Evaluation of the carbon cycle components of CMIP5 ESMs

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with **significant** inputs from P. Cox and A. Anav (Uexeter) and S. Piao (Beijing University)

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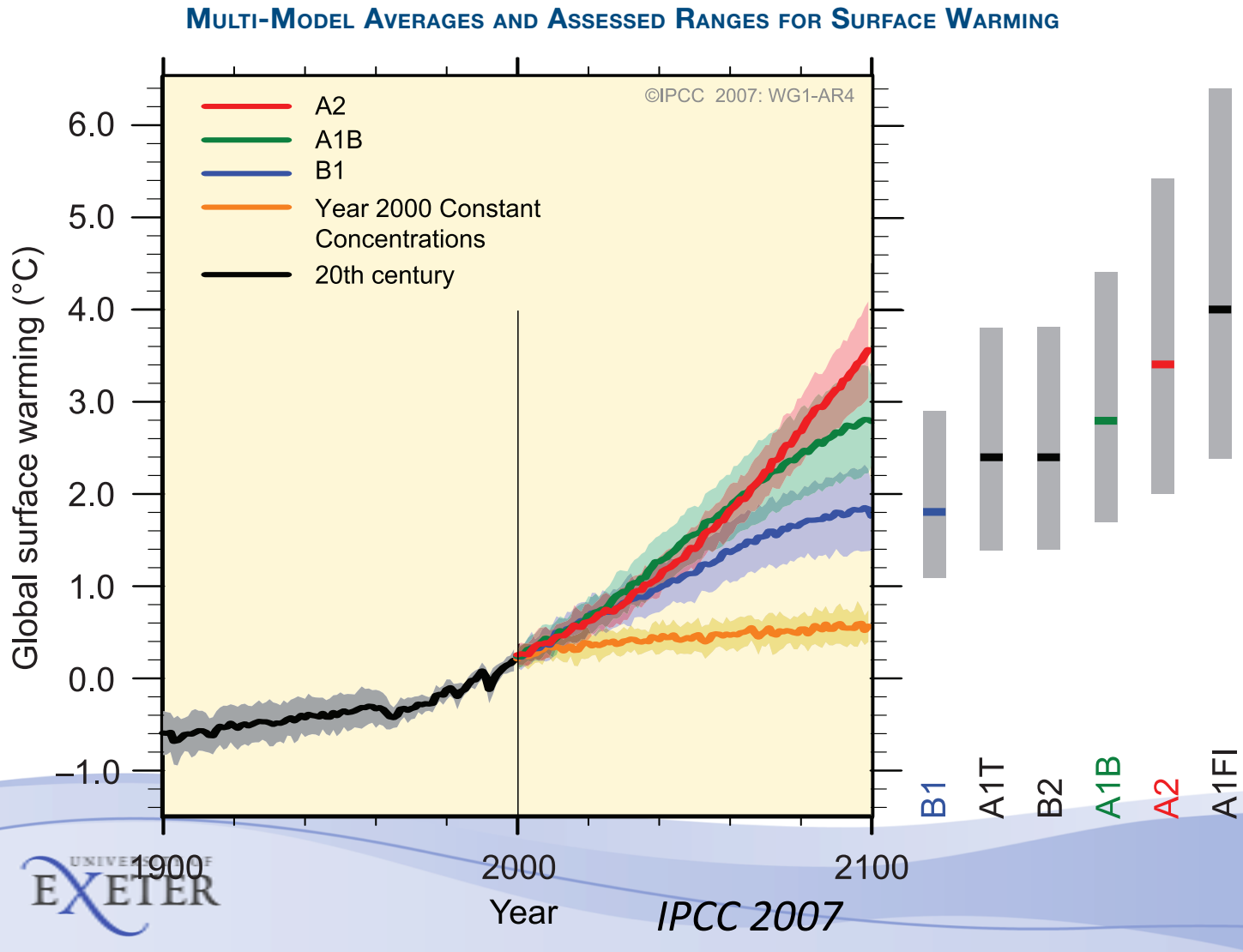
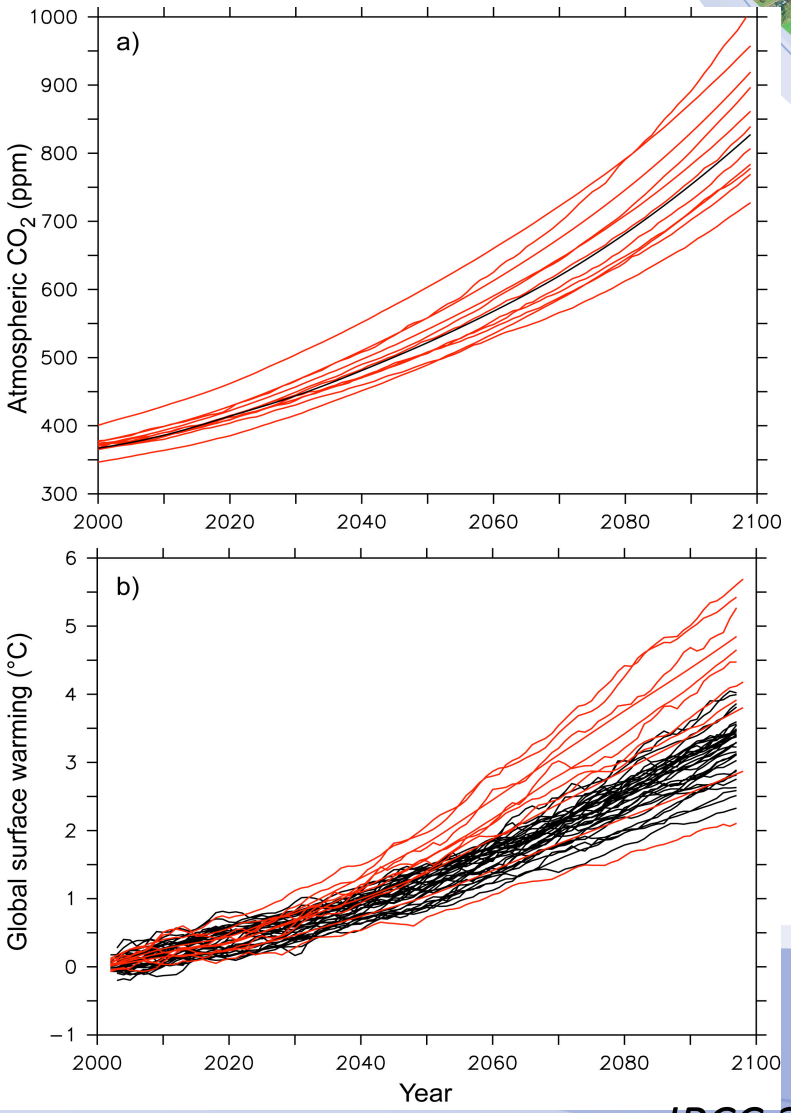
AR4 projections



Carbon cycle in ESMs

- In IPCC AR4
  - OAGCM models driven by CO2 concentration
  - C4MIP models driven by CO2 emissions
- General findings:
  - Large uncertainty in CO2 projections
  - Adds uncertainty on climate projections
  - Positive climate-carbon cycle feedback leads to larger warming.
- BUT, no evaluation of carbon cycle models at that time
- Lots have been done since (e.g. Randerson et al. 2009, Cadule et al. 2010, Blyth et al. 2010, Roy et al. 2011.

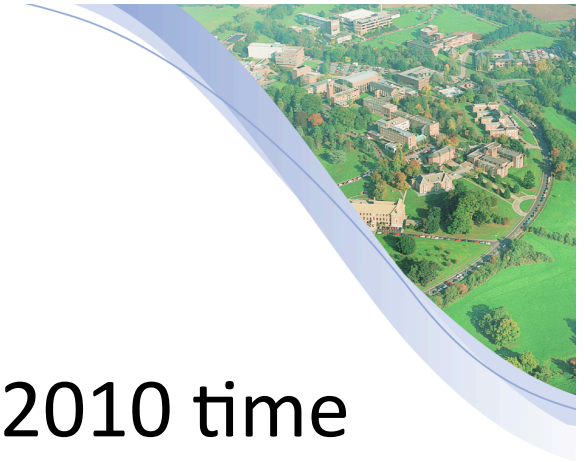


IPCC 2007

Current on-going evaluation

(presented here)

- Evaluation of state-of-the-art DGVMs offline historical simulations (TRENDY project)
- Evaluation of CMIP5 ESMs online historical simulations
- Process-oriented of climate-carbon cycle feedback



TRENDY runs

- DGVMs forced by observed 1900-2010 time series of key forcings
  - Climate, atmospheric CO2 *and land use change*
- Analysis of land carbon and water fluxes (climatology and interannual variability, and trends)

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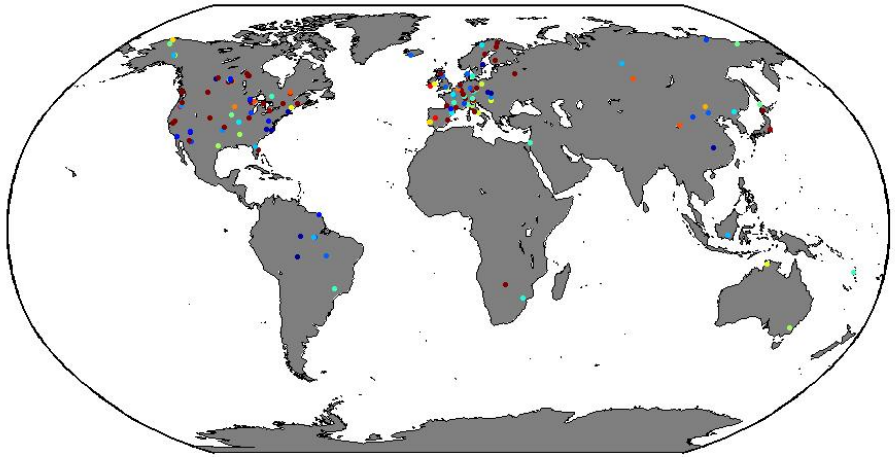
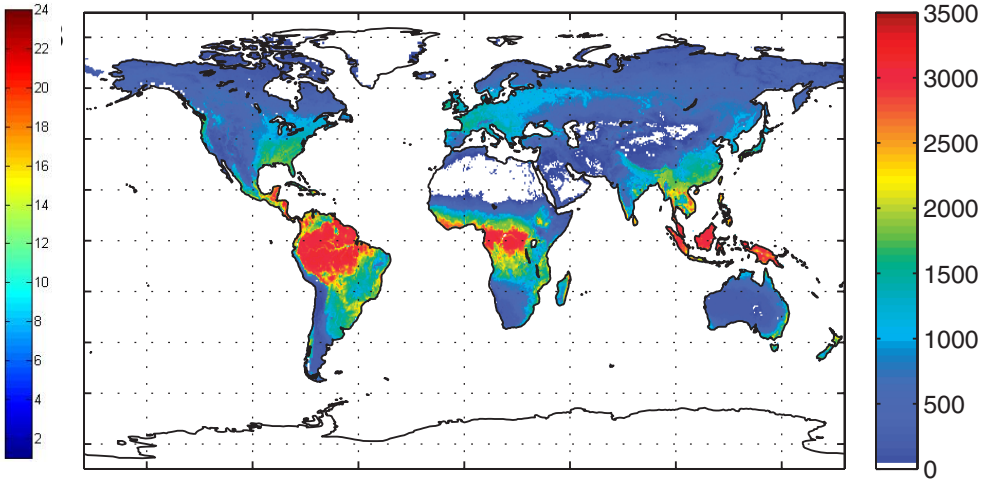
Evaluation dataset

