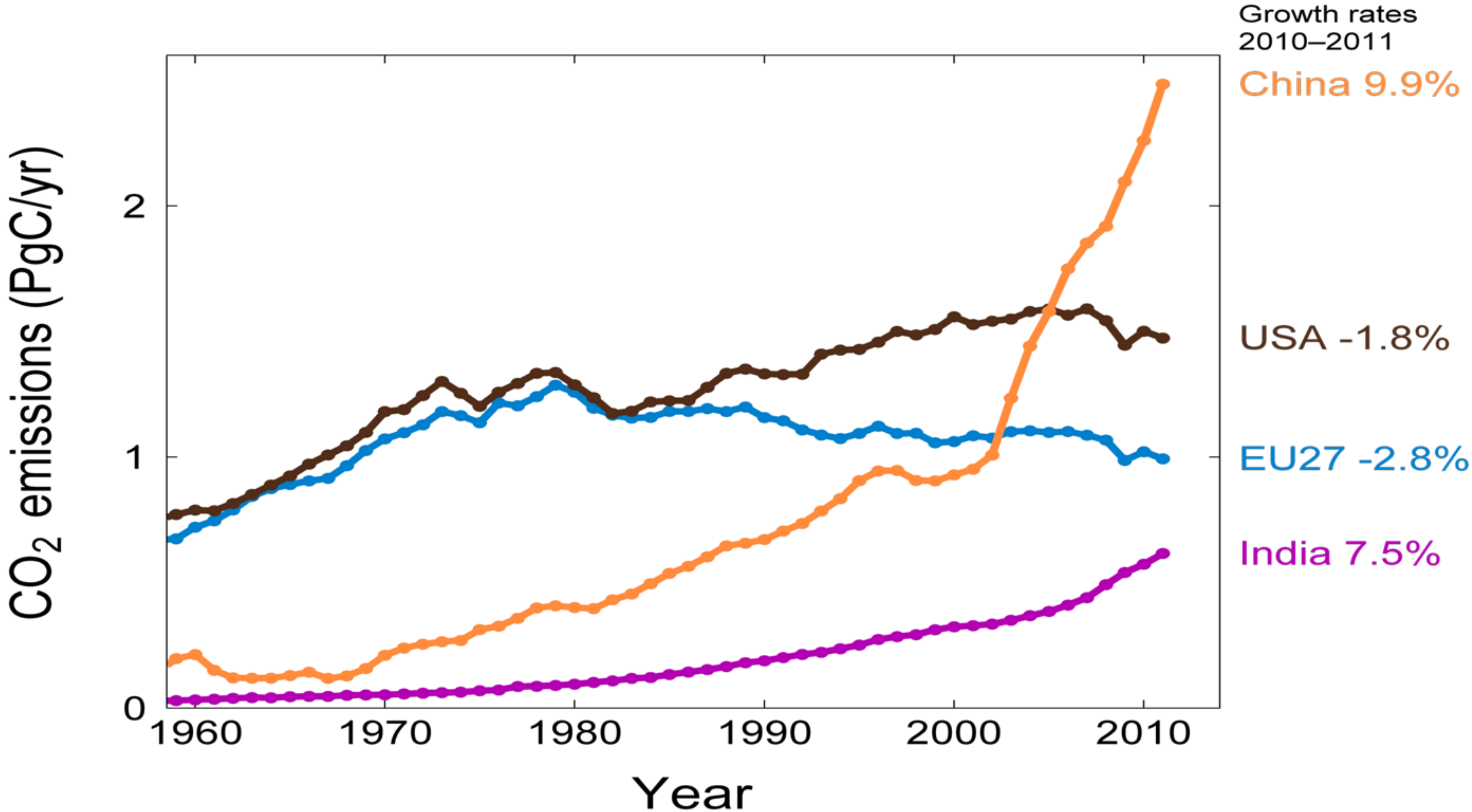
Emissions growth 2000-2011: coal (4.9%/yr), oil (1.1%/yr), gas (2.7%/yr), cement (6.9%/yr), flaring (4.3%/yr, not shown)



Source: CDIAC Data; Le Quéré et al. 2012; Global Carbon Project 2012

Top Fossil Fuel Emitters (Absolute)

Top four emitters in 2011 covered 62% of global emissions
China (28%), United States (16%), EU27 (11%), India (7%)



The growing gap between EU27 and USA is due to emission decreases in Germany (45% of the 1990-2011 cumulative difference), UK (19%), Romania (13%), Czech Republic (8%), and Poland (5%)

Source: CDIAC Data; Le Quéré et al. 2012; Global Carbon Project 2012

The Human Perturbation of the CO_2 Budget (2000-2009)

7.7±0.5 PgC y^{-1}

+

1.1±0.7 PgC y^{-1}

4.1±0.1 PgC y^{-1}

47%

2.4 PgC y^{-1}

27%

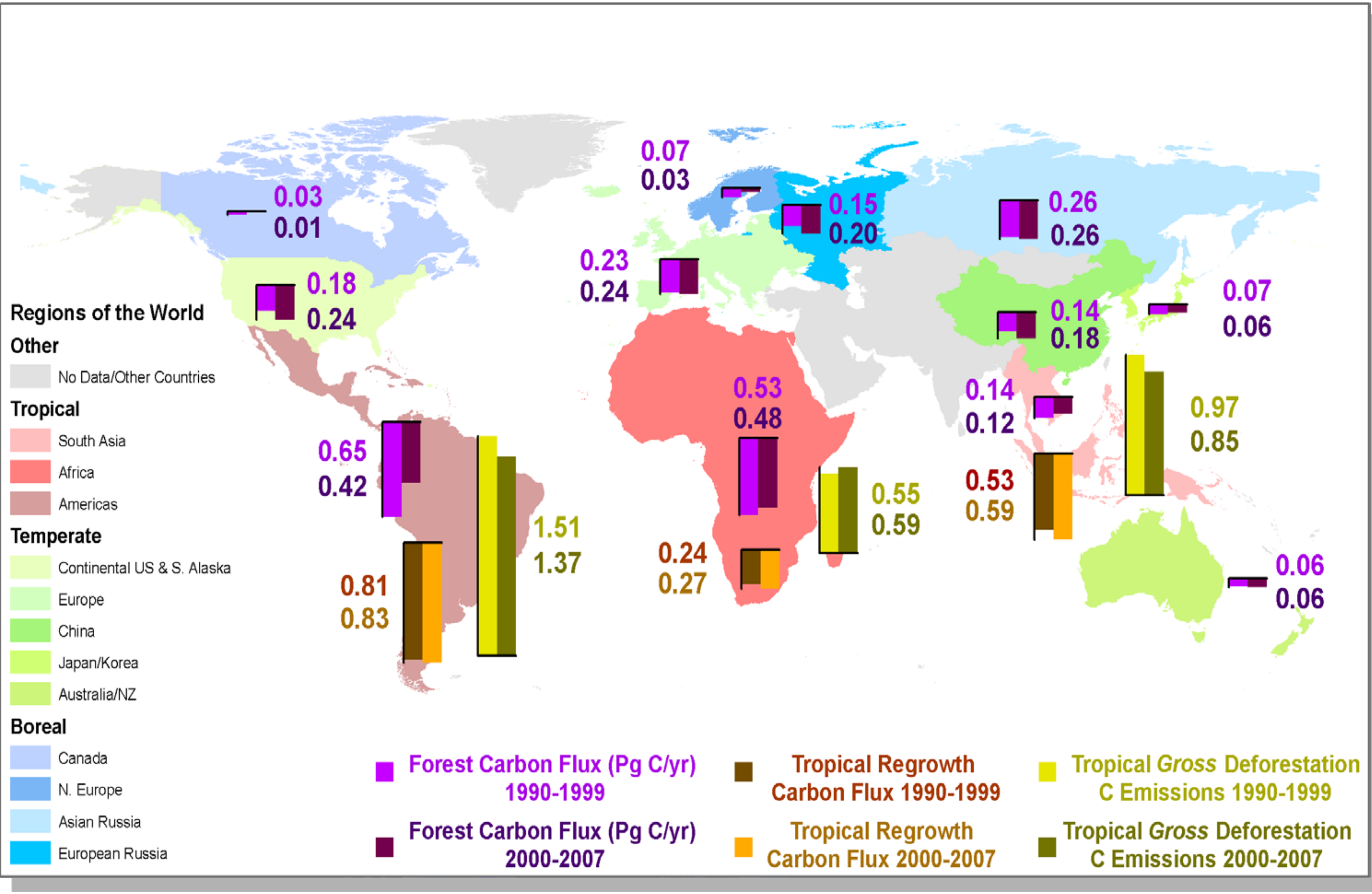
Calculated as the residual

26%

2.3±0.4 PgC y^{-1}

Global Carbon Project 2010; http://www.globalcarbonproject.org/carbonbudget/index.htm

Large and Consistent Global Forest Carbon Sink

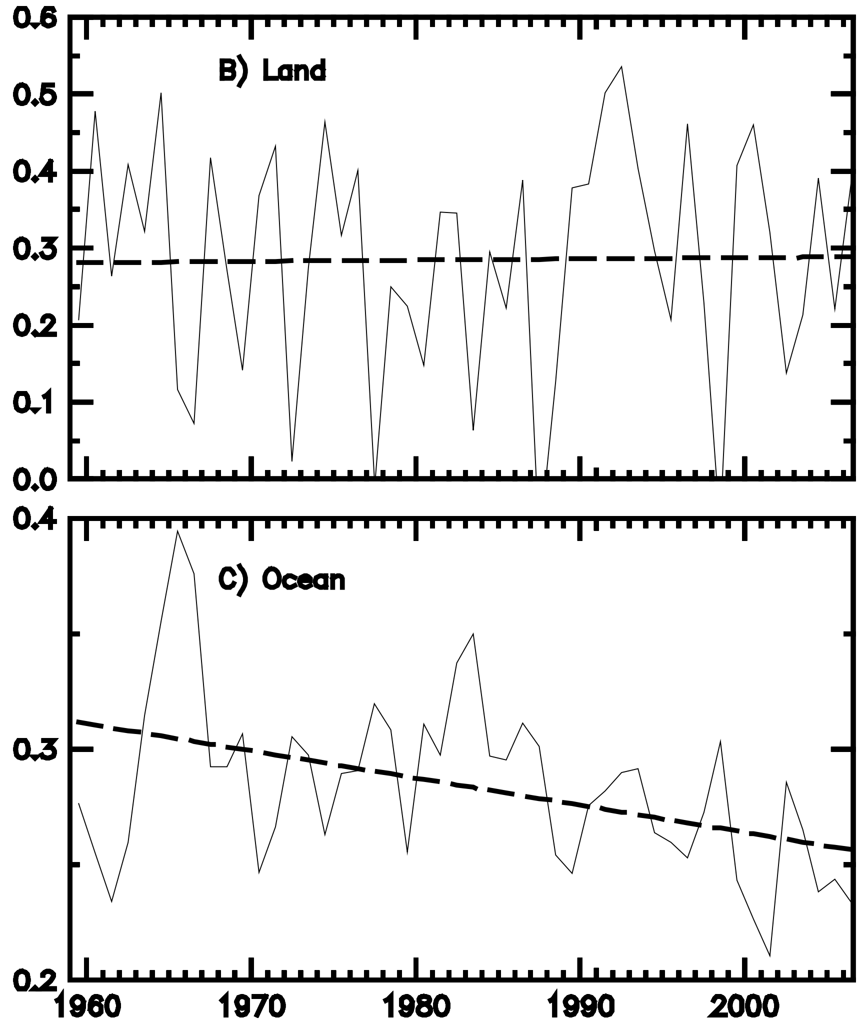


Pan et al. 2011, Science

Efficiency of Natural Sinks

Land Fraction

Ocean Fraction



Canadell et al. 2007, PNAS

Earth System Science Partnership

NASA Technical Memorandum 85841

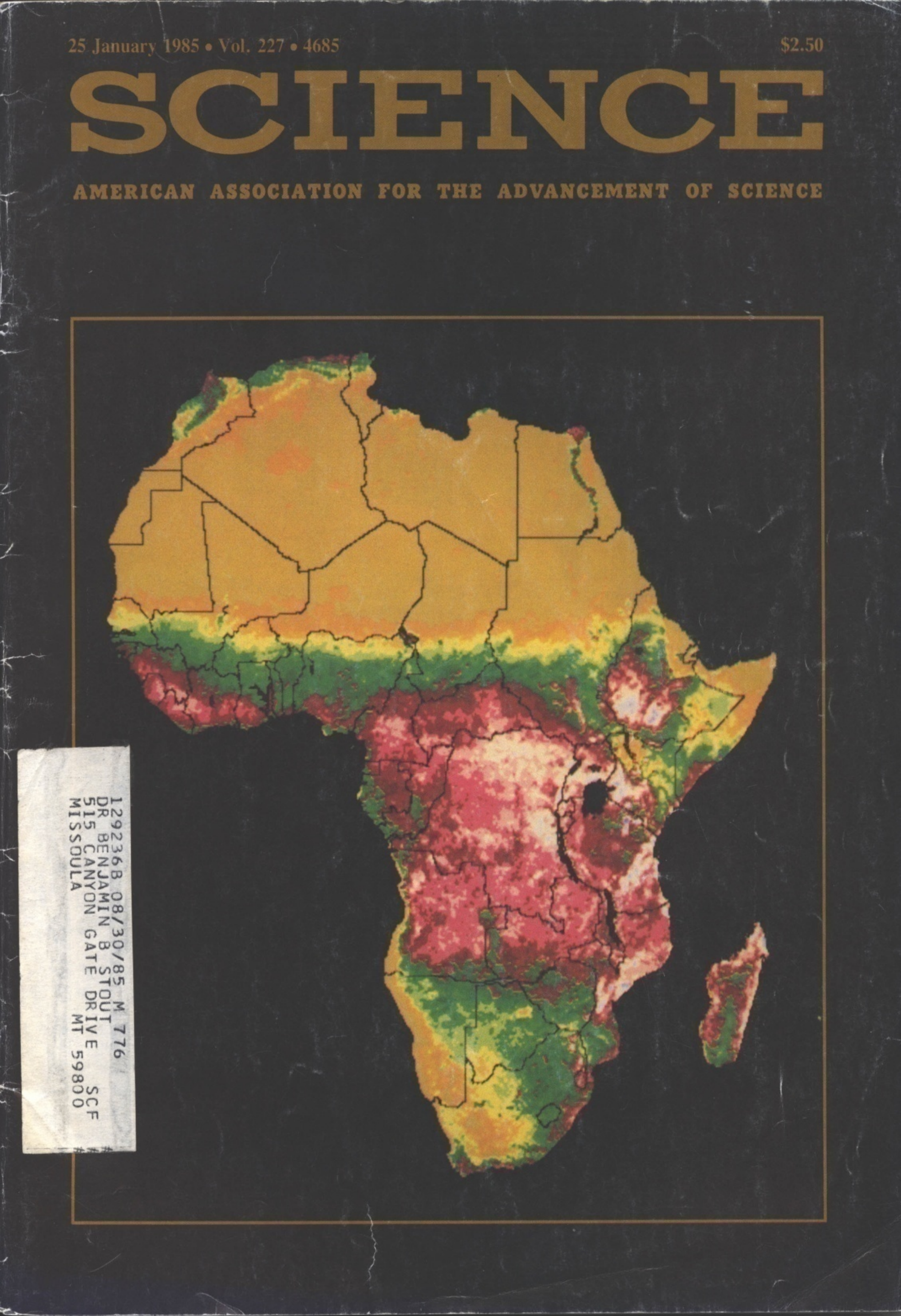
Land-Related Global Habitability Science Issues

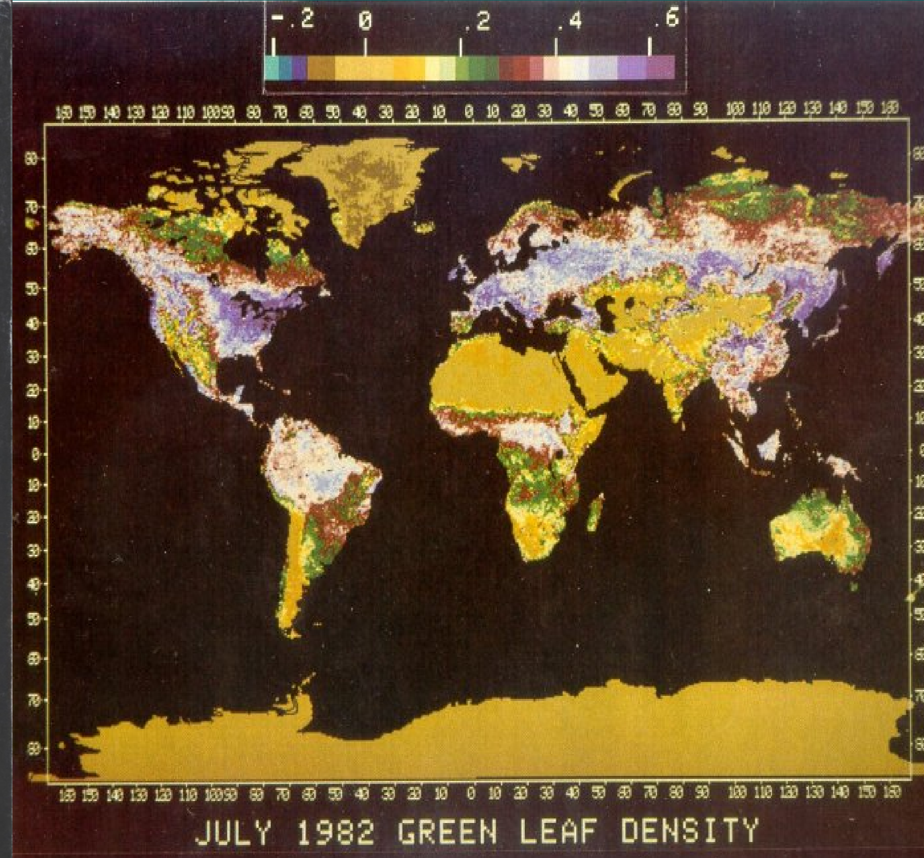
Land-Related Global Habitability
Sciences Working Group

JULY 1983

25th Anniversary
1958-1983

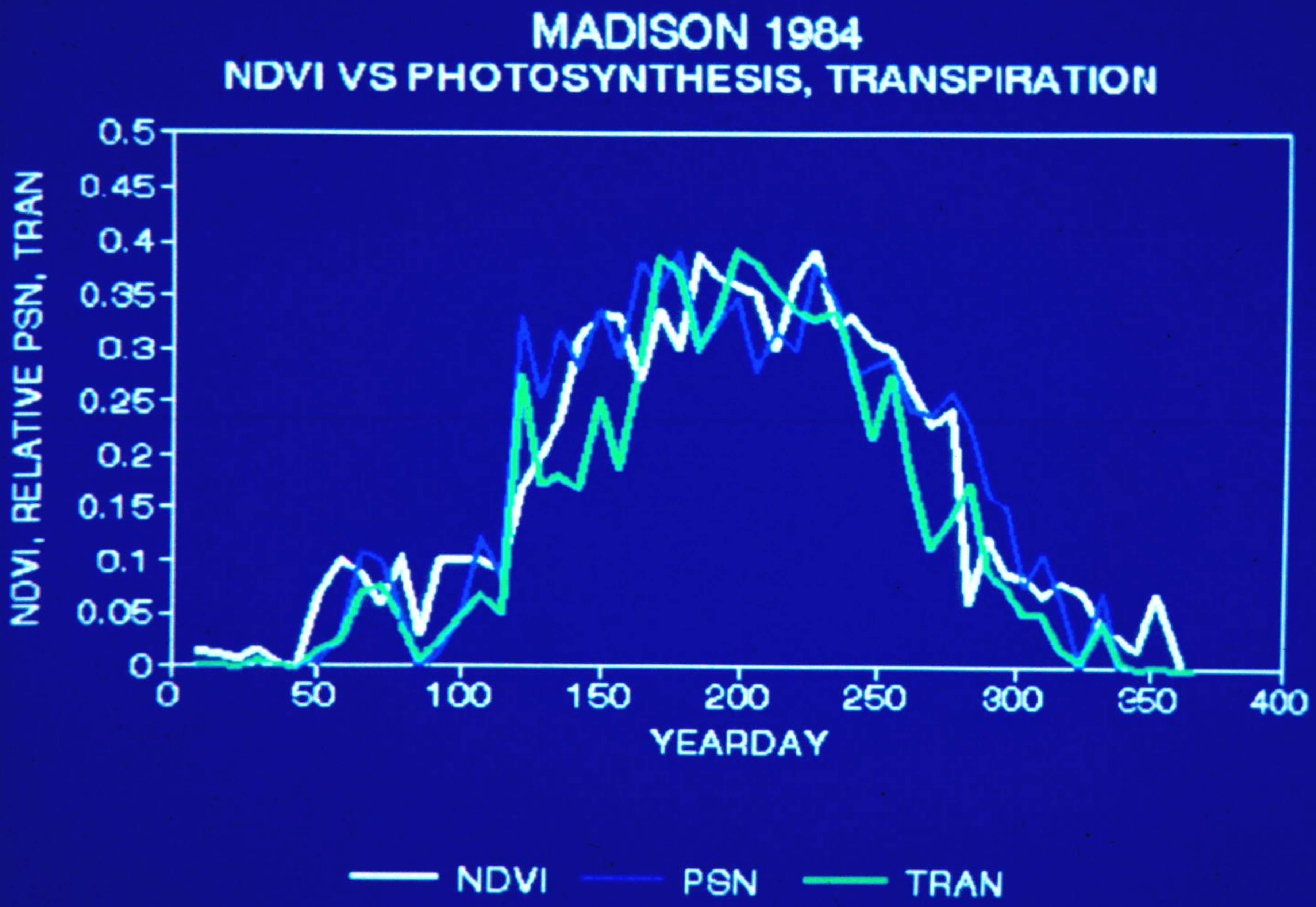
NASA

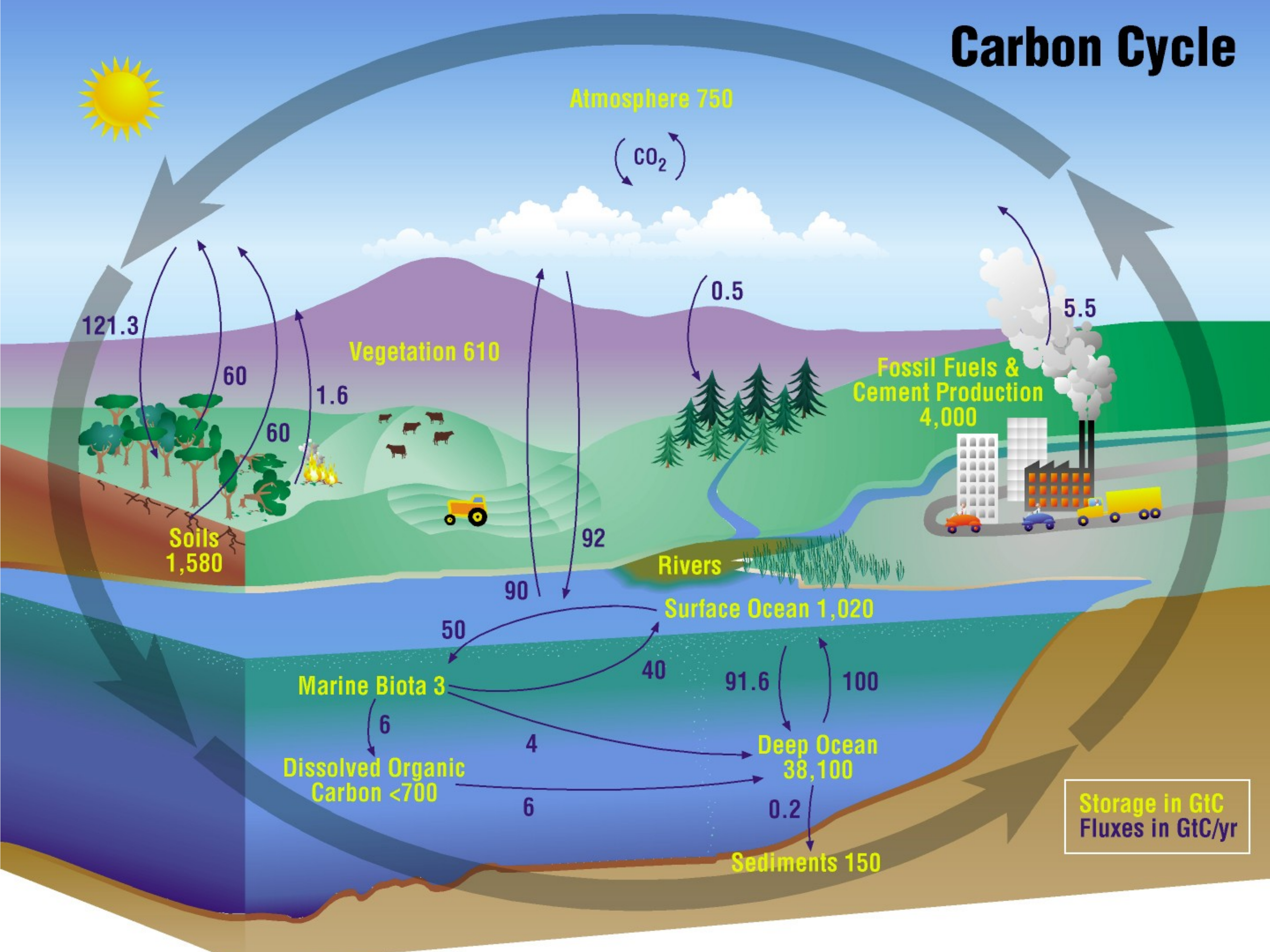

25 January 1985 • Vol. 227 • 4685
$2.50
SCIENCE
AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE
129236B 08/30/85 M 776
DR BENJAMIN B STOUT
515 CANYON GATE DRIVE SCF
MISSOULA MT 59800


