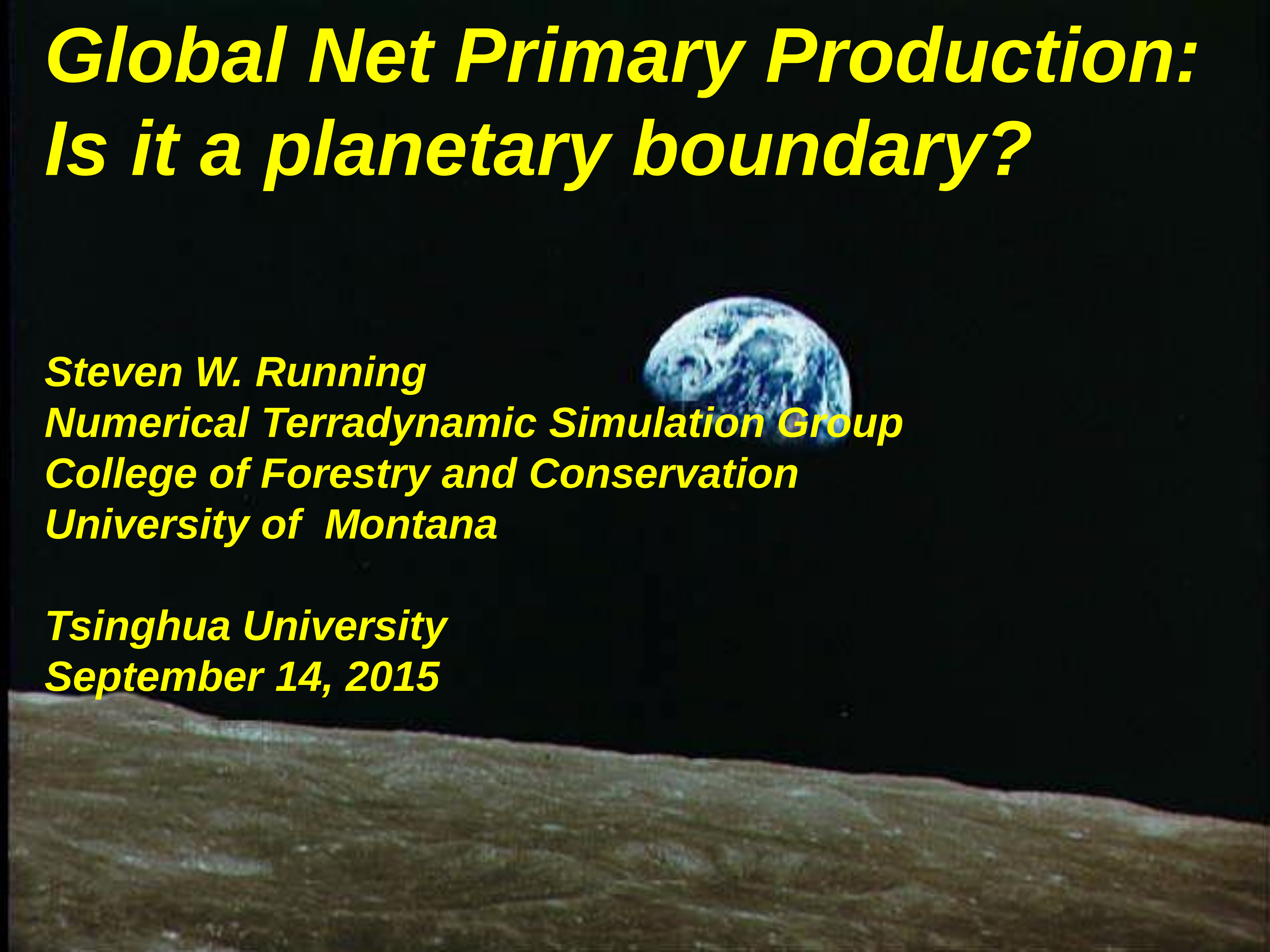

Global Net Primary Production:
Is it a planetary boundary?
Steven W. Running
Numerical Terradynamic Simulation Group
College of Forestry and Conservation
University of Montana
Tsinghua University
September 14, 2015

# Diurnal stomatal conductance and leaf water potential, MS thesis, Oregon 1973

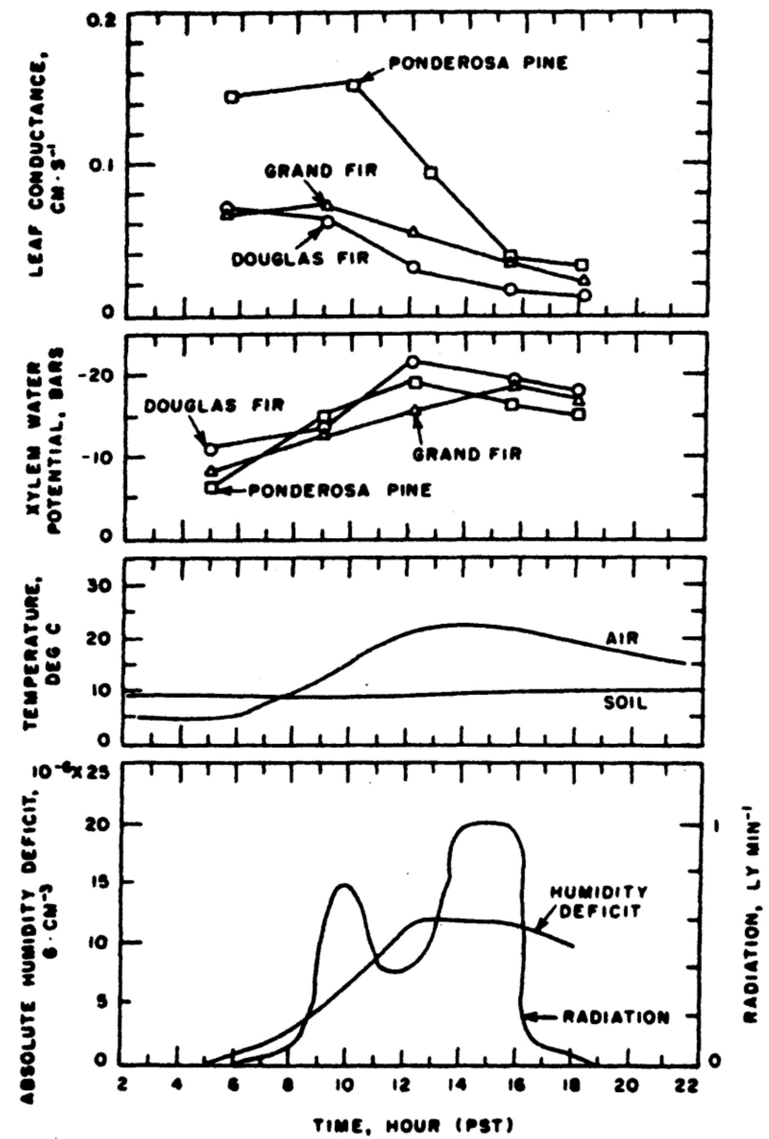



FIG. 5. Environmental and physiological data for Douglas fir, ponderosa pine, and grand fir, taken August 20, 1974, on the Metolius River site. Each leaf-conductance point represents a canopy average of four measurements on 0- to 3-year needle-age classes, three trees, 1 to 3 m tall (1 bar = $10^5$ Pa, 1 ly $min^{-1}$ = 69.8 mW $cm^{-2}$).

# First systems model of tree water balance, 1975

S. W. Running *et al.*

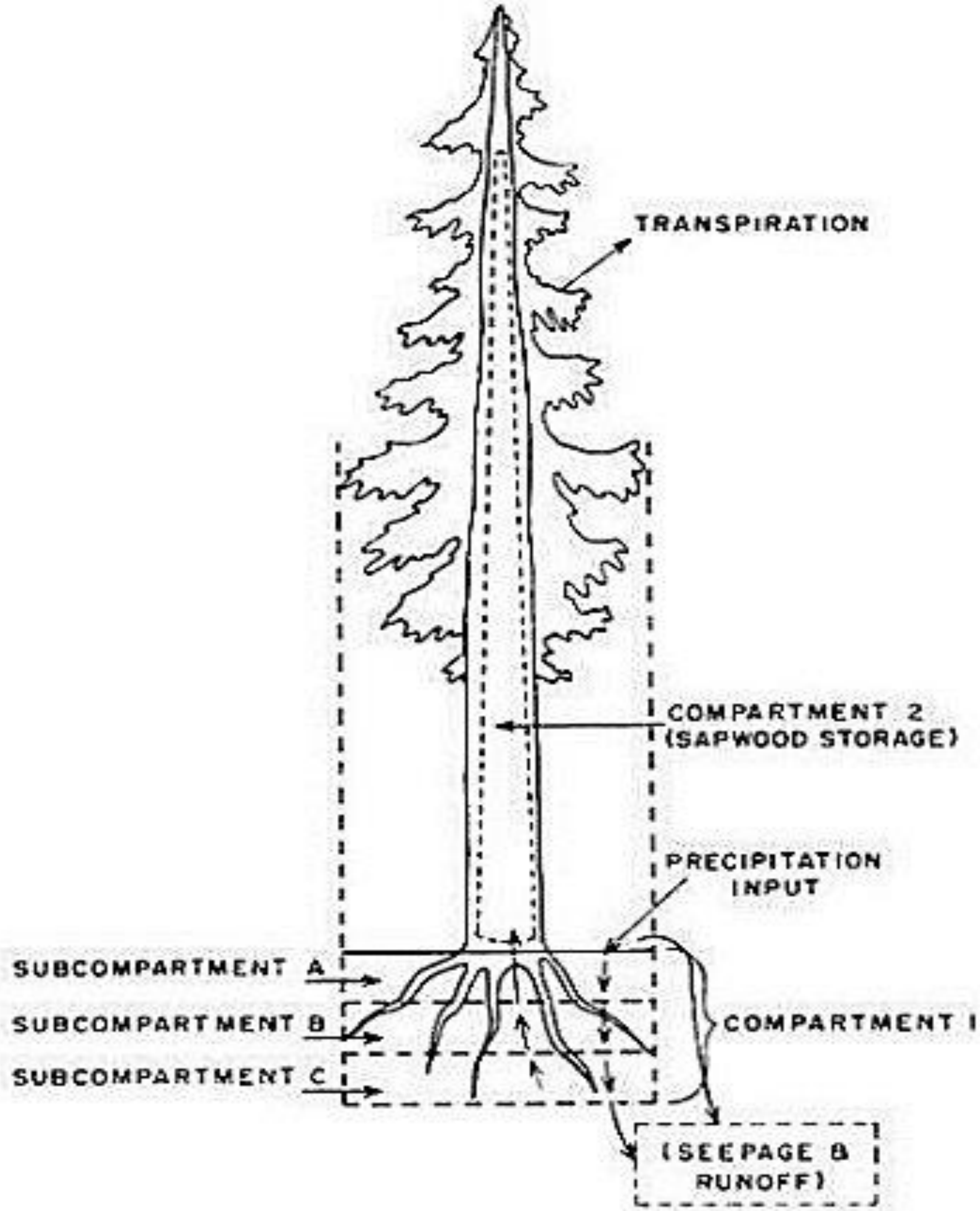



Fig. 1. Components of water flux model

# Original FOREST-BGC flow diagram, emphasizing dual time steps, critical role of LAI, C-H2O-N interactions, and remote sensing applications, 1988

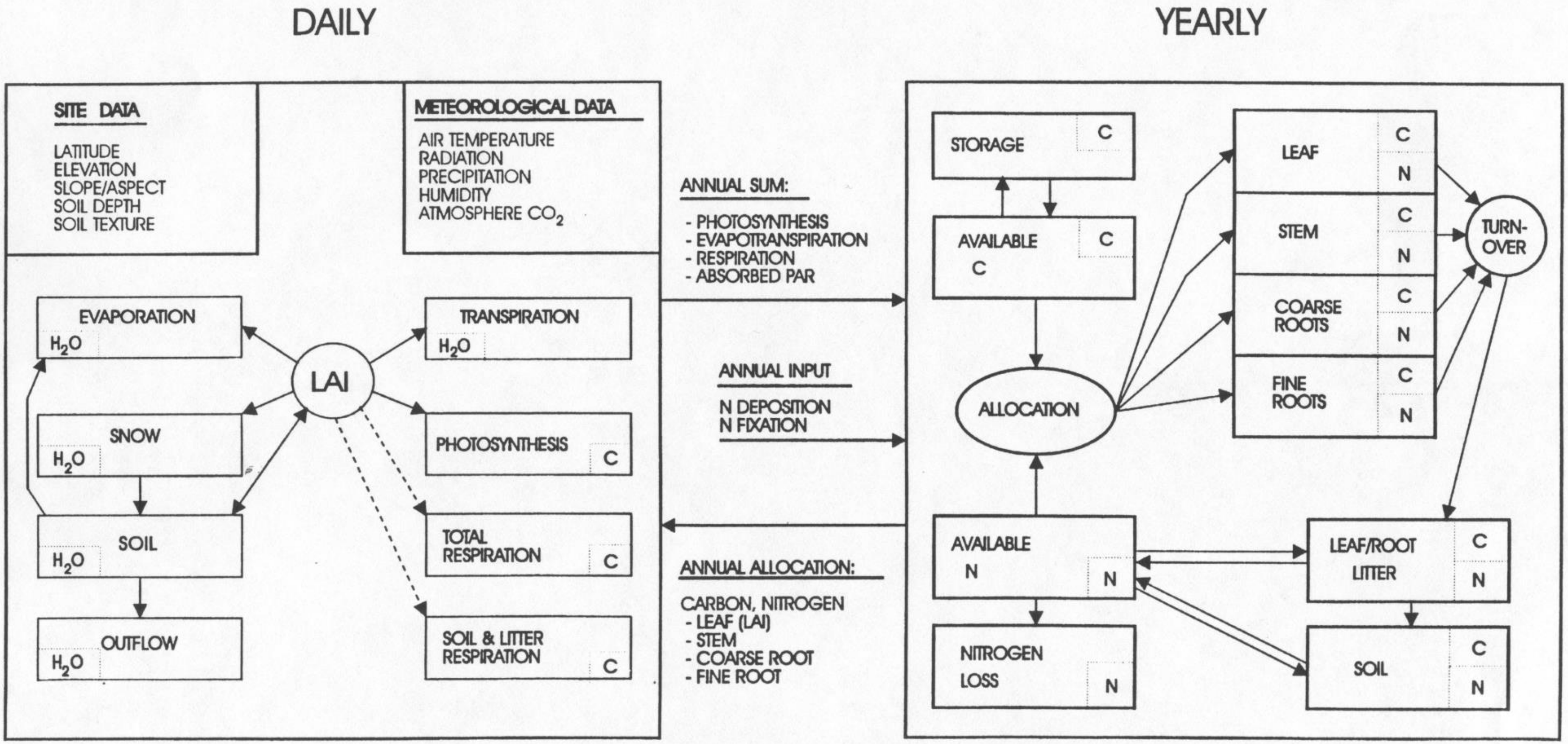
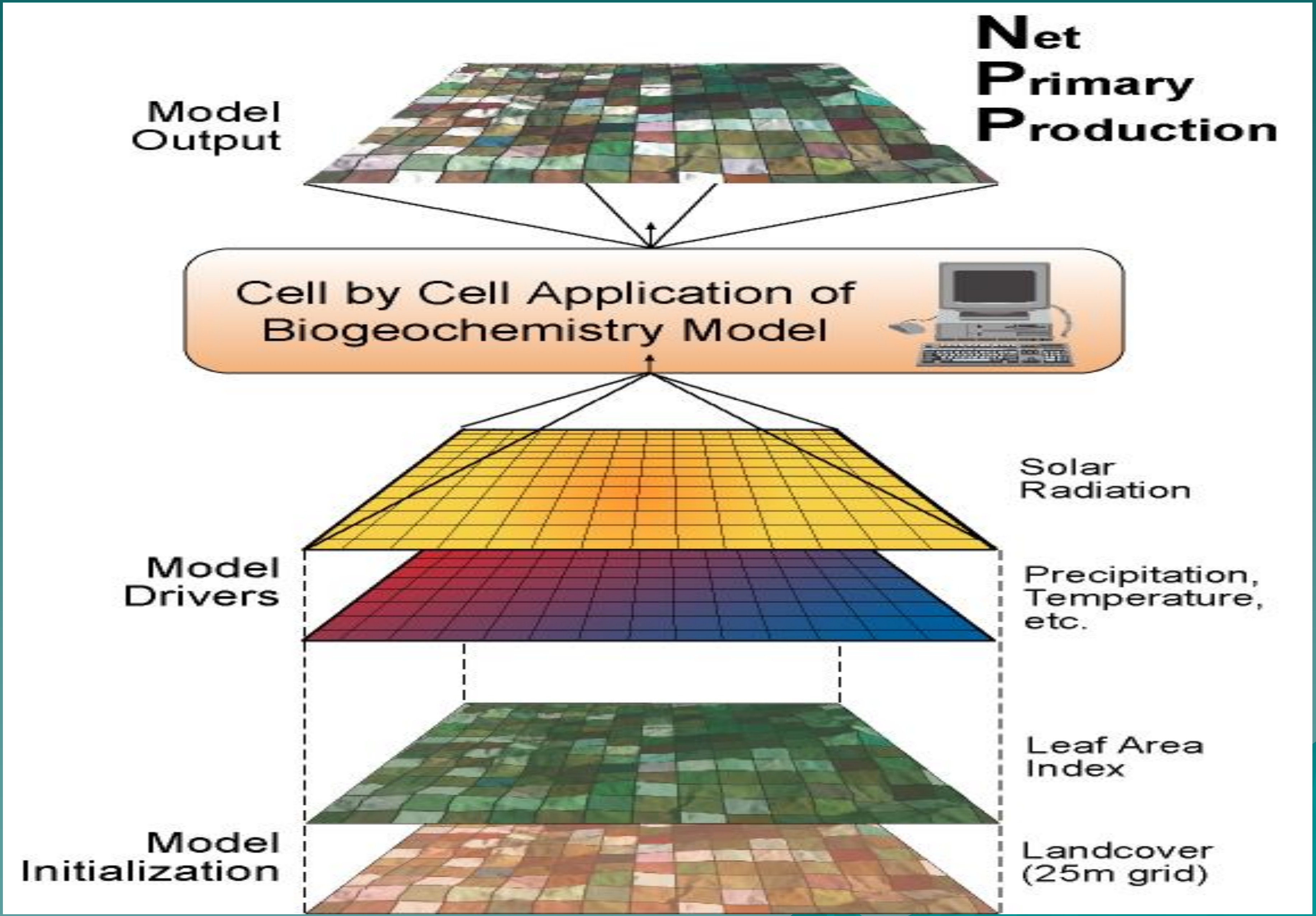
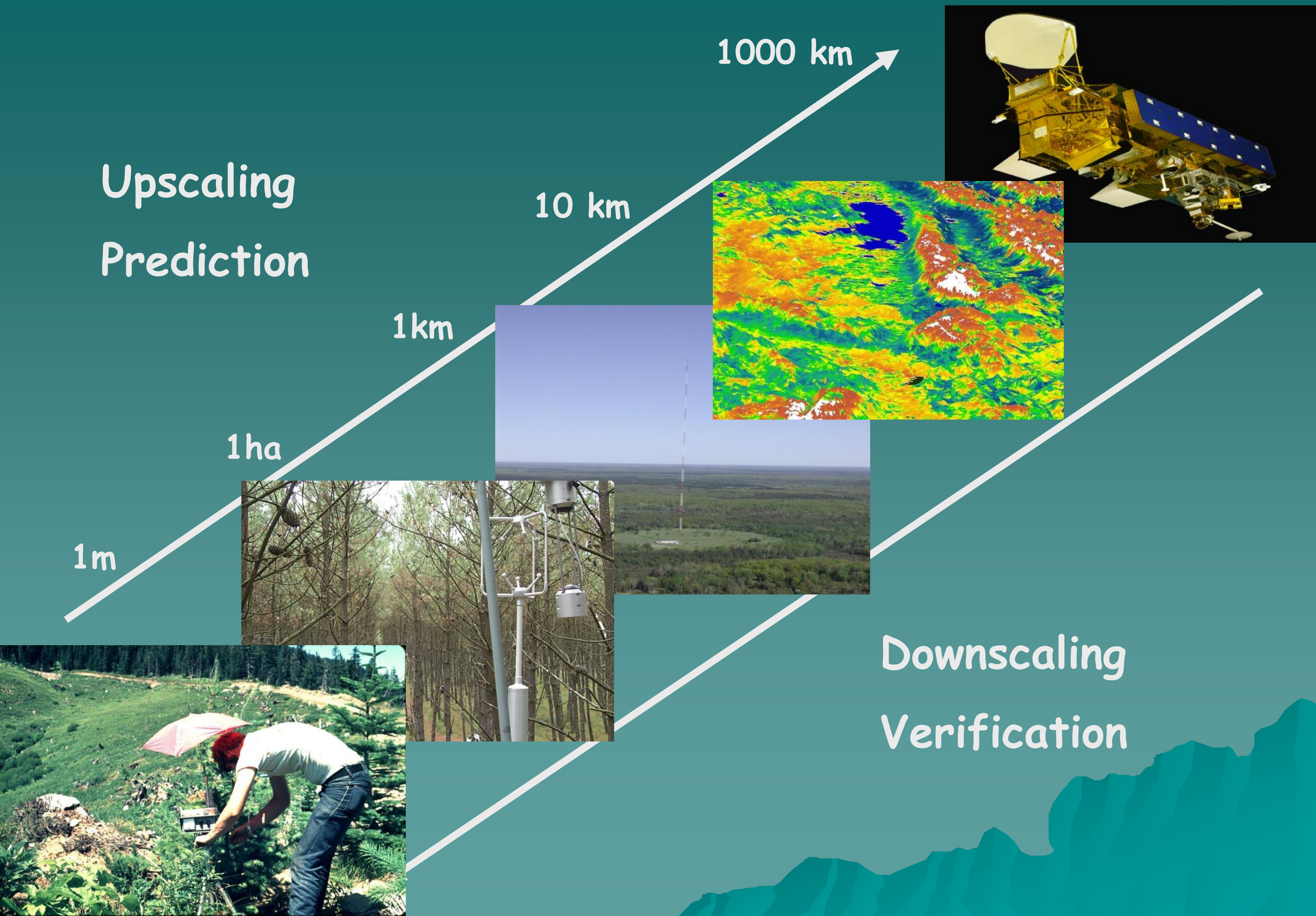


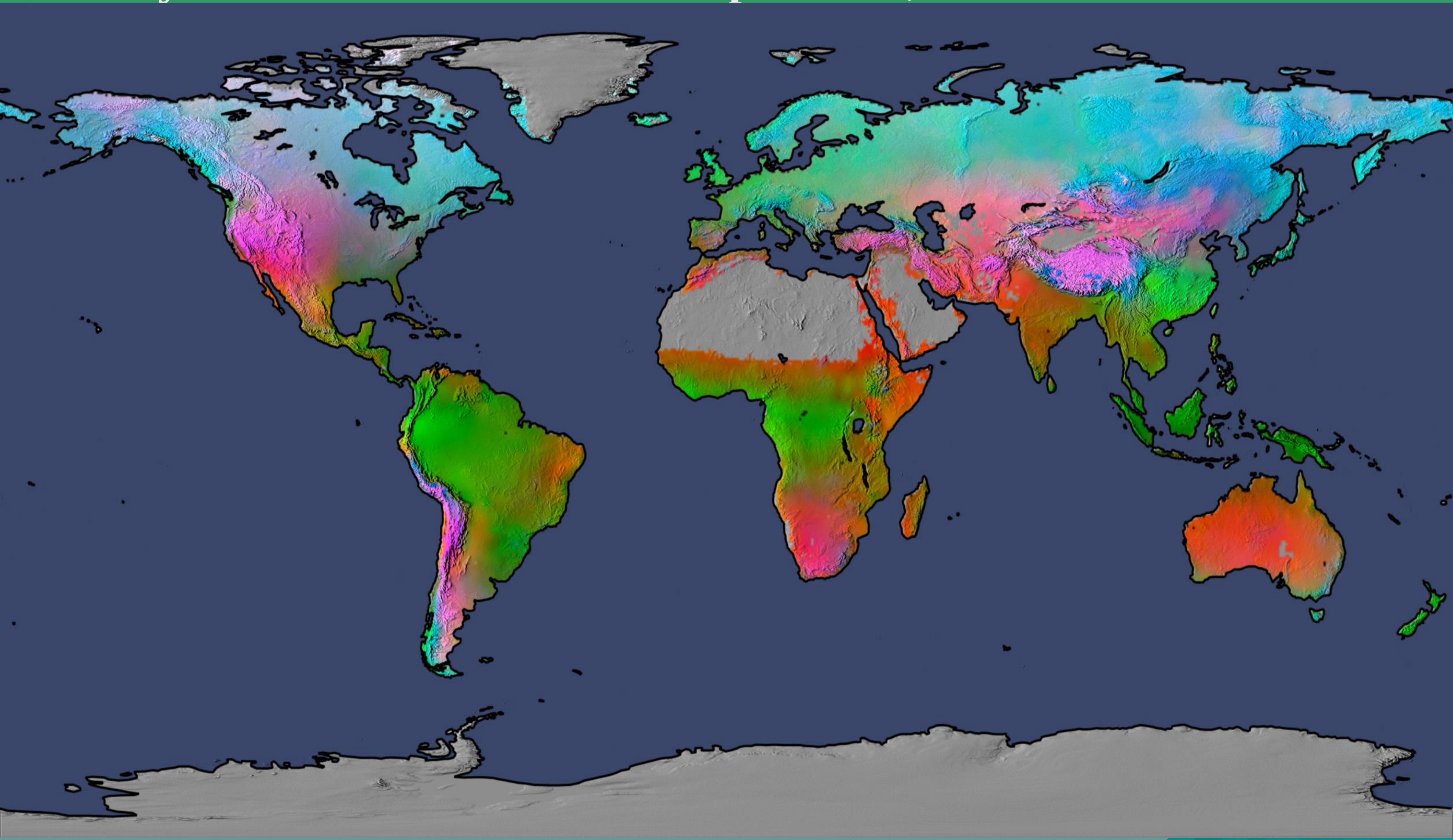

**Figure 1.2.** Compartment flow diagram for the FOREST-BGC ecosystem simulation model. This diagram illustrates the state variables of carbon, water, and nitrogen, the critical mass flow linkages, the combined daily and annual time resolution, and the daily meteorological data required for executing the model. The major variables and underlying principles associated with the model were developed specifically for application at multiple time and space scales, and for compatibility with remote-sensed definition of key ecosystem properties.