- Evaluation against GPP- FUXNET gridded dataset (Jung et al., 2009, Beer et al., 2010)
- Upscaling of site-level data, using a neural network
- Training tree model

Site level actual data



Upscaled gridded dataset product



Jung et al., 2009

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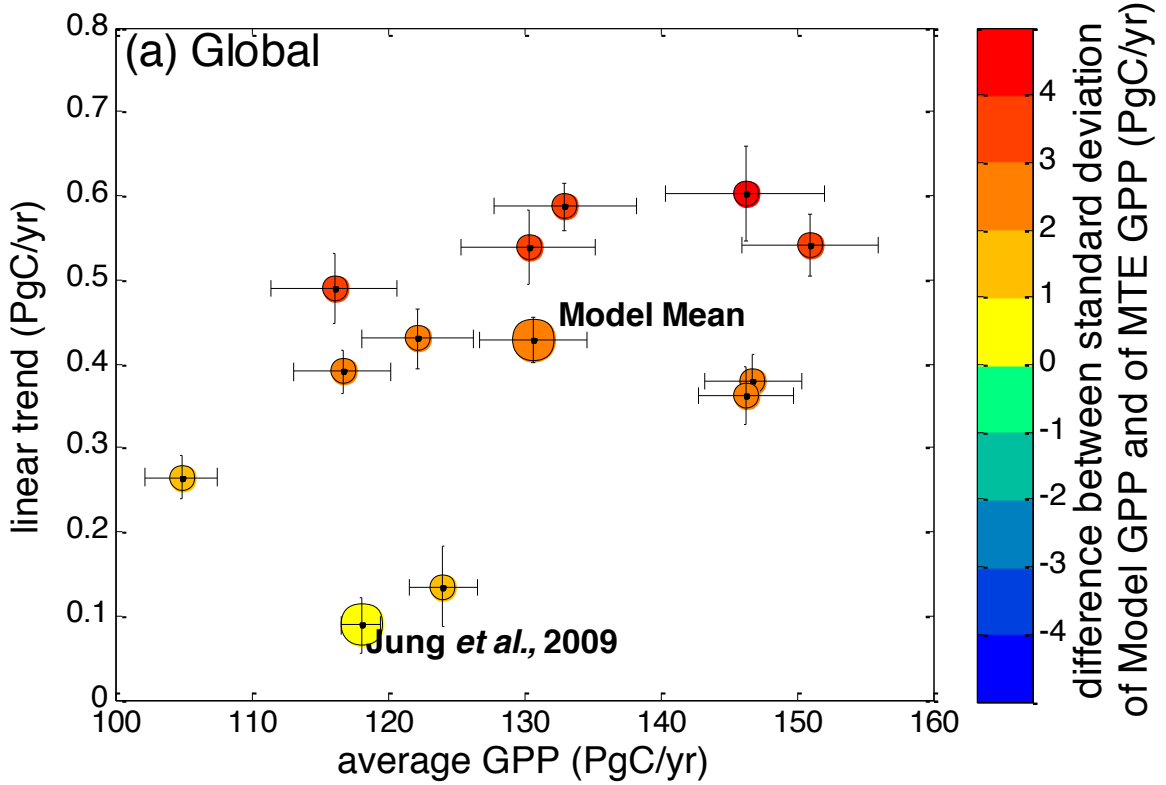
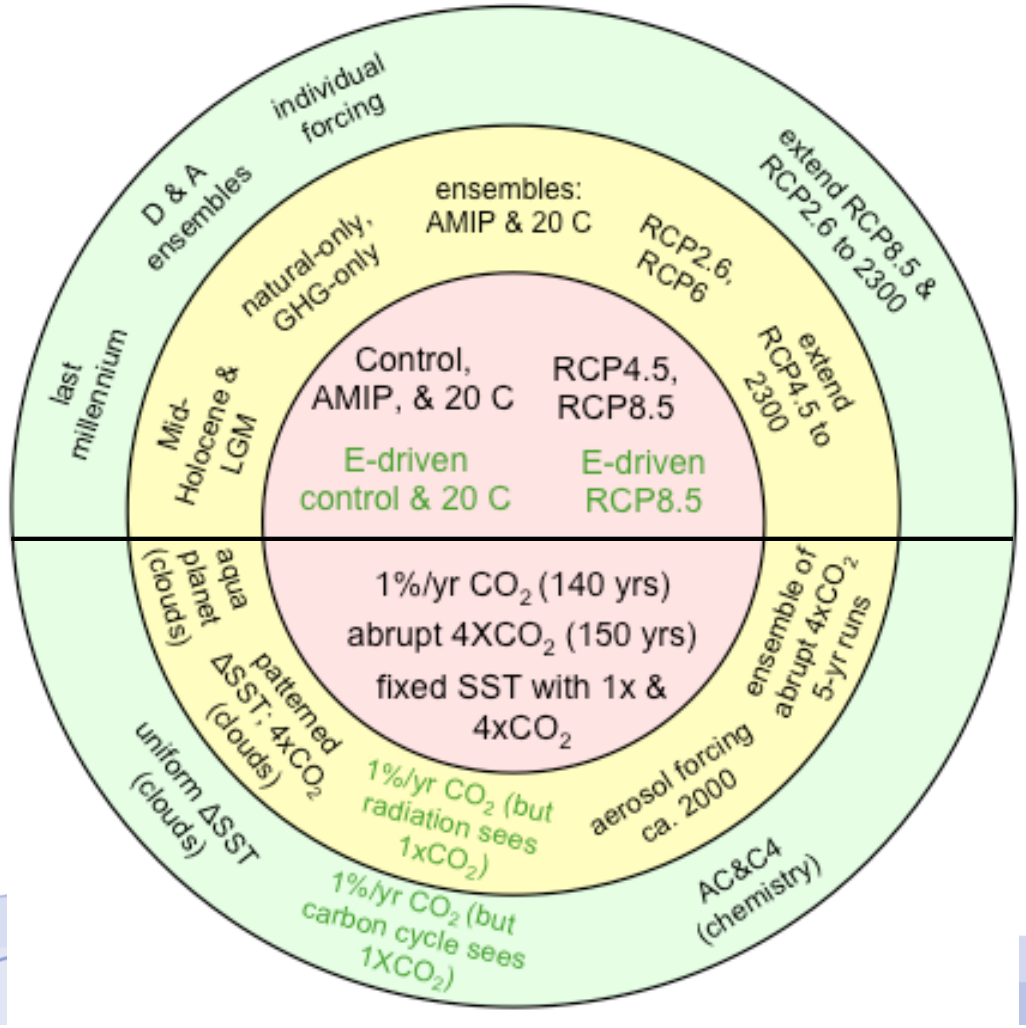
To be used with caution

Offline evaluation of DGVMS

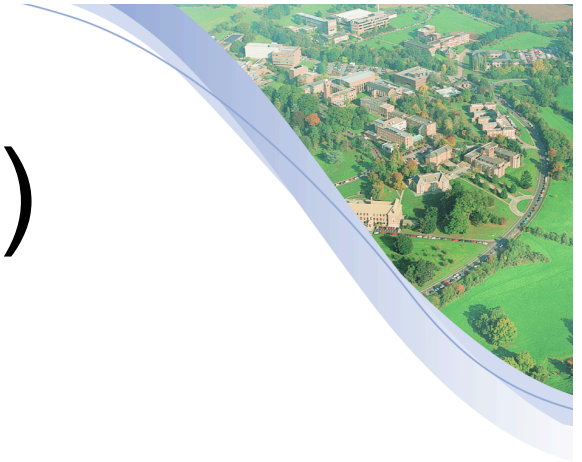


To be used with caution

CMIP5 Protocol



- Historical runs (C-driven)



ESMs* involved (so far)

- CanESM2
- HadGEM2-ES
- IPSL-CM5
- BCC
- INMCM4
- NorESM-1

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* = with carbon cycle

Historical runs evaluation

- LAI
  - annual mean and seasonal cycle
  - evaluated against MODIS LAI
- *GPP*
  - *annual mean and seasonal cycle*
  - *"evaluated" against gridded FluxNET product*
- C uptake
  - decadal mean and IAV
  - Evaluated against atmospheric inversions
- and more can be done…