-.2 0 .2 .4 .6
JULY 1982 GREEN LEAF DENSITY

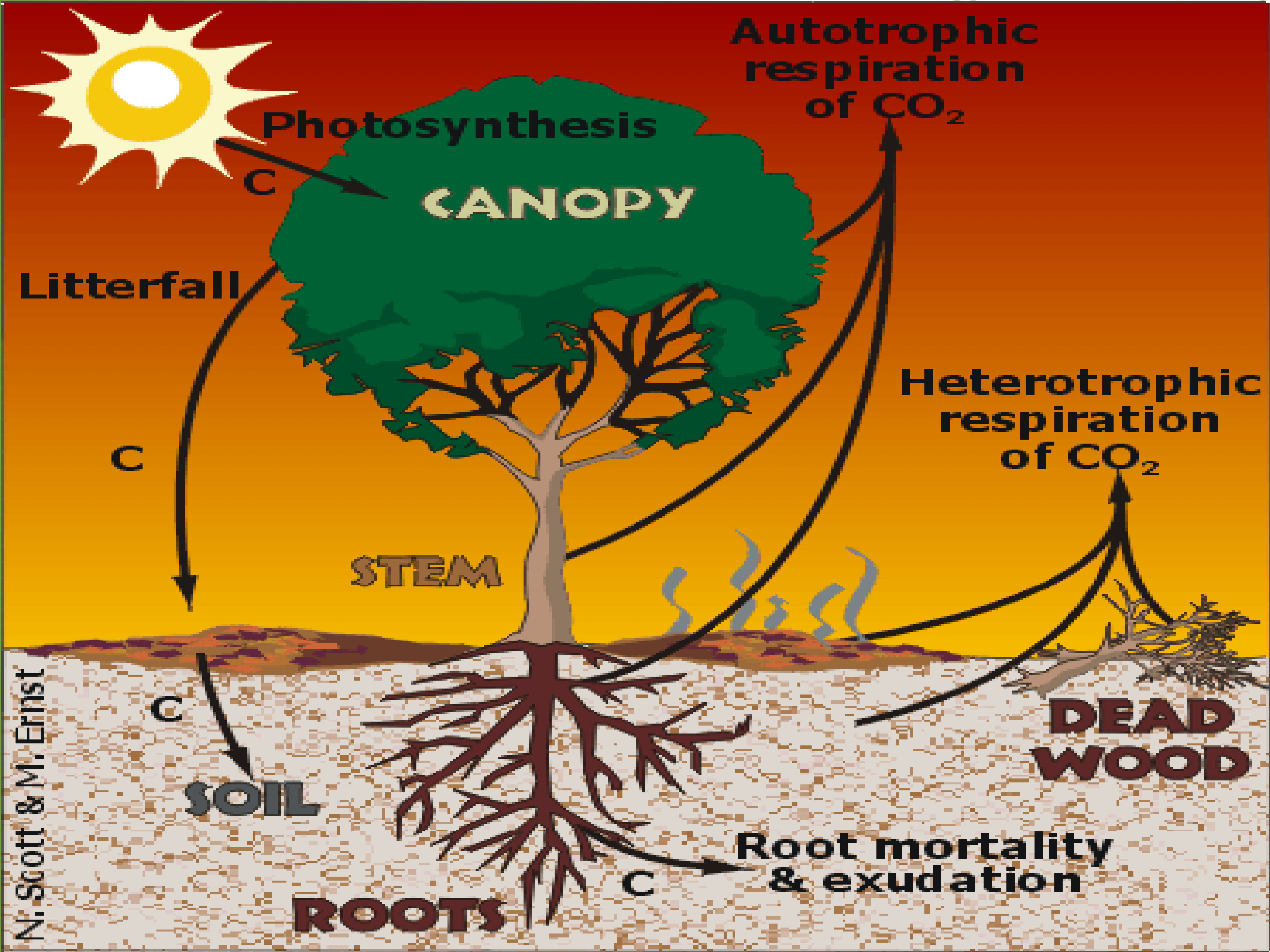

JUL 20 2003

Relating transpiration and photosynthesis to NDVI, 1988





Carbon Cycle
Atmosphere 750
CO_2
121.3
60
60
1.6
Vegetation 610
90
92
0.5
5.5
Fossil Fuels &
Cement Production
4,000
Soils
1,580
Rivers
Surface Ocean 1,020
50
40
Marine Biota 3
91.6
100
6
4
Deep Ocean
38,100
Dissolved Organic
Carbon <700
6
0.2
Sediments 150
Storage in GtC
Fluxes in GtC/yr



Autotrophic respiration of CO_2
Photosynthesis
C
CANOPY
Litterfall
C
Heterotrophic respiration of CO_2
STEM
C
SOIL
DEAD WOOD
Root mortality & exudation
C
ROOTS
N. Scott & M. Ernst

Driving ecosystem models with satellite data, concept for NASA Global Habitability, 1983

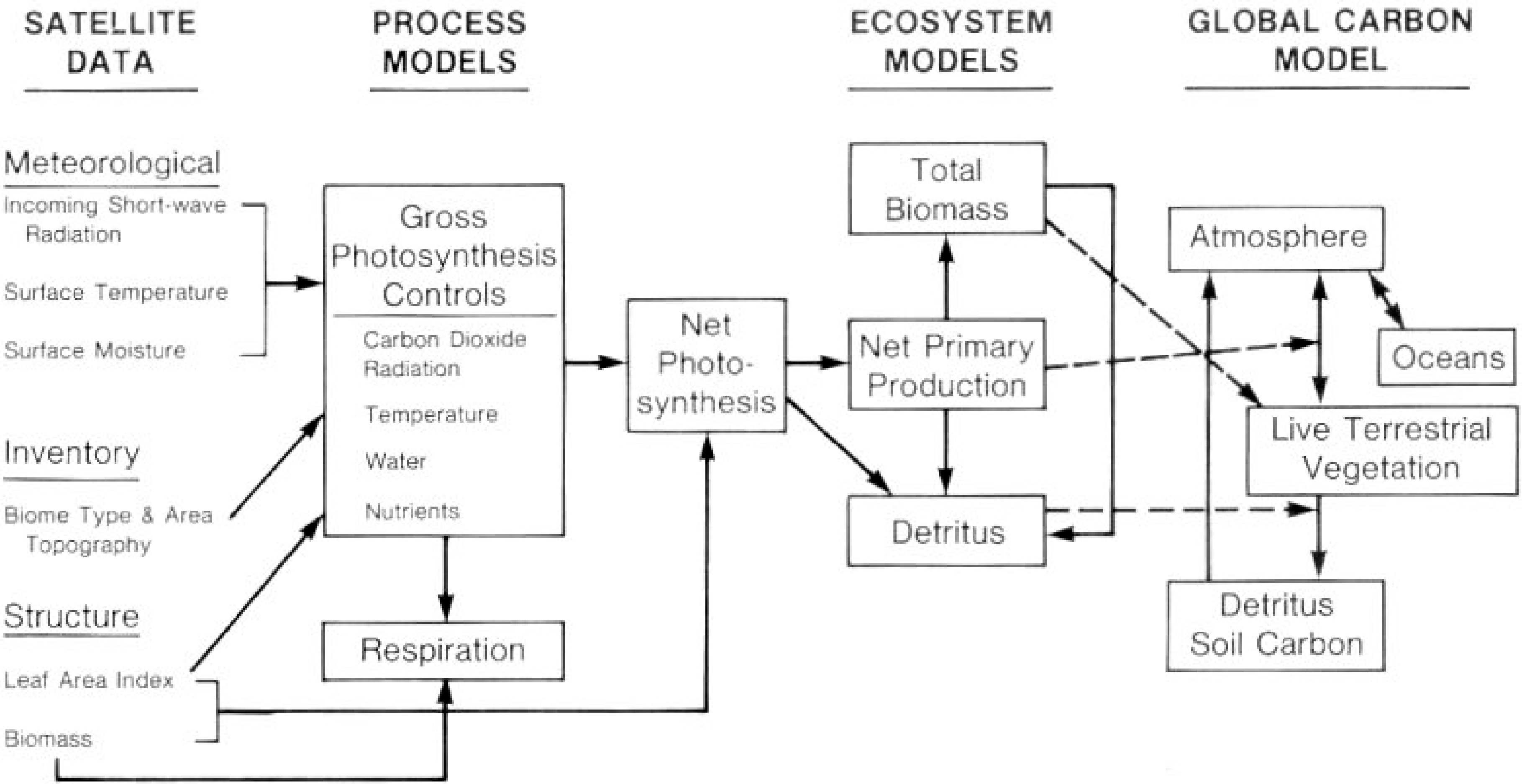


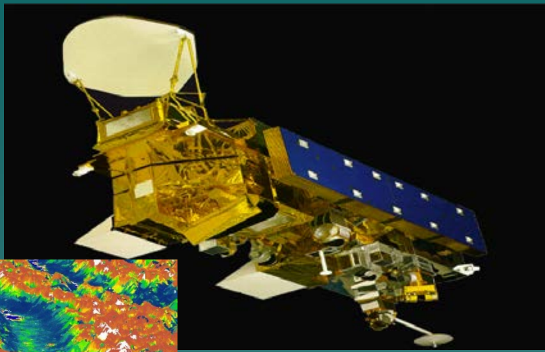
Figure 2. Organizational diagram of a proposed model of net primary production for a coniferous forest. All driving variables are derived from satellite data. Potential linkages to a global carbon model are shown by dashed lines (Running, 1984).

Integrated, Multiple Constraints on the Biosphere

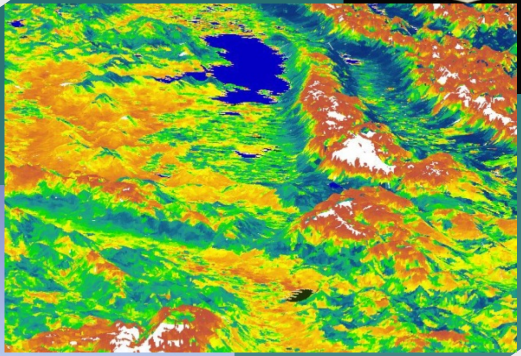
Upscaling

Prediction

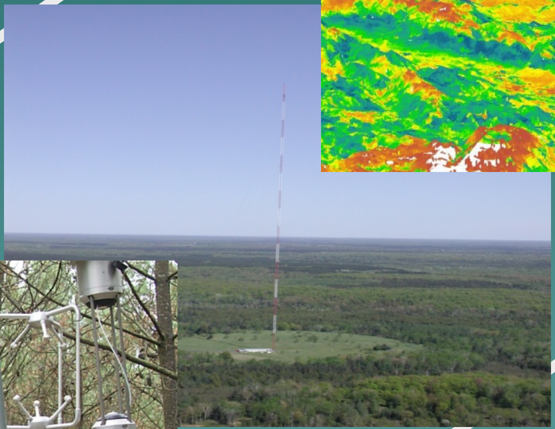
1000 km



10 km



1km

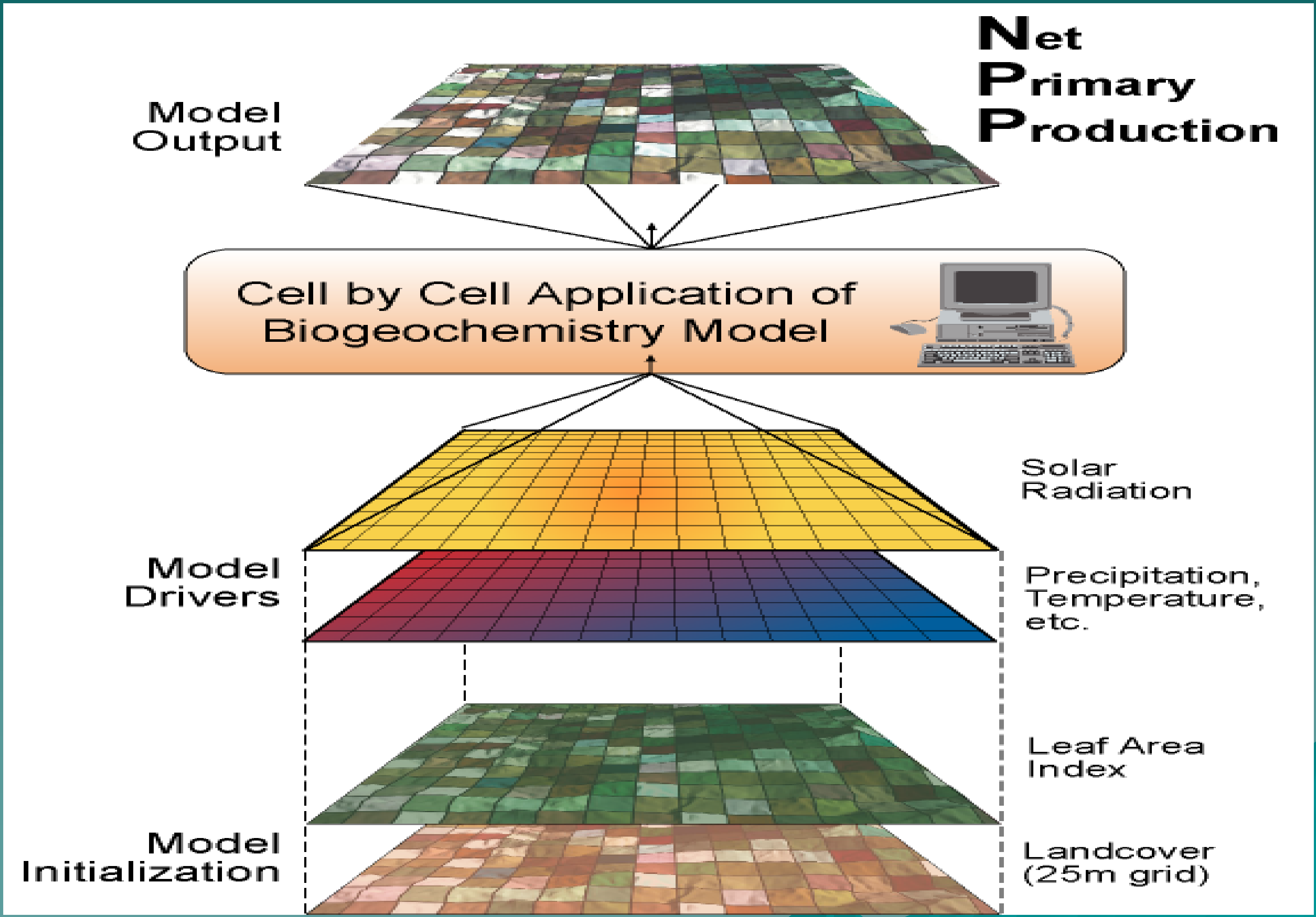


1ha

1m

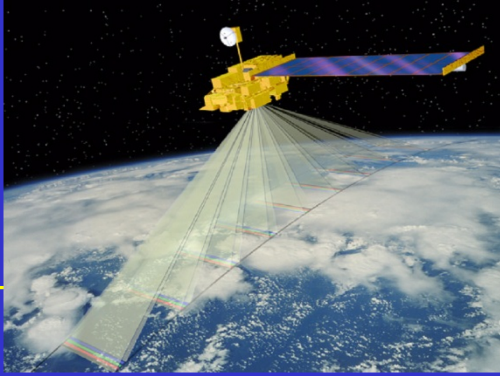
Downscaling

Verification

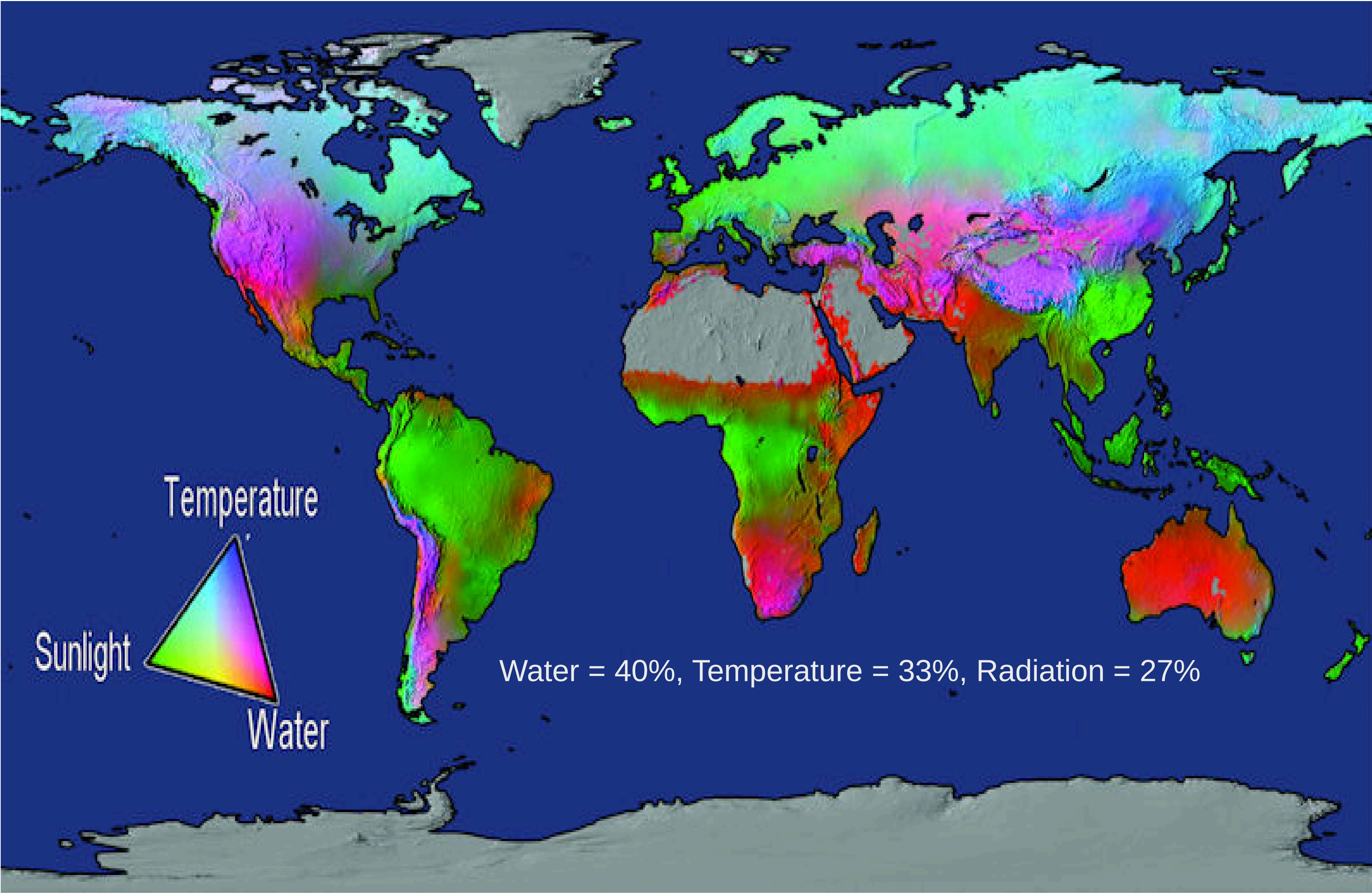

Net
Primary
Production
Model
Output
Cell by Cell Application of
Biogeochemistry Model
Solar
Radiation
Model
Drivers
Precipitation,
Temperature,
etc.
Leaf Area
Index
Model
Initialization
Landcover
(25m grid)

EOS TERRA launch
Dec. 18, 1999

MODIS LAND PRODUCTS

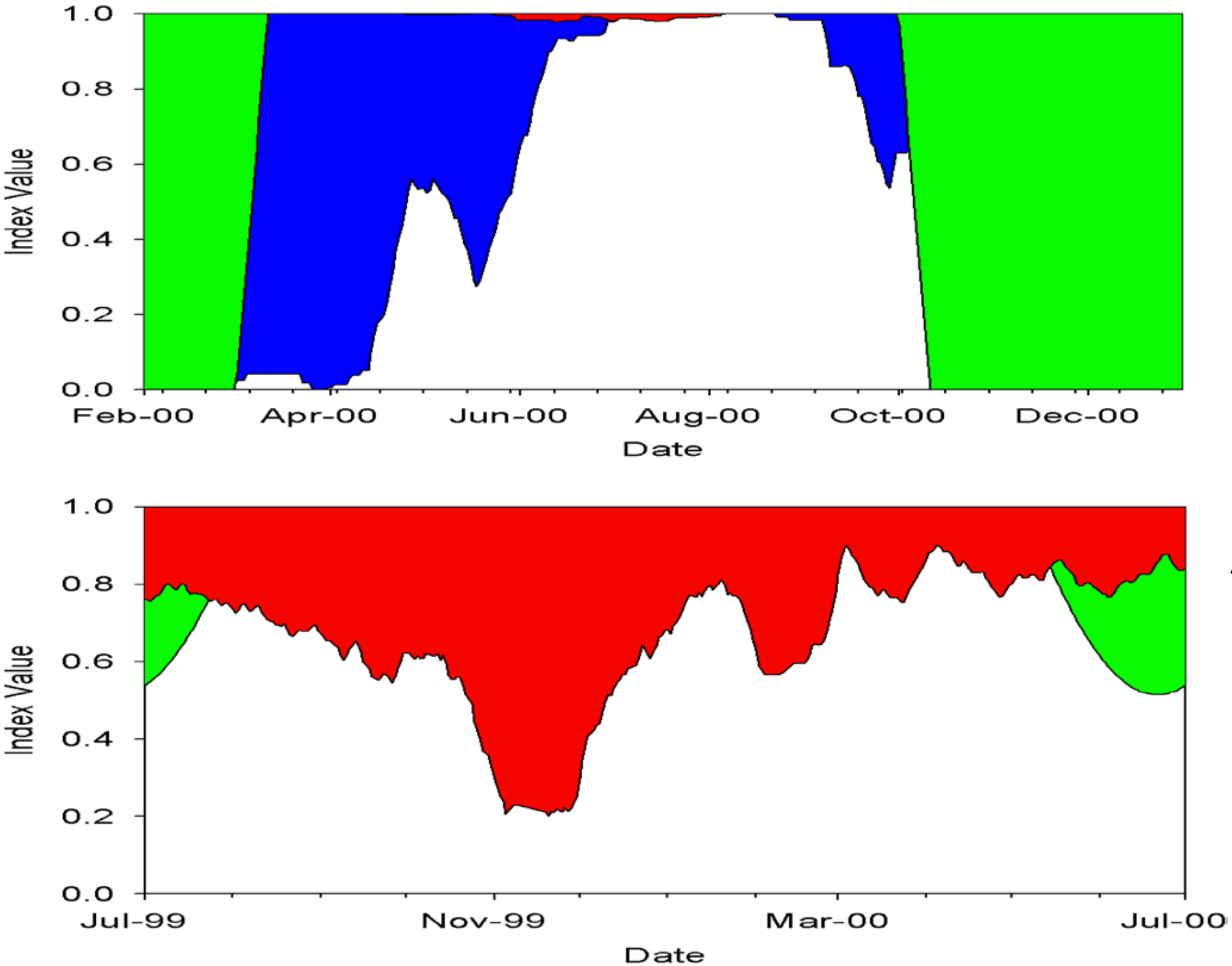


- **MOD 09** Surface Reflectance
- **MOD 11** Land Surf. Temp. / Emissivity
- **MOD 12** Land Cover / Change
- **MOD 13** Vegetation Indices
- **MOD 14** Thermal Anomalies / Fire
- ***MOD 15 Leaf Area Index / FPAR***
- ***MOD 16 Evapotranspiration/SR***
- ***MOD 17 Primary Production***
- **MOD 43** BRDF / Albedo
- **MOD 44** Vegetation Continuous Fields



Potential limits to vegetation net primary production based on fundamental physiological limits by solar radiation, water balance, and temperature (from Churkina & Running, 1998; Nemani et al., 2003; Running et al., 2004).

