The Changing CO_2 Seasonal Cycle
Contribution from the Agricultural Green Revolution

Ning Zeng

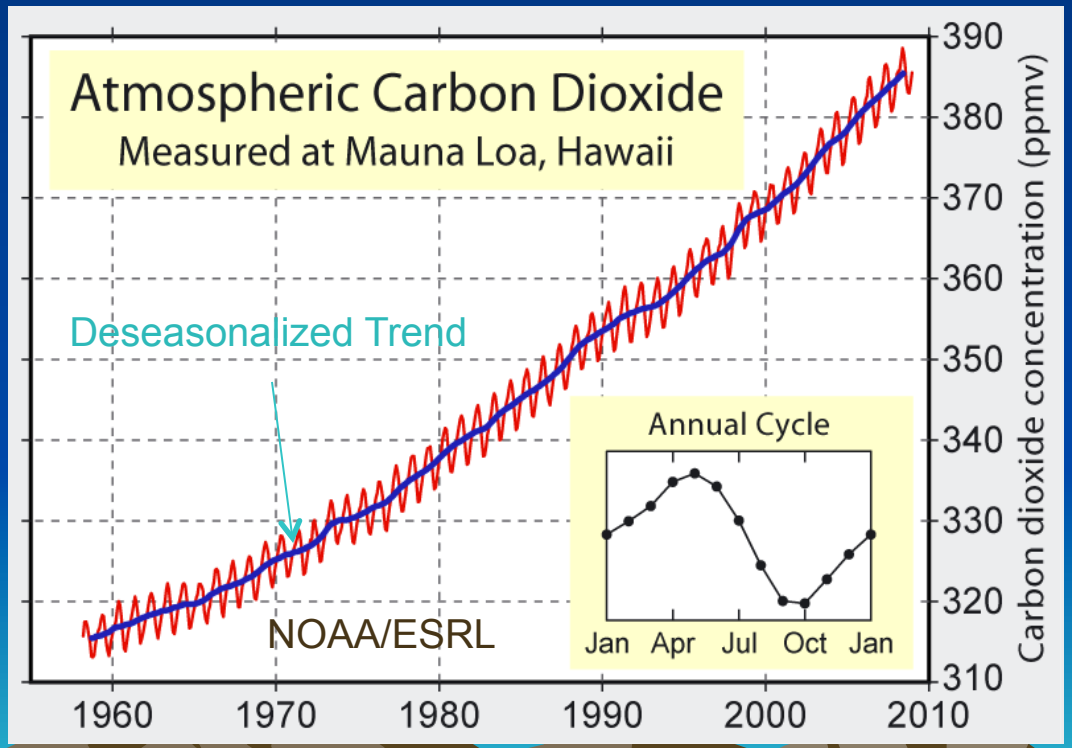
Dept. Atmospheric and Oceanic Science and
Earth System Science Interdisciplinary Center
University of Maryland

With F. Zhao, J. Collatz, E. Kalnay, T. West, R. Salawitch, L. Guanter

CO2 Seasonal Amplitude (CSA)

Major signals in the Keeling Curve:

Trends (long-term change)
Seasonal cycle
Interannual-decadal variabilities



Mean seasonal cycle:

Max in May, min in October
CO2 drawdown for 5 months.
Not symmetric, not exactly sinusoidal
Seasonal amplitude (max-min) ~ 6 ppm

Increased activity of northern vegetation inferred from atmospheric CO_2 measurements

C. D. Keeling*, J. F. S. Chin† & T. P. Whorf*

* Scripps Institution of Oceanography, La Jolla, California 92093-0220, USA
† Mauna Loa Observatory, NOAA/CMDL, Hilo, Hawaii 96721, USA

NATURE · VOL 382 · 11 JULY 1996

The CO2 seasonal amplitude (CSA) increased by 20% at MLO, 40% at Barrow from 1960-1995

