Enhanced terrestrial carbon uptake: global drivers and implications for the growth rate of atmospheric CO_2.

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BGC Friday Meeting Jan 20th 2016

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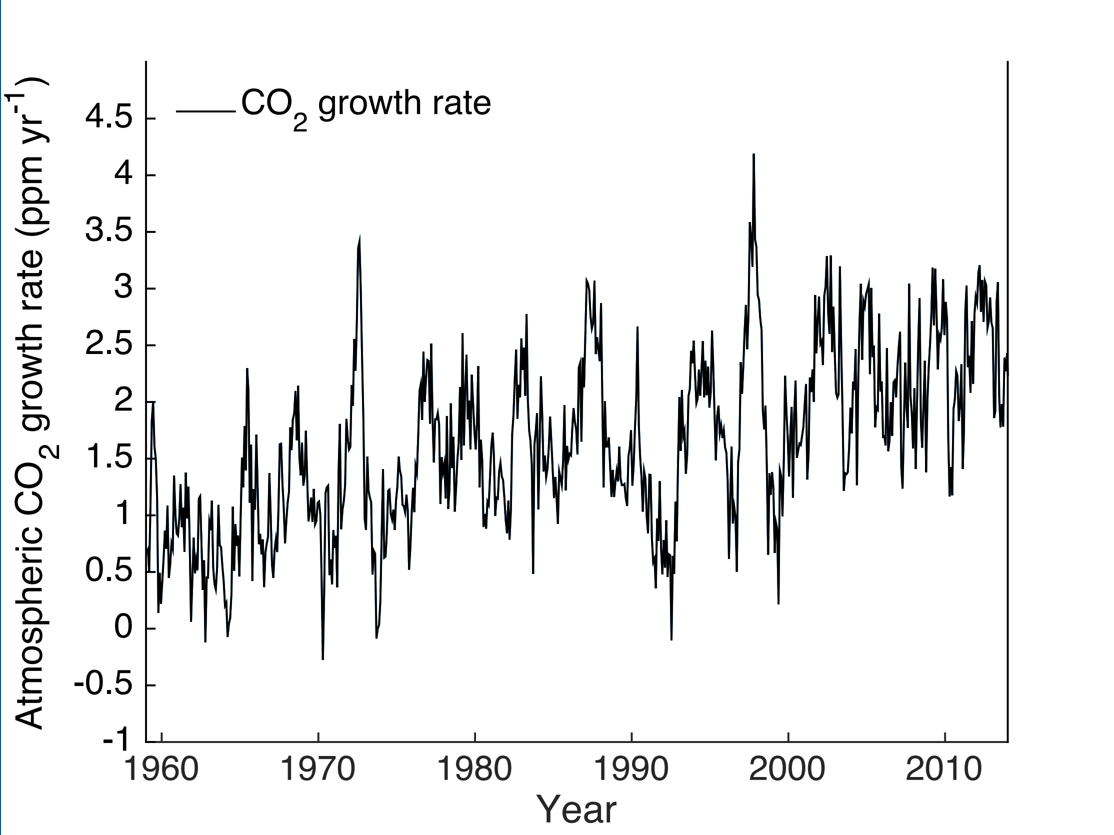
The growth rate of atmospheric CO_2

GR_{CO2} = emissions (fossil fuels, land use change, cement production)

- Terrestrial CO_2 sinks

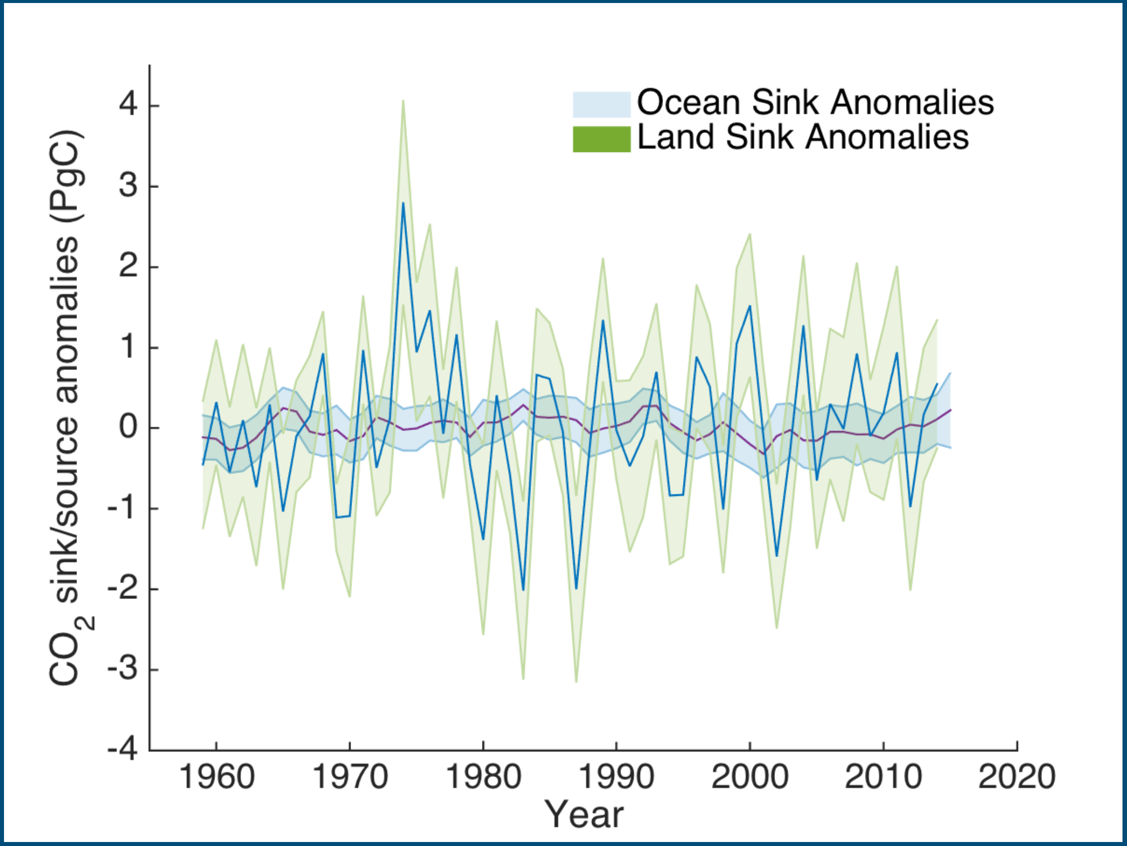
- Oceanic CO_2 sinks

The growth rate of atmospheric CO_2



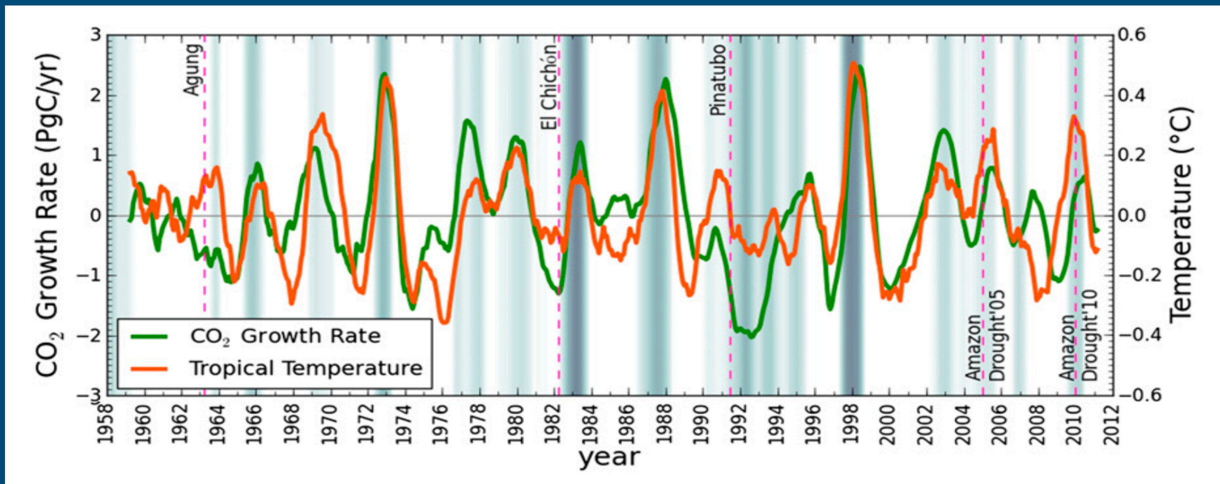
Data source: Scripps CO_2 program @ Mauna Loa

Land drives variability in the growth rate



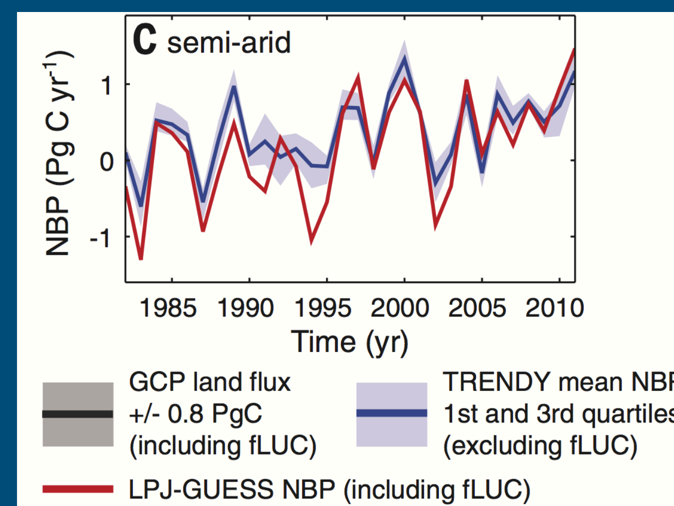
Data source: Global Carbon Project

Linking the growth rate to the land



Weile Wang et al. (2013)

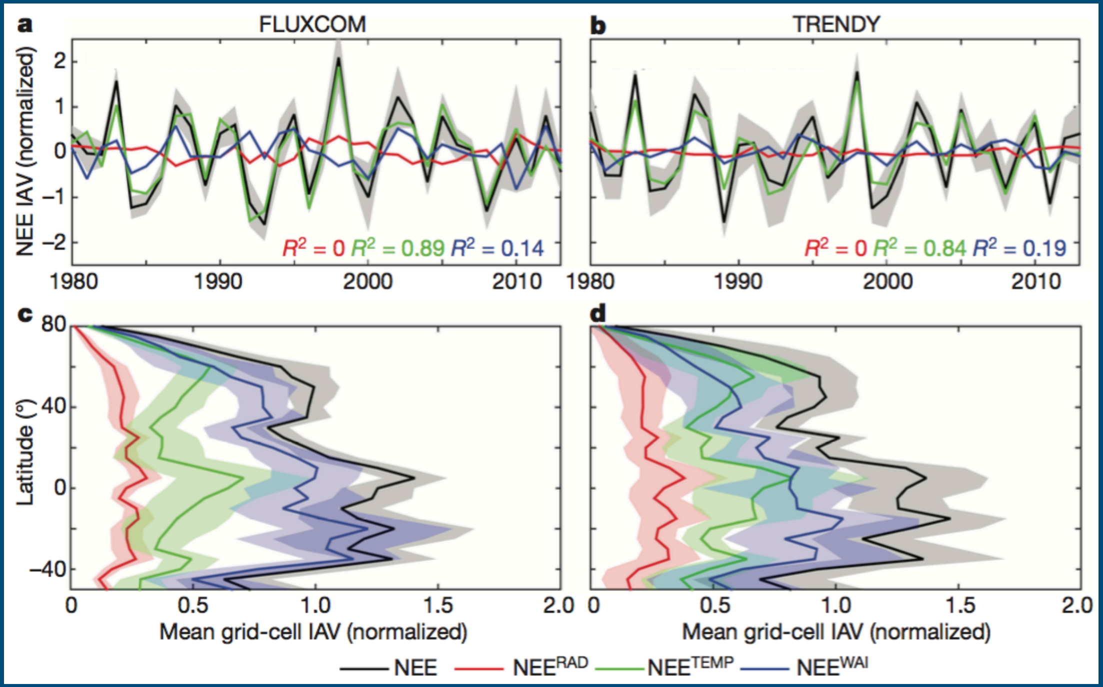
Ahlström et al. (2015); Poulter et al. (2015)



Variation in the growth rate tightly coupled to tropical temperatures.

Semi-arid regions also play an important role.