Seasonal Growing Season Constraints



Russia, Boreal

Africa, Savannah

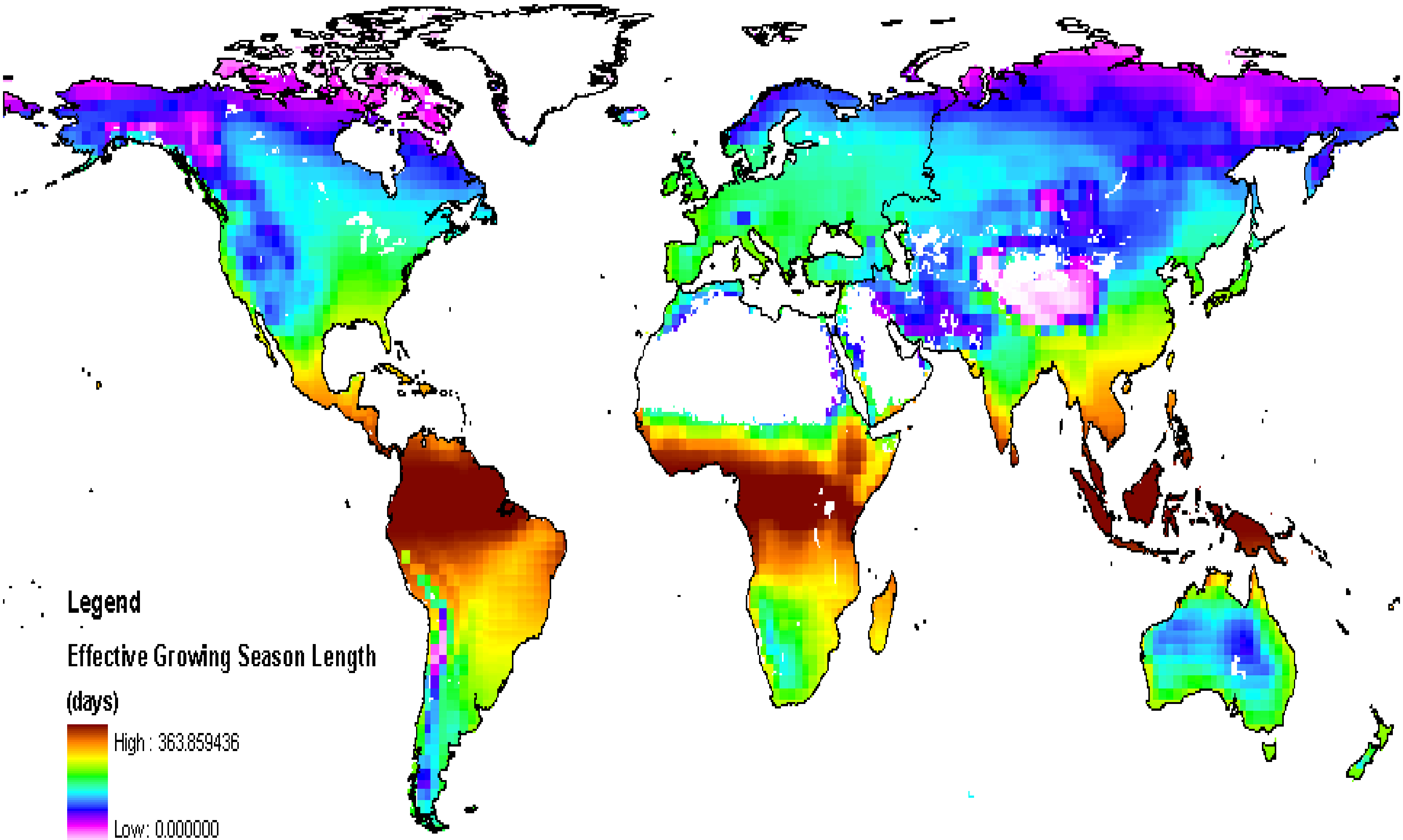
Vapor Pressure Deficit

Daylength

Minimum Temperaure

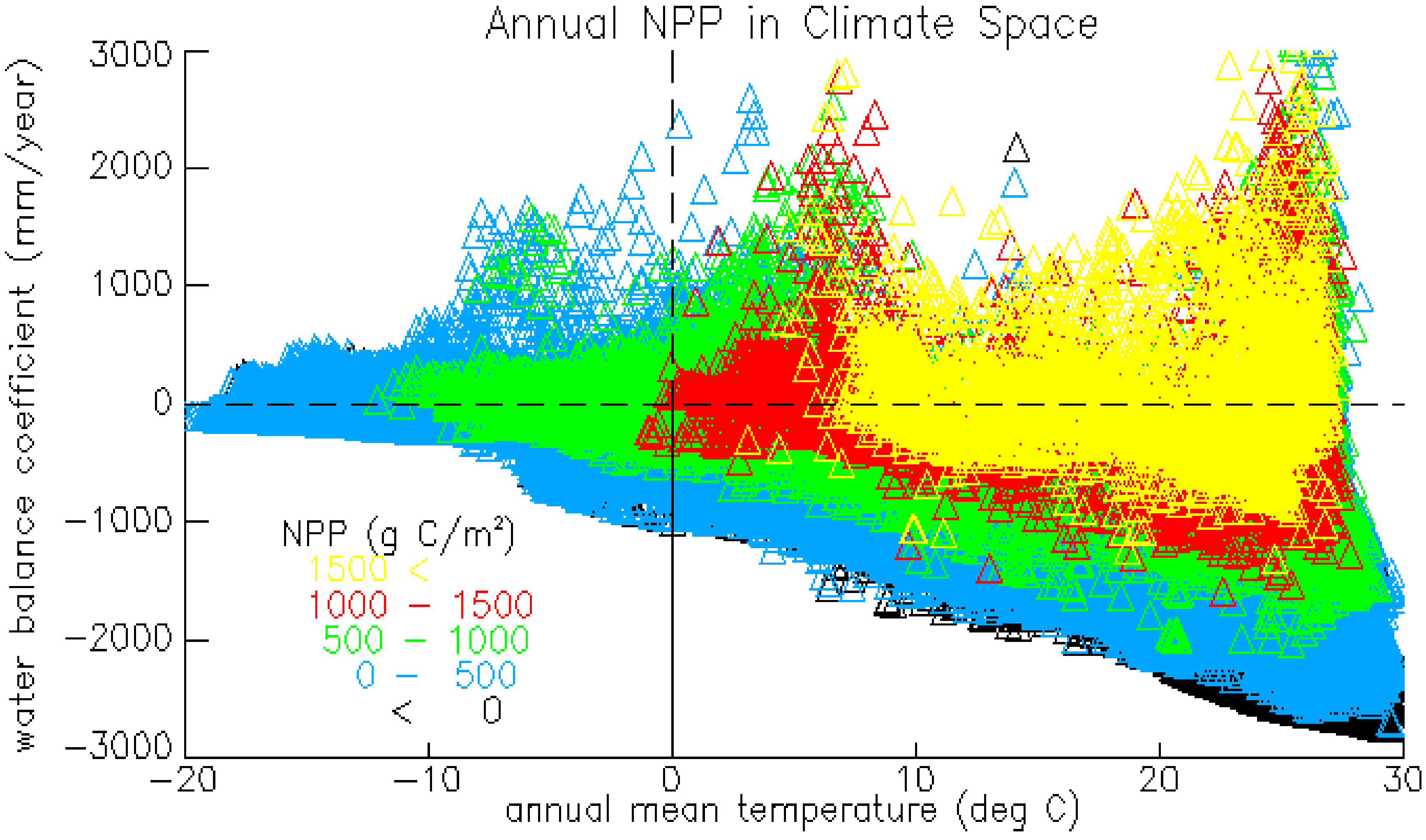
Jolly, Nemani, Running. Global Change Biology 2005

Global Effective Growing Season Length



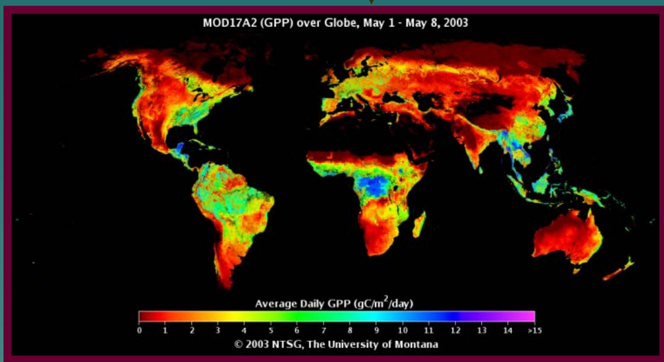
Jolly, Nemani, Running. Global Change Biology 2005

Climate space of global NPP

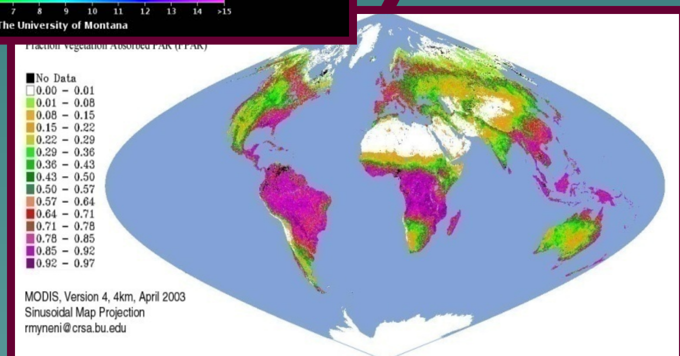


GPP = Light X Conversion Efficiency

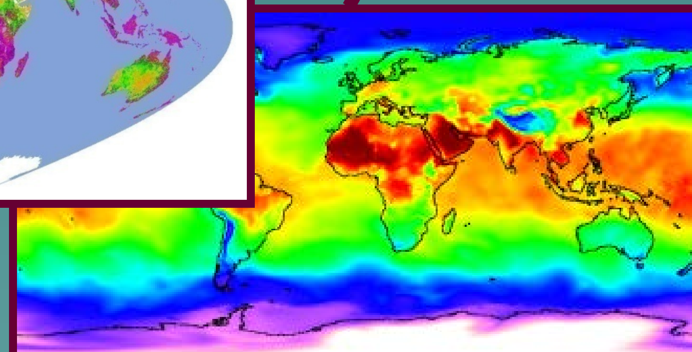
$$GPP = f\,(PAR) \times \varepsilon$$



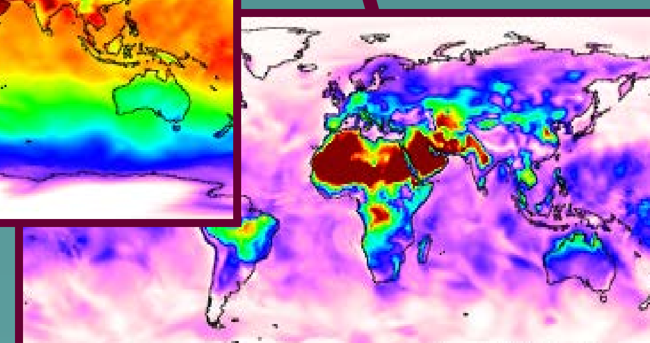
GPP



fPAR, PAR



Temperature

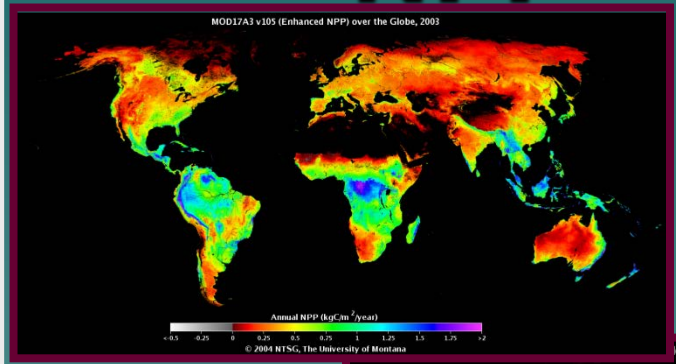


VPD

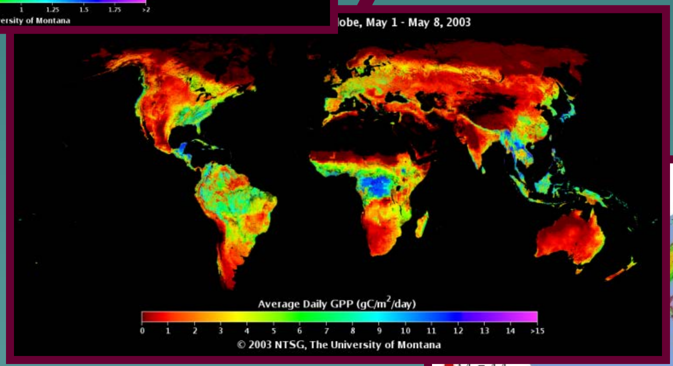
Biome Properties Look-Up Table (ε_{max})

NPP = Annual GPP - Autotrophic Respiration

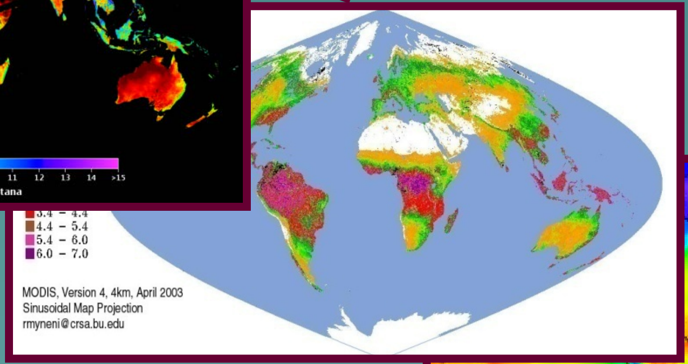
$$NPP = \sum GPP - (R_m + R_g)$$



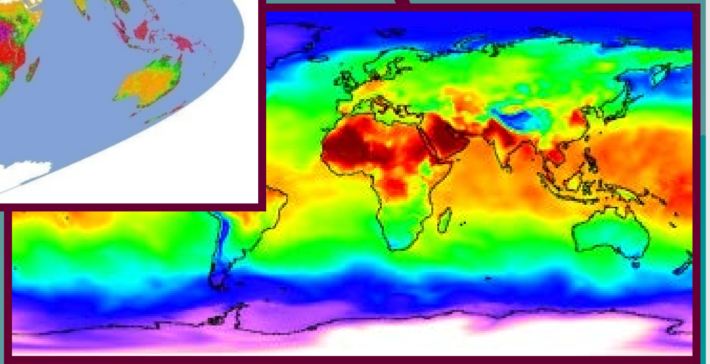
NPP



GPP



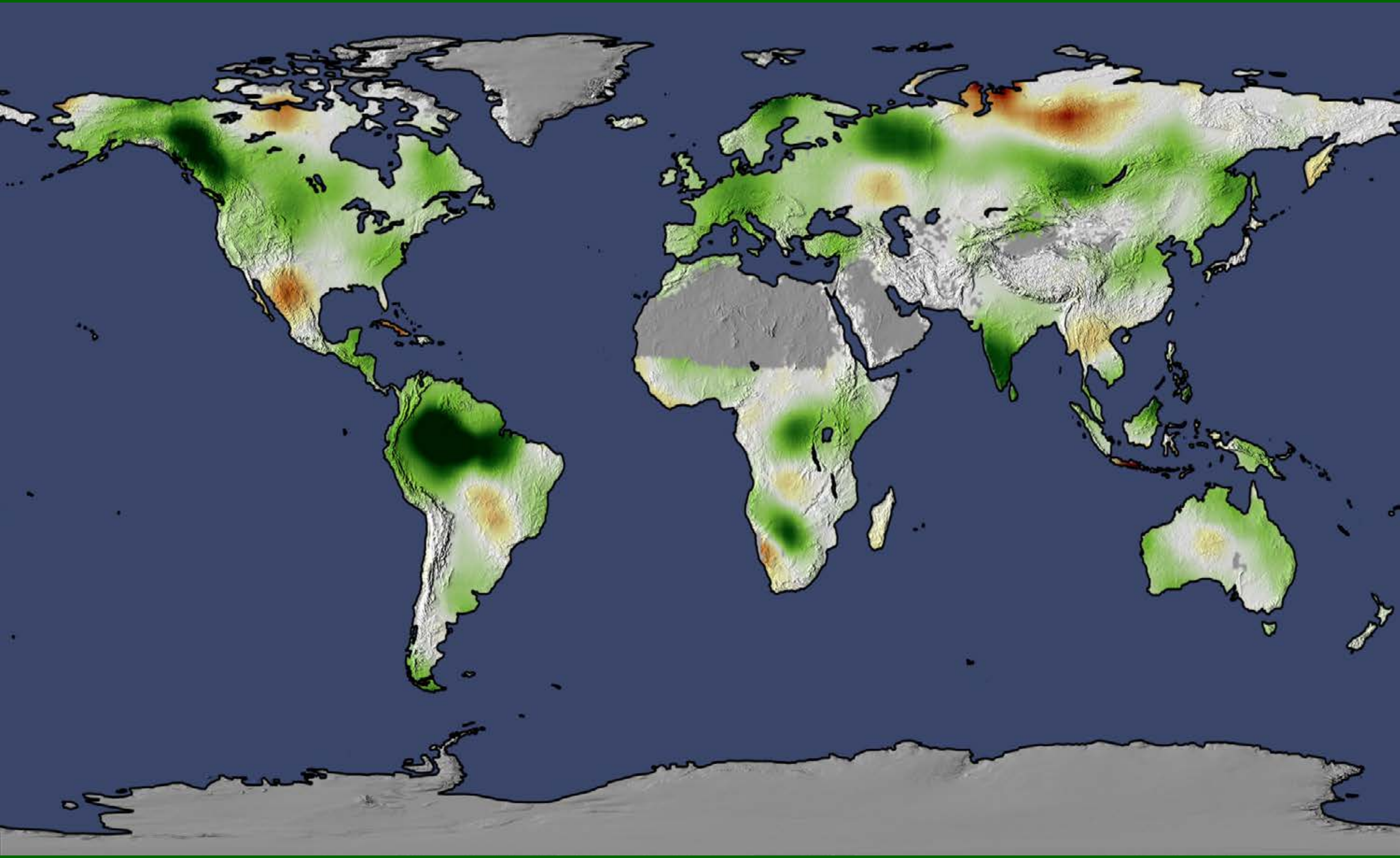
LAI



Temperature

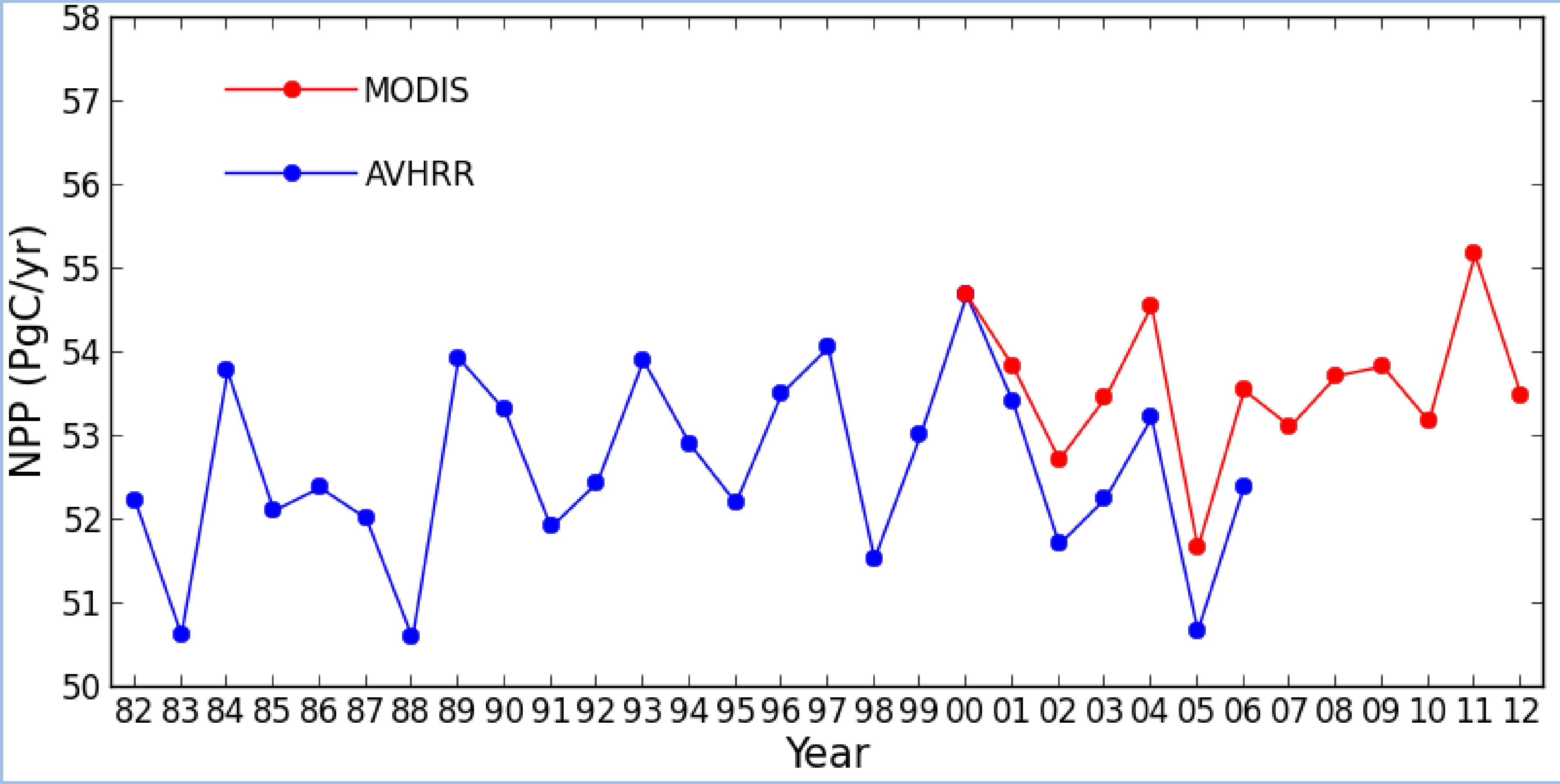
Biome Properties Look-Up Table

Change in Terrestrial NPP from 1982 to 1999



Nemani et al., Science June 6th 2003

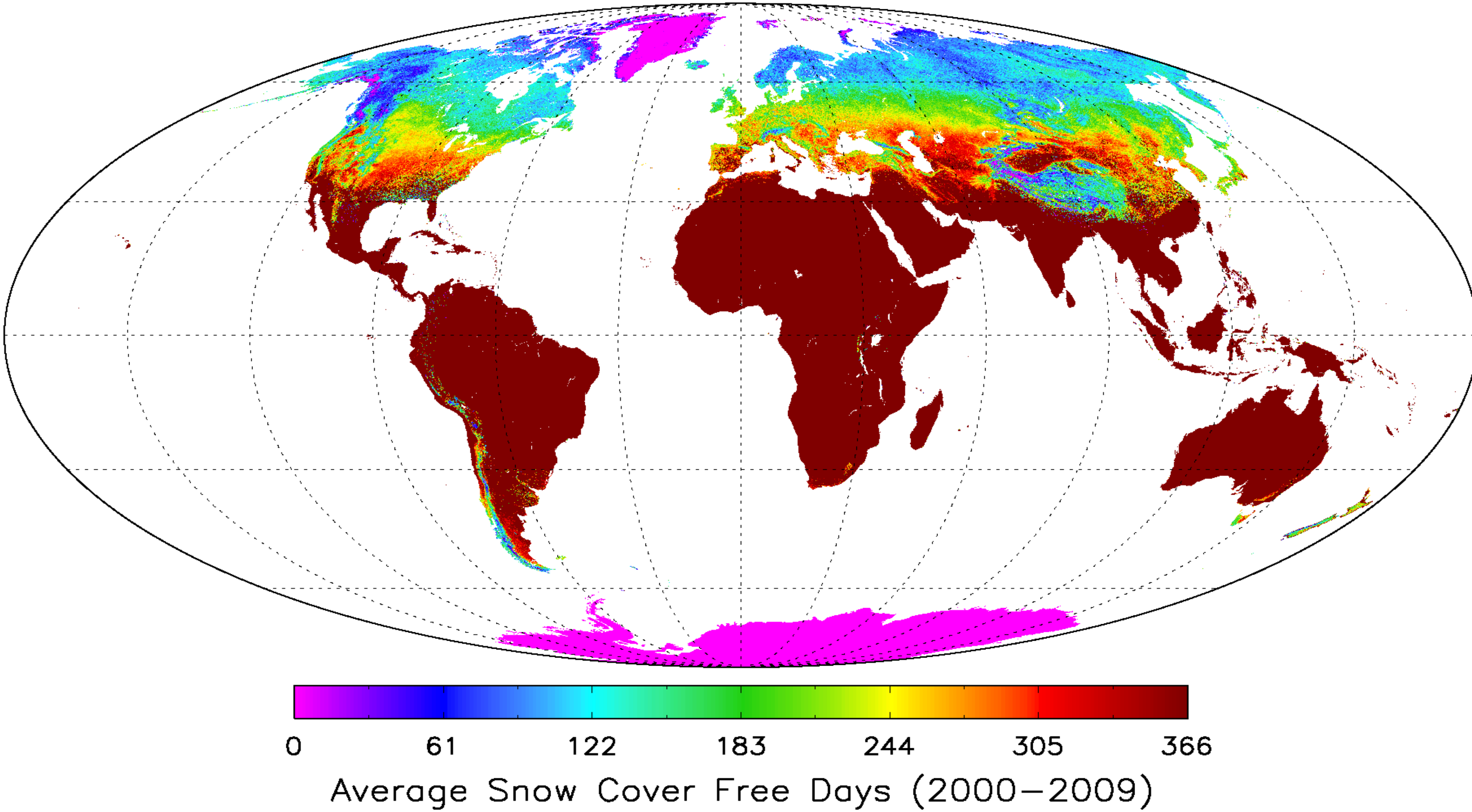
Global Terrestrial Net Primary Production (1982-2012)