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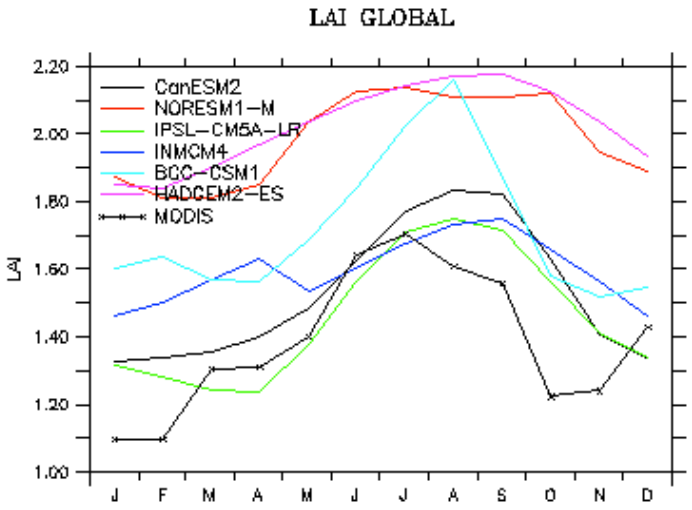
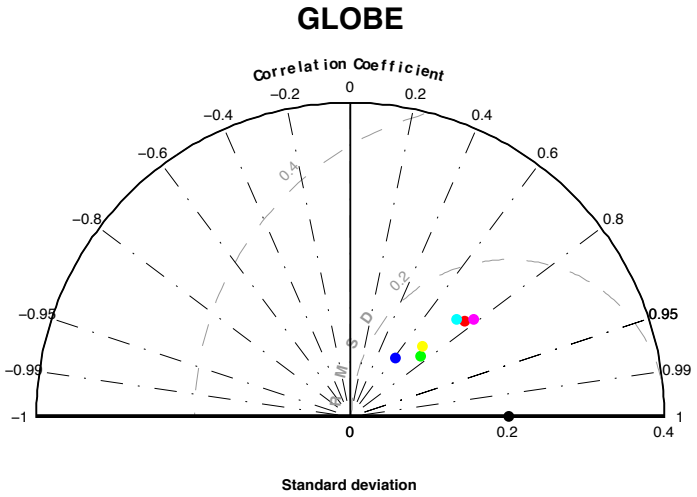
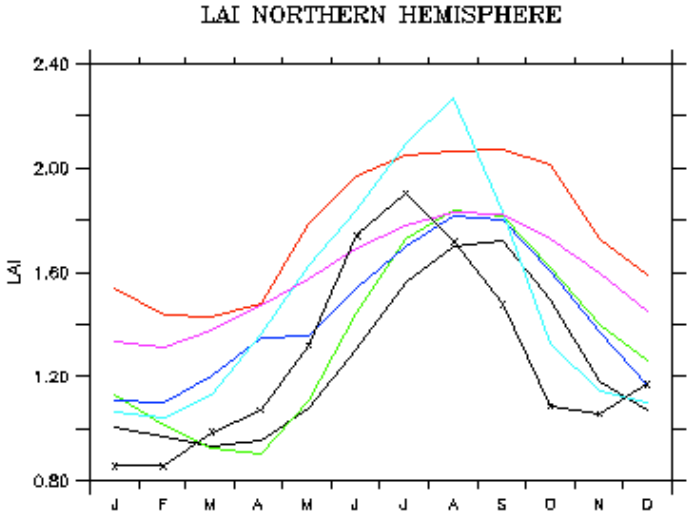
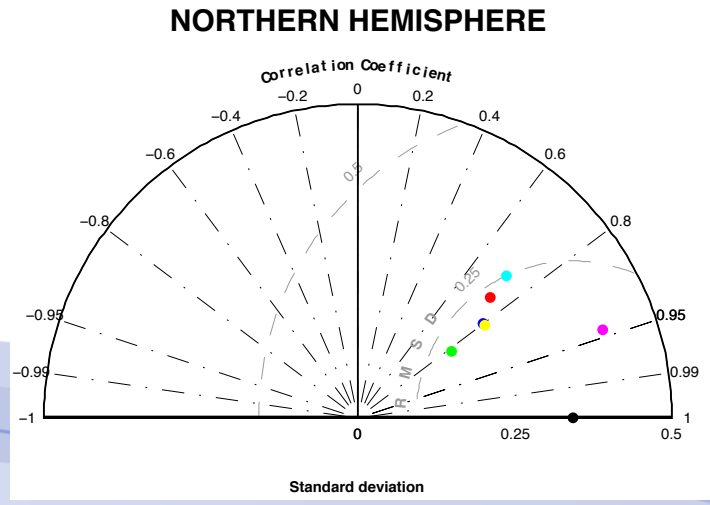
LAI seasonal cycle

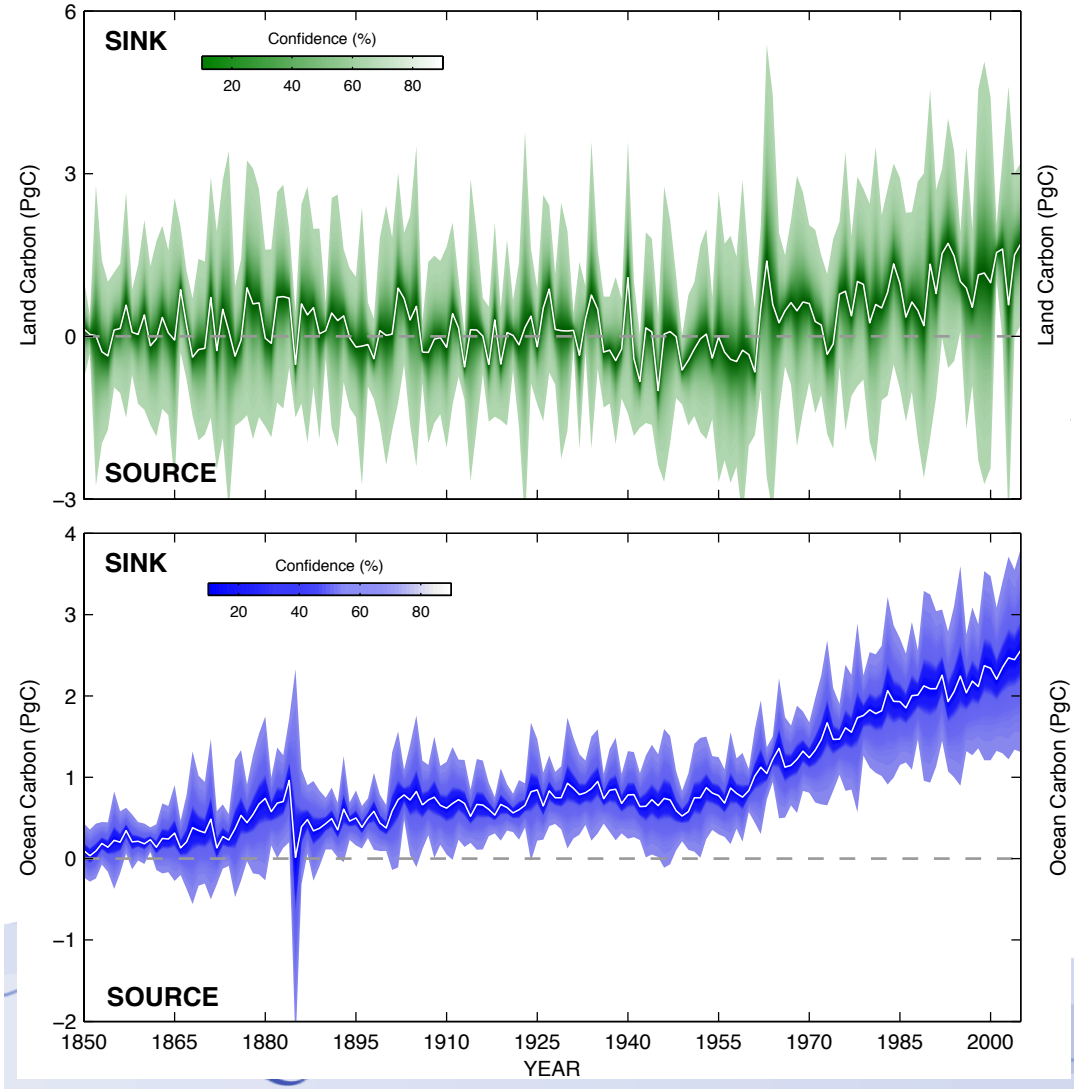








Long-term trend
Global land and ocean sink

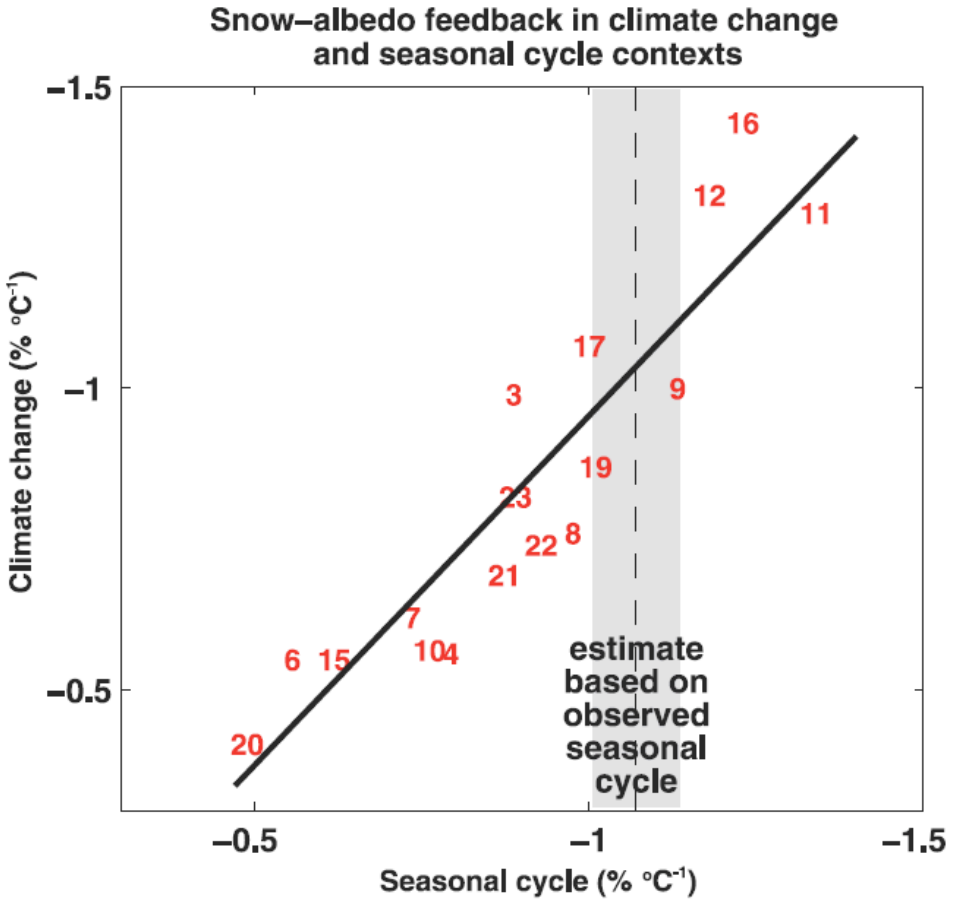


IPCC AR4
1990's average

0.9 to 4.3

2.2 ± 0.4

Process oriented evaluation an example from Climate Science

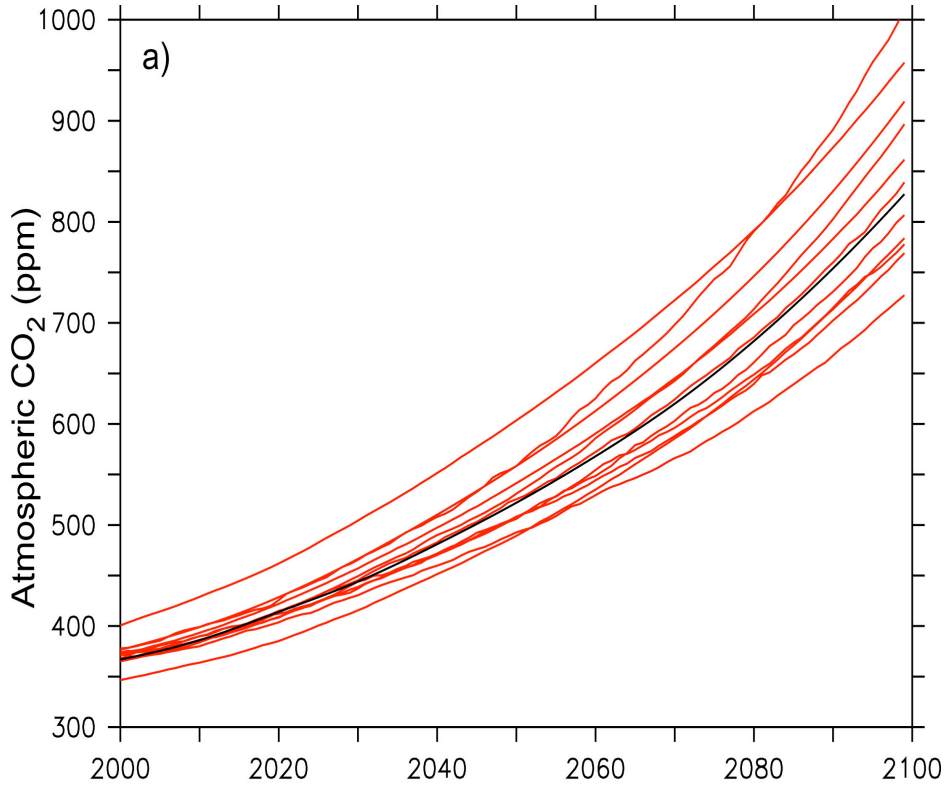


- In models, snow cover dynamic in the short-term (seasonal) is correlated to dynamic in the long-term (climate change)
- Short-term changes are being observed
- Long-term changes can be inferred.

