Tipping Points in the Response of the Biosphere to Climate Change

How can we predict the unpredictable?

Peter Cox
Professor of Climate System Dynamics
University of Exeter

Definitions of Tipping Point

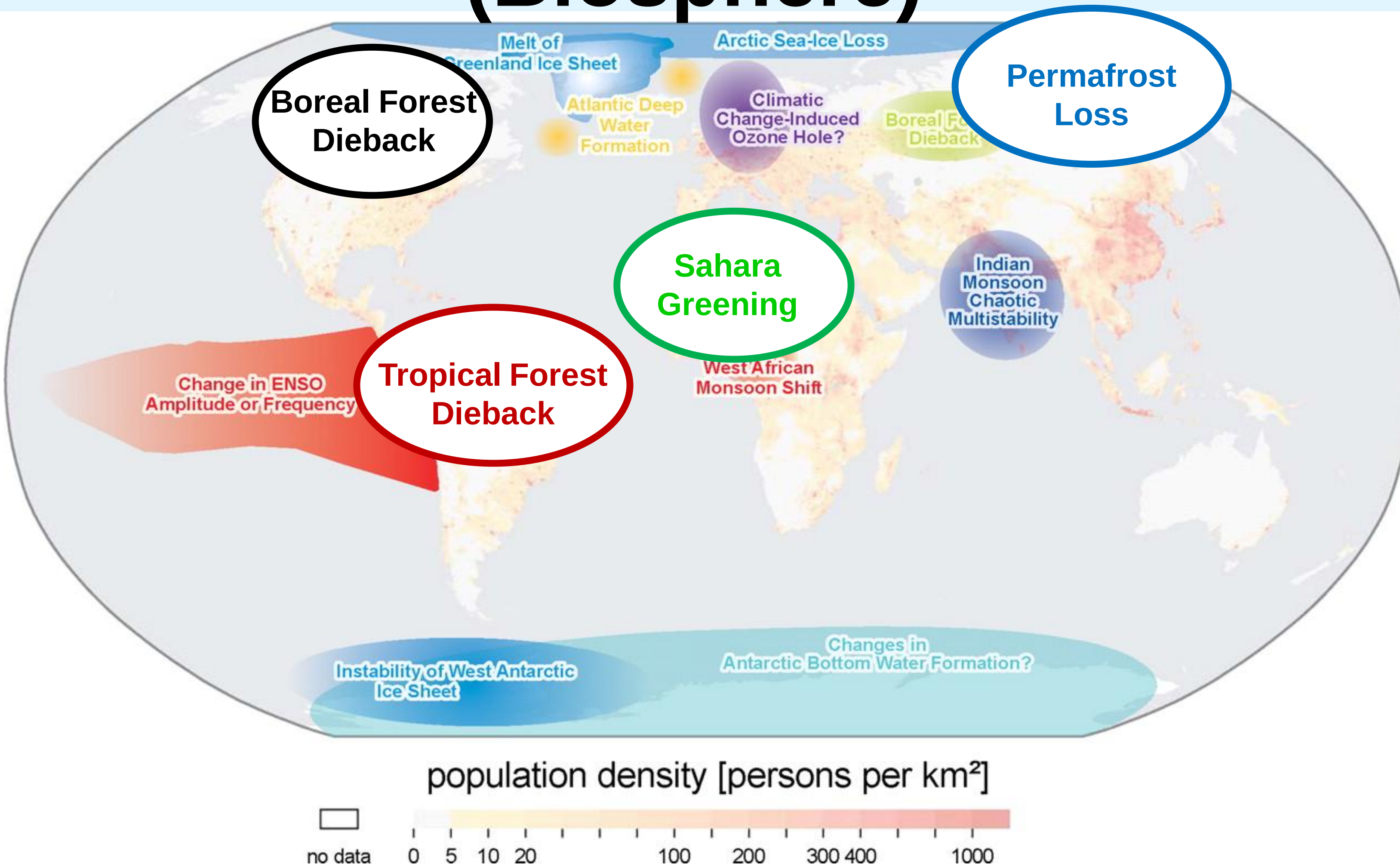
- "The tipping point is the ….critical point ..at which the future state of the system…can be switched into a qualitatively different state by small perturbations"

  (*based on Lenton et al., 2008*)

- "when the climate system is forced to cross some threshold, triggering a transition to a new state at a rate determined by the climate system itself and faster than the cause"

  (*Abrupt Climate Change*, NAS, 2002)

Potential Tipping Points (Biosphere)



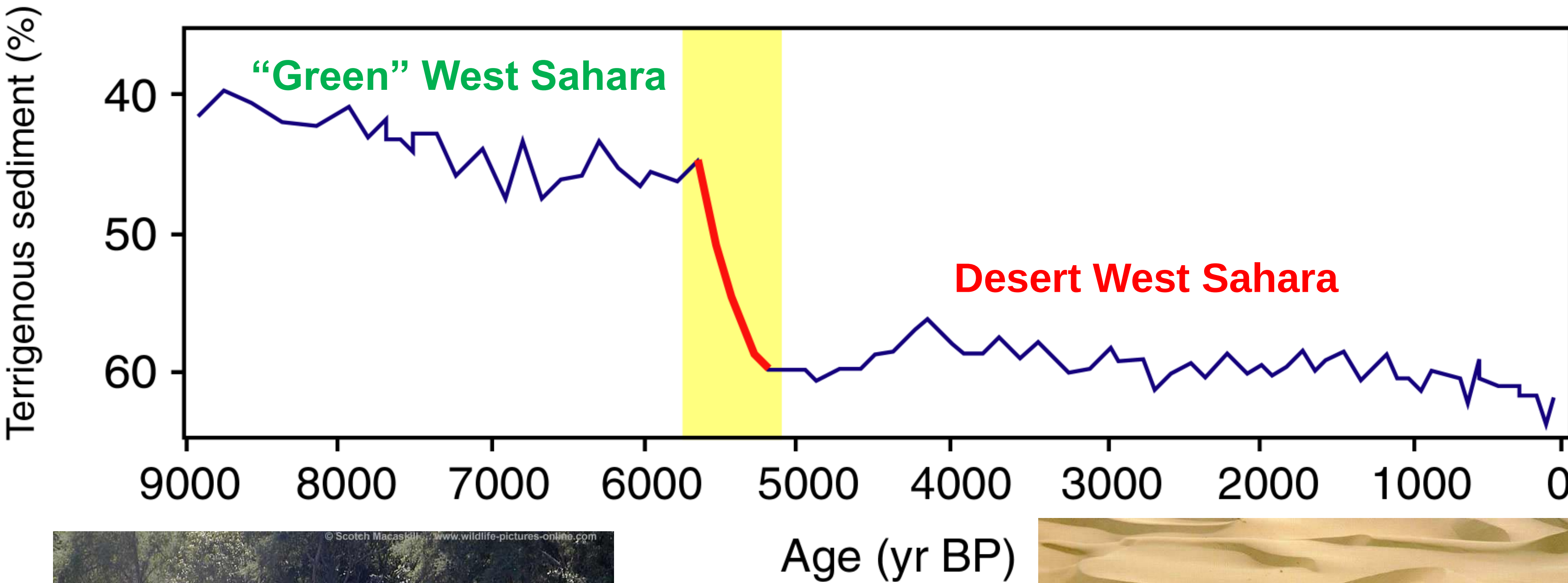
Lenton T. M. et.al. PNAS 2008

PNAS

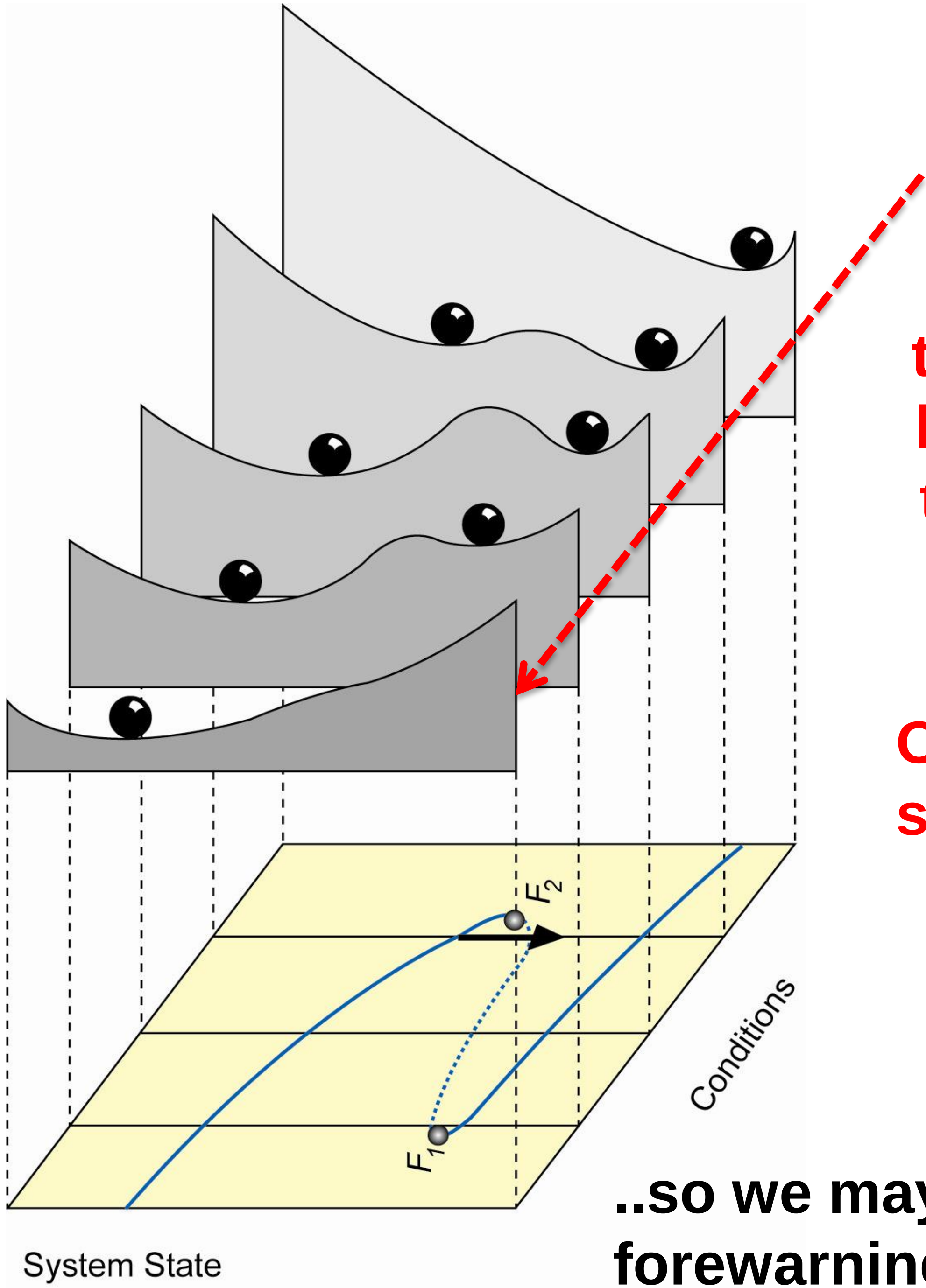
Summary I

- Tipping points are potentially abrupt and/or irreversible changes in the climate system. Many of these are associated with ecosystem-climate feedbacks.