+/- 1Pg or about 2%

Nemani et al 2003, Zhao and Running 2010

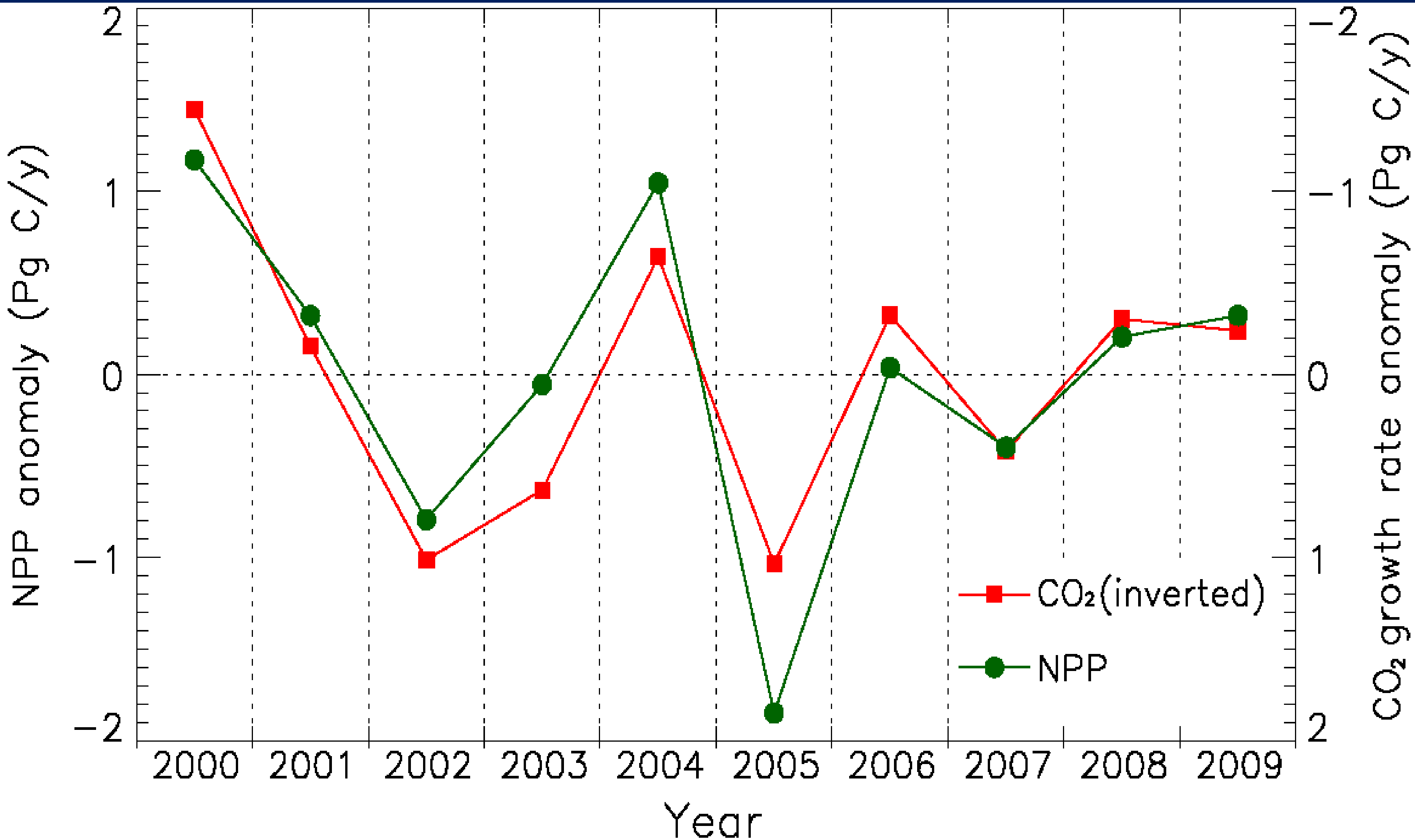
Temperature is a control factor of growing season for NH but not SH !



For NH, 125 days snow cover
For SH, 7.5 days snow cover

Zhao & Running 2010, *Science*

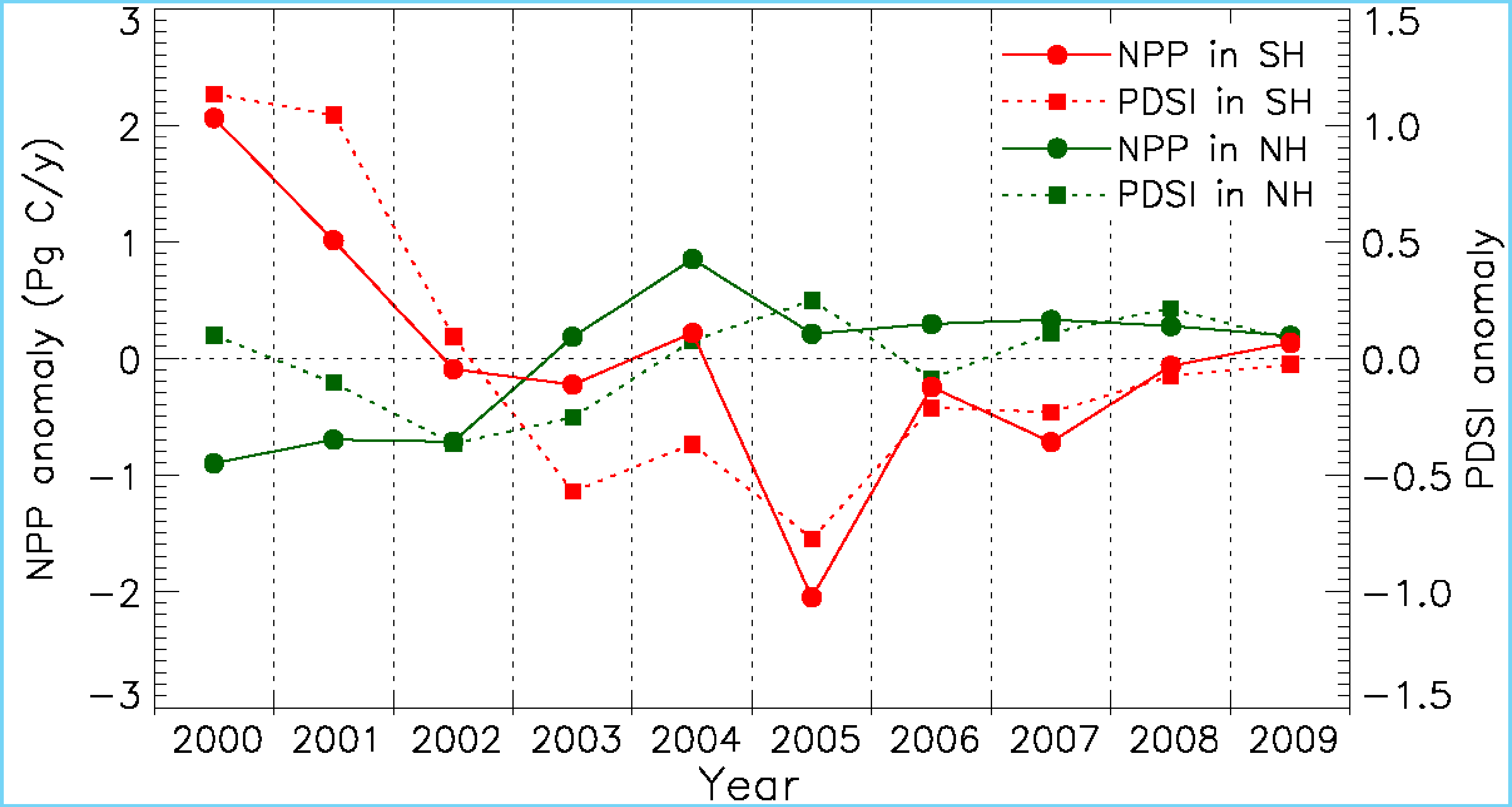
Global MODIS NPP Anomaly



$R = -0.89$, $p < 0.0006$

Zhao & Running 2010, *Science*

NPP over two hemisphere trend (2000-2009)



For NH, R = 0.39, $p < 0.27$

For SH, R = 0.87, $p < 0.001$

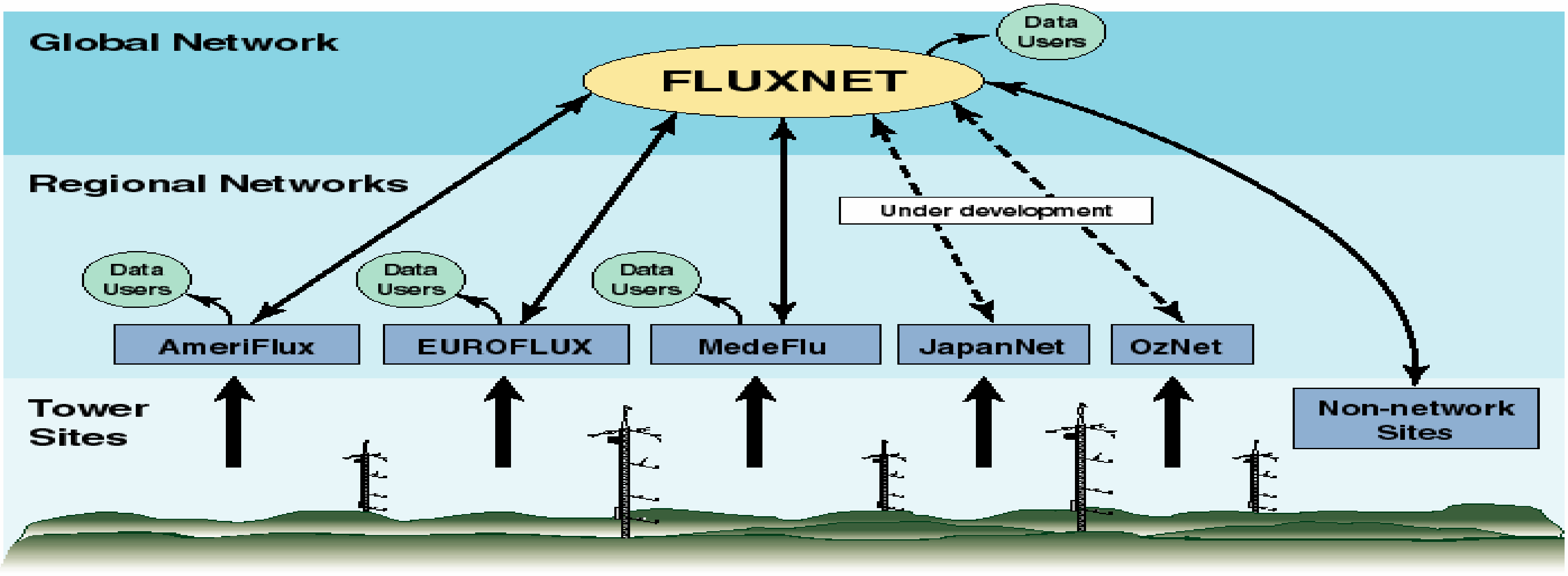
Zhao & Running 2010, *Science*

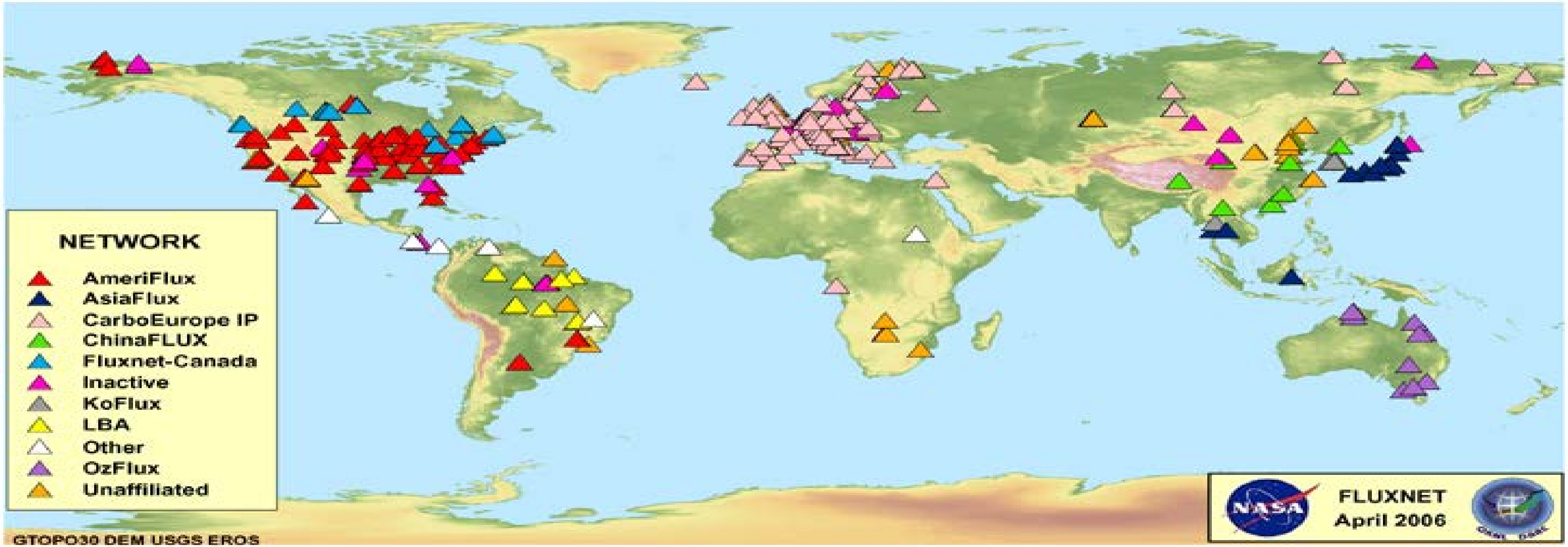
Comparison of GPP from Terra-MODIS and AmeriFlux Network Towers

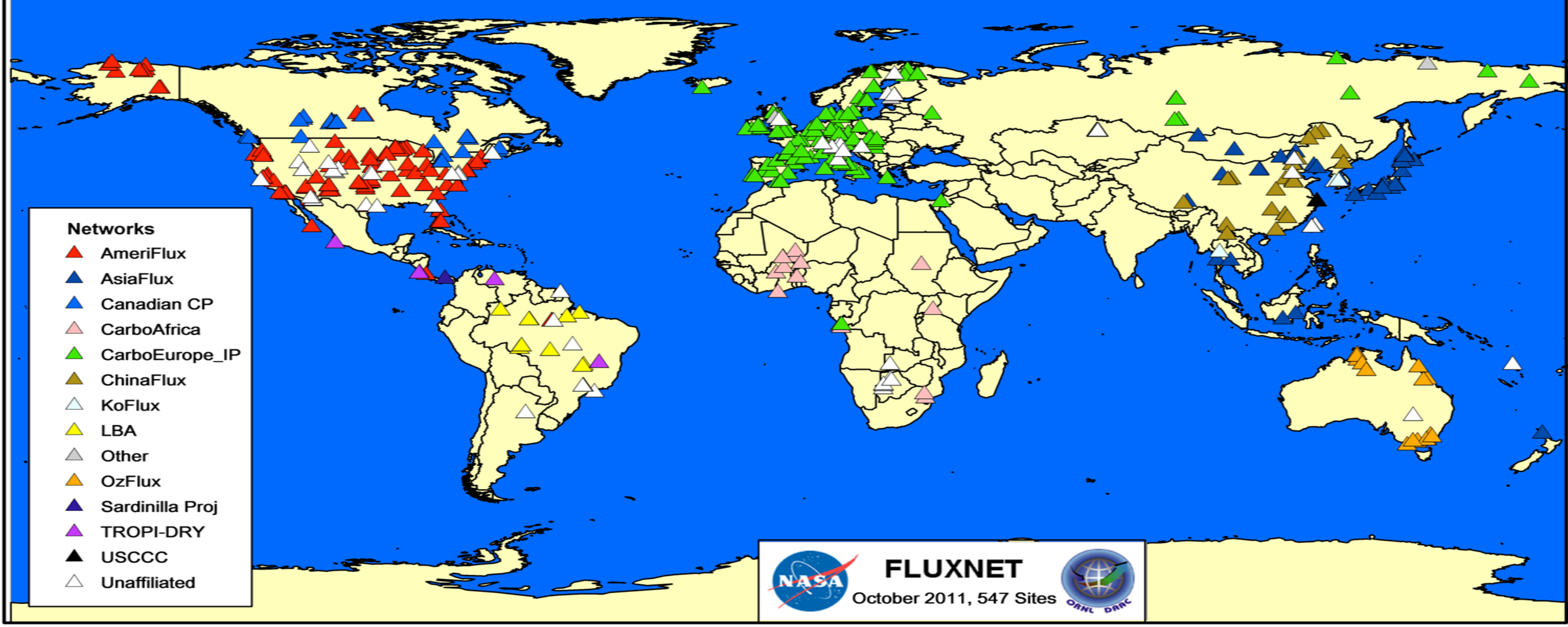
The AmeriFlux network, established in 1996, provides continuous observations of ecosystem level exchanges of CO2, water, energy and momentum spanning diurnal, synoptic, seasonal, and interannual time scales.

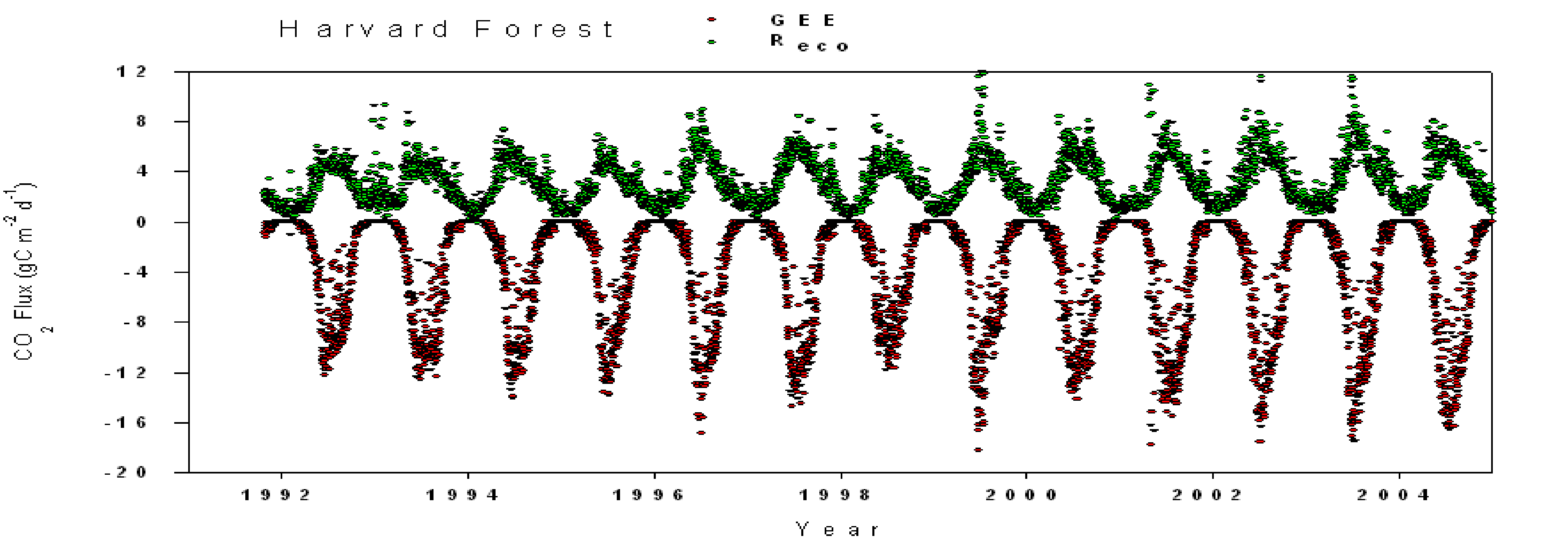
Biome types used in comparison: forests (evergreen needleleaf, deciduous broadleaf, and mixed species), oak savanna, grassland, tundra, and chaparral.

