The Role of the Terrestrial Biosphere in global climate and carbon cycles

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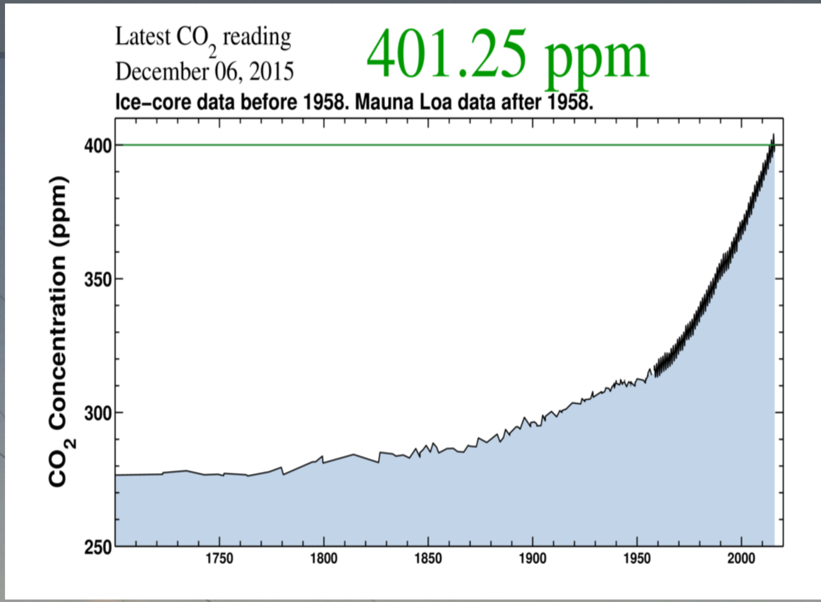
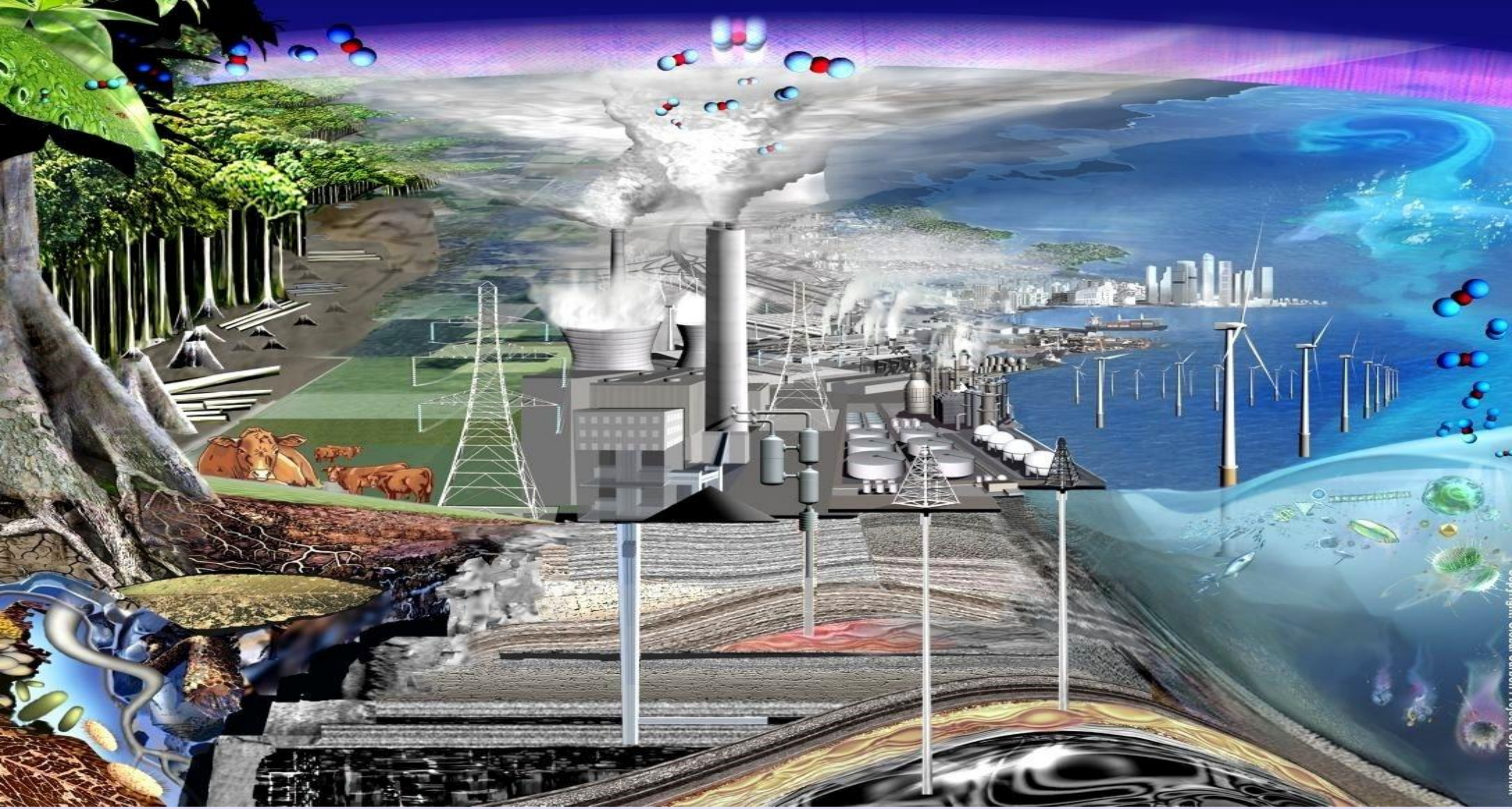
NASA NAC Science Committee
March 10, 2016

Carbon dioxide has risen by 38% since preindustrial



Mauna Loa Observatory on Hawai’i



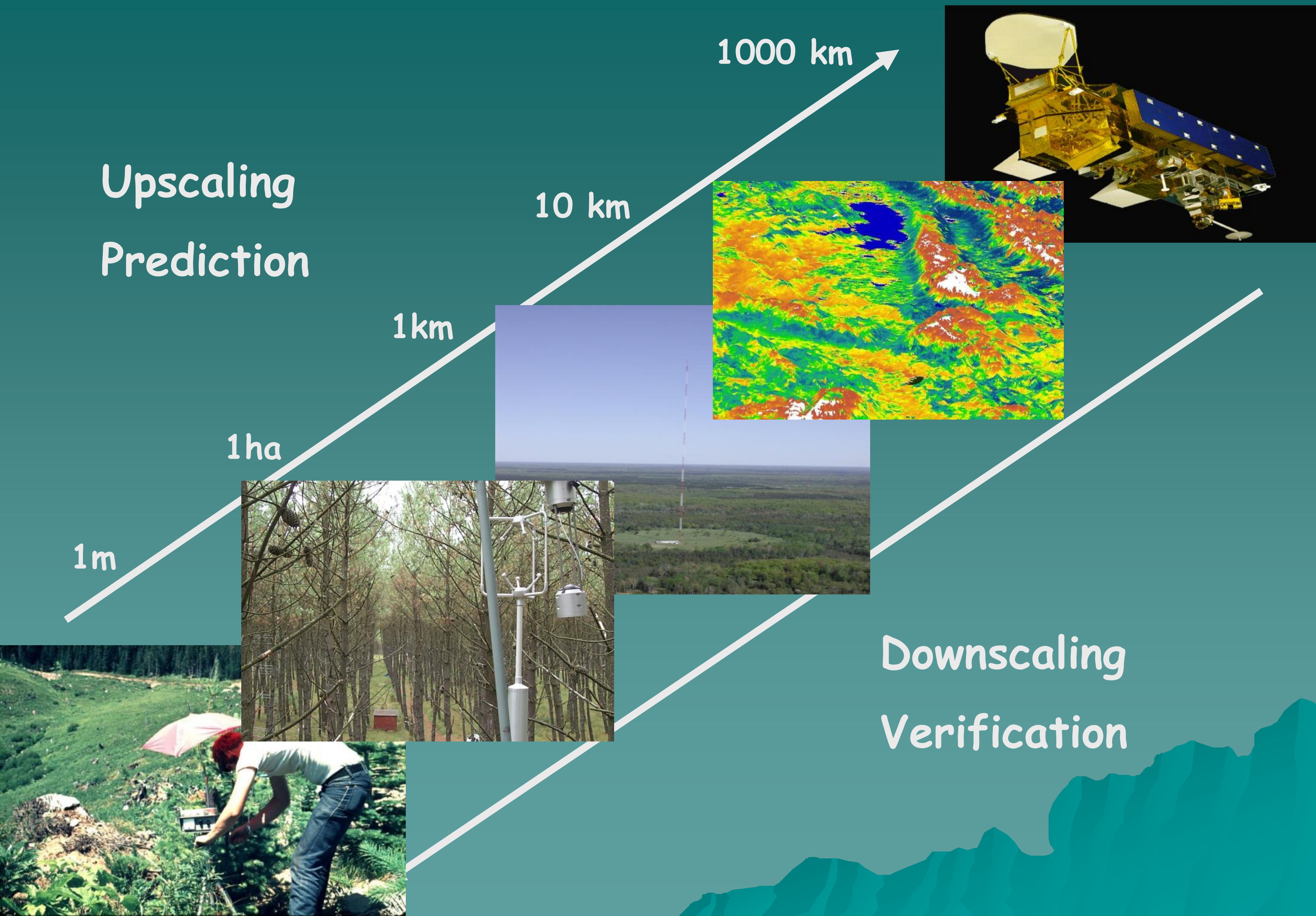
"The rise in CO_2 is proceeding so slowly that most of us today will, very likely, live out our lives without perceiving that a problem may exist"

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

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

When I started, none of us worried about policy relevance, or explaining our science to journalists (or taxpayers)

Integrated, Multiple Constraints on the Biosphere



		-180			-150			-120			-90			-60			-30			0			30			60			90			120			150		
LAT	J	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
90.0	24																																				
82.2	23								0	0	0	0	0	0	0	0	0	0	0		0	0	0						0	0							
74.3	22	0		0	0			3	3	1	2	3	0	0	0	0	0	2				0	0		1	0	1	2	4	7	6	5	3	3	1	0	
66.5	21	4	1	14	23	18	16	14	7	6	5	2	5	0	2	0	0	2	0		5	17	24	14	18	19	17	20	24	23	27	28	22	18	22	19	12
58.7	20	0	0	9	8	7	18	25	20	17	4	2	8	2	0	0			1	5	17	14	27	28	28	29	25	26	28	29	29	30	30	17	8	9	3
50.9	19						6	28	34	30	22	22	27	15	2				4	23	32	33	34	36	28	31	35	36	28	34	33	34	34	20		3	
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35.2	17							14	22	39	42	31							8	14	9	4	6	20	29	23	26	10	10	31	40	23	19	13			
27.4	16							0	10	18	8	8							10	2	2	3	3	4	11	19	15	37	48	36	71	39					
19.6	15			0					1	21	28	3	7					2	5	9	7	7	2	6	2	1	9	38	25	63	26	8					
11.7	14										14	20	24	10				3	31	37	39	37	33	20	9		2	19		23	9	12	2				
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-19.6	10	1											23	32	45	24					3	36	31	12	20						1	13	25	33	16		1
-27.4	9												16	24	36						0	15	30	0	2						1	13	12	21	24		
-35.2	8	3											13	32	4							3	5									4	1	14	17		1
-43.0	7	3											23	1																					6		14
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-58.7	5												1																								
-66.5	4												0	0						0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
-74.3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-82.2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-90.0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LAT	J	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
		-180			-150			-120			-90			-60			-30			0			30			60			90			120			150		

Fig. 2. Global distribution of NPP (× 10 gm C/m²/yr) at the tracer model resolution.