How could a Hippo have predicted the Aridification of the Western Sahara 5500 years ago?



Marten Scheffer, Kavli CentreTipping Points meeting, Yesterday



Restoring force towards equilibrium becomes weaker as the Tipping Point is approached

Oscillations become slower but larger

..so we may be able to get some forewarning of Tipping Points

Summary I

- Tipping points are potentially abrupt and/or irreversible changes in the climate system. Many of these are associated with ecosystem-climate feedbacks.

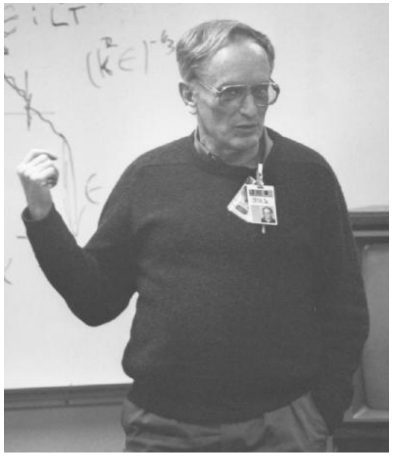
- Tipping points are very difficult to predict, but we may get a forewarning through changes in variability (prior to the tipping point (e.g. *Critical Slowing Down*) .

- More generally, we should expect to see a relationship between the variability of a system and its sensitivity to external forcing (e.g. via the *Fluctuation-Dissipation Theorem*).

Fluctuation-Dissipation Theorem

A very general result in statistical thermodynamics which links the response of a system to external forcing, to internal fluctuations of the system in thermal equilibrium.

First applied to the climate system by Chuck Leith



Slide from Tim Palmer

Summary I

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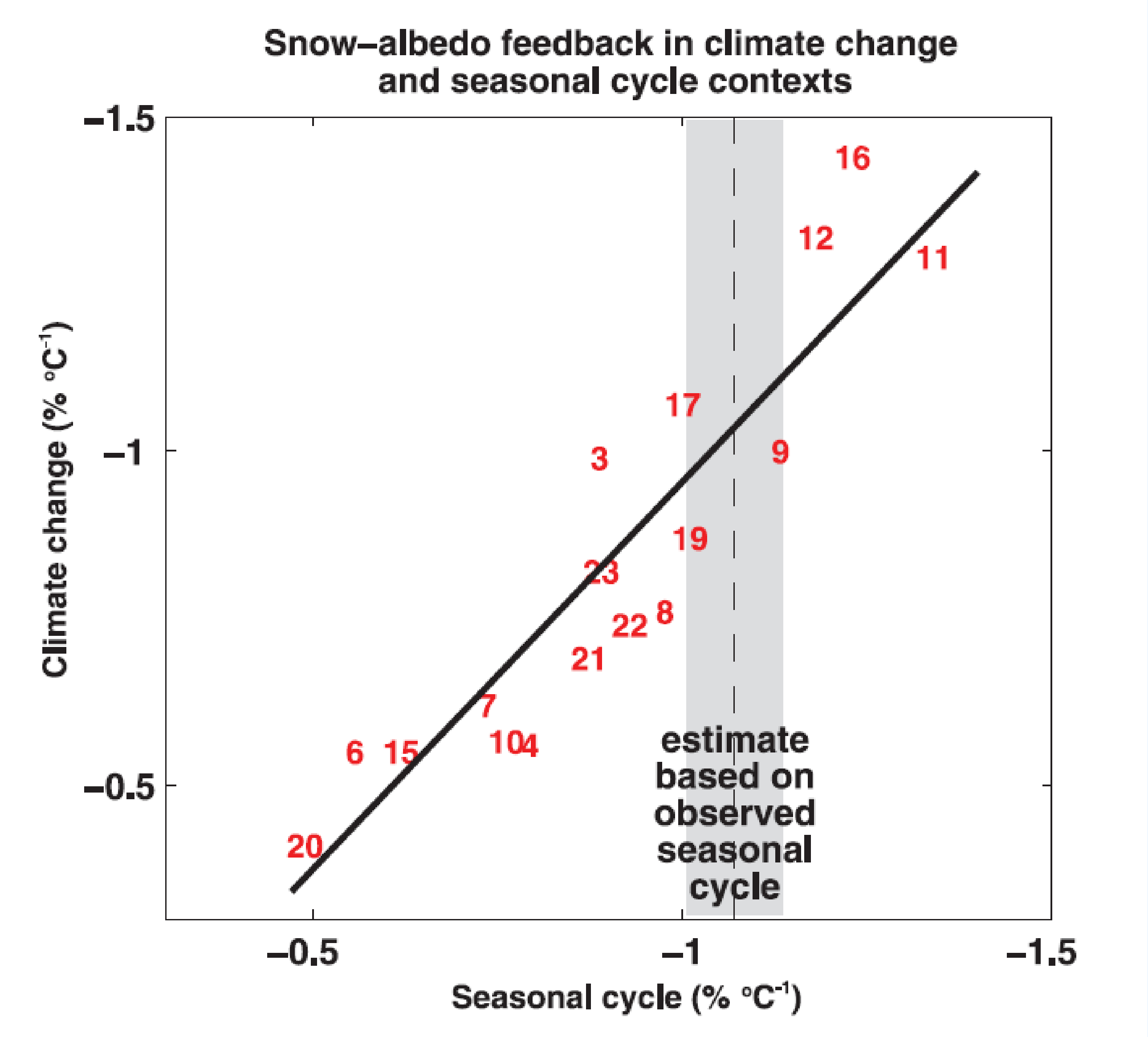
- Tipping points are very difficult to predict, but we may get a forewarning through changes in variability (prior to the tipping point (e.g. *Critical Slowing Down*) .
- More generally, we should expect to see a relationship between the variability of a system and its sensitivity to external forcing (e.g. via the *Fluctuation-Dissipation Theorem*).
- These factors motivate us to look for *Emergent Constraints*, i.e. robust relationships between Earth System sensitivities to anthropogenic forcing and observable features of ES variability, across the ensemble of climate-carbon cycle models.

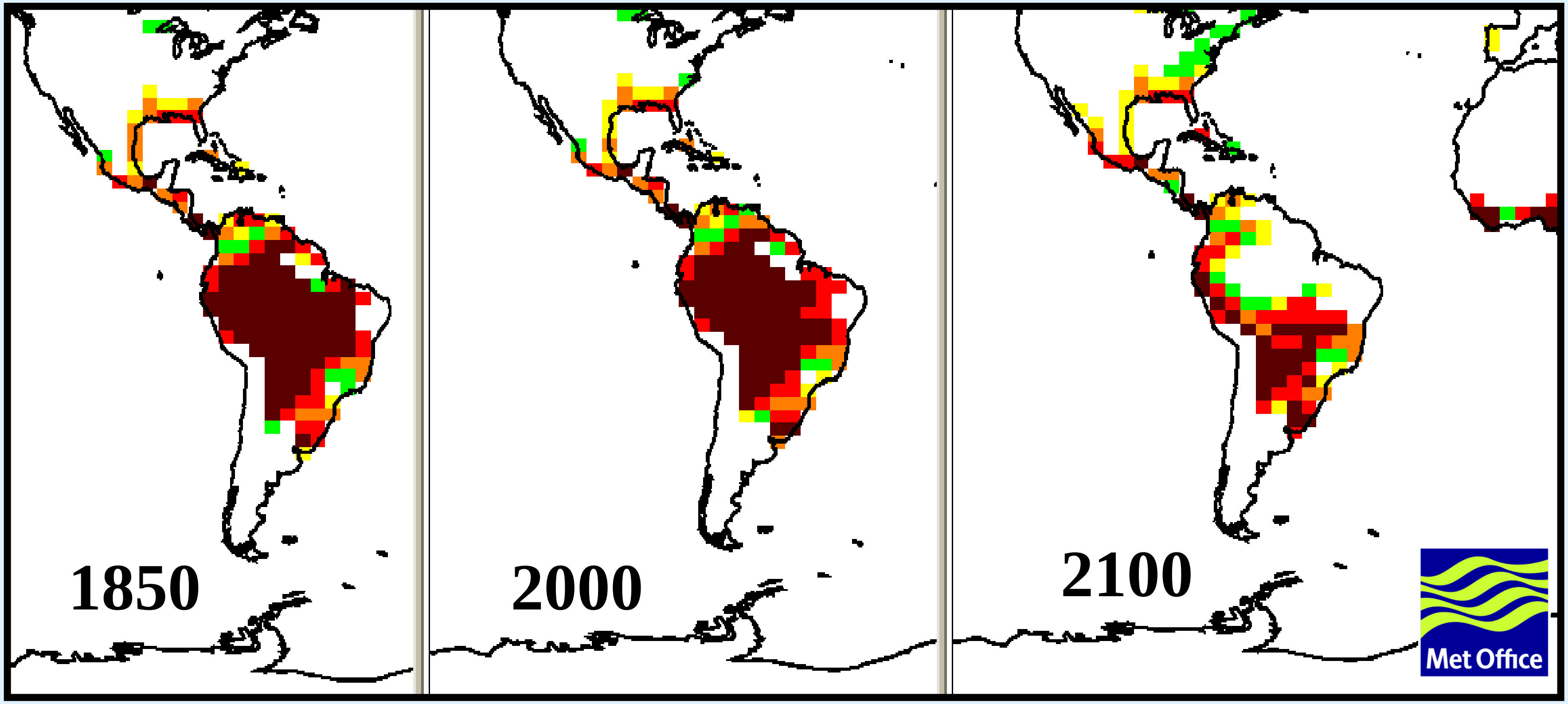
An Emergent Constraint on Snow-Albedo Feedback