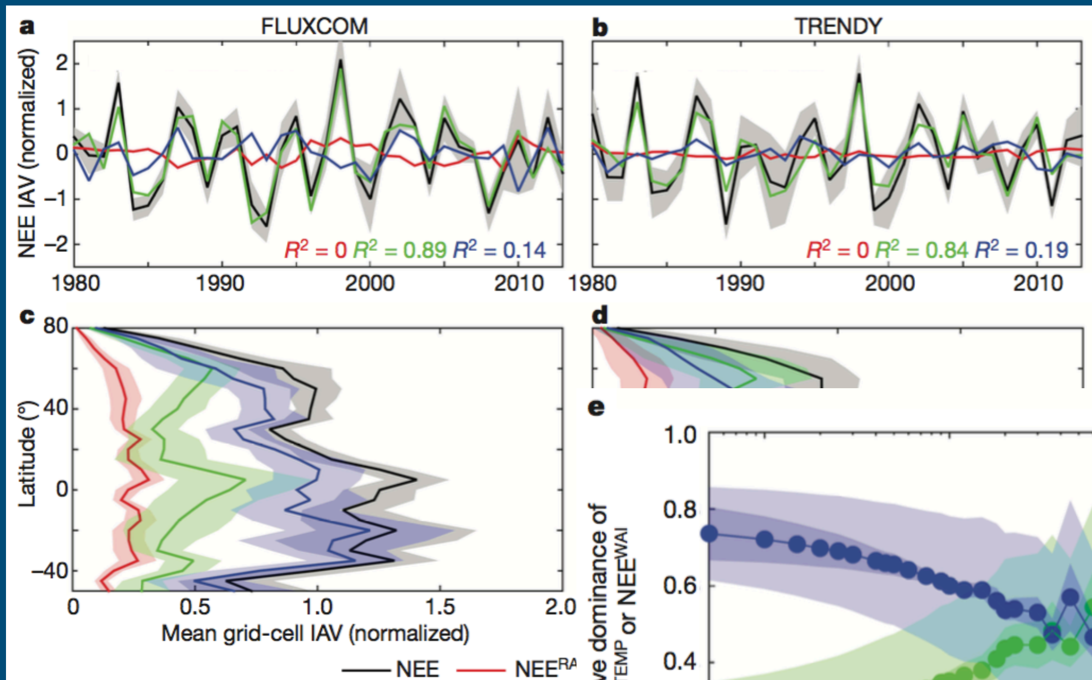
Linking the growth rate to the land



Jung et al. 2017

Water matters!

Linking the growth rate to the land



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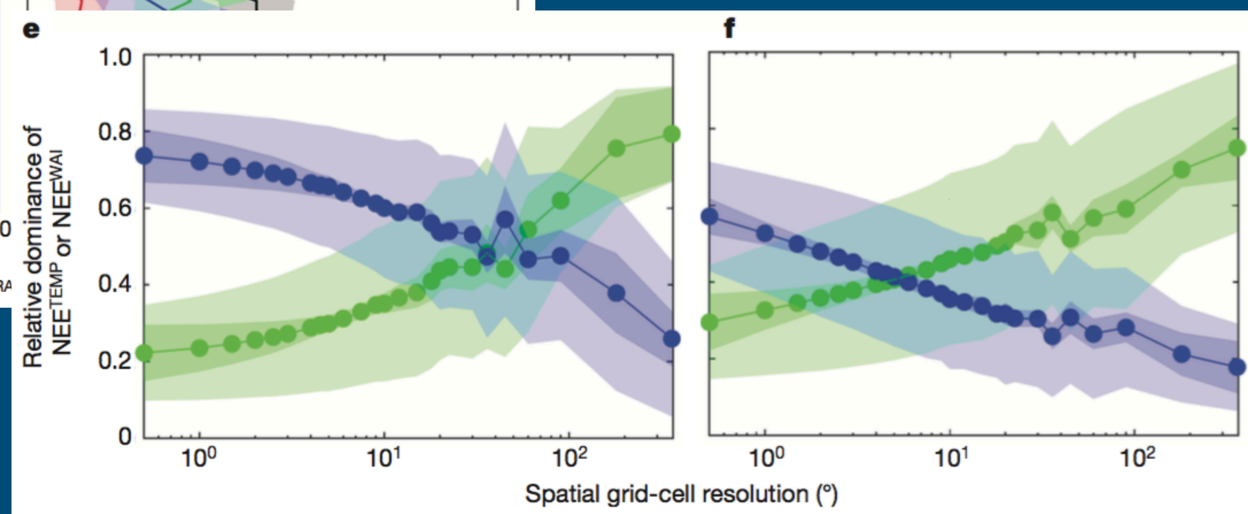
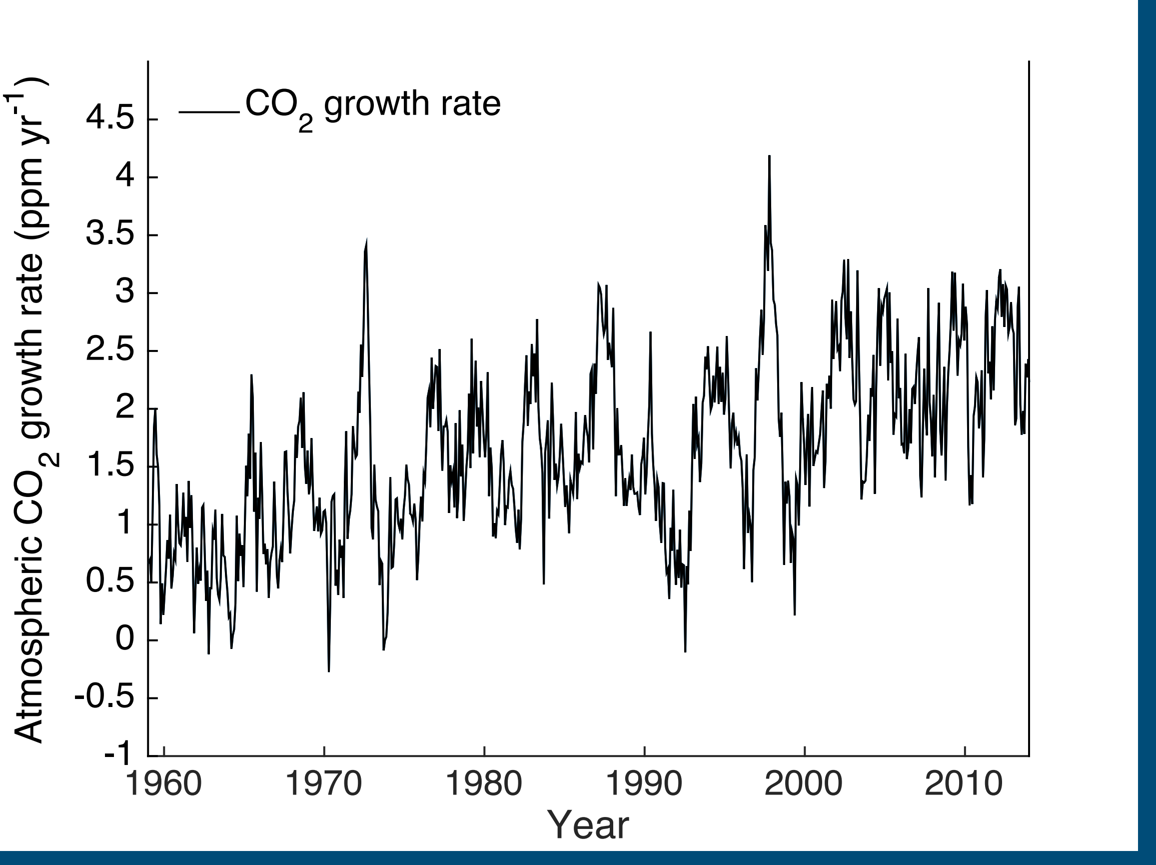


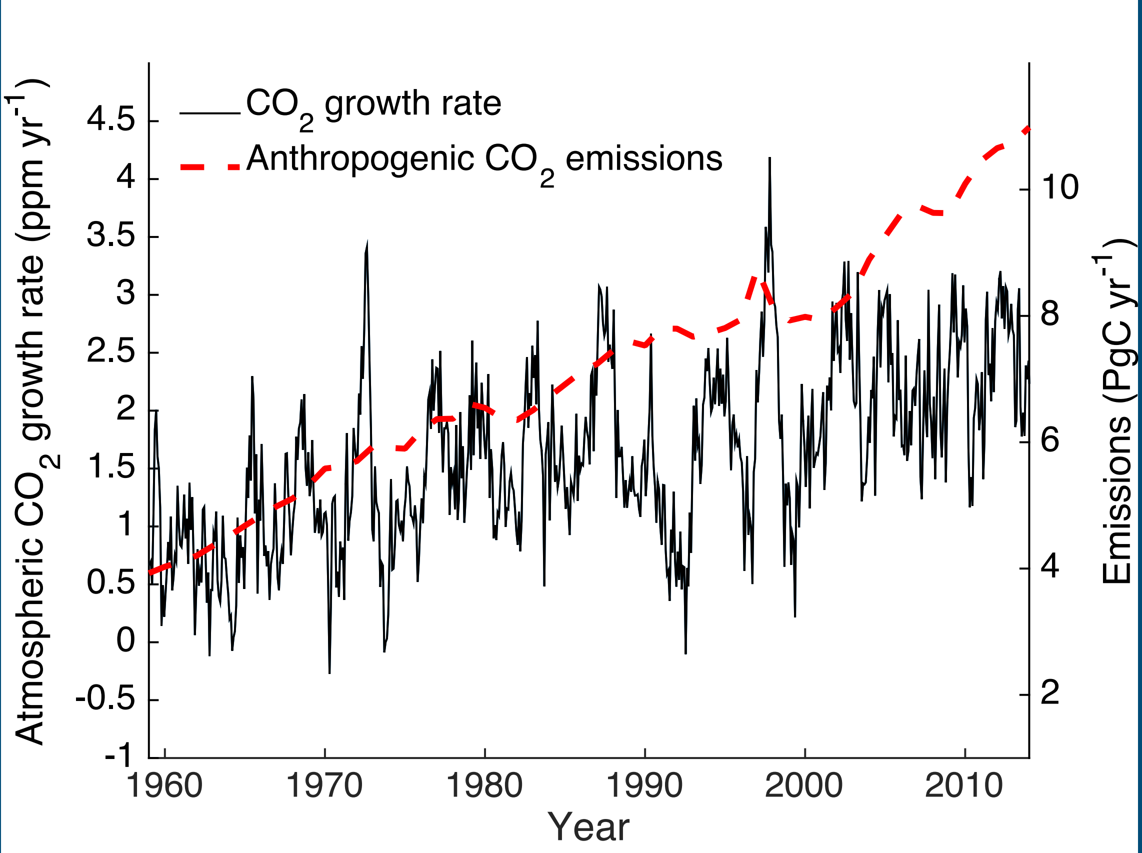
… at almost all scales but the globe!

The growth rate of atmospheric CO_2



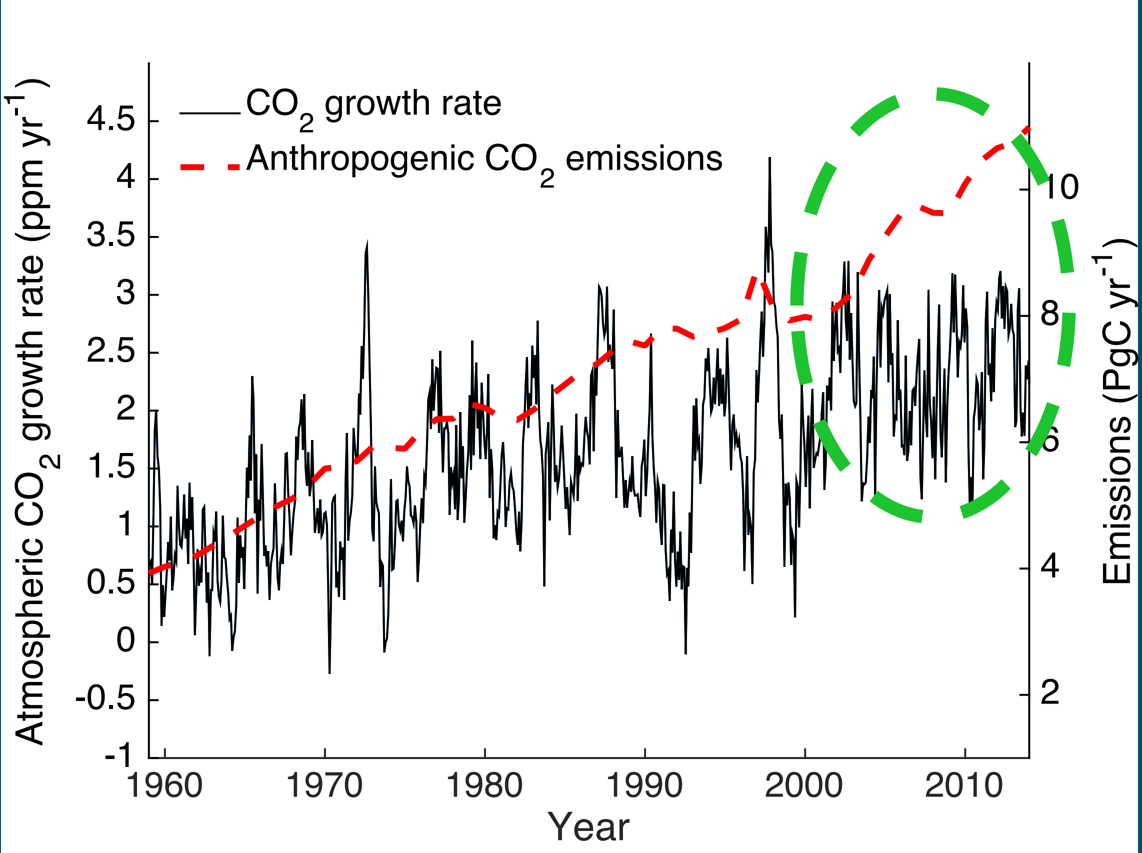
Data source: Scripps CO_2 program @ Mauna Loa

The growth rate of atmospheric CO_2



Data source: Scripps CO_2 program & GCP

The growth rate of atmospheric CO_2



Data source: Scripps CO_2 program & GCP

First-order diagnostics of the growth rate

Construct a linear model by assuming that the sink is a linear function of atmospheric CO_2 concentration:

$$F_{sink} = M + F_0$$

where *β* is the inverse residence time for excess carbon against the processes of land and ocean uptake.

$$GR_{CO2} = F_{fossil} + F_{LUC} - F_{SINK}$$

First-order diagnostics of the growth rate

- Predict the growth rate using the linear model
- Examine dynamics of the residuals over time
- Any change in the residuals suggests a deviation of global sinks from the assumption of linearity.