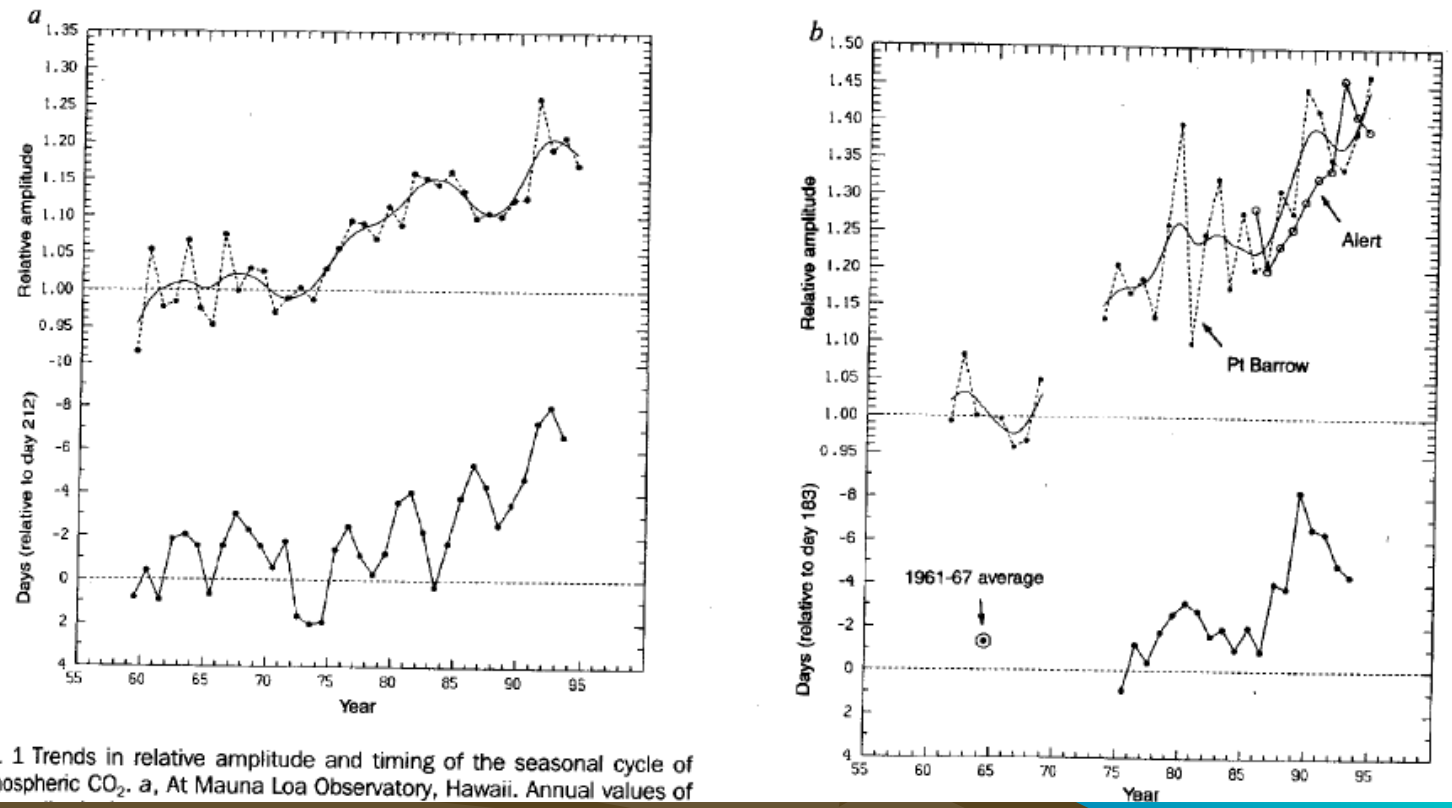


FIG. 1 Trends in relative amplitude and timing of the seasonal cycle of atmospheric CO_2. *a*, At Mauna Loa Observatory, Hawaii. Annual values of

Also:
Pearman and Hyson, 1981
Cleveland, 1983
Bacastow et al., 1985
Graven et al., 2013

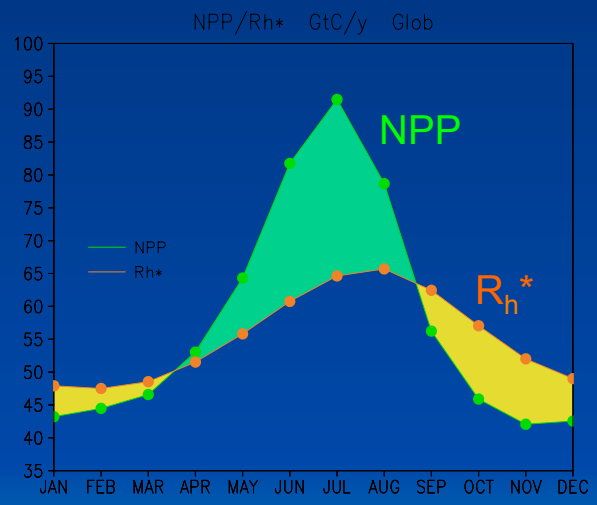
Our analysis: Data/model products

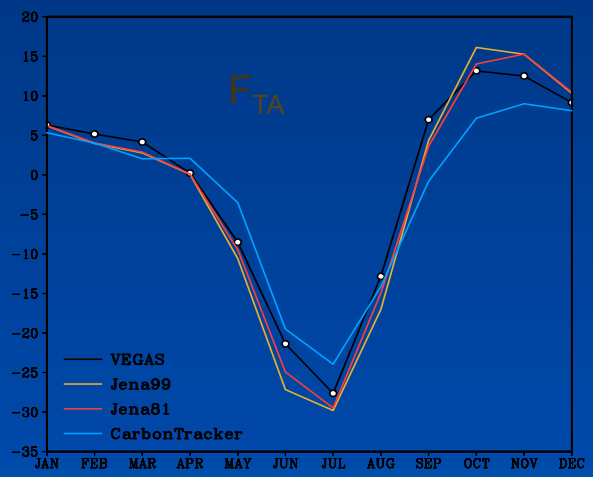
- MLO CO2
- Global CO2 index based on 20+ marine stations (NOAA/ESRL)
- Atmospheric inversions v3.4 (MPI/Jena)
- CarbonTracker 2011 (NOAA/ESRL)
- Terrestrial carbon models: VEGAS (UMD) + LPJ + ORCHIDEE
- Statistics (population, land use, crop production etc.)
- FLUXNET (Global network of eddy correlation towers to measure surface fluxes of evaporation, heat, CO2, etc.)

The mean CO2 seasonal cycle I
The dominance of Northern Hemisphere vegetation

- Vegetation takes up atmospheric CO2 during spring/summer growing season, while respiration and decomposition has a much weaker seasonal cycle

- $F_{TA} = R_h^* - NPP$



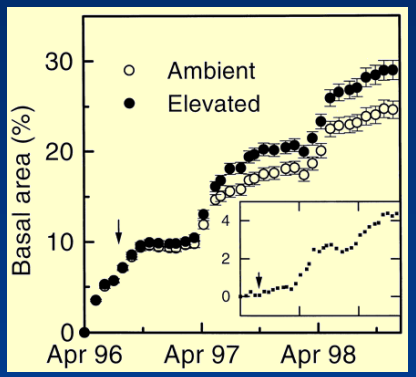


F_{TA} -- Net land-atmosphere carbon flux

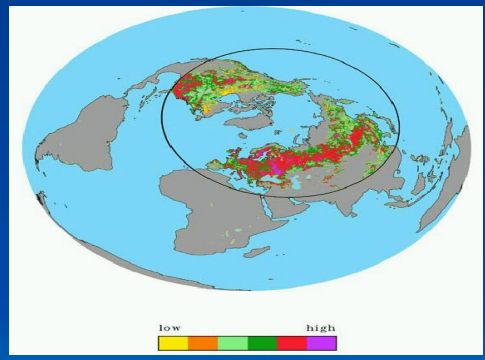
R_h^*-- Respiration extended (including heterotrophic respiration, fire and other losses to the atmosphere).

What caused CSA increase?