Hall & Qu (2006)

Tropical Forest Dieback

Amazon Forest "dieback" in HadCM3LC Model



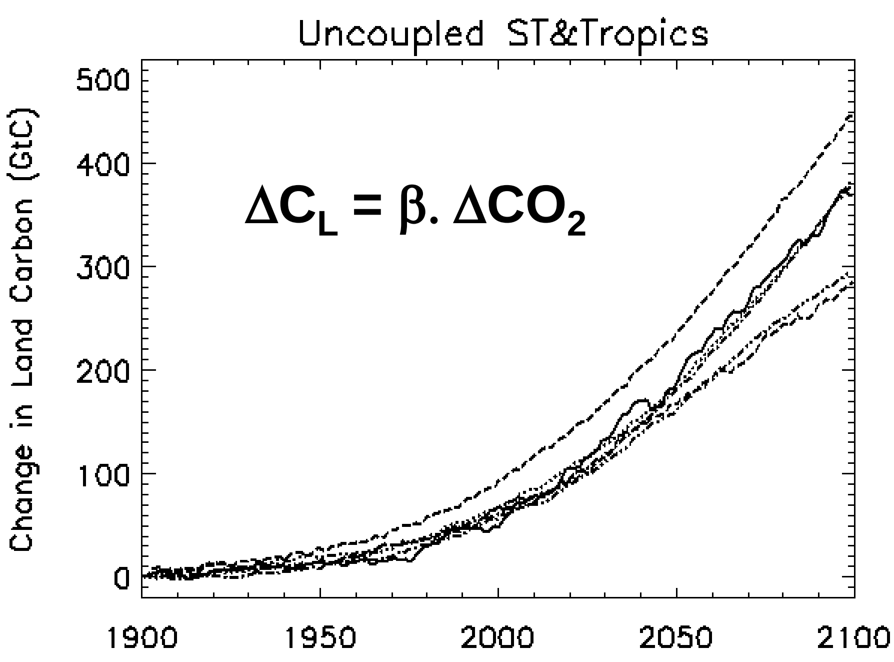
How likely is this in the real world ?

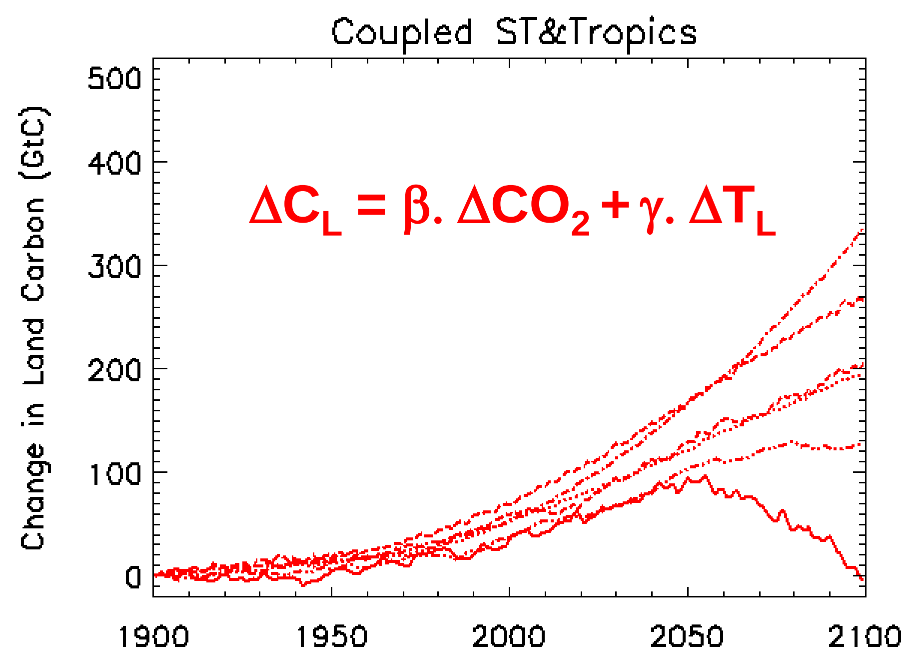
Uncertainty in Future Land Carbon Storage in Tropics (30ºN-30ºS)

C^4MIP Models (Friedlingstein et al., 2006)

Models without climate affects on Carbon Cycle

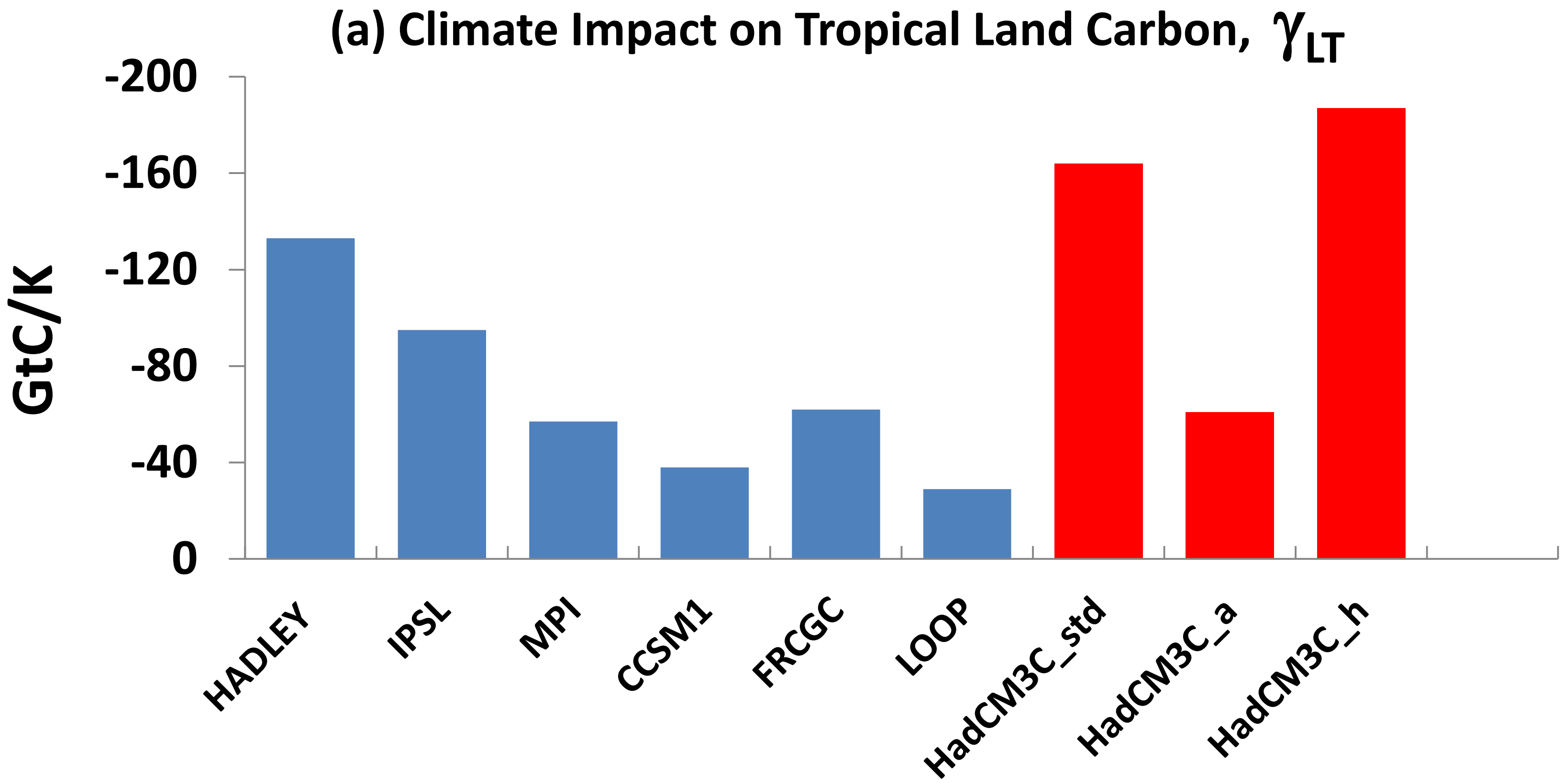
Models with climate affects on Carbon Cycle





