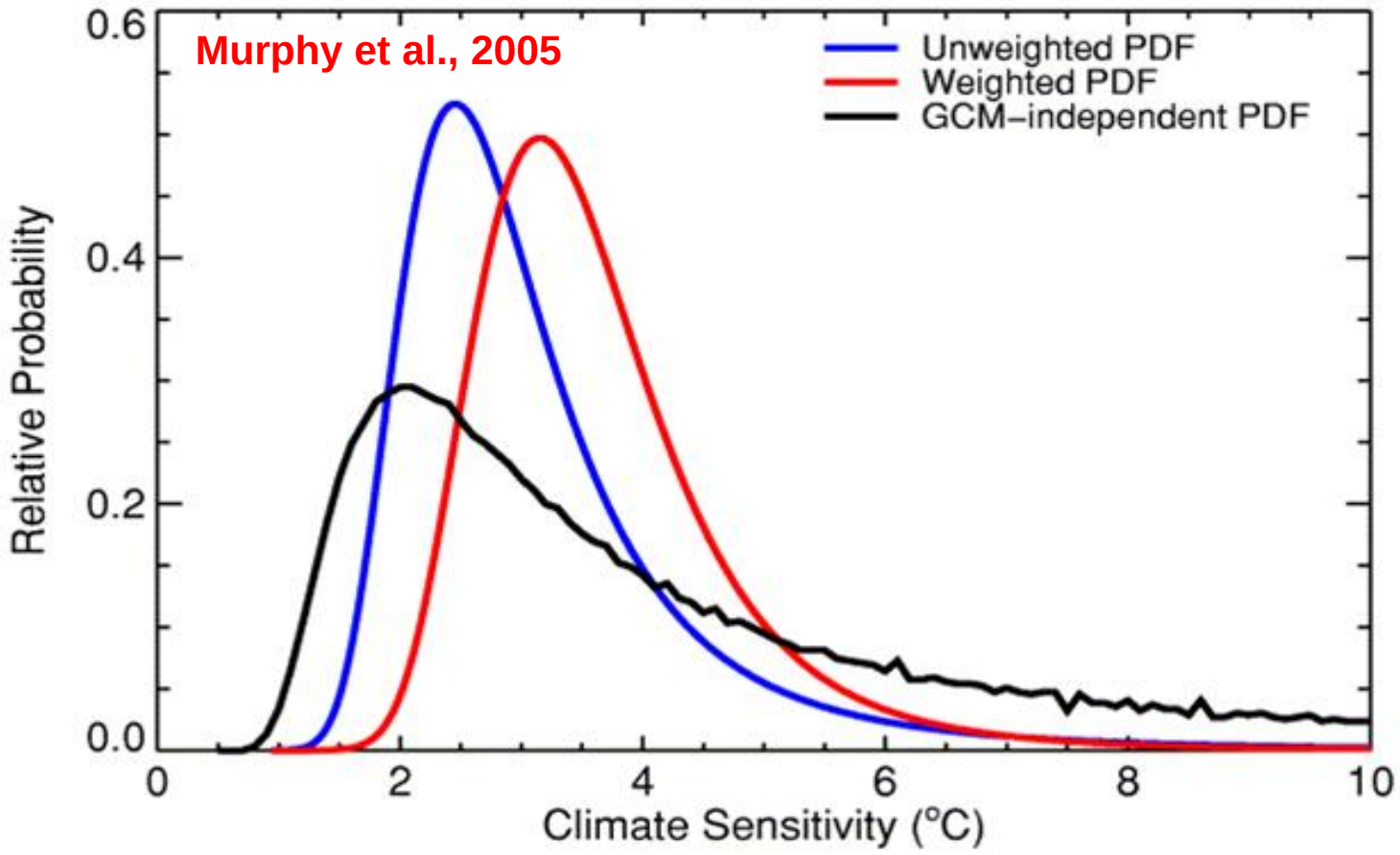
Estimating Climate System Sensitivities from Temporal Variability

Peter Cox
Professor of Climate System Dynamics
University of Exeter

How can we constrain long-term Climate Projections using short-term Observations ?

Climate Sensitivity to Doubling CO_2 remains uncertain….



Due to uncertainties in climate feedbacks….

The Timescale Problem in the Evaluation of Earth System Models

We need to find constraints on changes in the Earth System over the next century

BUT

The observational data that we have relates to shorter timescales.

What can we do?