Architecture of Global/Regional Flux Networks

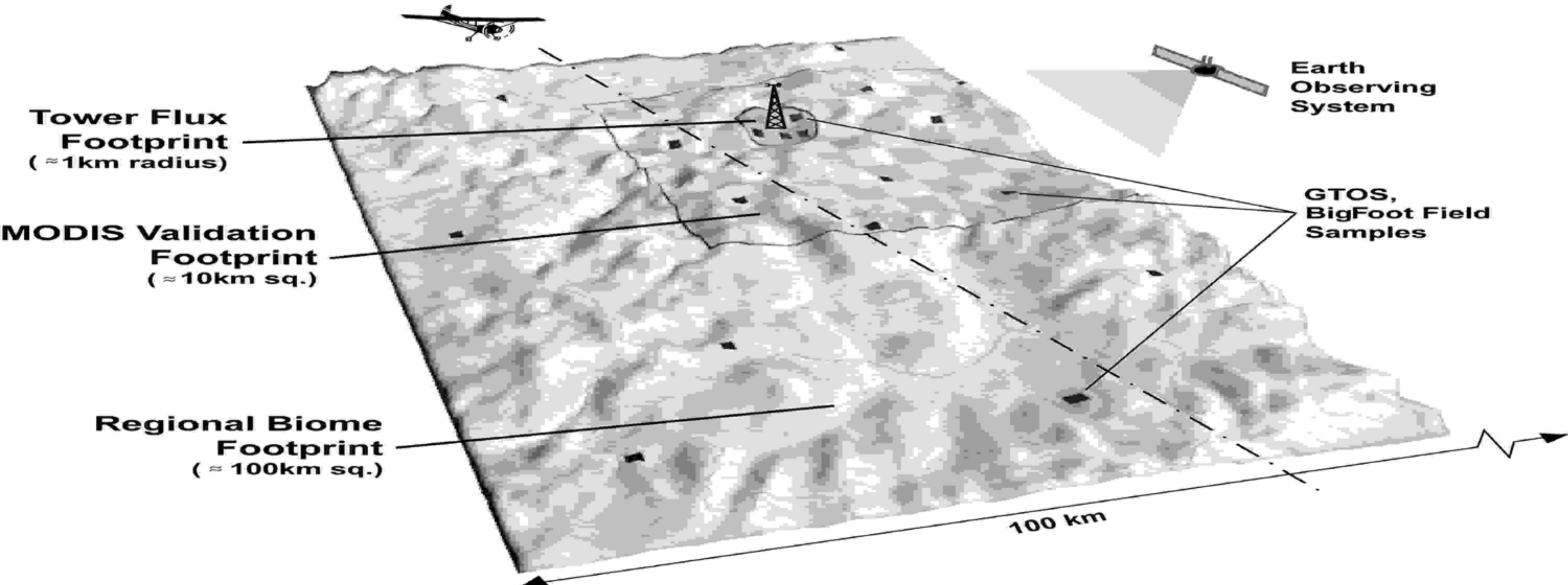




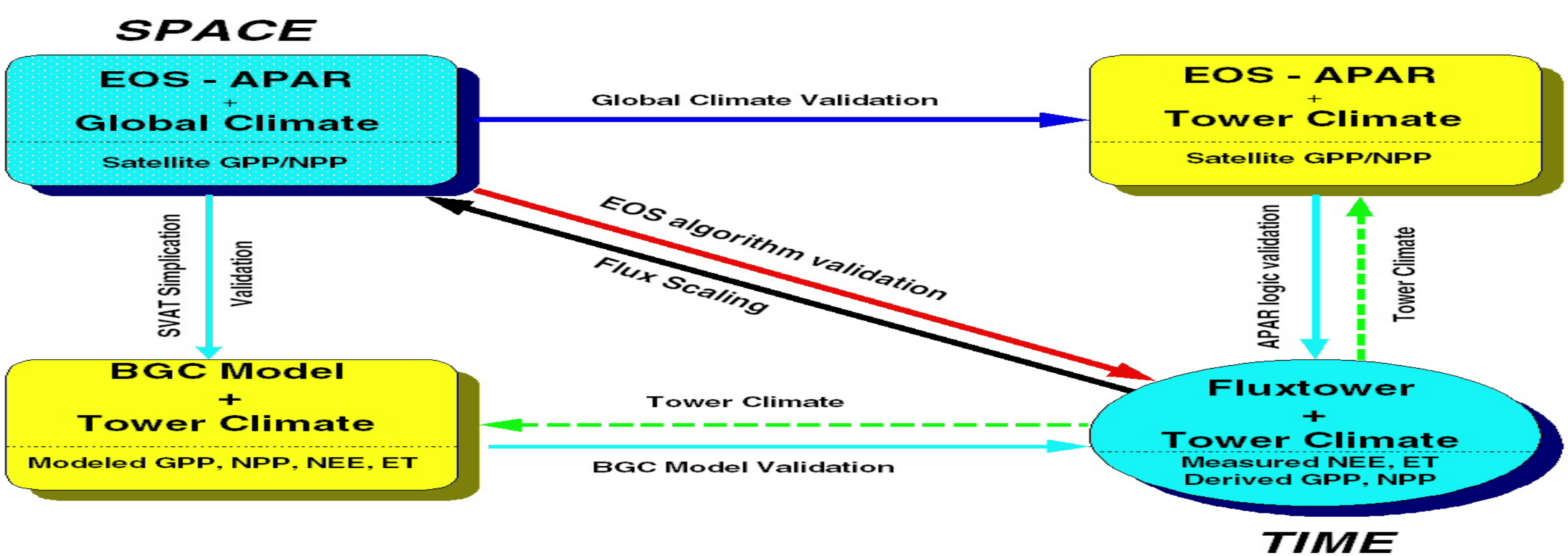

Networks
AmeriFlux
AsiaFlux
Canadian CP
CarboAfrica
CarboEurope_IP
ChinaFlux
KoFlux
LBA
Other
OzFlux
Sardinilla Proj
TROPI-DRY
USCCC
Unaffiliated
NASA
FLUXNET
October 2011, 547 Sites
ORNL DAAC


Harvard Forest
GEE
Reco
12
8
4
0
-4
-8
-12
-16
-20
CO2 Flux (gC m-2 d-1)
1992
1994
1996
1998
2000
2002
2004
Year

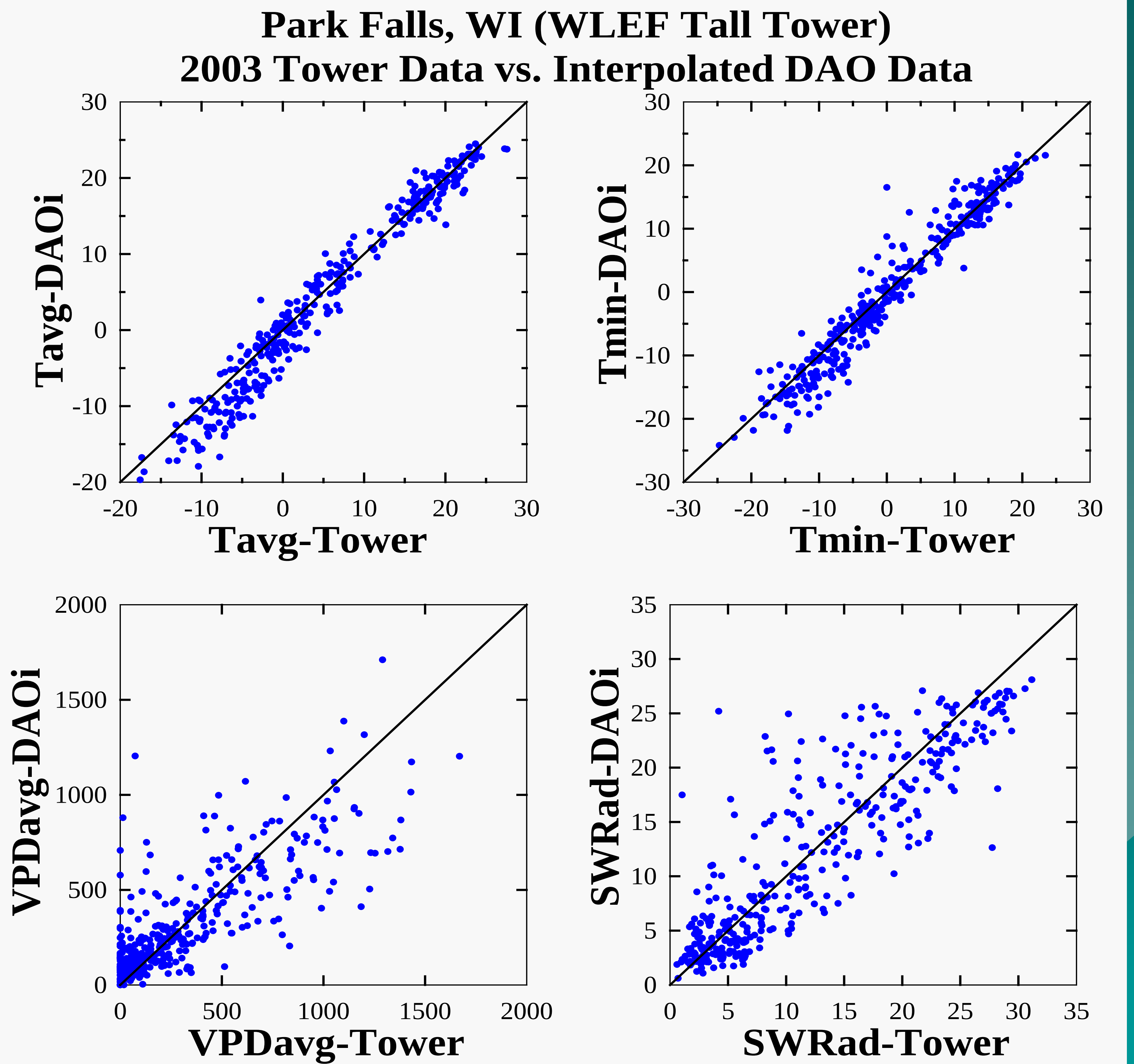
Multi-scale Measurement Strategy



FLUX TOWER BASED VALIDATION FOR MODIS GPP/NPP

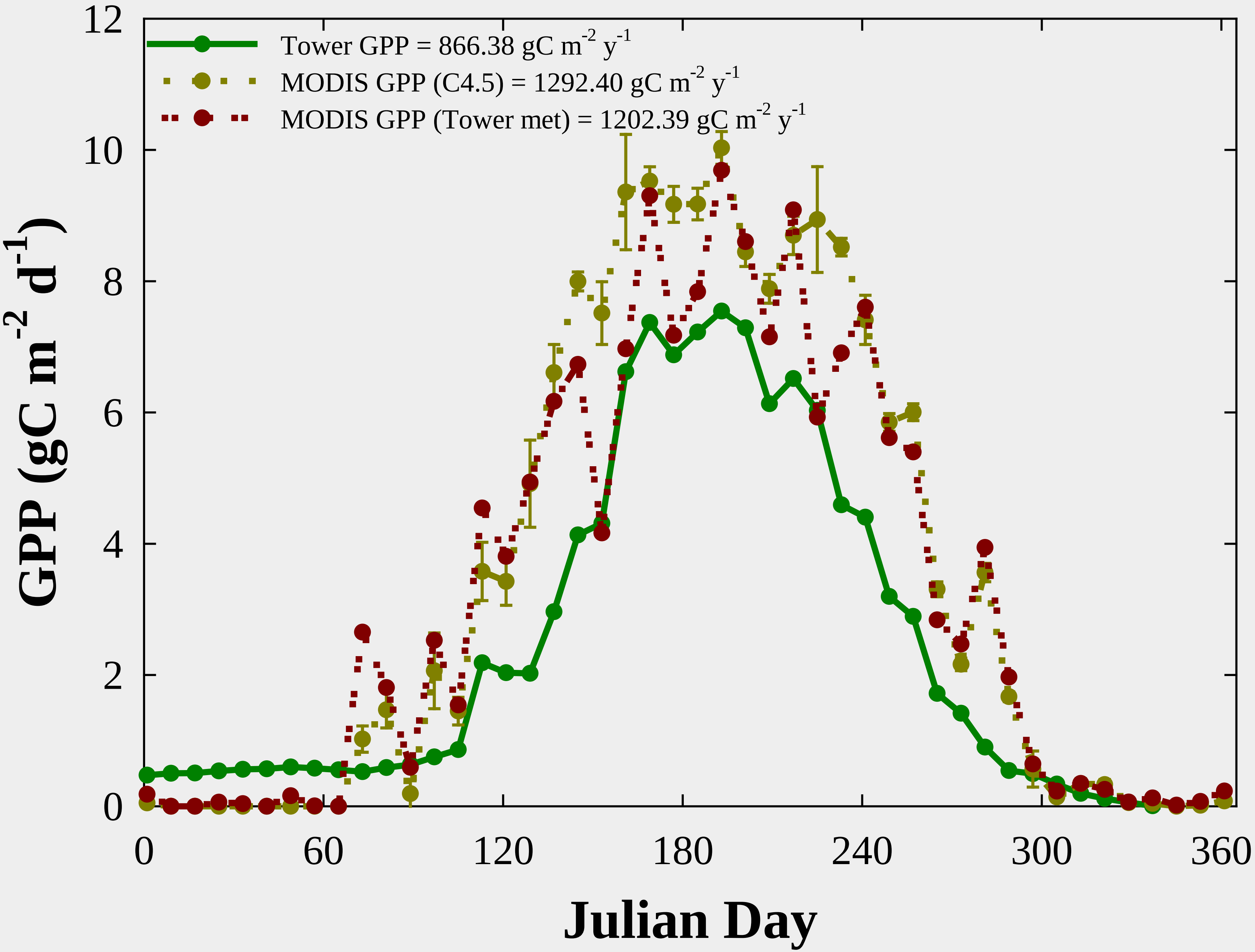


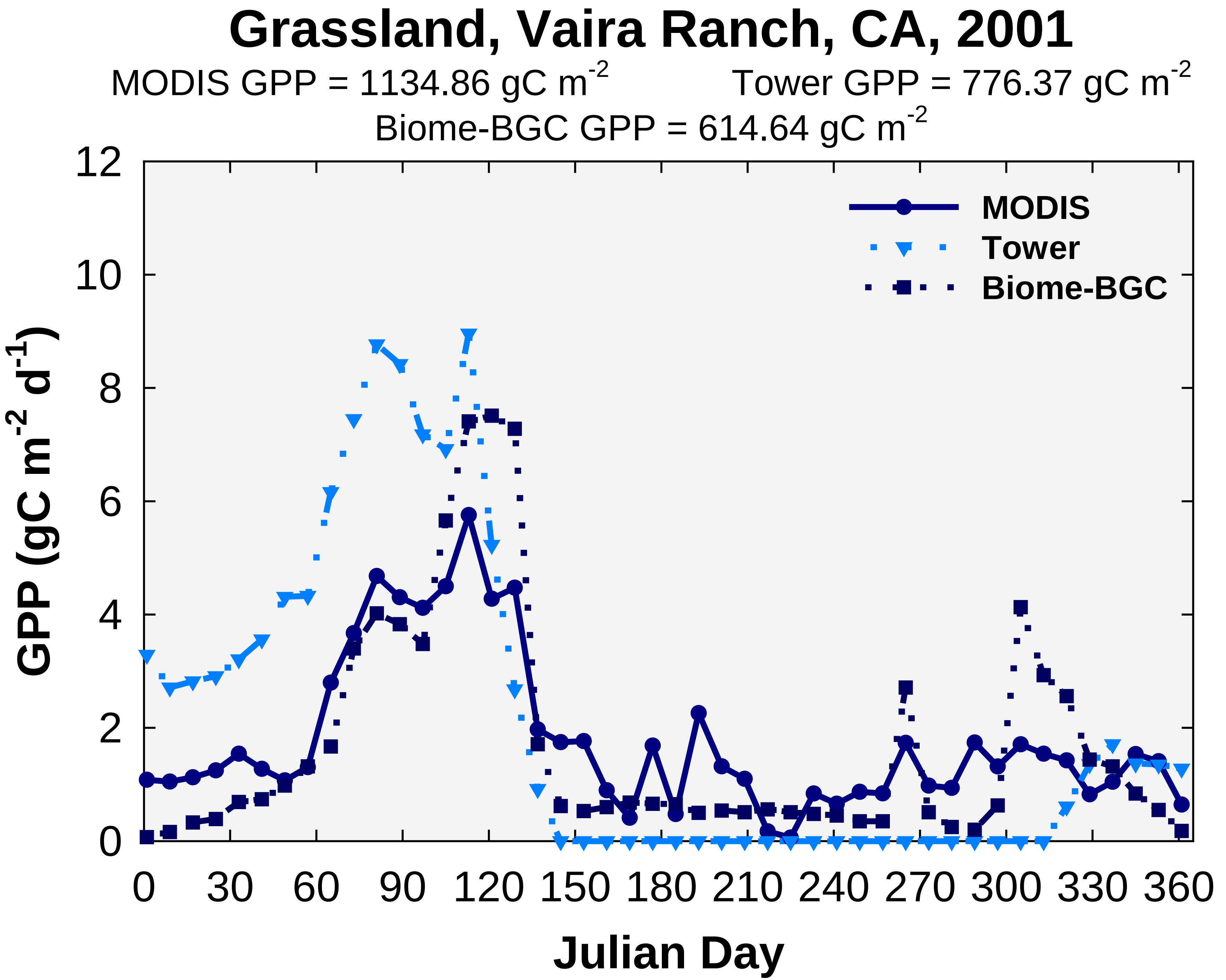
Climate



Park Falls, WI (WLEF Tall Tower)
2003 Tower Data vs. Interpolated DAO Data
Tavg-DAOi
Tavg-Tower
Tmin-DAOi
Tmin-Tower
VPDavg-DAOi
VPDavg-Tower
SWRad-DAOi
SWRad-Tower

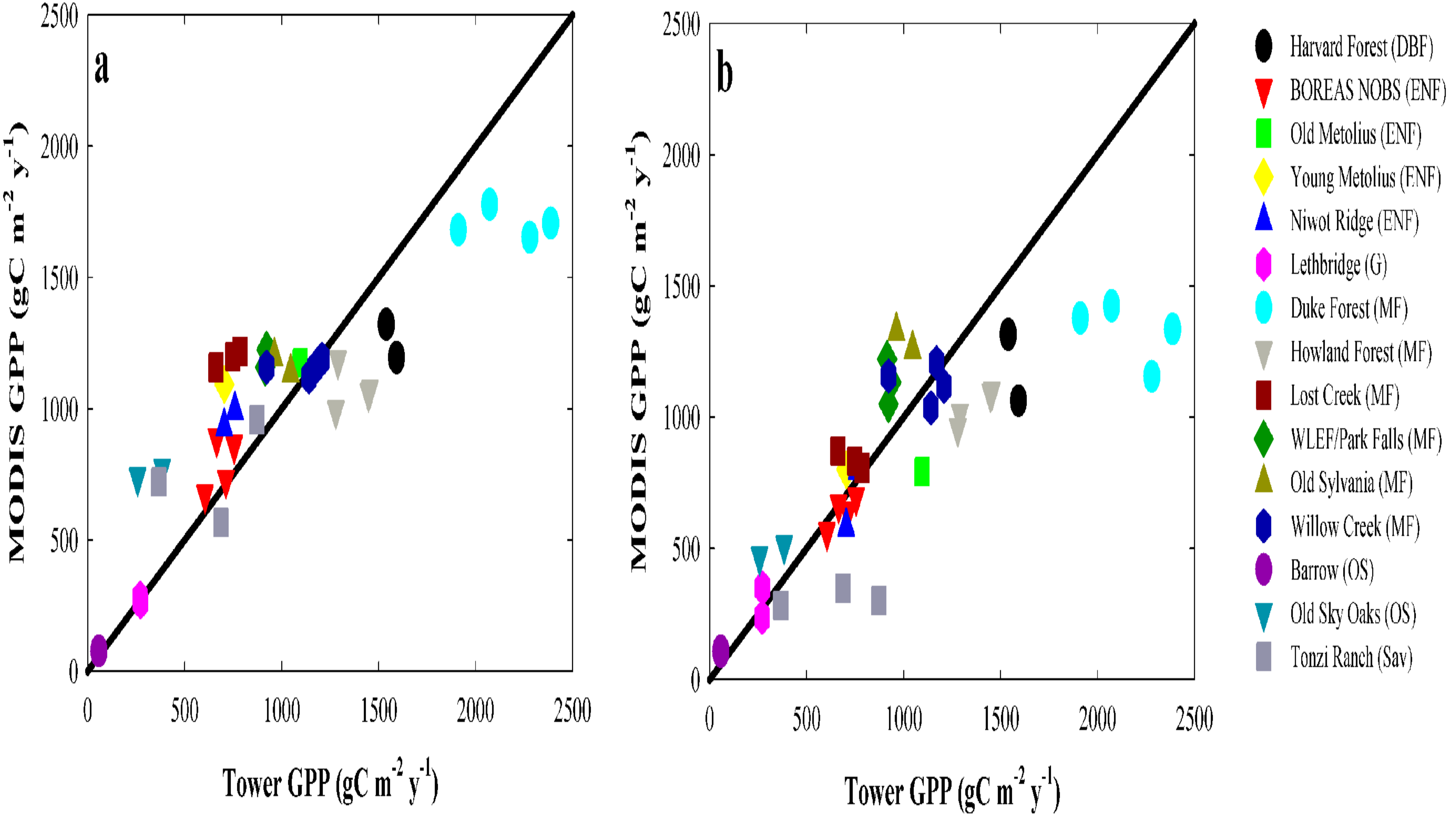
Park Falls, WI (WLEF Tall Tower), 2003



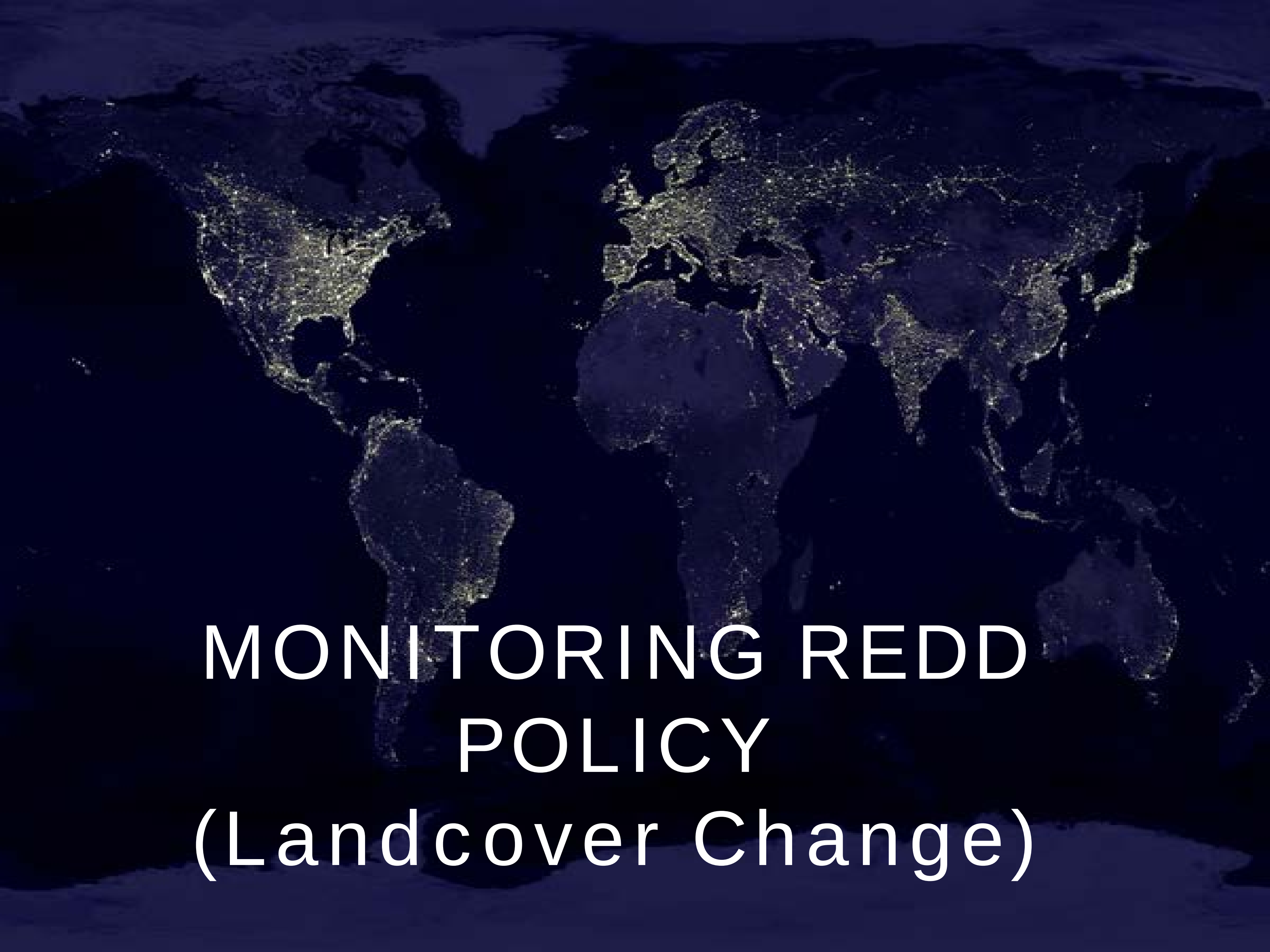


Grassland, Vaira Ranch, CA, 2001
MODIS GPP = 1134.86 gC m-2
Tower GPP = 776.37 gC m-2
Biome-BGC GPP = 614.64 gC m-2
MODIS
Tower
Biome-BGC
GPP (gC m-2 d-1)
Julian Day
0
2
4
6
8
10
12
0 30 60 90 120 150 180 210 240 270 300 330 360

Validation MODIS GPP (annual total)