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

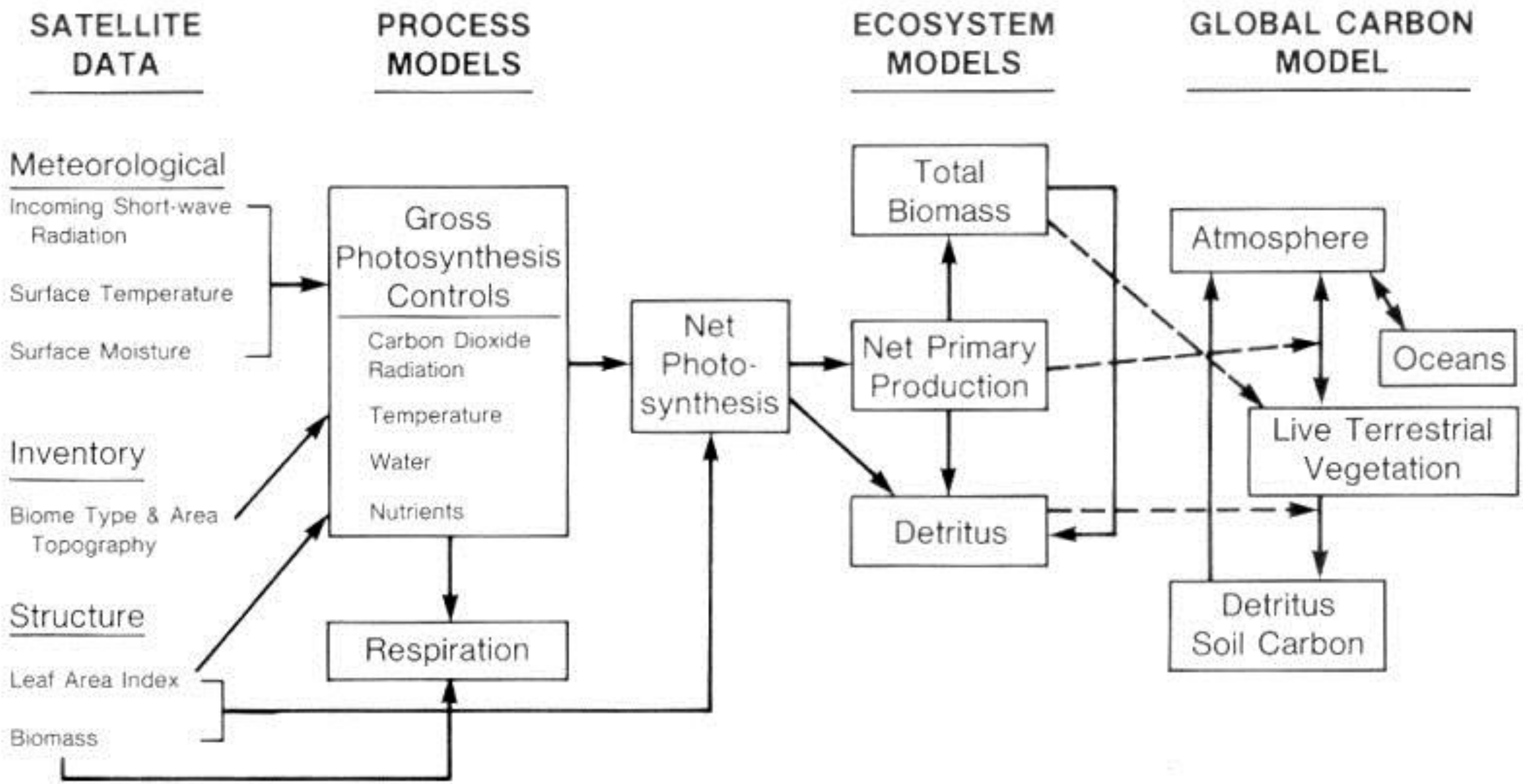
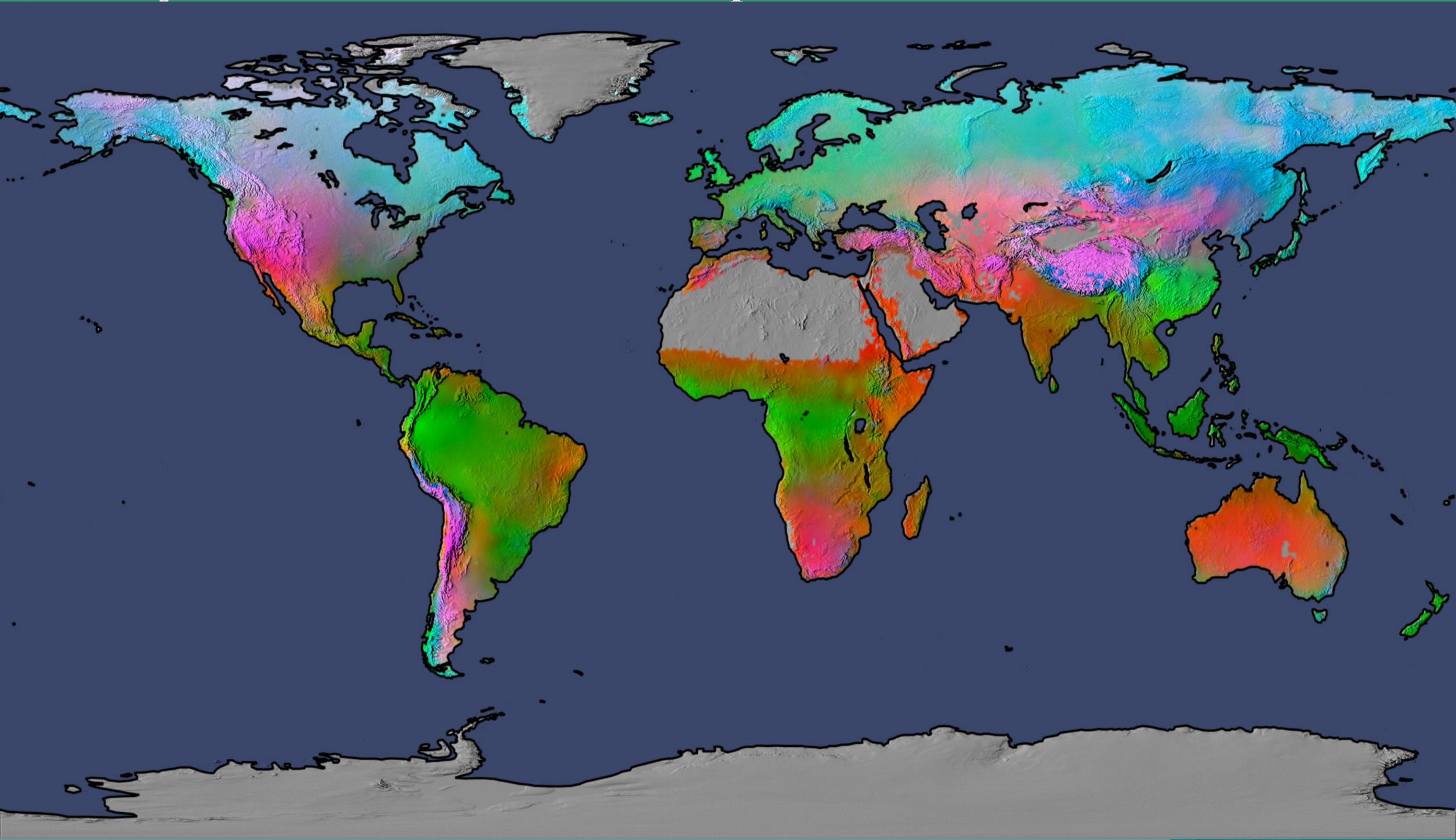


Figure 2. Organizational diagram of a proposed model of net primary production for a coniferous forest. All driving variables are derived from satellite data. Potential linkages to a global carbon model are shown by dashed lines (Running, 1984).

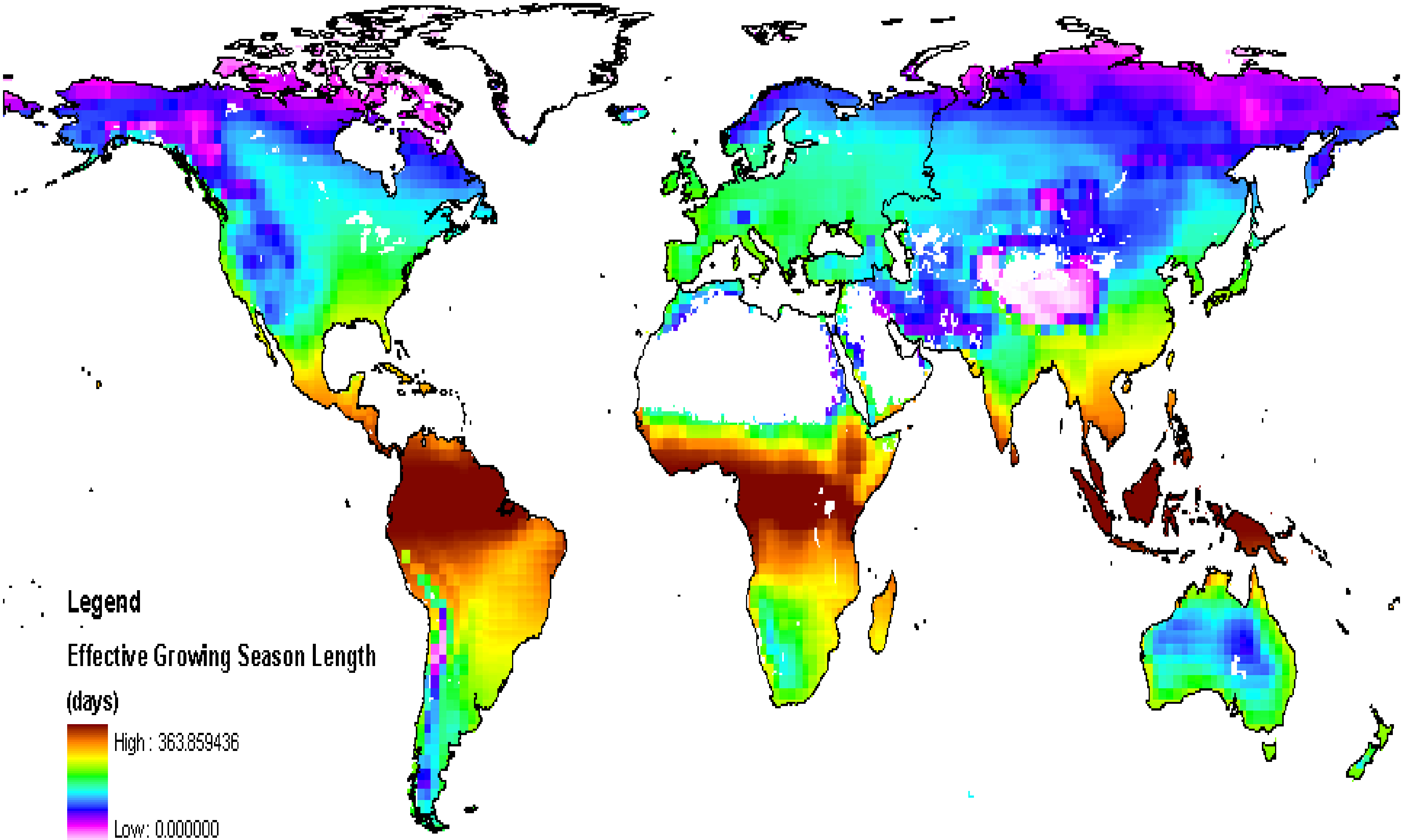
Potential climate limits to plant growth derived from long-term monthly statistics of minimum temperature, cloud cover and rainfall.



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

Nemani et al. 2003
Running et al 2004

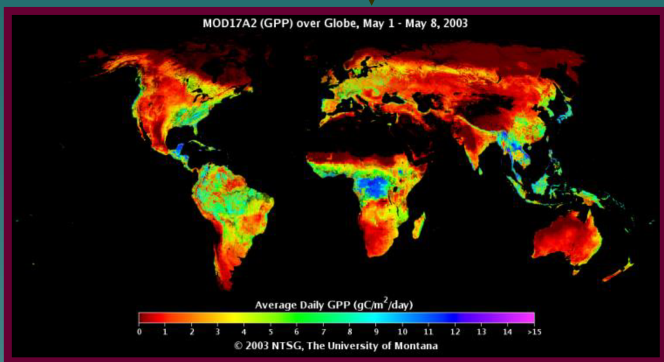
Global Effective Growing Season Length



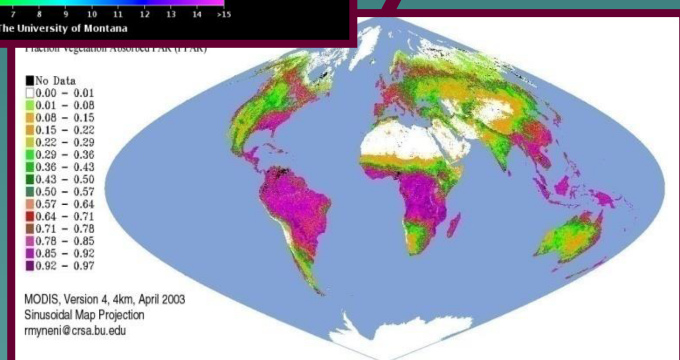
Jolly, Nemani, Running. Global Change Biology 2005

GPP = Light X Conversion Efficiency

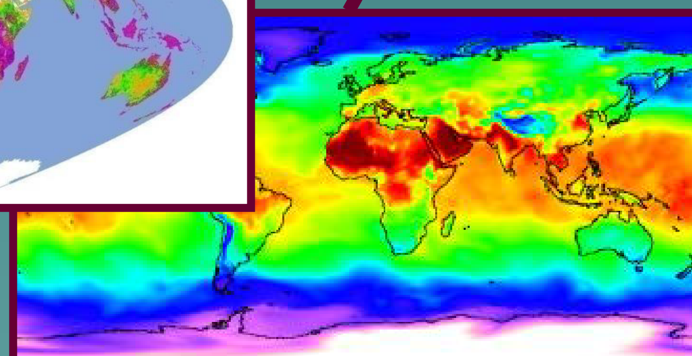
$$GPP = f\,(PAR) \times \varepsilon$$



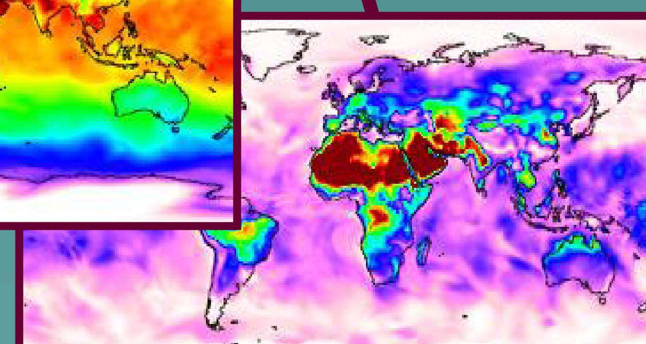
GPP



fPAR, PAR



Temperature

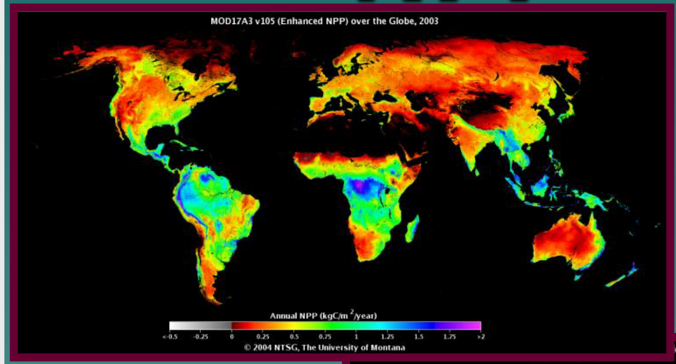


VPD

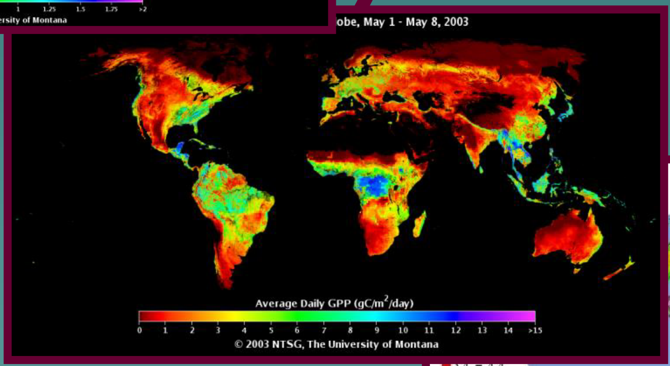
Biome Properties Look-Up Table (ε_{max})