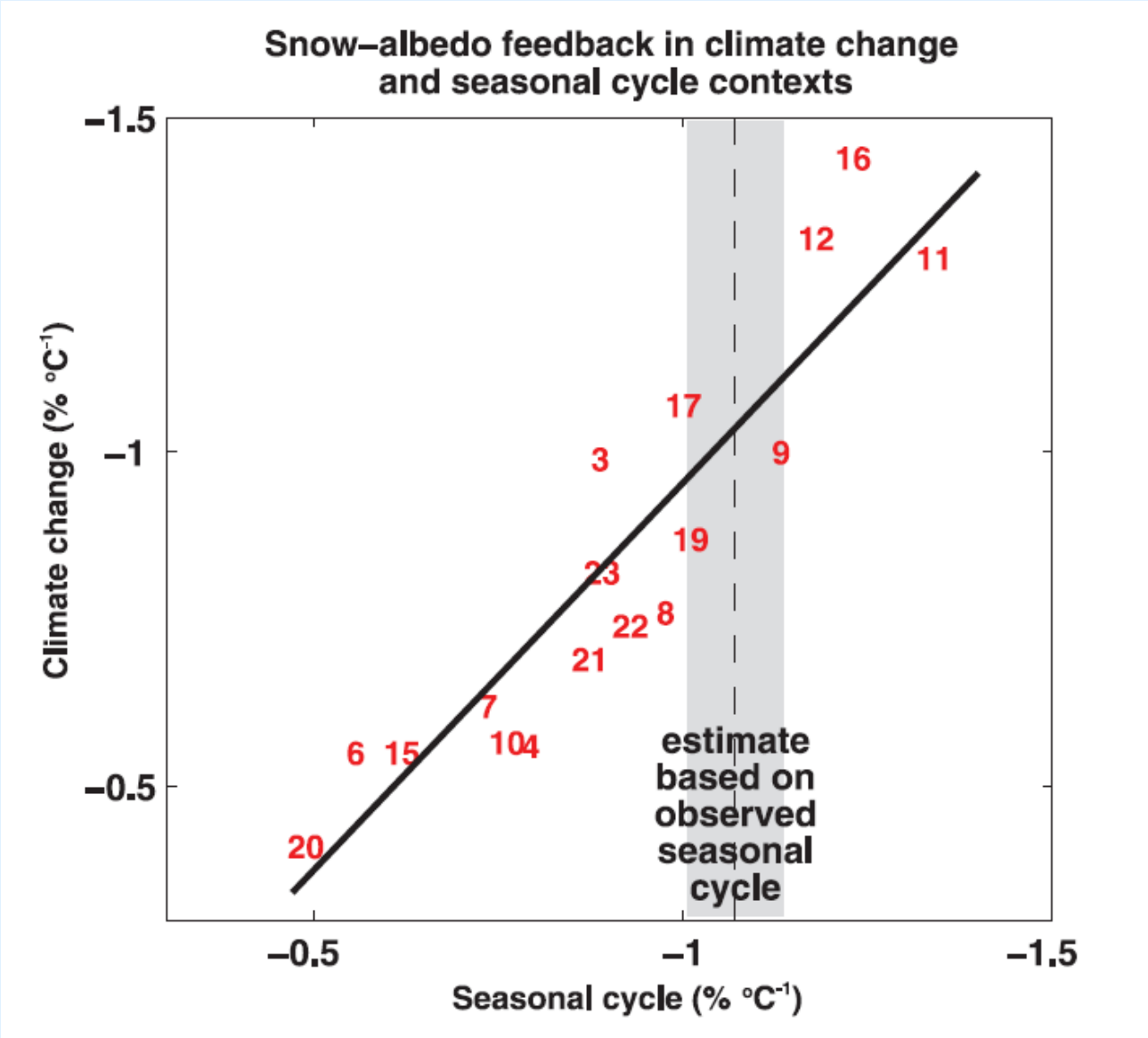
Emergent Constraints

- First coined in the context of climate projections by Allen & Ingram (2002)
- ***Emergent Constraint*** : *a relationship between an Earth System sensitivity to anthropogenic forcing and an observable (or already observed) feature of the ES.*
- **Emergent** because it emerges from the ensemble of ESMs.
- **Constraint** because it enables an observation to constrain the estimate of the ES sensitivity in the real world.

Emergent Constraints:

Using ESMs to identify the relationships between observable contemporary variability and future sensitivity

Archetypal Example of an *Emergent Constraint*



Hall & Qu (2006)

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

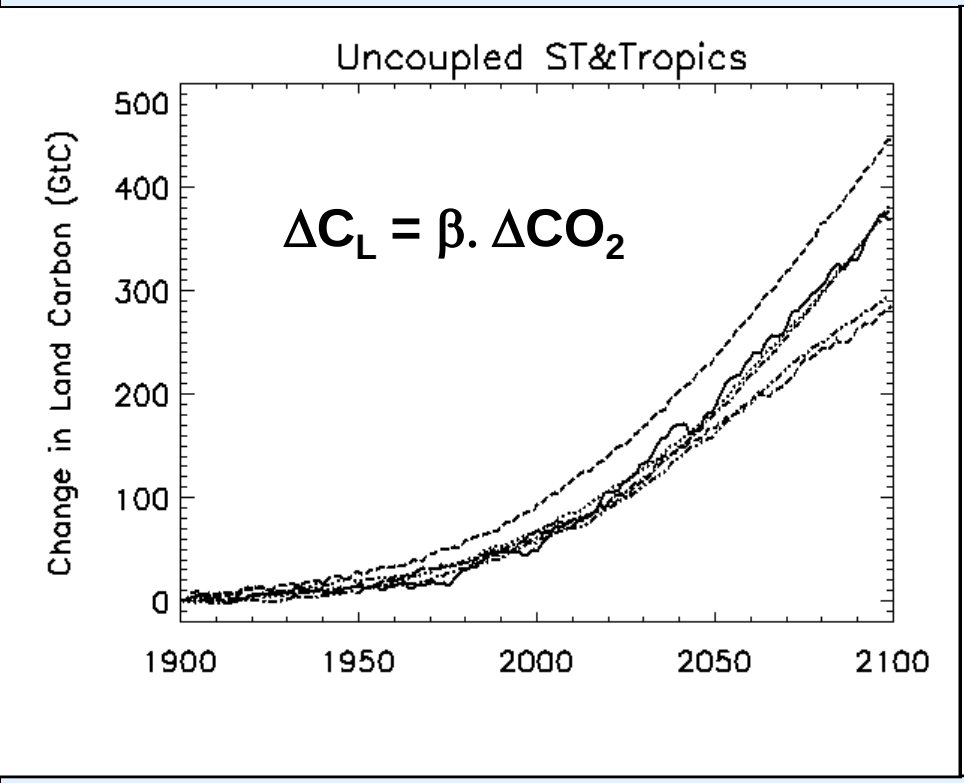
Peter M. Cox[1], David Pearson[2], Ben B. Booth[2], Pierre Friedlingstein[1], Chris Huntingford[3], Chris D. Jones[2] & Catherine M. Luke[1]

published in February

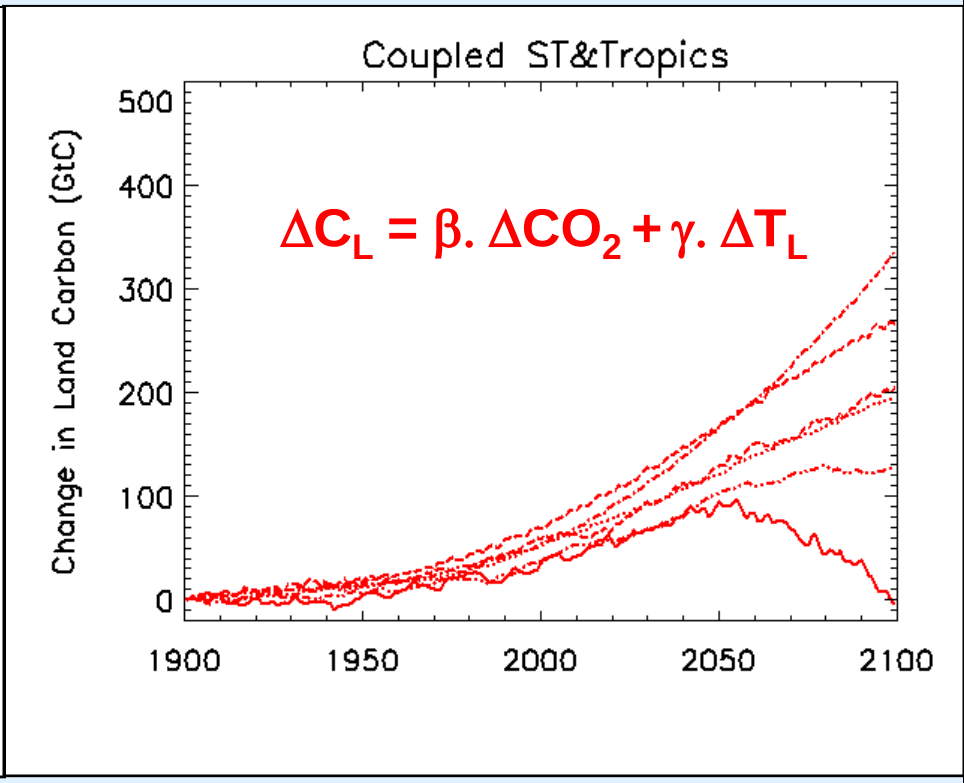
Uncertainty in Future Land Carbon Storage in Tropics (30°N-30°S)