- CO2 fertilization effect
- High latitude warming
- FFE and ocean



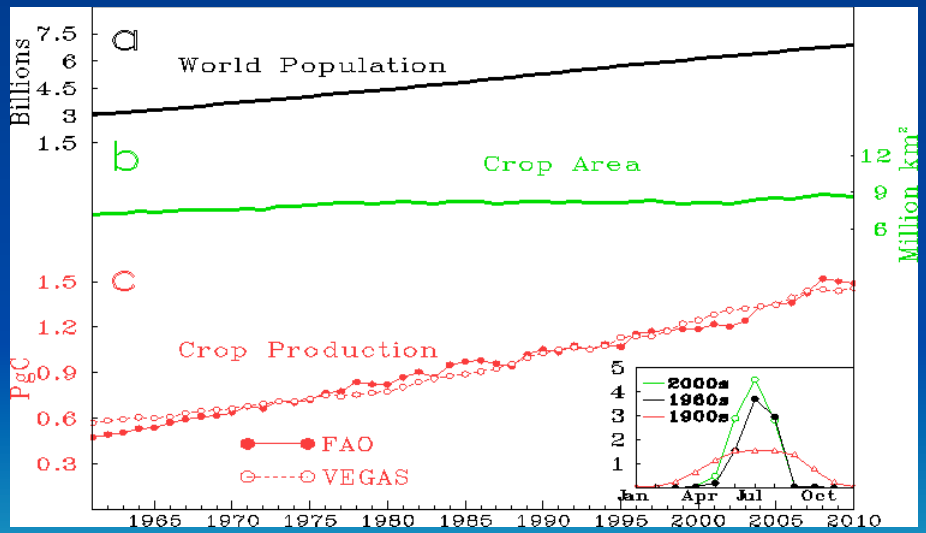
- Land use and management (LULUCF): impact on long-term sink, but seasonal cycle?

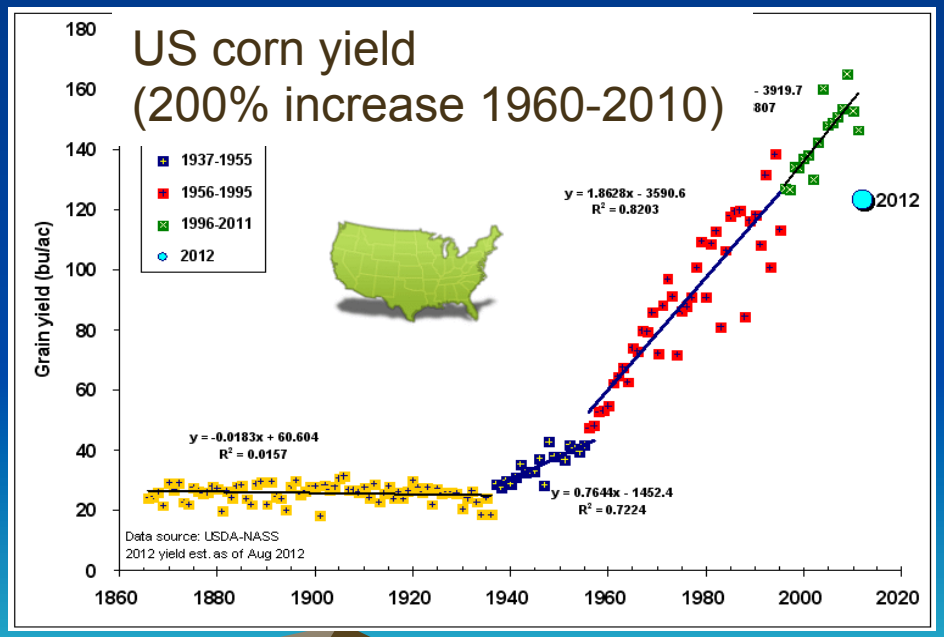


A closer look at land use

Not just land cover change, but also management intensity

- Over the last 5 decades (1961-2010)
  - World population increased from 3 to 7 billion (130%)
  - Crop production increased from 0.5 to 1.5 PgC/y (200%)
  - Major crop area 7.2 to 8.7 Mkm2 (20%)