NPP = Annual GPP - Autotrophic Respiration

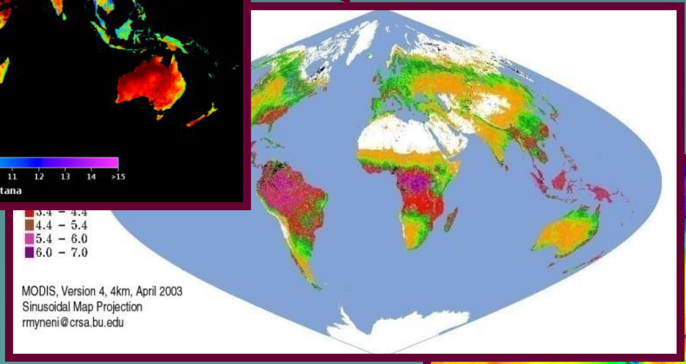
$$NPP = \sum GPP - (R_m + R_g)$$



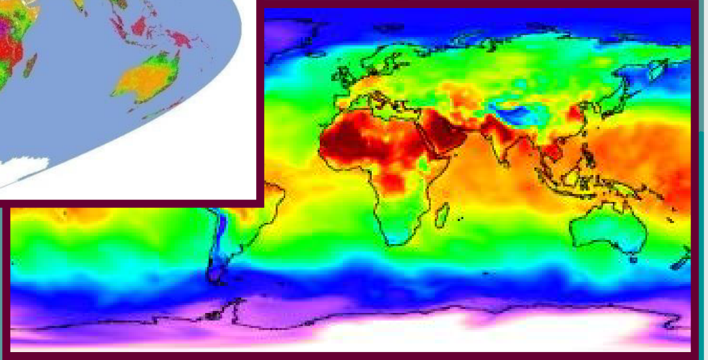
NPP



GPP



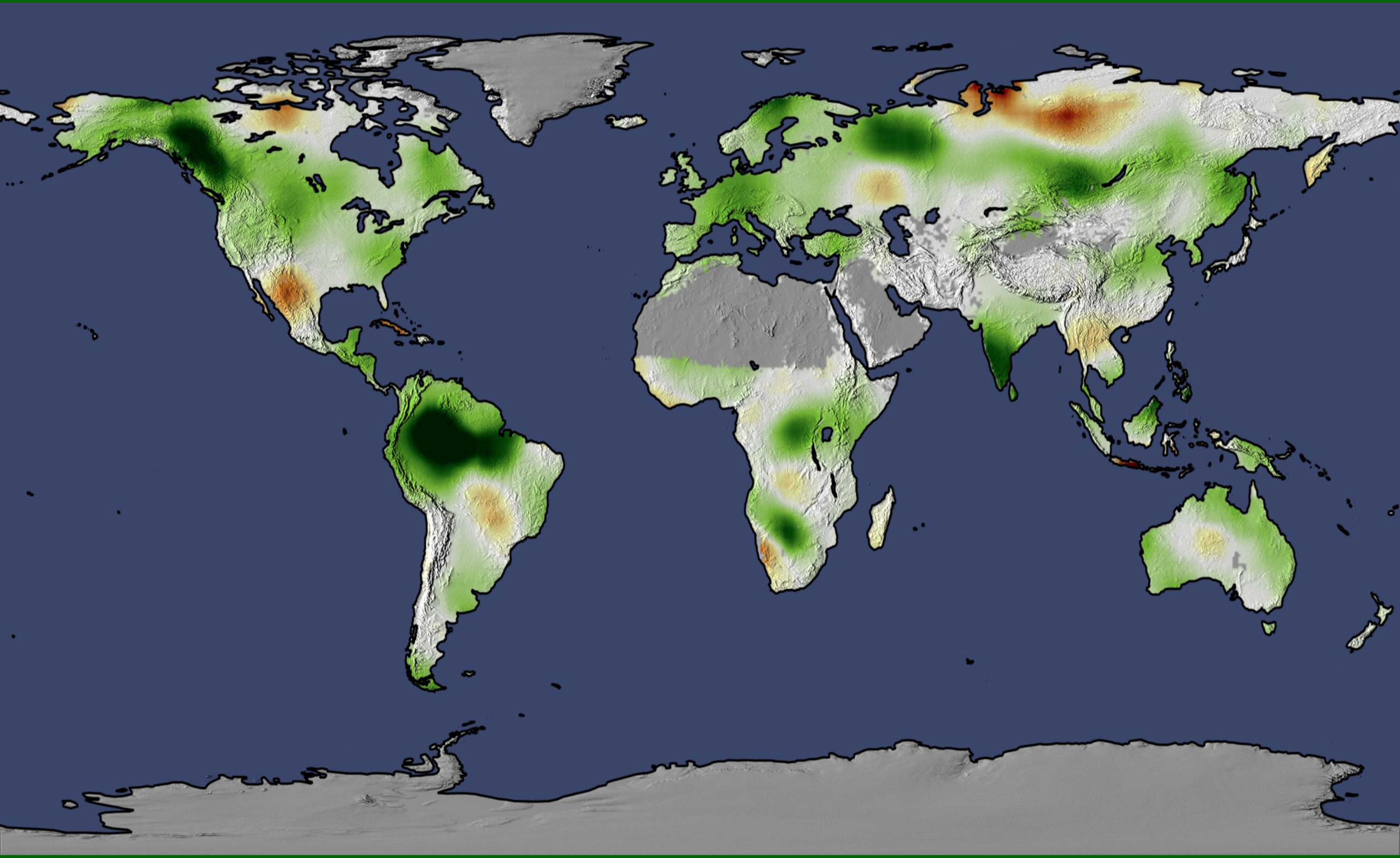
LAI



Temperature

Biome Properties Look-Up Table

Change in Terrestrial NPP from 1982 to 1999

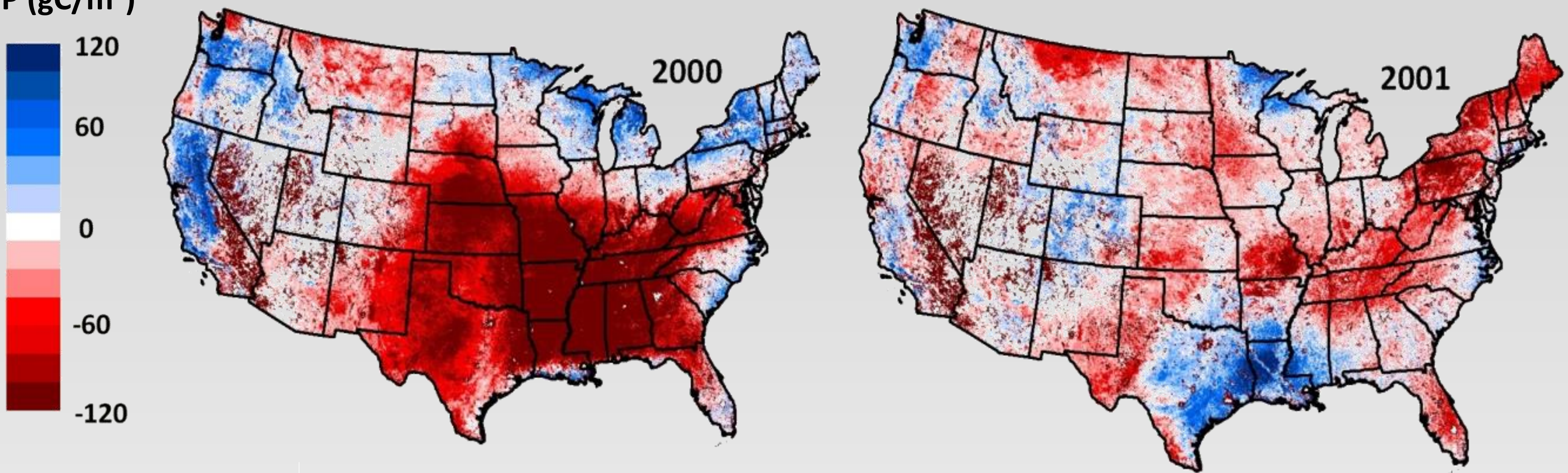


Nemani et al., Science June 6th 2003

Net Primary Productivity Indicator

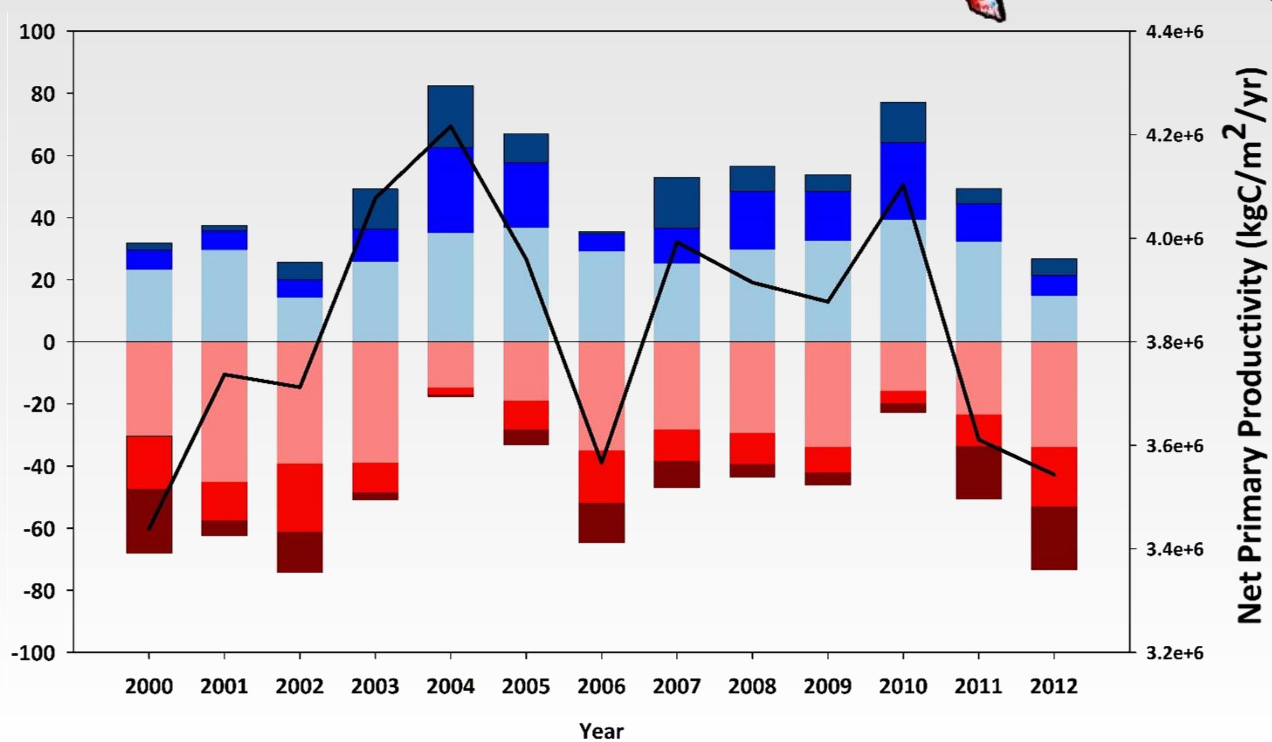
Net Primary Productivity Yearly Anomaly

NPP (gC/m²)

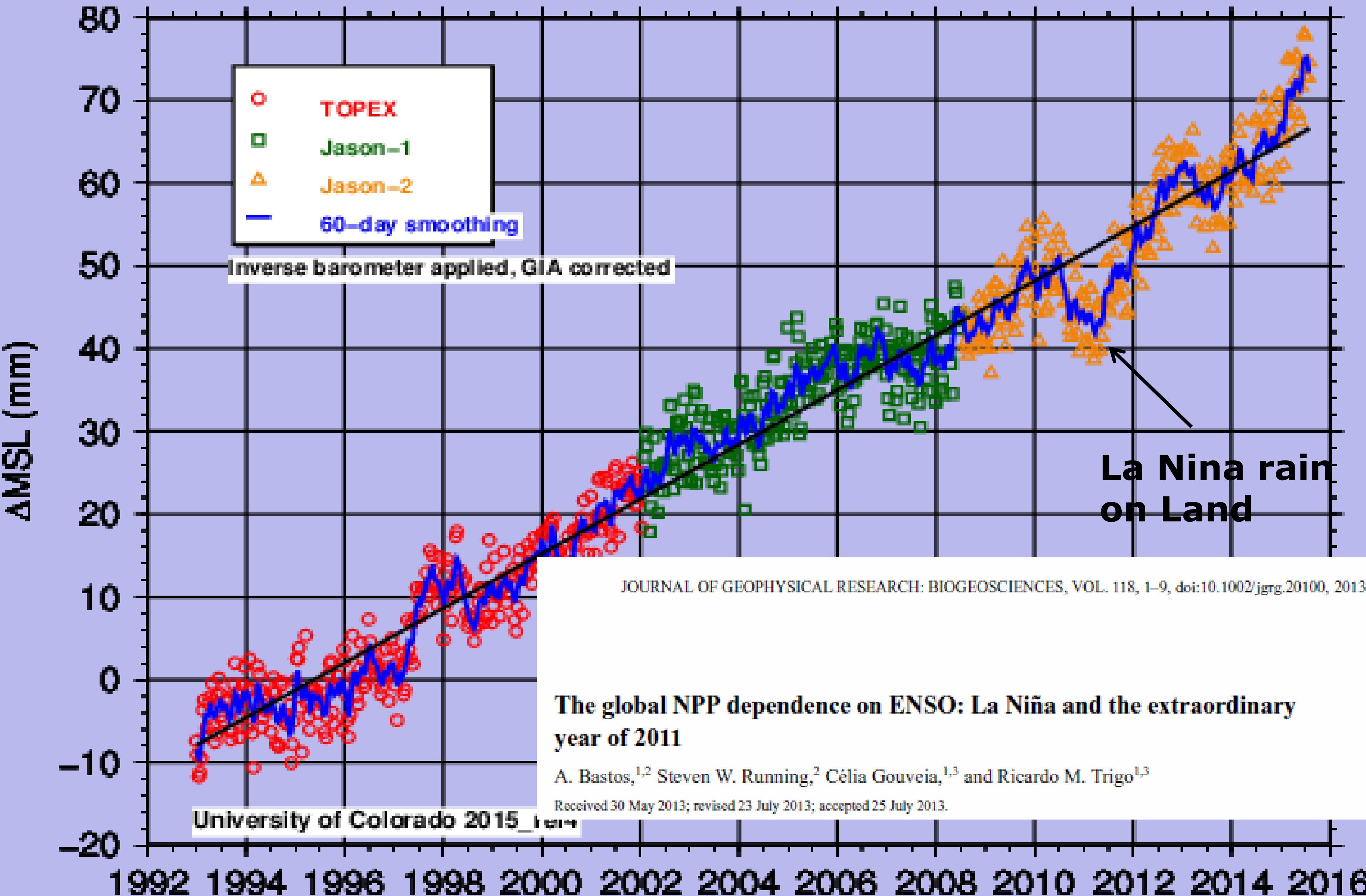


Percentage of area above or below the 13-year NPP average

- > 80 gC m² yr⁻¹
- > 40 gC m² yr⁻¹
- > 0 gC m² yr⁻¹
- < 0 gC m² yr⁻¹
- < -40 gC m² yr⁻¹
- < -80 gC m² yr⁻¹



SEA LEVEL RISE



JOURNAL OF GEOPHYSICAL RESEARCH: BIOGEOSCIENCES, VOL. 118, 1–9, doi:10.1002/jgrg.20100, 2013

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

A. Bastos,[1,2] Steven W. Running,[2] Célia Gouveia,[1,3] and Ricardo M. Trigo[1,3]

Received 30 May 2013; revised 23 July 2013; accepted 25 July 2013.