C⁴MIP Models (Friedlingstein et al., 2006)

Models without climate affects on Carbon Cycle

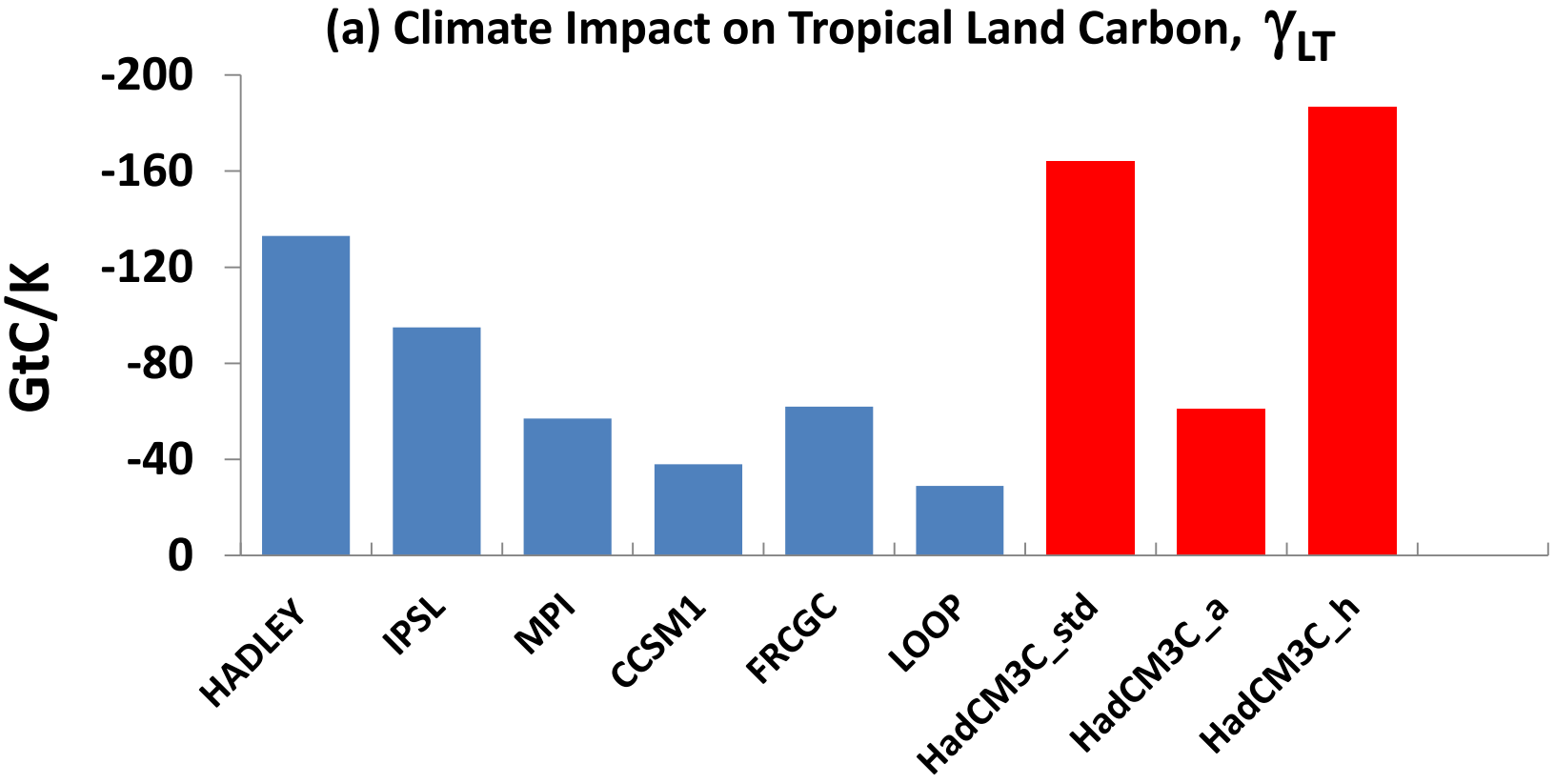


Models with climate affects on Carbon Cycle



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

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?**

Interannual Variability as an Emergent Constraint

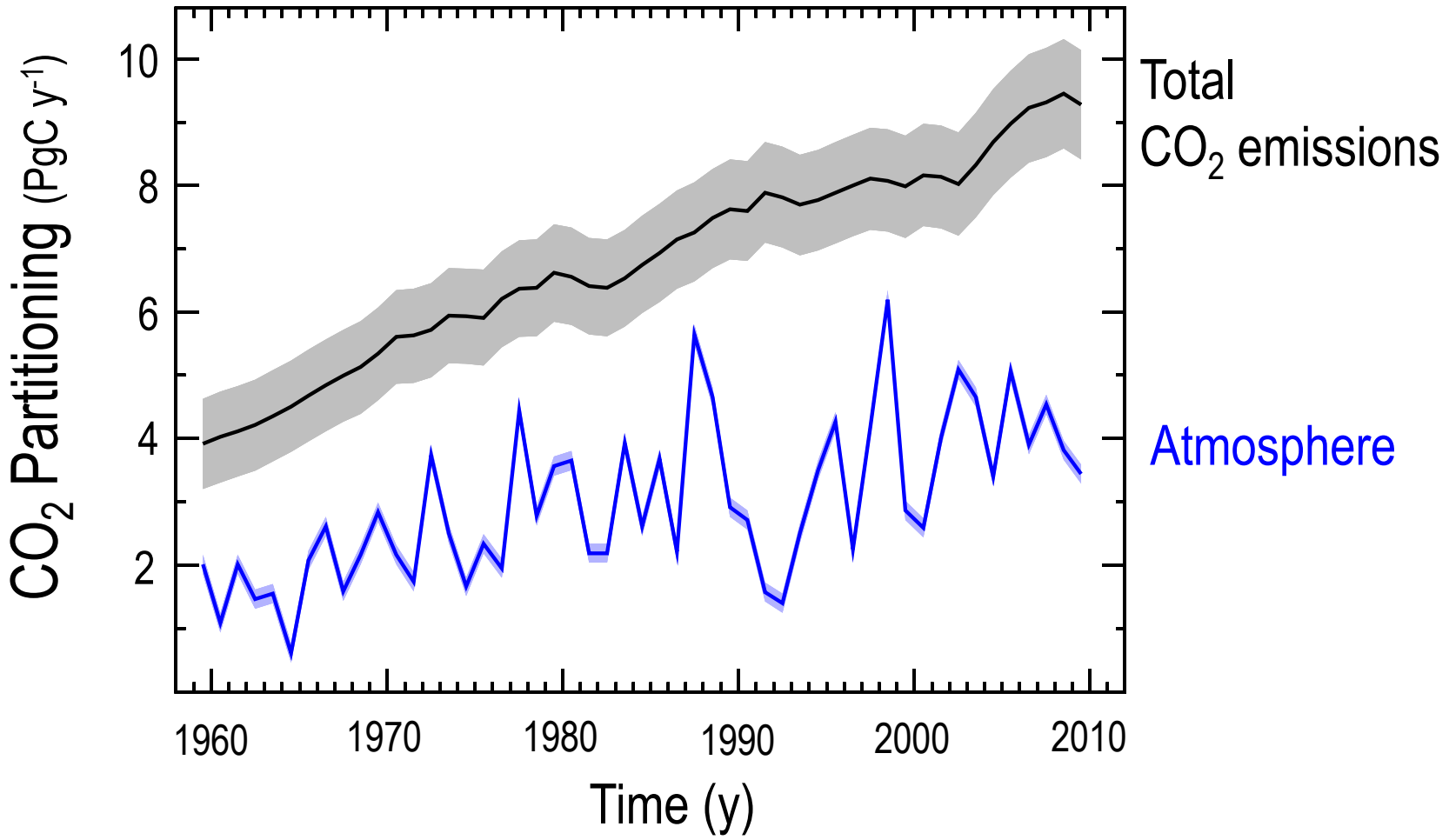
..on Tropical Forest Dieback...