Keenan et al. (2016)

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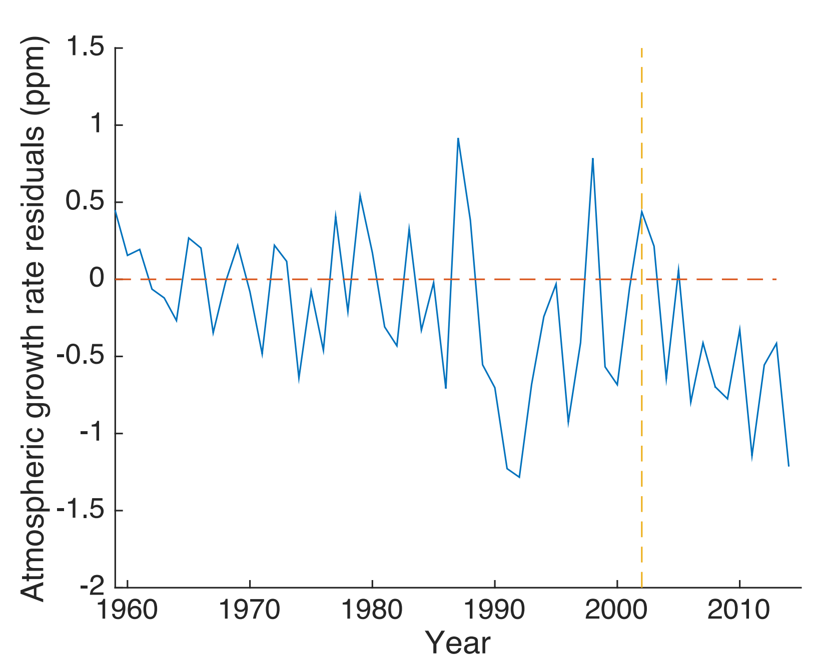
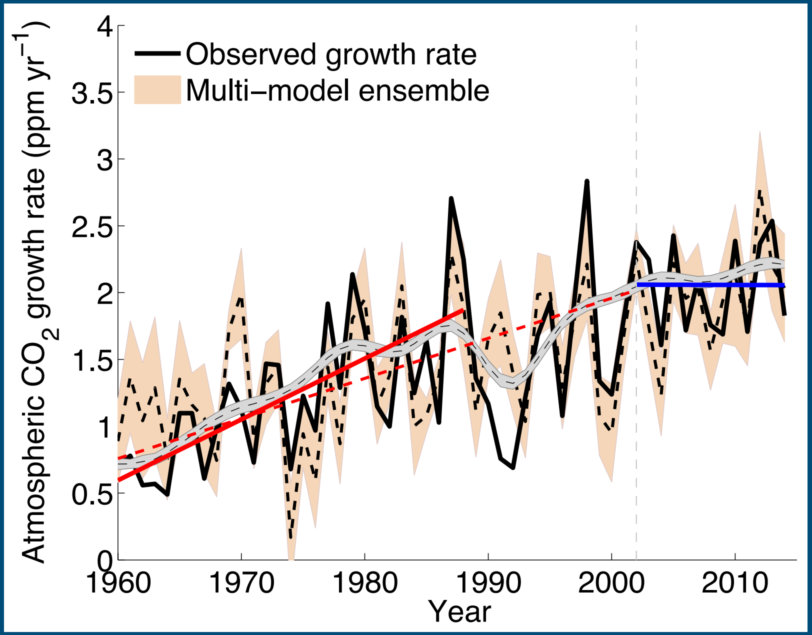
Residuals



Keenan et al. (2016)

Growth Rate pause



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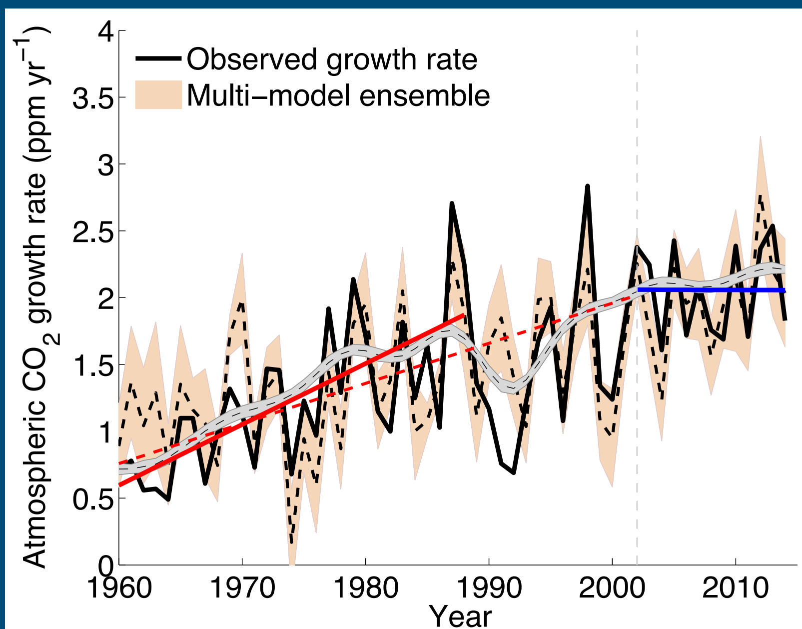
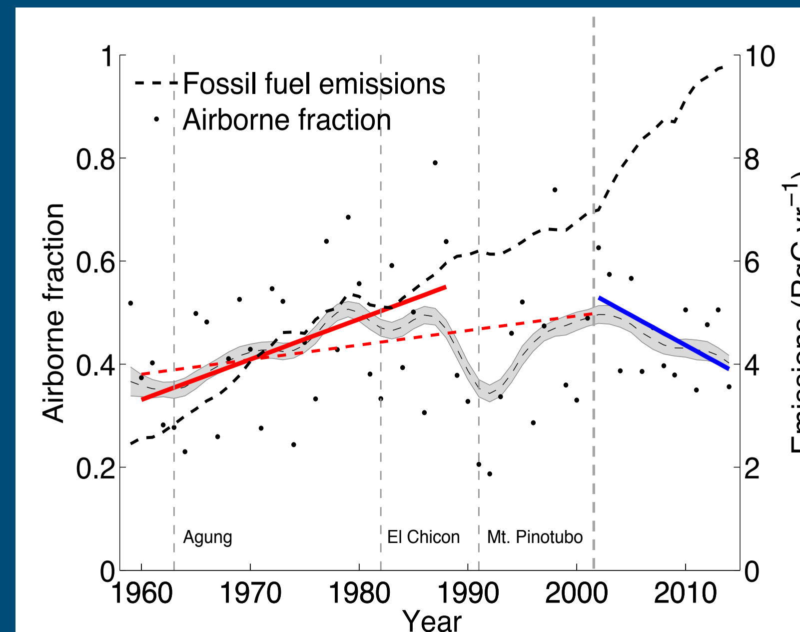
Growth Rate pause

Airborne Fraction decline



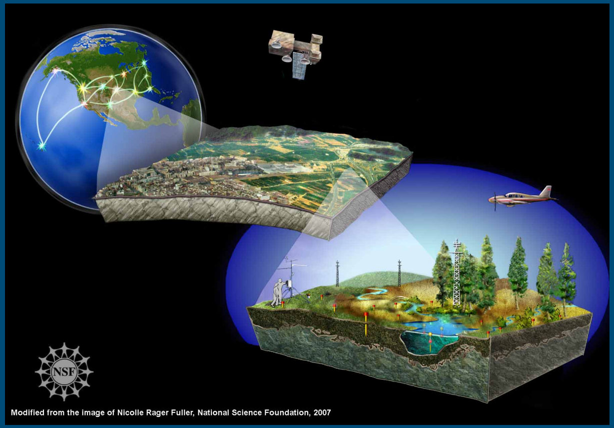


Keenan et al. (2016)

Examining long-term changes in the Global Carbon Cycle

- Global Carbon Project data (Le Quere et al., 2015)
- Dynamic global vegetation models (Sitch et al., 2015)
- A diagnostic model of the global carbon cycle
- Validation: FLUXNET, NOAA, Jena GPP, DGVMs, NOAA atmospheric CO_2 concentrations

Design of a global diagnostic model



Design of a global diagnostic model

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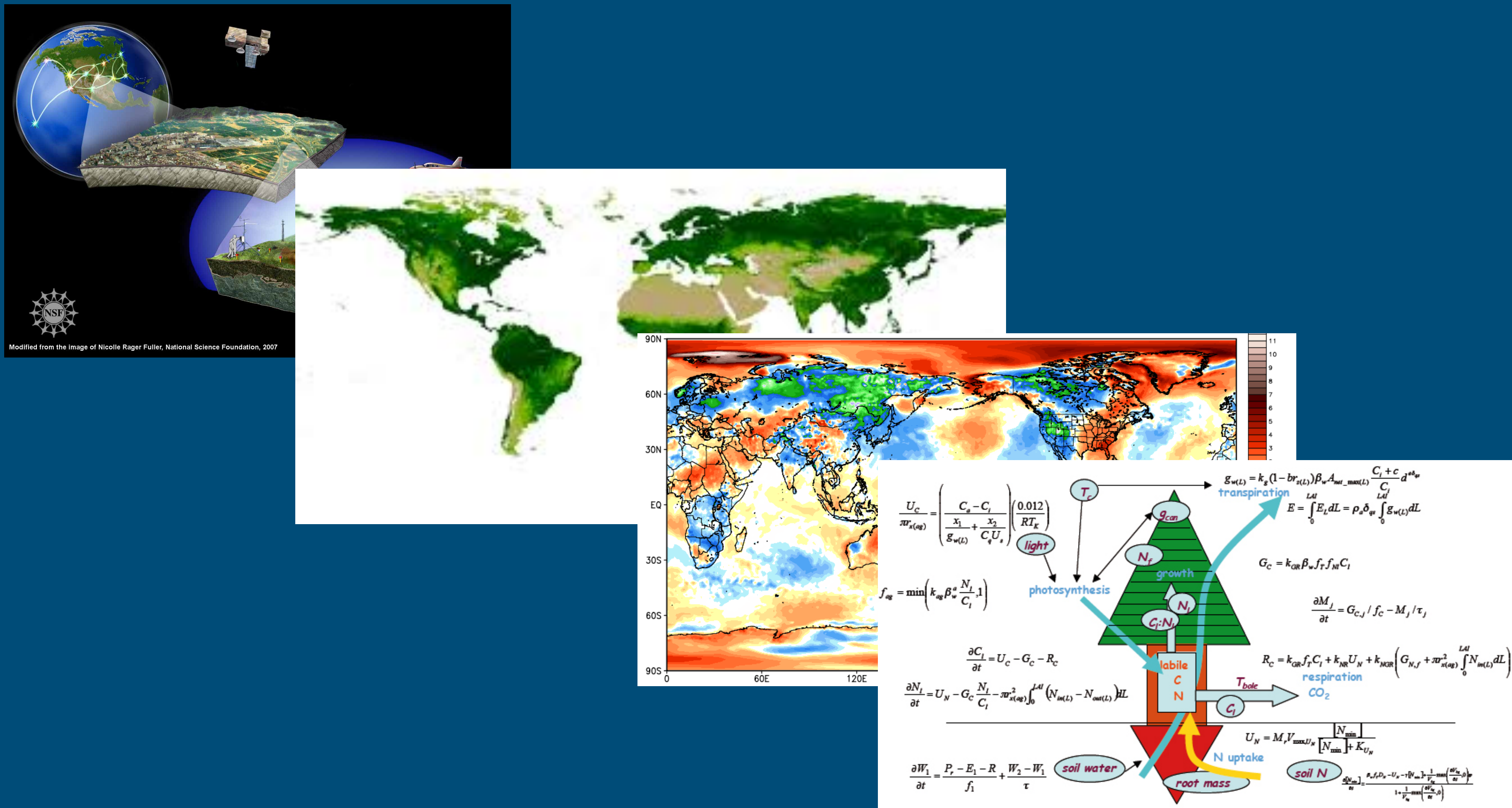