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:

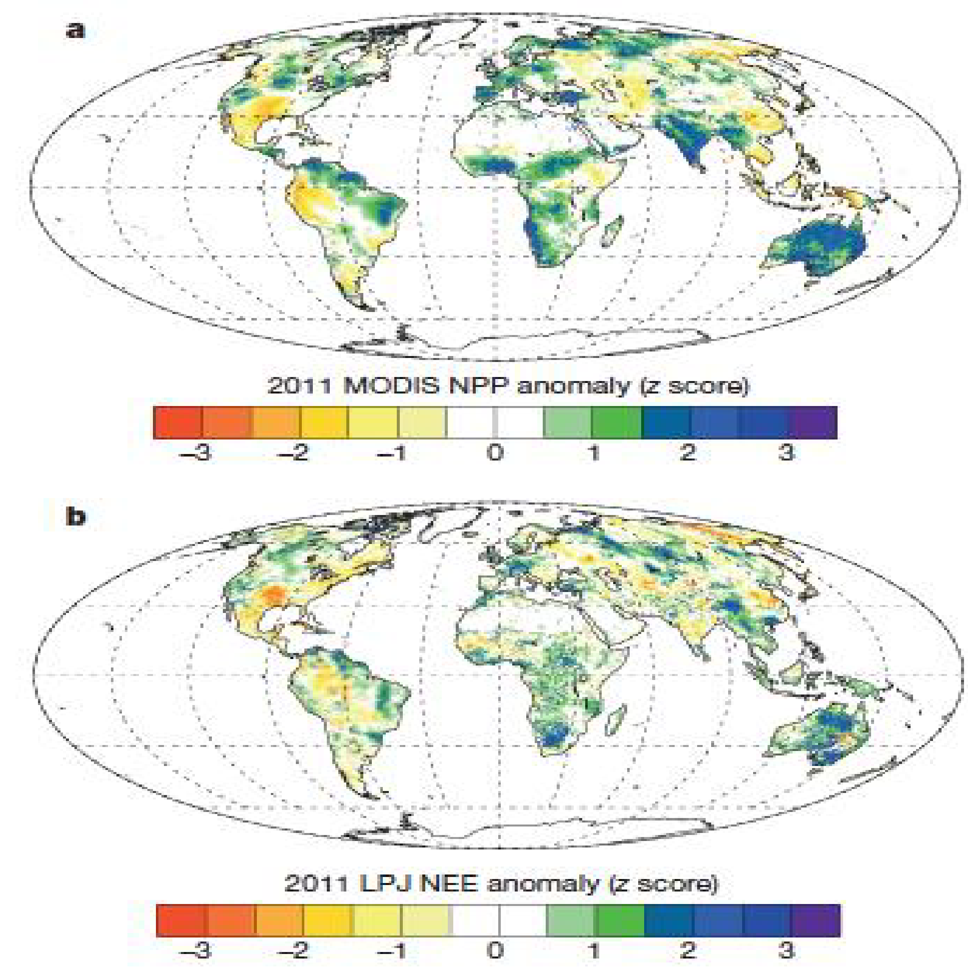
- 45% increase in NPP (LPJ and MODIS)
- 9% increase in Rh (LPJ)
- 29% decrease in fire emissions from GFED & GFAS observations

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)

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.

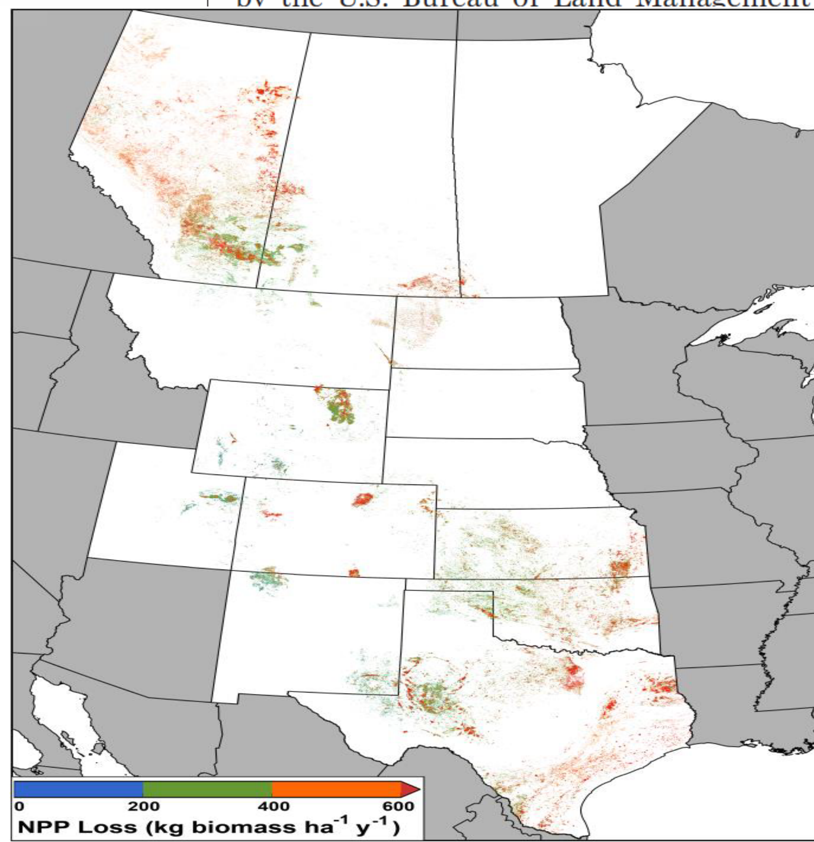
We estimate that vegetation removal by oil and gas development from 2000 to 2012 reduced NPP by ~4.5 Tg of carbon or 10 Tg of dry biomass across central North America (see the chart on page 402, left). The total amount lost in rangelands is the equivalent of approximately five million animal unit months (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

<u>From 2000 – 2012</u>

50,000 new wells / year

3 million ha land lost

4.5 Tg C of NPP lost / yr

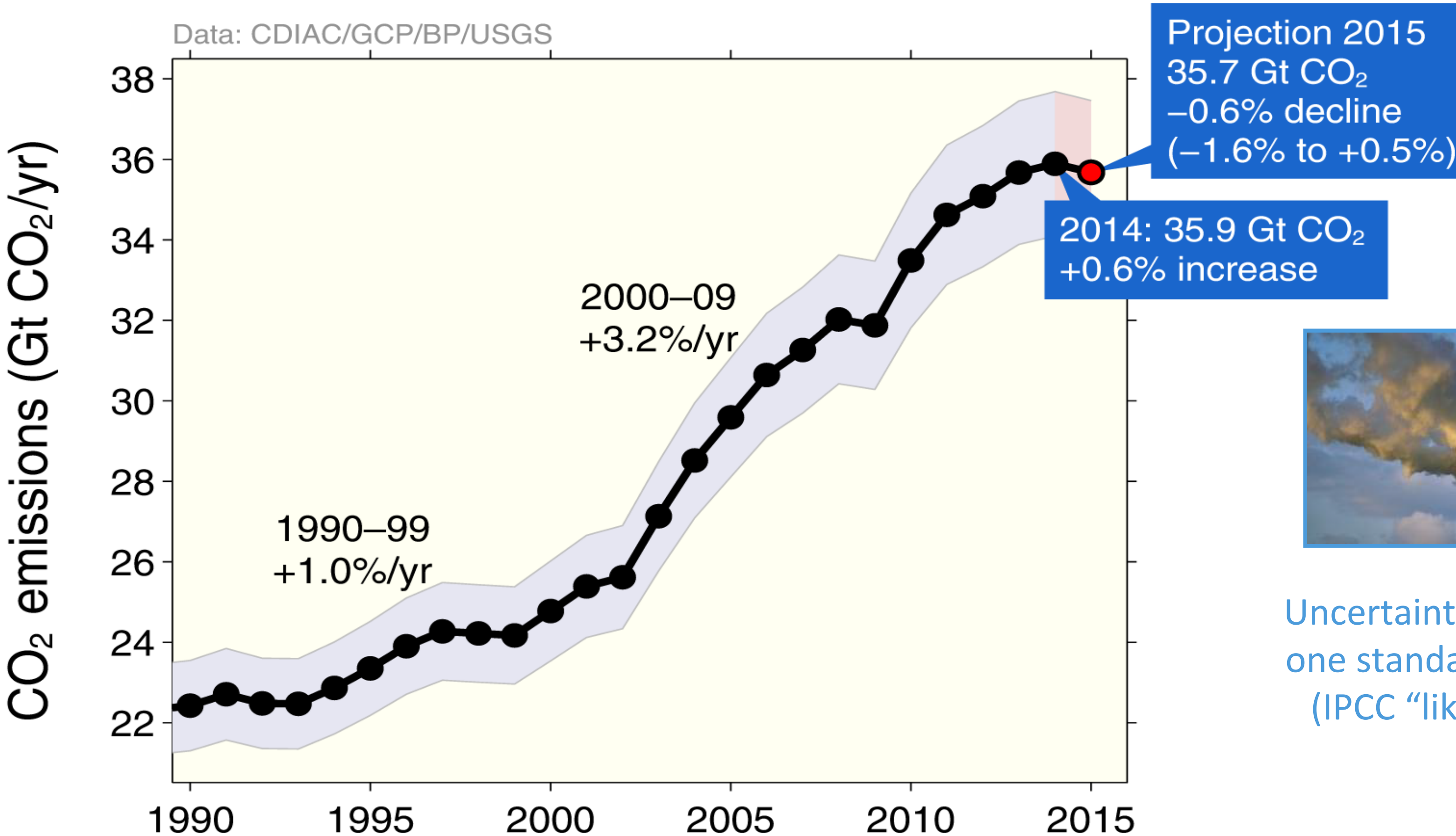


Published by AAAS

Emissions from fossil fuel use and industry

Global emissions from fossil fuel and industry: 35.9 ± 1.8 $GtCO_2$ in 2014, 60% over 1990