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)

# Integrated, Multiple Constraints on the Biosphere



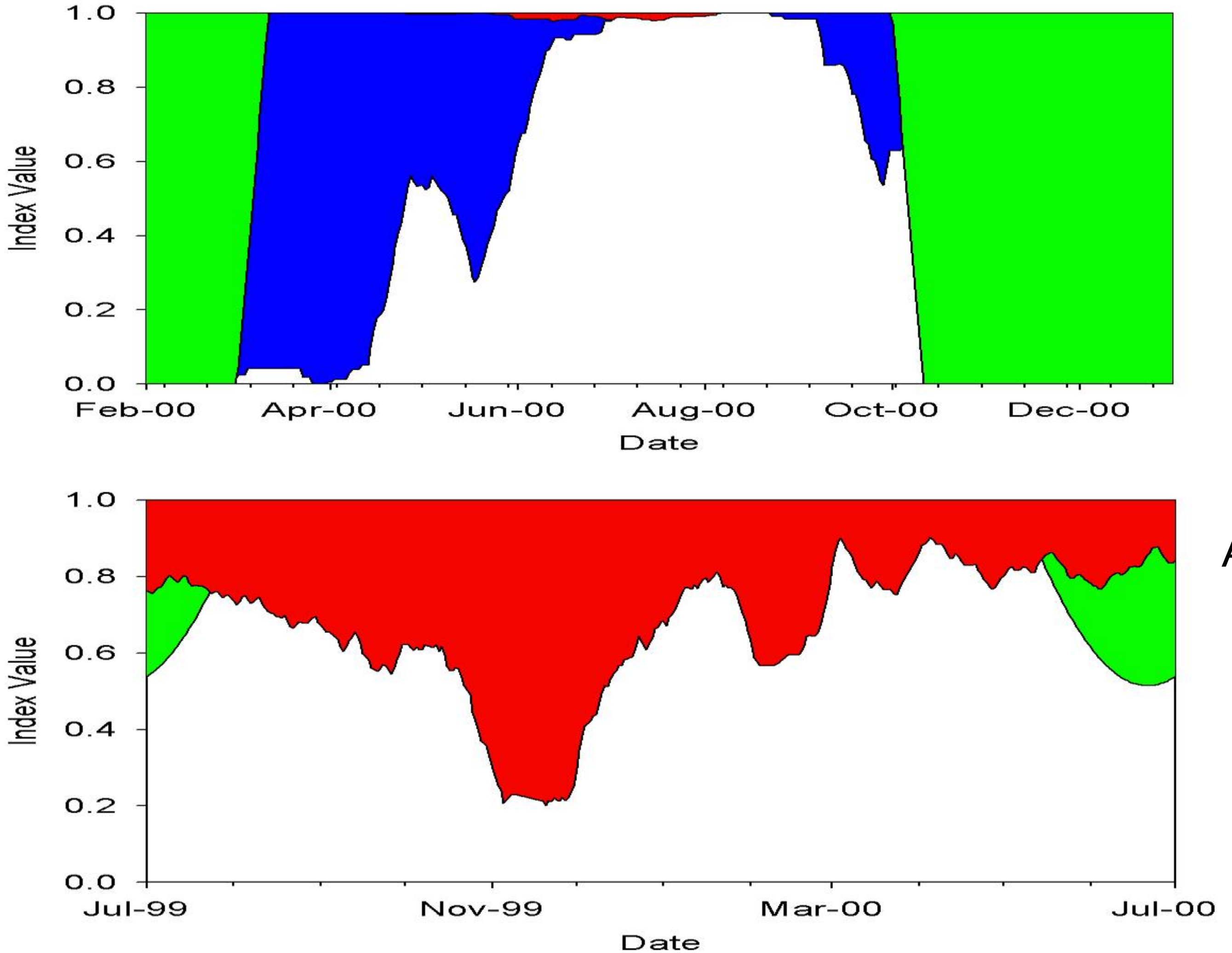
# Potential climate limits to plant growth derived from long-term monthly statistics of minimum temperature, cloud cover and rainfall.



Water = 40%, Temperature = 33%, Radiation = 27%

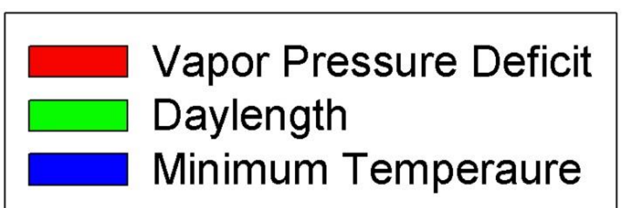
Nemani et al. 2003
Running et al 2004

# Seasonal Growing Season Constraints



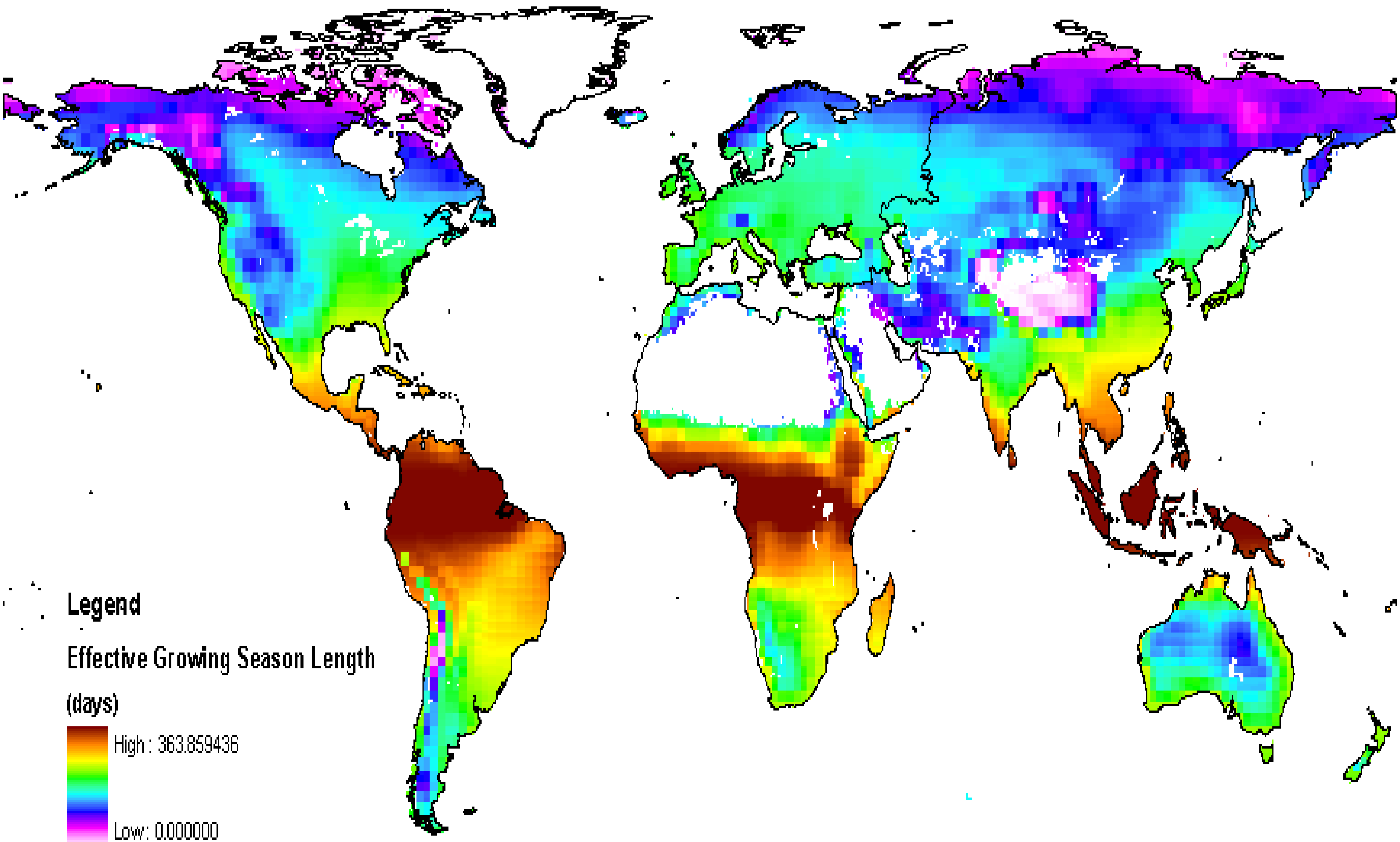

Russia, Boreal

Africa, Savannah




**Jolly, Nemani, Running. Global Change Biology 2005**

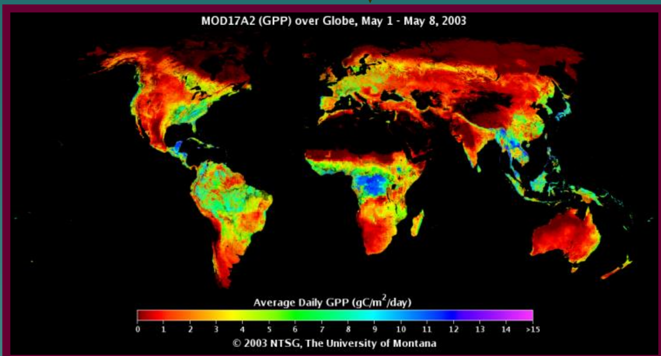
# Global Effective Growing Season Length



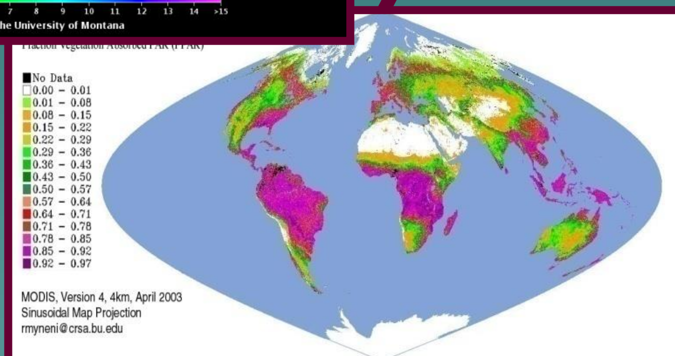

Jolly, Nemani, Running. Global Change Biology 2005

# GPP = Light X Conversion Efficiency

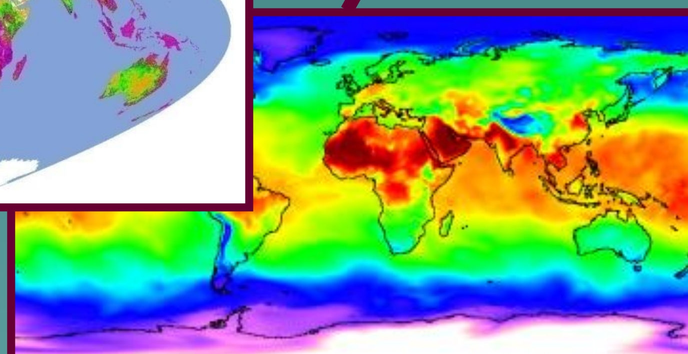
## $GPP = f(PAR) \times \varepsilon$



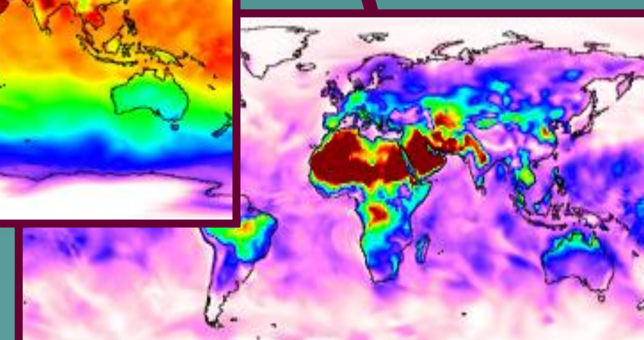

**GPP**




**fPAR, PAR**



**Temperature**

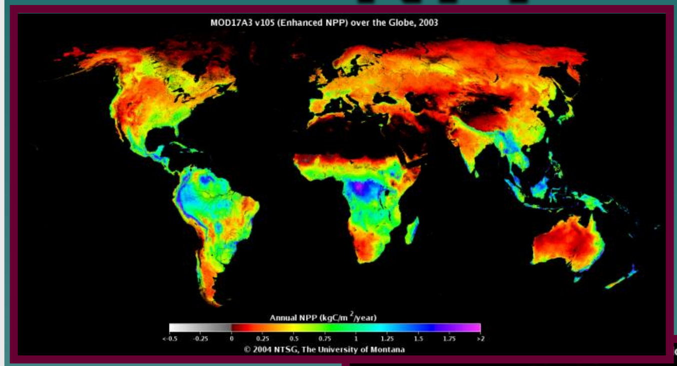


**VPD**

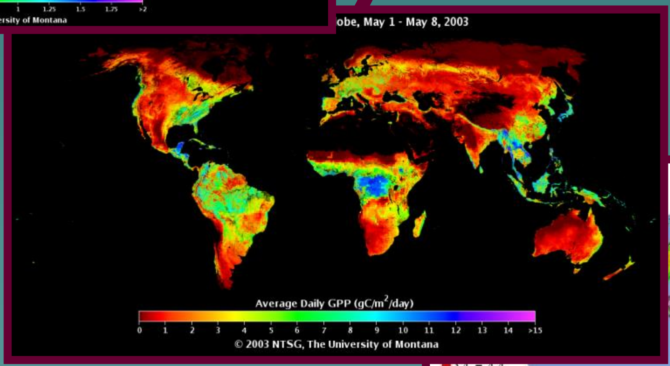
**Biome Properties Look-Up Table ($\varepsilon_{max}$)**