Design of a global diagnostic model

The co-limitation hypothesis:

"Plants allocate nitrogen to maintain a balance between two processes ... each of which potentially limits photosynthesis"

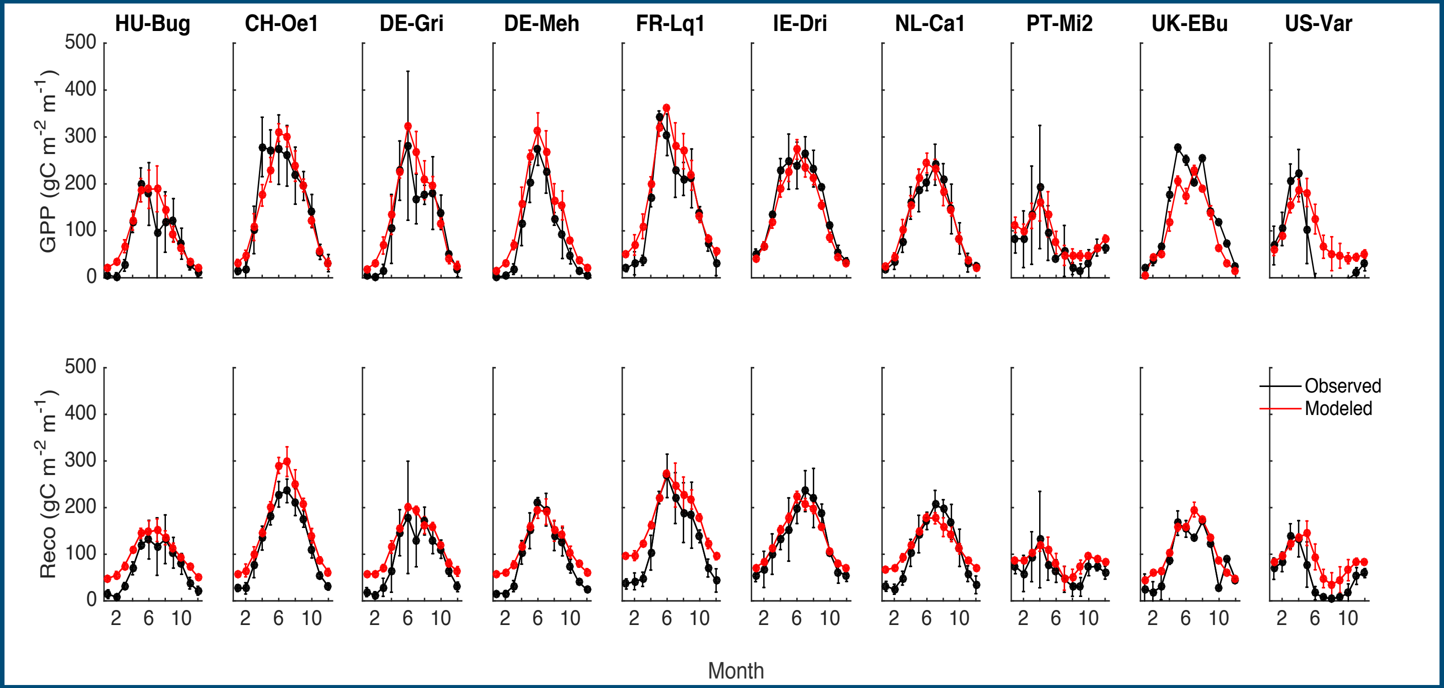
Chen et al. 1993

The least cost hypothesis:

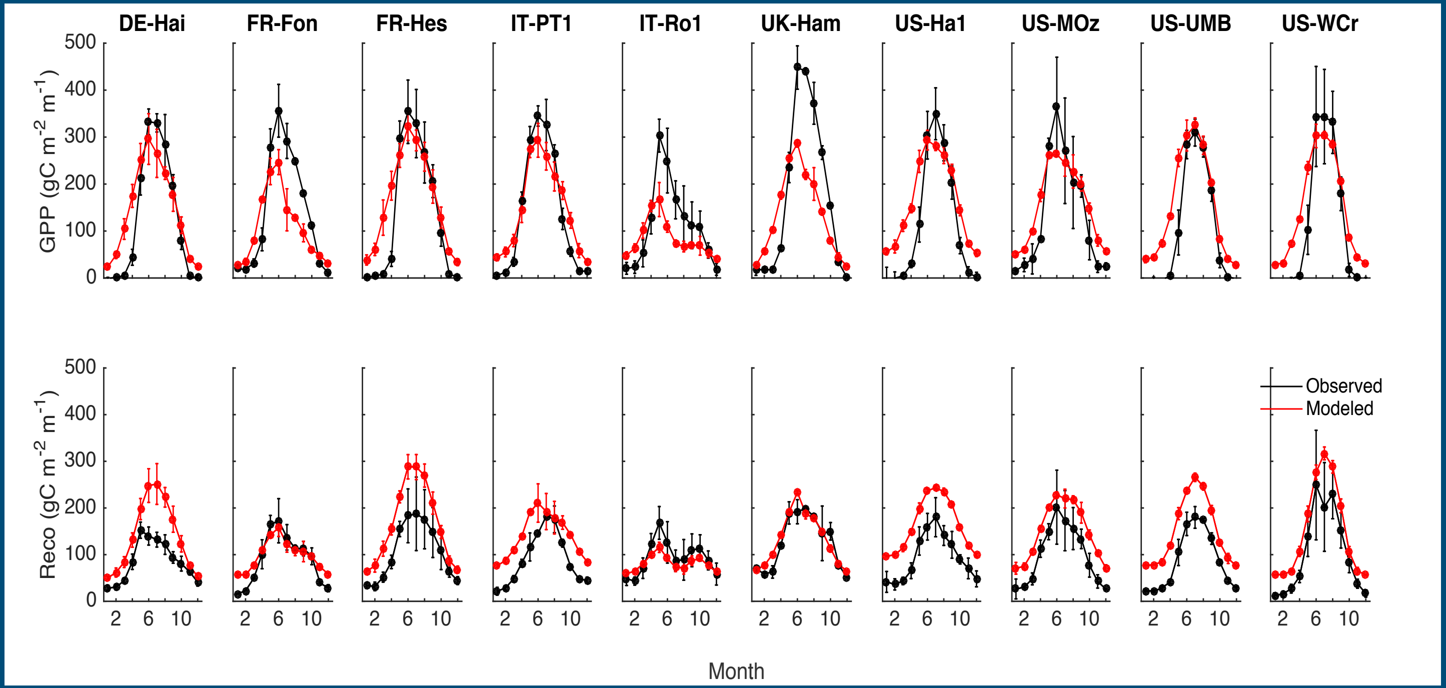
"the ratio of leaf-internal to ambient CO_2 partial pressure should minimize the combined costs of maintaining the capacities for carboxylation and transpiration. "