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

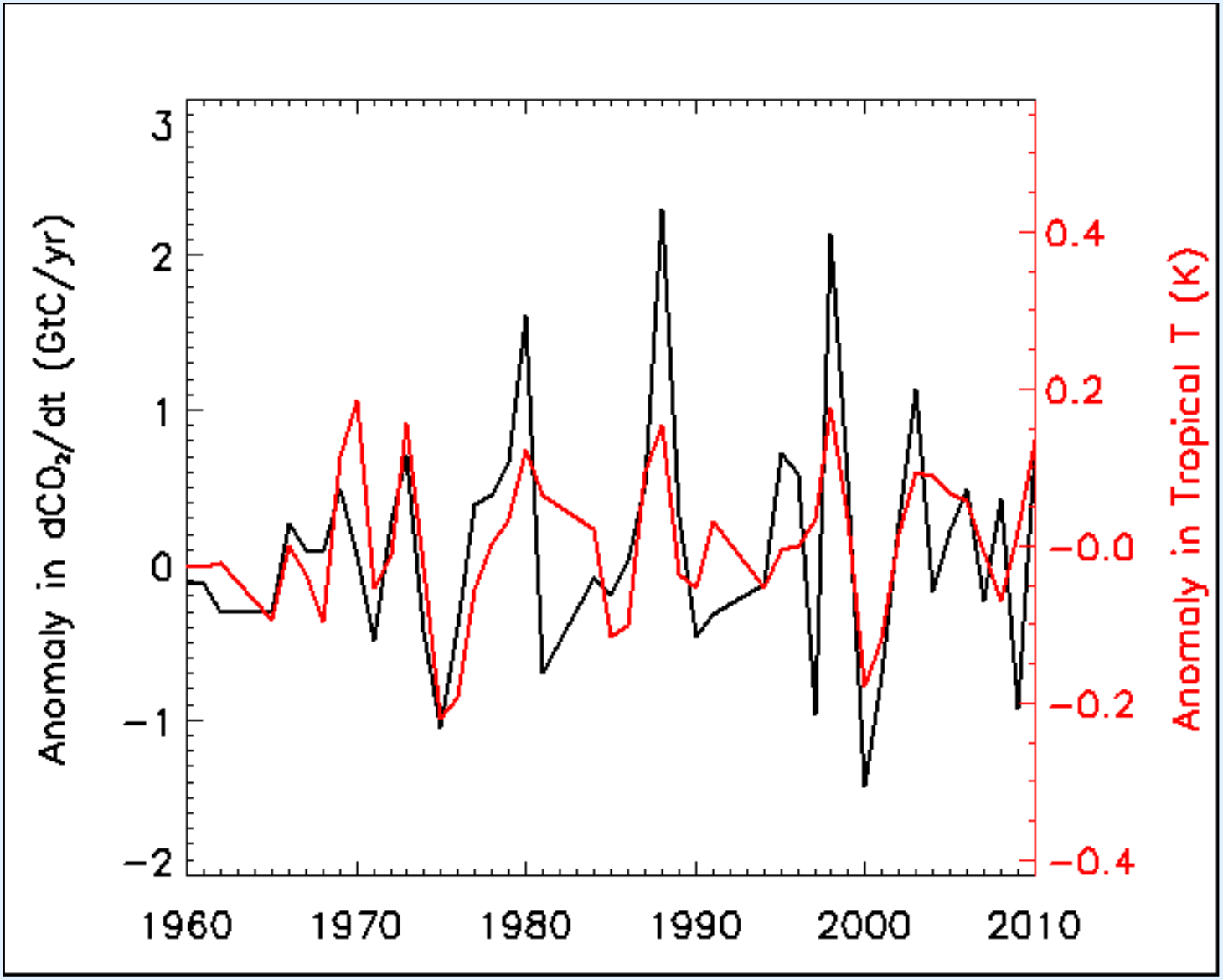


Updated from Le Quéré et al. 2009, Nature Geoscience; Data: NOAA 2010, CDIAC 2010

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.