# NPP = Annual GPP - Autotrophic Respiration

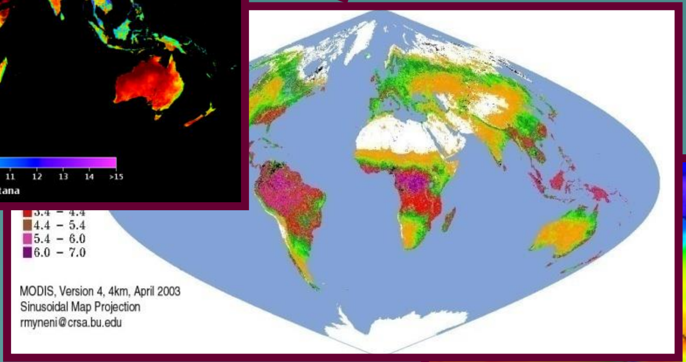
$$NPP = \sum GPP - (R_m + R_g)$$



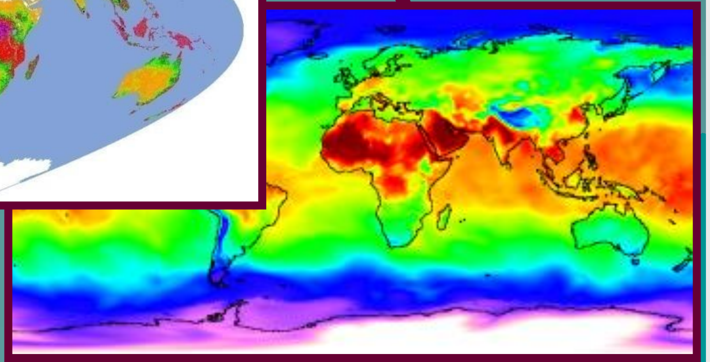

***NPP***




**GPP**




**LAI**



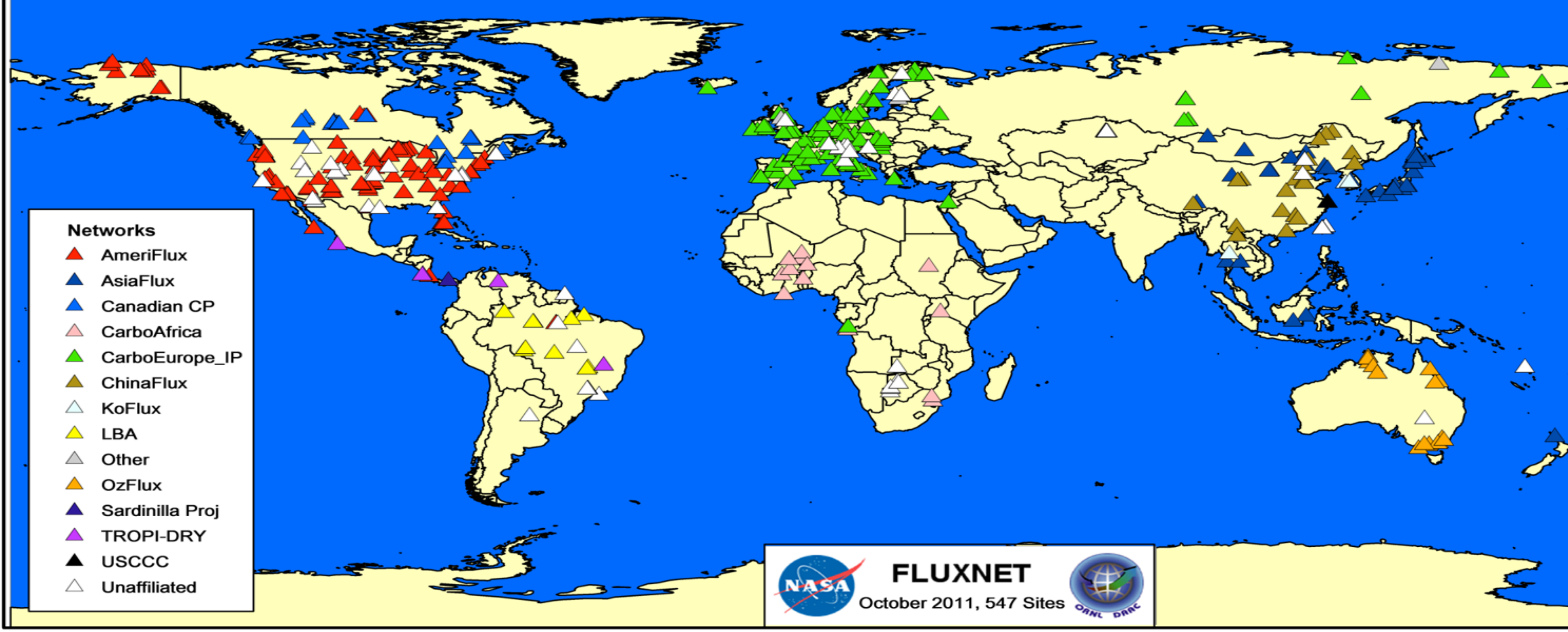
**Temperature**

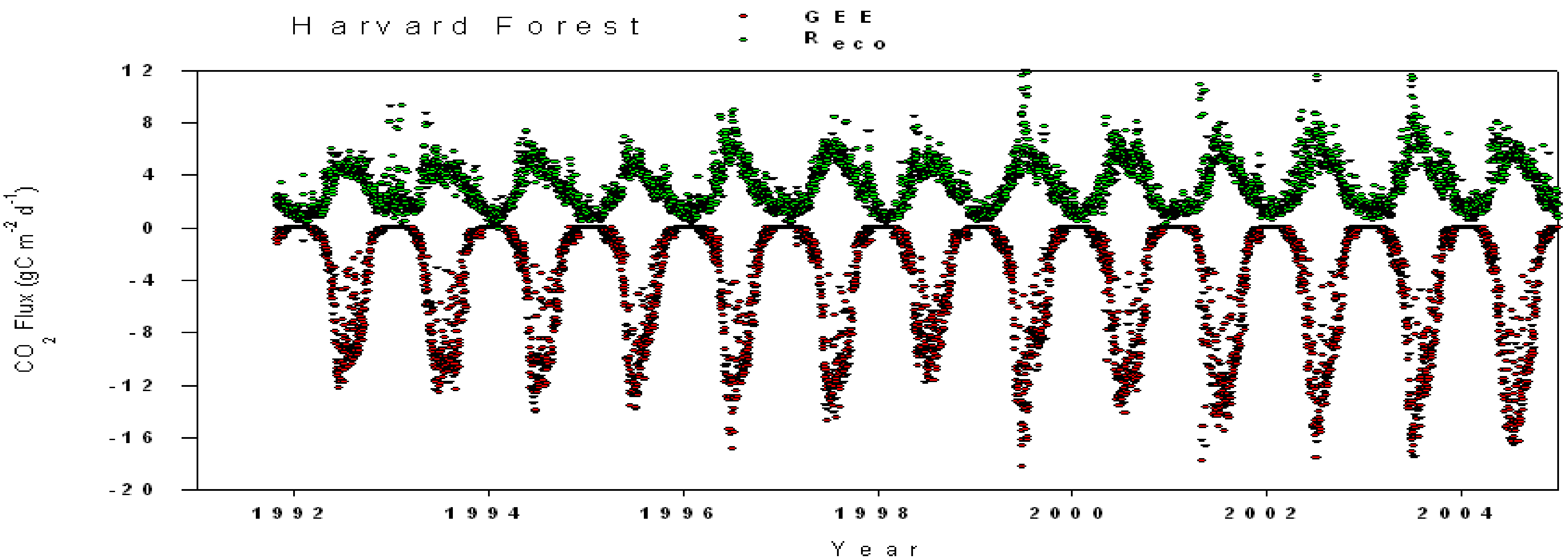
**Biome Properties Look-Up Table**

# Comparison of GPP from Terra-MODIS and AmeriFlux Network Towers

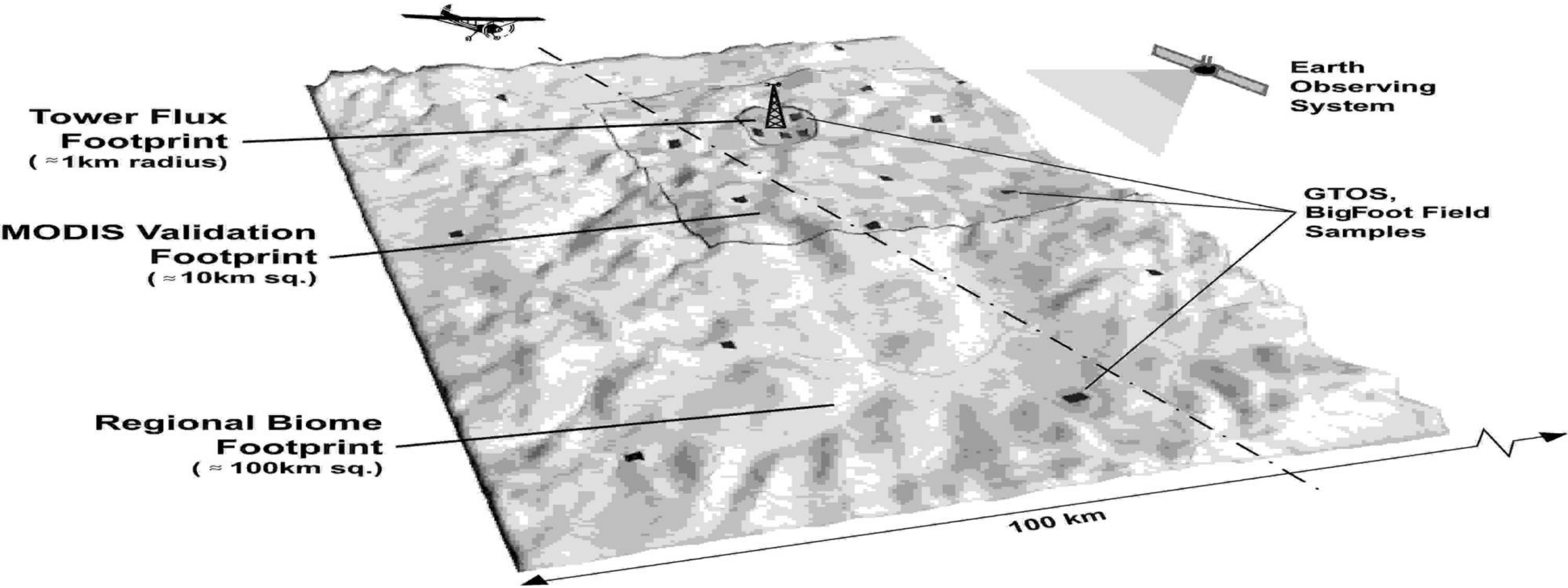
The AmeriFlux network, established in 1996, provides continuous observations of ecosystem level exchanges of CO2, water, energy and momentum spanning diurnal, synoptic, seasonal, and interannual time scales.

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

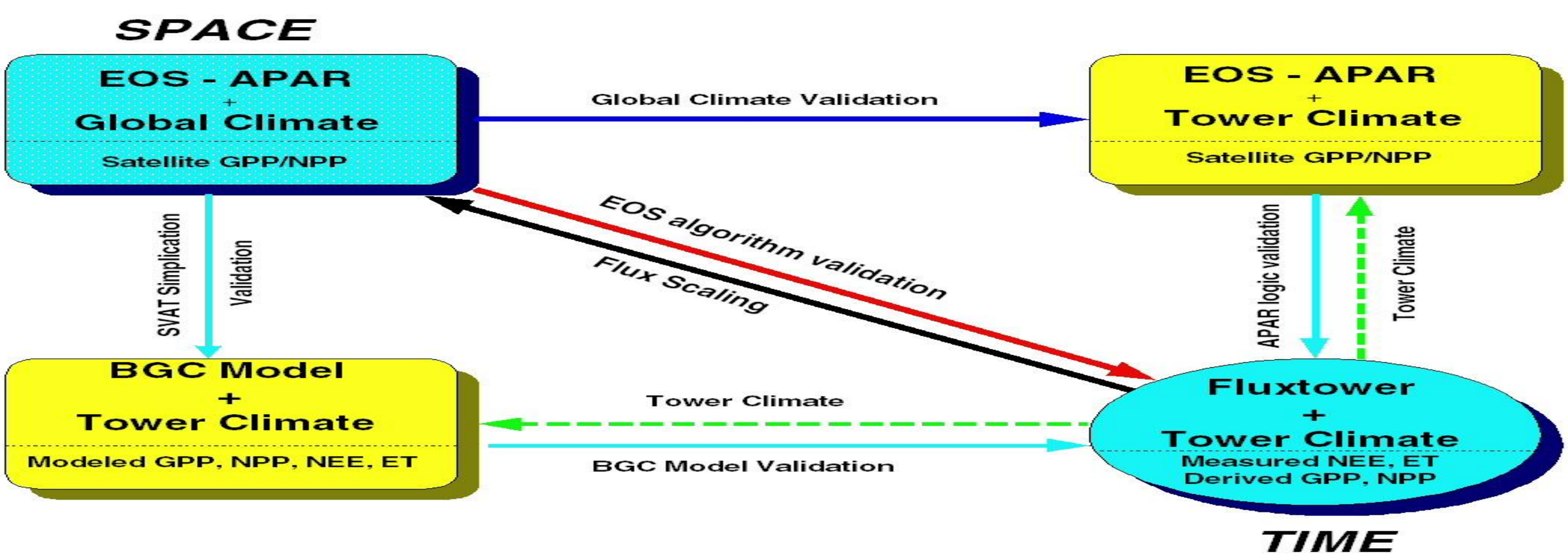

Networks
AmeriFlux
AsiaFlux
Canadian CP
CarboAfrica
CarboEurope_IP
ChinaFlux
KoFlux
LBA
Other
OzFlux
Sardinilla Proj
TROPI-DRY
USCCC
Unaffiliated
FLUXNET
October 2011, 547 Sites


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



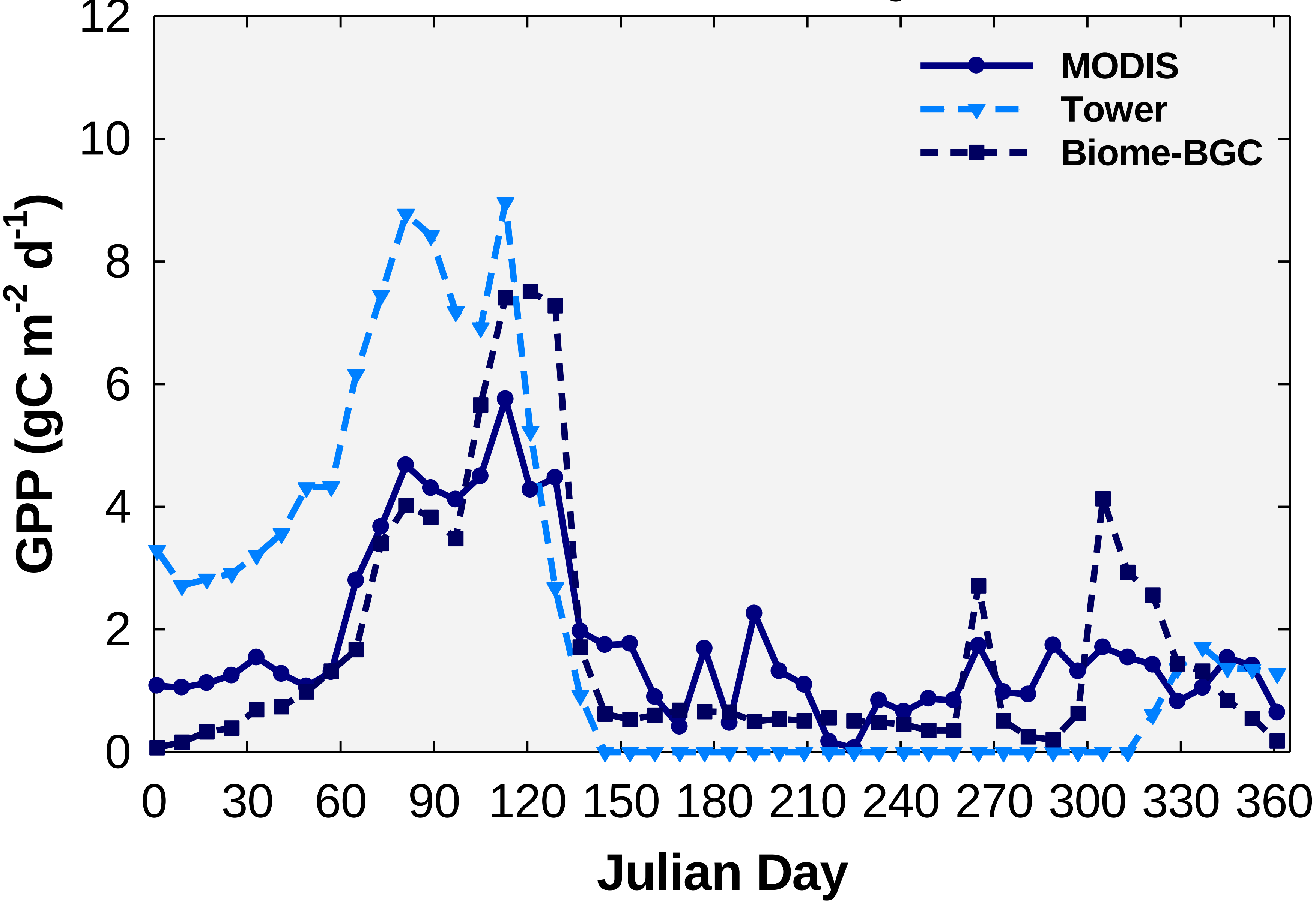

## FLUX TOWER BASED VALIDATION FOR MODIS GPP/NPP



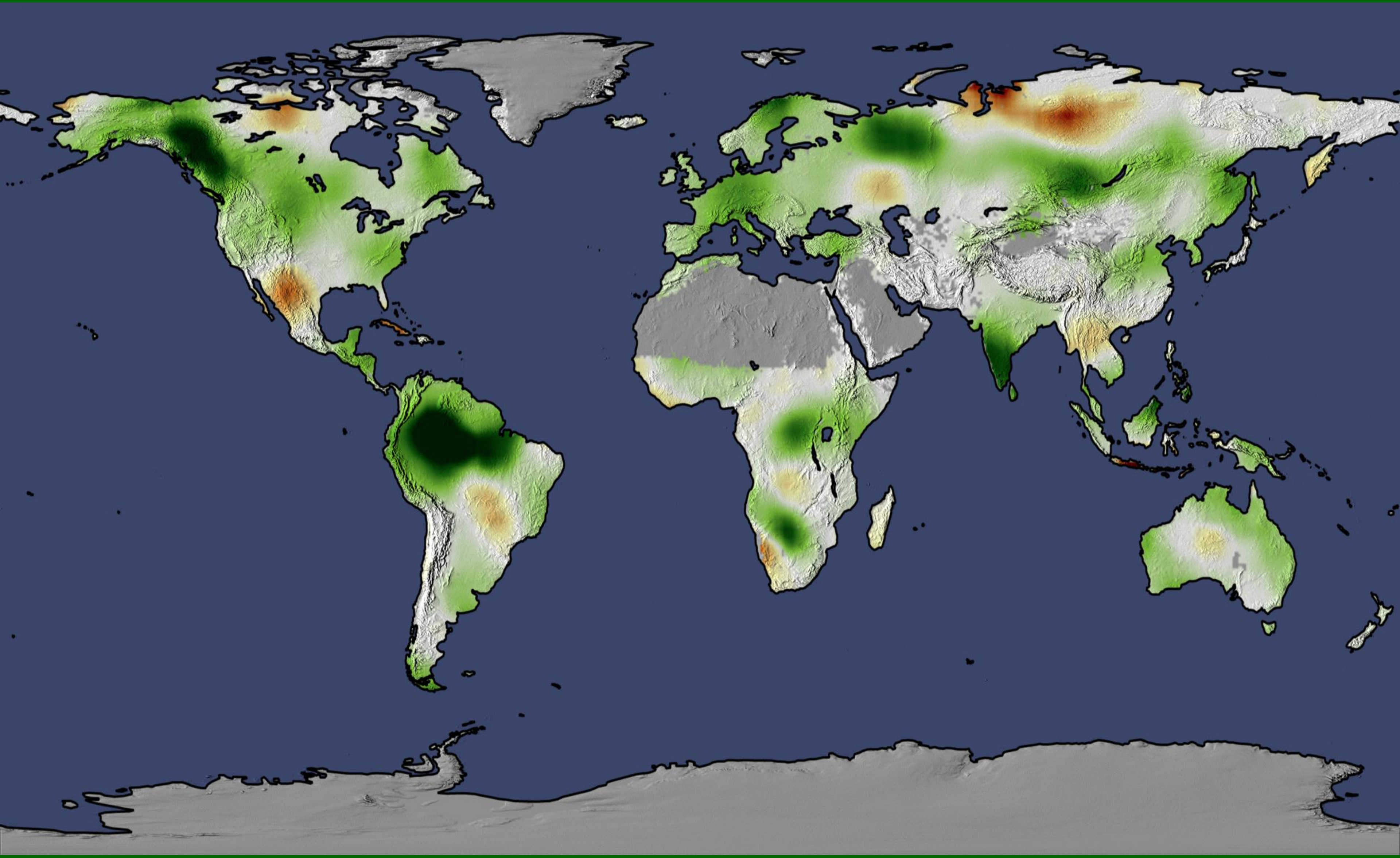
# Grassland, Vaira Ranch, CA, 2001

MODIS GPP = 1134.86 gC $m^{-2}$ Tower GPP = 776.37 gC $m^{-2}$

Biome-BGC GPP = 614.64 gC $m^{-2}$

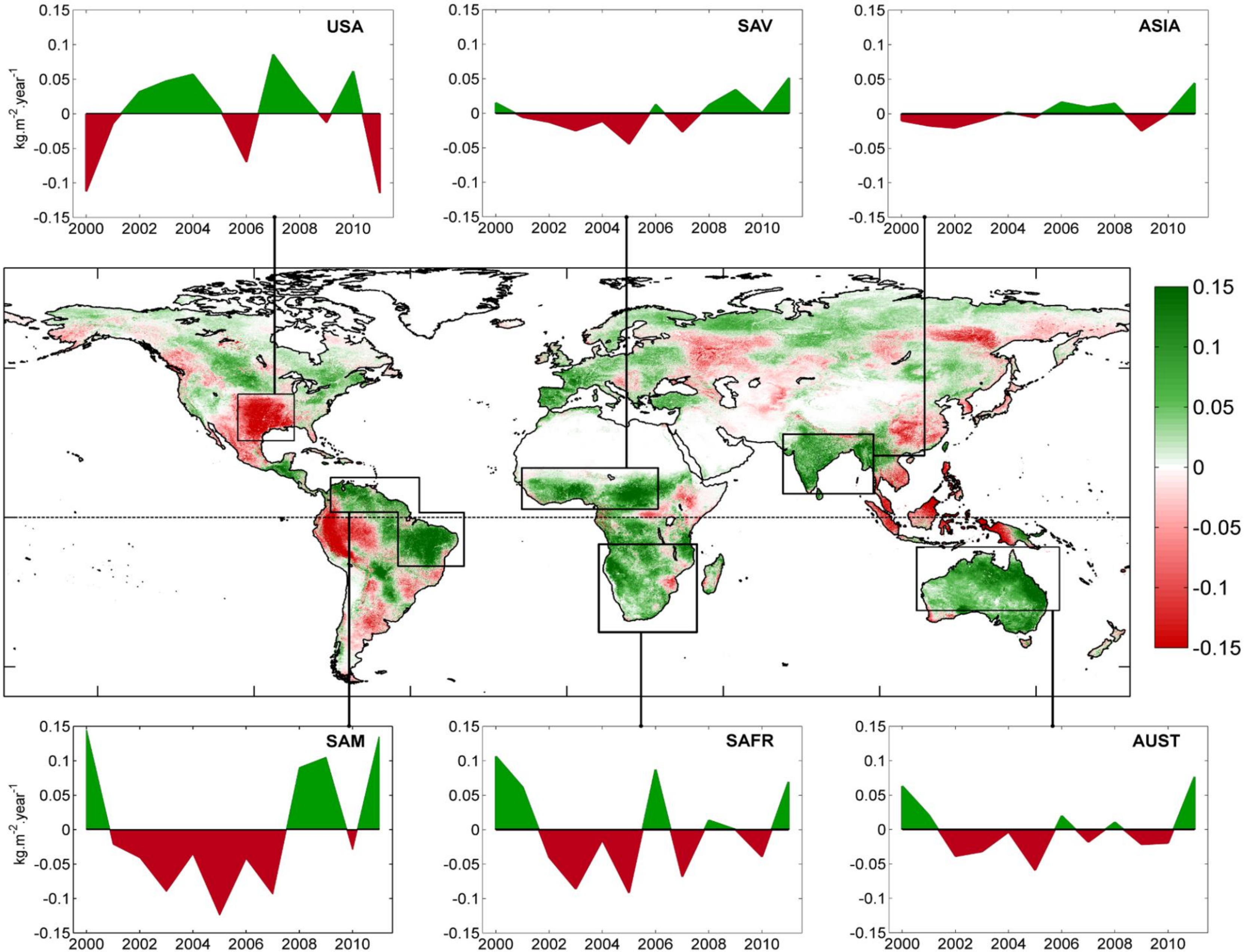


# Change in Terrestrial NPP from 1982 to 1999



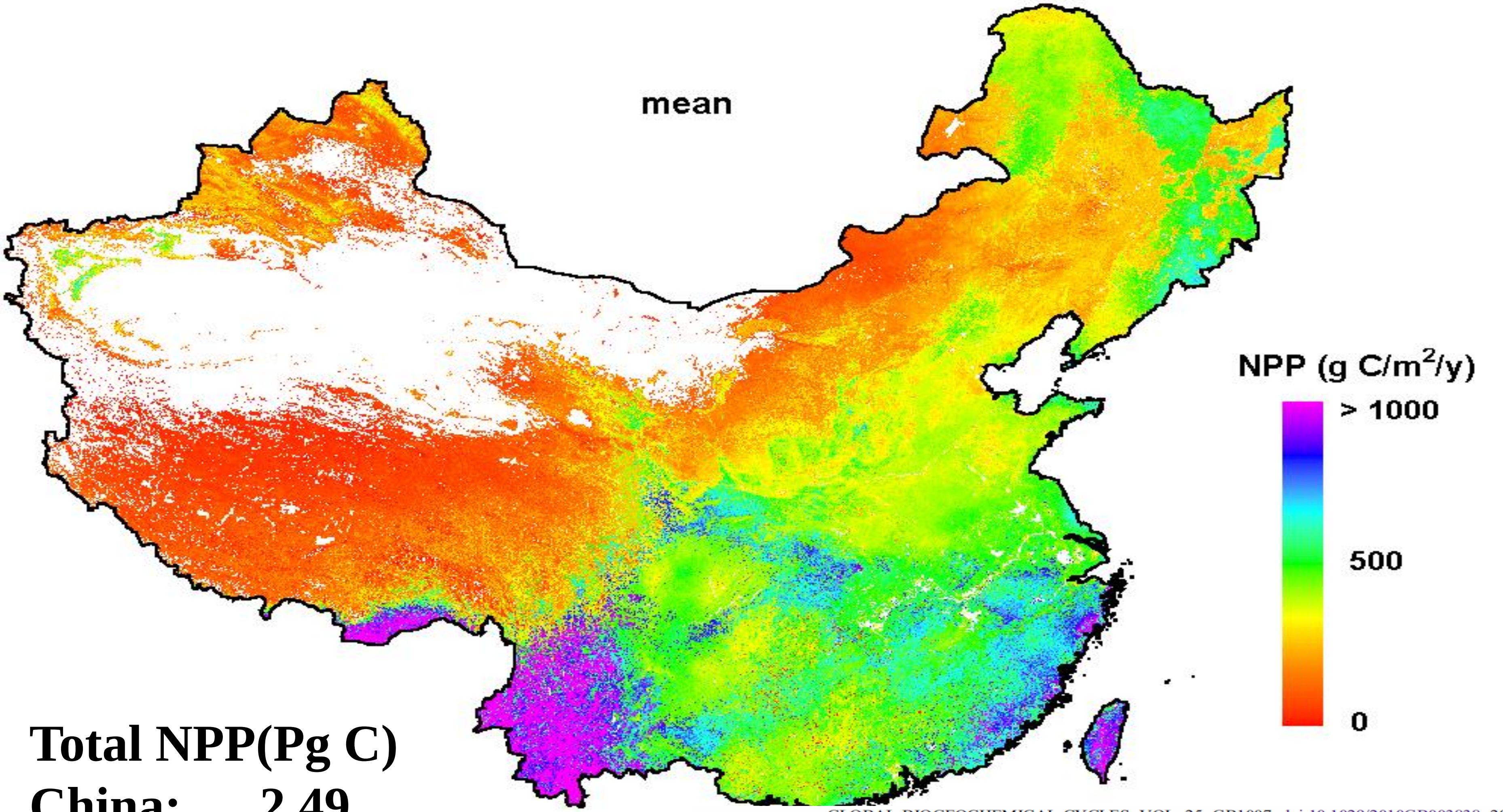
Nemani et al., Science June 6th 2003

# The global NPP dependence on ENSO: La Niña and the extraordinary year of 2011




Bastos et al 2013

# Our first MODIS NPP over China, 2004




GLOBAL BIOGEOCHEMICAL CYCLES, VOL. 25, GB1007, doi:10.1029/2010GB003838, 2011

**Total NPP(Pg C)**
**China: 2.49**
**Globe: 56.04**
**Percent: 4.78%**

**China's terrestrial carbon balance: Contributions from multiple global change factors**

Hanqin Tian,[1,2] Jerry Melillo,[3] Chaoqun Lu,[1,2] David Kicklighter,[3] Mingliang Liu,[1,2] Wei Ren,[1,2] Xiaofeng Xu,[1,2] Guangsheng Chen,[1,2] Chi Zhang,[1,2] Shufen Pan,[1,2] Jiyuan Liu,[4] and Steven Running[5]

# LETTER

doi:10.1038/nature13376

## Contribution of semi-arid ecosystems to interannual variability of the global carbon cycle

Benjamin Poulter[1,2], David Frank[3,4], Philippe Ciais[2], Ranga Myneni[5], Niels Andela[6], Jian Bi[5], Gregoire Broquet[2], Josep G. Canadell[7], Frederic Chevallier[2], Yi Y. Liu[8], Steven W. Running[9], Stephen Sitch[10] & Guido R. van der Werf[6]

For example, in Australia:

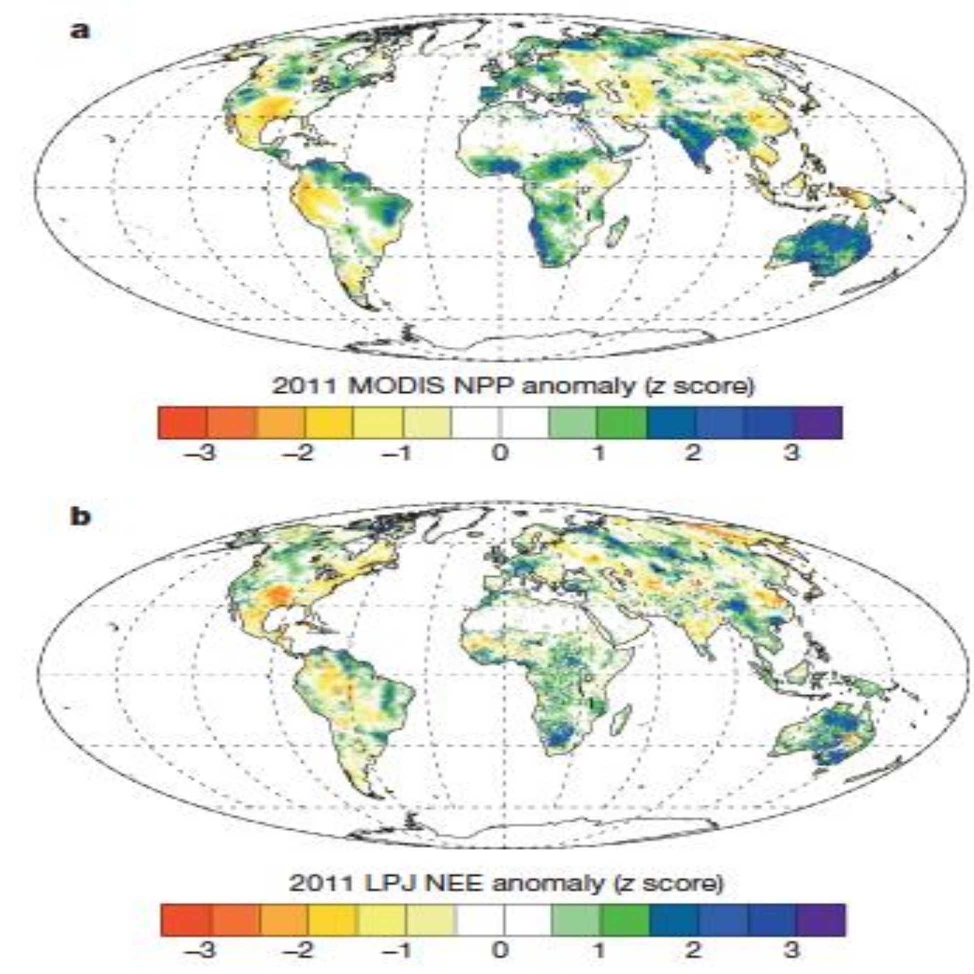
- 45% increase in NPP (LPJ and MODIS)
- 9% increase in Rh (LPJ)
- 29% decrease in fire emissions from GFED & GFAS observations

Net effect

- 0.84 Pg C sink in Australia
- Explained 60% of global anomaly
- Semi arid regions explained 51% of total land sink in 2011

Climate attribution

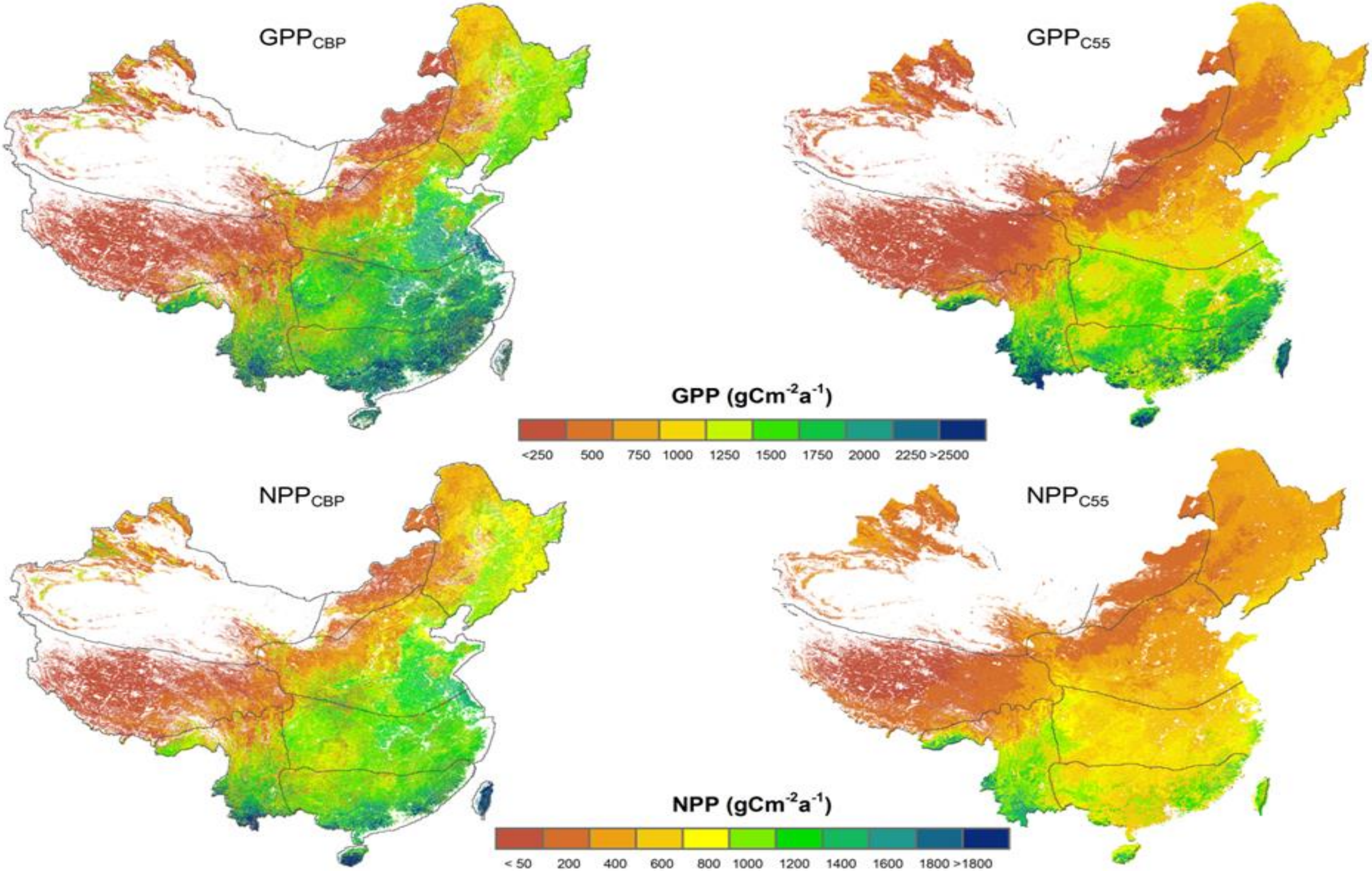
- Precipitation driven
- Regional lag effects
  - Enhanced soil moisture from 2010 precipitation in semi-arid regions
  - Decrease in tropical Rh after 2010

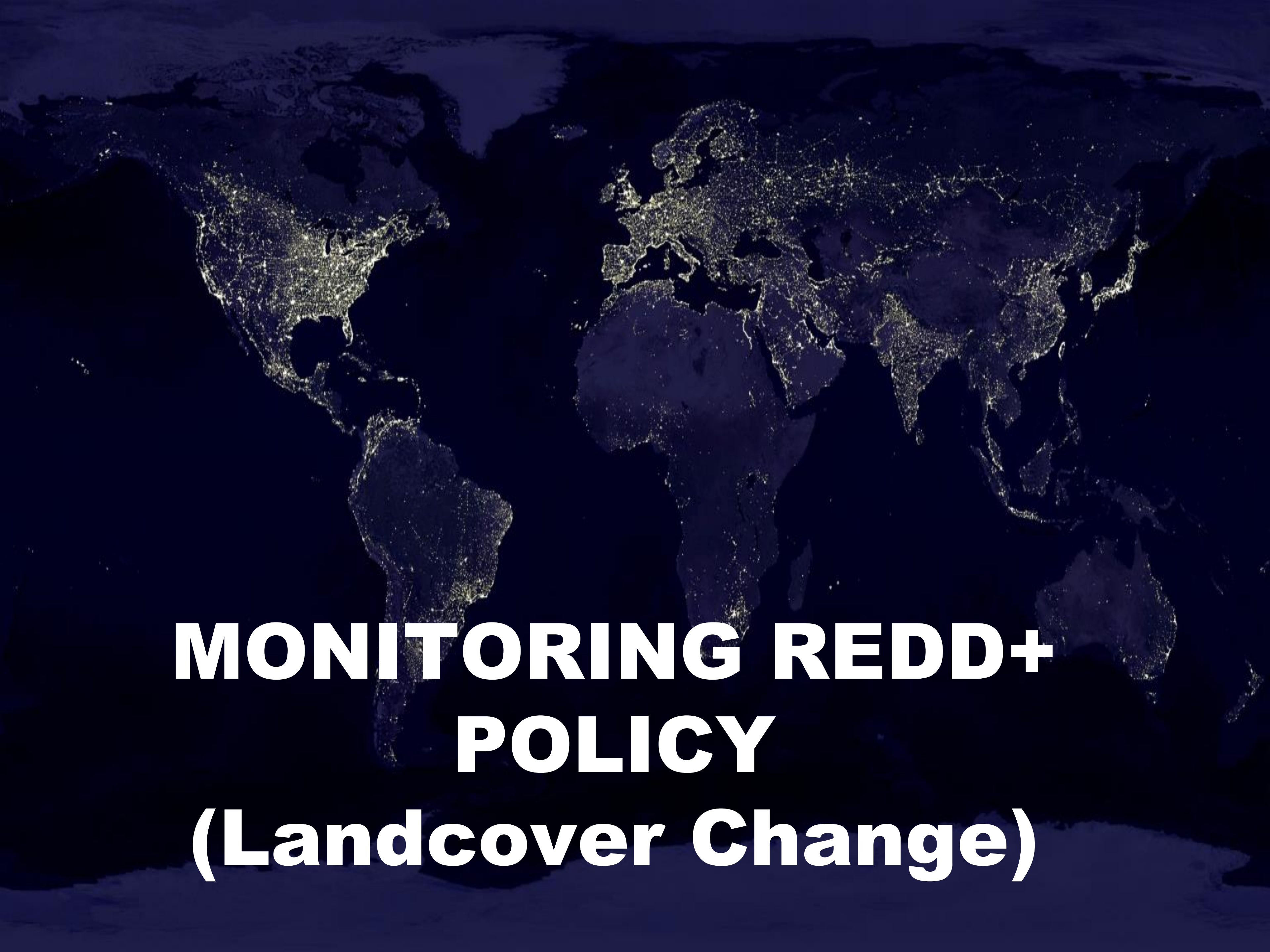



(Poulter et al 2014)

# Newest MODIS GPP and NPP

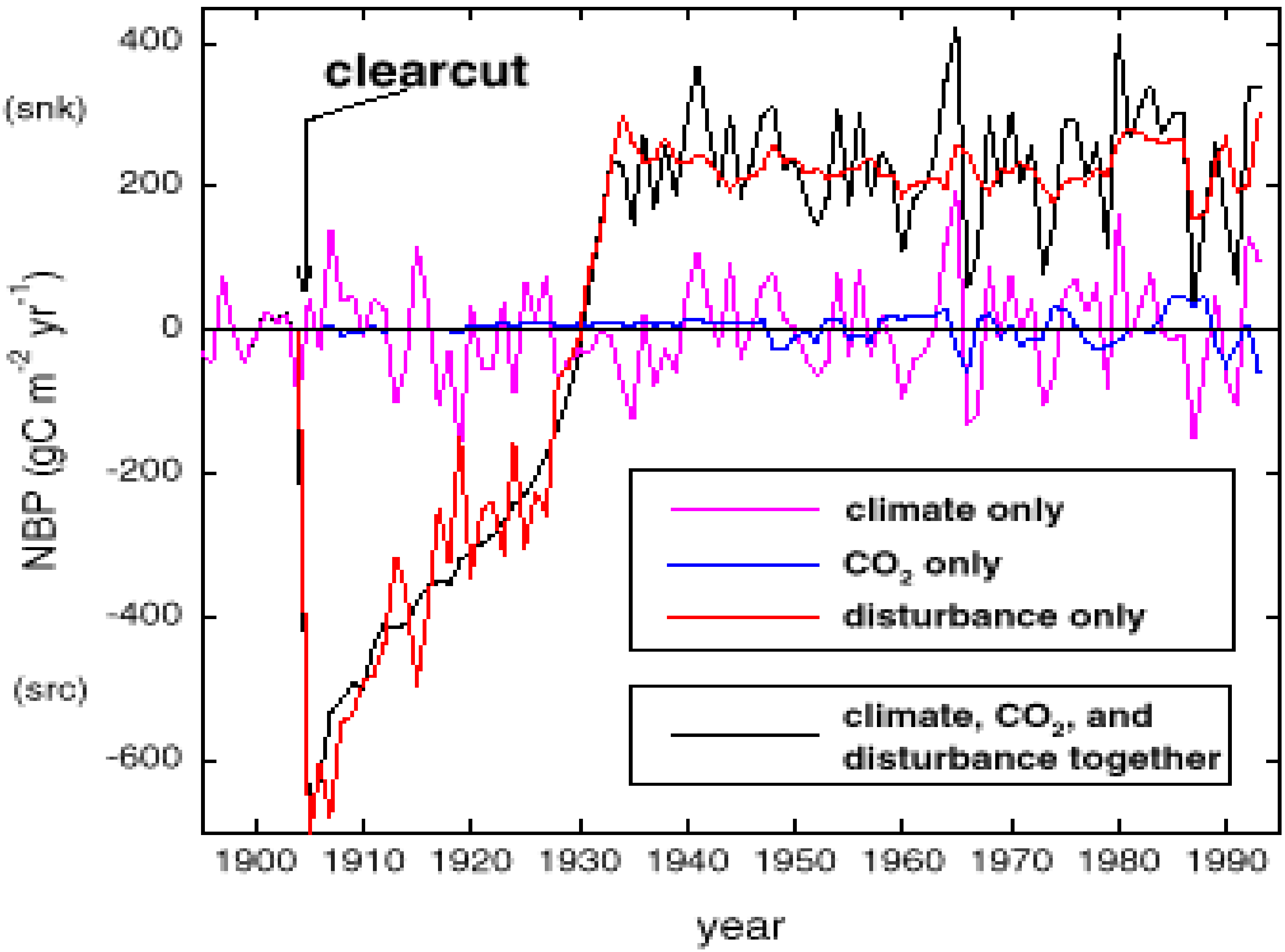
*from Junbang Wang, Inst of Geographic Sciences and Natural Resources Res, submitted to Global Change Biology*





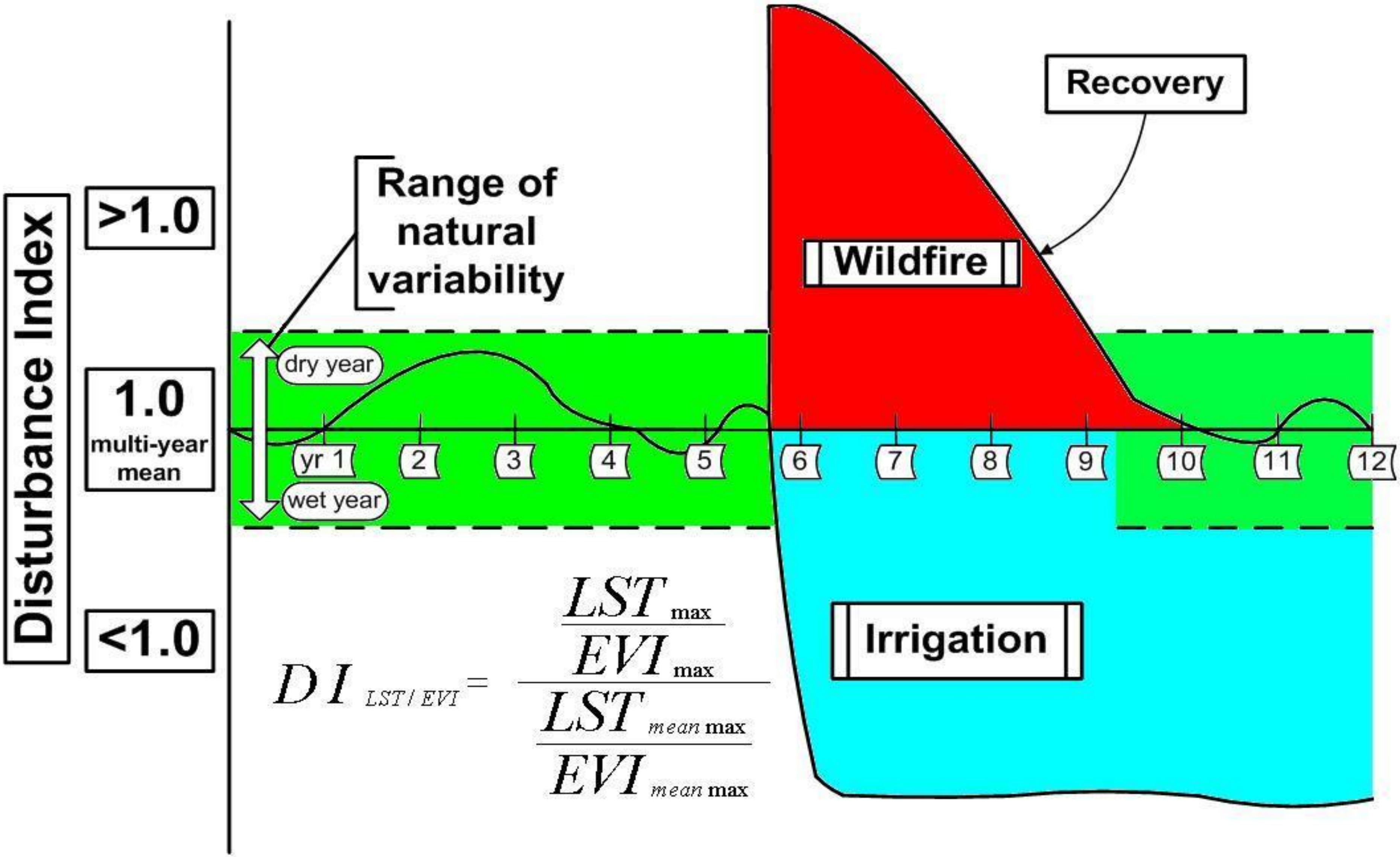
# MONITORING REDD+ POLICY (Landcover Change)

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




VEMAP II: variance due to climate and CO

# GLOBAL Generalized Disturbance Index

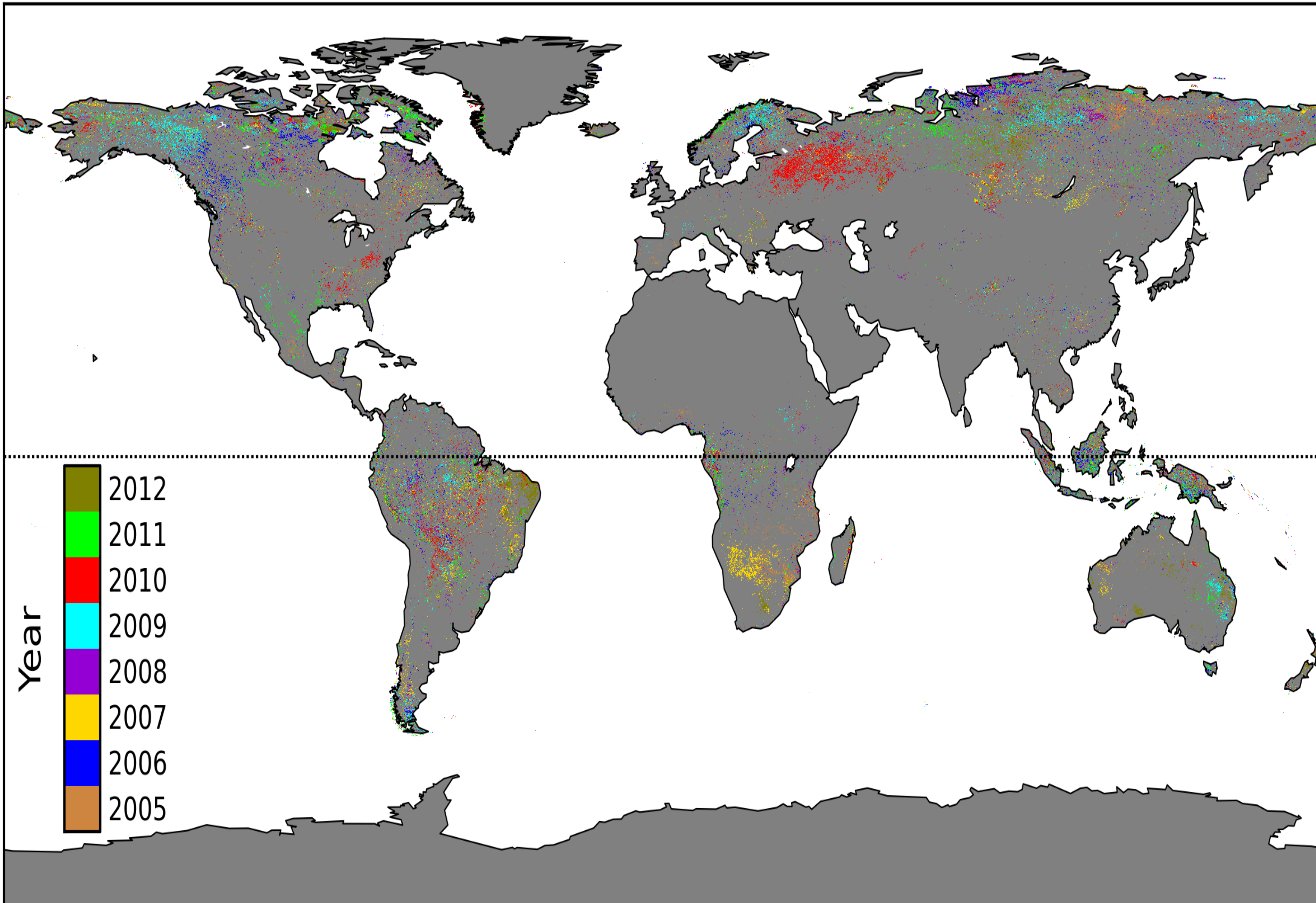



$$DI_{LST/EVI} = \frac{\frac{LST_{max}}{EVI_{max}}}{\frac{LST_{mean\,max}}{EVI_{mean\,max}}}$$