Prentice et al. 2014

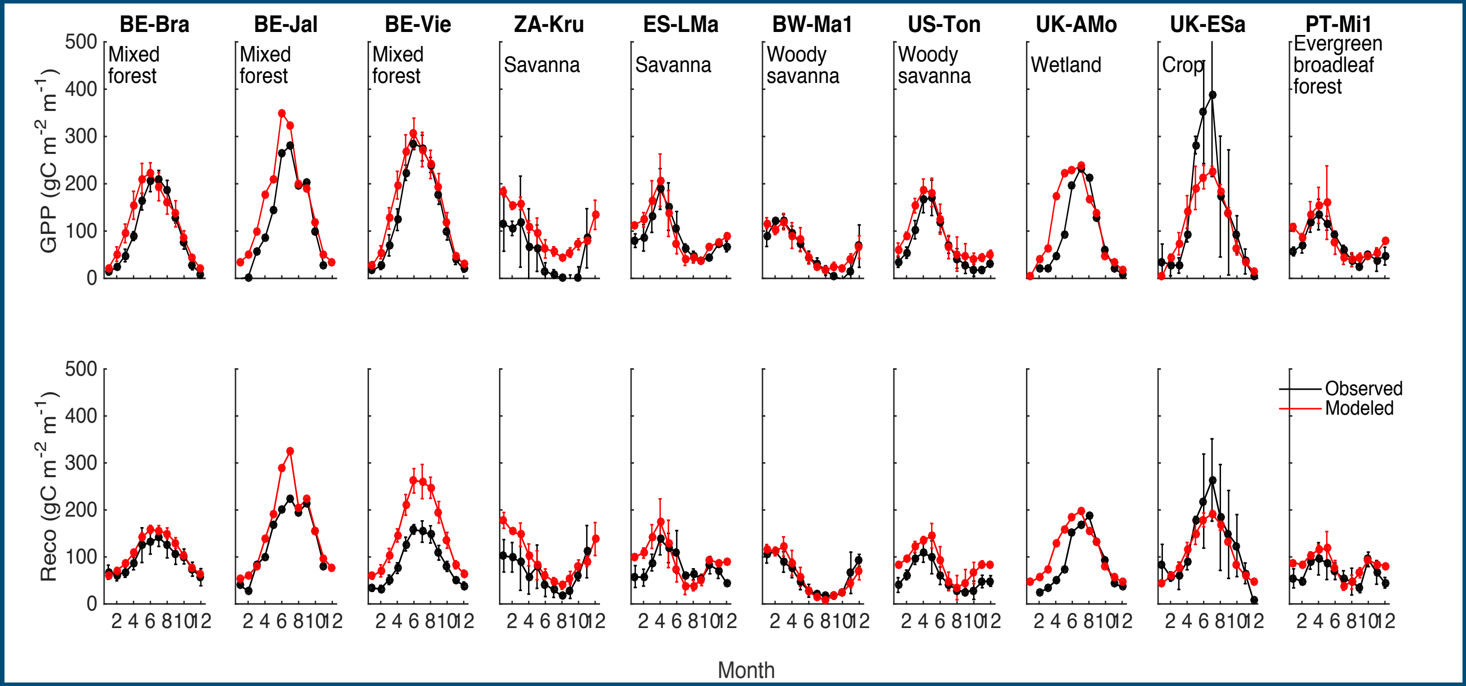
Testing at global grassland sites



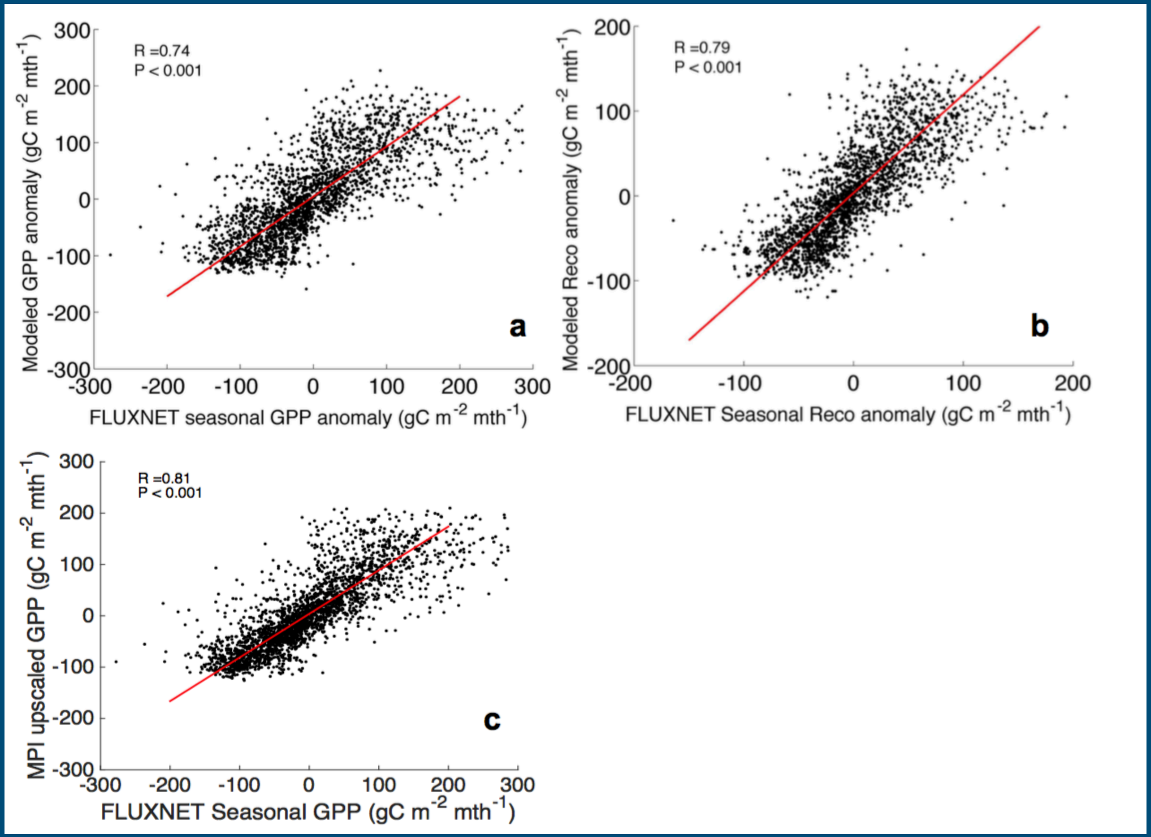
Testing at global DBF sites



Testing at global varied PFTs



Comparing to the MPI Fluxnet upscaling product



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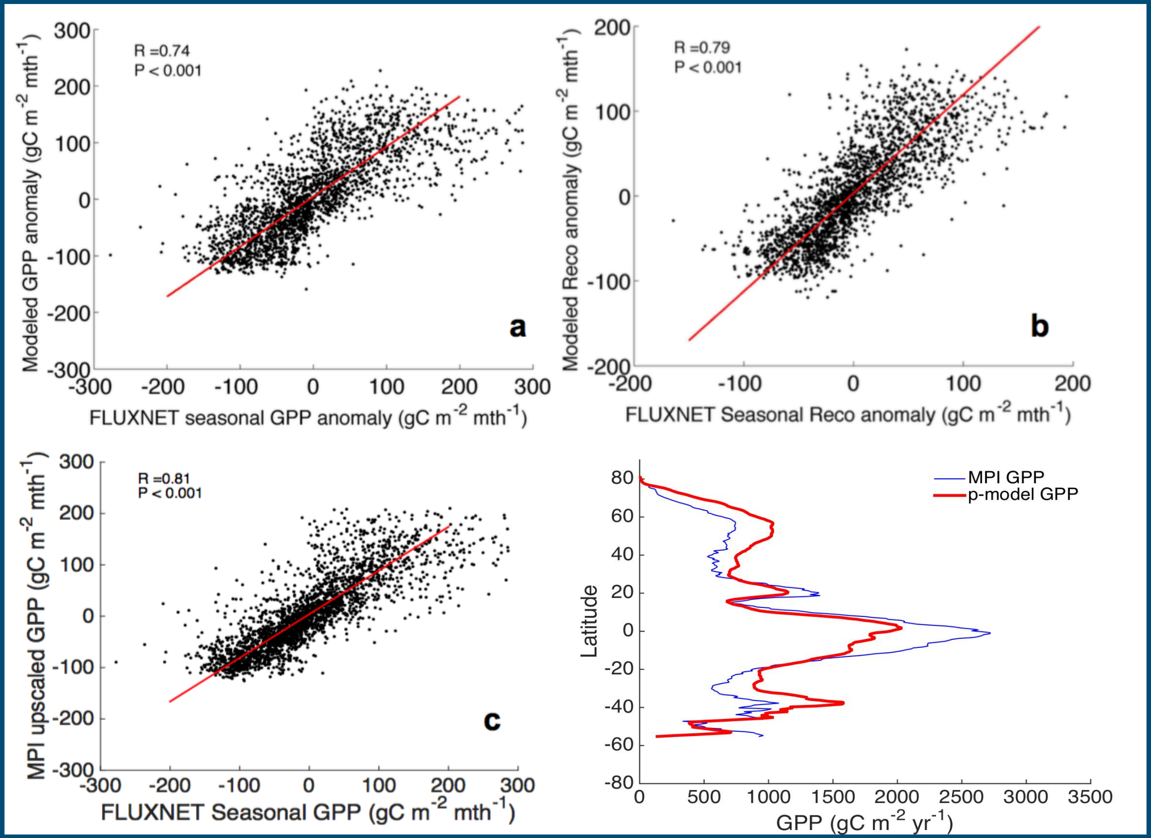

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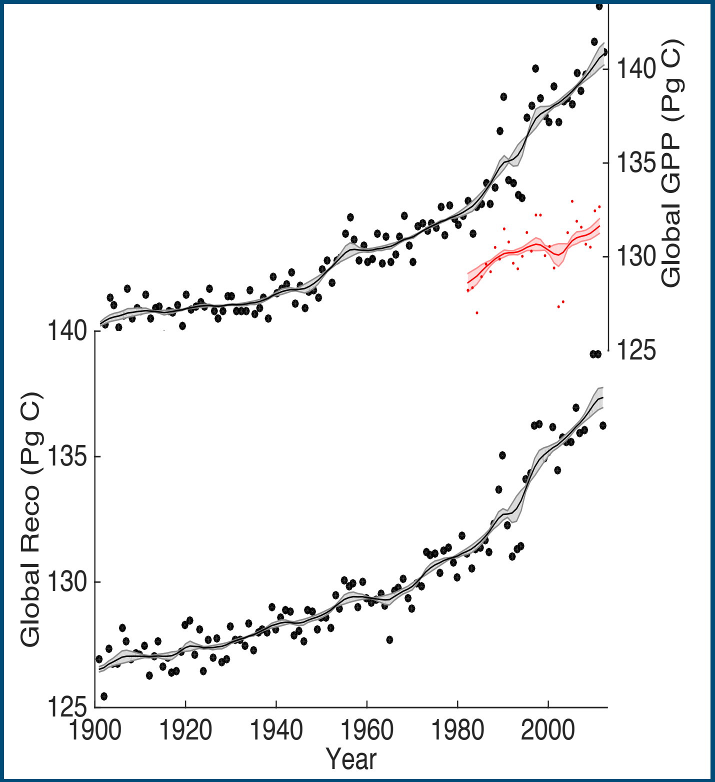

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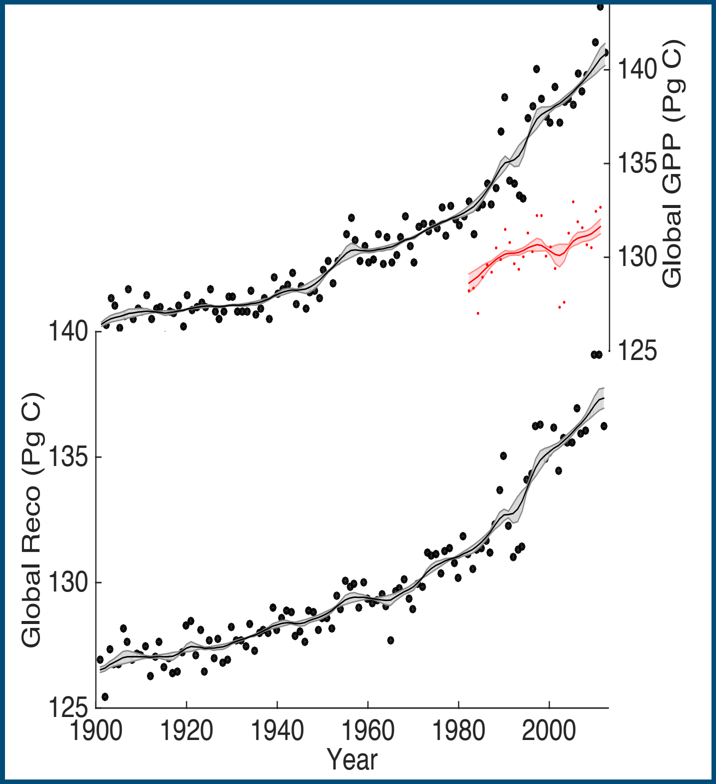
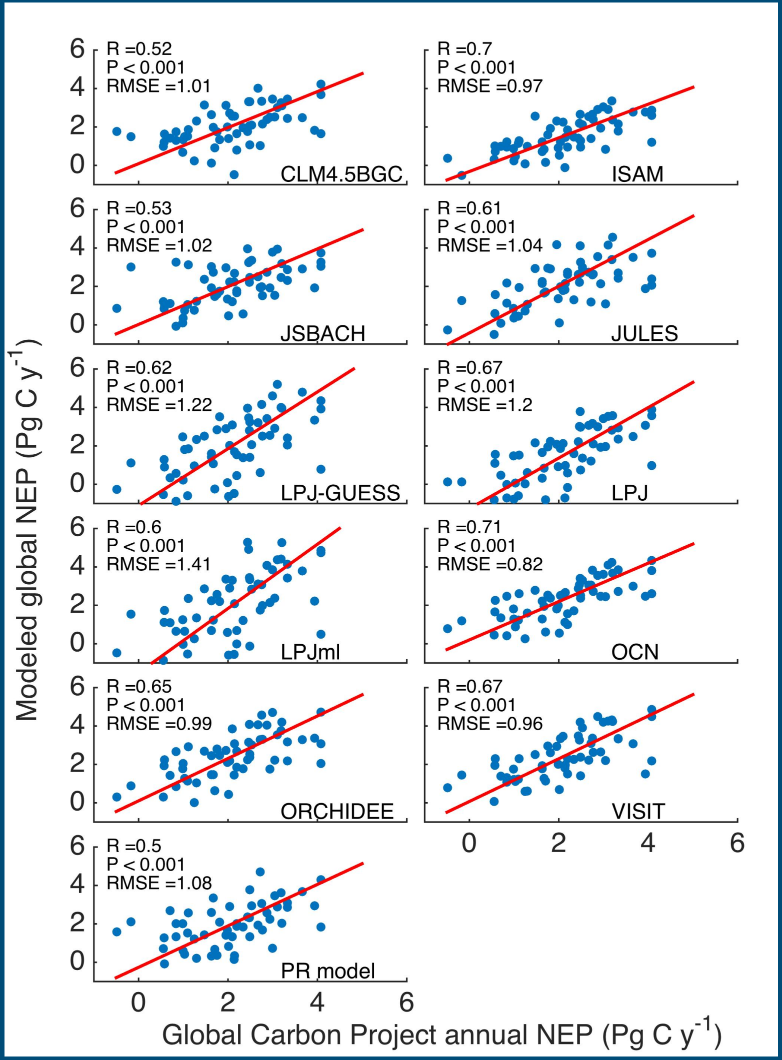


Difference between empirical Jung et al. approach and physiologically based approach?

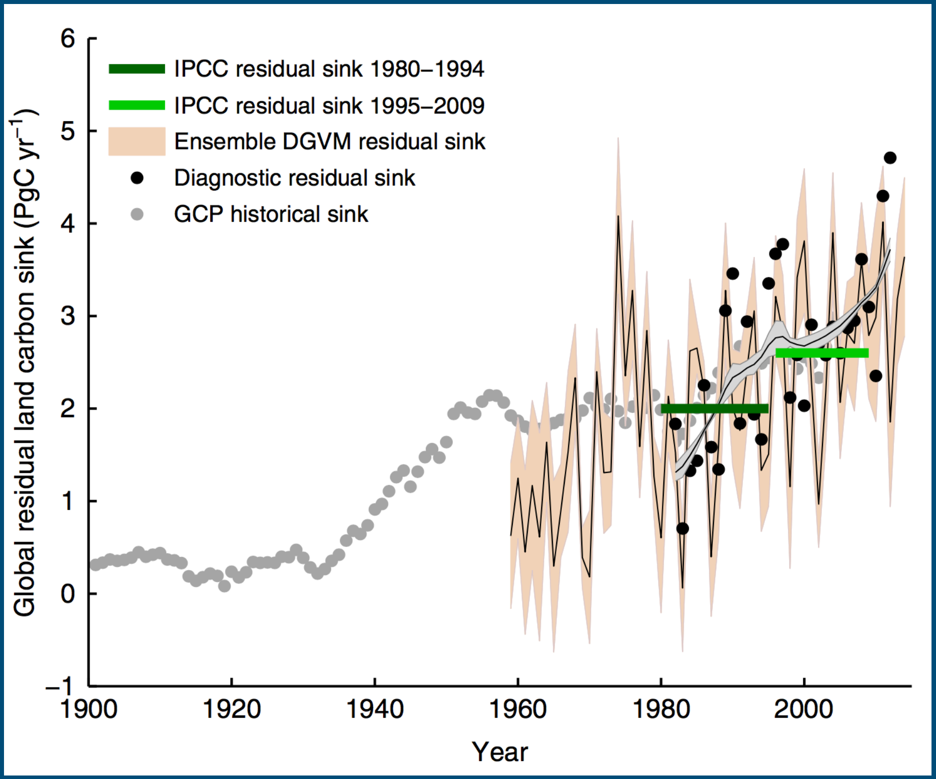
Comparing to Global Dynamic Vegetation Models