$$\Delta C_L = \beta . \Delta CO_2 + \gamma . \Delta T_L$$

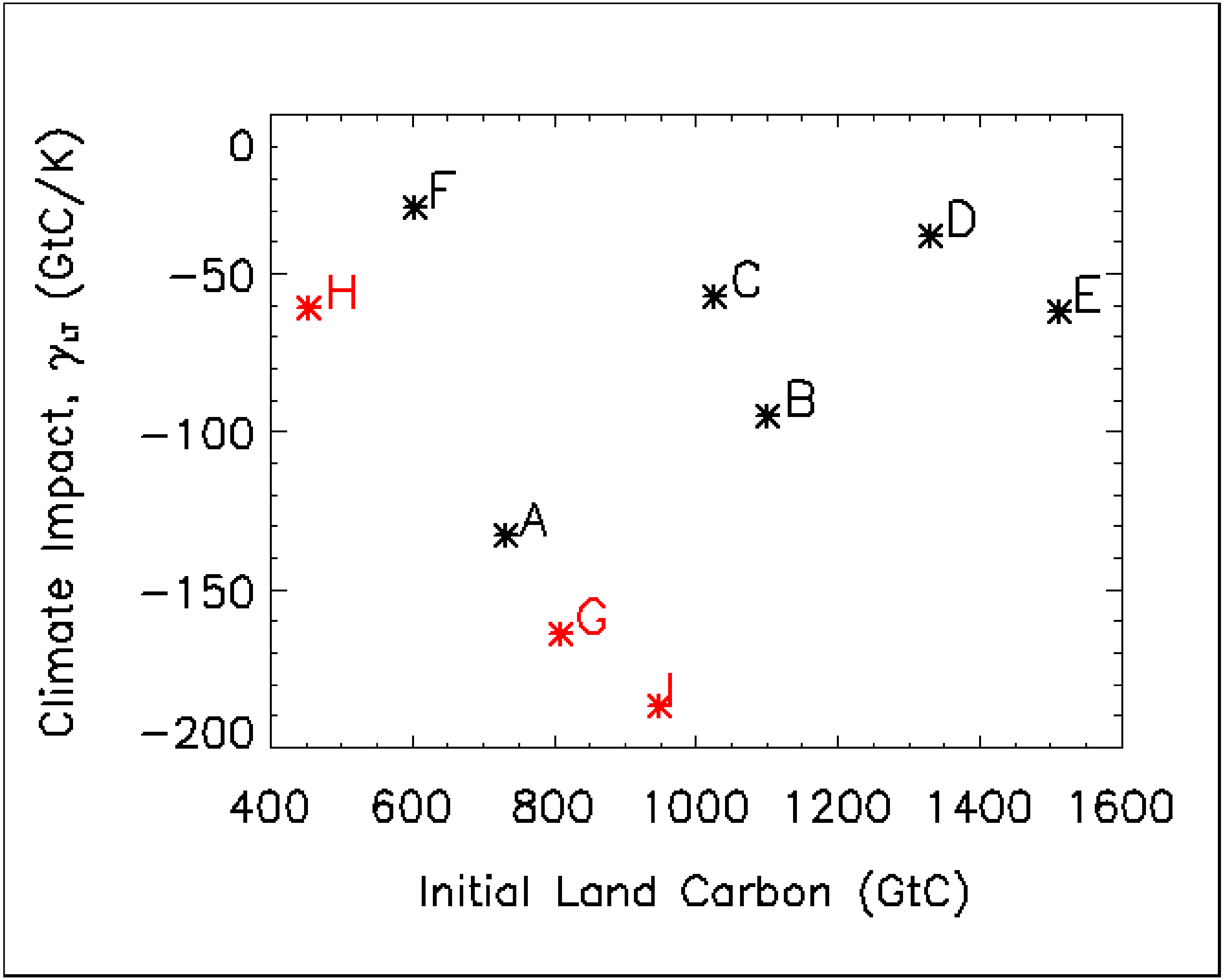
Change in Land Carbon	=	CO_2 Fertilization x Change in CO_2	+	Climate impact on land C x Change in Temperature



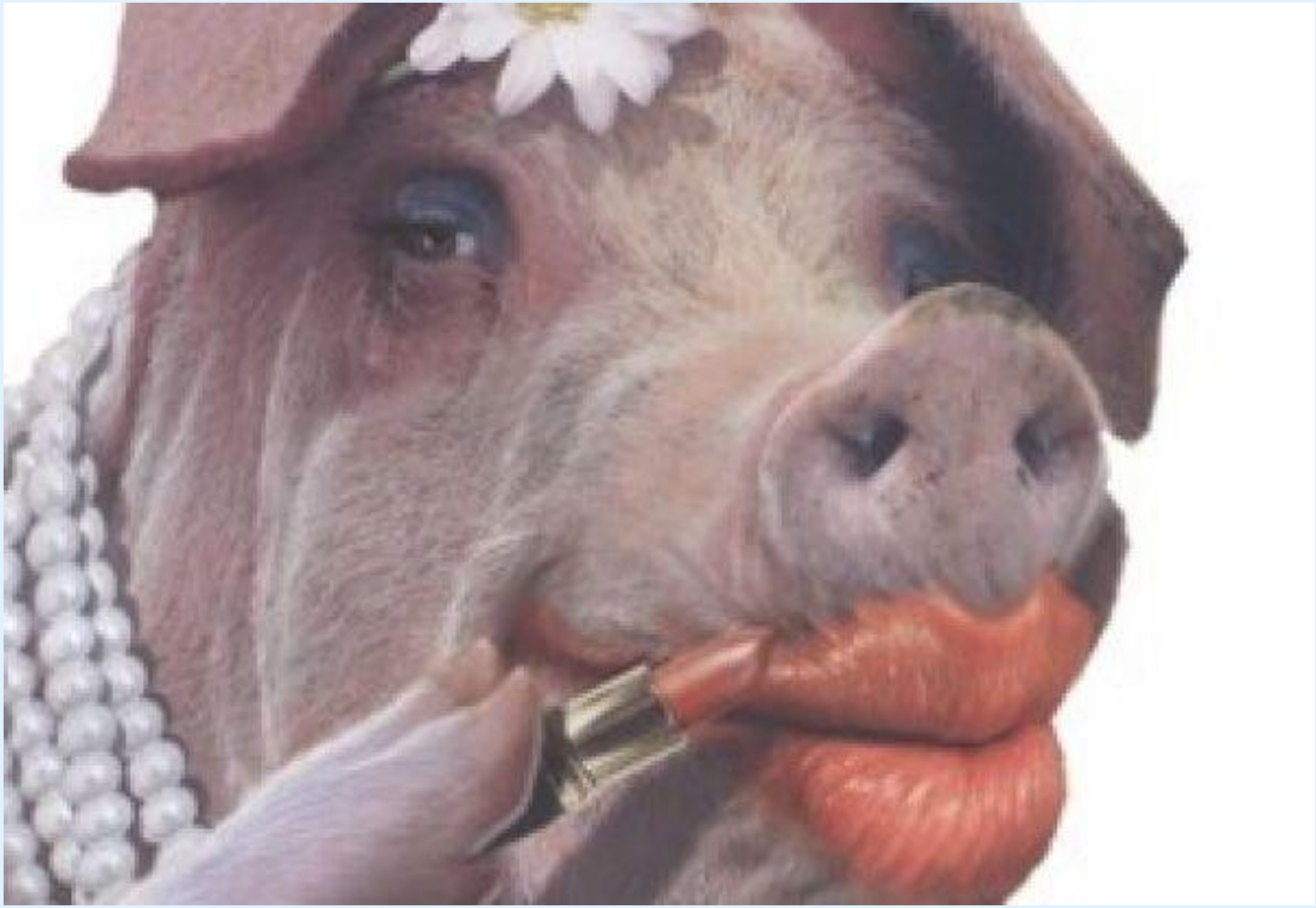
- **How can we constrain this sensitivity?**

- **Normally in climate modelling we assume that models that simulate the current state "realistically" are more likely to have realistic sensitivities. ......but is this sound ?**

Initial Carbon Content – Poor Predictor of Sensitivity



Time for Model Evaluation to become more than a beauty contest ?



An Emergent Constraint on Carbon Loss from Tropical Land under Climate Change

LETTER

doi:10.1038/nature11882

Sensitivity of tropical carbon to climate change constrained by carbon dioxide variability

Peter M. Cox[1], David Pearson[2], Ben B. Booth[2], Pierre Friedlingstein[1], Chris Huntingford[3], Chris D. Jones[2] & Catherine M. Luke[1]