● Projection for 2015: 35.7 ± 1.8 $GtCO_2$, 59% over 1990



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

Estimates for 2012, 2013, 2014, and 2015 are preliminary

Source: CDIAC; Le Quéré et al 2015; Global Carbon Budget 2015

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

7.7±0.5 PgC y^{-1}

\+

1.1±0.7 PgC y^{-1}

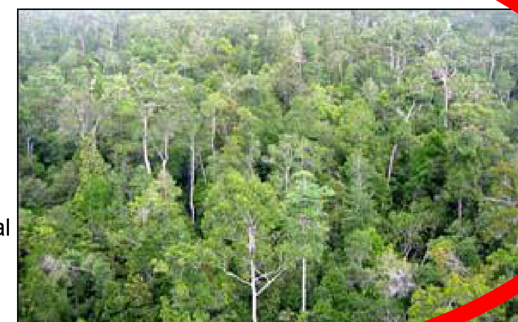
4.1±0.1 PgC y^{-1}

47%

2.4 PgC y^{-1}

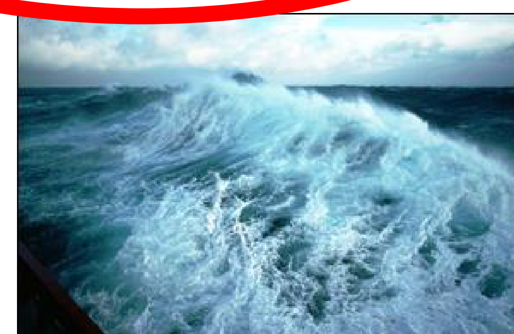
27%

Calculated as the residual



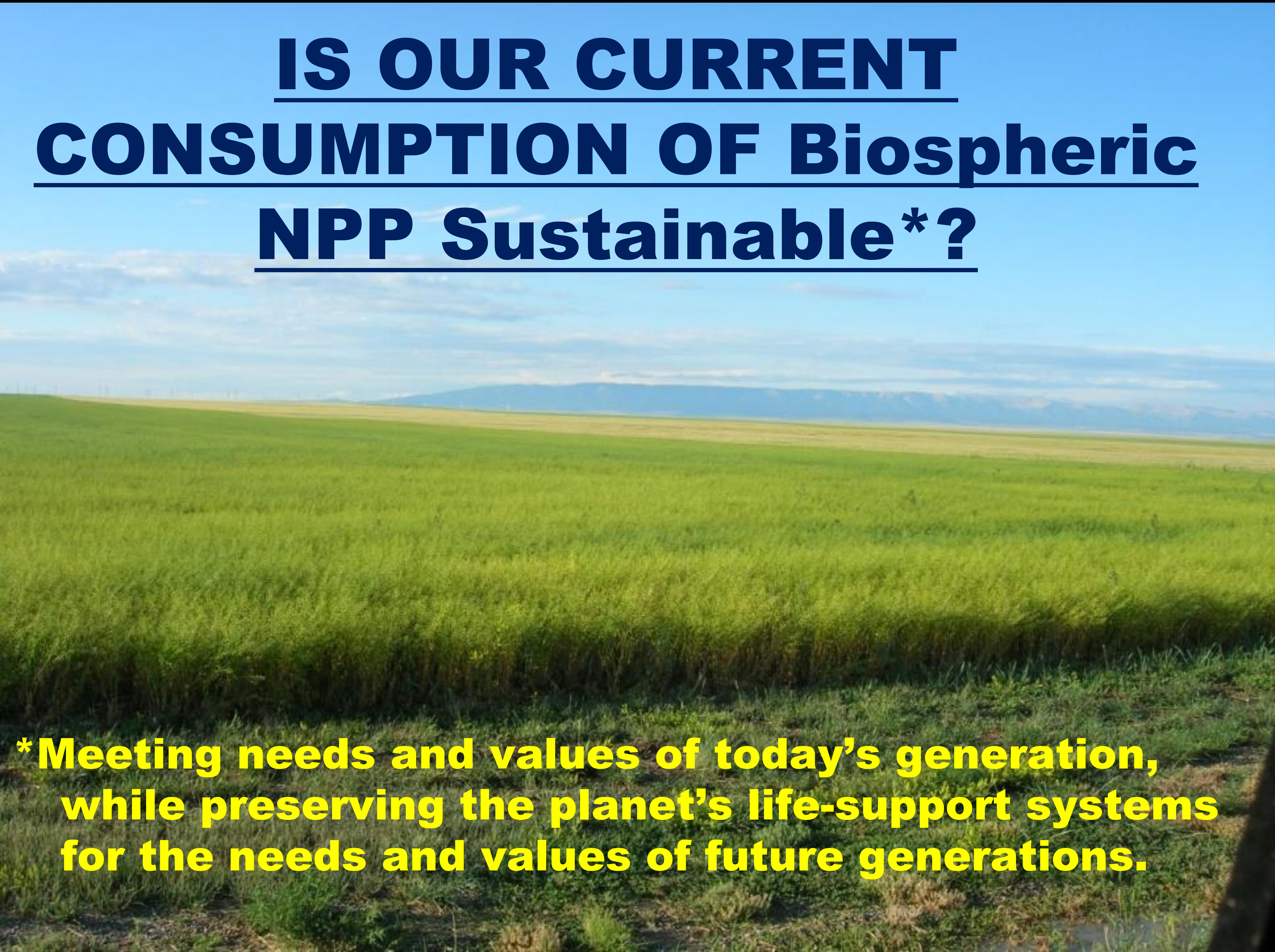
26%

2.3±0.4 PgC y^{-1}

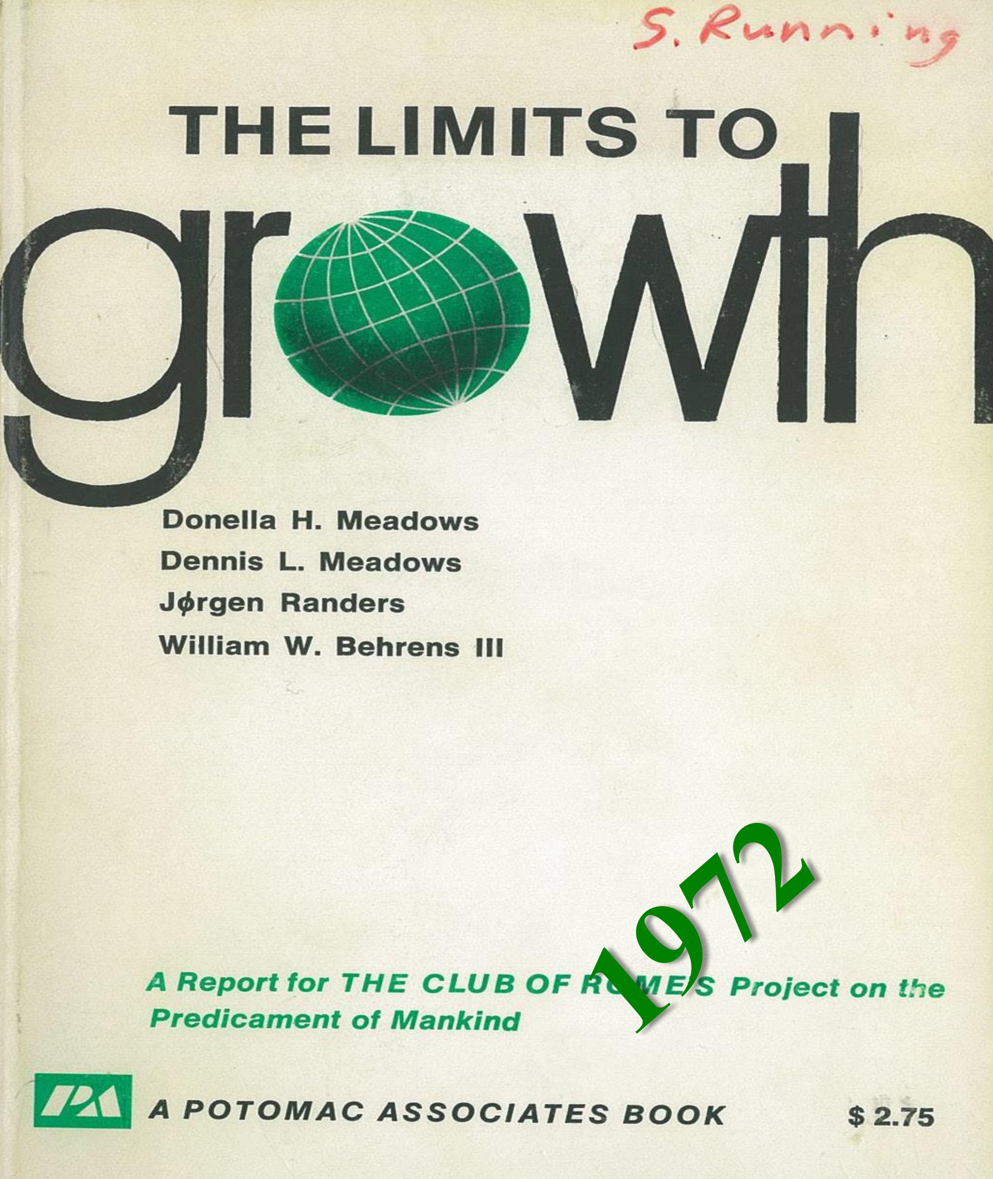


Global Carbon Project 2010; http://www.globalcarbonproject.org/carbonbudget/index.htm

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.



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

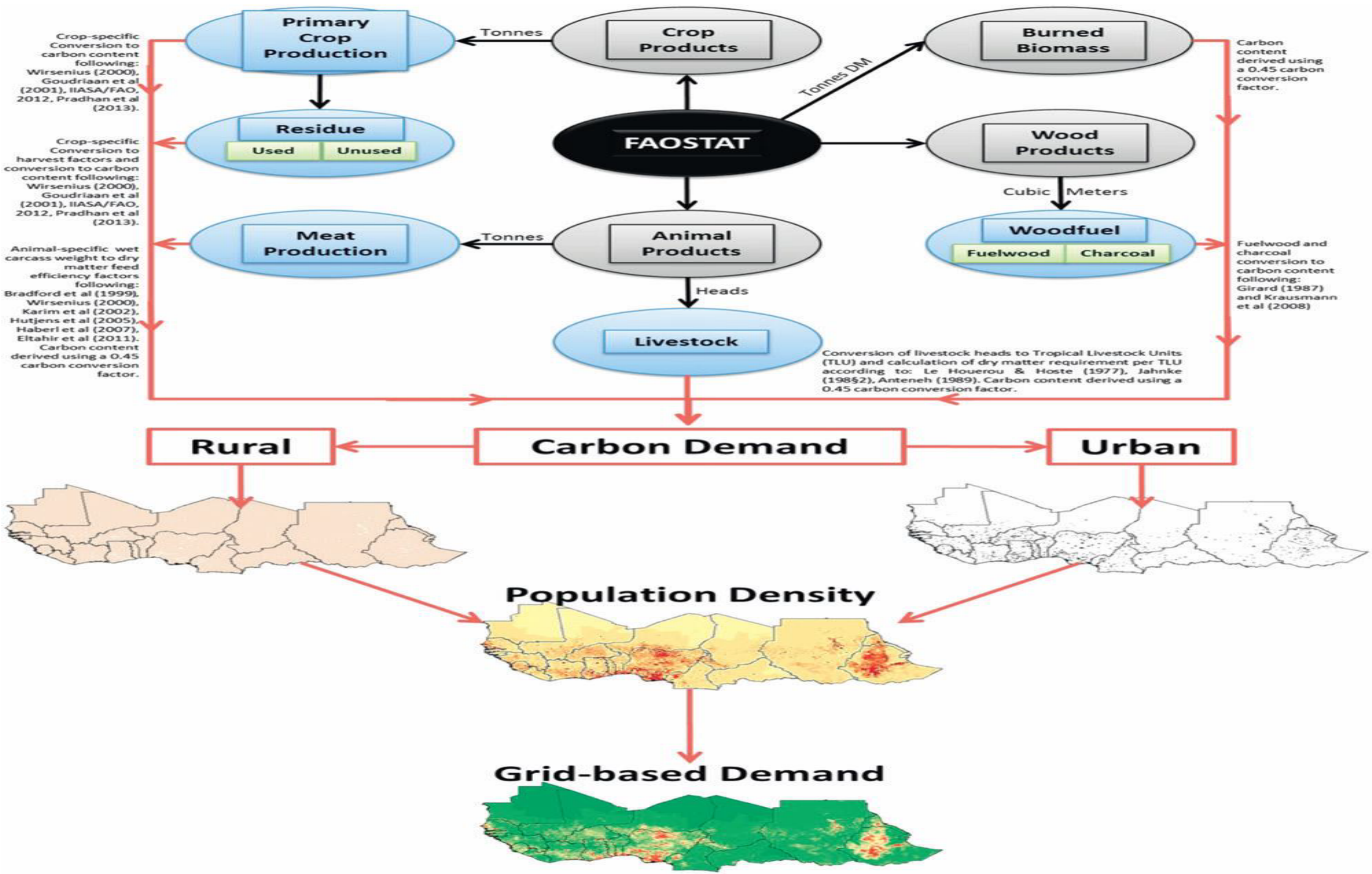
OPEN ACCESS
IOP Publishing
Environmental Research Letters
Environ. Res. Lett. 9 (2014) 111003 (3pp)
doi:10.1088/1748-9326/9/11/111003

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.