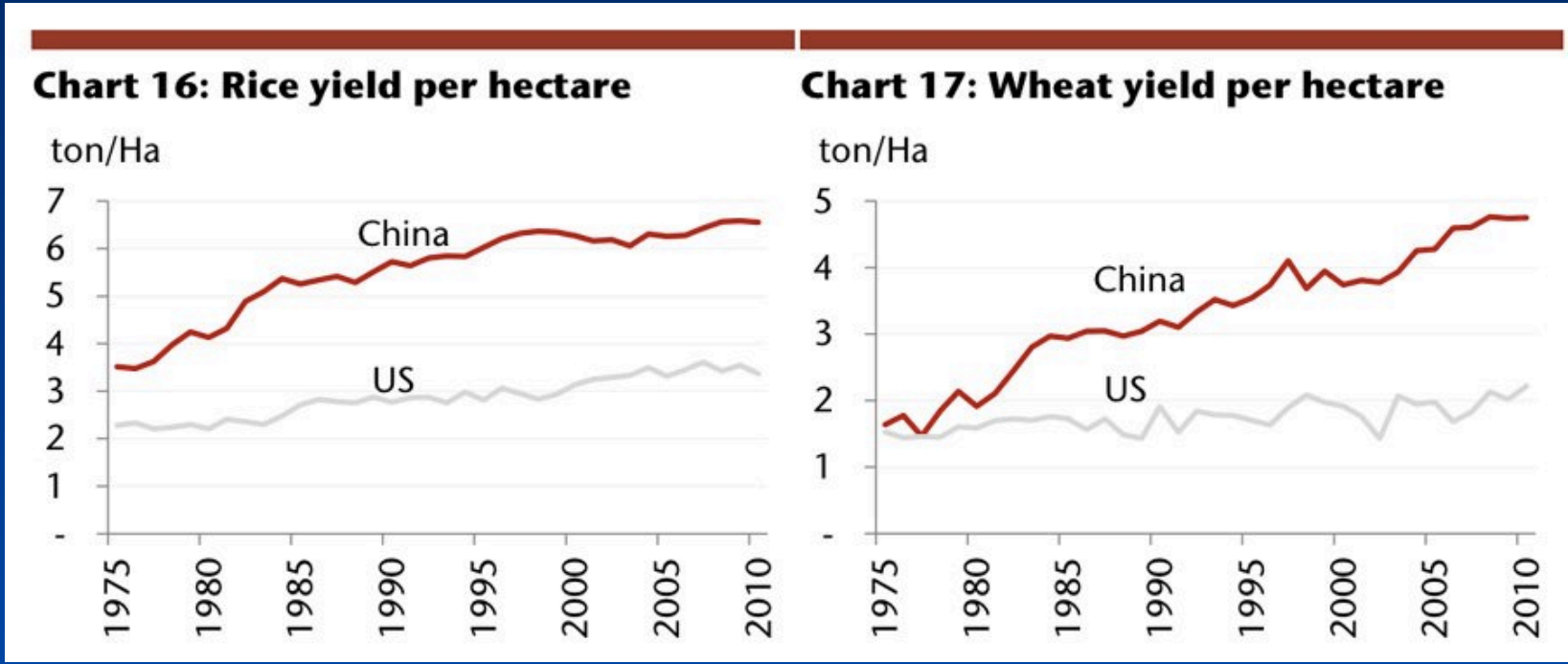




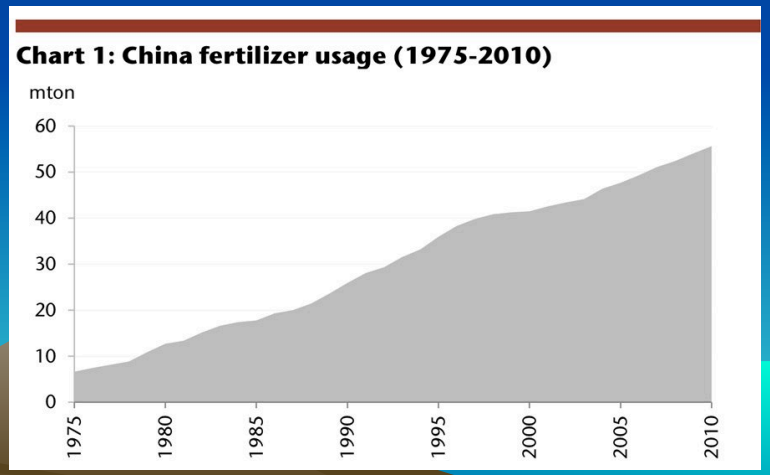
Hoerling et al., BAMS 2014

In comparison, cropland area hardly increased

China vs. US: Yield



Yield: China is 2 times higher
Fertilizer use per hectare: China is three times higher

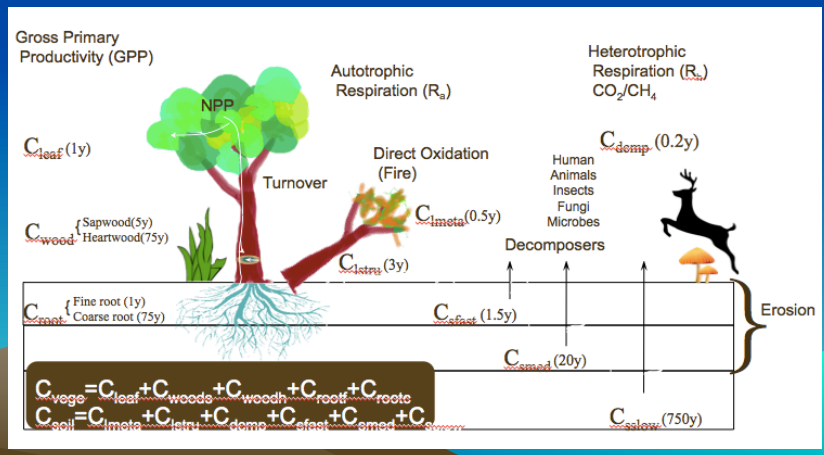


Can intensification of agriculture contribute to CSA increase?

- Global NPP is 60 PgC/y, of which about 6-8 PgC/y is human appropriated NPP (HANPP)
- Now assume HANPP doubled as the result of the agricultural Green Revolution since 1960, so that ΔNPP=3 PgC/y
- Further assume that seasonal characteristics (shape/phase) of NPP and Rh do not change (e.g., Randerson et al., 1999)

This leads to a NPP change of 3/60=5% change, 1/3 of observed CSA increase at MLO

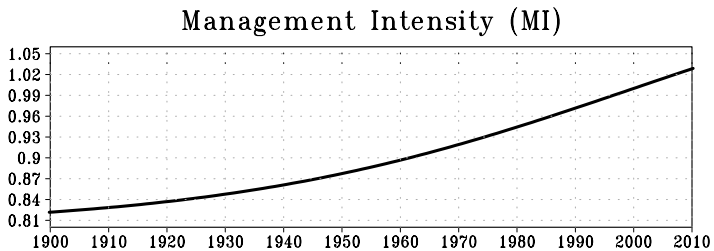
Test this hypothesis in a mechanistic model…



The VEGAS model
Participant of MsTMIP and TRENDY
Zeng et al. 2003-2014

Cropland management change over time
---Modeling the Agricultural Green Revolution

- Three major factors changed over time and are thought to have contributed equally to increase in agricultural productivity in the later half of the 20th century (Sinclair, 1998)
  - High-yield cultivars
  - Fertilizer/pesticide
  - Irrigation



- Due to lack of data, simple rules are used. A management intensity factor (MI) due to cultivar and fertilizer enhanced productivity is a function of space (M_1, regional difference) and time:

$$MI = M_0 M_1 (1 + 0.2 \tanh(\frac{year - 2000}{70})$$

- Irrigation enhances GPP by a 'gentle' enhancement of the soil moisture dependent function:

$$\beta = 1 - \frac{1 - w_1}{W_{irrg}}$$

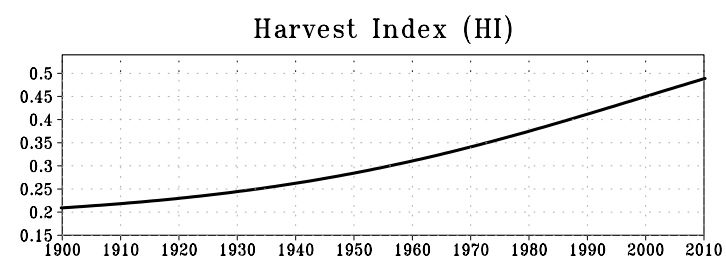
- **A main drawback** is the lack of regionally specific information: may be OK with the global CO2 sea cyle

Planting and havesting
Harvest Index (HI) change over time

- Planting is allowed whenever climate condition is suitable, .e.g. due to spring warming in cold/temperate climate, i.e., “potential crop”
  - Captures much of temperate agriculture
  - Doesn’t get winter wheat which grows earlier
- Harvest occurs when leaf area index (LAI) growth rate slows to a threshold
  - May lead to double crop in some tropical regions
- After harvest, grain goes into a harvest pool while the remainder goes to the two litter pools. The harvest grain is laterally transported according to population density and trade
- Harvest Index (HI) is the ratio of grain and total above ground biomass.