Mildrexler et al 2006

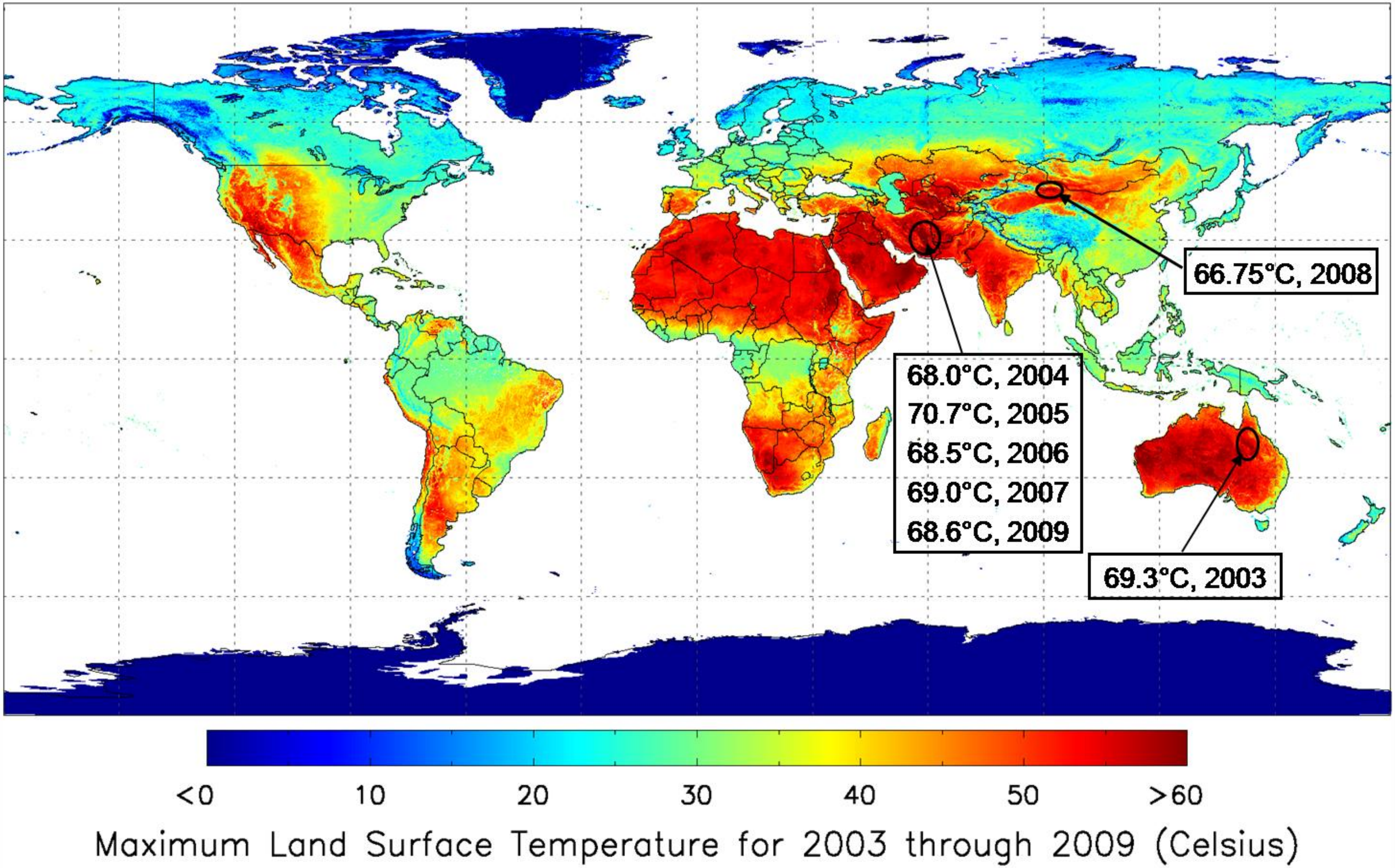
Mildrexler et al 2006

# MODIS ANNUAL DISTURBANCE




Lut Desert, Iran
70 degC
Flaming Mtn, China 2004
2004 10 13

# Aqua MODIS Maximum Annual Land Surface Temperature (2003-2009)




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

Review

CellPress

# Global satellite monitoring of climate-induced vegetation disturbances

Nate G. McDowell[1], Nicholas C. Coops[2], Pieter S.A. Beck[3], Jeffrey Q. Chambers[4], Chandana Gangodagamage[1], Jeffrey A. Hicke[5], Cho-ying Huang[6], Robert Kennedy[7], Dan J. Krofcheck[8], Marcy Litvak[8], Arjan J.H. Meddens[5], Jordan Muss[1], Robinson Negrón-Juarez[4], Changhui Peng[9], Amanda M. Schwantes[10], Jennifer J. Swenson[10], Louis J. Vernon[1], A. Park Williams[11], Chonggang Xu[1], Maosheng Zhao[12], Steve W. Running[13], and Craig D. Allen[14]



*Trends in Plant Science* February 2015, Vol. 20, No. 2

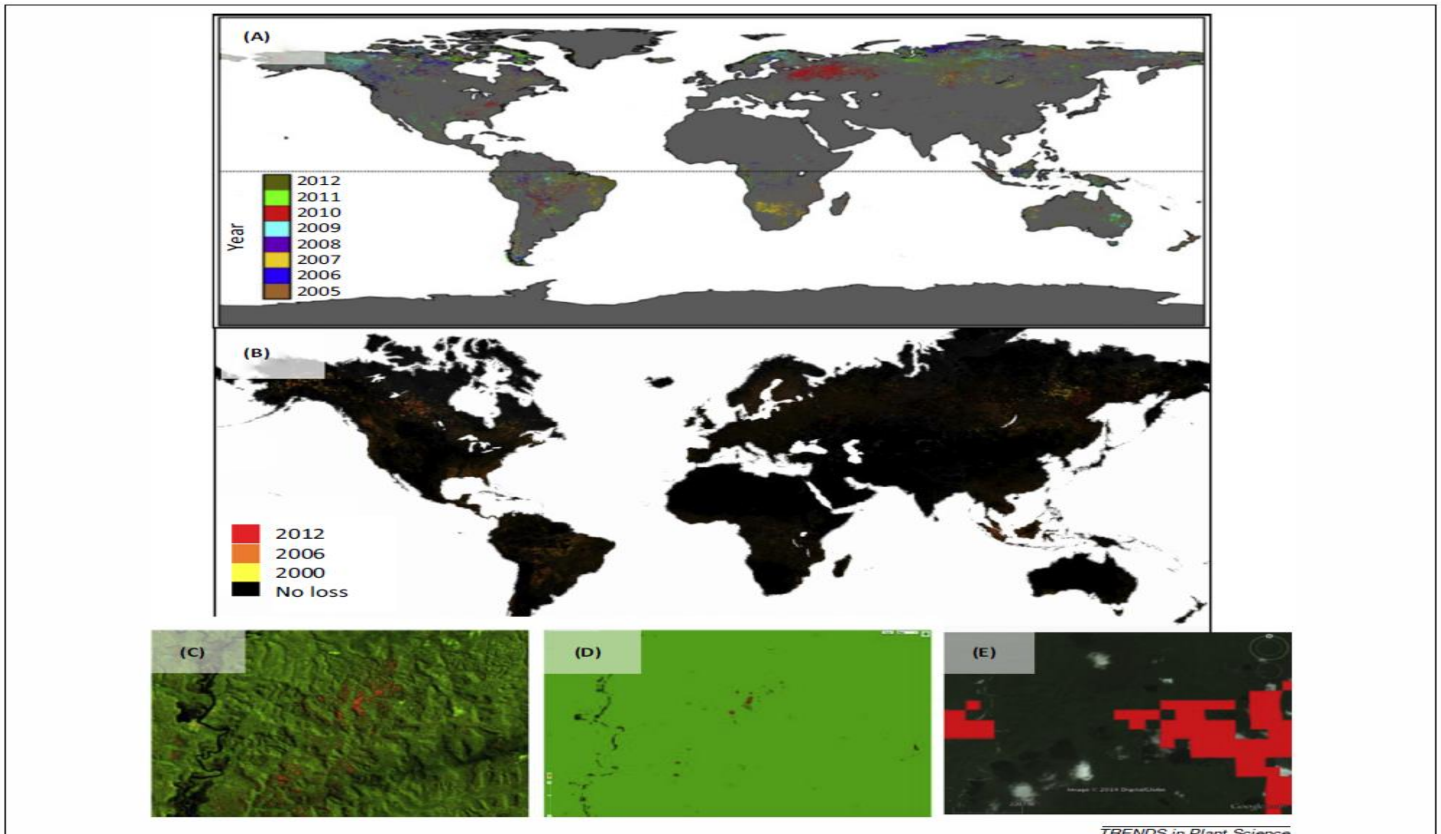
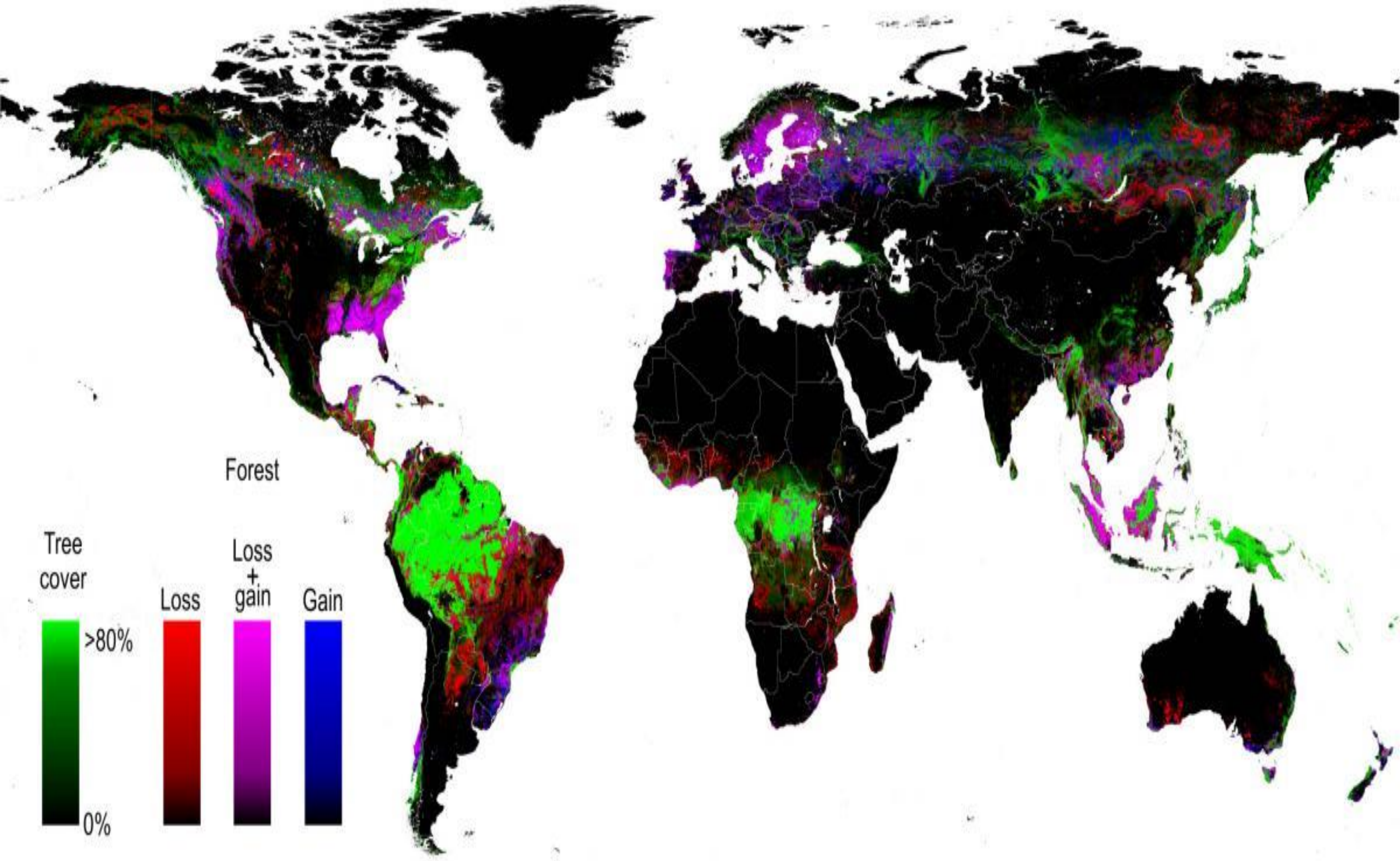



**Figure 2.** Examples of global monitoring capabilities. **(A)** The Moderate Resolution Imaging Spectrometer (MODIS) Global Disturbance Index (MGDI; 500 m), and **(B)** the Landsat-based global forest change detections (30 m). The approximate year of detection for each system is provided within each legend. Each of these maps represents major breakthroughs for the time period. In (B), Hansen *et al.* [29] provided the first user-friendly, interactive web-based tool that allowed examination of the global patterns of forest loss and gain since year 2000 via 30-m resolution Landsat analysis. **(C–E)** show a zoomed-in landscape near Manaus, Brazil. The ground-referenced data set (C) is a Landsat 5 TM scene (30-m spatial resolution) collected on July 29 2010, comprising RGB using bands 5, 4, and 3, and the disturbance is a severe storm that hit the Amazon basin on January 16–18 2005 [51]. Forest loss from [29] is shown in (D), and (E) is the MGDI. (C,D) both show results from 30-m resolution imagery (Landsat); however, (C) was improved using ground-truth data. Comparing (C) and (D) highlights that, while the new tool from [29] is a radical step forward, without ground evaluation it fails to pick up mortality at finer scales that may be a dominant component of global mortality. Nonetheless, the improvement of using 30-m resolution imagery is clear when comparing (C,D) to MGDI (E), which has a resolution of 500 m.

# Global Forest Cover Change 2000 - 2012




**Hansen, M. et al.** ***Science 2013***

SUSTAINABILITY

# Ecosystem services lost to oil and gas in North America

## Net primary production reduced in crop and rangelands

*By* **Brady W. Allred,[1*] W. Kolby Smith,[1,2] Dirac Twidwell,[3] Julia H. Haggerty,[4] Steven W. Running,[1] David E. Naugle,[1] Samuel D. Fuhlendorf[5]**

water use. Before this work, little has been done in examining these types of data and their relations with ecosystem services at broad scales.

of carbon per year, we convert to equivalent biomass-based measurements to provide context and discussion.

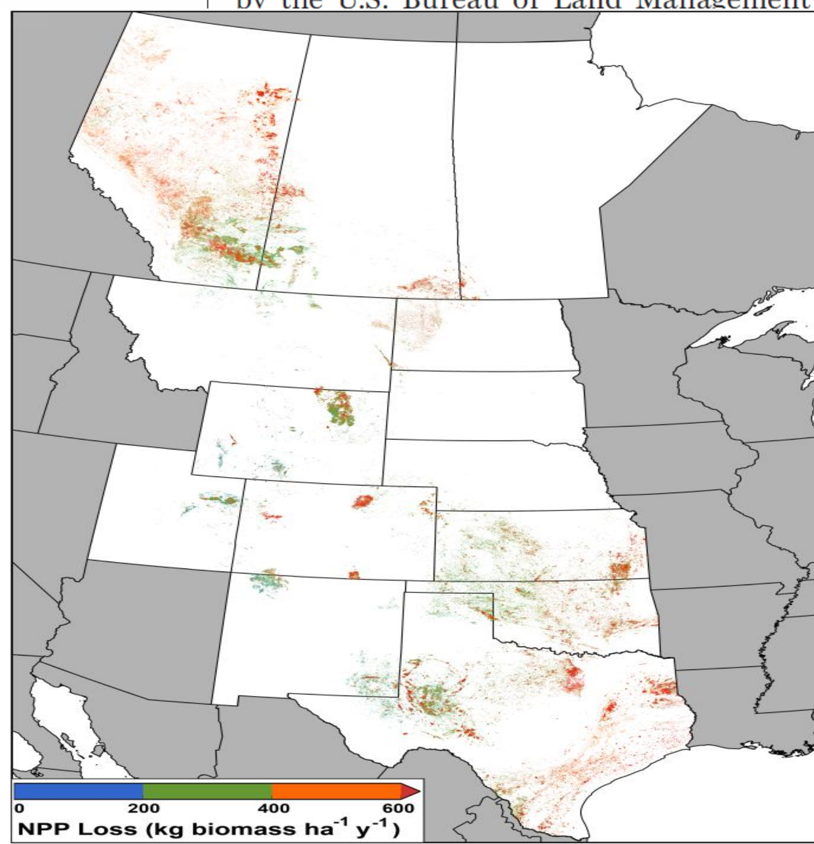
We estimate that vegetation removal by oil and gas development from 2000 to 2012 reduced NPP by ~4.5 Tg of carbon or 10 Tg of dry biomass across central North America (see the chart on page 402, left). The total amount lost in rangelands is the equivalent of approximately five million animal unit months (AUM; the amount of forage required for one animal for 1 month), which is more than half of annual available grazing on public lands managed by the U.S. Bureau of Land Management