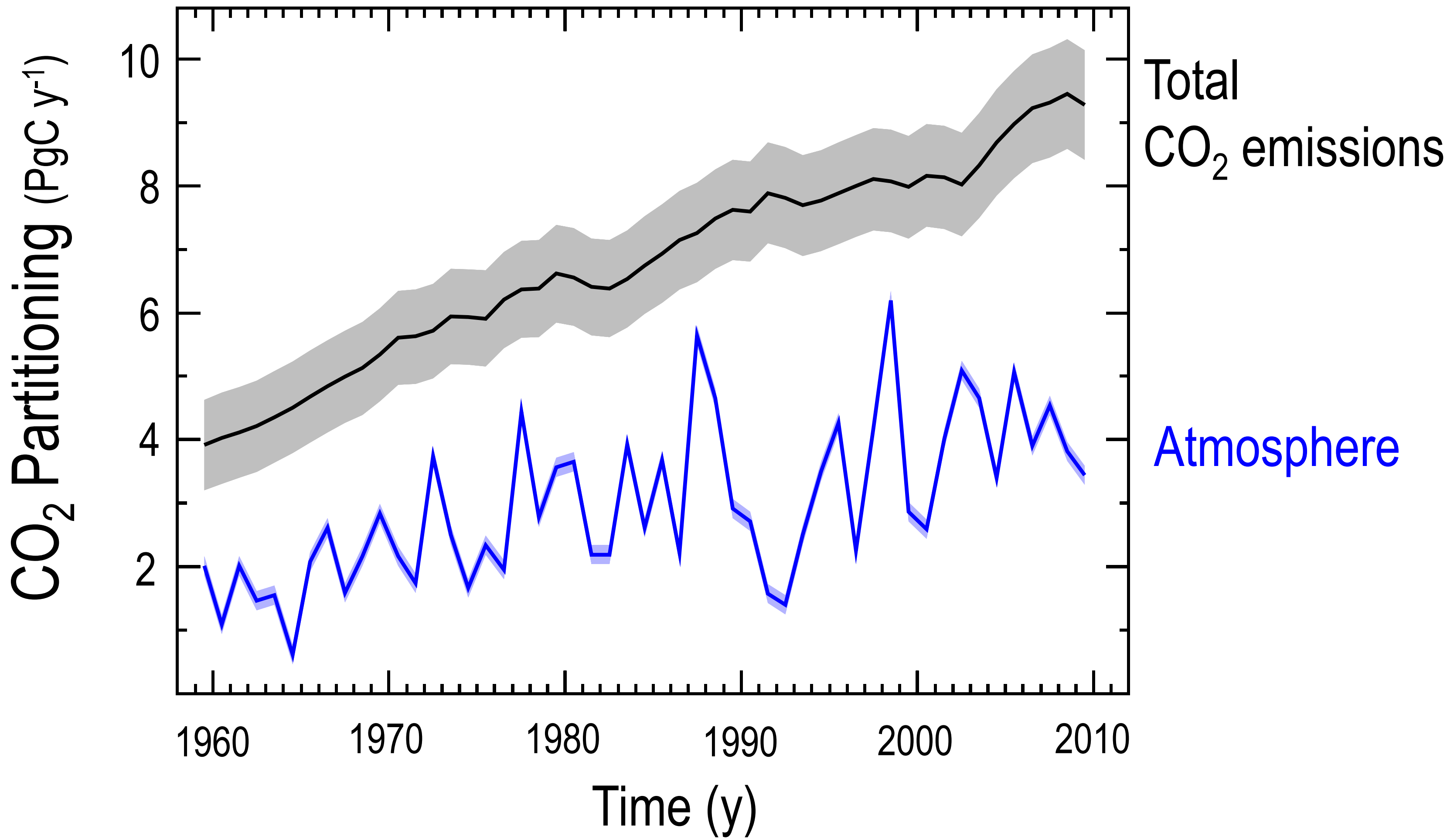
published in February

Rationale

- The growth-rate of atmospheric CO_2 varies significantly from year-to-year, and this variation is largely due to tropical land.

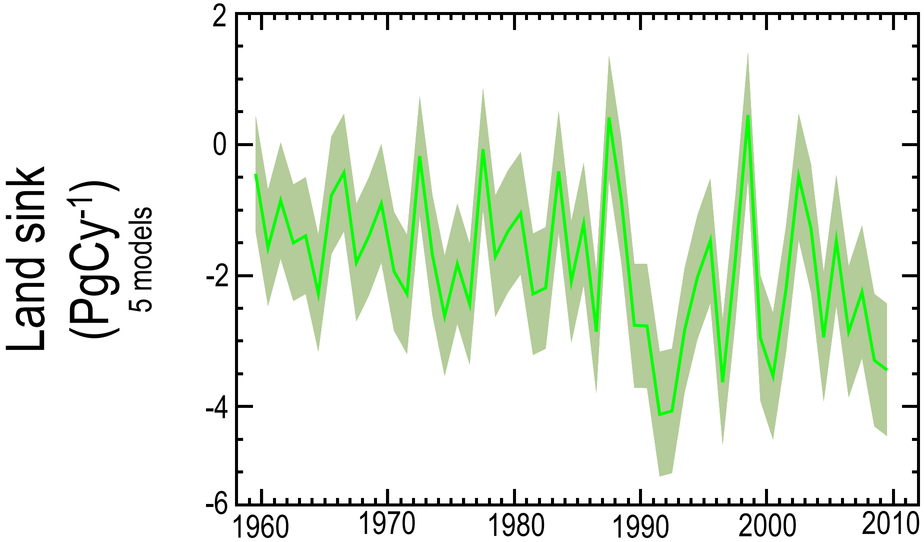
Interannual Variability in CO_2 Growth-rate

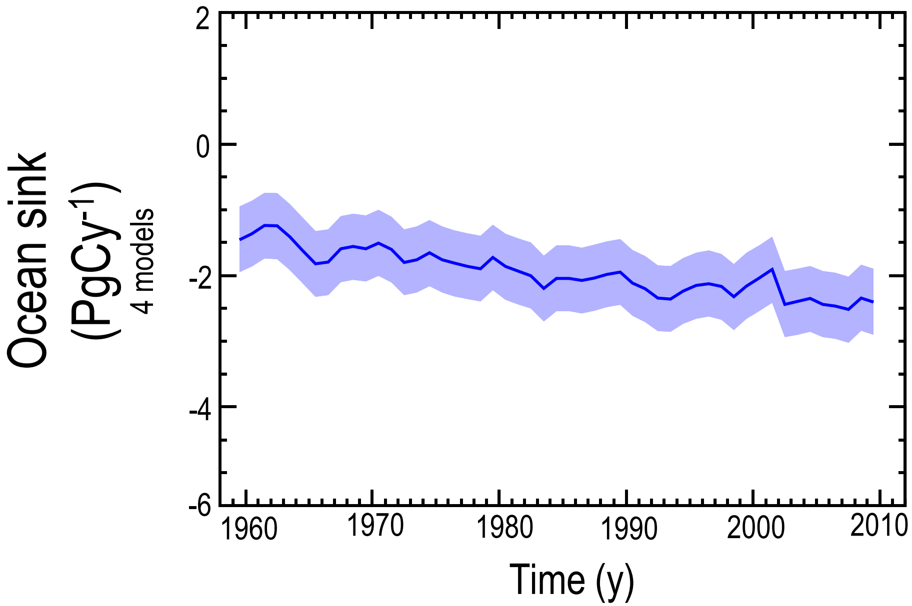
Evolution of the fraction of total emissions that remain in the atmosphere



Updated from Le Quéré et al. 2009, Nature Geoscience; Data: NOAA 2010, CDIAC 2010

Estimated Land and Ocean CO_2 Sinks



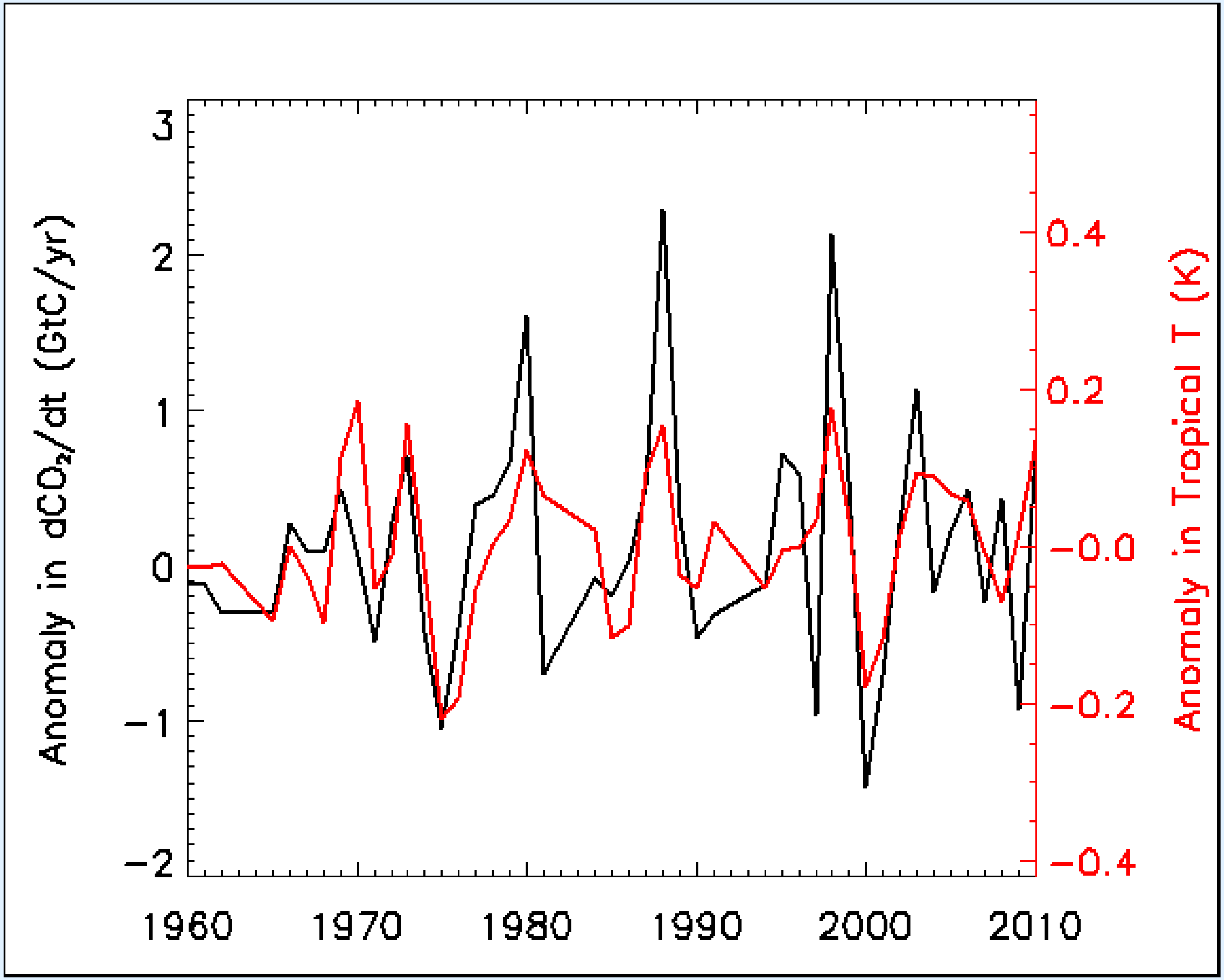


Updated from Le Quéré et al. 2009, Nature Geoscience

Rationale

- The growth-rate of atmospheric CO_2 varies significantly from year-to-year, and this variation is largely due to tropical land.
- These variations are driven by climate variability especially ENSO.

Relationship between CO_2 Growth-rate and Tropical Temperature - Observations



Rationale

- The growth-rate of atmospheric CO_2 varies significantly from year-to-year, and this variation is largely due to tropical land.
- These variations are driven by climate variability especially ENSO.
- Can we use the interannual variability in the CO_2 growth-rate as a constraint on the sensitivity of tropical land carbon to climate change ?