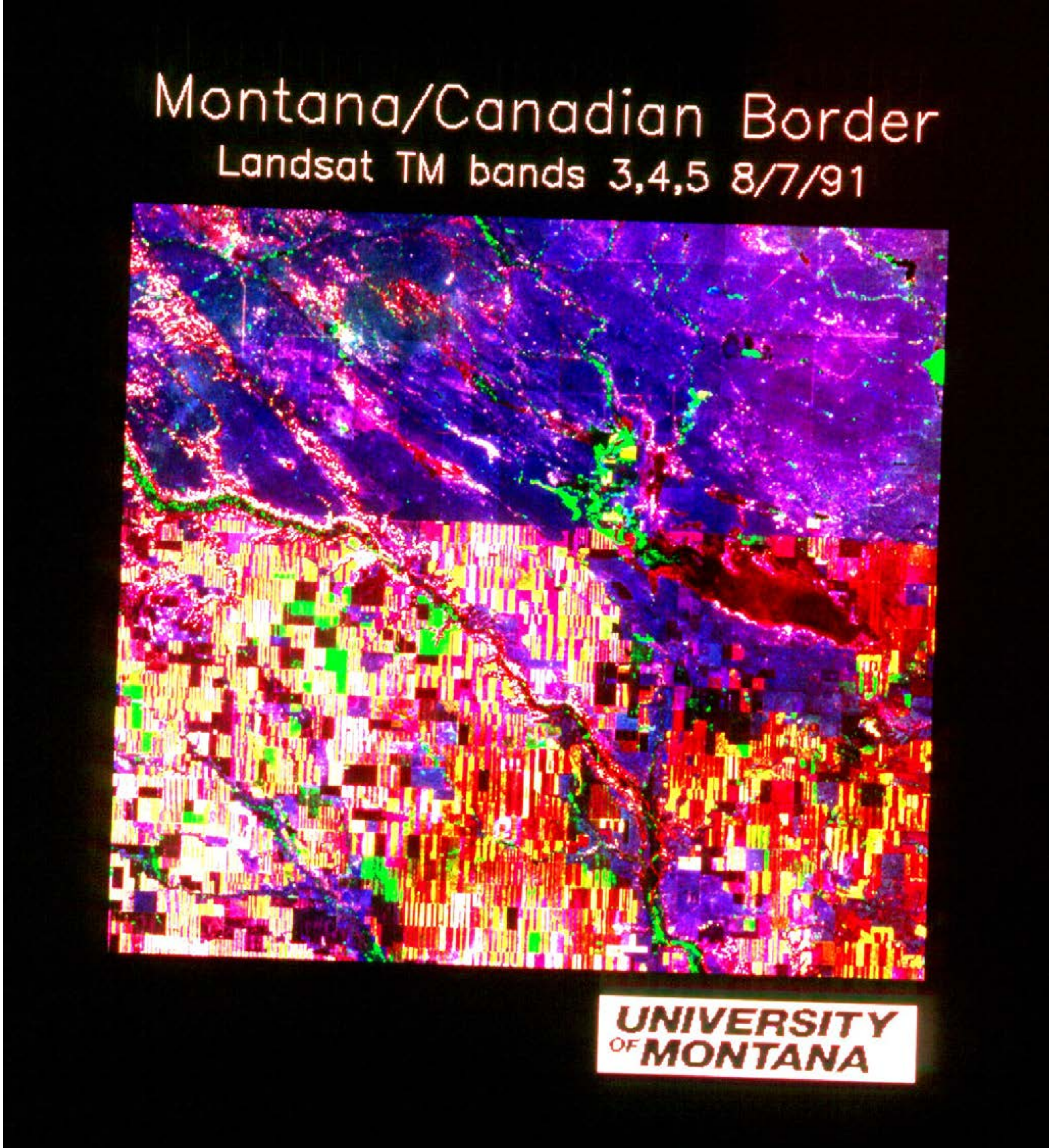


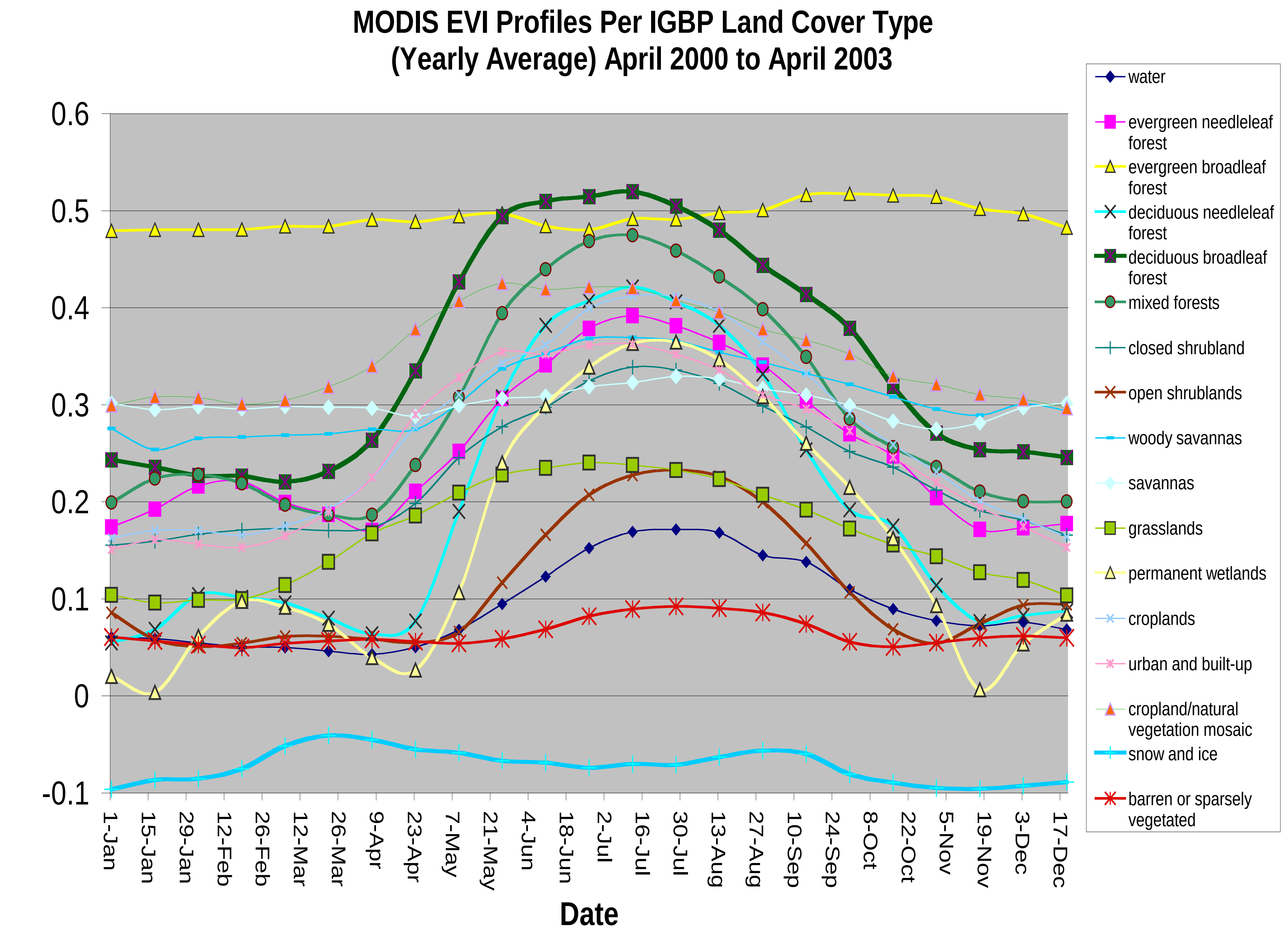
Heinsch et al., 2006, *ITGARS*



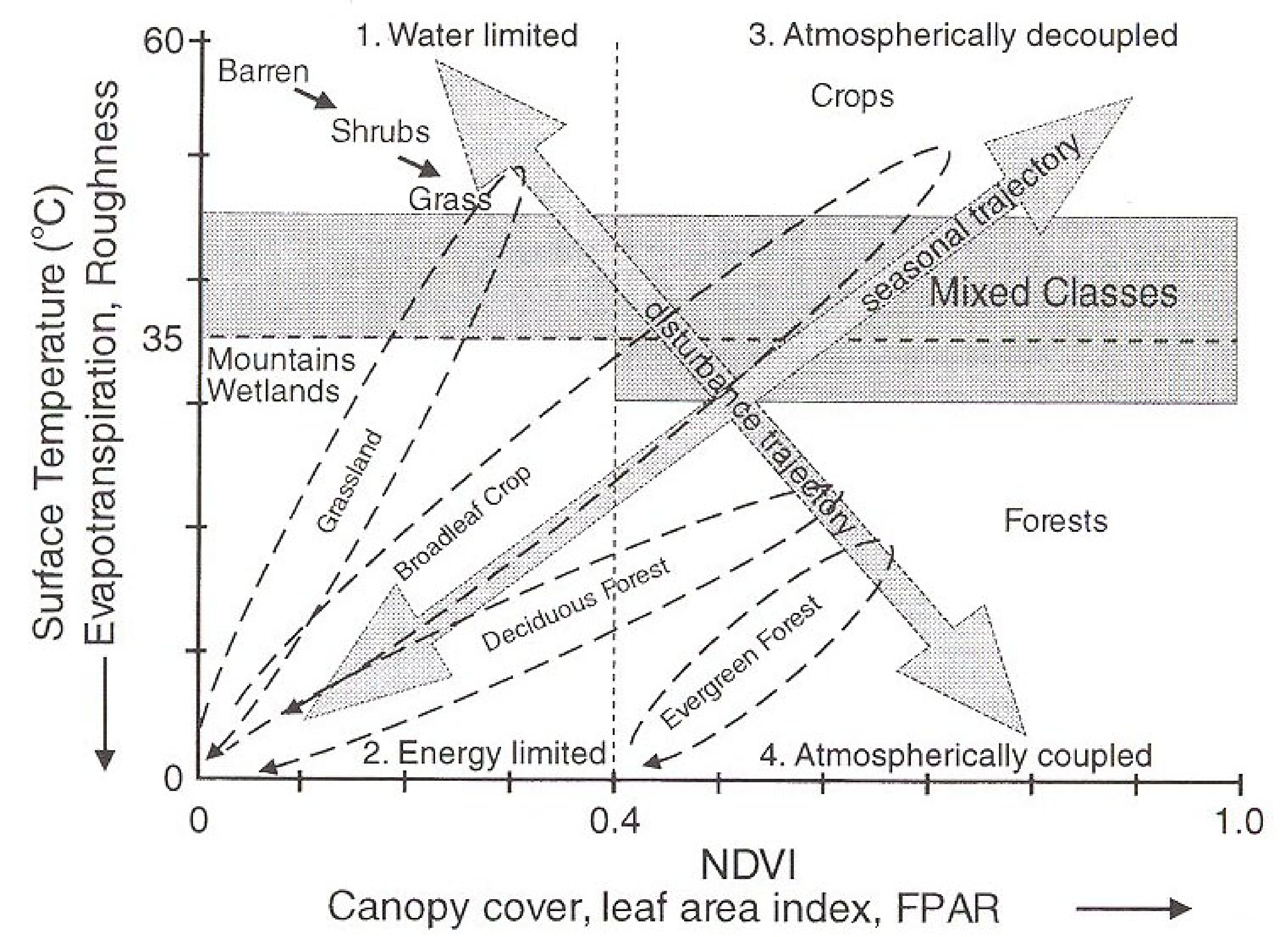
MONITORING REDD POLICY (Landcover Change)

The difference between potential" and "actual" landcover and the role of humans

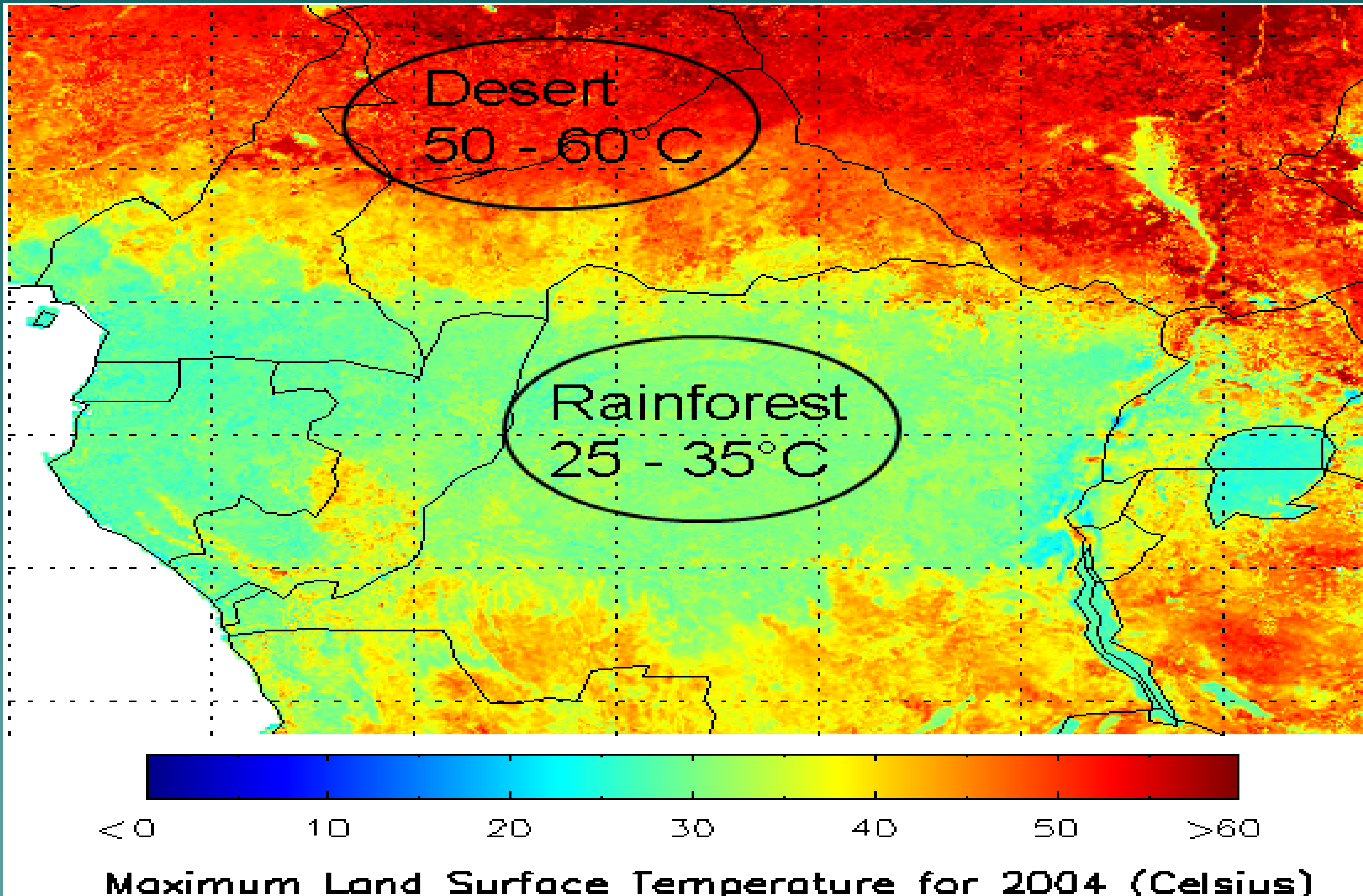



MODIS EVI Profiles Per IGBP Land Cover Type
(Yearly Average) April 2000 to April 2003
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
1-Jan
15-Jan
29-Jan
12-Feb
26-Feb
12-Mar
26-Mar
9-Apr
23-Apr
7-May
21-May
4-Jun
18-Jun
2-Jul
16-Jul
30-Jul
13-Aug
27-Aug
10-Sep
24-Sep
8-Oct
22-Oct
5-Nov
19-Nov
3-Dec
17-Dec
Date
water
evergreen needleleaf forest
evergreen broadleaf forest
deciduous needleleaf forest
deciduous broadleaf forest
mixed forests
closed shrubland
open shrublands
woody savannas
savannas
grasslands
permanent wetlands
croplands
urban and built-up
cropland/natural vegetation mosaic
snow and ice
barren or sparsely vegetated

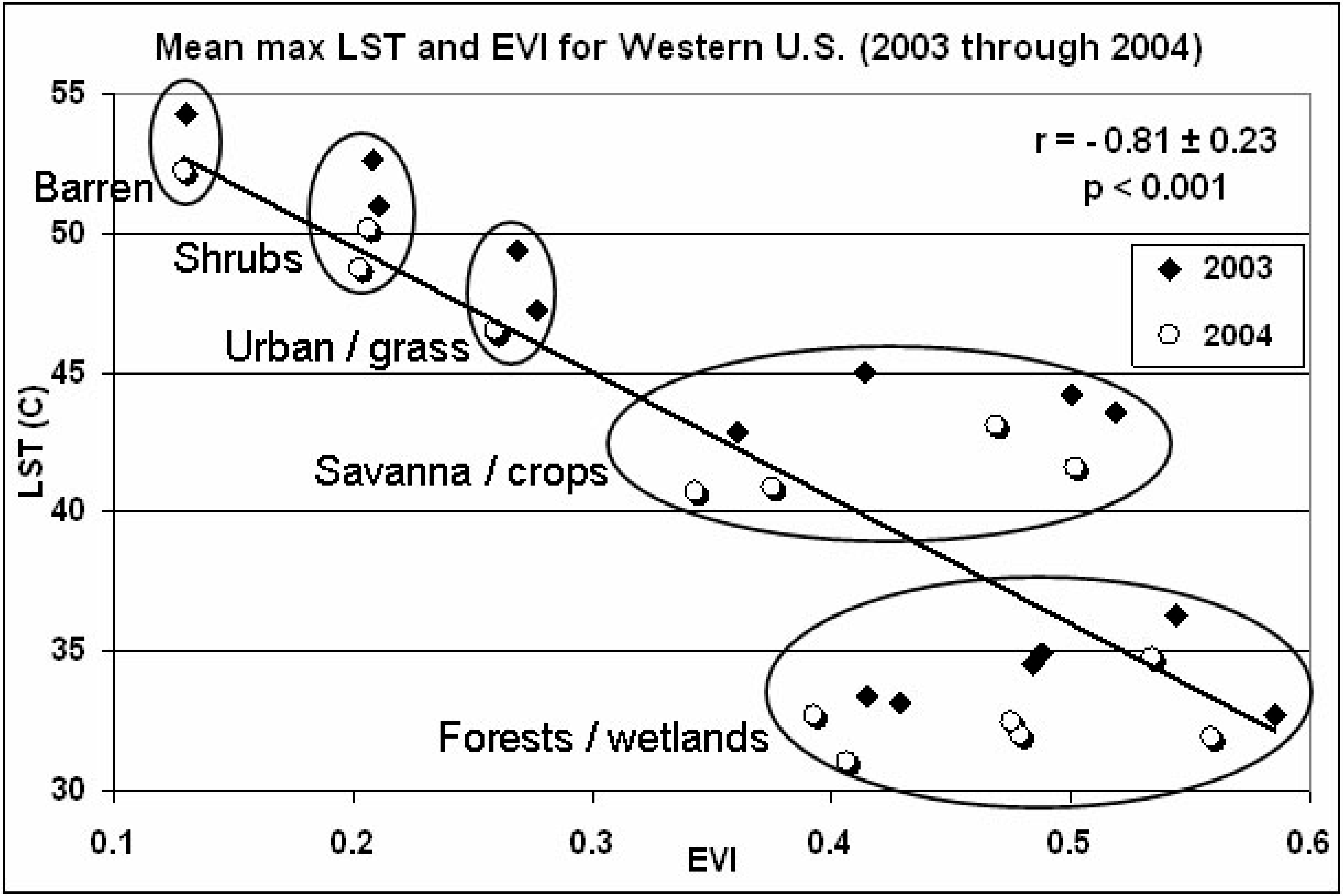
Cover of Ecological Applications
Nemani and Running 1997



Comparison of Land Surface Temperatures from Aqua MODIS
Sahara Desert vs central African Tropical Forest

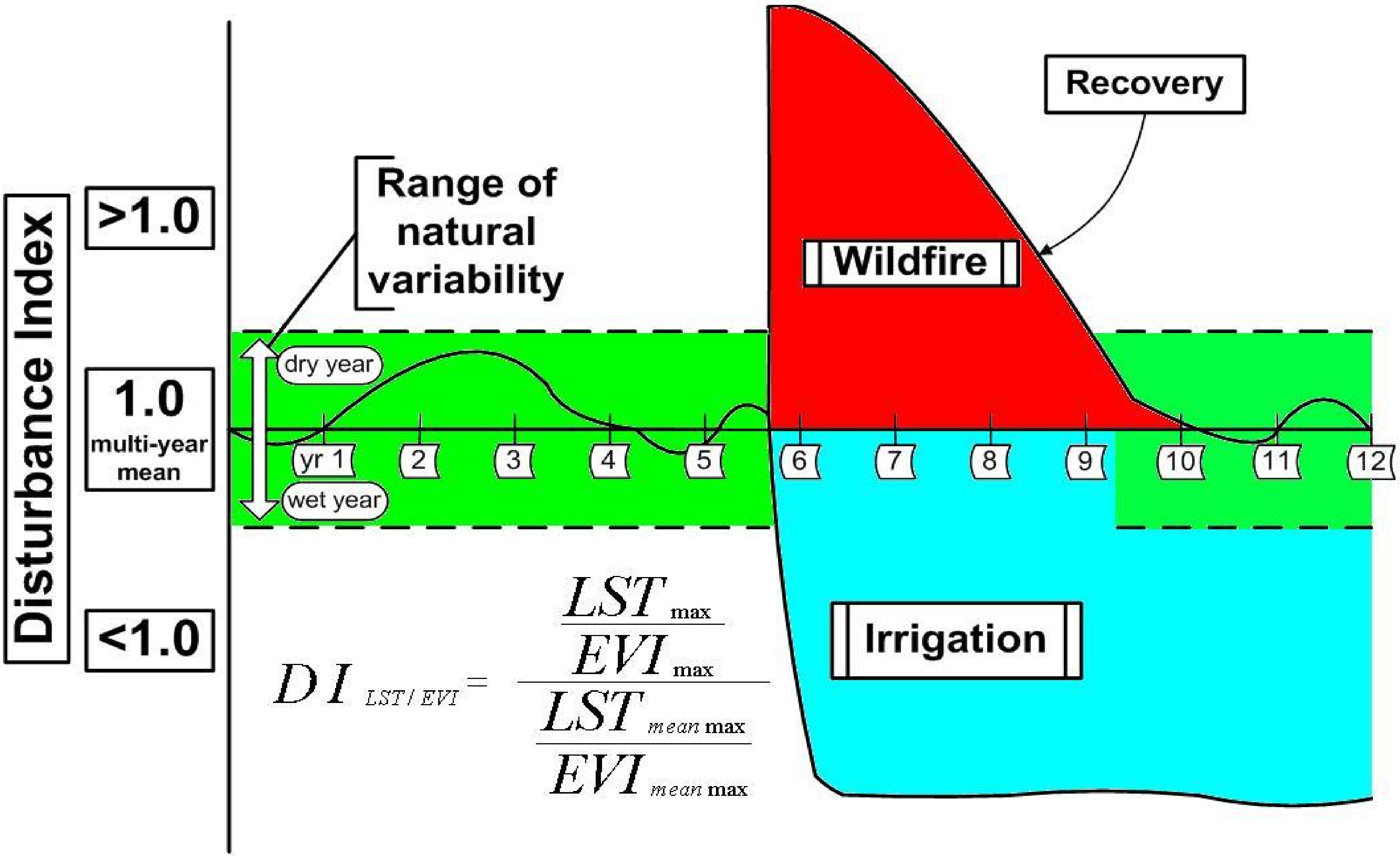


Mildrexler, Zhou, Running. AGU Eos 87:461, 2006



Mean max LST and EVI for Western U.S. (2003 through 2004)
r = - 0.81 ± 0.23
p < 0.001
2003
2004
Barren
Shrubs
Urban / grass
Savanna / crops
Forests / wetlands
LST (C)
EVI
55
50
45
40
35
30
0.1
0.2
0.3
0.4
0.5
0.6