- Could we do something similar for climate-carbon feedback?

IPCC 2007

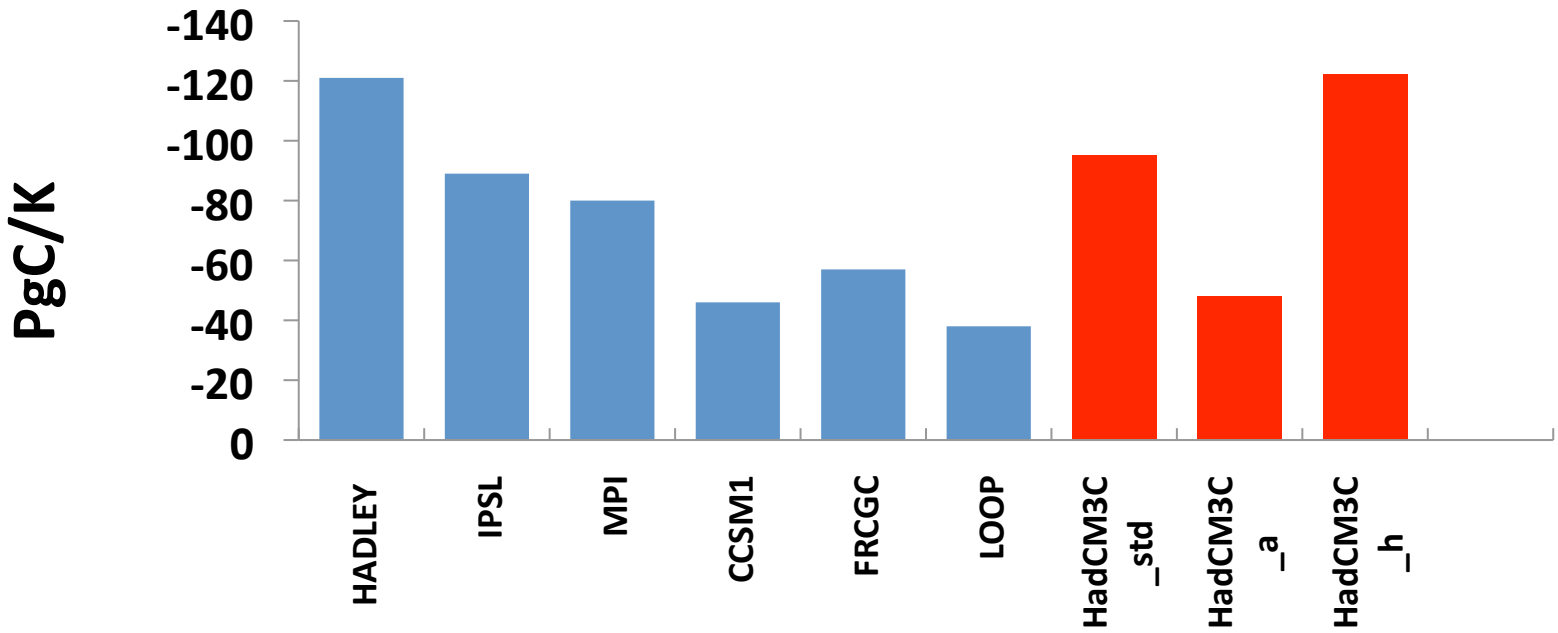
The climate-carbon cycle problem



- Carbon cycle uncertainty is primarily due to uncertainty in the land carbon cycle
- and in particular to uncertainty in the land carbon cycle response to climate change

IPCC 2007

Climate Impact on Tropical Land Carbon γ_{LT}



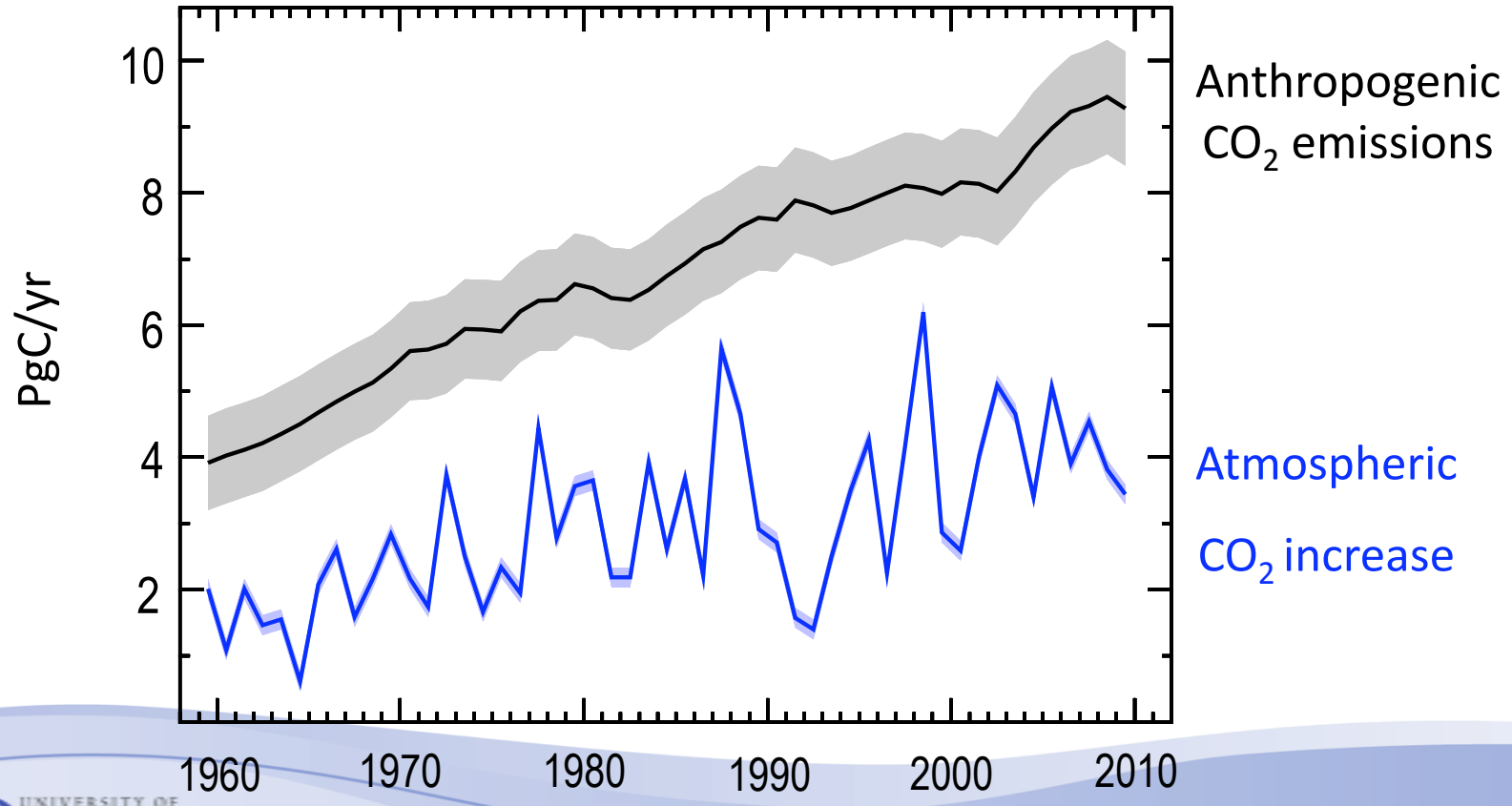
Amount of carbon loss in 2100 by tropical lands per unit of warming

Where is the truth ?

Can we constrain this quantity with current observations ?

Observational constrains

- The growth-rate of atmospheric CO_2 varies significantly from year-to-year



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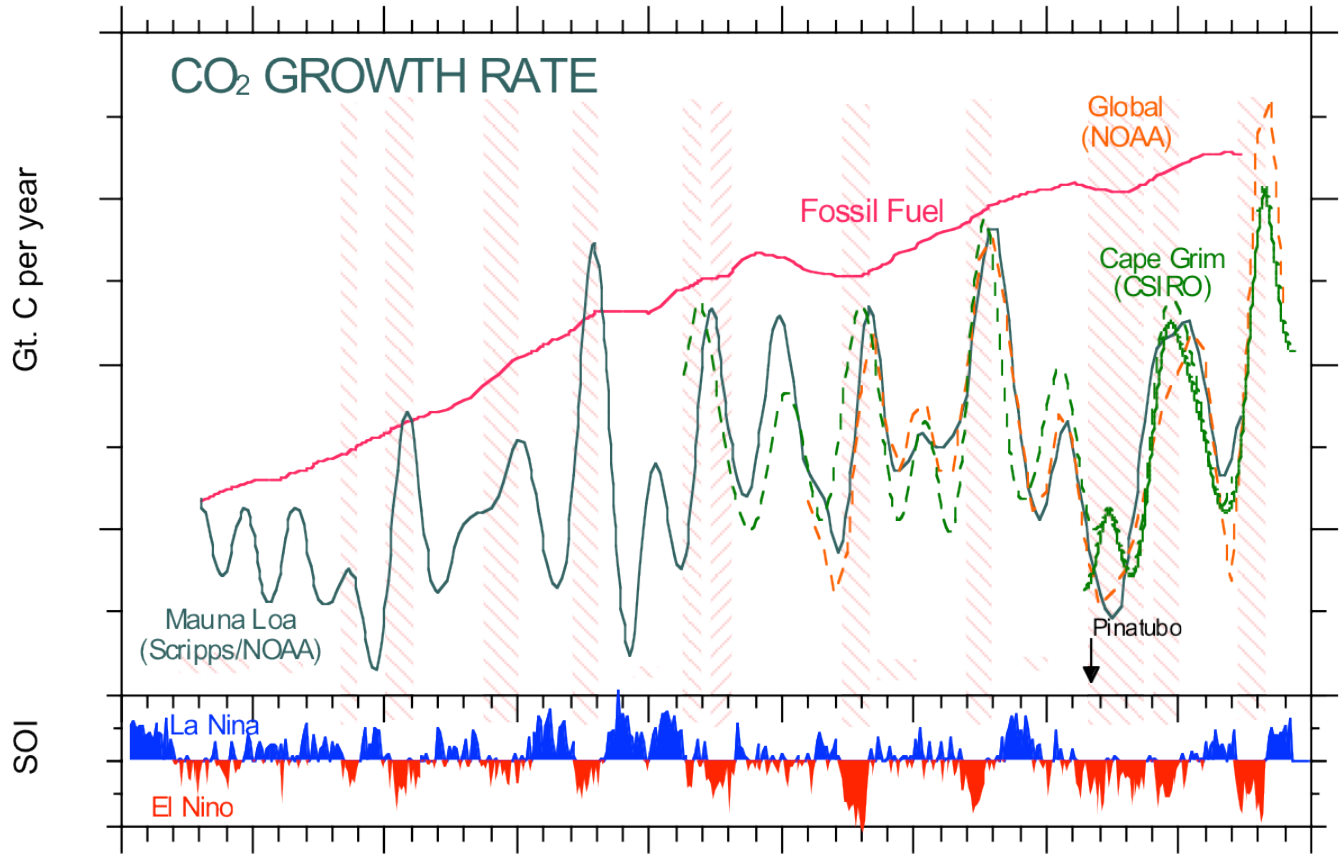
LeQuéré et al. , 2009

Observational constrains

- These variations are driven by climate variability especially ENSO.