CROP YIELDS WILL NOT KEEP UP WITH POPULATION GROWTH to 2050

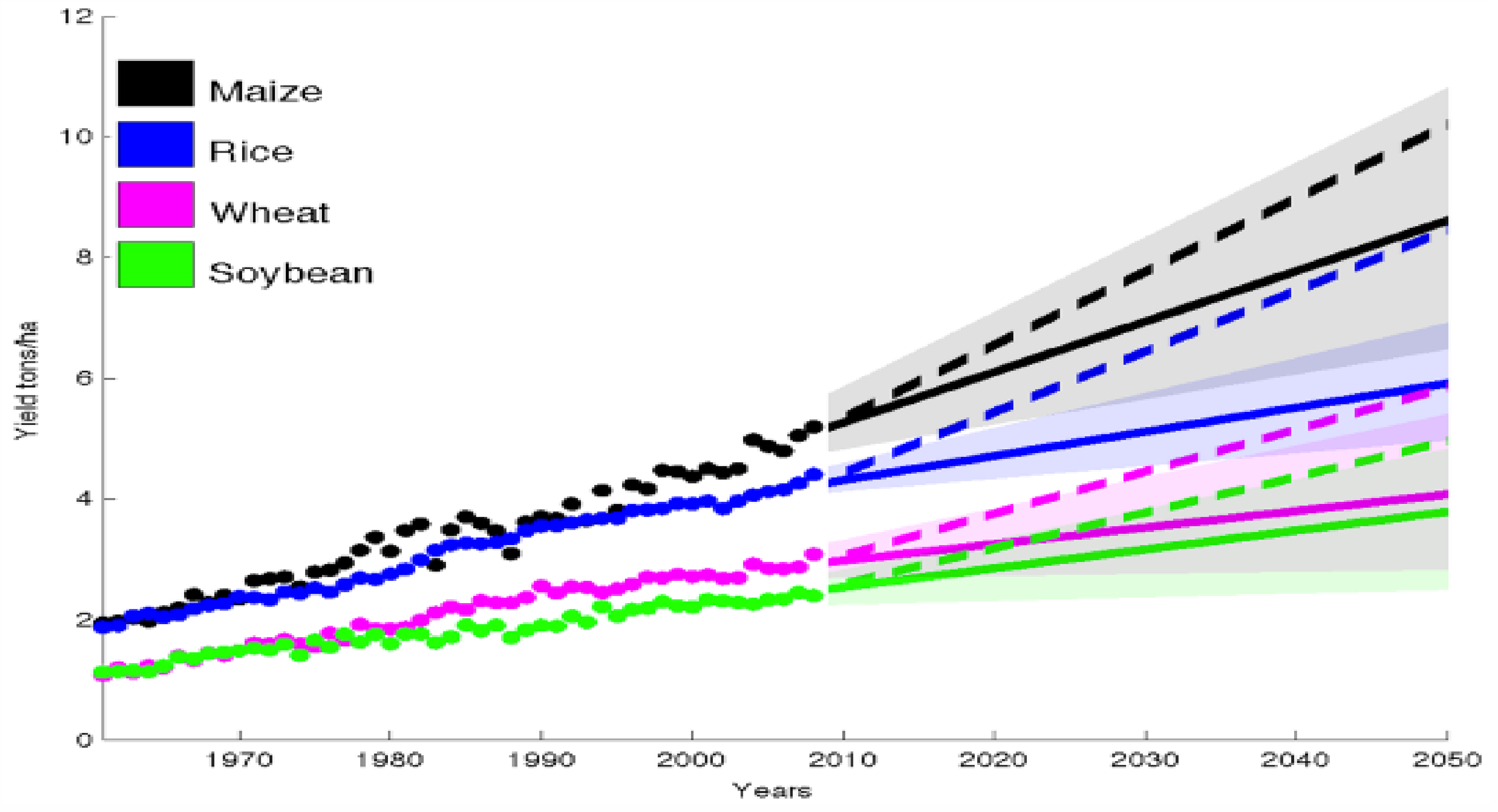
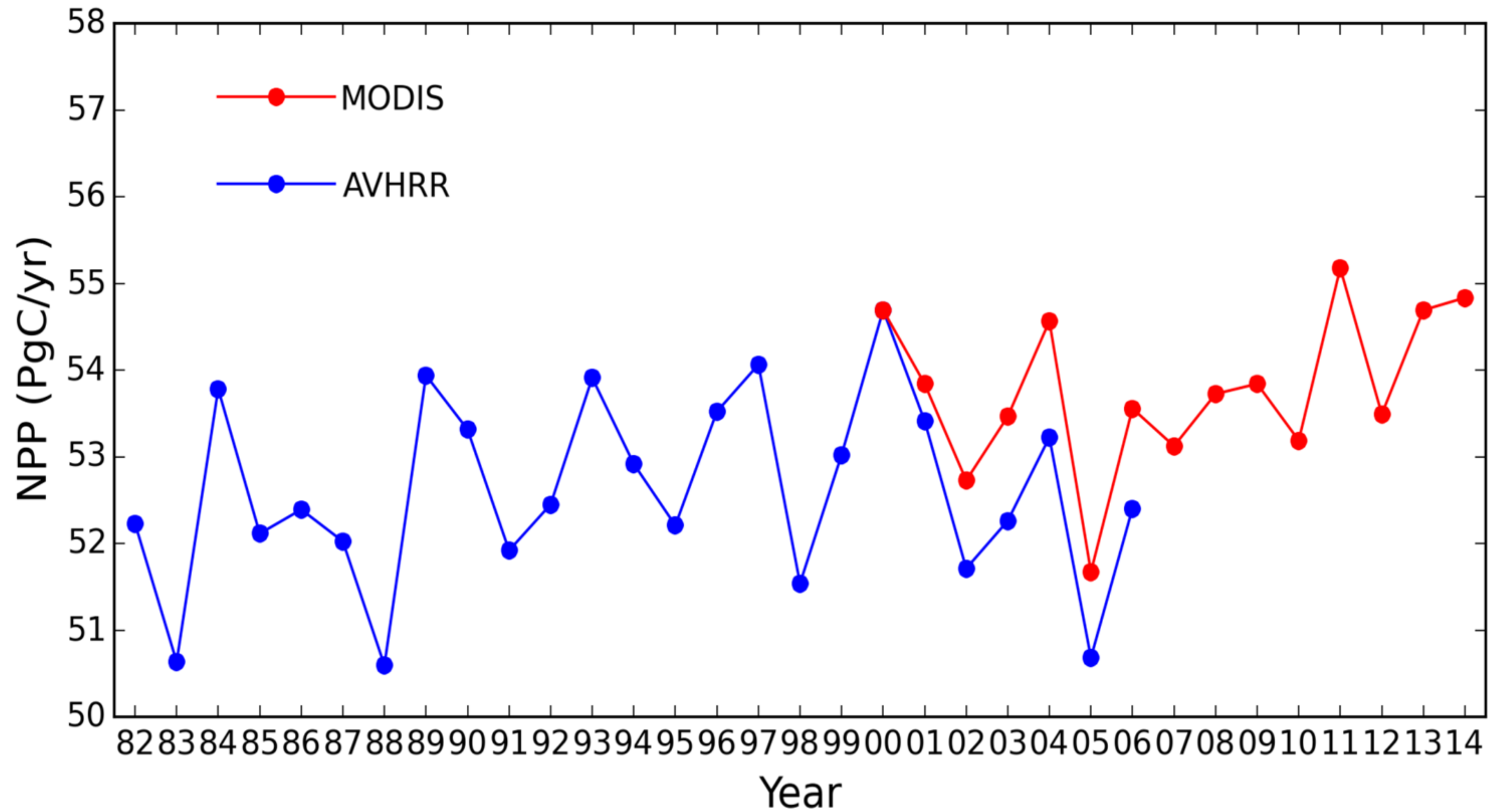


Figure 1. Global projections. Observed area-weighted global yield 1961–2008 shown using closed circles
for maize, rice, wheat, and soybean. Shading shows the 90% confidence region derived from 99 bootstrapp
trend of the ~2.4% yield improvement required each year to double production in these crops by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

D.K. Ray et al PlosOne 2013

Global Terrestrial Net Primary Production (1982-2014)



+/- 1Pg or about 2%

Nemani et al 2003, Zhao and Running 2010

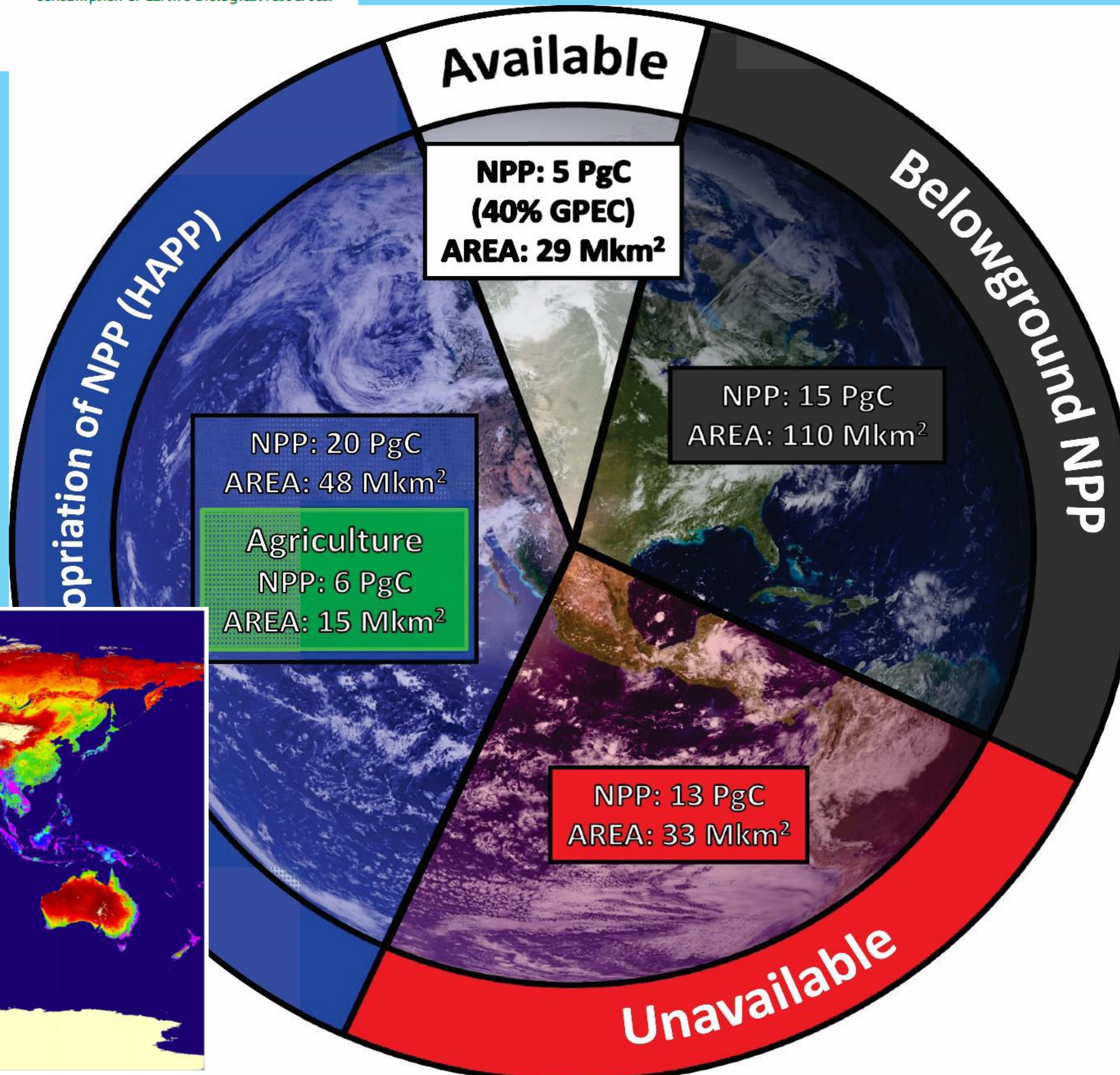
ECOLOGY

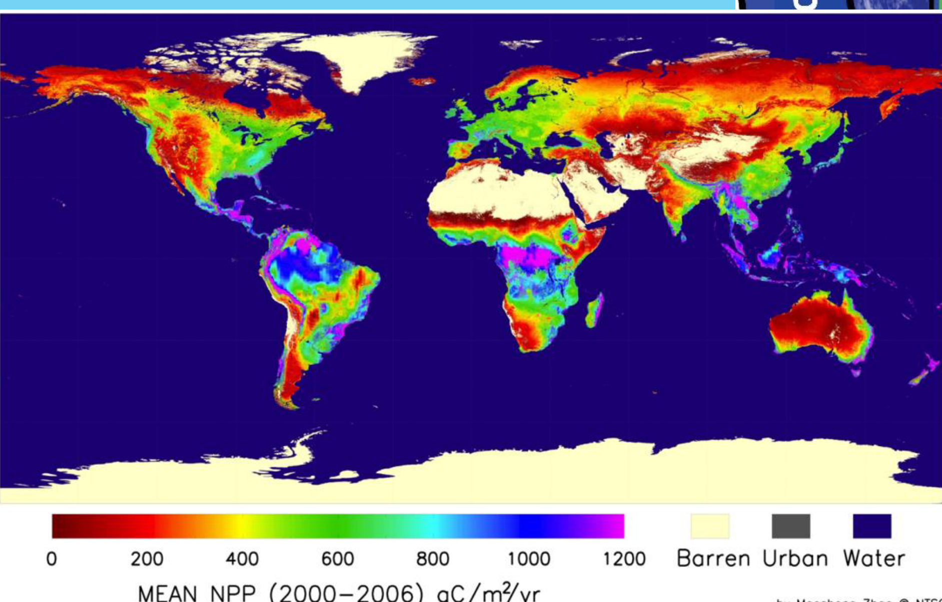
A Measurable Planetary Boundary for the Biosphere

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

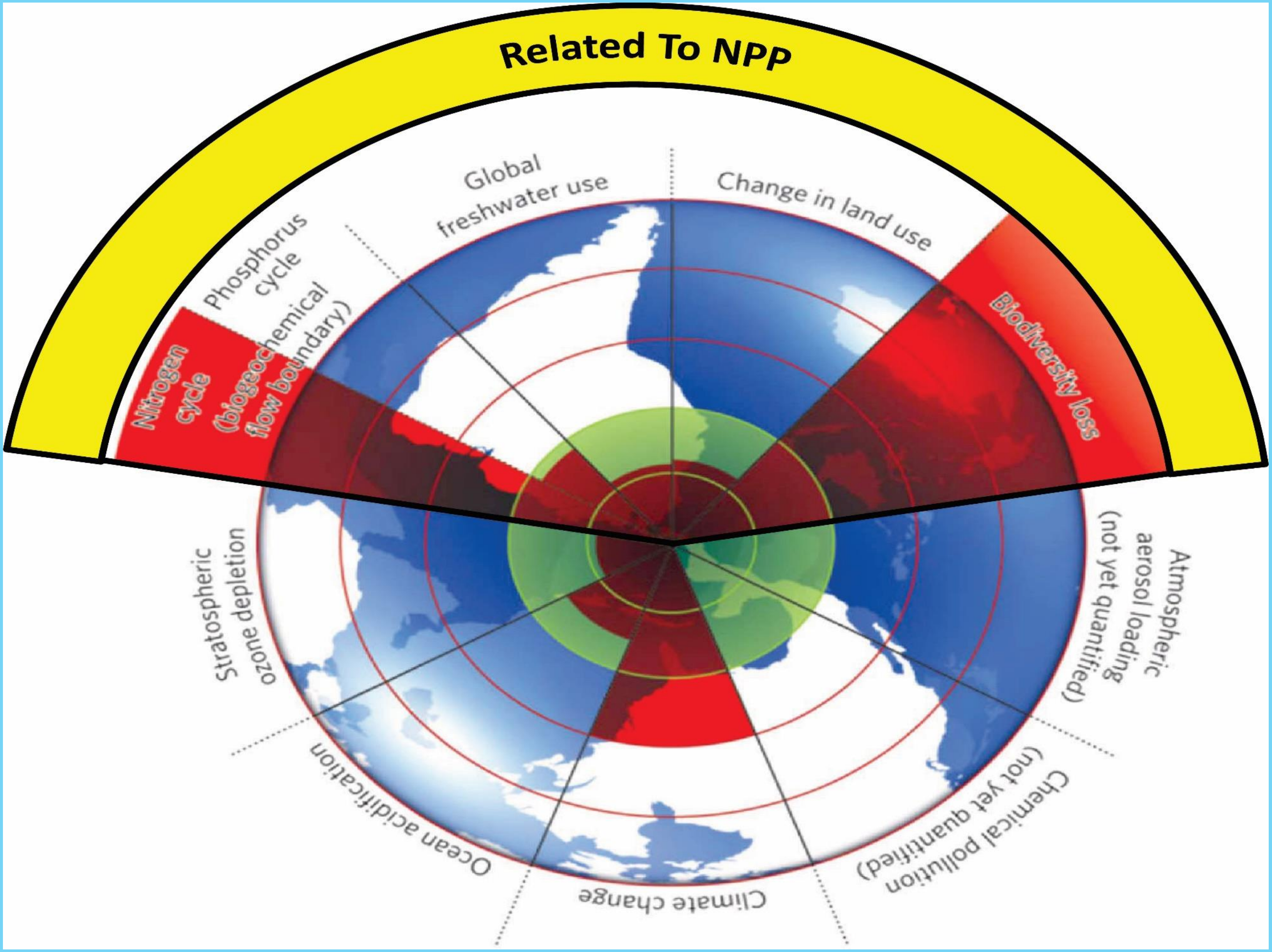
Steven W. Running

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





Zhao and Running.
***Science* 329: 940-043 (2009)**



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

Science AAAS

Enhanced seasonal CO_2 exchange caused by amplified plant productivity in northern ecosystems