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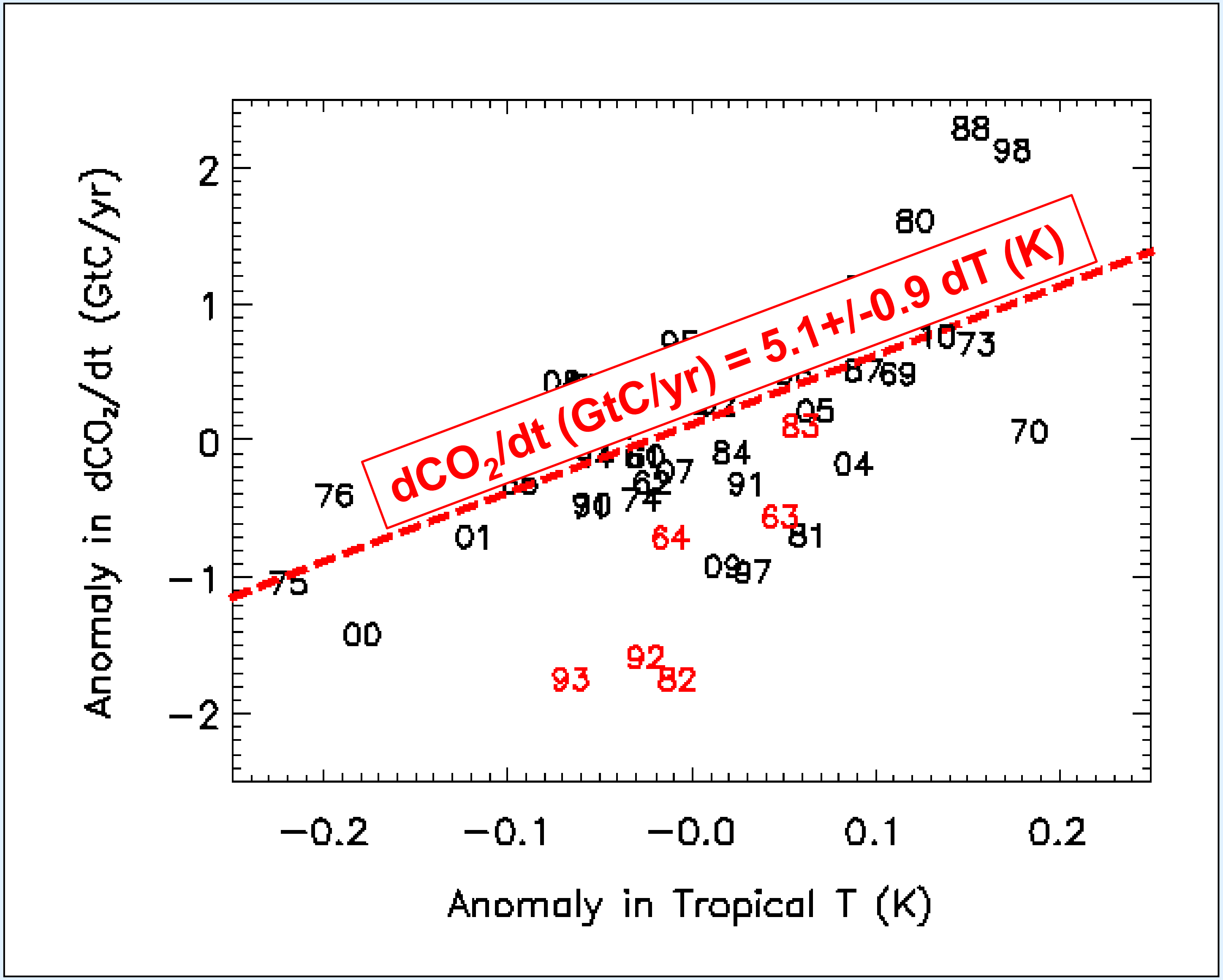
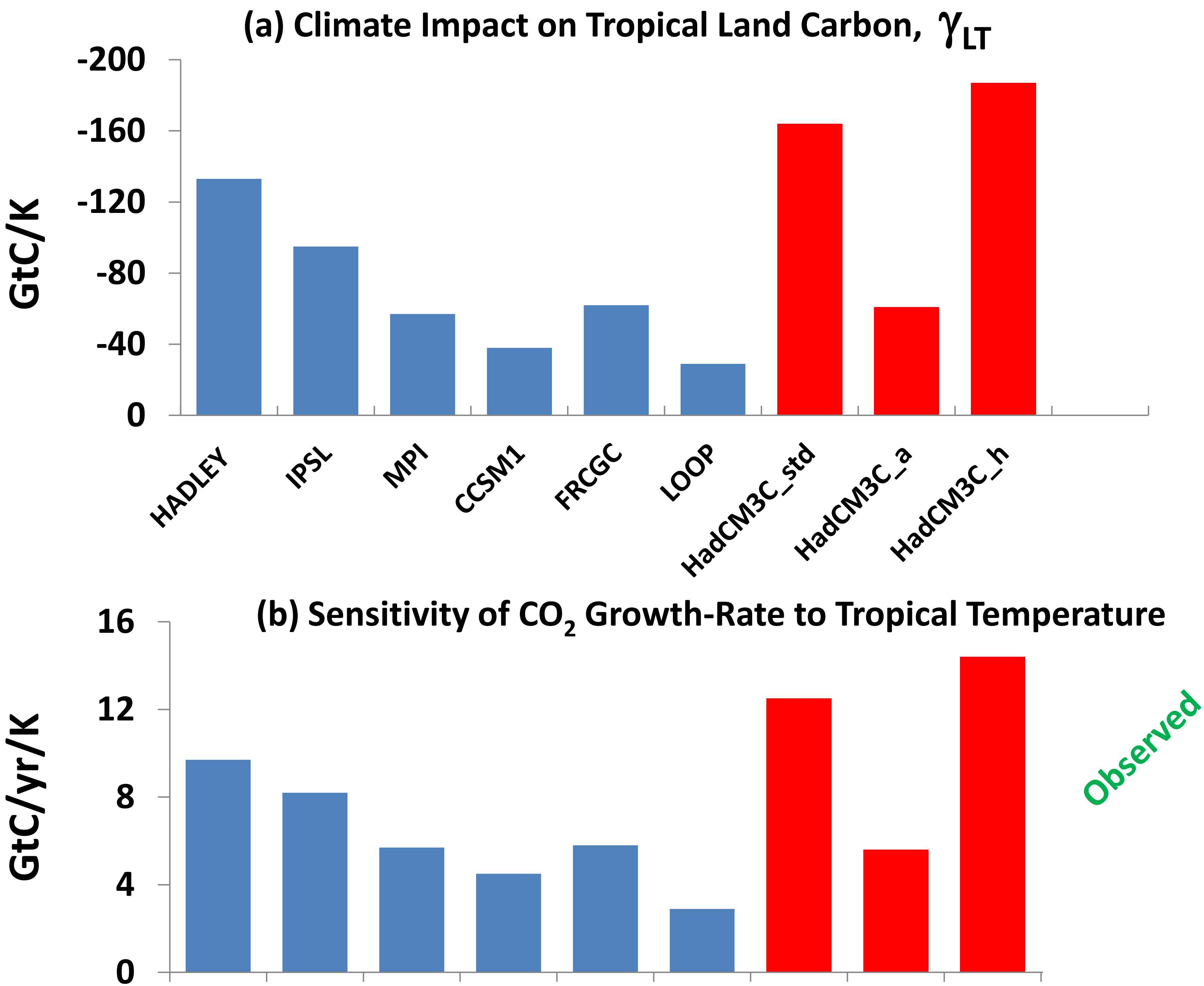
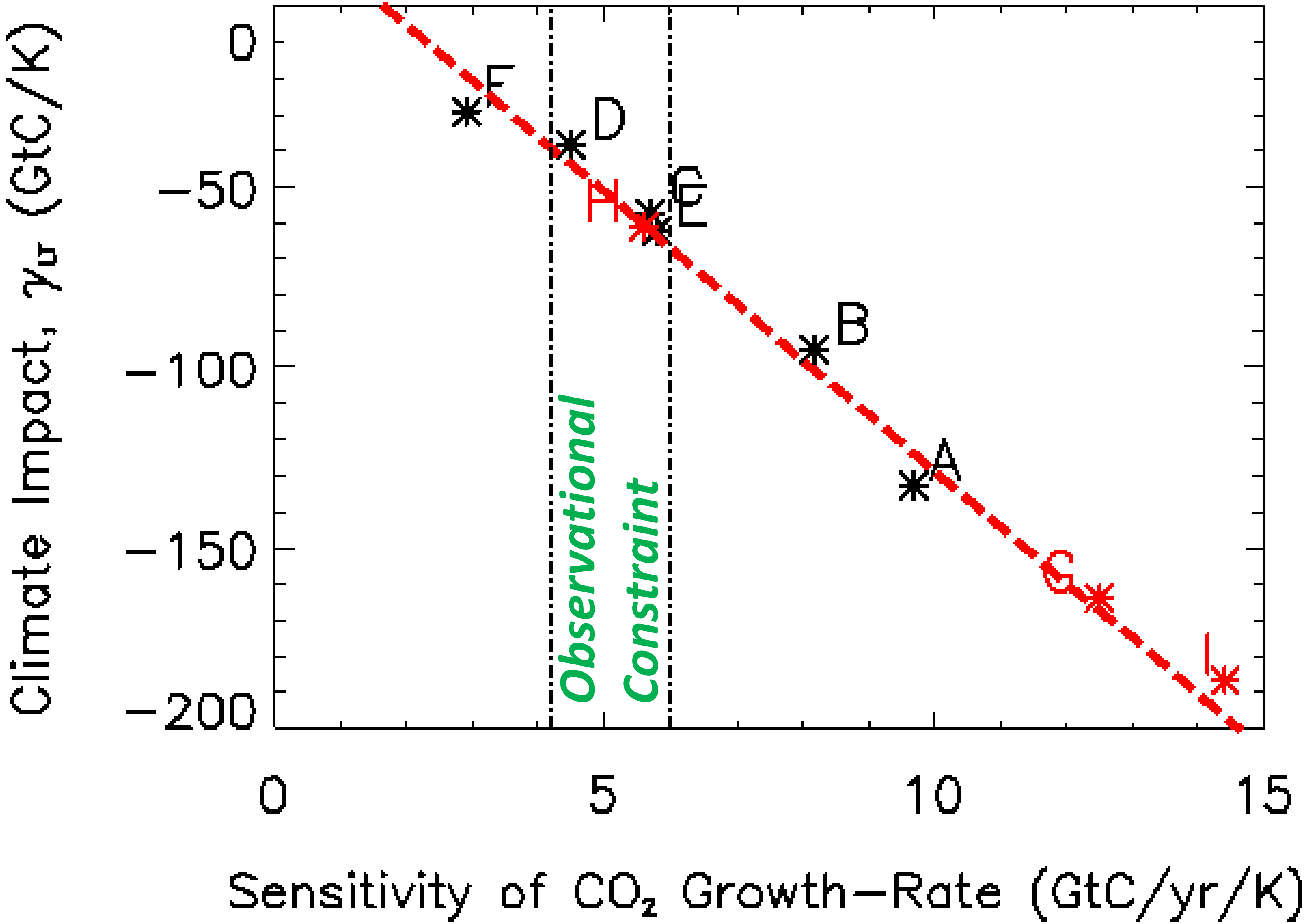