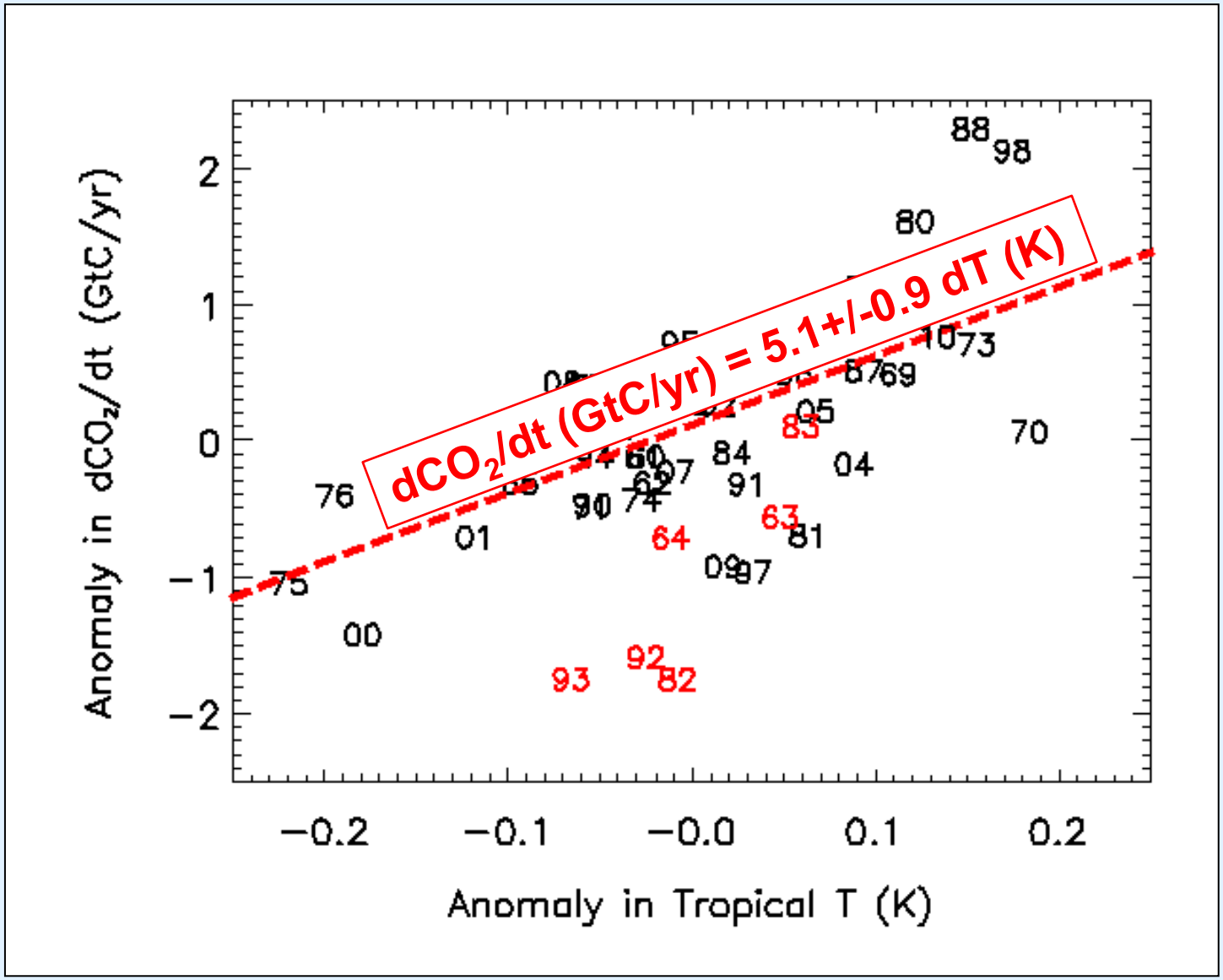
Relationship between CO_2 Growth-rate and Tropical Temperature - Observations

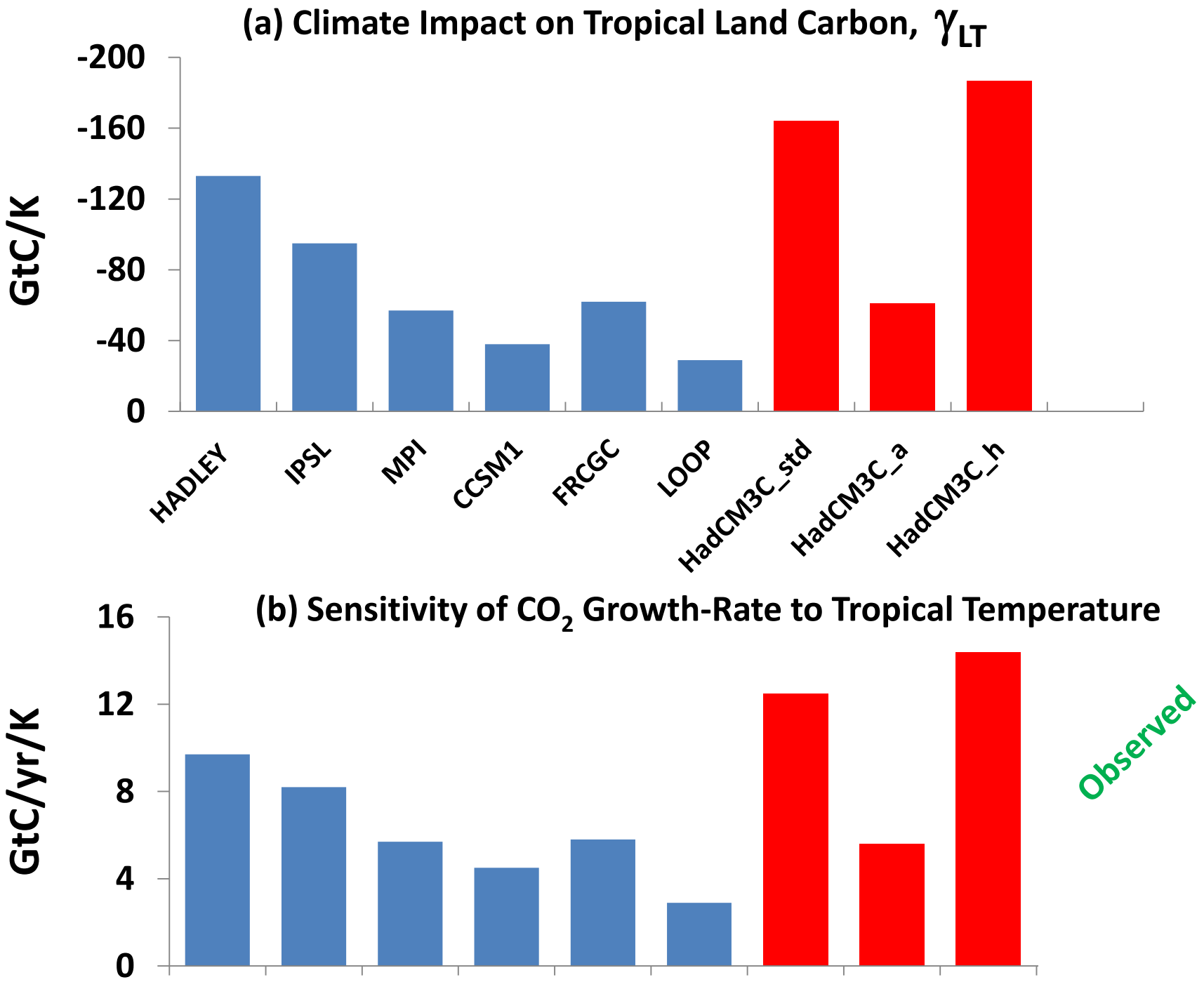


Rationale

- 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 ?