Examining long-term dynamics of the global carbon cycle

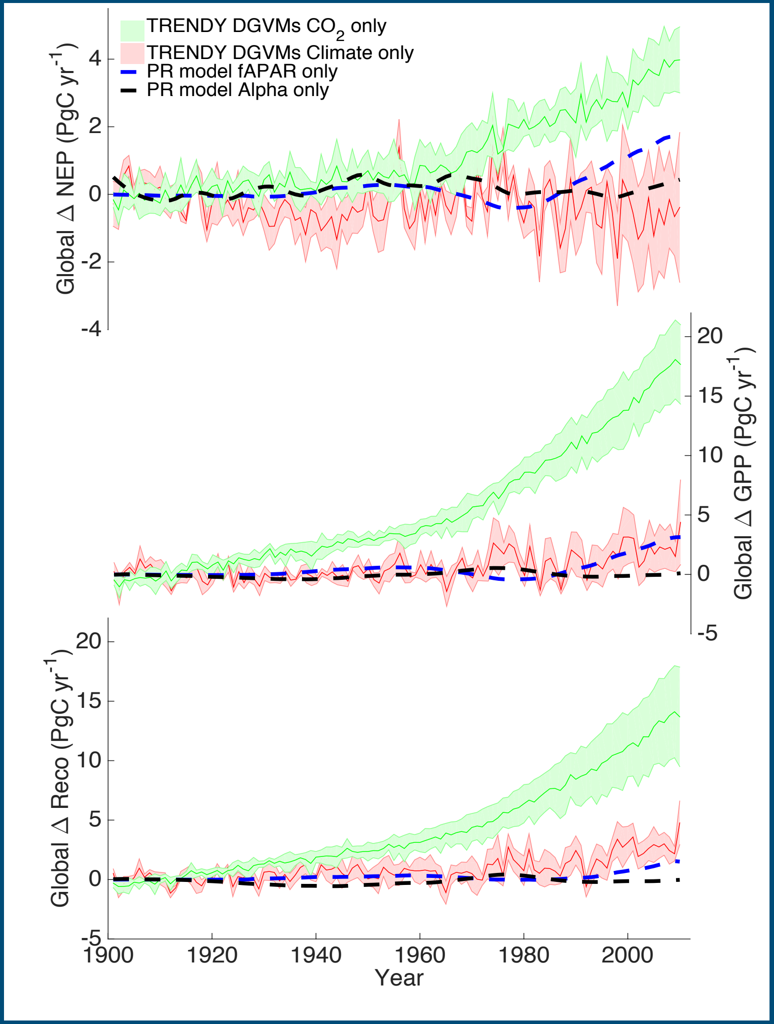
- Use 9 Dynamic Global Vegetation Models from the TRENDY project
  - CO_2 transient, other drivers fixed
  - Climate transient, other drivers fixed
- Use a diagnostic satellite-based model of global photosynthesis and respiration
  - Vegetation cover dynamic or fixed
  - Water availability dynamic or fixed

Enhanced land surface CO_2 uptake



Keenan et al. (2016)

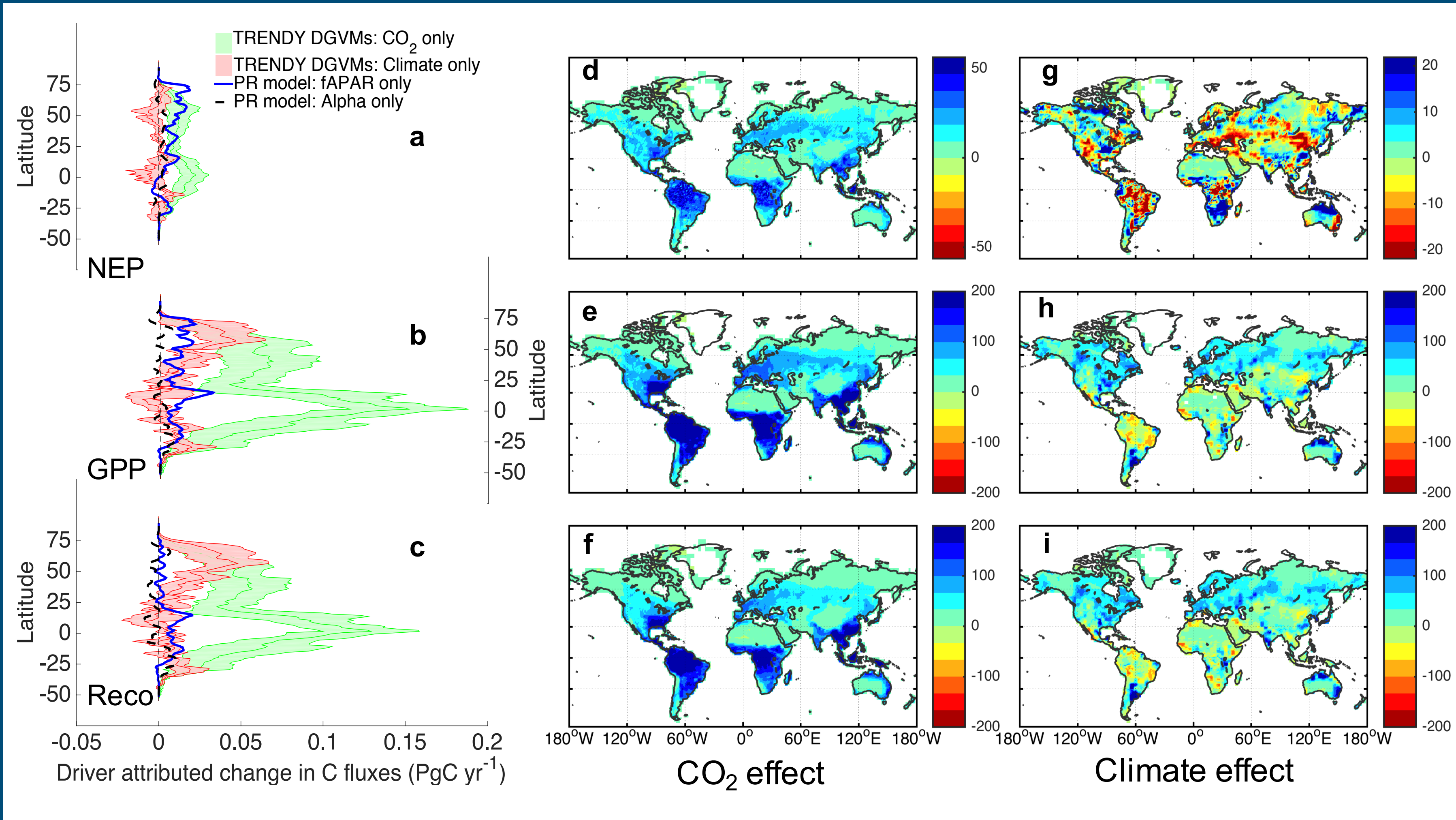
CO_2 Fertilization and Temperature



- CO_2 markedly increasing the net sink, photosynthesis and respiration.
- Vegetation greening a distant second.
- Warming increased both GPP and Respiration.
- No evidence for an increase in global water stress.

Keenan et al. (2016)

CO_2 Fertilization and Temperature



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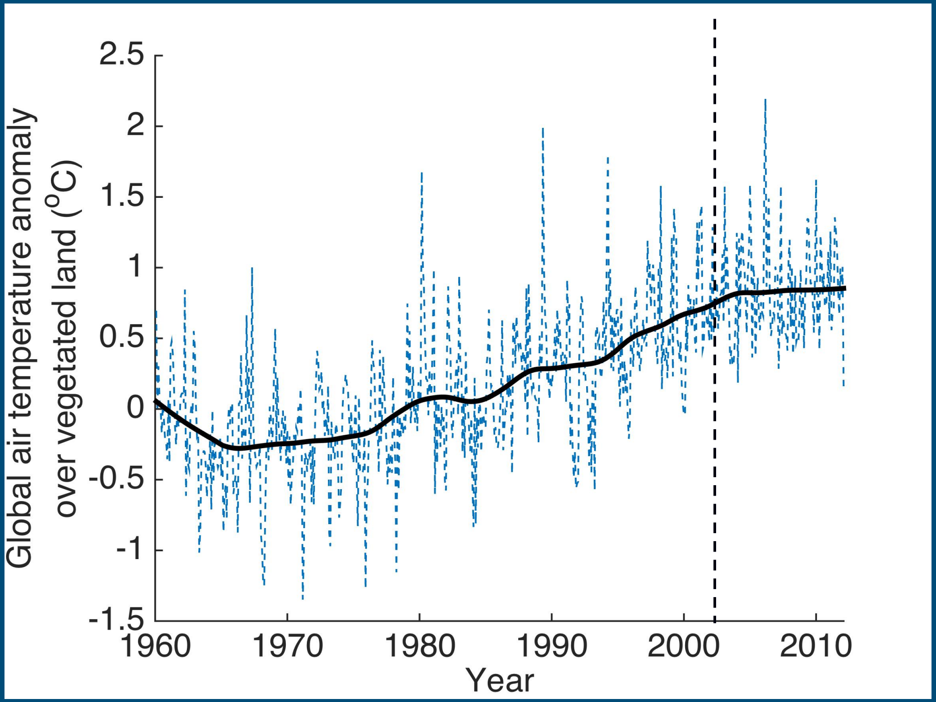
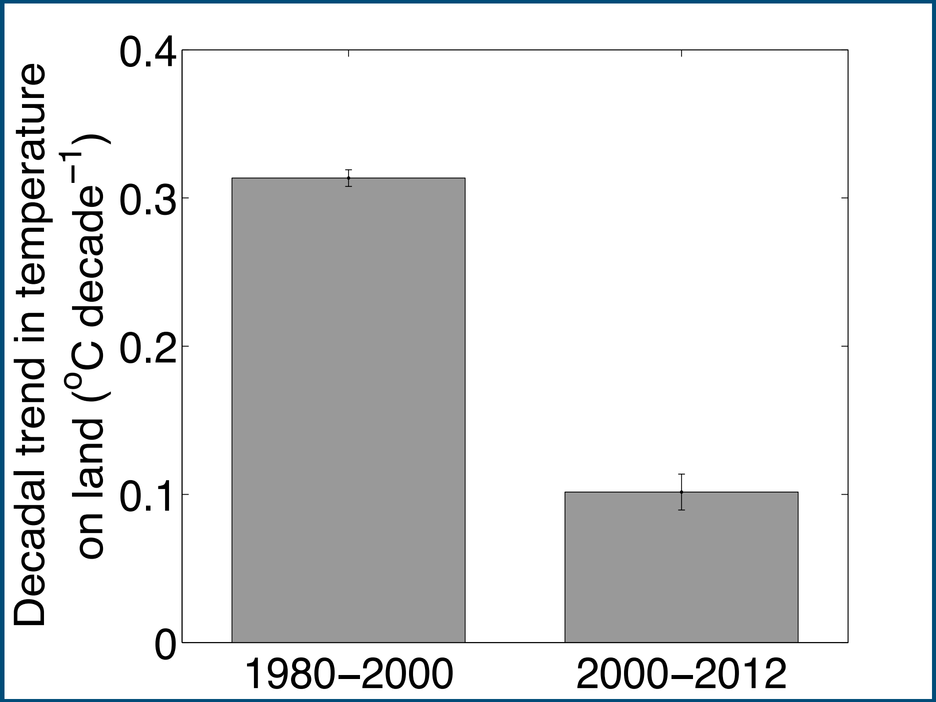


2002-2014 was a period of relatively slow growth in global temperatures over land.