$$HI_{crop} = 0.45(1 + 0.6\tanh(\frac{year - 2000}{70}))$$

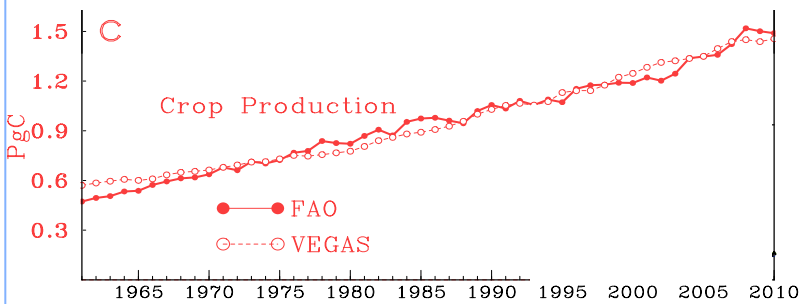
HI is 0.45 in 2000, and 0.31 in 1960: result of high yield cultivar



Validation of crop simulation in VEGAS

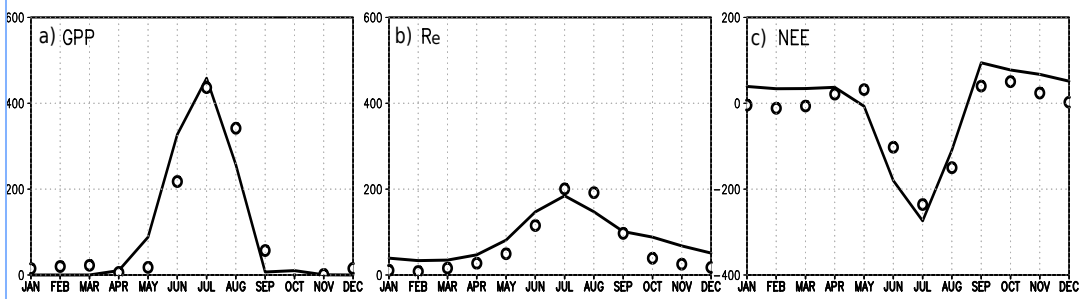
(Simulation: TRENDY protocol: forced by climate, CO2, and land use)

1. Crop production increased by 0.8, compared to FAO by 1 PgC/y



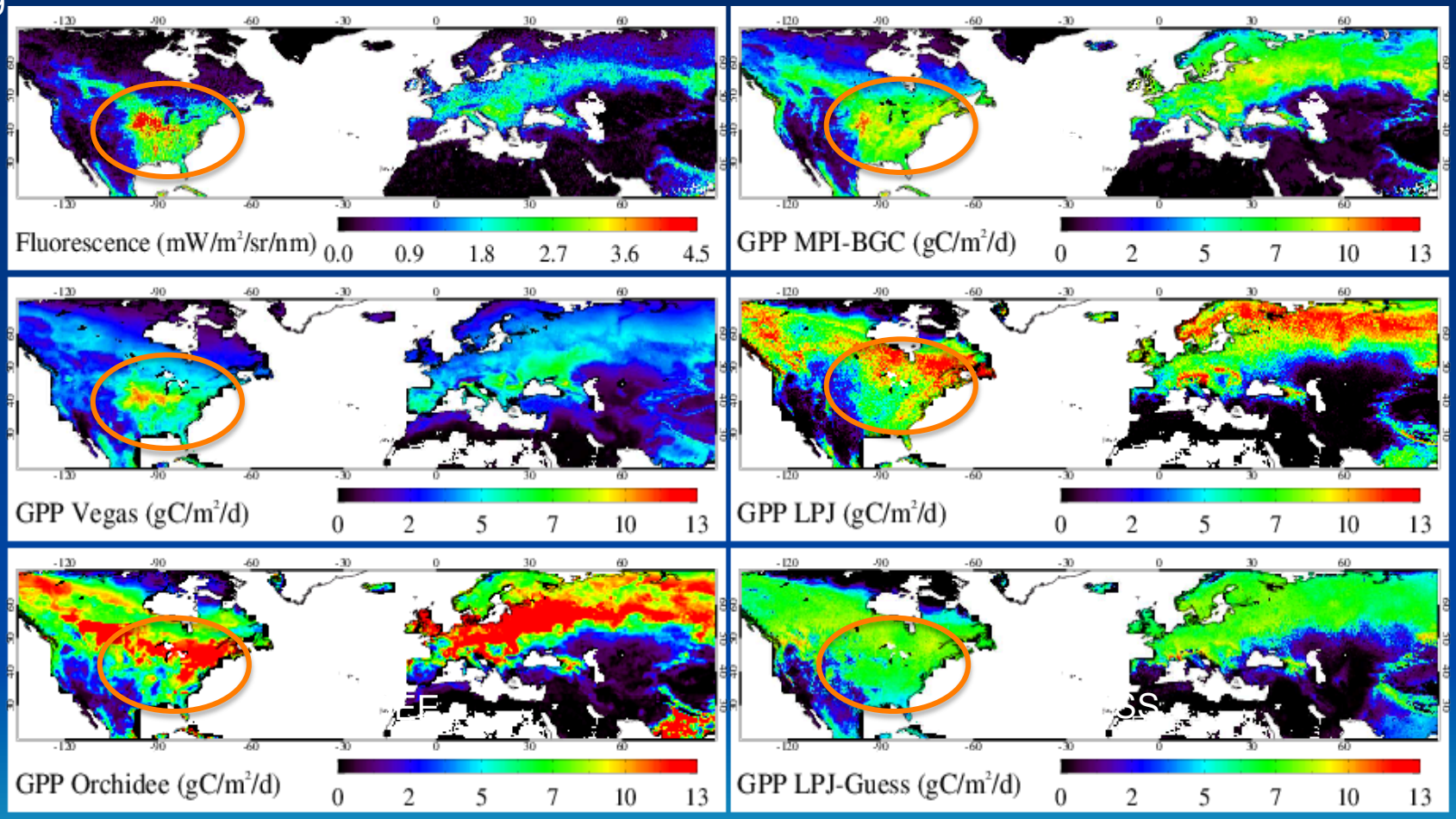
2. Simulated crop NPP_{crop} is 6.2 PgC/y, compared to HANPP 6-8 PgC/y (Vitousek et al., 1986; Haberl et al., 2006)