GLOBAL Generalized Disturbance Index

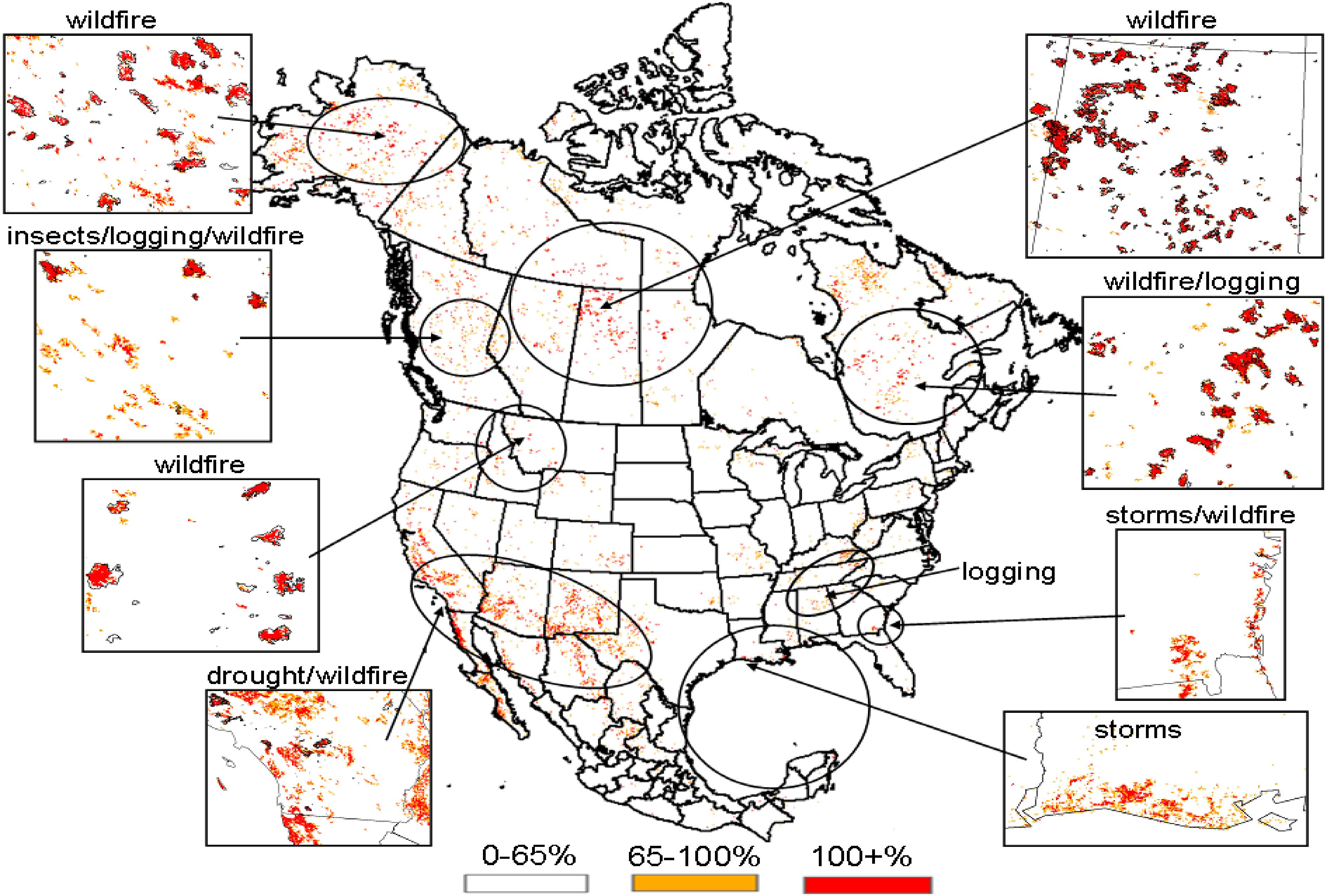


$$DI_{LST/EVI} = \frac{\dfrac{LST_{max}}{EVI_{max}}}{\dfrac{LST_{mean\ max}}{EVI_{mean\ max}}}$$

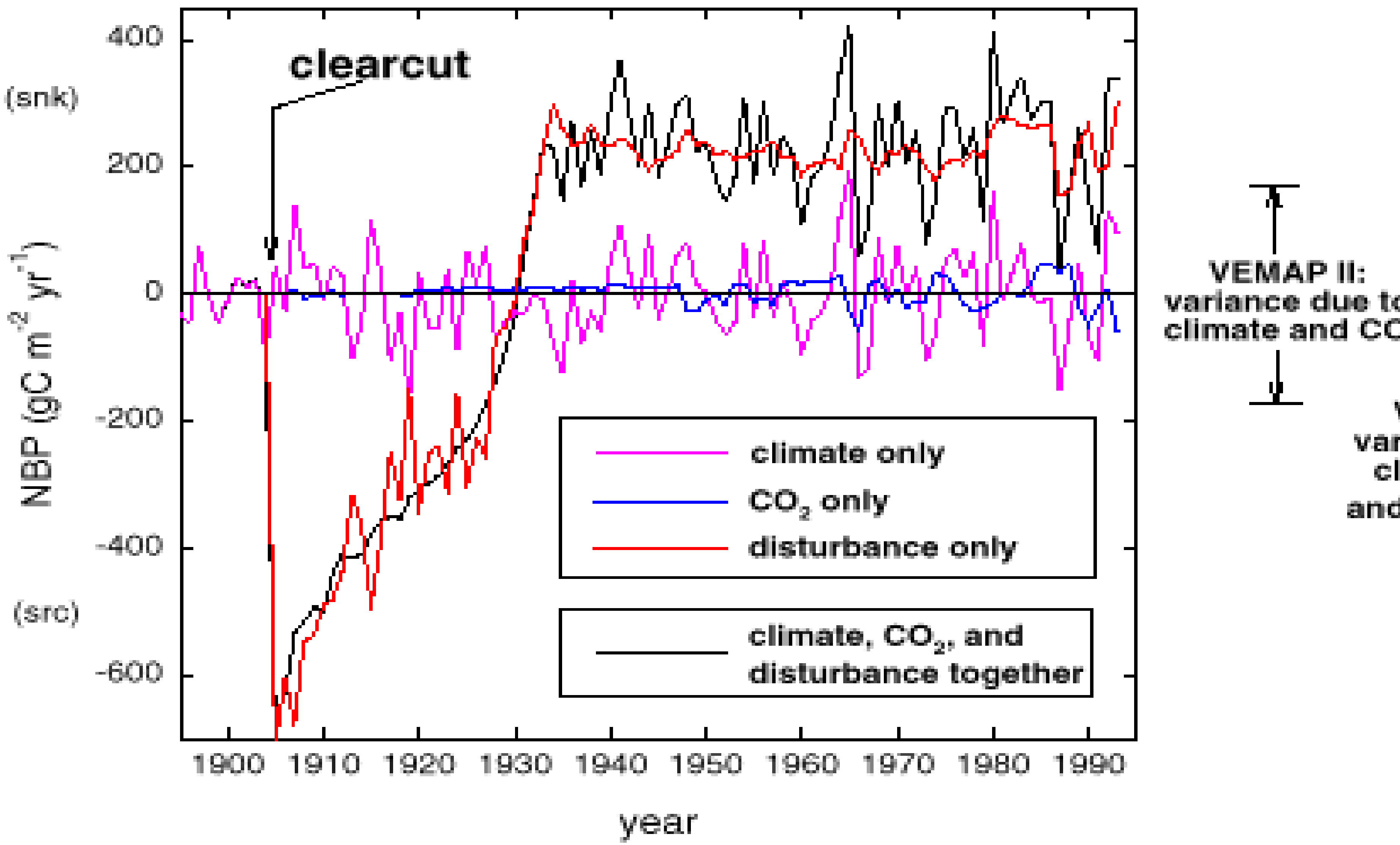
Mildrexler et al 2006

Mildrexler et al 2006

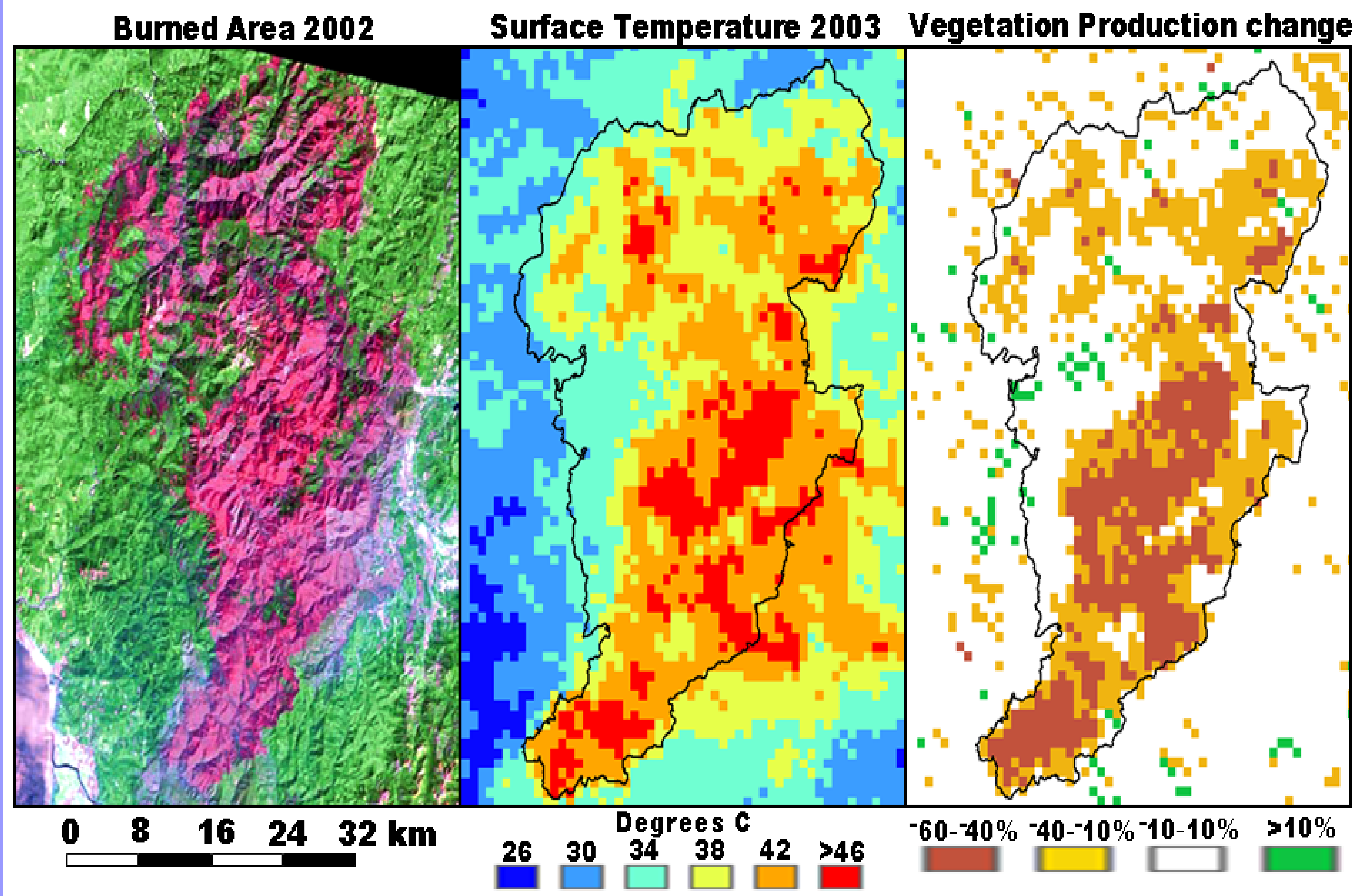
MODIS Annual Disturbance Index



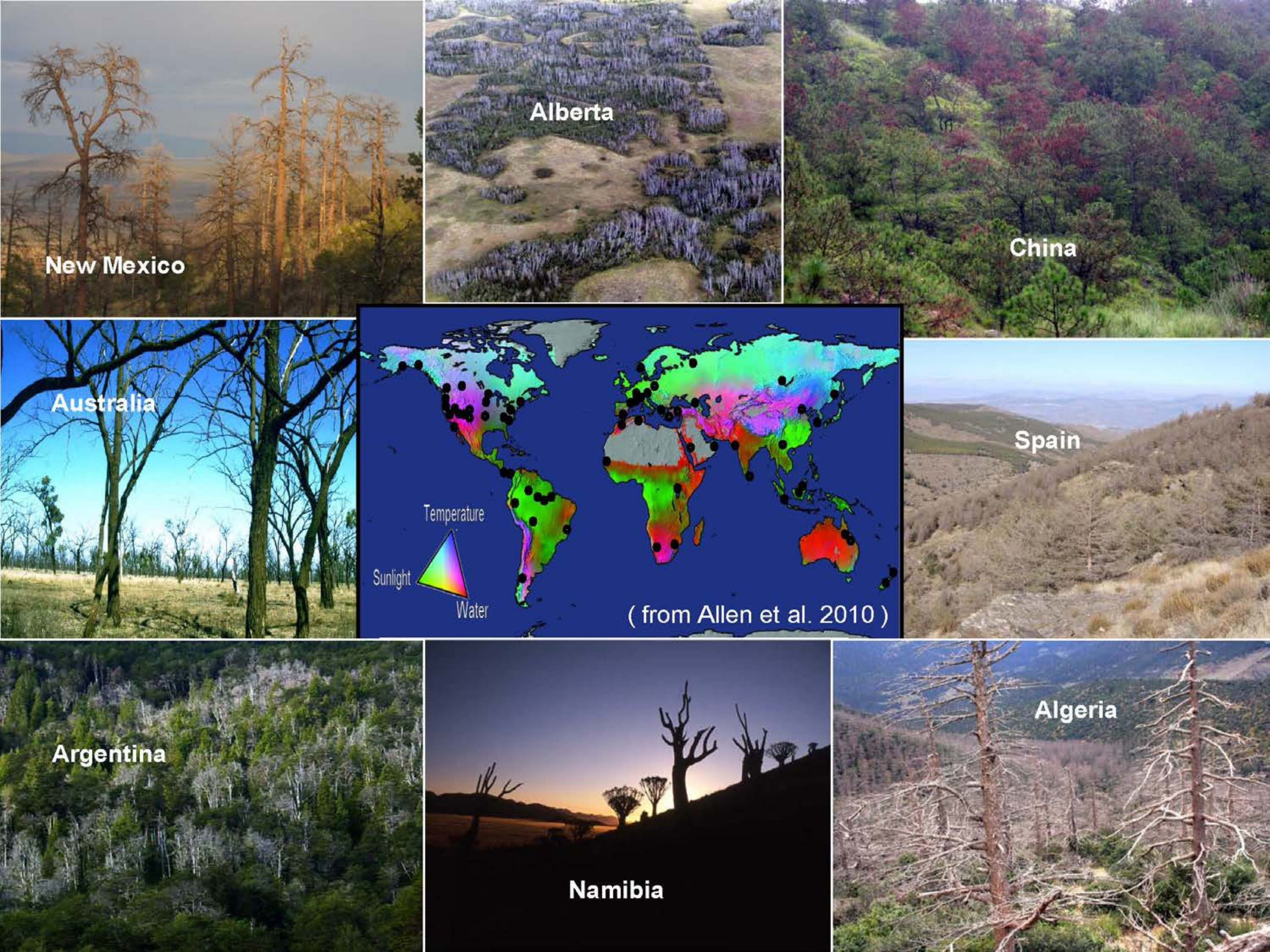
Influence of disturbance on net carbon exchange, relative to interannual climate variation and increasing CO_2



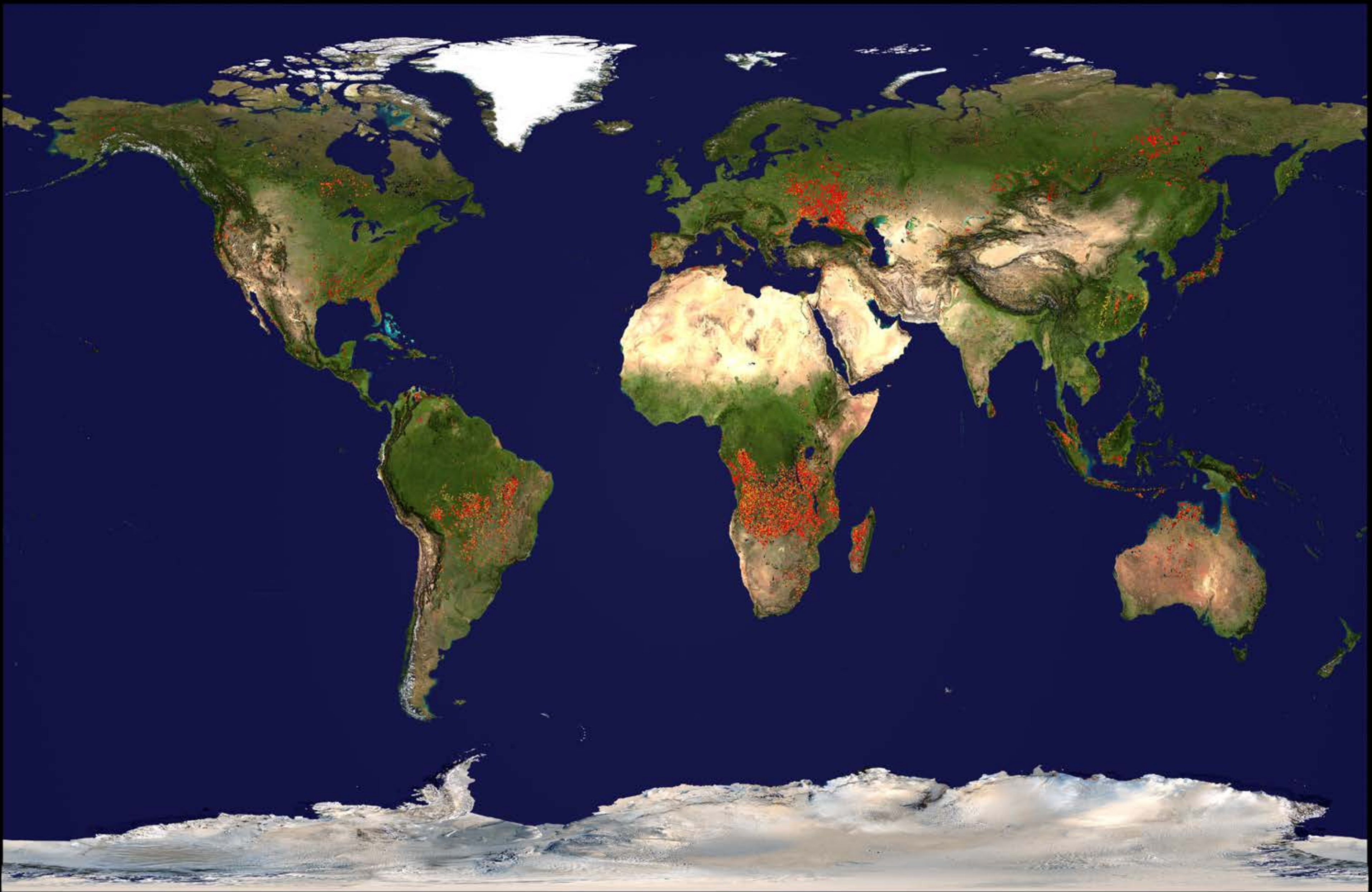
Disturbance Impact on Land Biophysics



Running, S. *Science 321, Aug* 2008


New Mexico
Alberta
China
Australia
Temperature
Sunlight
Water
(from Allen et al. 2010)
Spain
Argentina
Namibia
Algeria