Matthias Forkel *et al.*

Science **351**, 696 (2016);
DOI: 10.1126/science.aac4971

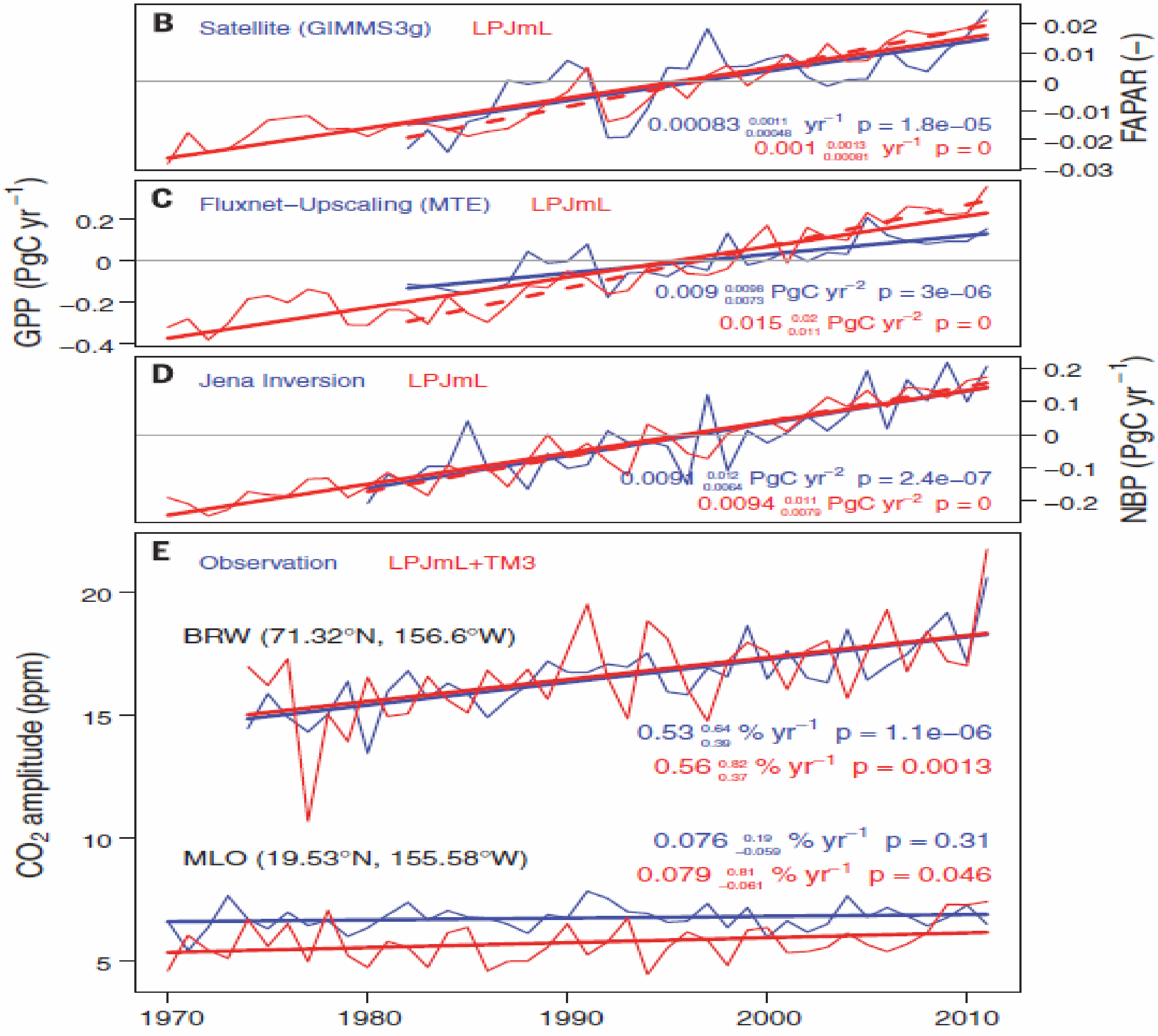
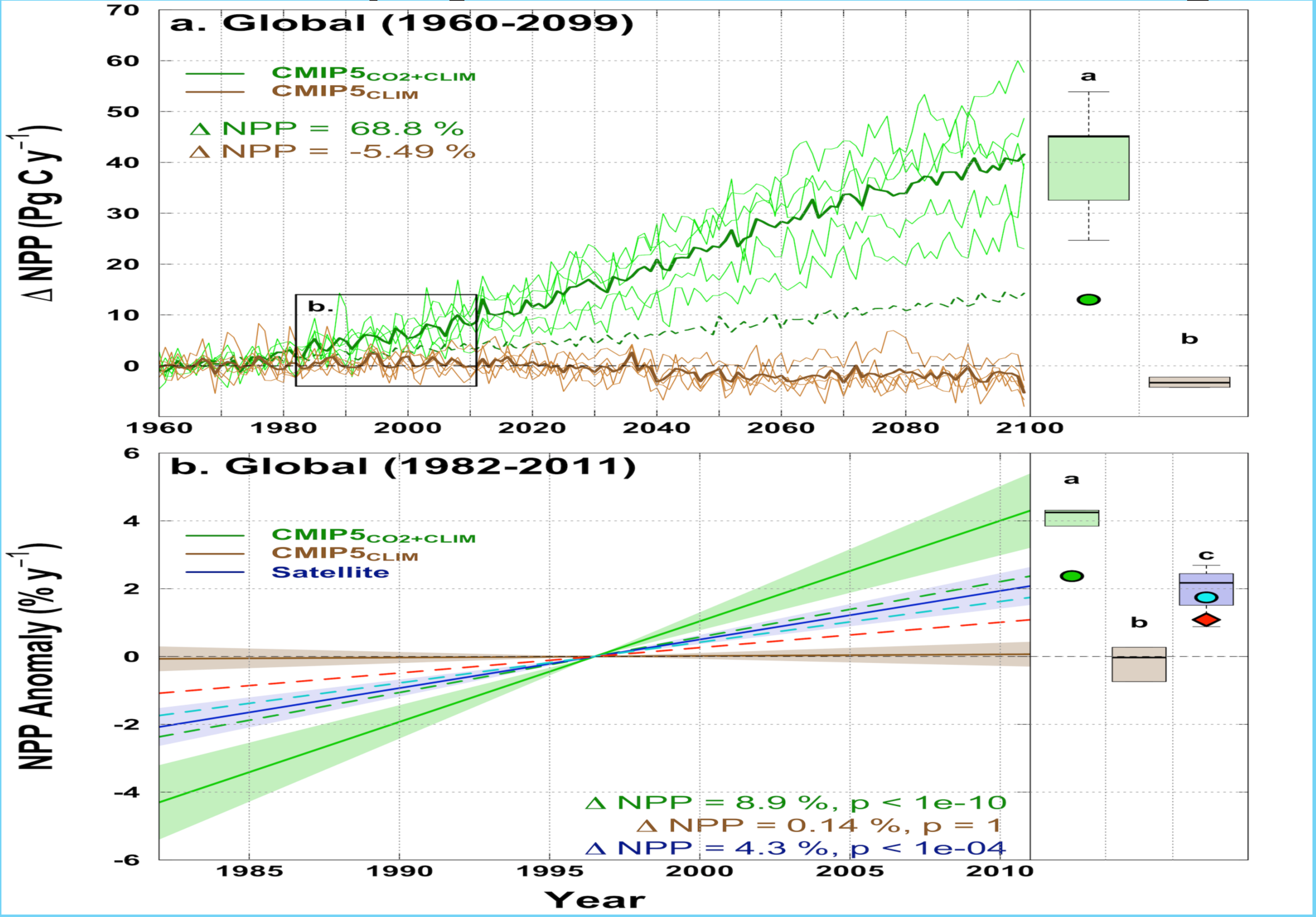


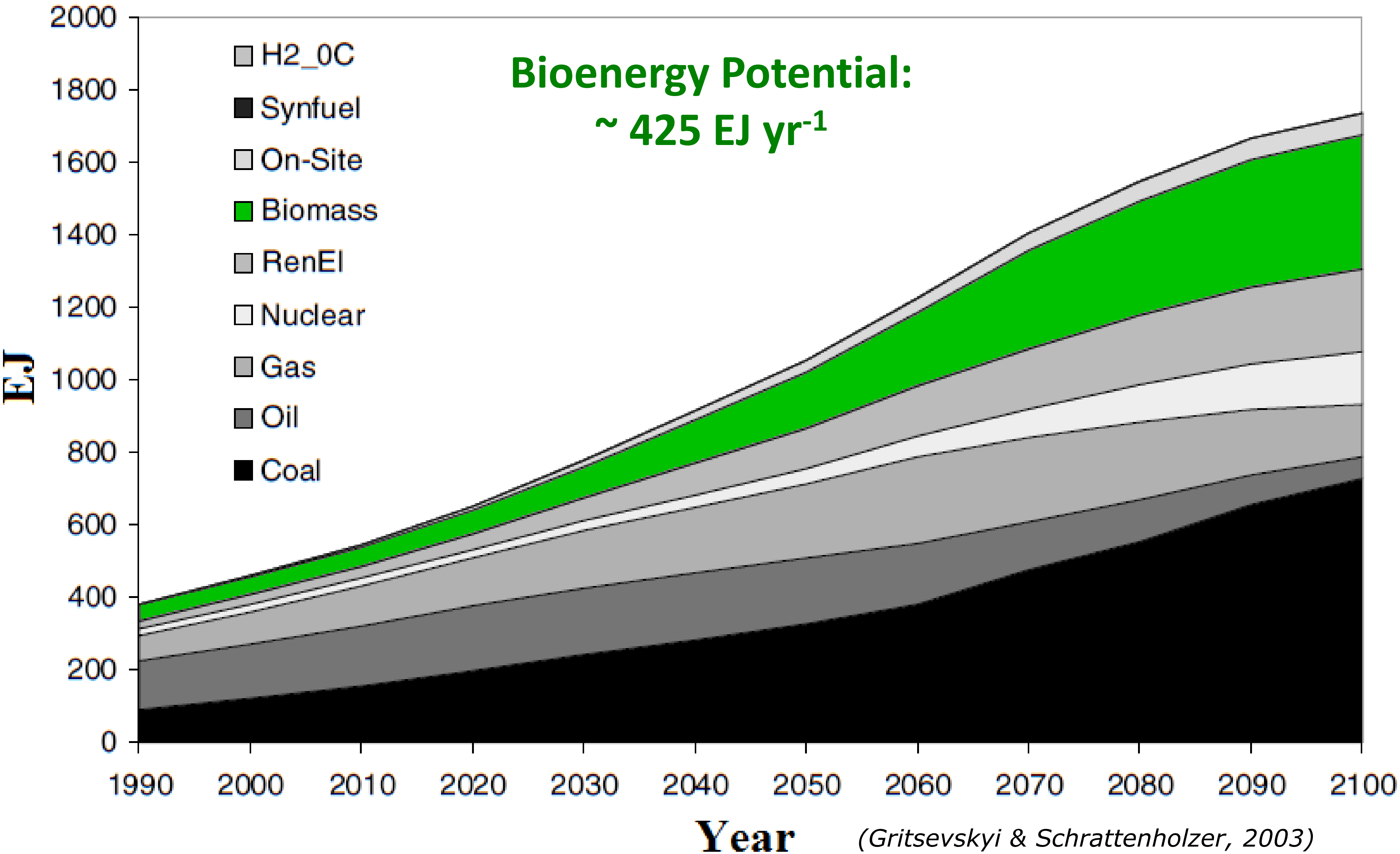
Fig. 1. Amplification of plant activity in the northern biosphere. (**A** to **E**) Annual time series and lin

CMIP5 projections of NPP are too strong



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

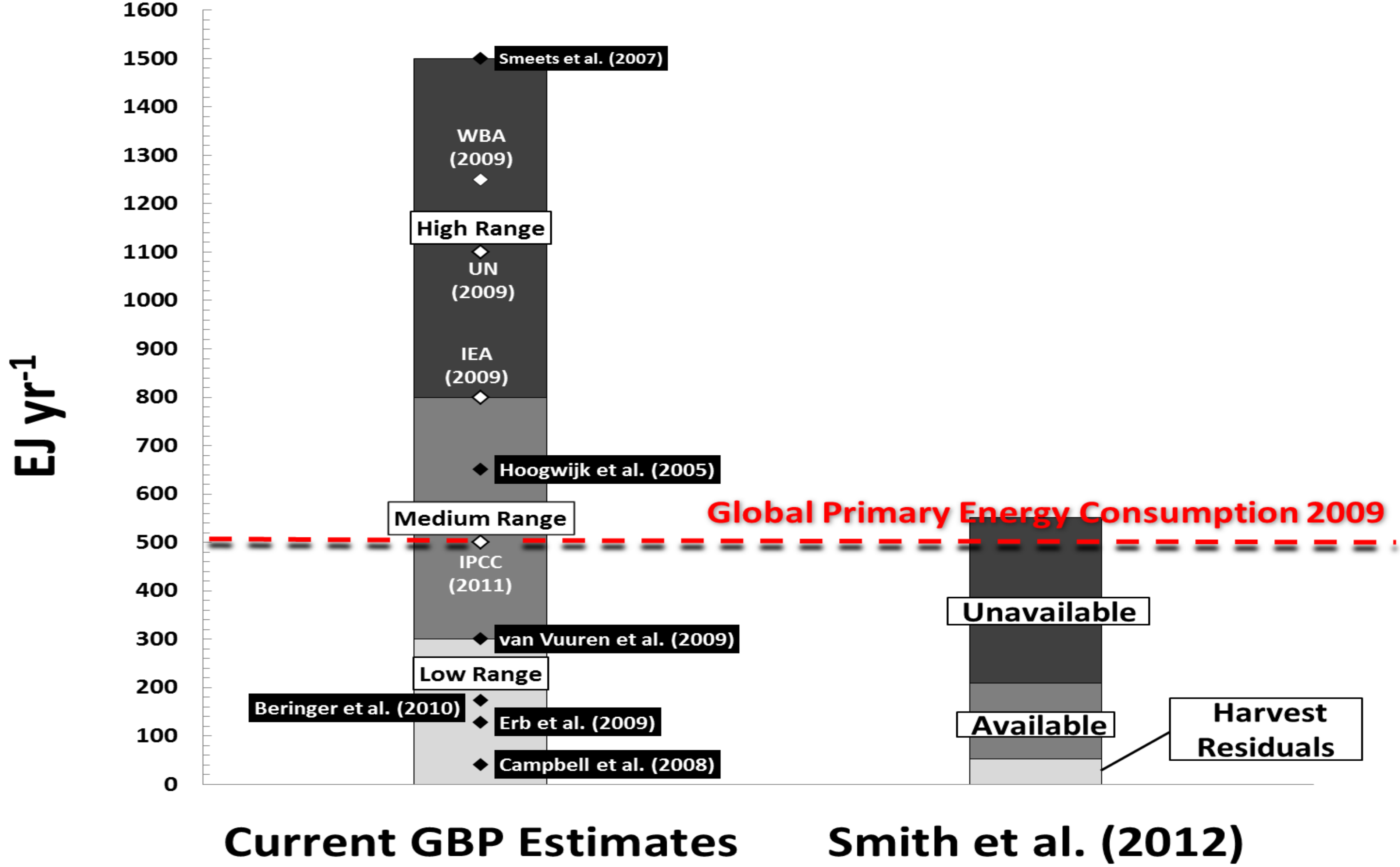
Future Bioenergy Potential (estimated by economists)