3. Comparison of VEGAS with FLUXNET measurement at Bondville, Illinois



Sun-induced Chlorophyll fluorescence (SIF):
Comparison with GPP from data-driven estimates MTE of MPI-Jena
and 4 TRENDY carbon models (LPJ, ORCHIDEE, LPJ-GUESS and VEGAS)

July 2009

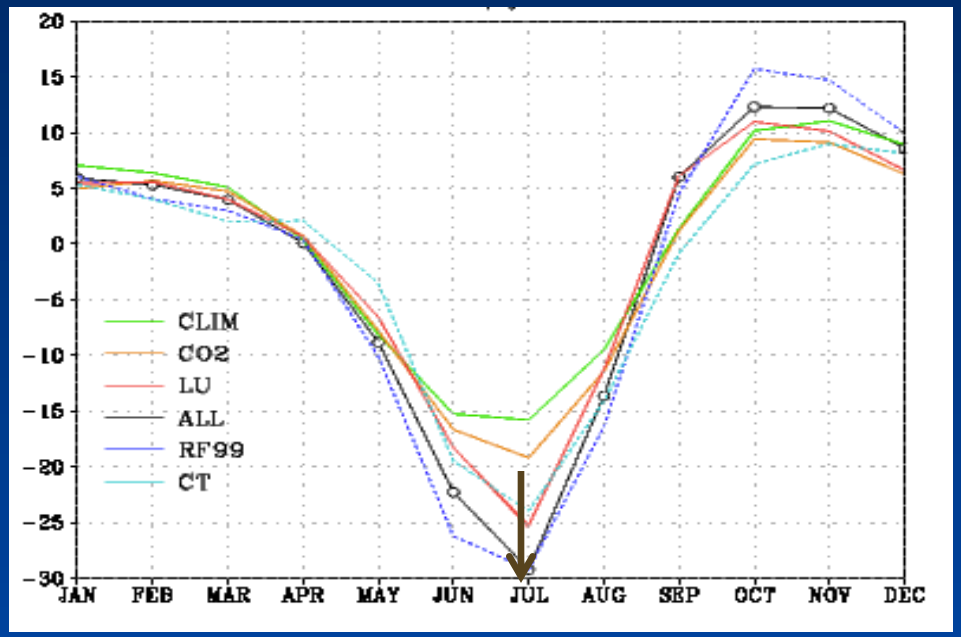


Most models miss the high productivity in agricultural region, except for one…

Guanter et al. (2014), PNAS

Impact of agriculture on modeled seasonal cycle

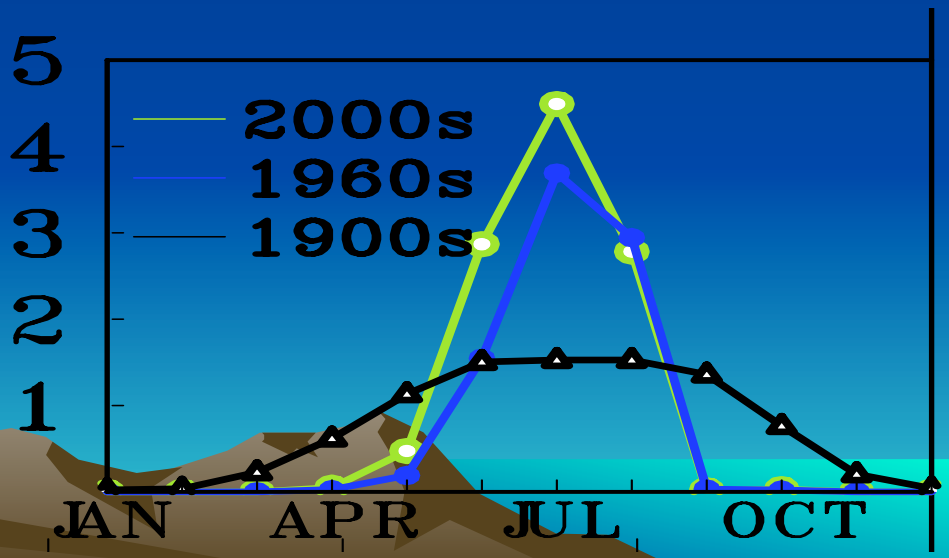
Mean seasonal cycle has a larger drawdown during growing season (~20%)