CO2 growth rate rises during El Nino falls during La Nina



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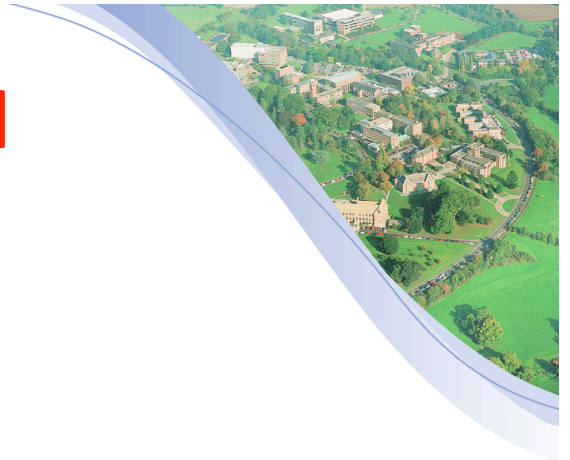
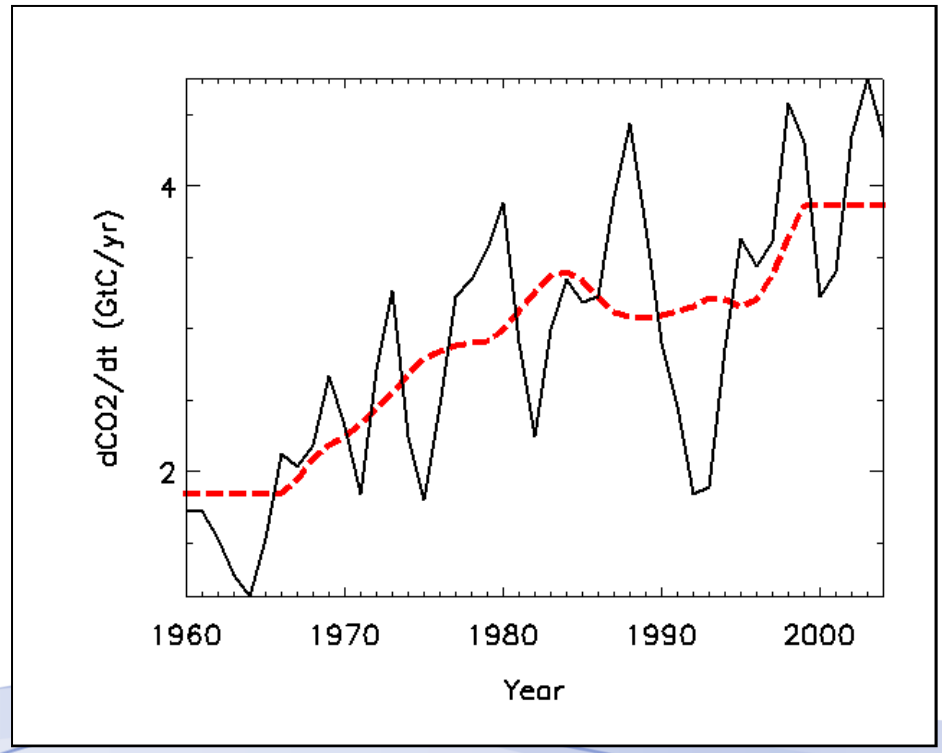
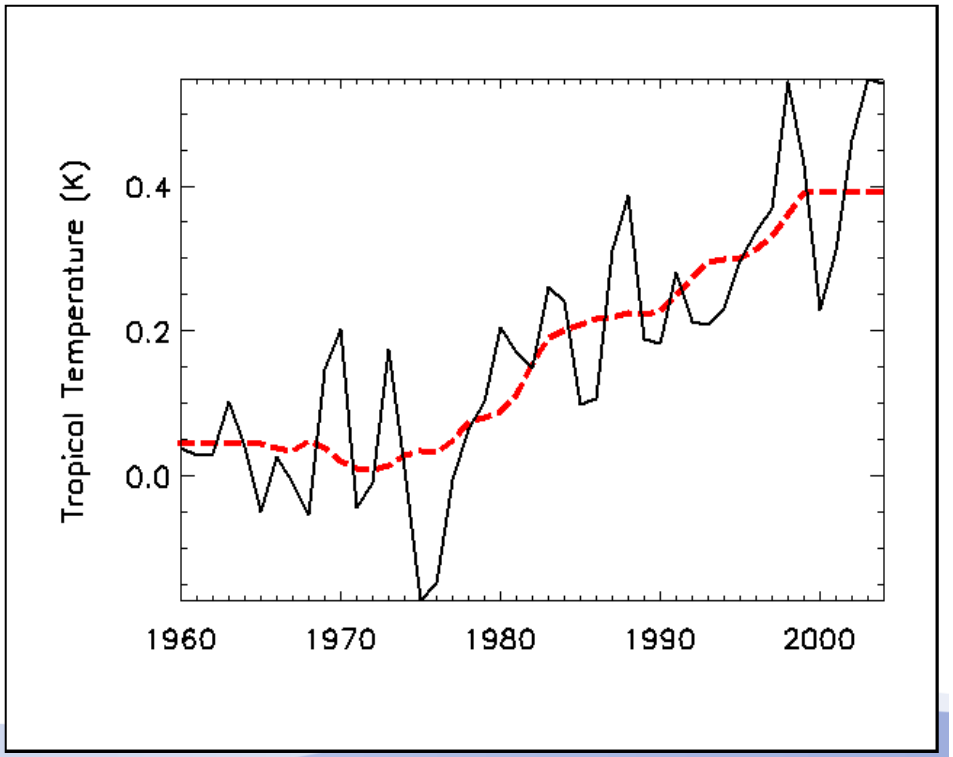
Constraints from Observed Interannual Variability