Relationship between CO_2 Growth-rate and Tropical Temperature - Observations

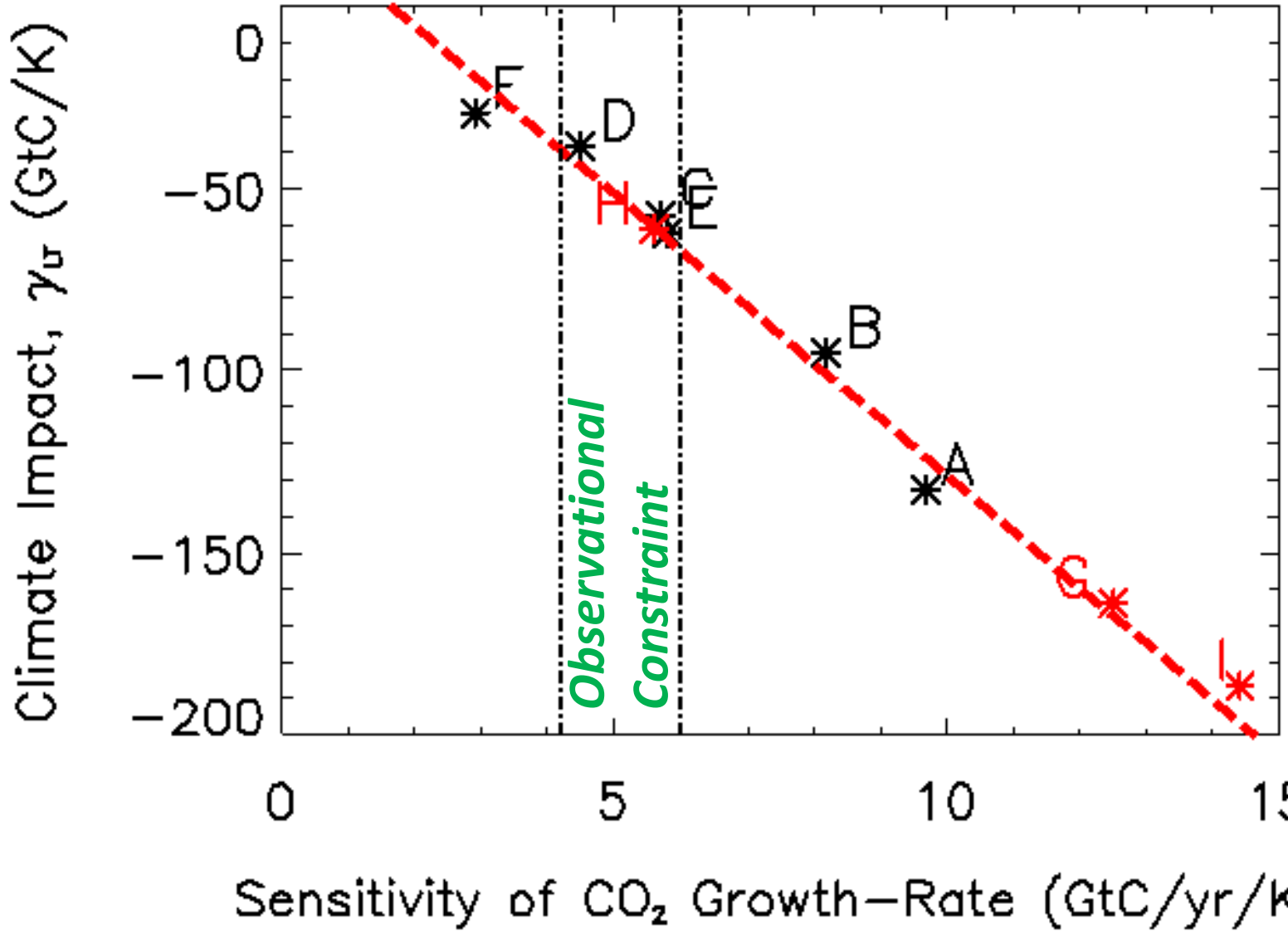



(a) Climate Impact on Tropical Land Carbon, γ_{LT}
GtC/K
-200
-160
-120
-80
-40
0
HADLEY
IPSL
MPI
CCSM1
FRCGC
LOOP
HadCM3C_std
HadCM3C_a
HadCM3C_h
(b) Sensitivity of CO_2 Growth-Rate to Tropical Temperature
GtC/yr/K
16
12
8
4
0
Observed