**From 2000 – 2012**

**50,000 new wells / year**

**3 million ha land lost**

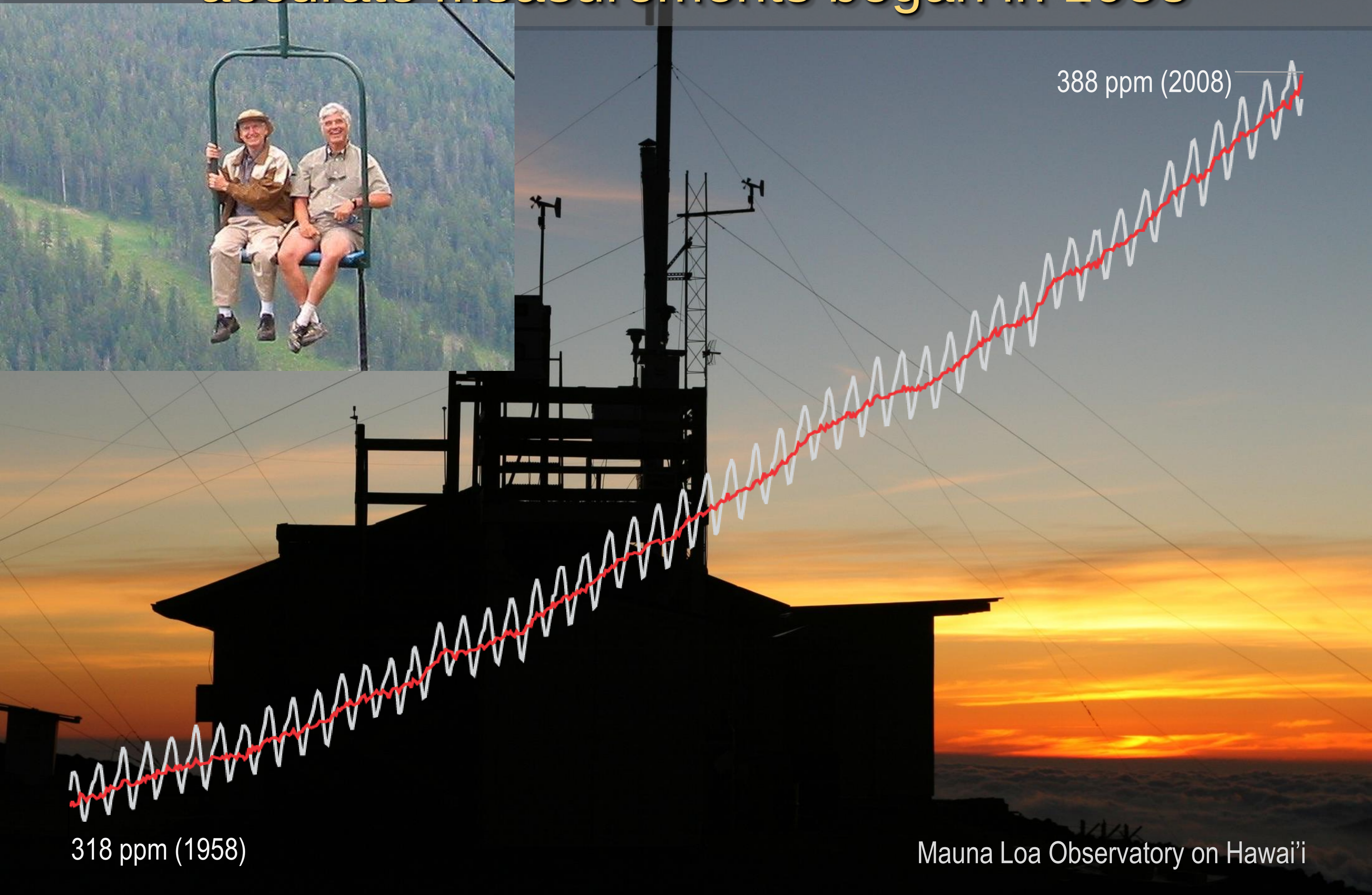
**4.5 Tg C of NPP lost / yr**

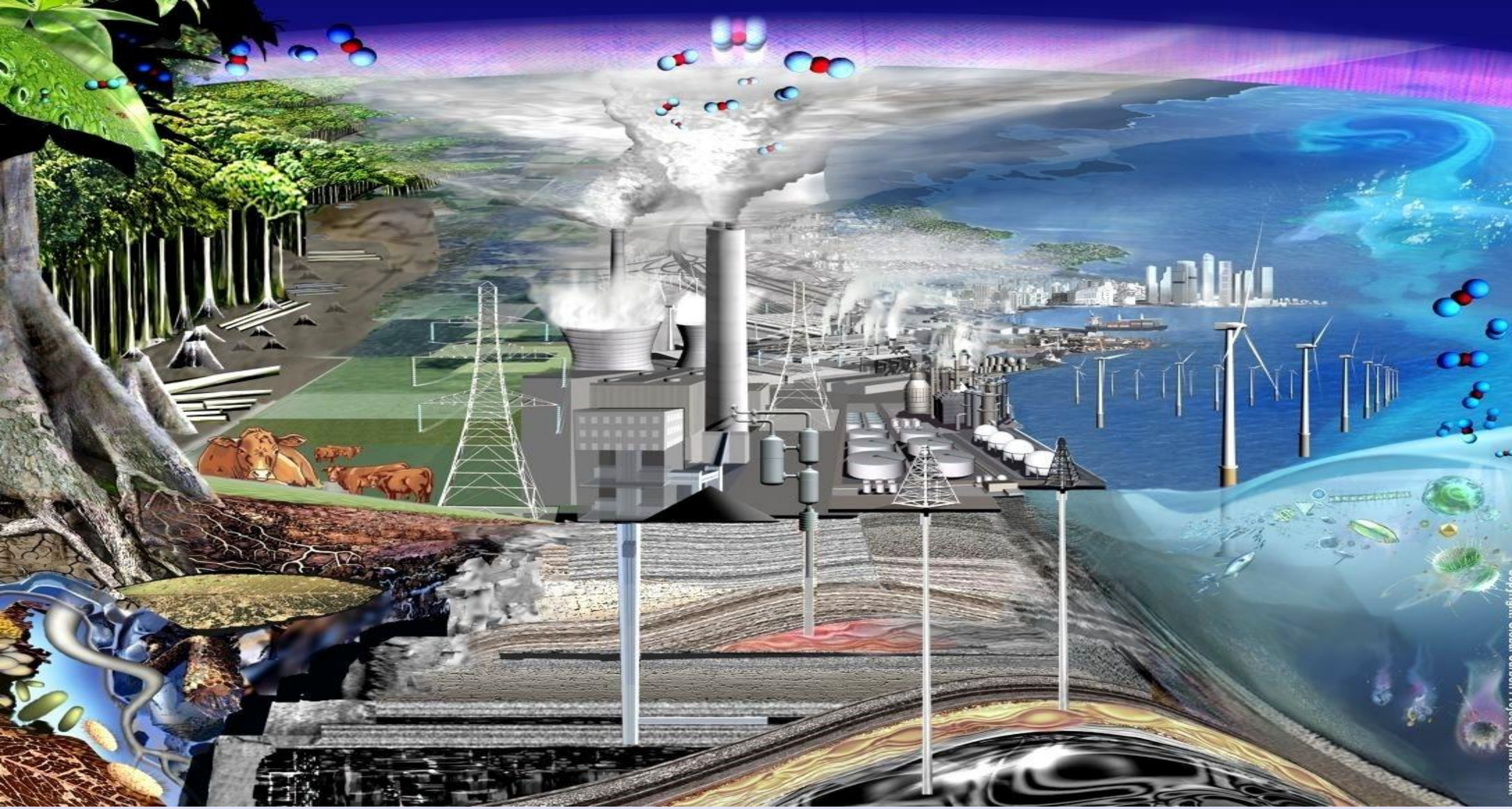





Published by AAAS

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



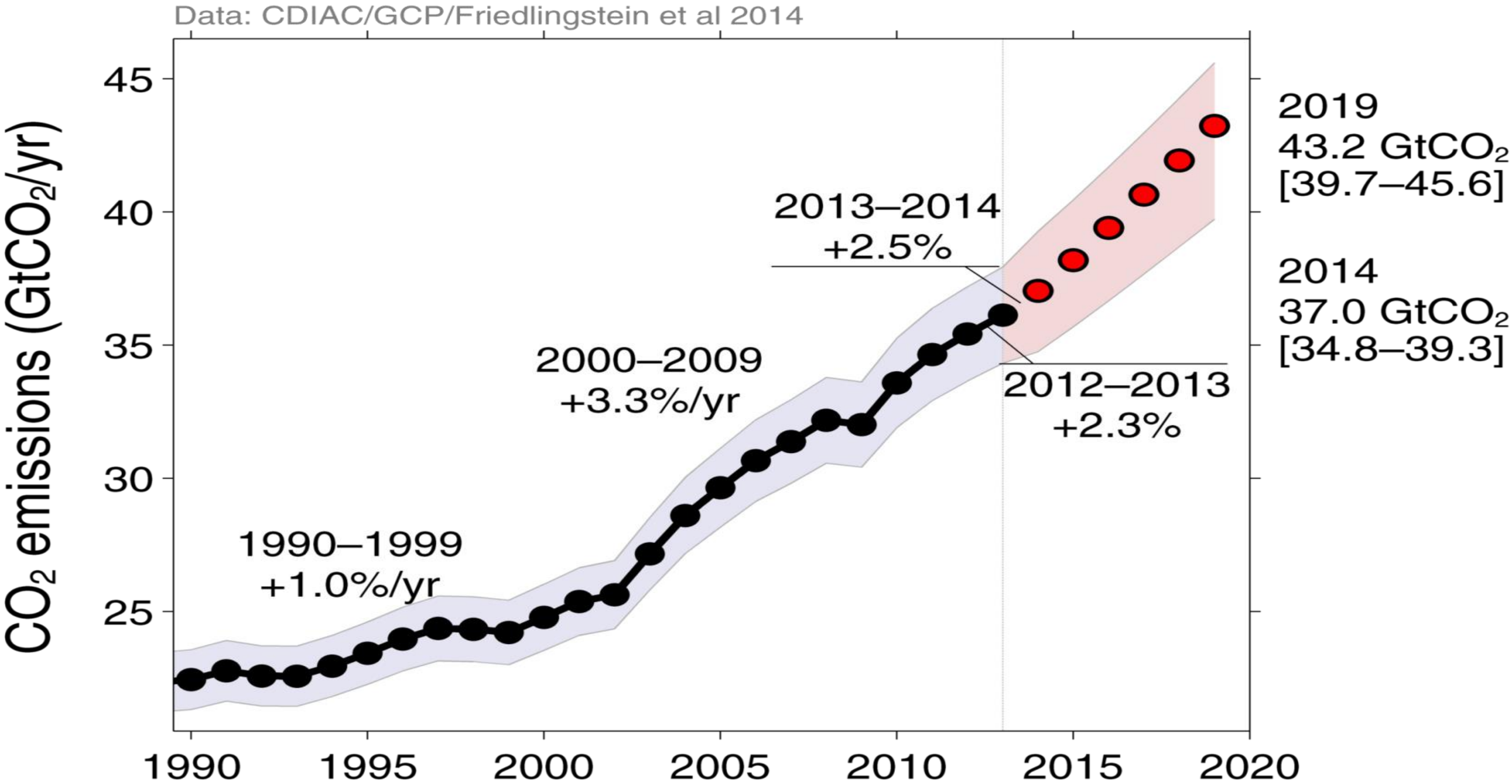


*“The rise in $CO_2$ is proceeding so slowly that most of us today will, very likely, live out our lives without perceiving that a problem may exist”*

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

# Persistent Growth – Global

**Assuming emissions follow projected GDP growth and accounting for improvement in carbon intensity, we project fossil fuel and cement emissions to grow 3.1%/yr to reach 43.2 $GtCO_2$/yr by 2019**




Economic growth based on IMF projections, fossil fuel intensity based on 10-year trend

Source: CDIAC; Friedlingstein et al 2014

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

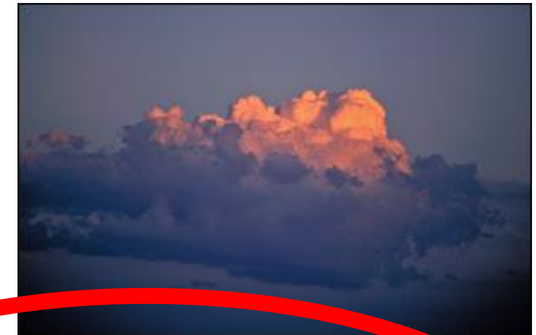
7.7±0.5 PgC $y^{-1}$

+

1.1±0.7 PgC $y^{-1}$

4.1±0.1 PgC $y^{-1}$

47%



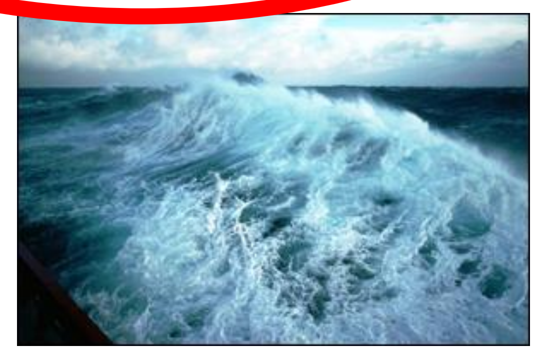
2.4 PgC $y^{-1}$

27%

Calculated as the residual

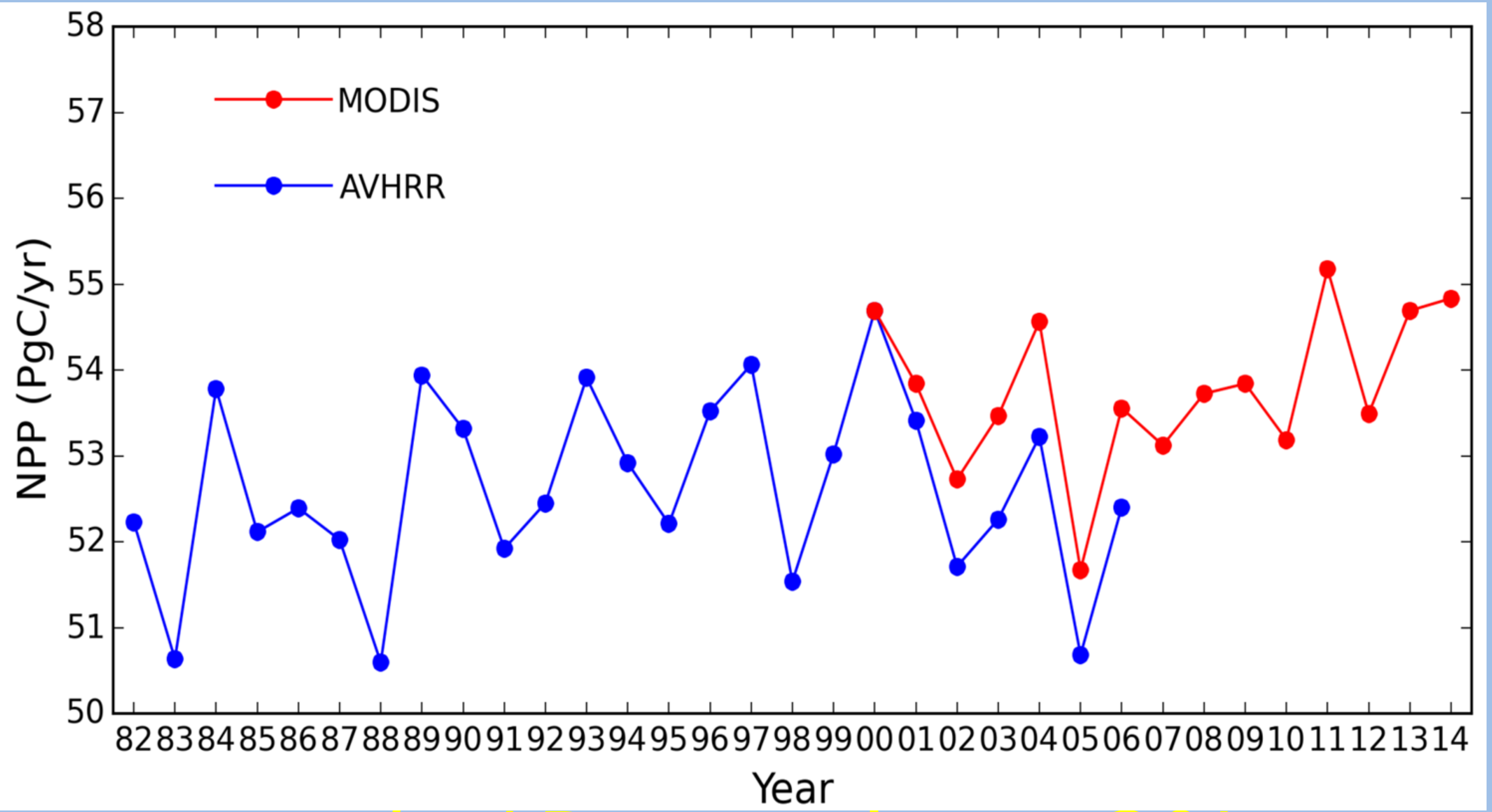
26%

2.3±0.4 PgC $y^{-1}$



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

# Global Terrestrial Net Primary Production (1982-2014)



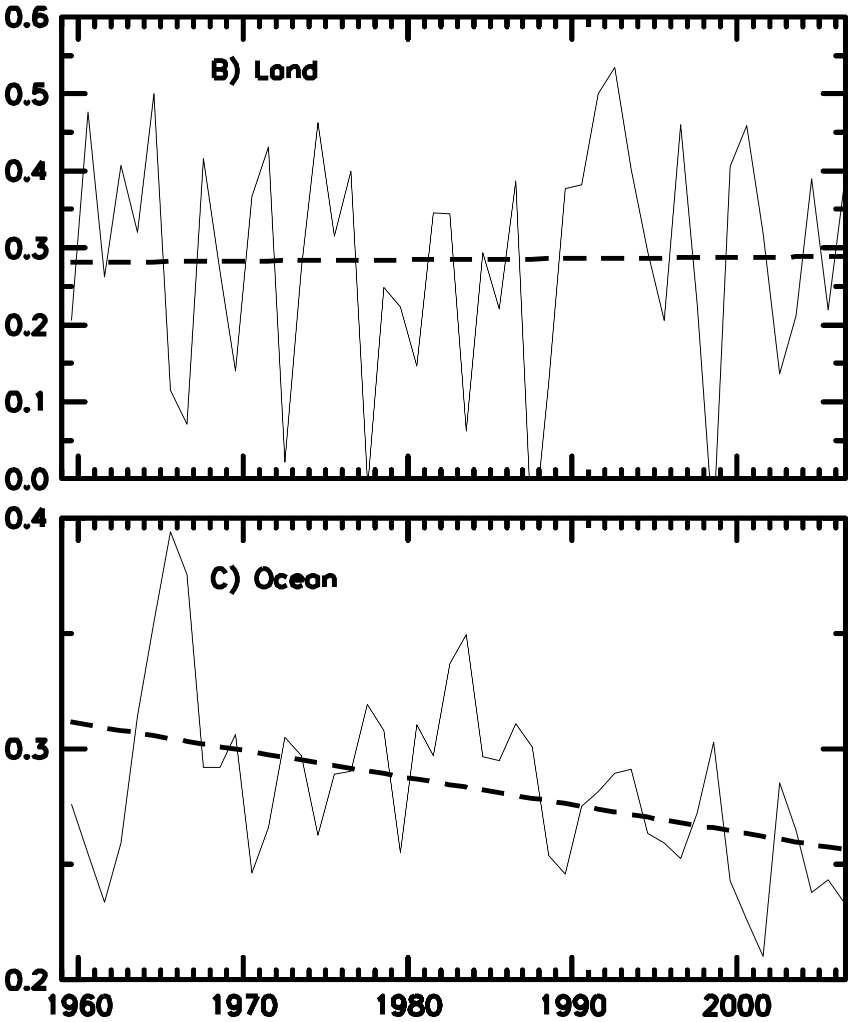

+/- 1Pg or about 2%

Nemani et al 2003, Zhao and Running 2010

# Efficiency of Natural Sinks

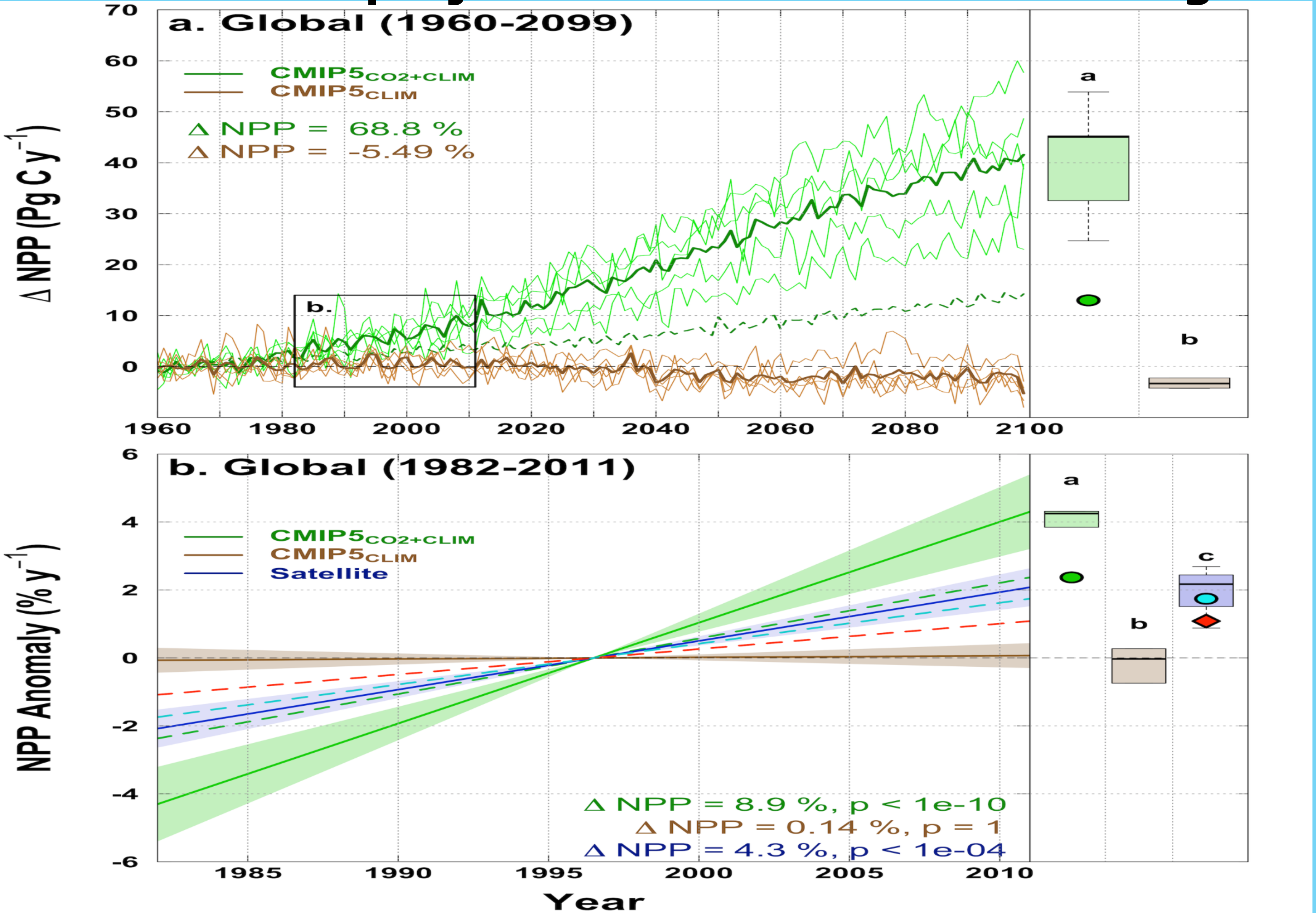
## Land Fraction

## Ocean Fraction




Canadell et al. 2007, PNAS

# CMIP5 projections of NPP are too strong




Smith et al 2015 Nature Climate Change, (in press)

# IS OUR CURRENT CONSUMPTION OF Biospheric NPP Sustainable*?

***Meeting needs and values of today's generation, while preserving the planet's life-support systems for the needs and values of future generations.**

# CROP YIELDS WILL NOT KEEP UP WITH POPULATION GROWTH to 2050

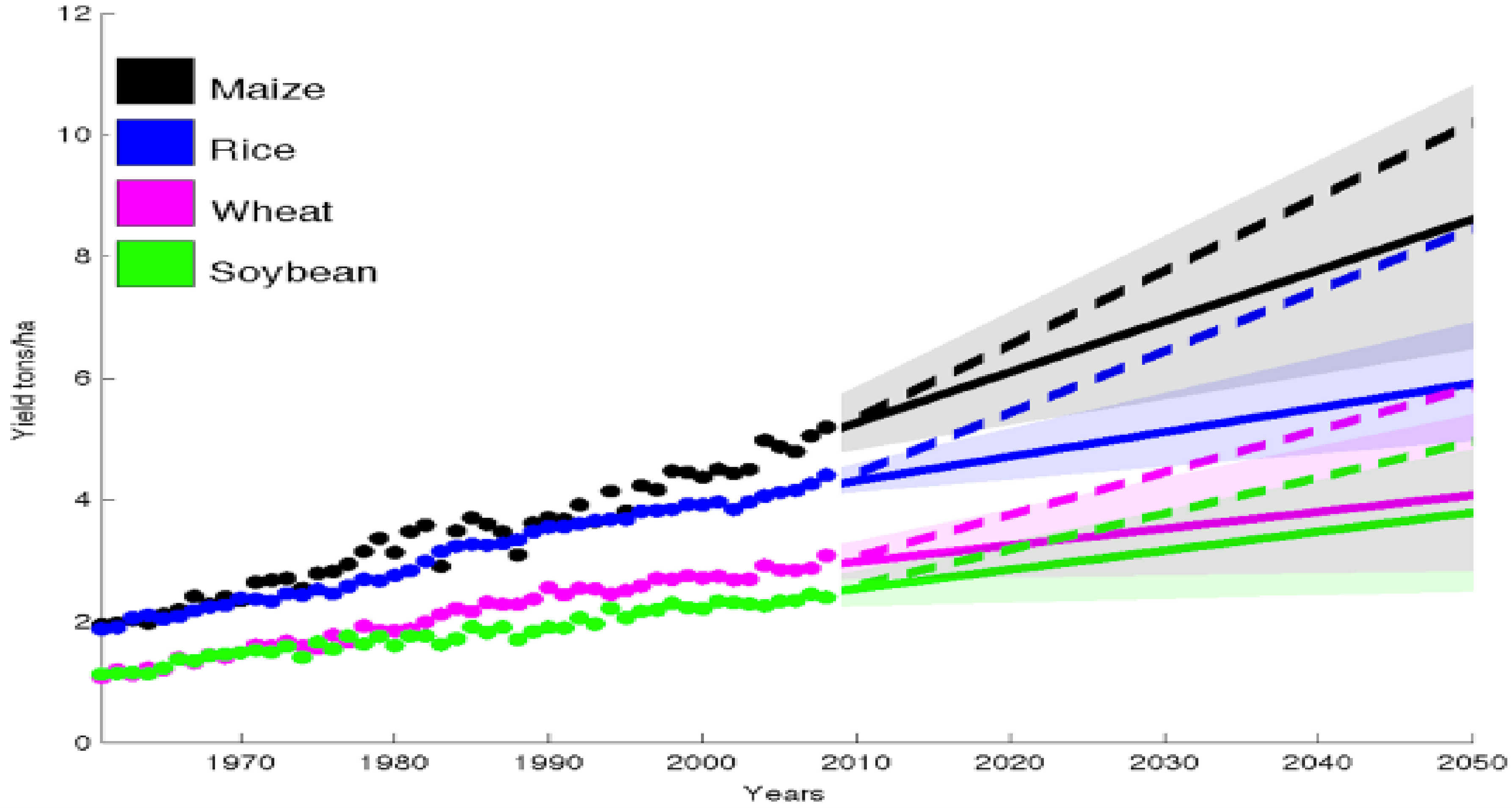
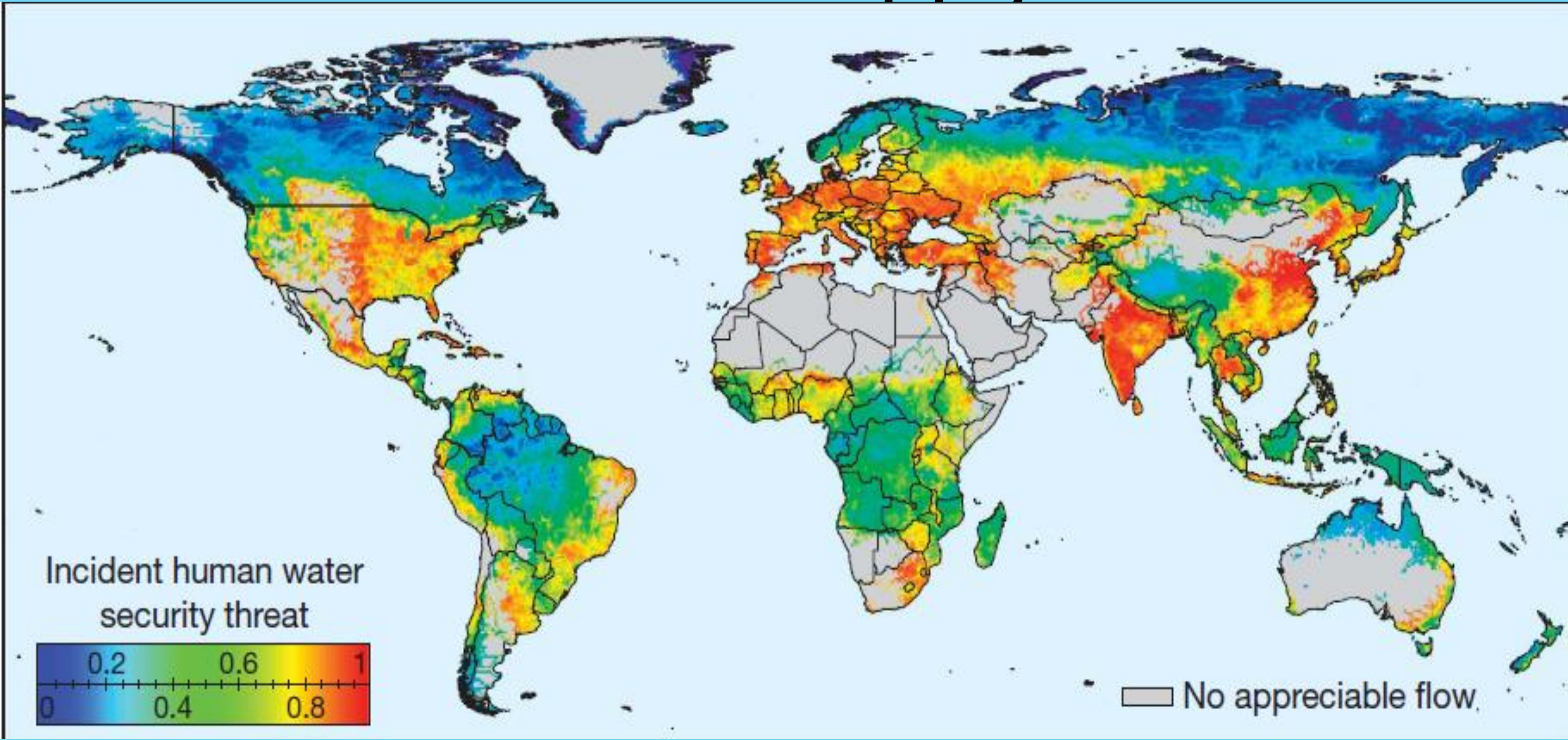



**Figure 1. Global projections.** Observed area-weighted global yield 1961–2008 shown using closed circle for maize, rice, wheat, and soybean. Shading shows the 90% confidence region derived from 99 bootstrap trend of the ~2.4% yield improvement required each year to double production in these crops by 2050 cultivation starting in the base year of 2008.