Data source: CRU monthly temperature data

Keenan et al. (2016)

CO_2 Fertilization and Temperature



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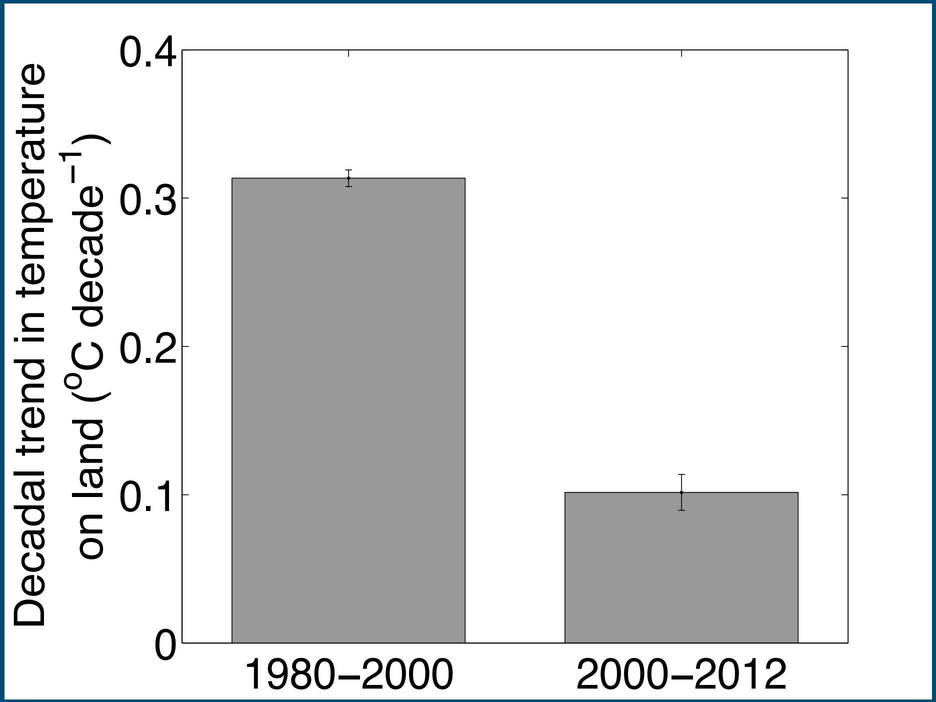

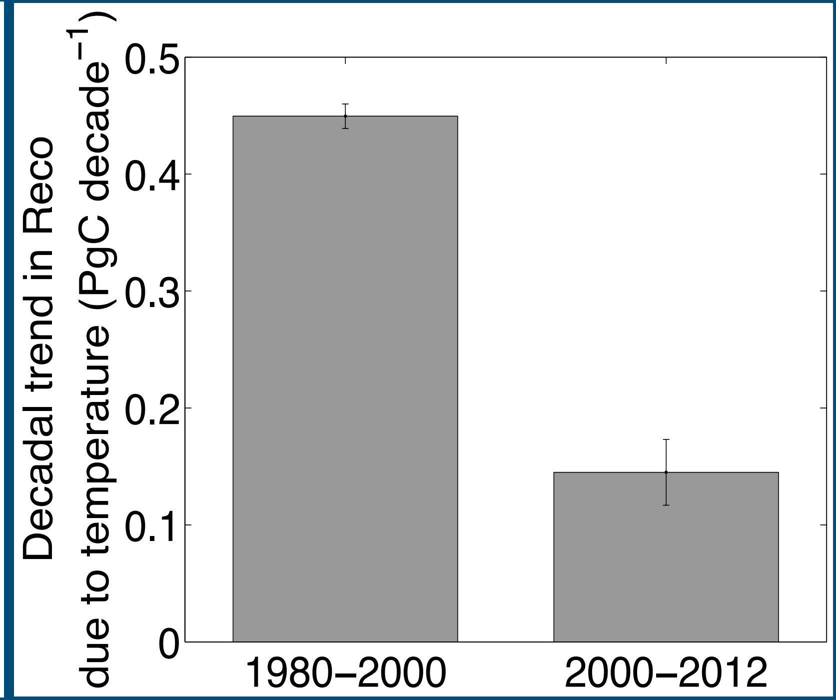

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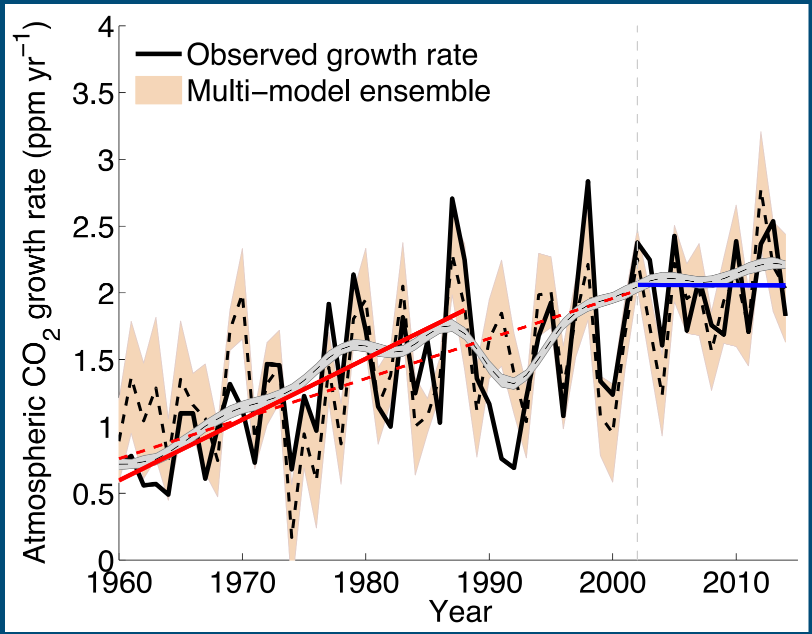

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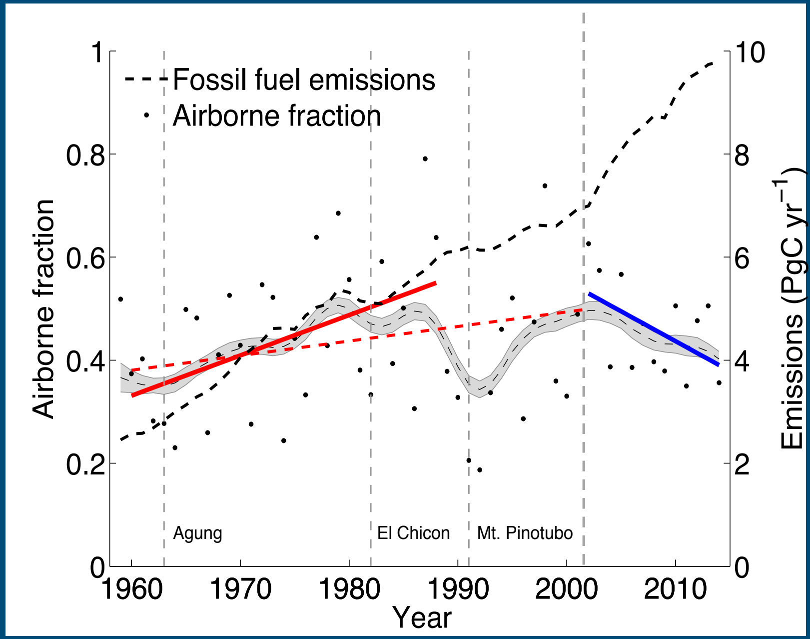

Keenan et al. (2016)

All good climate change stories must come to an end…

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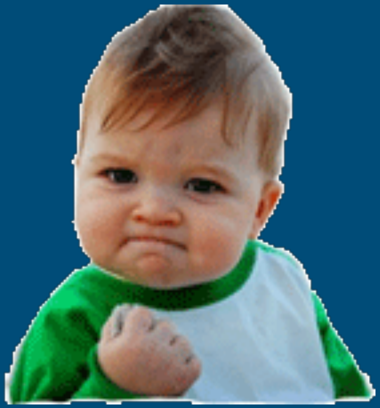
El Niño 2015



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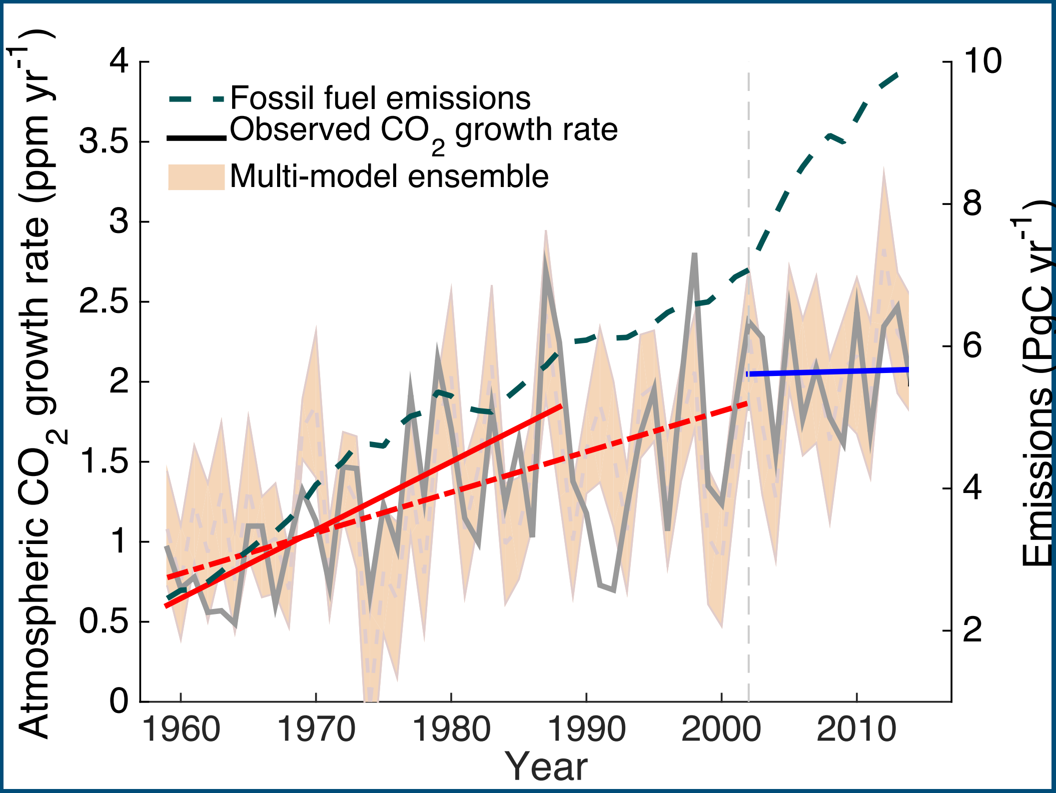