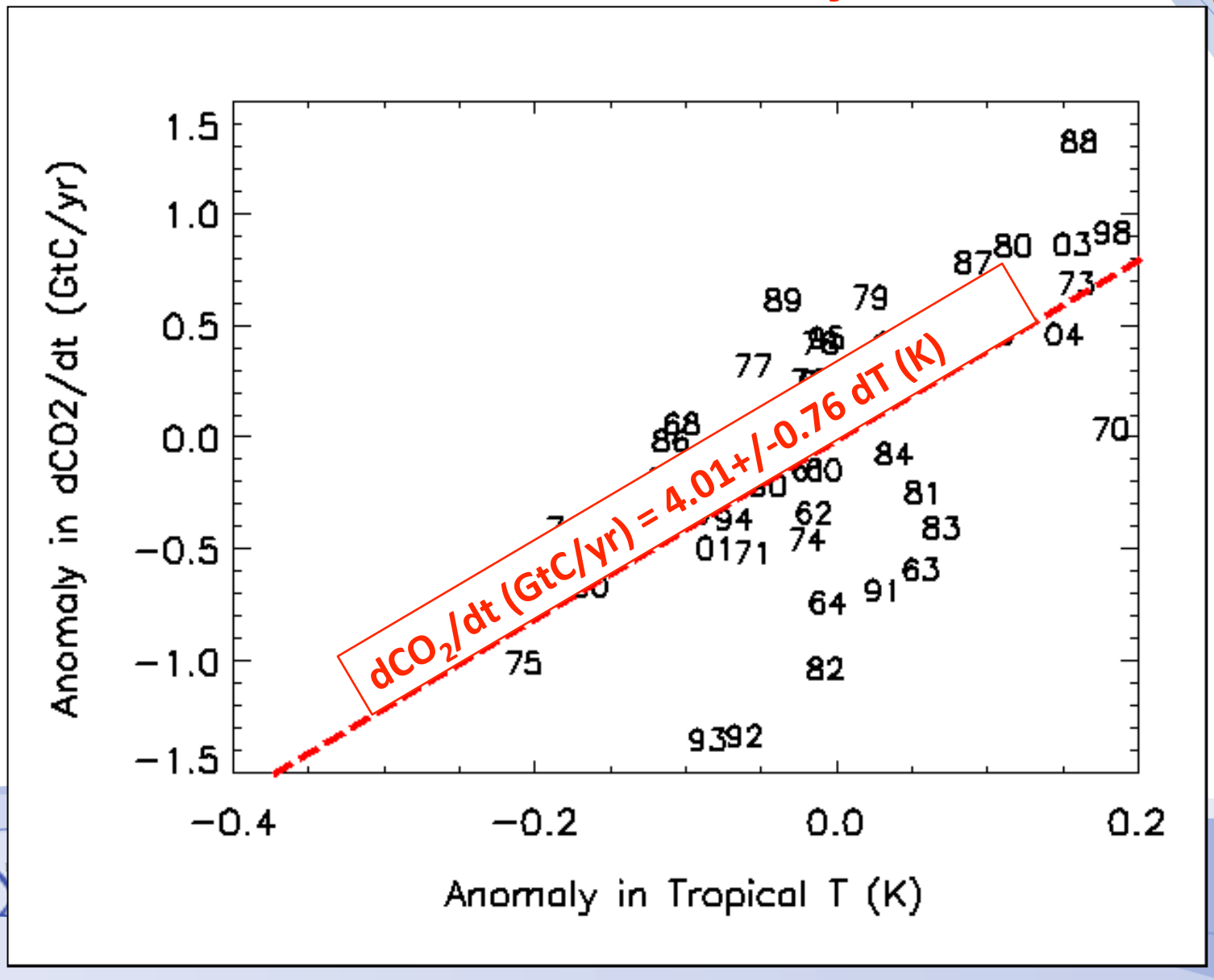
Global CO_2 Growth-rate



Mean Temperature 30°N-30°S



Constraints from Observed Interannual Variability



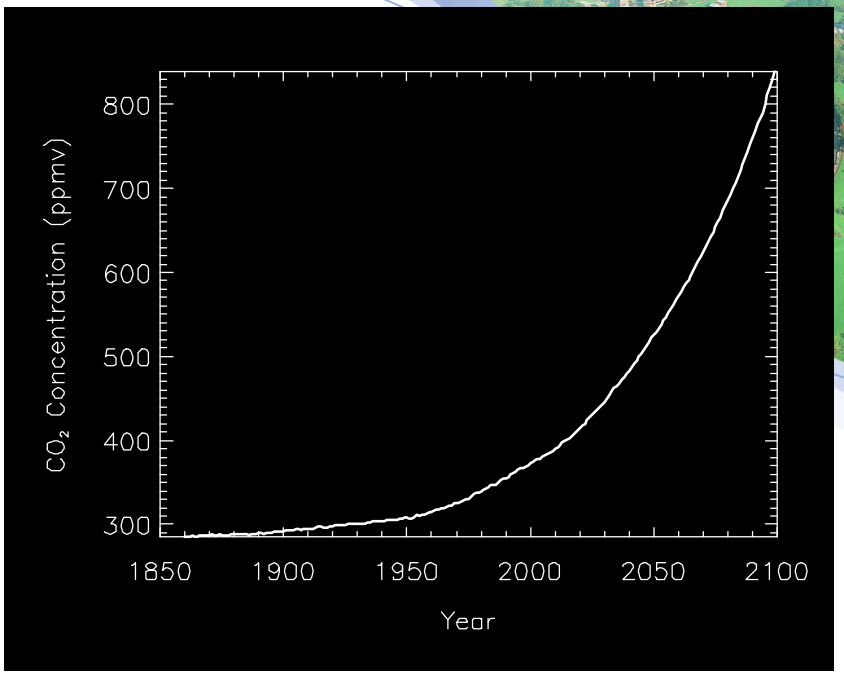
Observational constrains

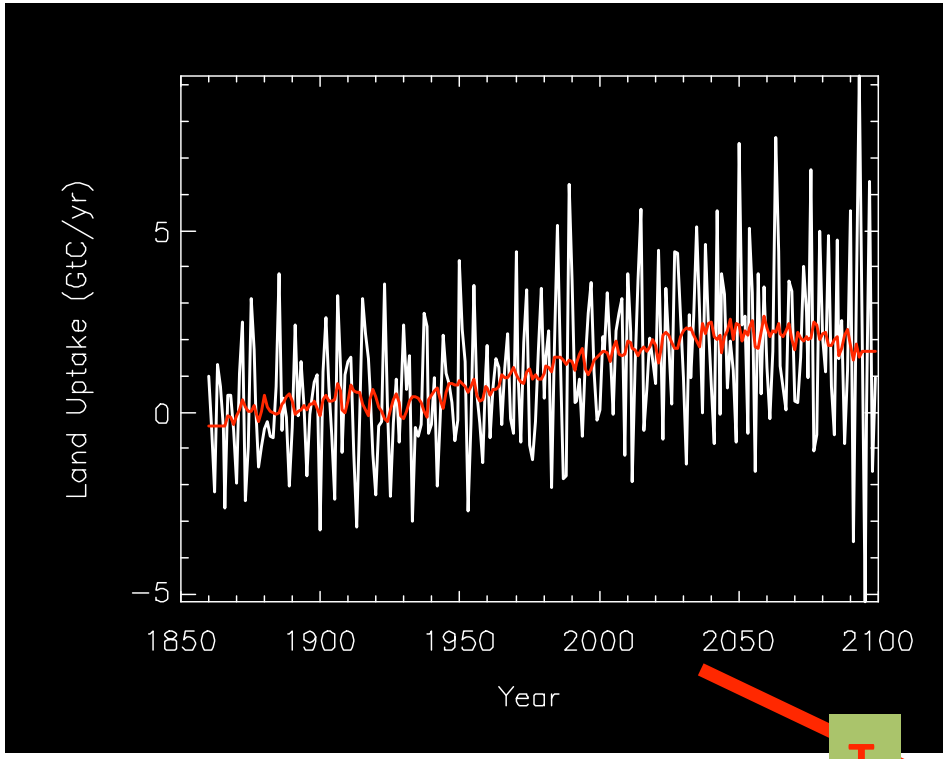
- Can we use this observed interannual variability in the CO_2 growth-rate as a constraint on the sensitivity of tropical land carbon to climate change ?

Try to Decompose the Land Carbon Sink into -

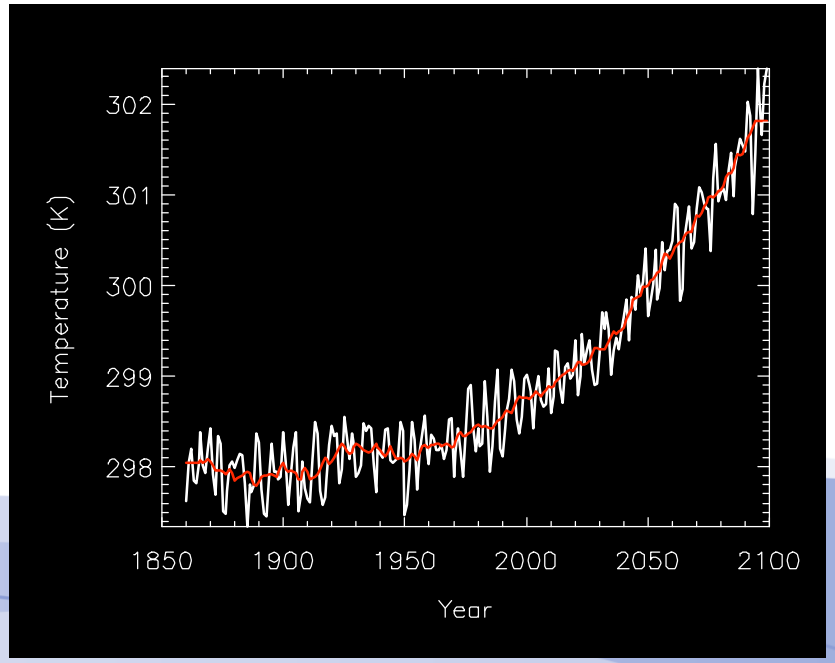
(MPI Model)

CO_2





T



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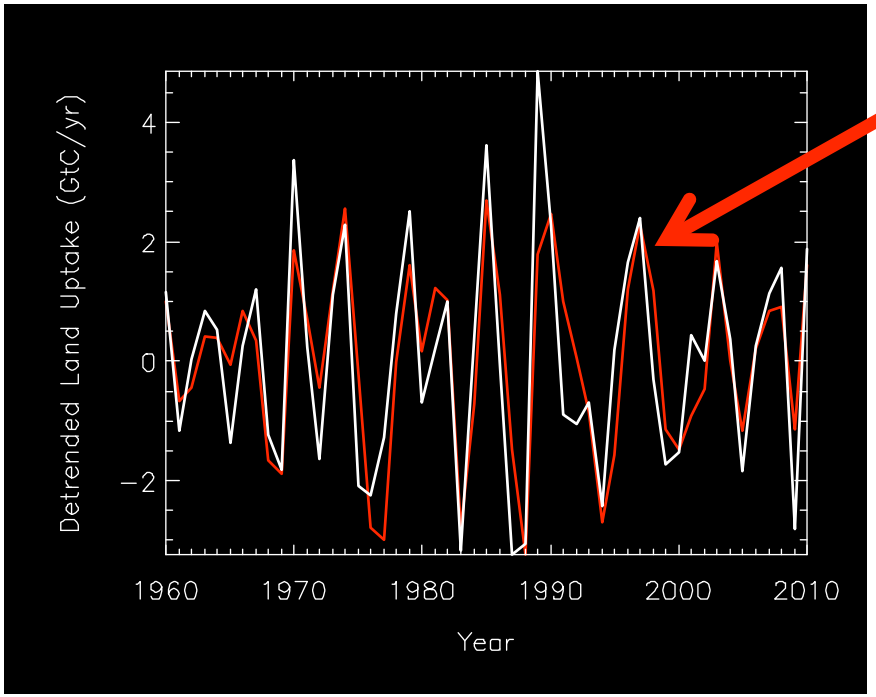
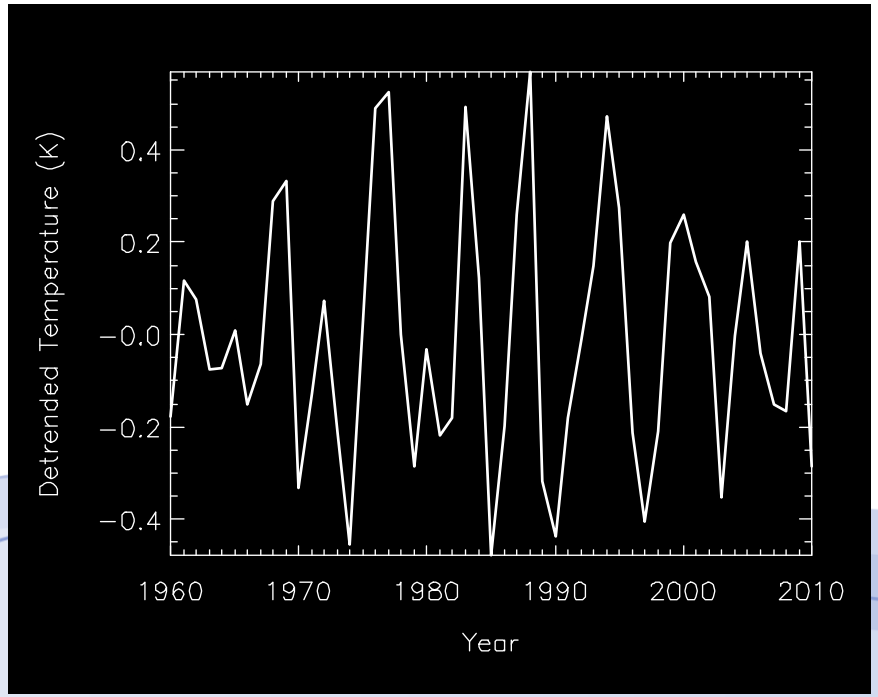
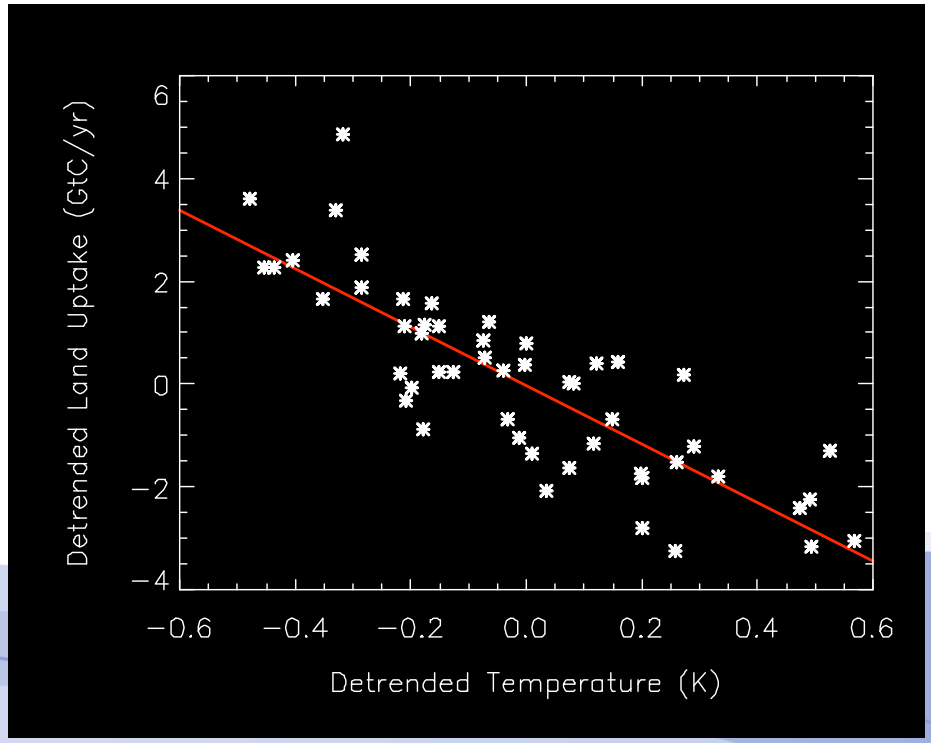