(a) Climate Impact on Tropical Land Carbon, γ_{LT}
GtC/K
-200
-160
-120
-80
-40
0
HADLEY
IPSL
MPI
CCSM1
FRCGC
LOOP
HadCM3C_std
HadCM3C_a
HadCM3C_h
(b) Sensitivity of CO_2 Growth-Rate to Tropical Temperature
GtC/yr/K
16
12
8
4
0
Observed

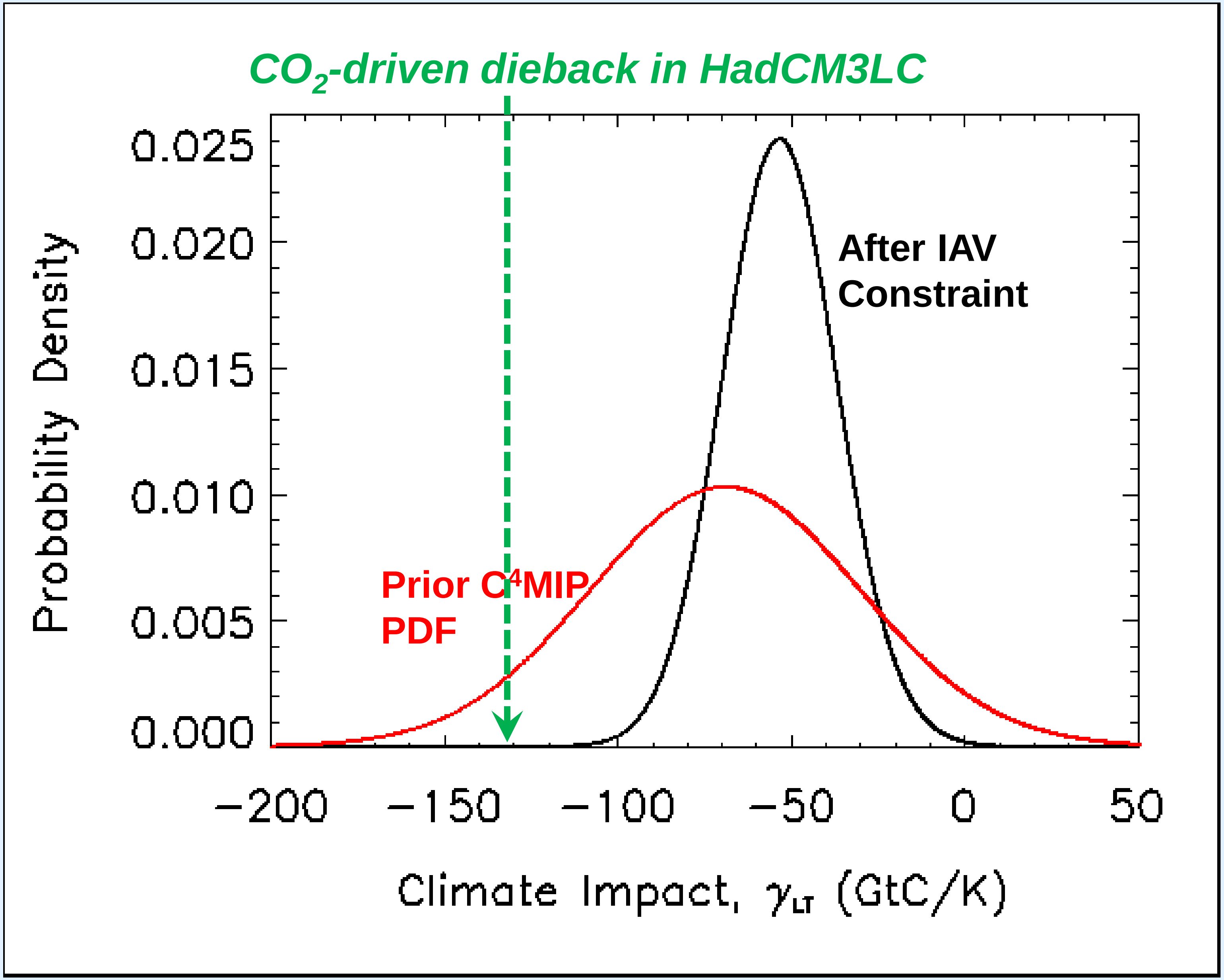
Summary II

- In the case of possible dieback of tropical forests, we find a relationship between the predicted loss of tropical land carbon under tropical warming and the modelled sensitivity of the annual growth-rate of CO_2 to tropical temperature anomalies.

IAV of dCO_2/dt – Excellent Predictor of Sensitivity



Probability Density Function for Climate Sensitivity of Tropical Forest



Summary II

- In the case of possible dieback of tropical forests, we find a relationship between the predicted loss of tropical land carbon under tropical warming and the modelled sensitivity of the annual growth-rate of CO_2 to tropical temperature anomalies.

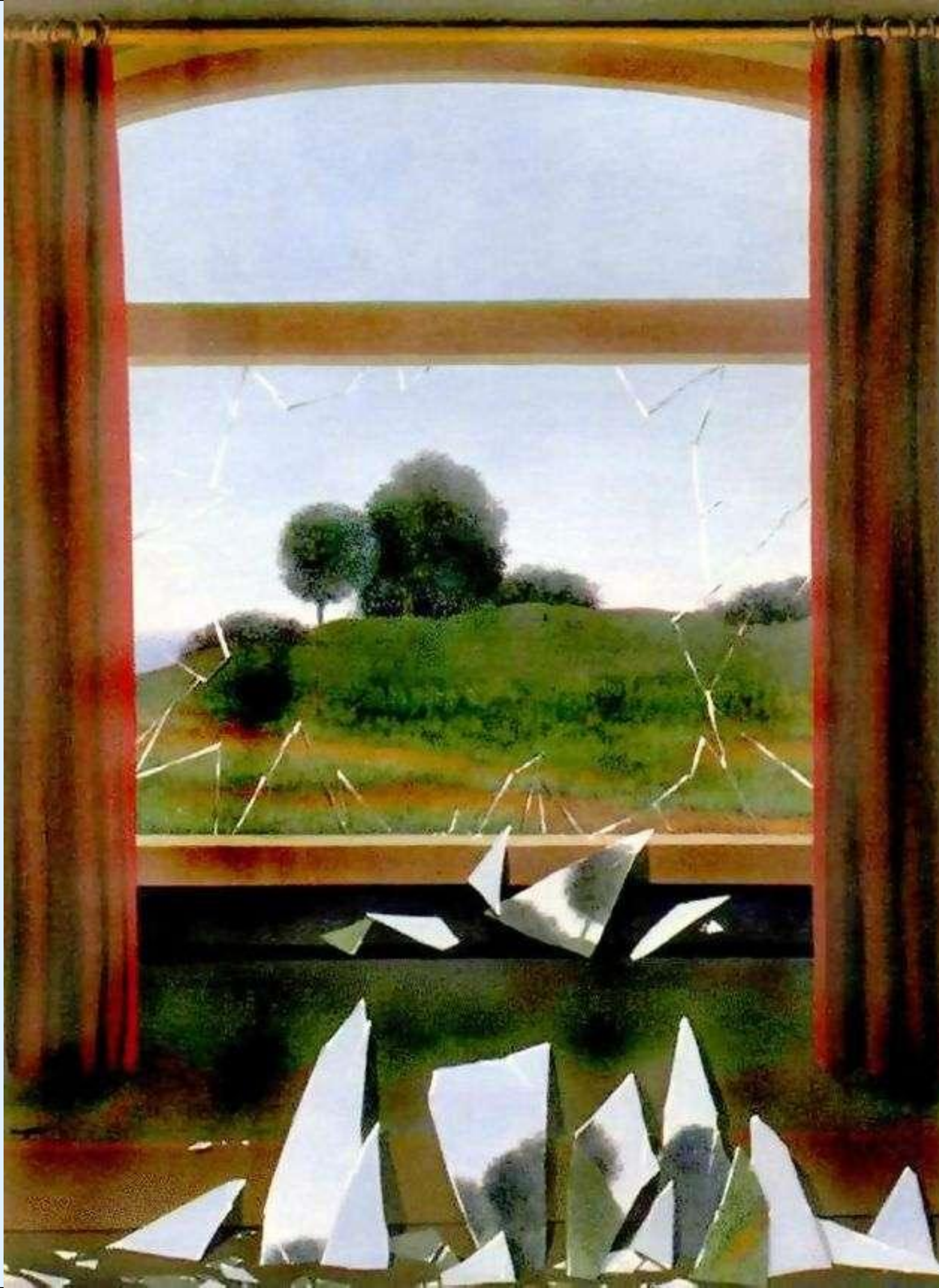
- When combined with the observed sensitivity of the annual growth-rate of CO_2, this gives an *Emergent Constraint* on the carbon loss from tropical lands to **-53 +/- 17 GtC/K**