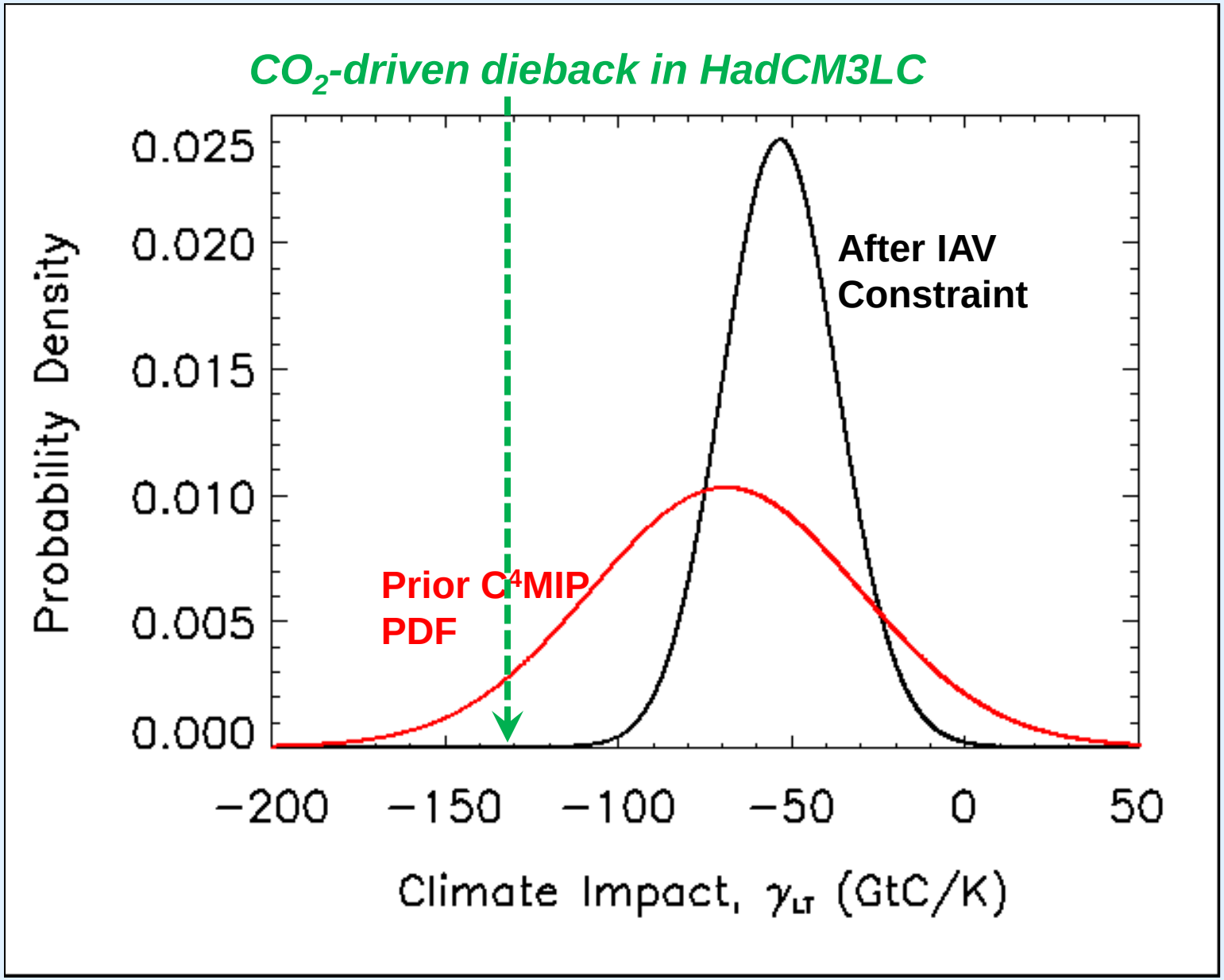
IAV Constraint on Tropical Carbon Loss

- 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

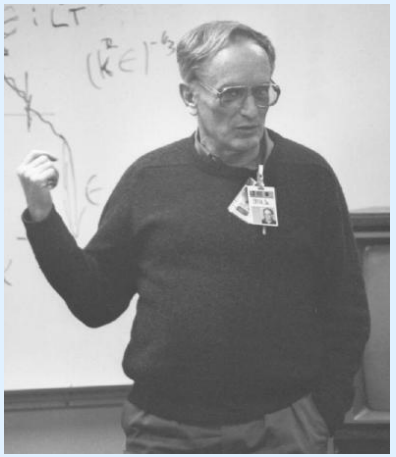


Why are Variability & Sensitivity Related?

Fluctuation-Dissipation Theorem

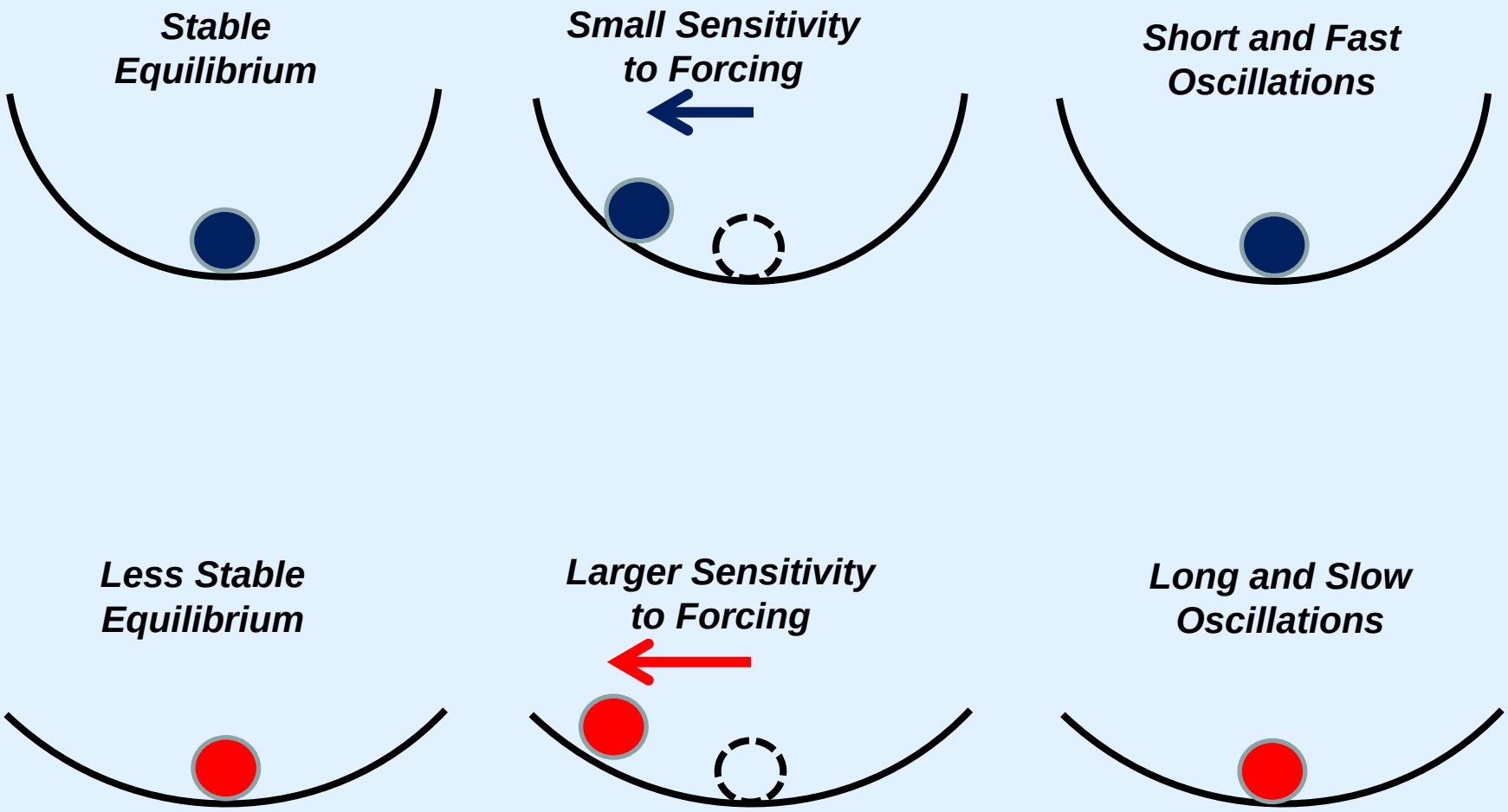
A very general result in statistical thermodynamics which links the response of a system to external forcing, to internal fluctuations of the system in thermal equilibrium.