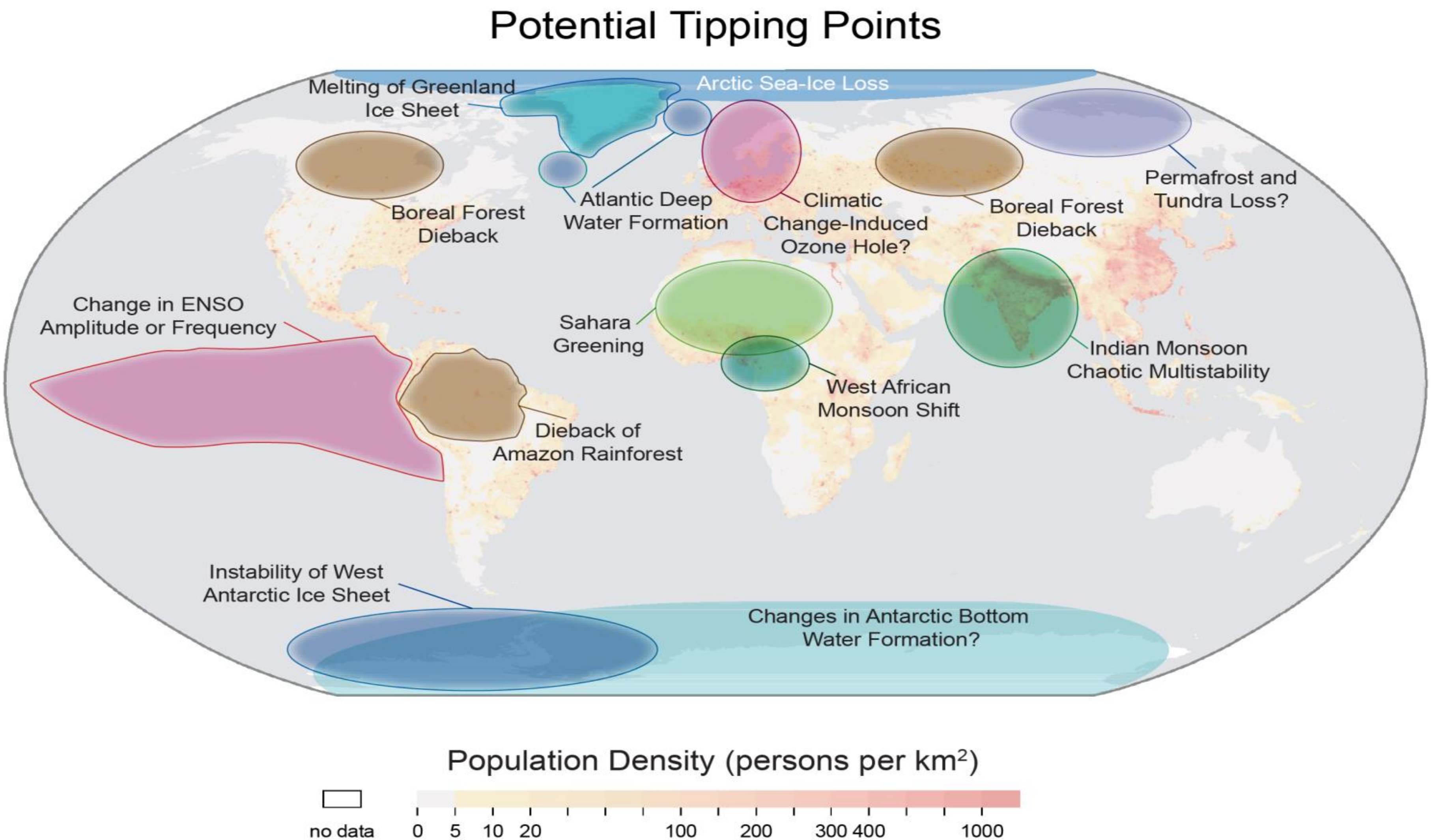
(Gritsevskyi & Schrattenholzer, 2003)

Global Bioenergy Capacity as Constrained by Observed Biospheric Productivity Rates

W. KOLBY SMITH, MAOSHENG ZHAO, AND STEVEN W. RUNNING



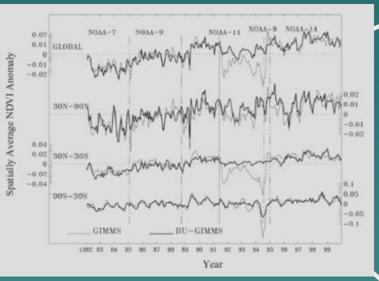
CAN WE MONITOR TIPPING POINTS WELL ENOUGH? HOW ABOUT PREDICTION?



From US National Climate Assessment 2014

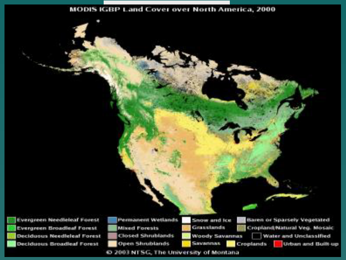
Terrestrial Carbon Monitor

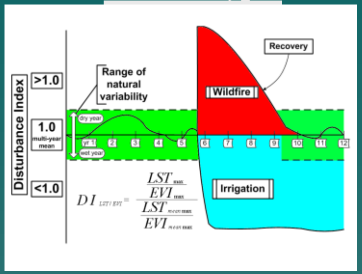
SATELLITE DATA



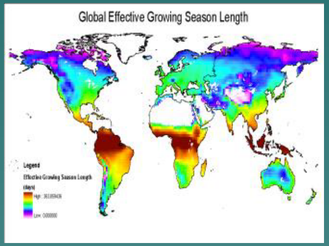
State | Change

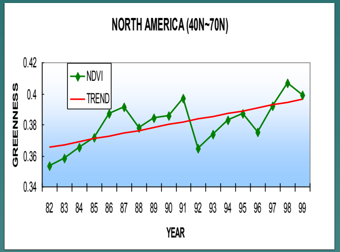
LANDCOVER



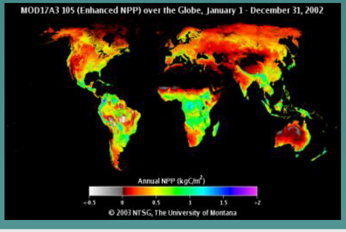


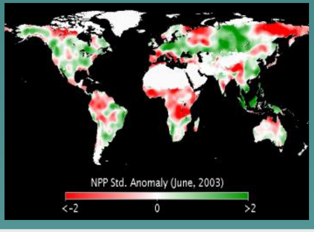
GROWING SEASON



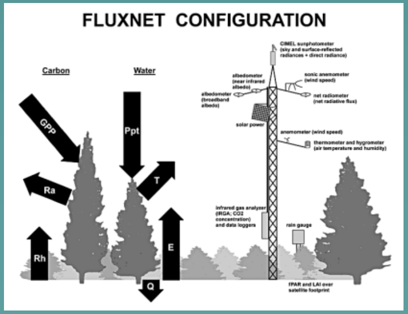


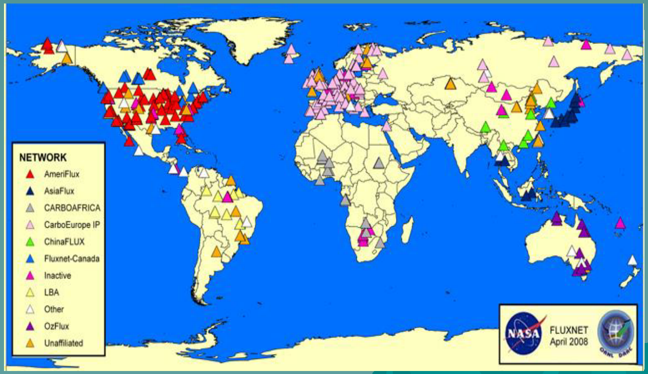
PRIMARY PRODUCTION

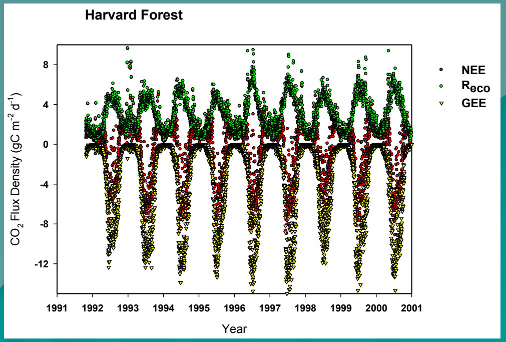




GROUND DATA

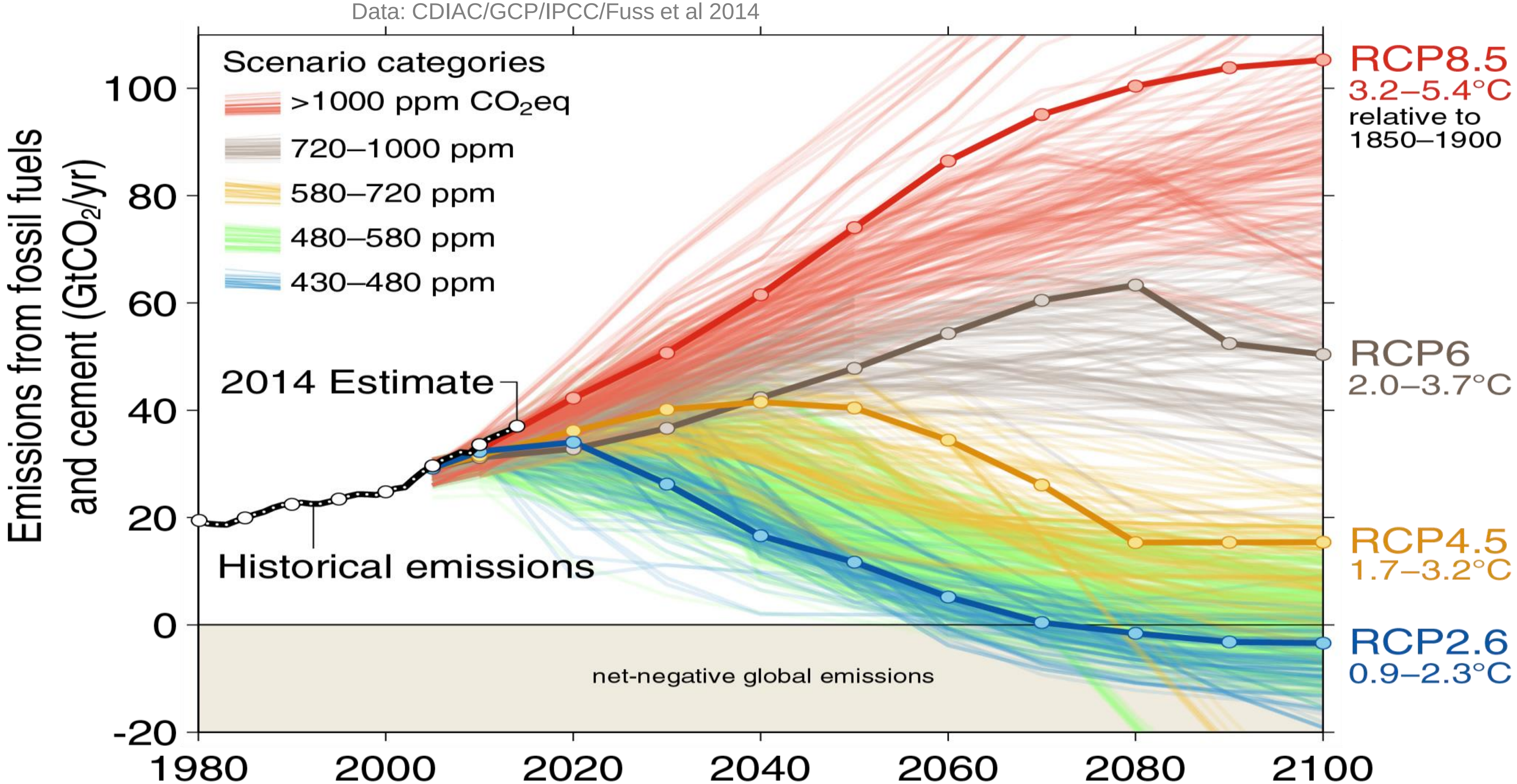






Observed Emissions and Emissions Scenarios

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