Best linear fit to detrended T

Relationship between Interannual Variability in Tropical Land Carbon Sink and Temperature (1960-2010)

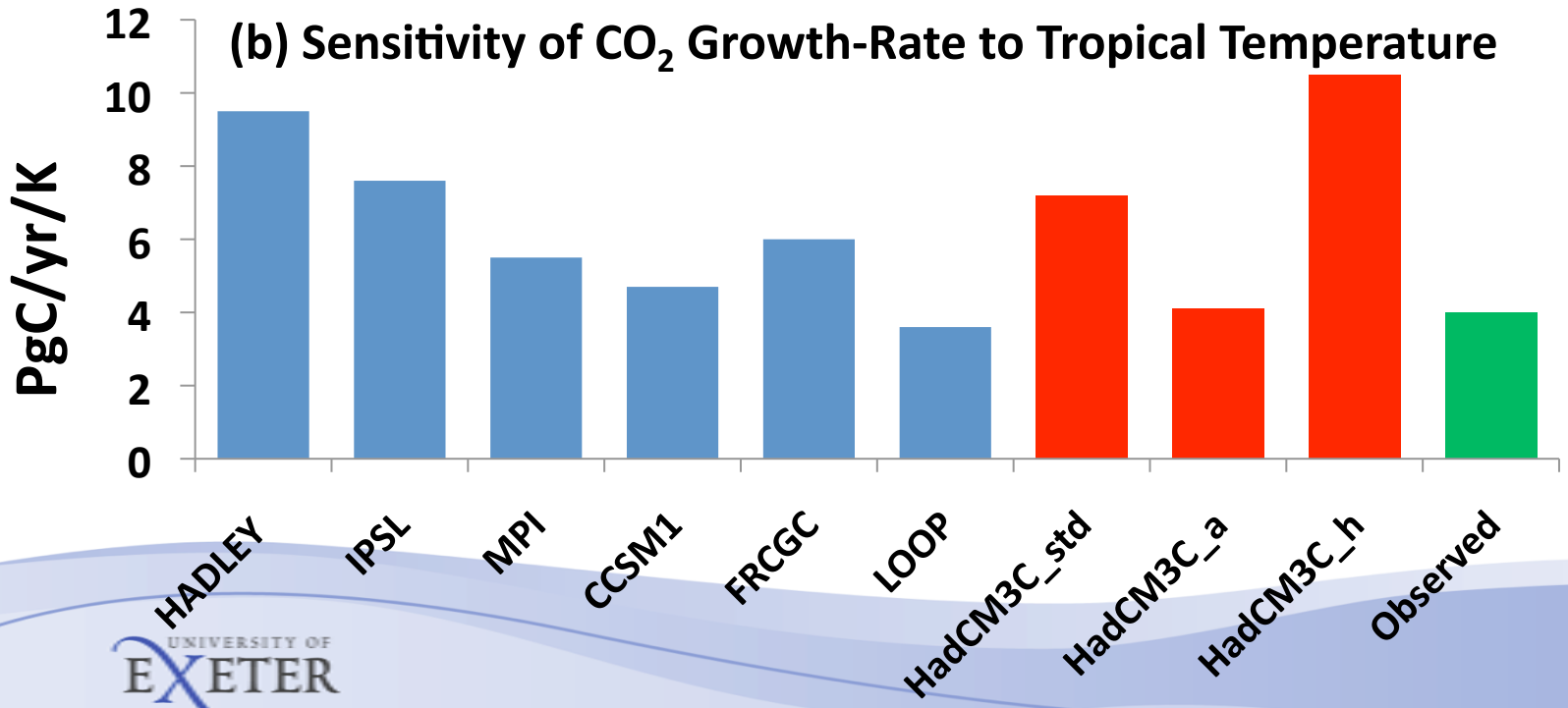
(MPI Model)





Observational constrains

- Estimate of the C4MIP models sensitivity of the CO_2 growth-rate to interannual variability in tropical temperatures (Υ_{IAV}).



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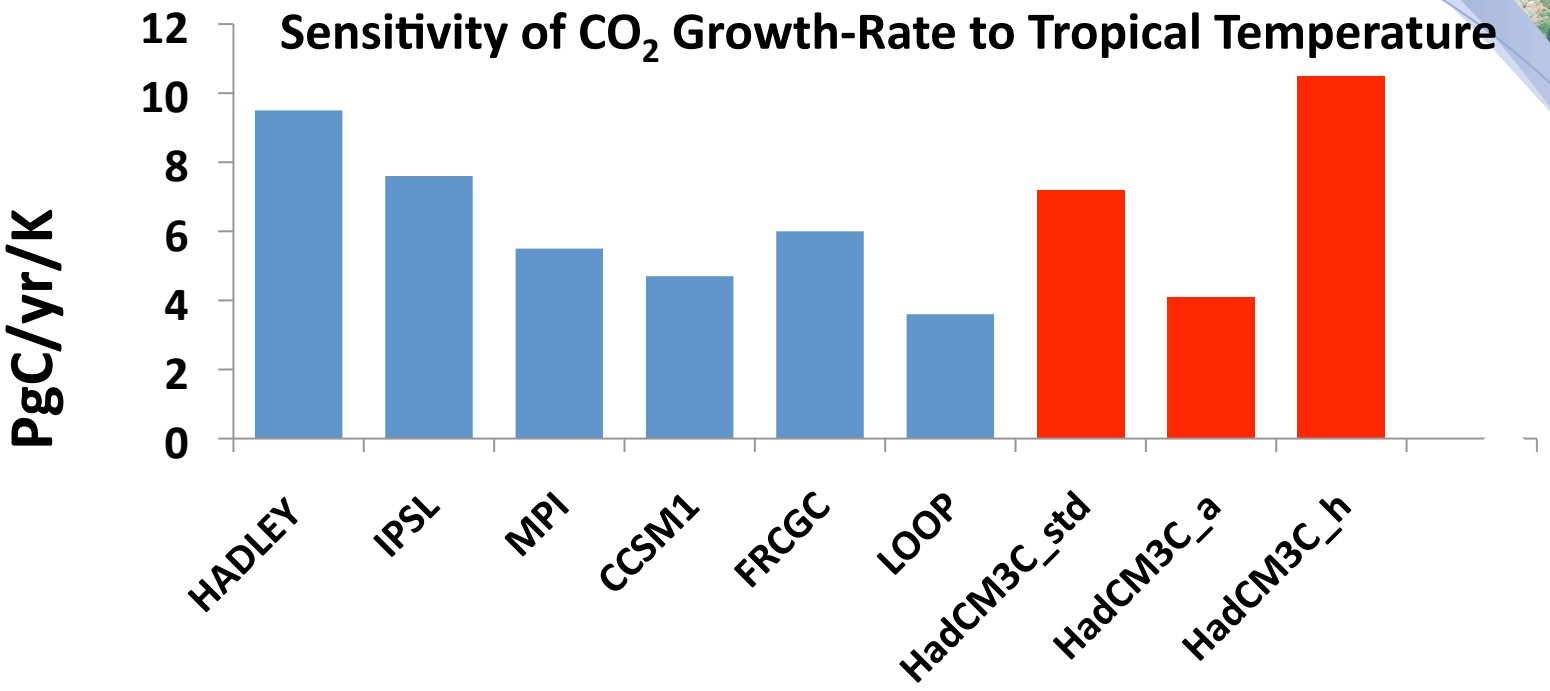
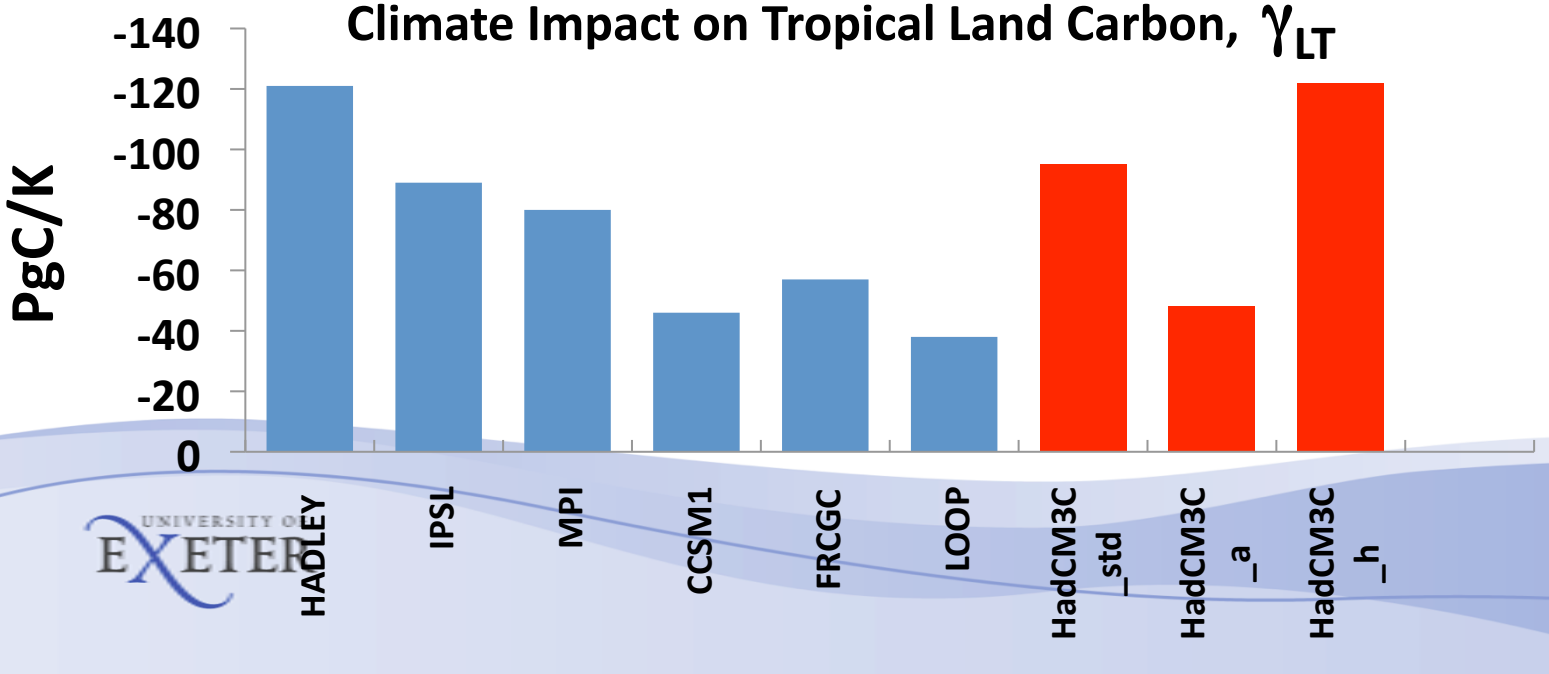
Observational constrains