First applied to the climate system by Chuck Leith



Slide from Tim Palmer

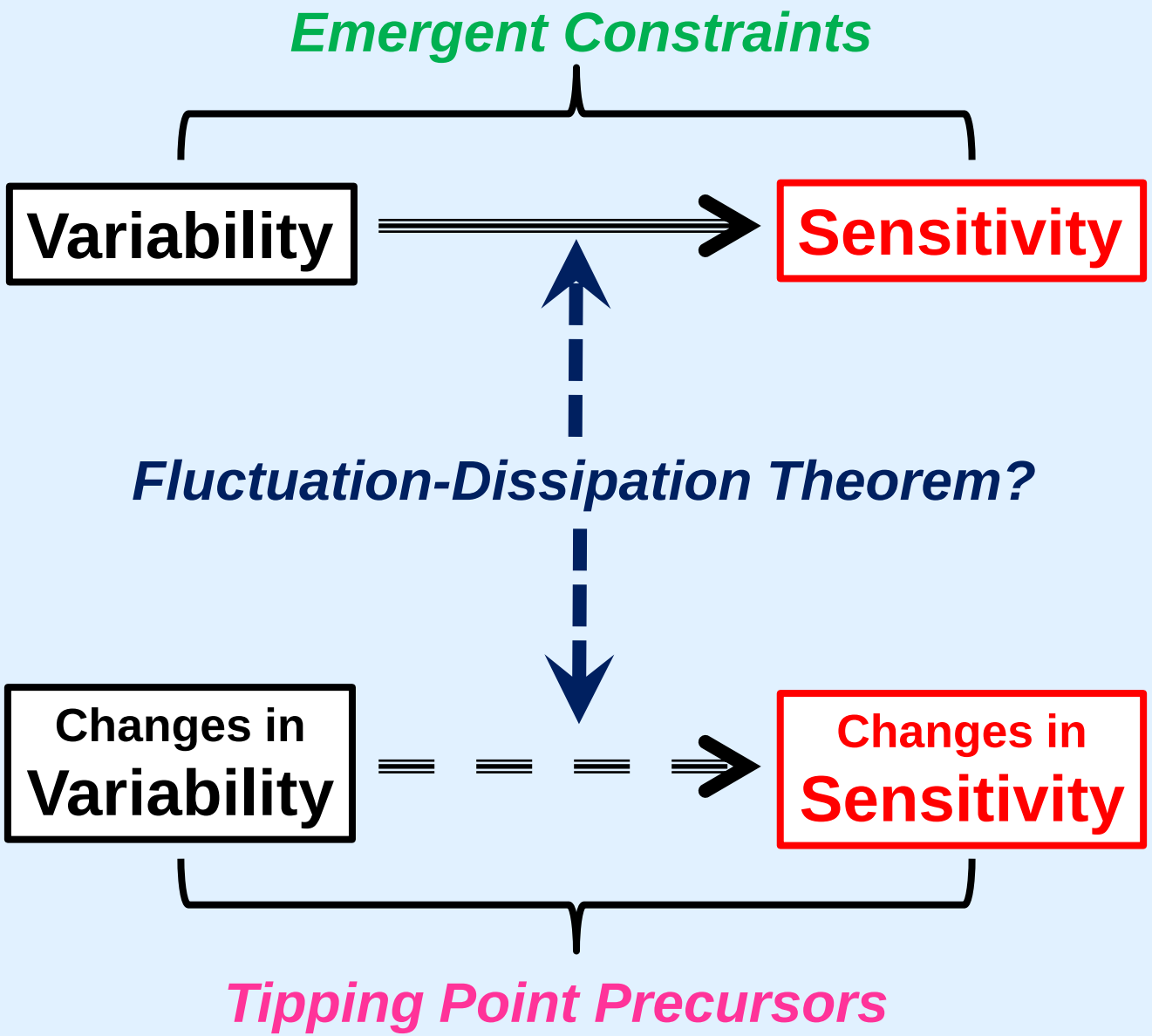
Stability, Sensitivity and Variability



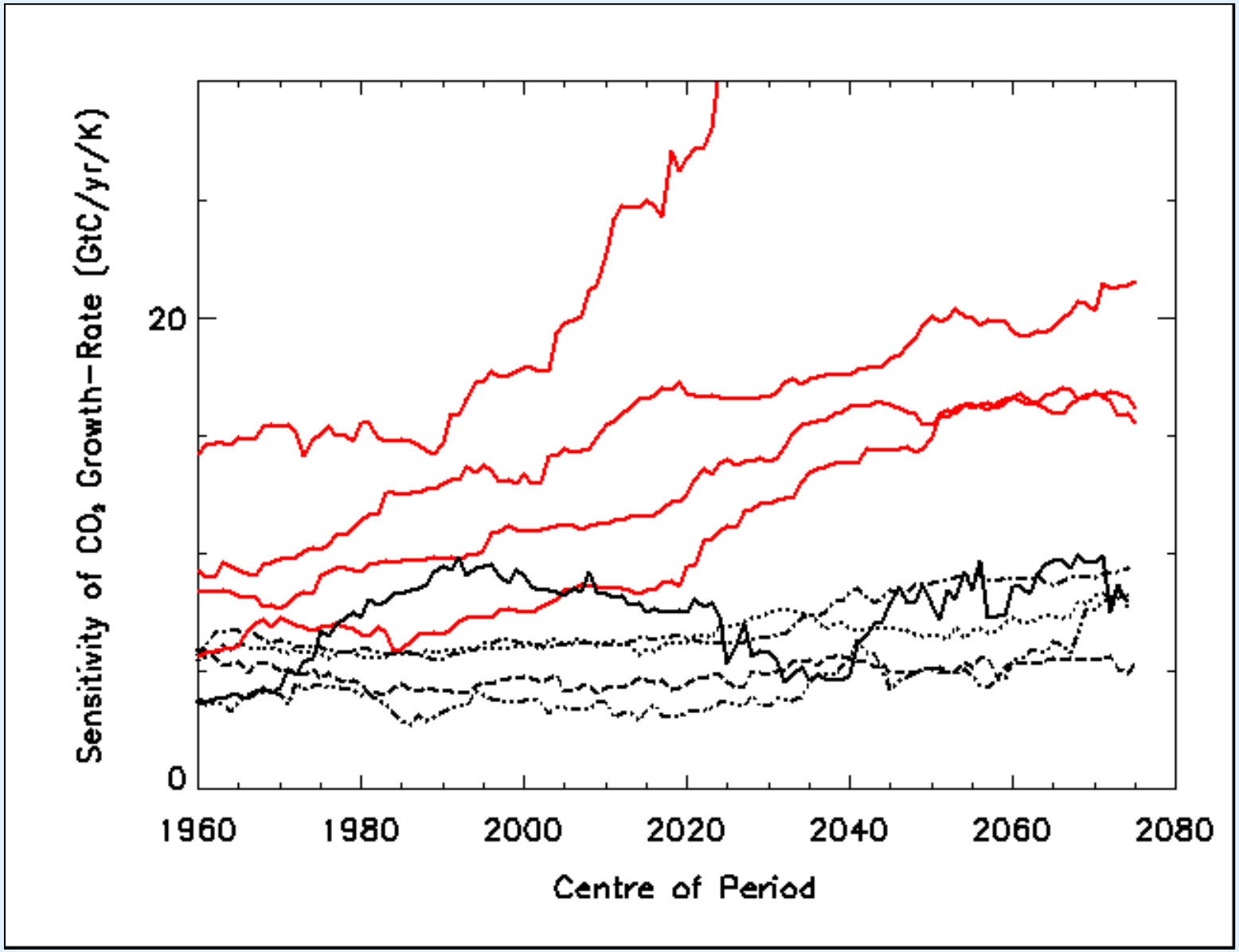
Conclusions

- The observed year-to-year variability in atmospheric CO_2 has been found to give a very useful emergent ***constraint on future loss of tropical land carbon***.
- Generally, we should expect to see some relationship between the variability of a system and its sensitivity to external forcing (e.g. via the ***Fluctuation-Dissipation Theorem***).
- These relationships underlie possible ***Precursors of Tipping Points*** as well as promising Emergent Constraints.

The Big Picture : Variability and Sensitivity



Trends in IAV Sensitivity from C^{4}MIP and HadCM3C Models



Thanks!

Any Questions?