Seasonal characteristics change

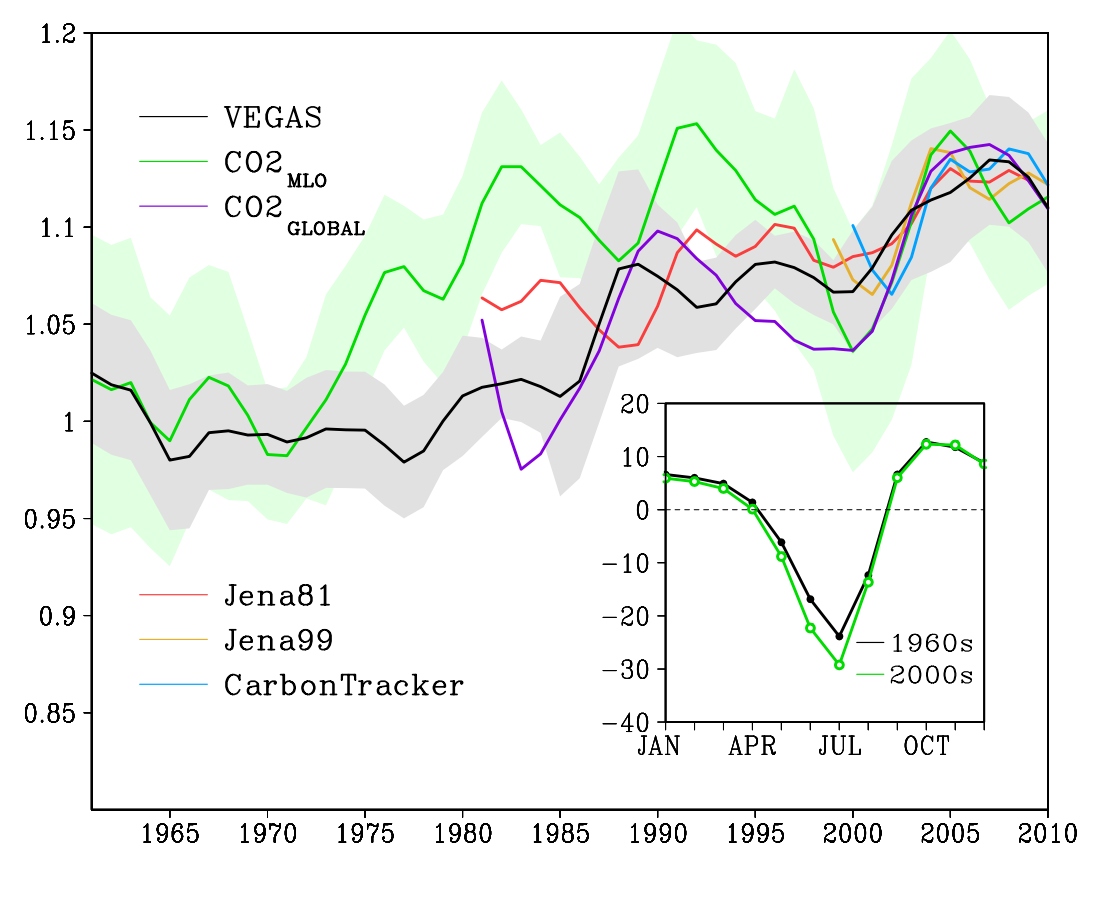
GPP change at a US Midwest location

- 1900s – Natural vegetation
- 1960s - Agriculture
- 2000s – Agriculture intensified



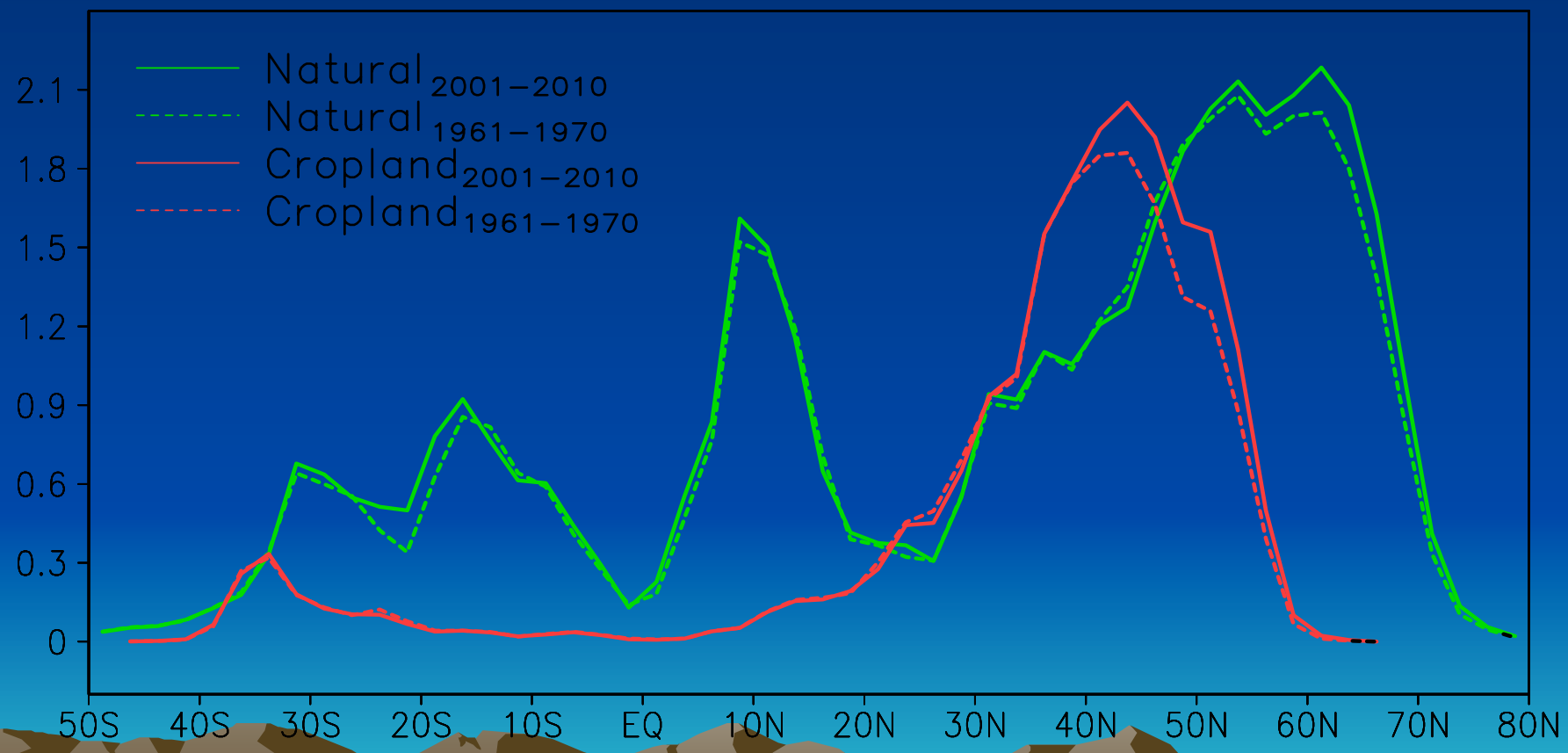
Change in CSA 1961-2010

- A long-term increase in seasonal amplitude (SA) by about 15% (MLO CO2g and VEGAS F_{TA})
- Large dacadal (interannual filtered out) variability
- Good (but not great) agreement on both trend and decadal variability among model, CO2 (MLO and GlOBAL), inversions (MPI/Jena and CarbonTracker)
- Compared to the 1960s, 2000s has a larger drawdown in NH spring/ summer; early by about 10 days
- Corresponding to an stronger mean carbon sink by 1.6 PgC/y