D.K. Ray et al PlosOne 2013

# Global Water Supply Threat



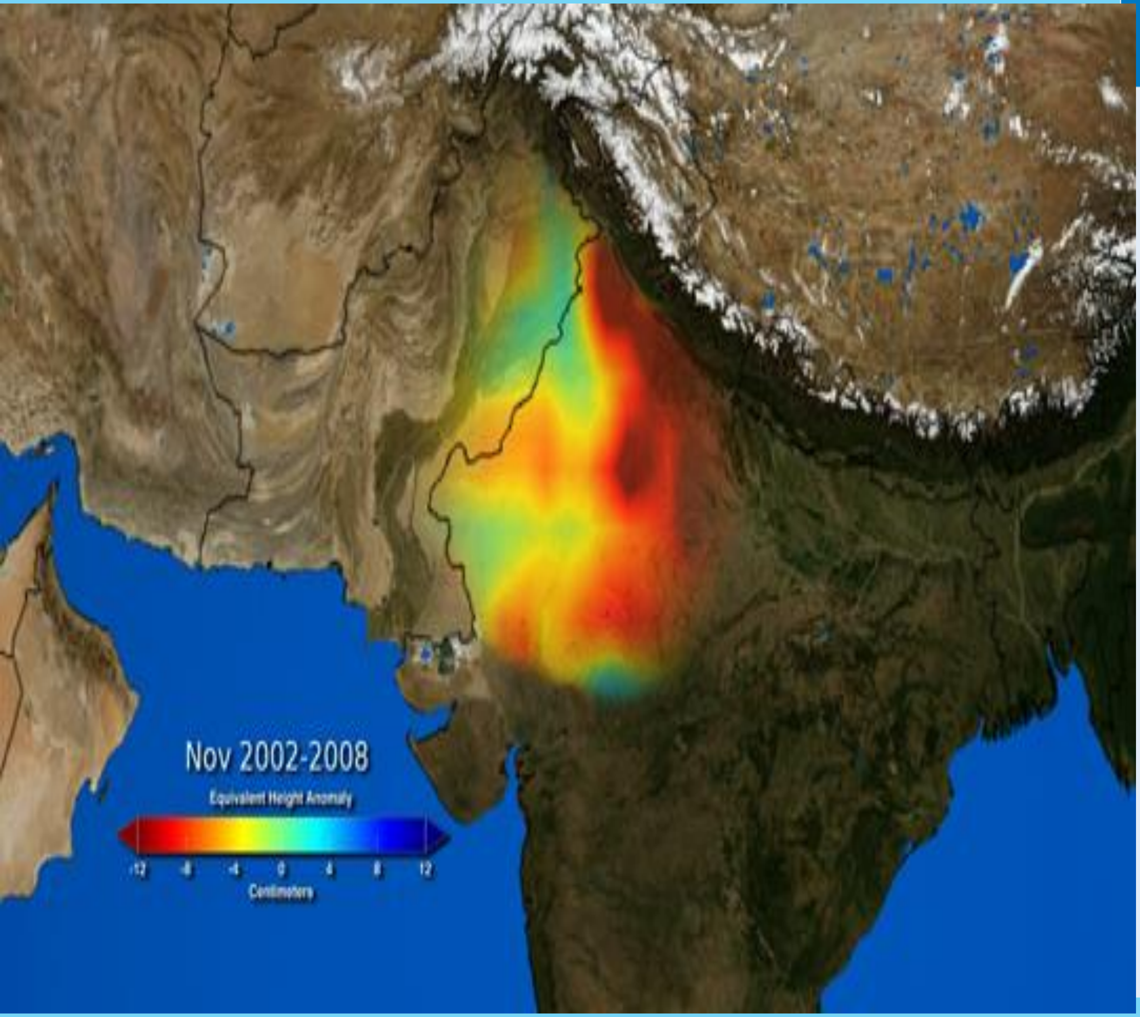

**Vorosmarty et al *Nature* 2010**

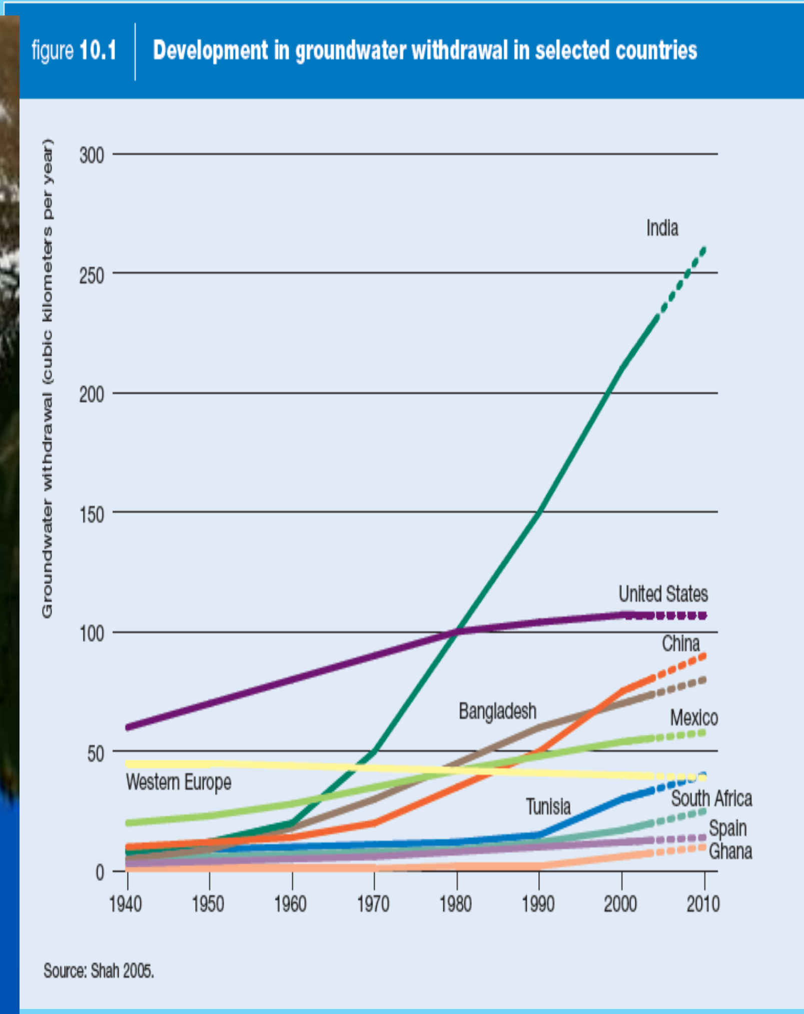
*The global percentage of dry areas has increased by about 1.74% (of global land area) per decade (11%) from 1950 to 2008*

*Aiguo Dai, J Geophysical Res 2011*

# Unsustainable groundwater withdrawal

**Depletion rate 4cm/yr**




**Groundwater withdrawals as % of recharge, 2002-2008.**
**Rodell et al Nature 2009**


# A REMOTELY SENSED GLOBAL TERRESTRIAL DROUGHT SEVERITY INDEX

y Qiaozhen Mu, Maosheng Zhao, John S. Kimball, Nathan G. McDowell, and Steven W. Running

A new global index uses operational satellite remote sensing as primary inputs and enhances near real-time drought monitoring and mitigation efforts.

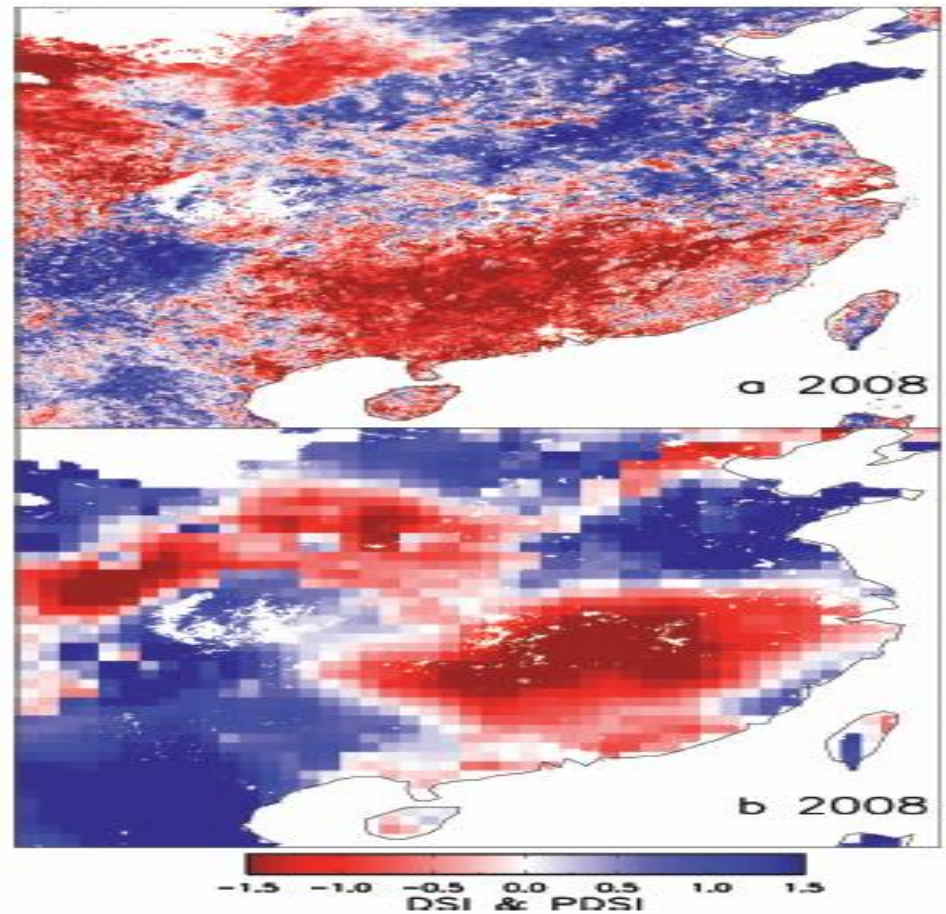
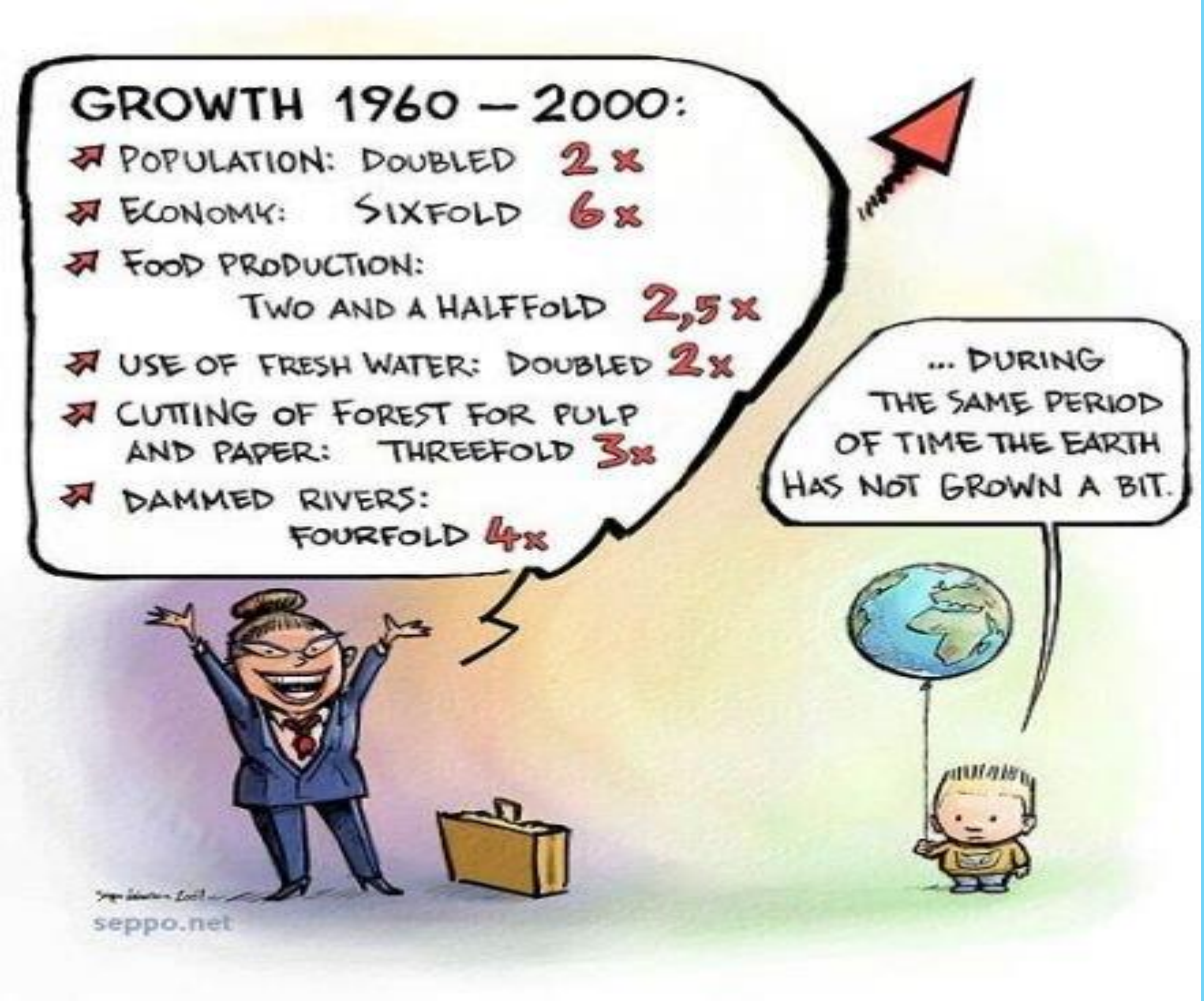
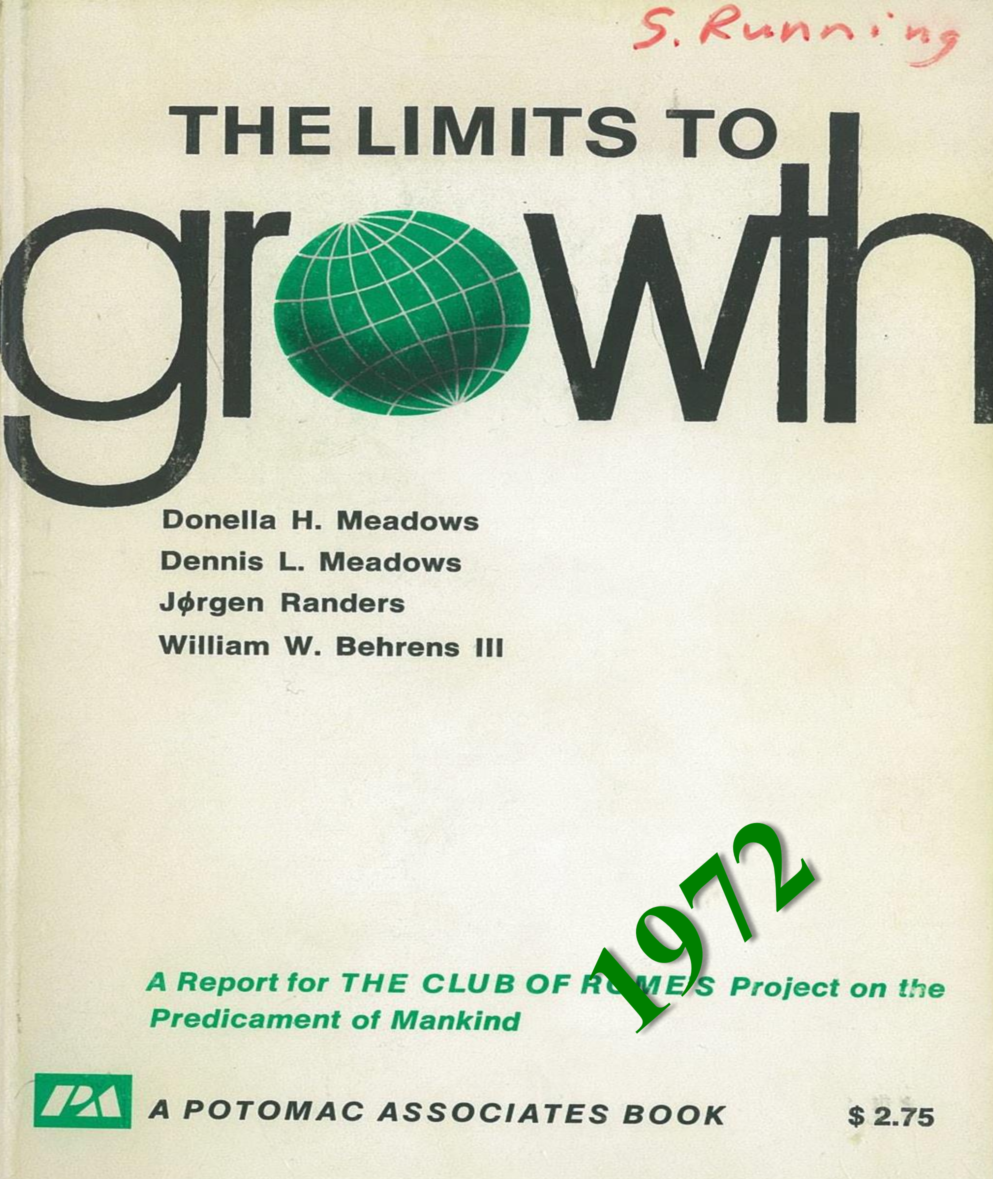



Fig. 5. Spatial patterns of (a) annual DSI and (b) growing-season PDSI over southern China (17.8°–40.8°N, 100°–123°E) in 2008.


GROWTH 1960 — 2000:
POPULATION: DOUBLED 2x
ECONOMY: SIXFOLD 6x
FOOD PRODUCTION: TWO AND A HALFFOLD 2,5x
USE OF FRESH WATER: DOUBLED 2x
CUTTING OF FOREST FOR PULP AND PAPER: THREEFOLD 3x
DAMMED RIVERS: FOURFOLD 4x
... DURING THE SAME PERIOD OF TIME THE EARTH HAS NOT GROWN A BIT.
seppo.net




# Human Appropriation of the Products of Photosynthesis

*Nearly 40% of potential terrestrial net primary productivity is used directly, co-opted, or foregone because of human activities*

Peter M. Vitousek, Paul R. Ehrlich, Anne H. Ehrlich, and Pamela A. Matson

# Human Domination of Earth's Ecosystems

Peter M. Vitousek, Harold A. Mooney, Jane Lubchenco, Jerry M. Melillo

OPEN ACCESS
IOP Publishing

Environmental Research Letters

Environ. Res. Lett. 9 (2014) 111003 (3pp)

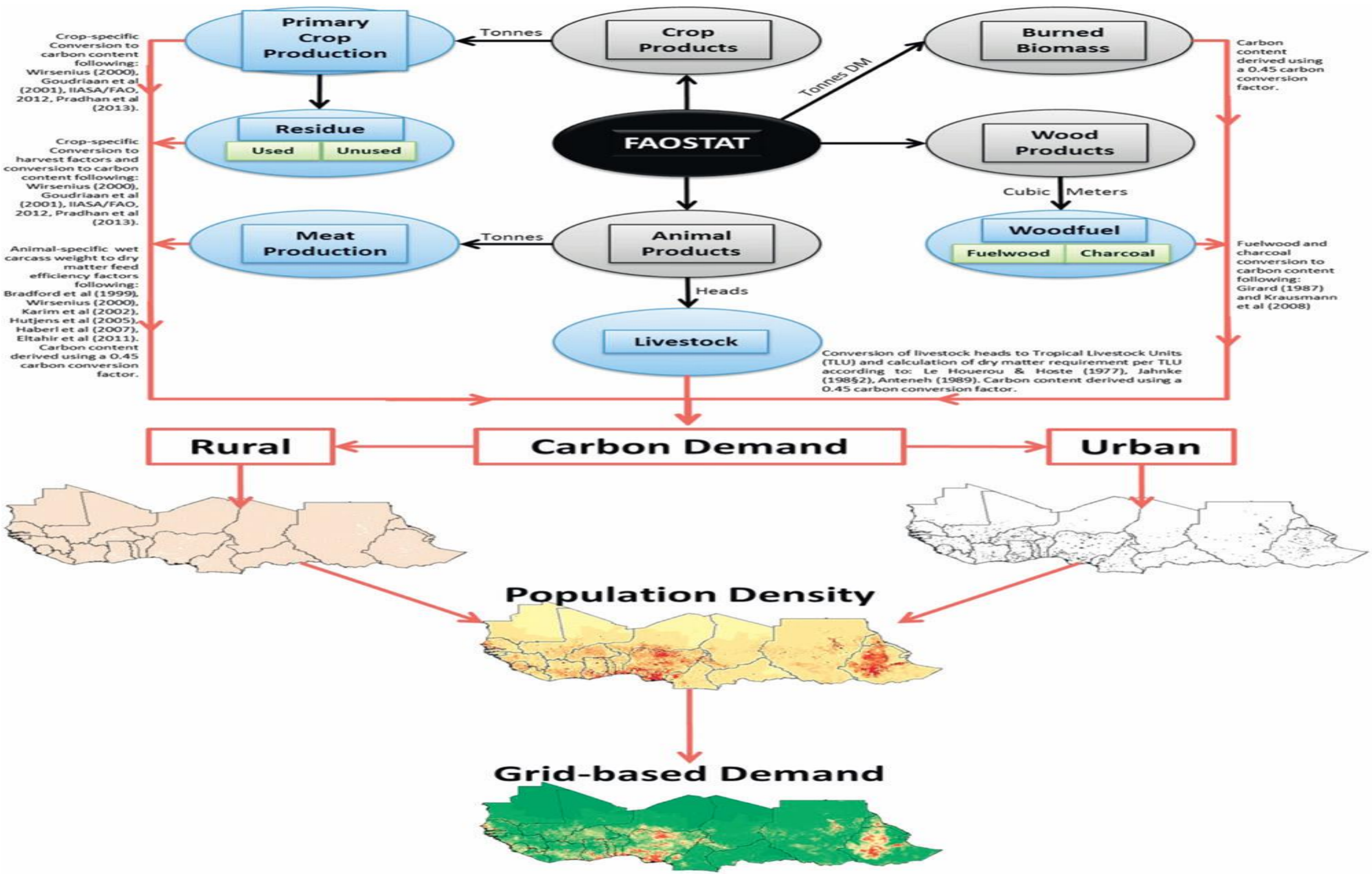
doi:10.1088/1748-9326/9/11/111003

Perspective

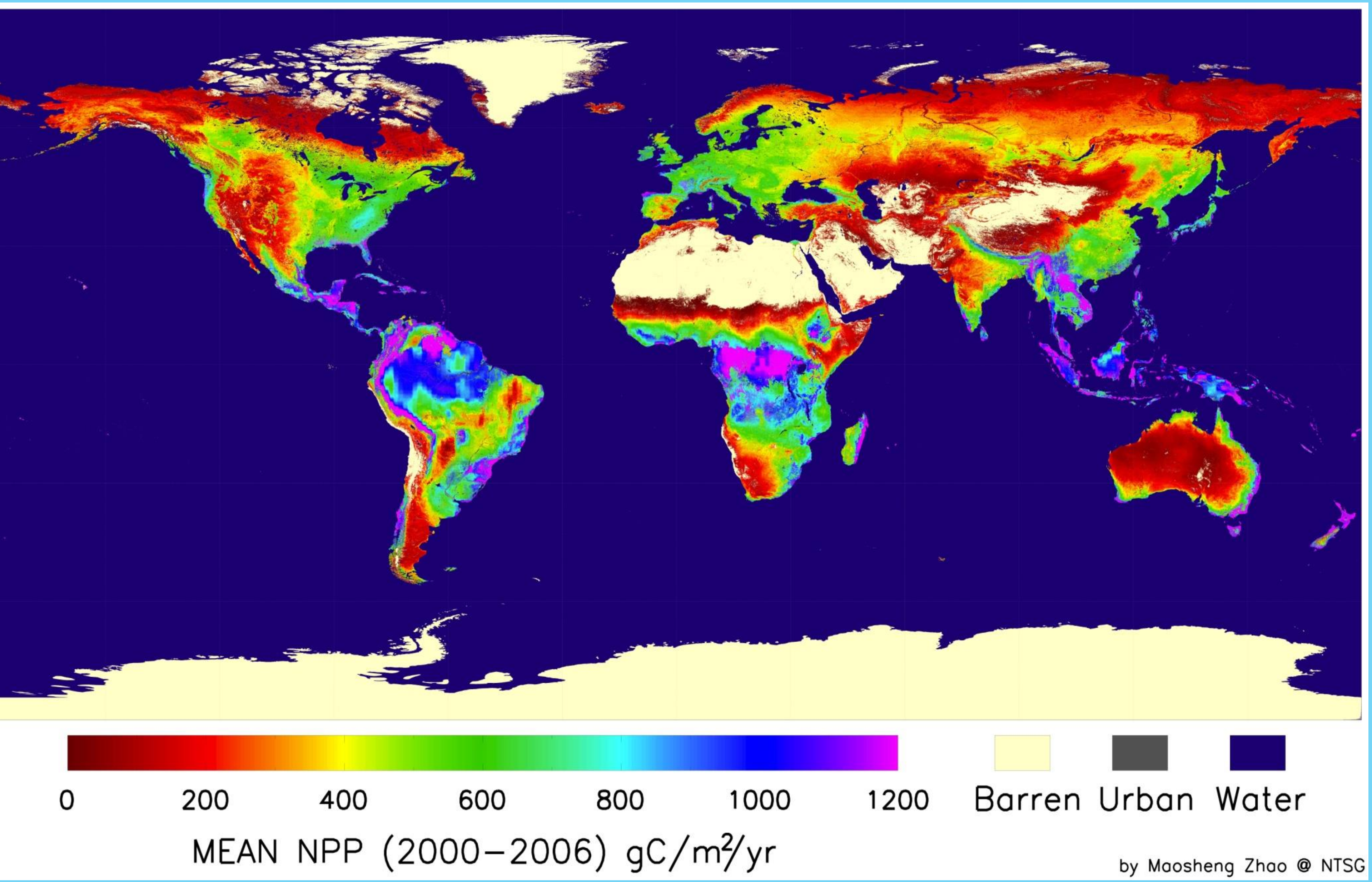
# A regional look at HANPP: human consumption is increasing, NPP is not