Summary II

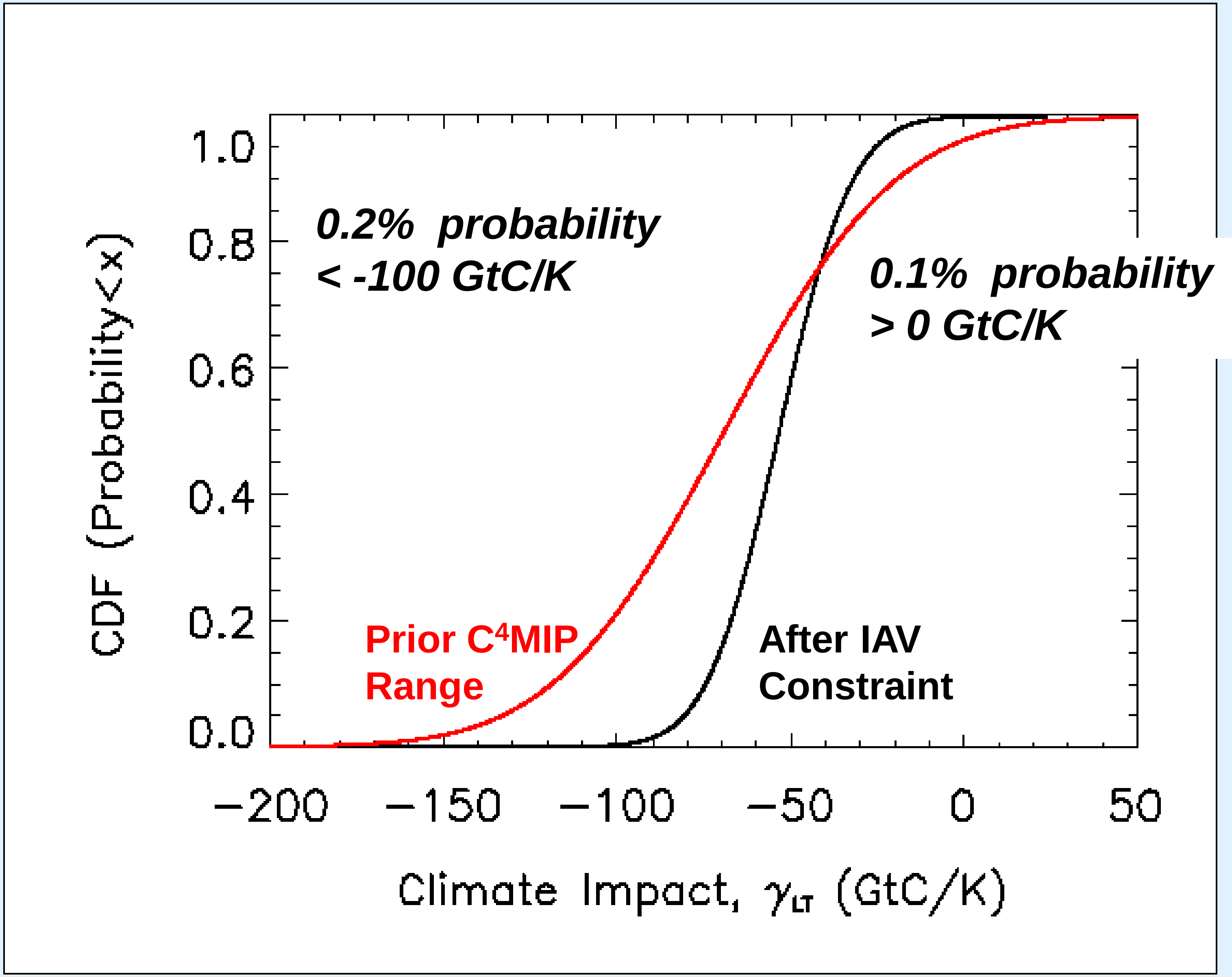
- In the case of possible dieback of tropical forests, we find a relationship between the predicted loss of tropical land carbon under tropical warming and the modelled sensitivity of the annual growth-rate of CO_2 to tropical temperature anomalies.
- When combined with the observed sensitivity of the annual growth-rate of CO_2, this gives an *Emergent Constraint* on the carbon loss from tropical lands to **-53 +/- 17 GtC/K**
- As a result, CO_2-driven tropical forest dieback is very unlikely ***if*** CO_2-fertilization in the tropics is as large as current models suggest.
- We are now searching for other Emergent Constraints on climate-carbon cycle feedbacks.

Thanks!

Any Questions?



CDF for
Climate Sensitivity of Tropical Forest



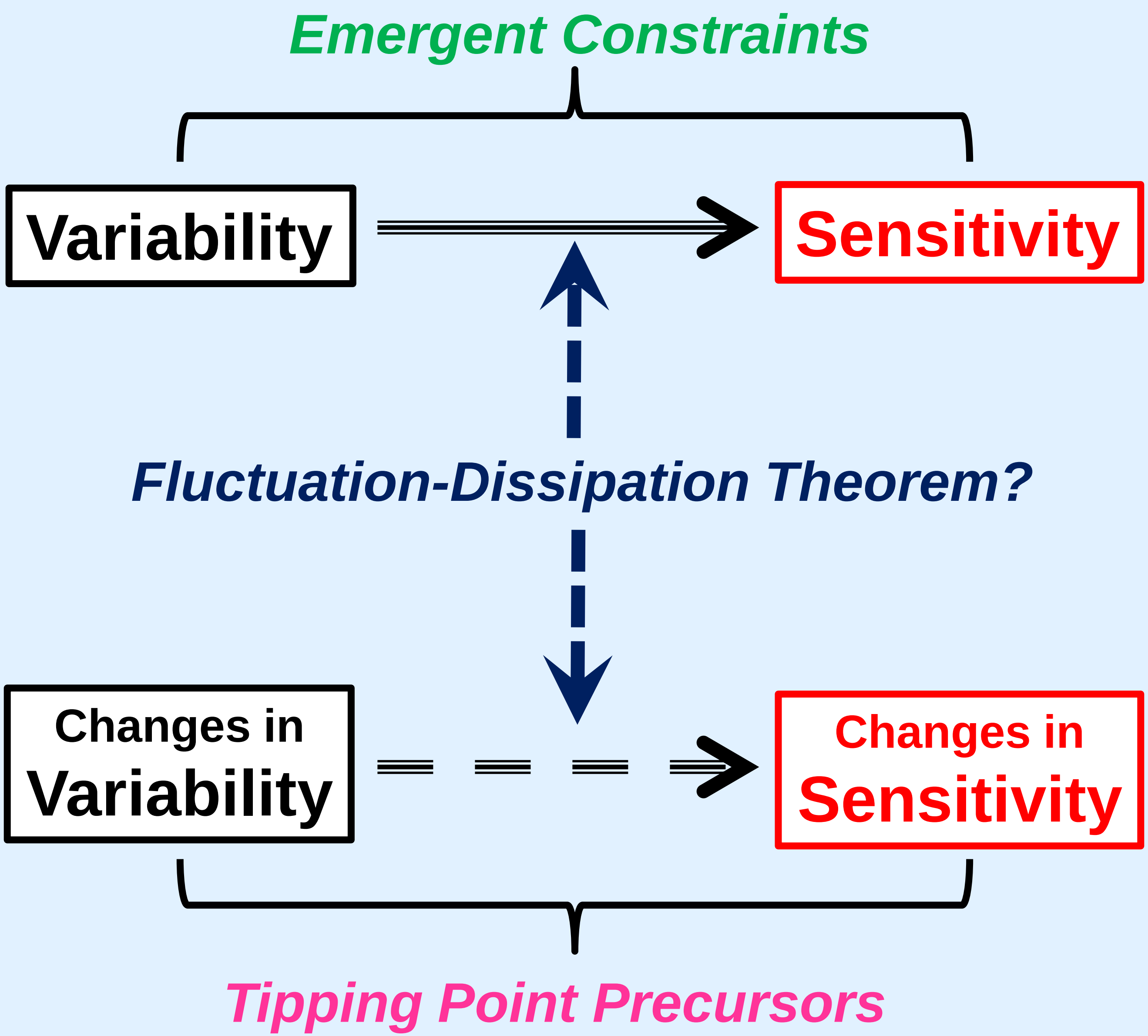
So, will the Amazon rainforest die-back under global warming?

- This is highly unlikely (<0.2% probability) if the warming is due to CO_2, and ***if*** forests in the real world benefit from CO_2 fertilization as in current models.

- However, some loss of tropical land carbon is highly likely (>99.1% probability) if the warming is not due to CO_2 - *with a best estimate of 53 billion tonnes of carbon lost per K*.

- Tropical forests are much more vulnerable to reductions in sulphate aerosol pollution or increases in non-CO_2 greenhouse gases (e.g. CH_4), than to increases in CO_2!

The Big Picture : Variability and Sensitivity



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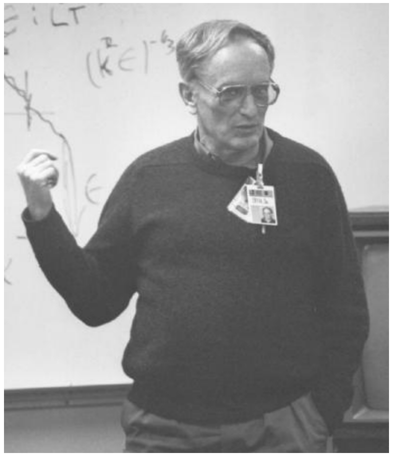

Slide from Tim Palmer

Model Projections in γ - β space