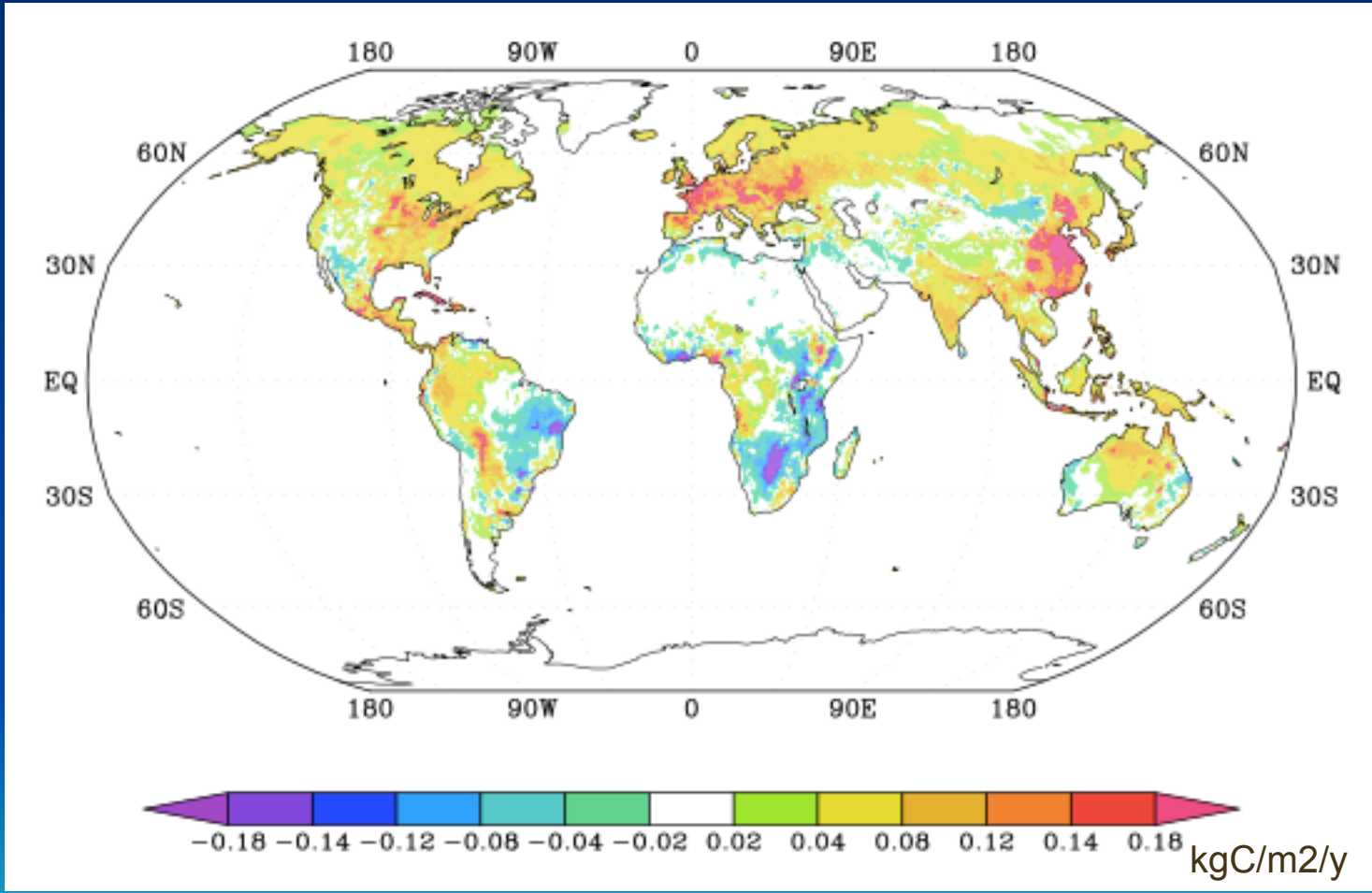


Zeng et al., 2014, Nature, revised

Separating cropland and natural vegetation



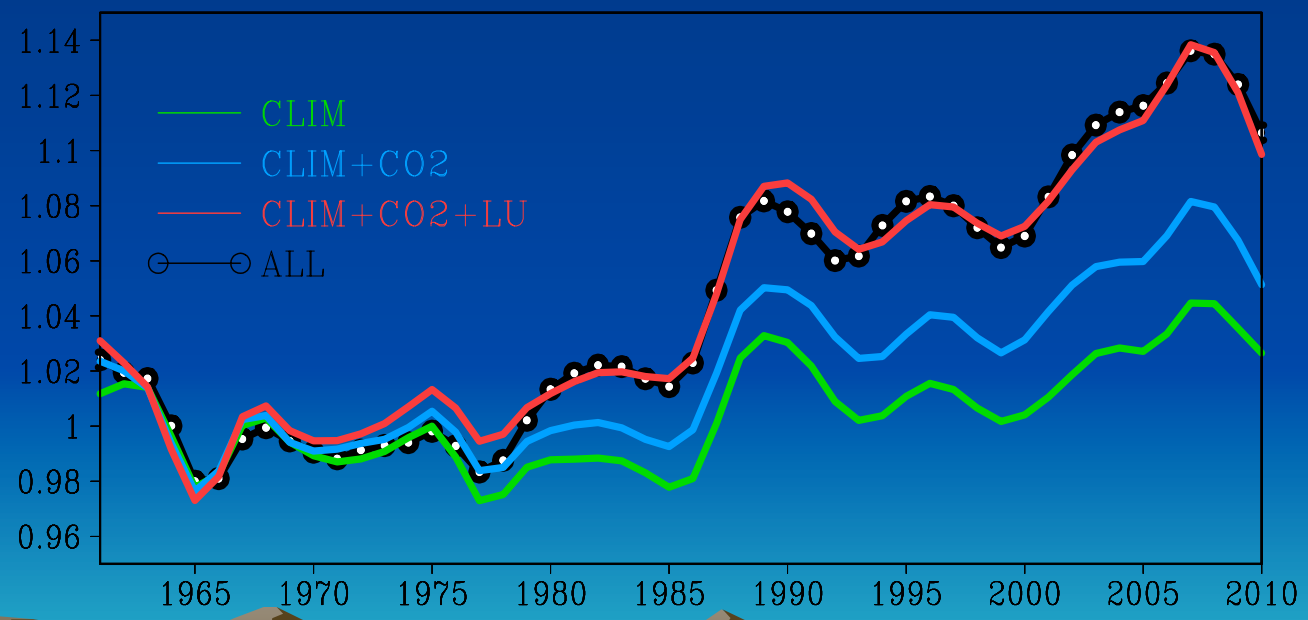
1961-2010 trend in NPP



Is there observational evidence for this?

Factorial sensitivity experiments

CLIM: Climate only
CO2: CO2 fertilization only
LU: Land use and management



Thank you!

Conclusion

- The basic rhythm of the biosphere: seasonal ‘breathing’ has been changing: 15% increase in CSA with large decadal-interannual variations
- CO2 fertilization, high latitude warming contributed
- We suggest a missing link: the intensification of agriculture

* Human impact on the biosphere/climate is complex

Question: How is this ‘enhanced’ activity related to the mean land carbon sink?