**Steven W Running**
*Numerical Terradynamic Simulation Group, University of Montana, Missoula Montana USA 59812*

**Abstract**
Abdi *et al* (2014 *Environ. Res. Lett.* **9** 094003), have adapted the concept of comparing supply and demand of annual plant production known as human appropriation of net primary production (HANPP) to a region of the Sahel with rapid population growth. They found that HANPP more than doubled over the study period of 2000–2010, from 19% to 41%, suggesting increasing vulnerability of these populations to food insecurity.



# Terrestrial NPP = Planetary Boundary??




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

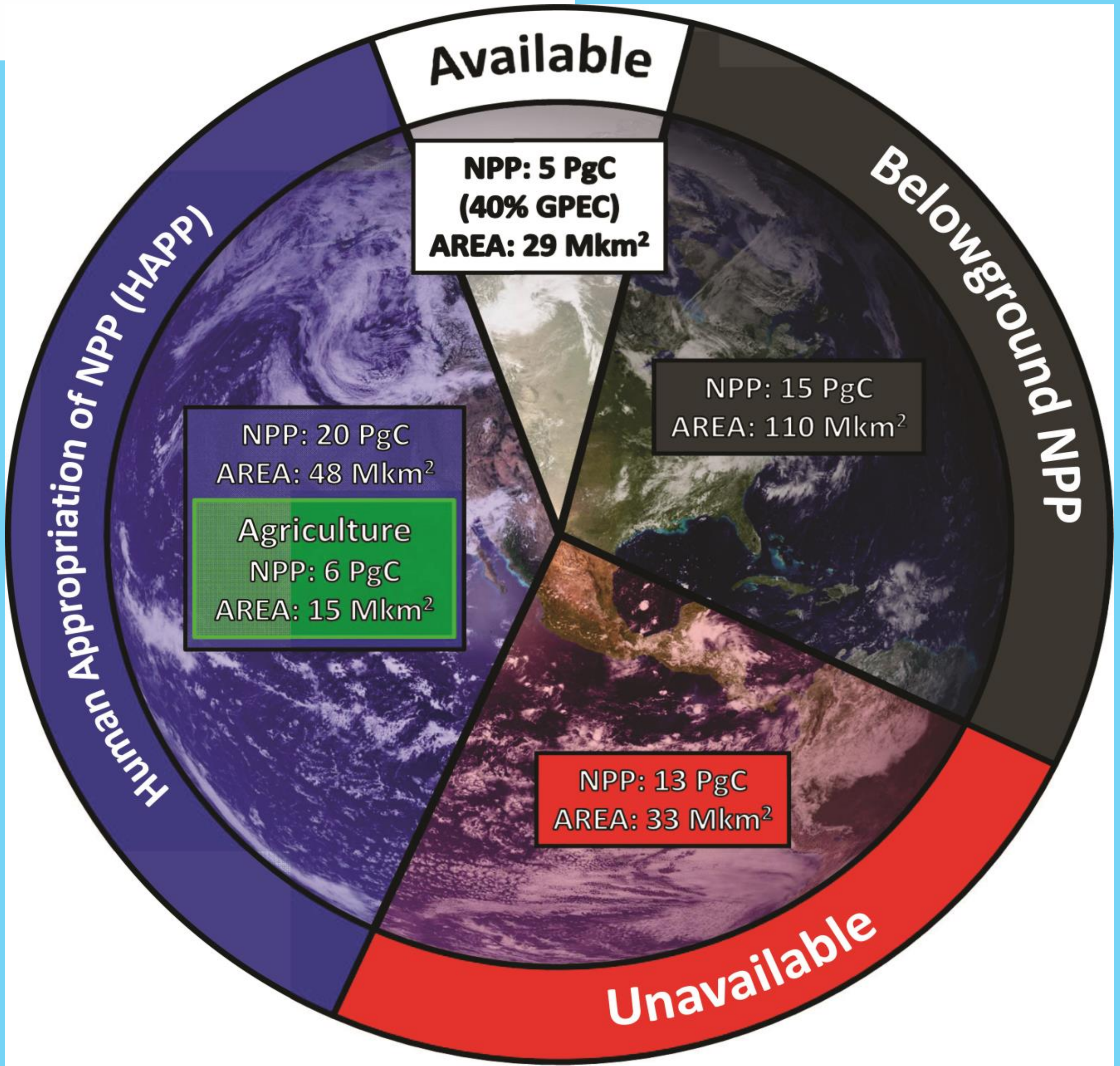
From Running, SW. *Science* 337 p1458-1459, 2012

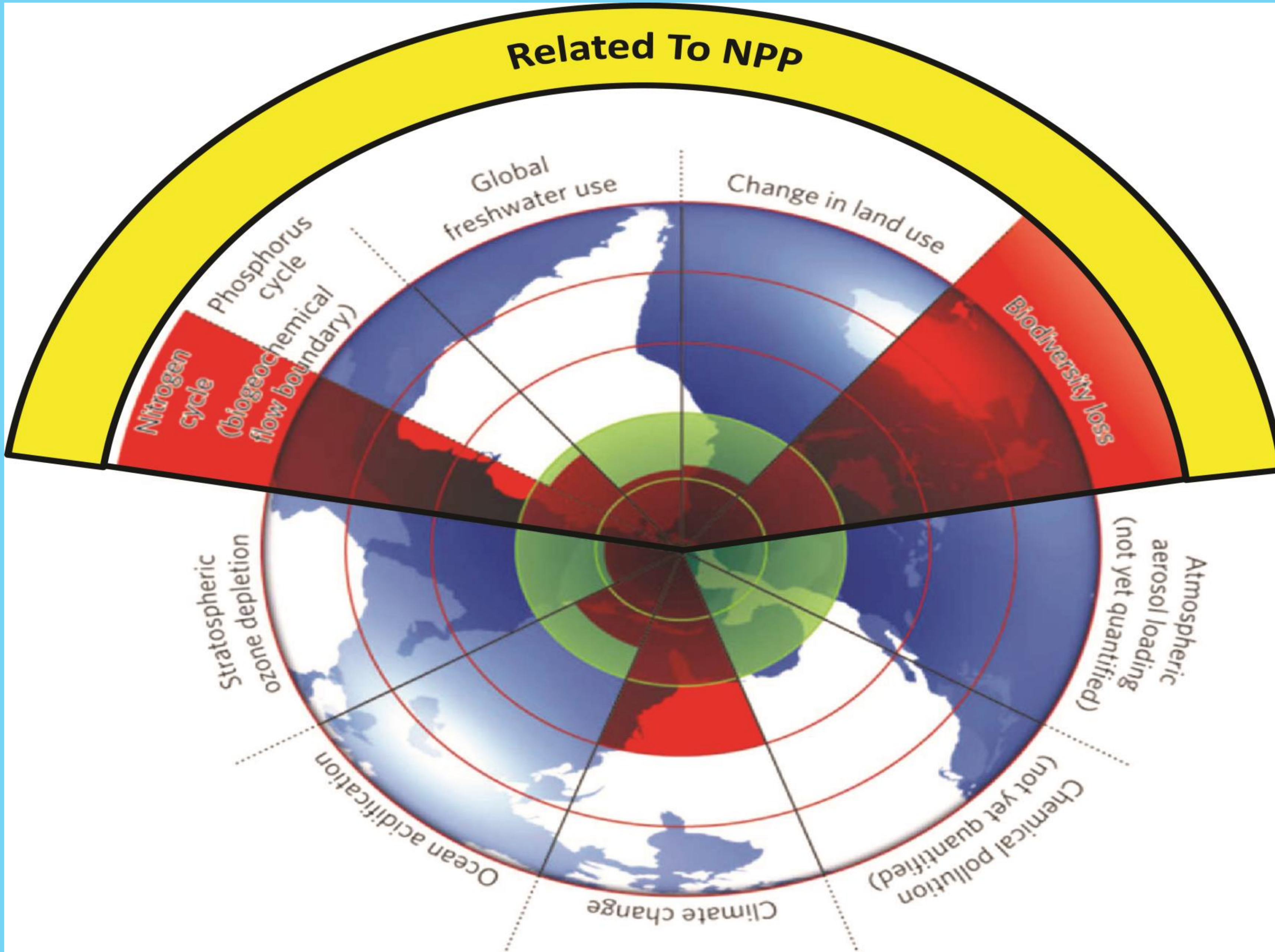
ECOLOGY

# A Measurable Planetary Boundary for the Biosphere

Terrestrial net primary (plant) production provides a measurable boundary for human consumption of Earth's biological resources.

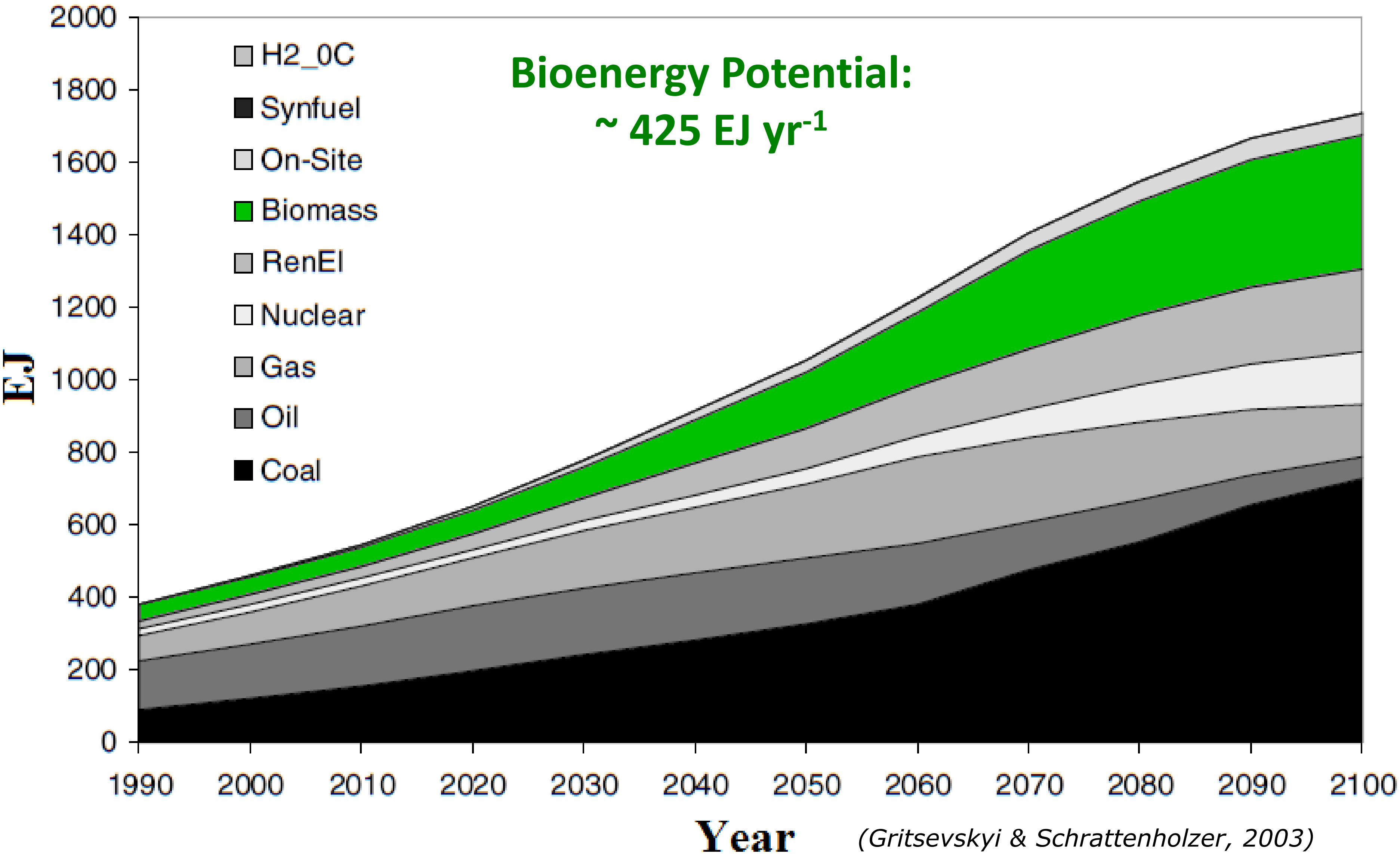
Steven W. Running





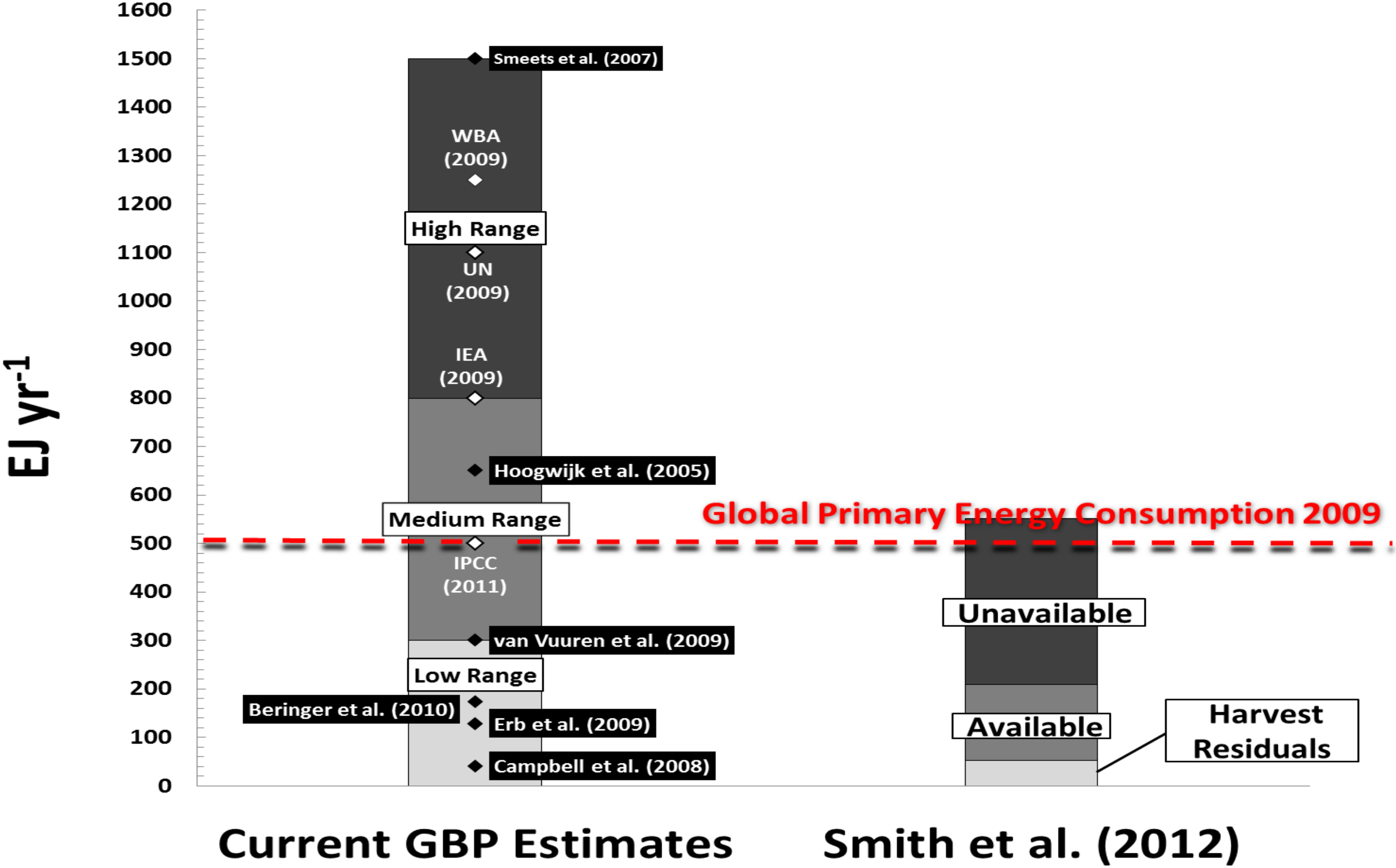

Planetary Boundaries, Rockstrom et al 2009, NATURE, Steffen et al 2015 SCIENCE

# Future Bioenergy Potential (estimated by economists)



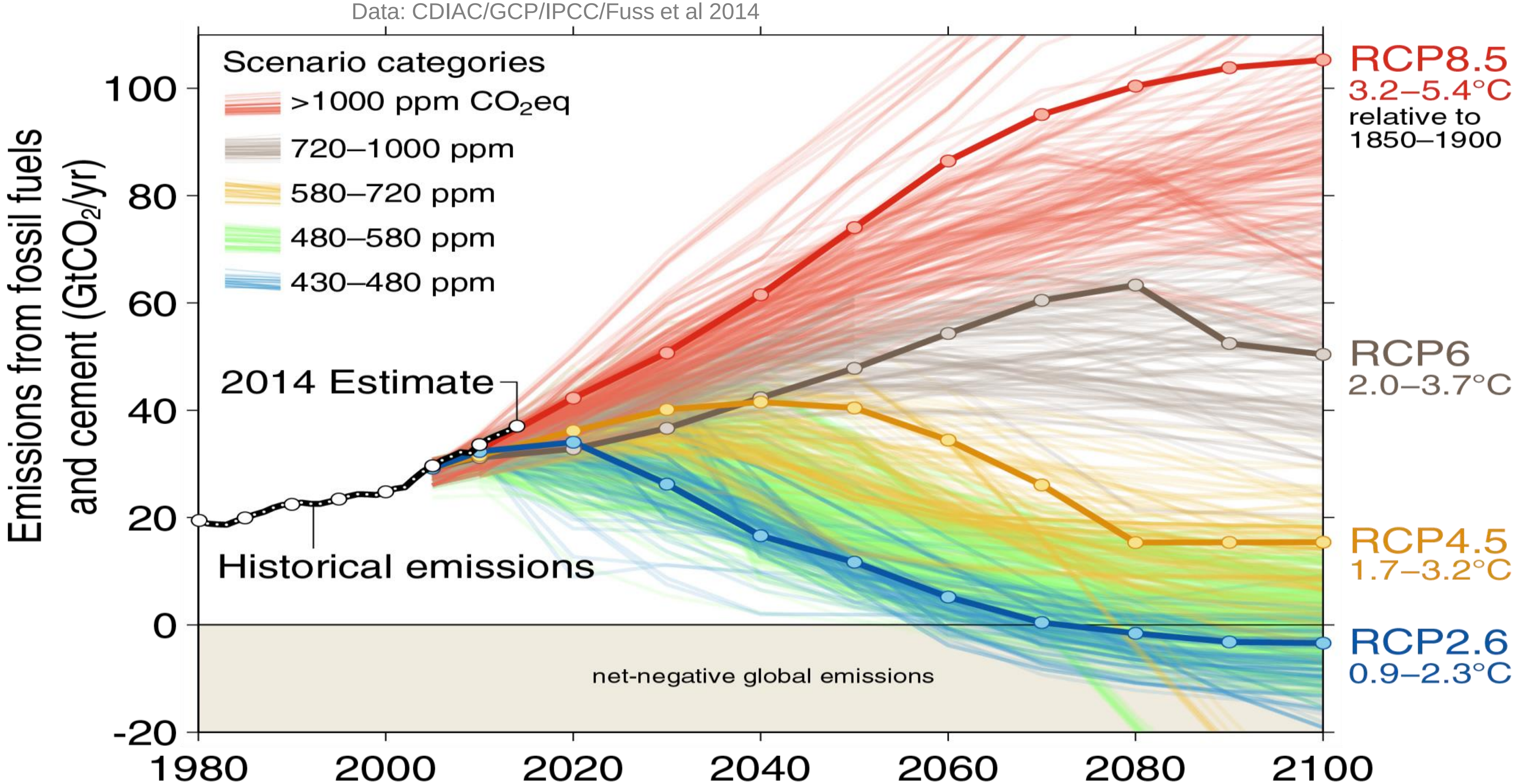

(Gritsevskyi & Schrattenholzer, 2003)

# Capacity for Bioenergy Production (estimated by ecologists)



# Observed Emissions and Emissions Scenarios

**Our knowledge, modeling and monitoring is now good enough for policy**




Over 1000 scenarios from the IPCC Fifth Assessment Report are shown

Source: Fuss et al 2014; CDIAC; Global Carbon Budget 2014

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

# WE BETTER NOT SCREW THIS PLANET UP