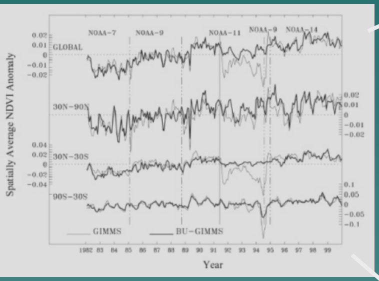
Global Fires for 10 Days



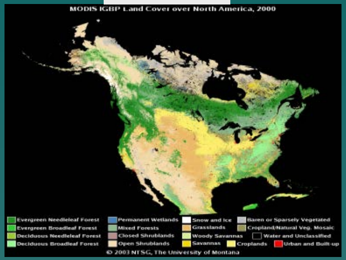
Terrestrial Carbon Monitor

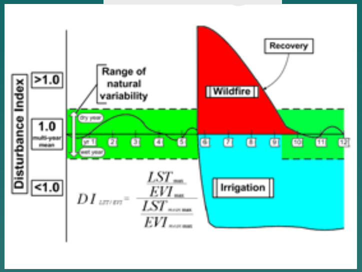
State | Change

SATELLITE DATA

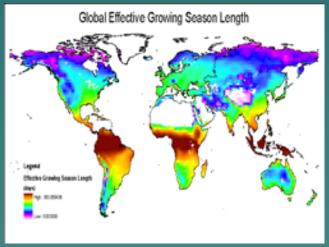


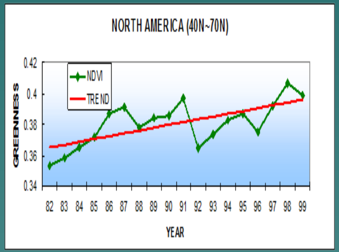
LANDCOVER



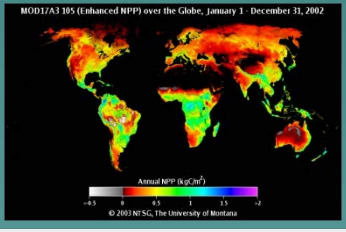


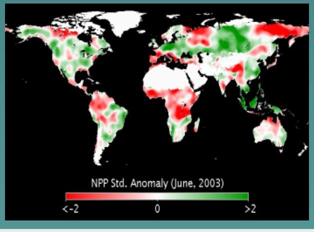
GROWING SEASON



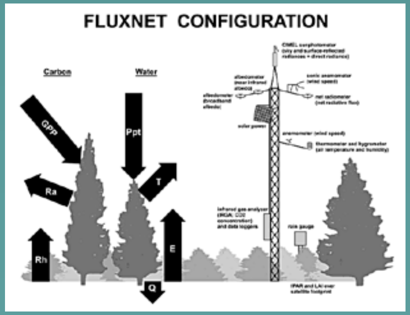


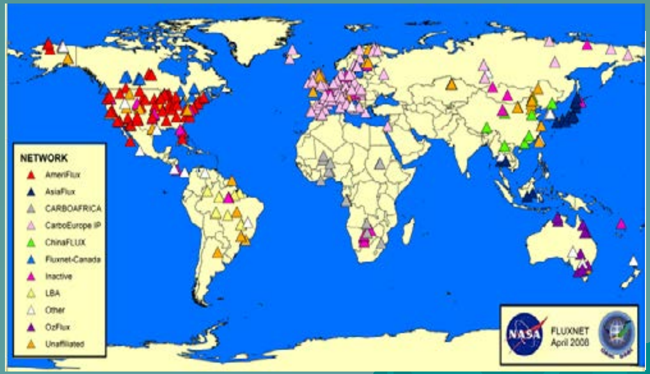
PRIMARY PRODUCTION

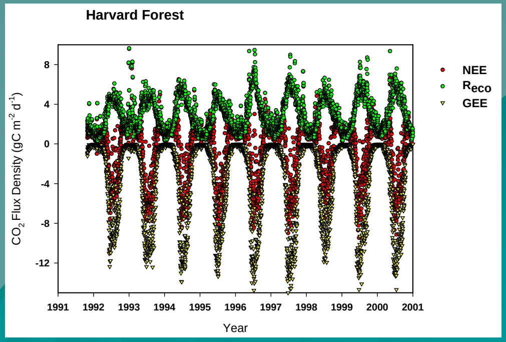




GROUND DATA



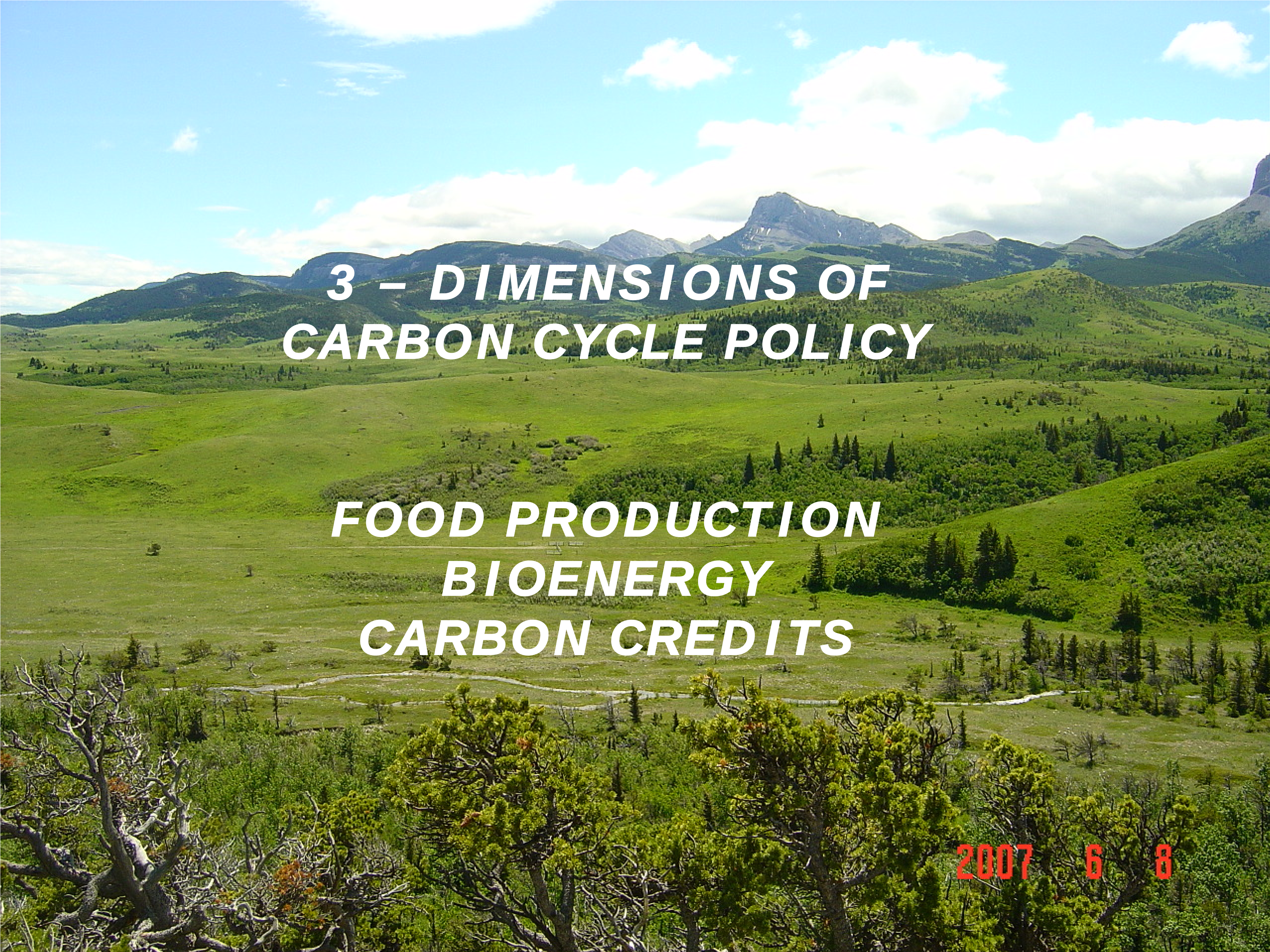


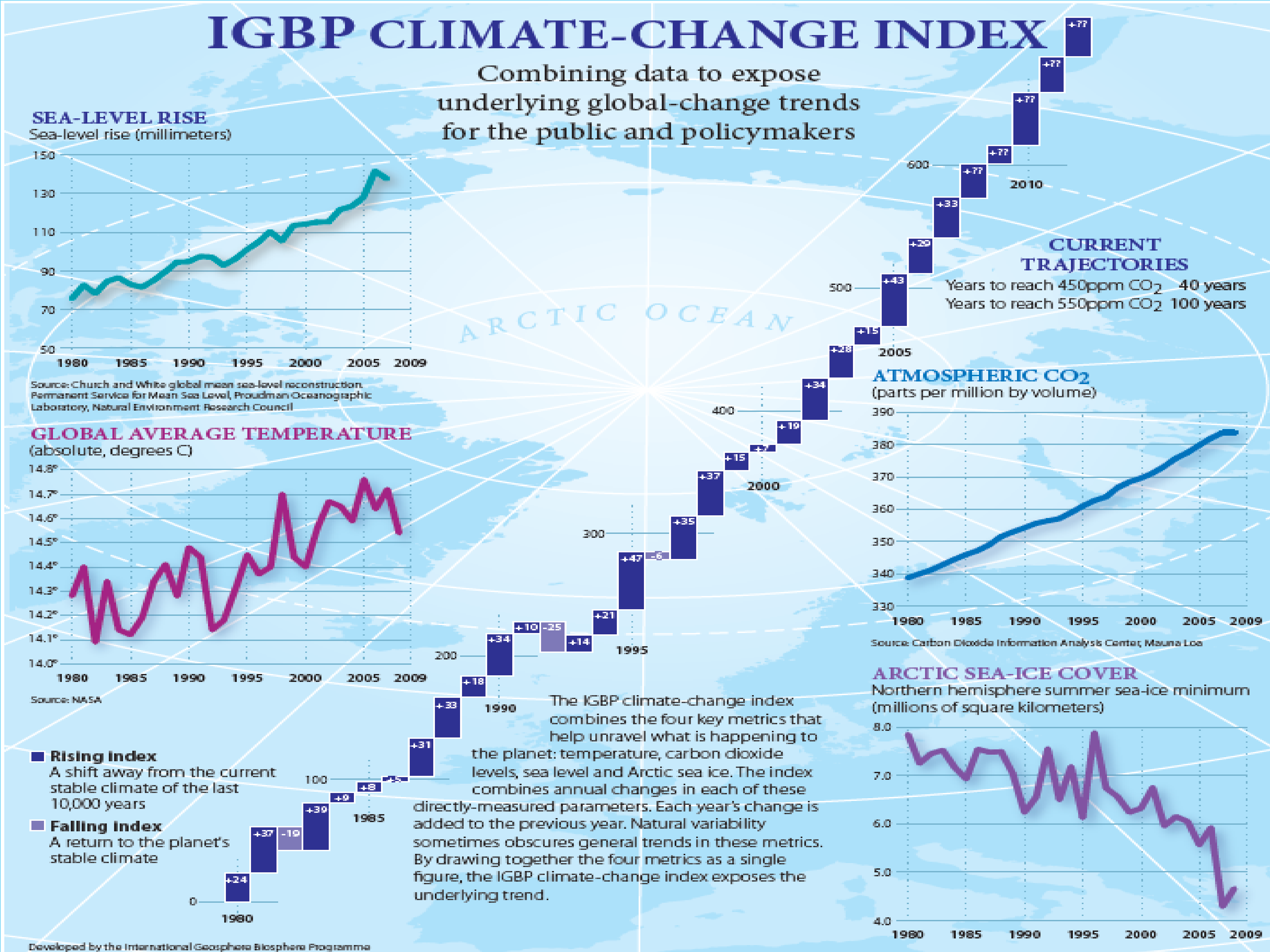


CEOS ECV (Essential Climate Variables) from GCOS – 138, Aug 2010

- Albedo
- Landcover
- FAPAR
- LAI
- Biomass (is NPP better?)
- Soil Carbon (from satellite?)
- Fire Disturbance
- Soil Moisture

[Note phenology is always implicitly part of other variables]

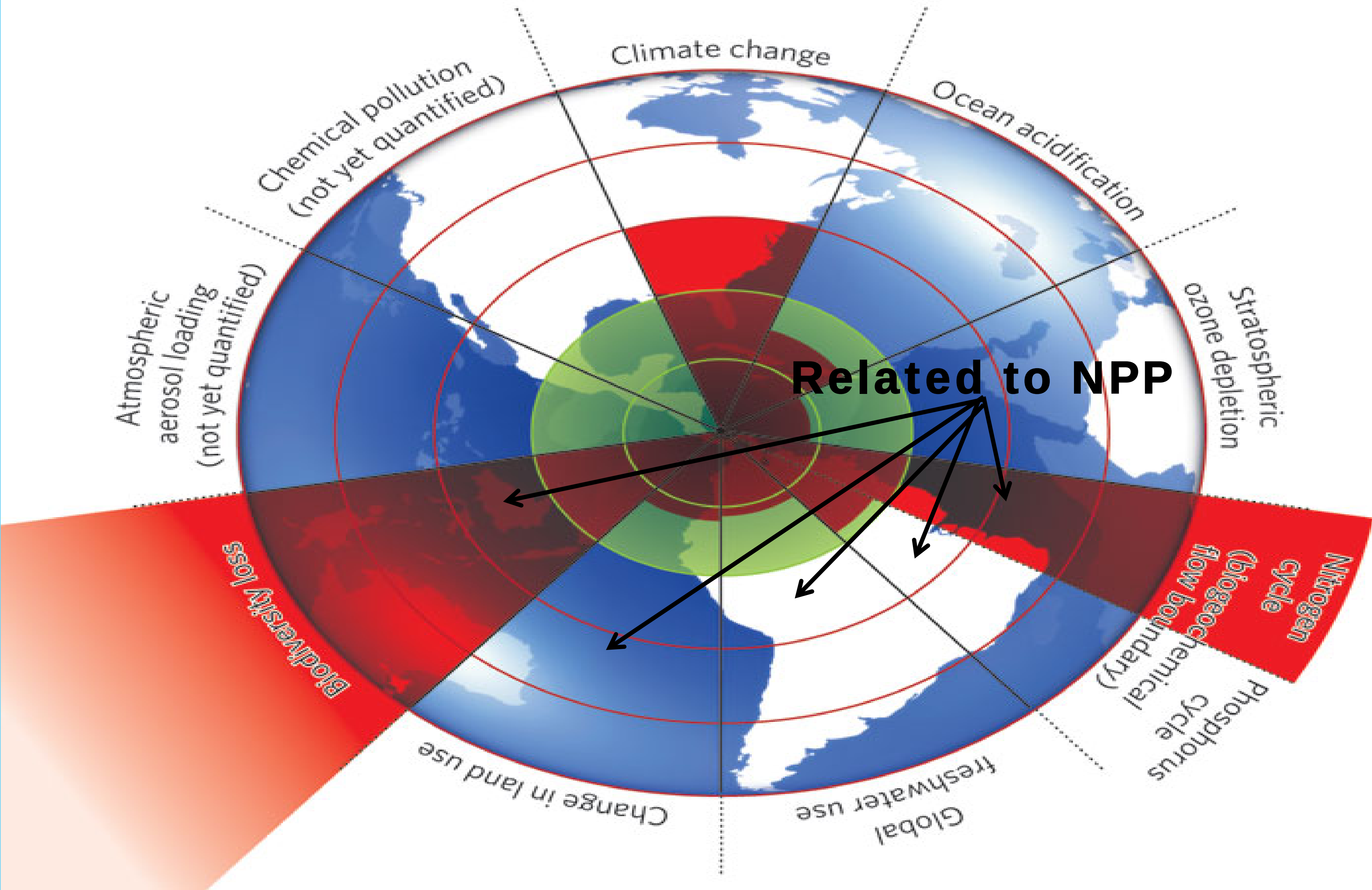

3 – DIMENSIONS OF
CARBON CYCLE POLICY
FOOD PRODUCTION
BIOENERGY
CARBON CREDITS
2007 6 8



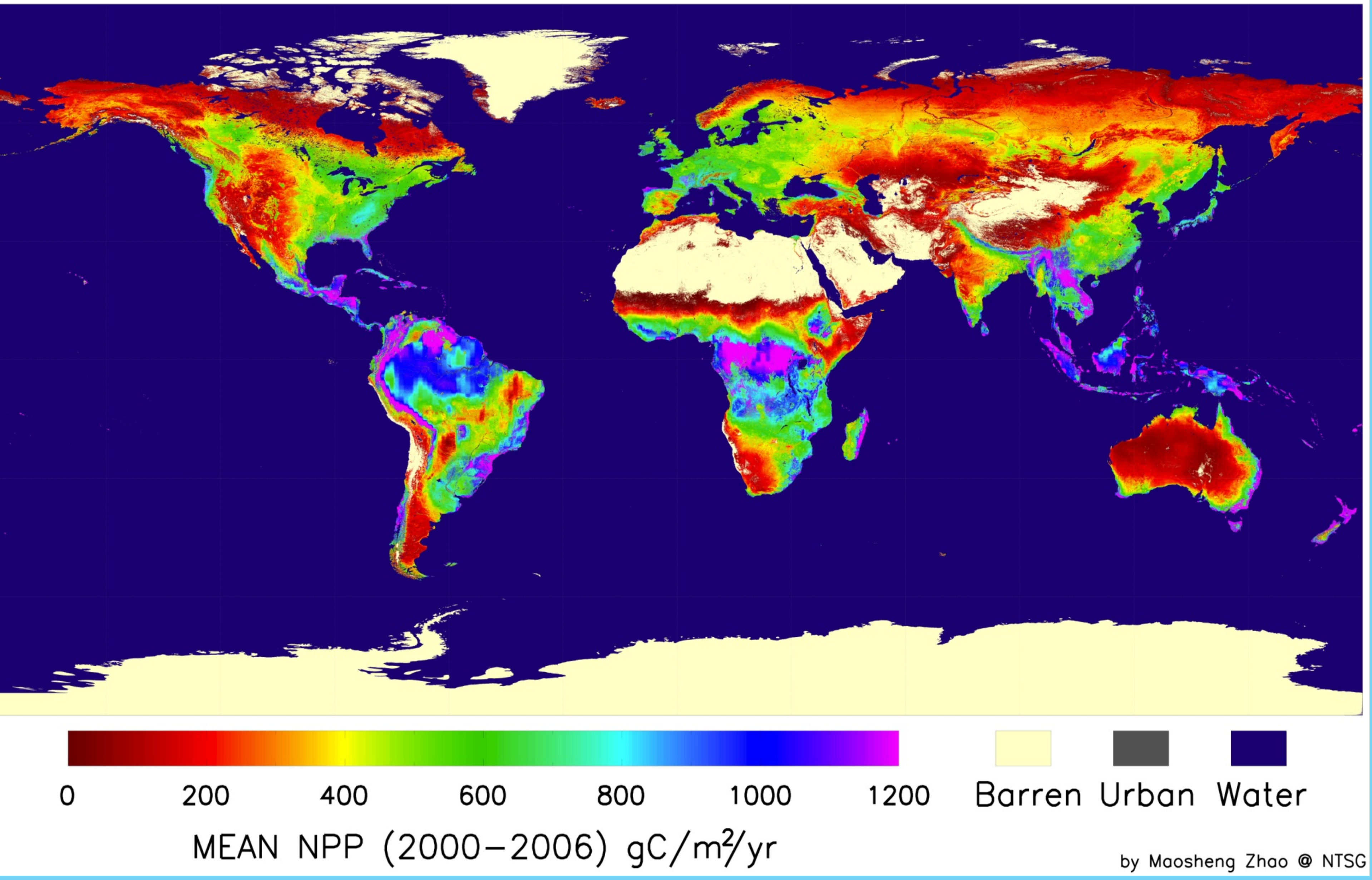
IGBP CLIMATE-CHANGE INDEX
Combining data to expose underlying global-change trends for the public and policymakers
SEA-LEVEL RISE
Sea-level rise (millimeters)
150
130
110
90
70
50
1980 1985 1990 1995 2000 2005 2009
Source: Church and White global mean sea-level reconstruction. Permanent Service for Mean Sea Level, Proudman Oceanographic Laboratory, Natural Environment Research Council
GLOBAL AVERAGE TEMPERATURE
(absolute, degrees C)
14.8°
14.7°
14.6°
14.5°
14.4°
14.3°
14.2°
14.1°
14.0°
1980 1985 1990 1995 2000 2005 2009
Source: NASA
Rising index
A shift away from the current stable climate of the last 10,000 years
Falling index
A return to the planet's stable climate
0
100
200
300
400
500
600
+24 +37 -19 +39 +9 +8 +5 +31 +33 +18 +34 +10 -25 +14 +21 +47 -6 +35 +37 +15 +7 +19 +34 +28 +15 +43 +29 +33 +77 +77 +77 +77 +77
1980
1985
1990
1995
2000
2005
2010
ARCTIC OCEAN
CURRENT TRAJECTORIES
Years to reach 450ppm CO_2 40 years
Years to reach 550ppm CO_2 100 years
ATMOSPHERIC CO_2
(parts per million by volume)
390
380
370
360
350
340
330
1980 1985 1990 1995 2000 2005 2009
Source: Carbon Dioxide Information Analysis Center, Mauna Loa
ARCTIC SEA-ICE COVER
Northern hemisphere summer sea-ice minimum (millions of square kilometers)
8.0
7.0
6.0
5.0
4.0
1980 1985 1990 1995 2000 2005 2009
The IGBP climate-change index combines the four key metrics that help unravel what is happening to the planet: temperature, carbon dioxide levels, sea level and Arctic sea ice. The index combines annual changes in each of these directly-measured parameters. Each year's change is added to the previous year. Natural variability sometimes obscures general trends in these metrics. By drawing together the four metrics as a single figure, the IGBP climate-change index exposes the underlying trend.
Developed by the International Geosphere Biosphere Programme

PLANETARY BOUNDARIES

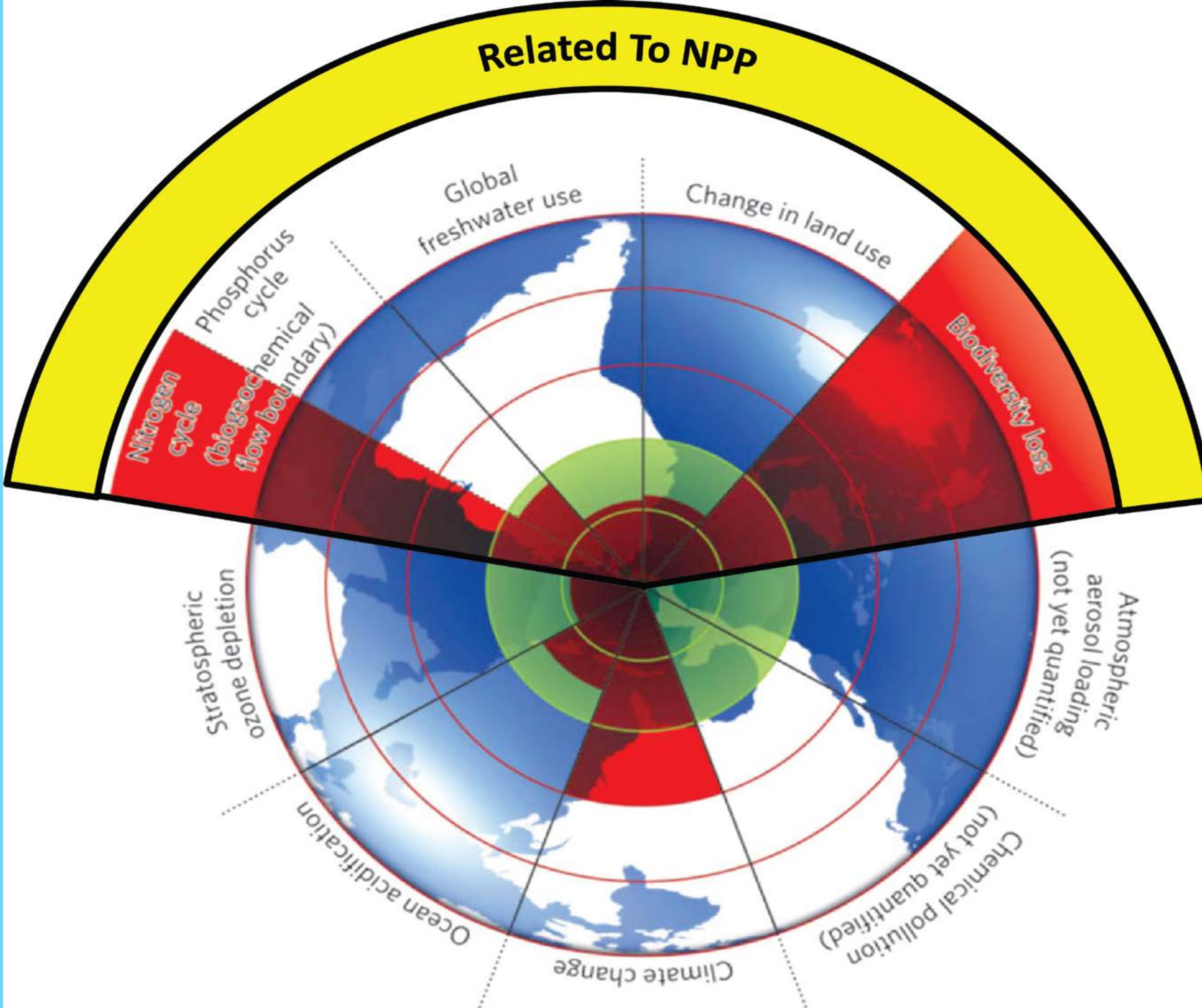
Rockstrom et al. *Nature* 2009



Terrestrial NPP = Planetary Boundary??

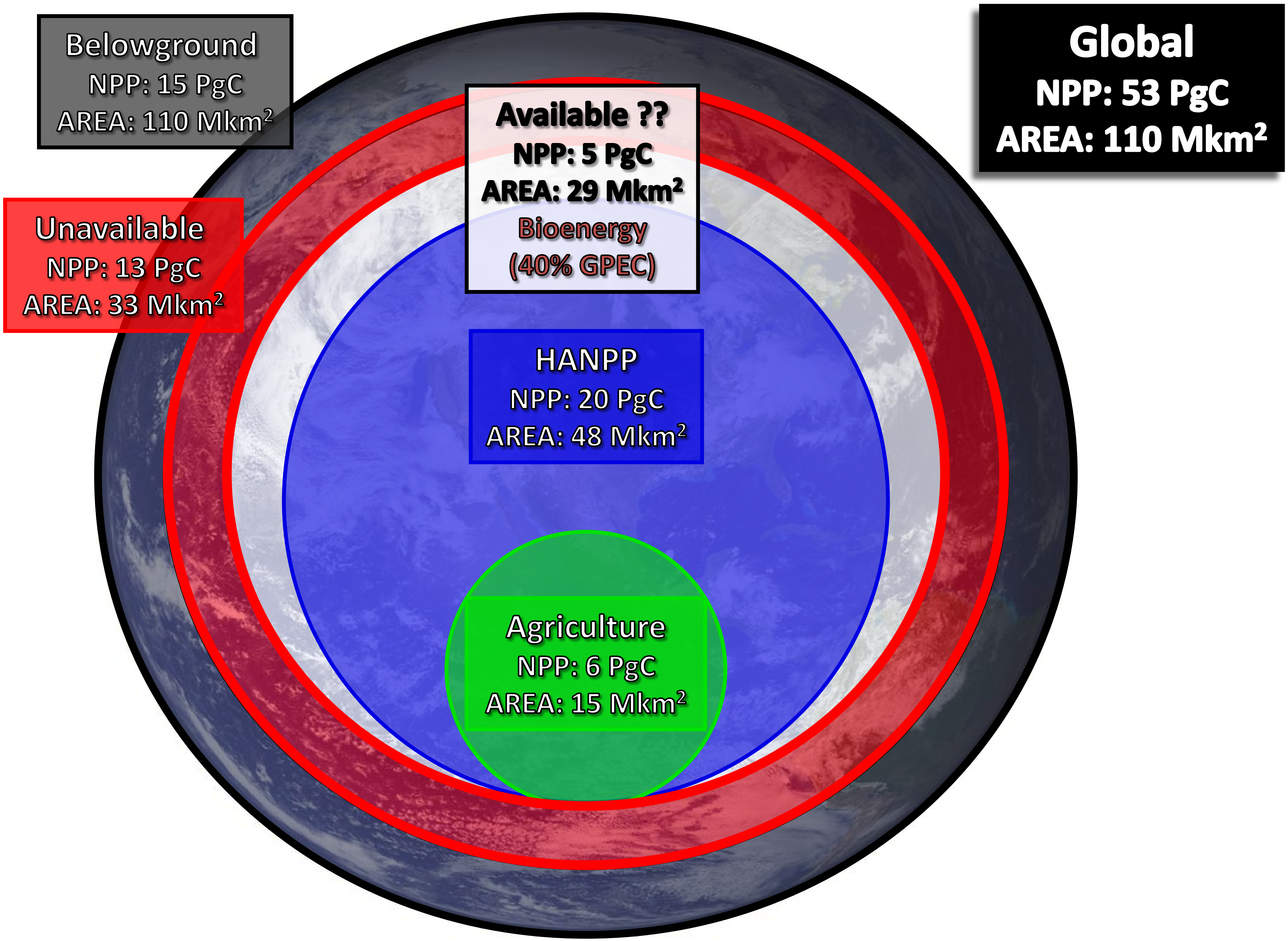


Zhao et al., 2005, *Remote Sensing of Environment*



Related To NPP
Global freshwater use
Change in land use
Biodiversity loss
Atmospheric aerosol loading (not yet quantified)
Chemical pollution (not yet quantified)
Climate change
Ocean acidification
Stratospheric ozone depletion
Nitrogen cycle (biogeochemical flow boundary)
Phosphorus cycle

PARTITIONING OF GLOBAL NPP



THE MOST DISTANT IMAGE OF EARTH EVER TAKEN, *1 BILLION KM*

WE BETTER NOT SCREW THIS PLANET UP