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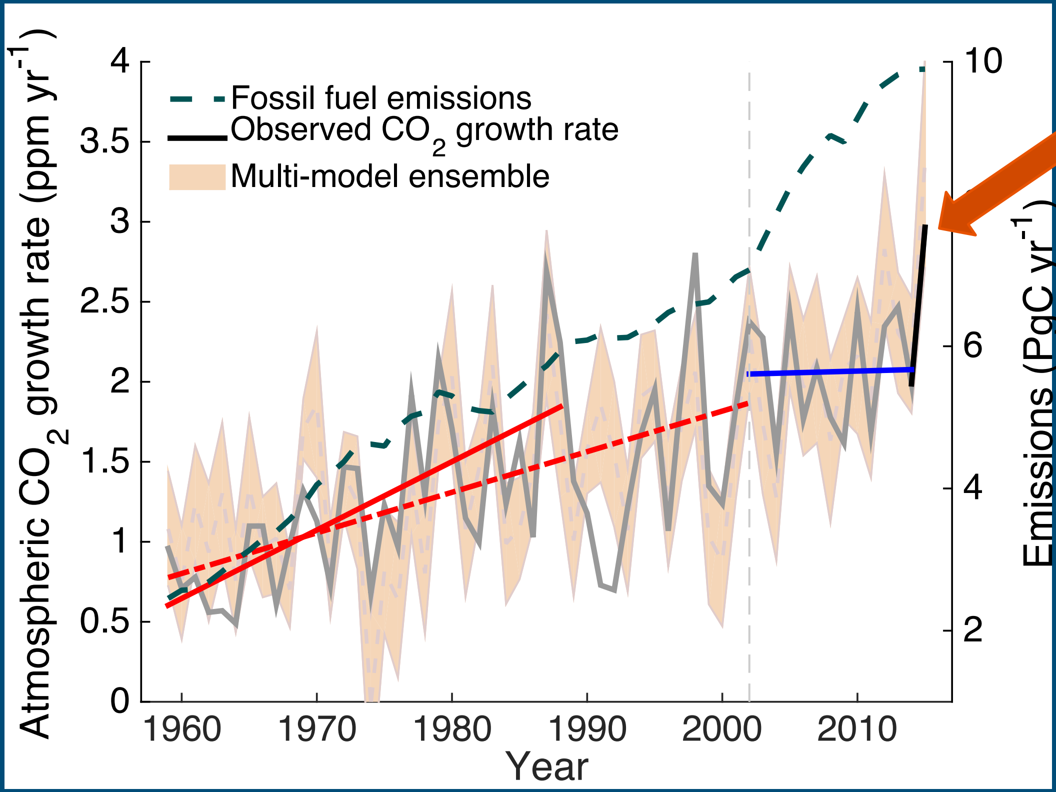
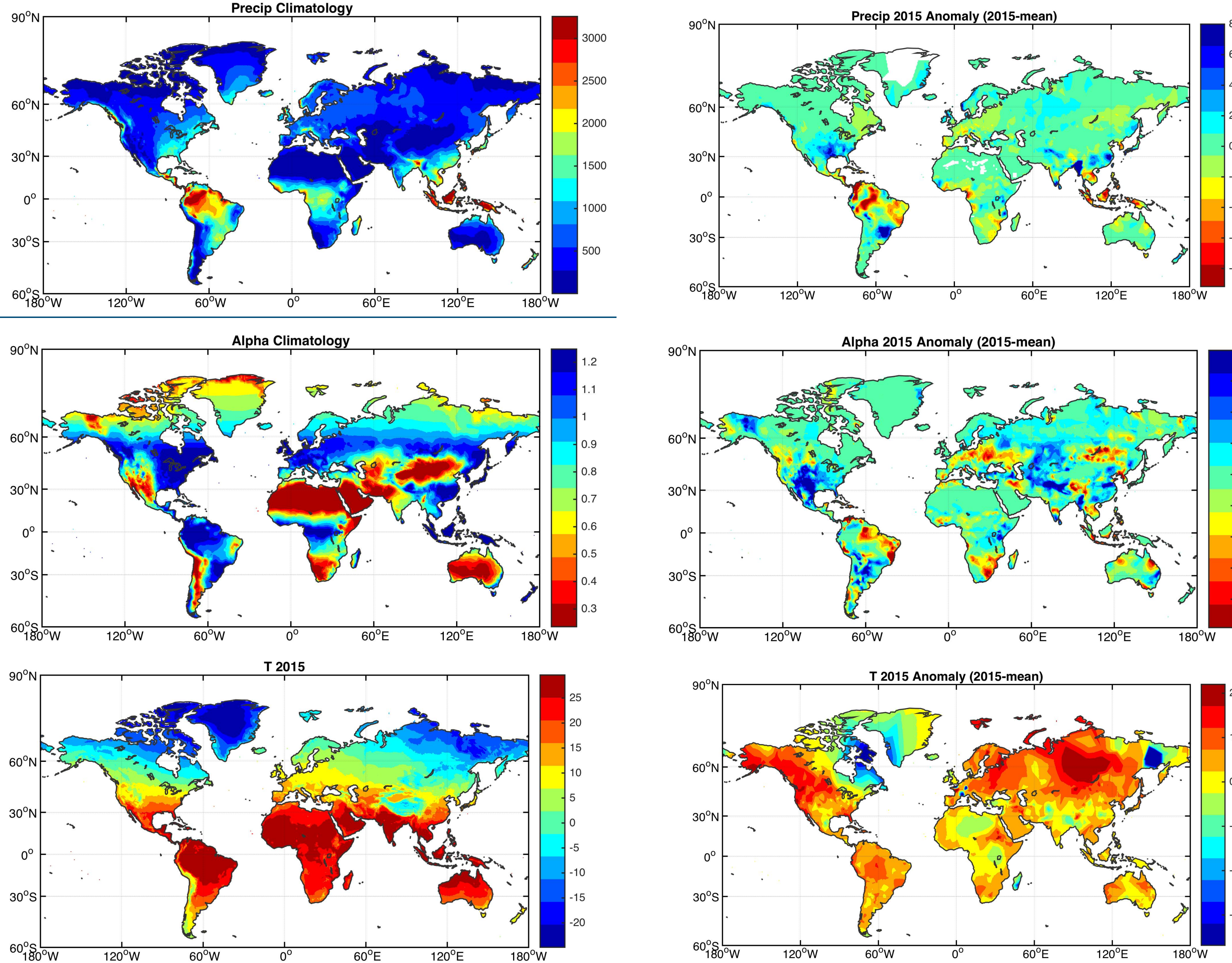
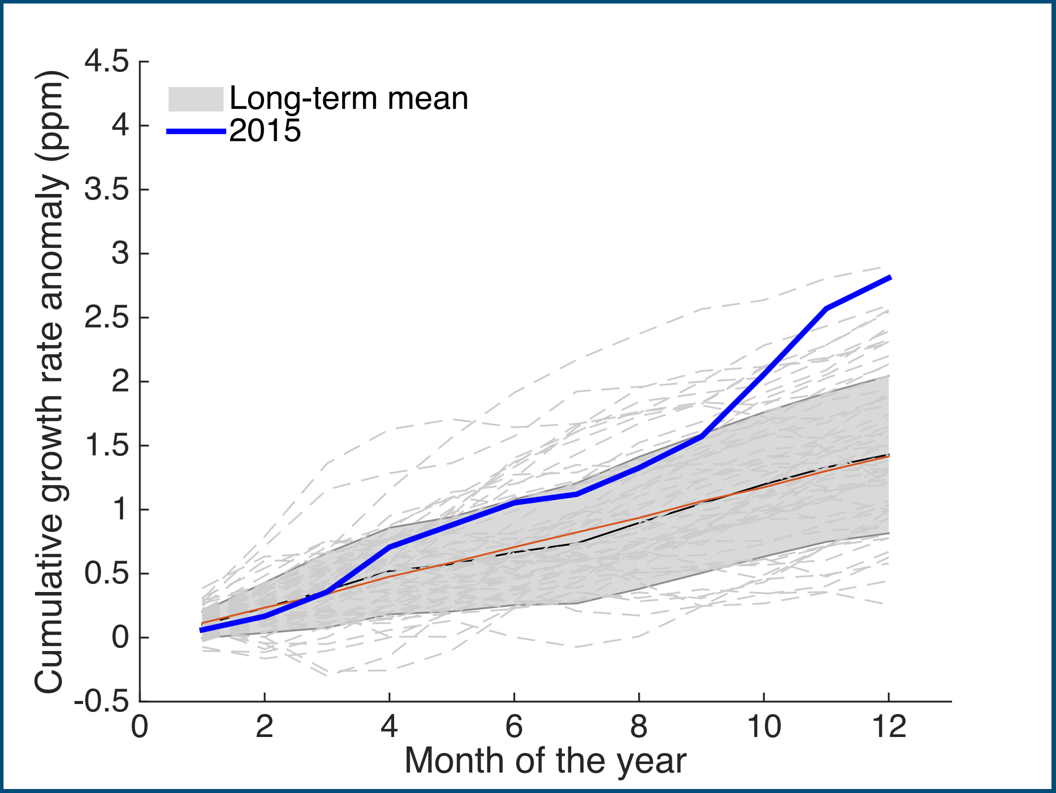


Largest growth recorded



Precip Climatology
3000
2500
2000
1500
1000
500
Precip 2015 Anomaly (2015-mean)
800
600
400
200
0
-200
-400
-600
-800
Alpha Climatology
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
Alpha 2015 Anomaly (2015-mean)
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
T 2015
25
20
15
10
5
0
-5
-10
-15
-20
T 2015 Anomaly (2015-mean)
2
1
0
-1
-2
-3
90°N
60°N
30°N
0°
30°S
60°S
180°W
120°W
60°W
0°
60°E
120°E
180°W

Growth rate of atmospheric CO_2



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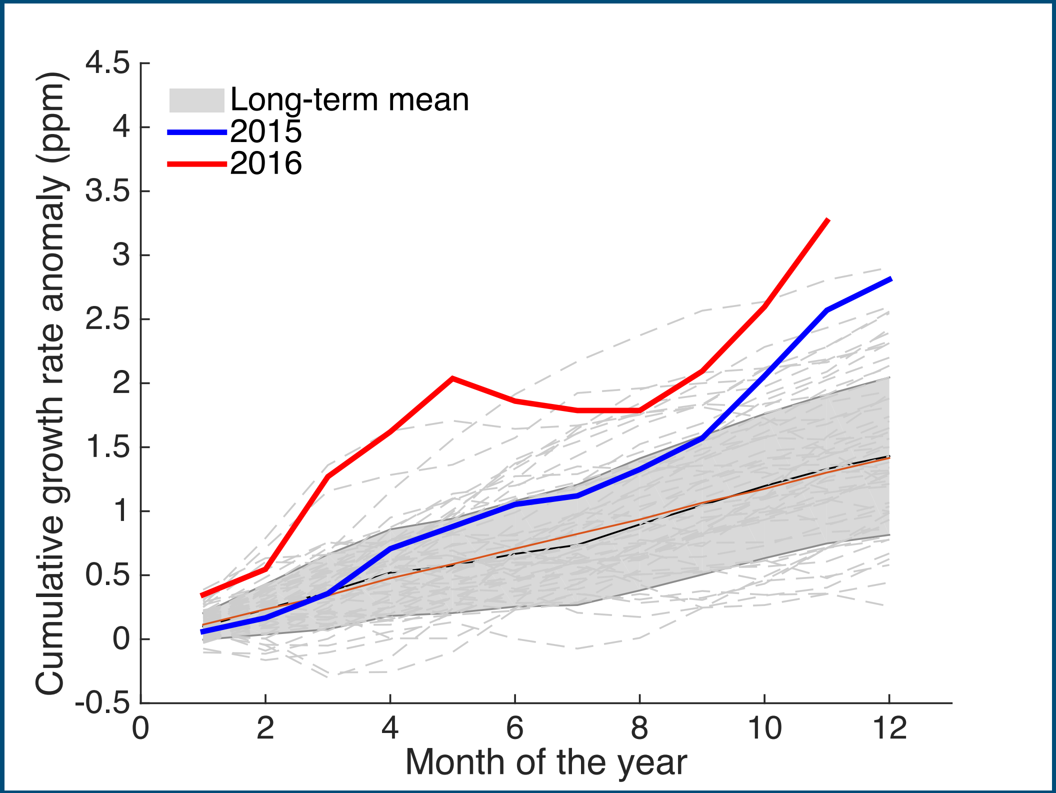

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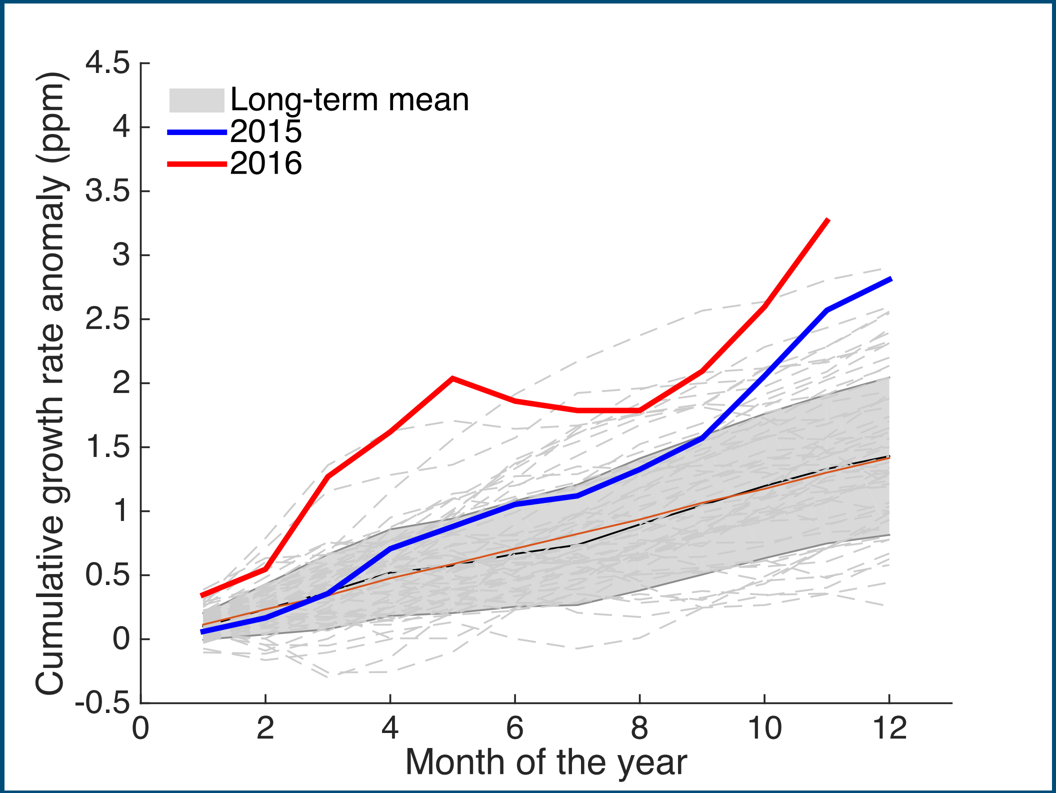

2016: Likely the largest atmospheric CO_2 growth in the modern record

Take home messages:

1. Elevated CO_2 is stimulating increased plant C uptake
2. Warmer temperatures are leading to increased CO_2 release from ecosystems
3. The net effect is a large increase in terrestrial C uptake

Implications:

1. Recent enhancement sufficiently large to result in a temporary pause in the growth rate of atmospheric CO_2
2. El Niño in 2015 caused a large increase in the growth rate
3. 2016 possilby by far the largest increase in the modern record

Plan going forward:

Examining El Nino 2015/2016 impacts using:

1. ACME global runs
2. BESS diagnostic model simulations
3. NGEE tropics data

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Thank you!

DOE, NOAA,

FLUXNET PIs, TRENDY modeling teams

Keenan, T. F. et al. 2016 Recent pause in the growth rate of atmospheric CO_2 due to enhanced terrestrial carbon uptake. Nat. Comm. 7, 13428.

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