- The tropical "γ_{LT}" across the C^{4}MIP GCMs is linearly-related to the sensitivity of the CO_2 growth-rate to interannual variability in tropical temperatures (Υ_{IAV}).





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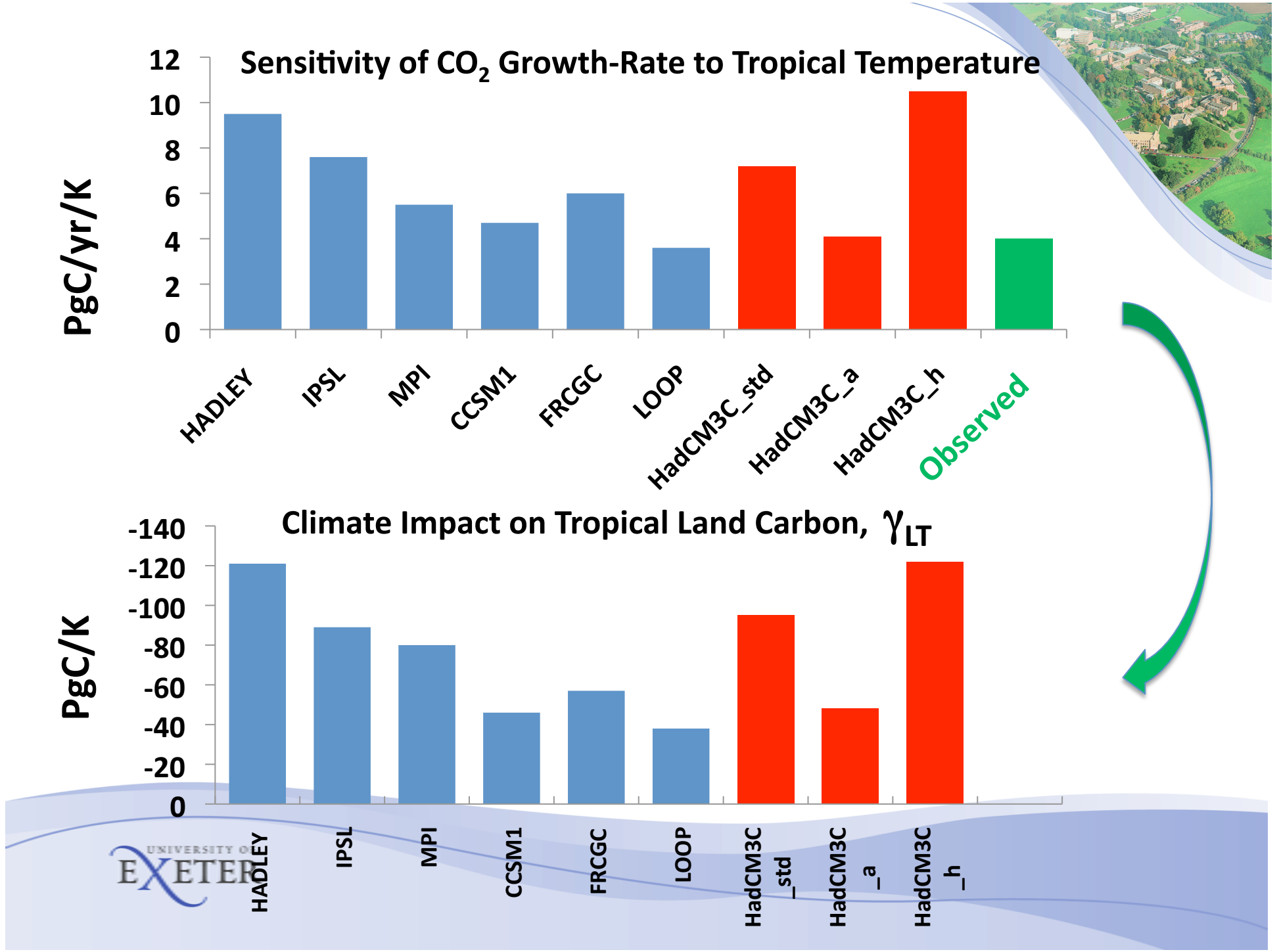
Sensitivity of CO_2 Growth-Rate to Tropical Temperature
PgC/yr/K
12
10
8
6
4
2
0
HADLEY
IPSL
MPI
CCSM1
FRCGC
LOOP
HadCM3C_std
HadCM3C_a
HadCM3C_h
Observed
Climate Impact on Tropical Land Carbon, γ_{LT}
PgC/K
-140
-120
-100
-80
-60
-40
-20
0
HADLEY
IPSL
MPI
CCSM1
FRCGC
LOOP
HadCM3C_std
HadCM3C_a
HadCM3C_h
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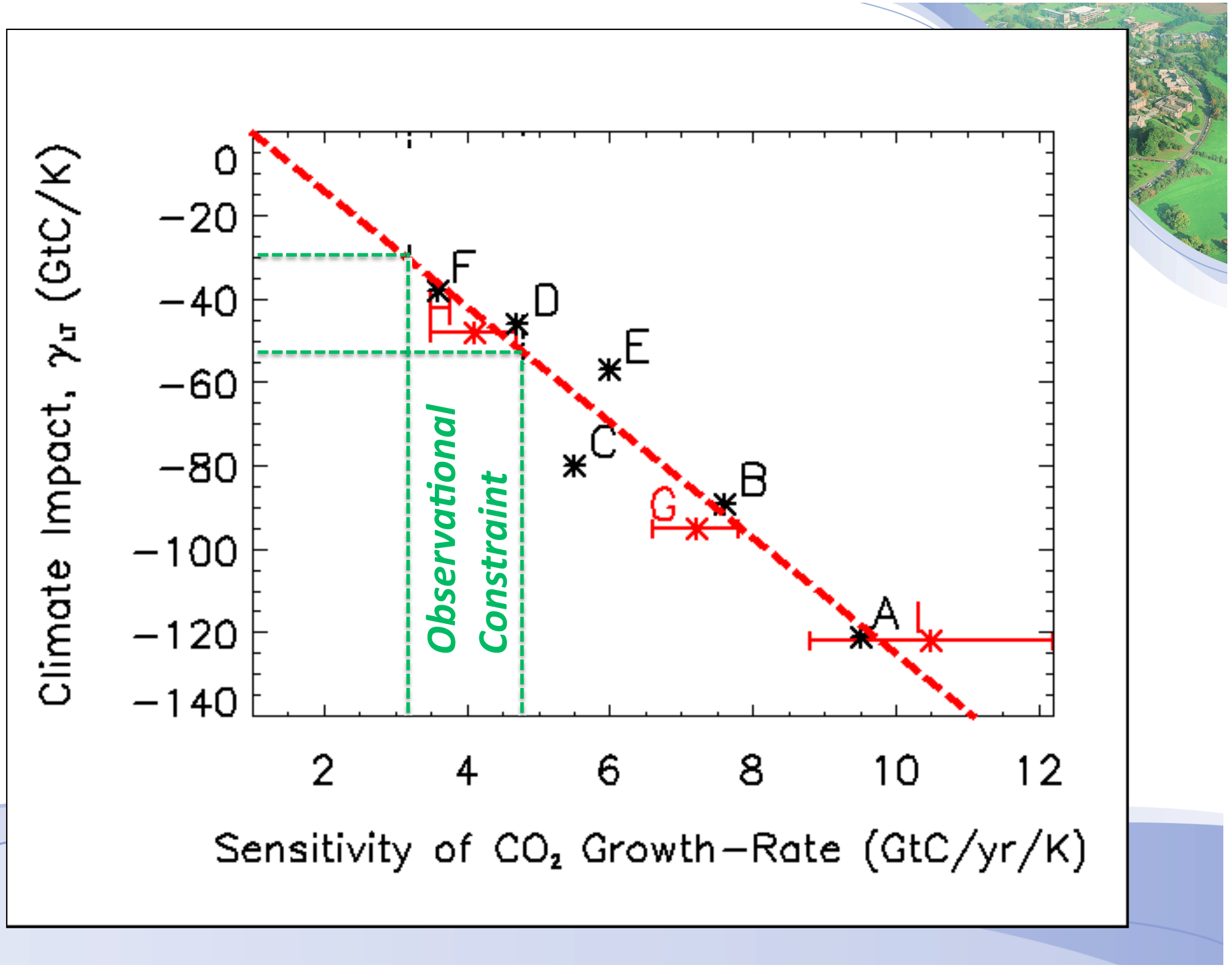
Climate Impact, γ_{LT} (GtC/K)
0
−20
−40
−60
−80
−100
−120
−140
2
4
6
8
10
12
Sensitivity of CO_2 Growth−Rate (GtC/yr/K)
F
D
E
C
B
G
A
Observational
Constraint

Conclusions

- Online and offline benchmarking can be used now for carbon cycle component of ESMs

Conclusions

- Online and offline benchmarking SHOULD be used now for carbon cycle component of ESMs

Conclusions

- Online and offline benchmarking SHOULD be used now for carbon cycle component of ESMs
- This is not trivial as many observations have known (unknown ?) limitations
- Models show significant correlation between CO2-T relationship on interannual and on long-term (climate change) time-scales
- The observed CO_2 record suggests a real-world relatively weak sensitivity of tropical land carbon to climate change.

That's good news !

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