Doing the Obvious:

Linearizing

Straight Lines are Easy to Interpret

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Cut to the Chase

- (Differential) CO_2 forcing is (IPCC *TAR*)

$$\Delta F = 5.35 \ln\left(\frac{C}{C_0}\right) \quad \frac{\mathrm{W}}{\mathrm{m}^2}$$

- Temperature rise (first order): $\Delta T = \lambda \Delta F$

$$\therefore \quad \Delta T = \gamma \ln\left(\frac{C}{C_0}\right) \quad \gamma \text{ unknown}$$

- … a direct proportion. *PLOT THE DATA!*

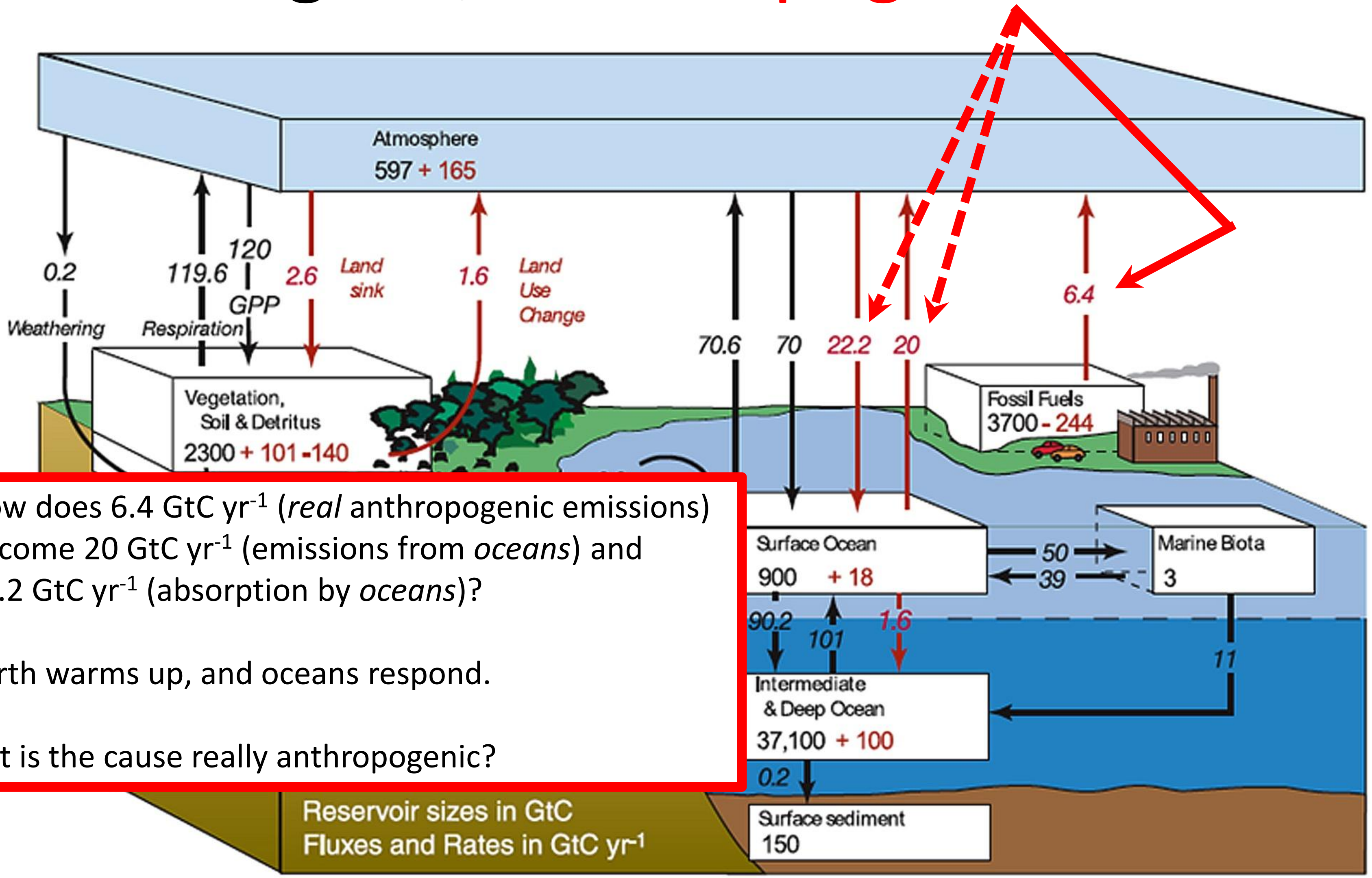
What to Plot?

- Plot ΔT versus $\ln\left(C / C_0\right)$ to determine
  - *Whether* the plot is linear
  - *Whether* there is a *direct proportion*
  - The slope γ if the line is straight
  - The sensitivity to CO_2 doubling, $\Delta T_{\text{doub}} = \gamma \ln(2)$
- Standard operating procedure in all fields of science:
  - Plot effect versus cause.
    - Example: Dose-Response curves

Boltzmann Factors

BUT WAIT! THERE'S MORE!

IPCC Fig 7.3; “Anthropogenic” in Red



How does 6.4 GtC yr^{-1} (*real* anthropogenic emissions) become 20 GtC yr^{-1} (emissions from *oceans*) and 22.2 GtC yr^{-1} (absorption by *oceans*)?

Earth warms up, and oceans respond.

But is the cause really anthropogenic?

CO_2: Affinity for Water (?)

- If so, affinity corresponds to some “binding energy” (for lack of a better word) ε

$$\frac{C_{\text{atm}}}{C_{\text{water}}} = \exp\left(\frac{-\varepsilon}{kT}\right)$$

- NB: If there is no affinity, then $\varepsilon = 0$
- But if $\varepsilon = 0$, then Henry’s Law and van’t Hoff’s equation are out the window.

And if the temperature changes?

- Temperature rises from T_0 to T:

$$\left(\frac{C}{C_0}\right)_{\text{atm}} = \exp\left\{-\frac{\varepsilon}{k}\left(\frac{1}{T}-\frac{1}{T_0}\right)\right\} \quad \text{if } C_{\text{water}} \approx \text{ const}$$

or

$$\left(\frac{C}{C_0}\right)_{\text{atm}} = \exp\left\{+\frac{\varepsilon}{k}\left(\frac{\Delta T}{T T_0}\right)\right\}$$

Simplifying …

- T and T_0 are both about 300 K; $\Delta T \approx 1$ K

$$\ln\left(\frac{C}{C_0}\right)_{\text{atm}} = \frac{\varepsilon}{kT^2}\Delta T$$

$$= \frac{\Delta T}{\tau}$$

or

$$\Delta T = \tau \ln\left(C / C_0\right)_{\text{atm}} \quad \tau \text{ unknown}$$

A direct proportion

Co-Mingled Cause & Effect

EFFECT CAUSE

- CO_2 radiative forcing ➔ $\Delta T = \gamma \ln\left(C / C_0\right)$

Two unknowns, but only one measureable slope!

- Boltzmann Factors ➔ $\Delta T = \tau \ln\left(C / C_0\right)$

EFFECT CAUSE

What to graph?

- We have yet another reason to plot

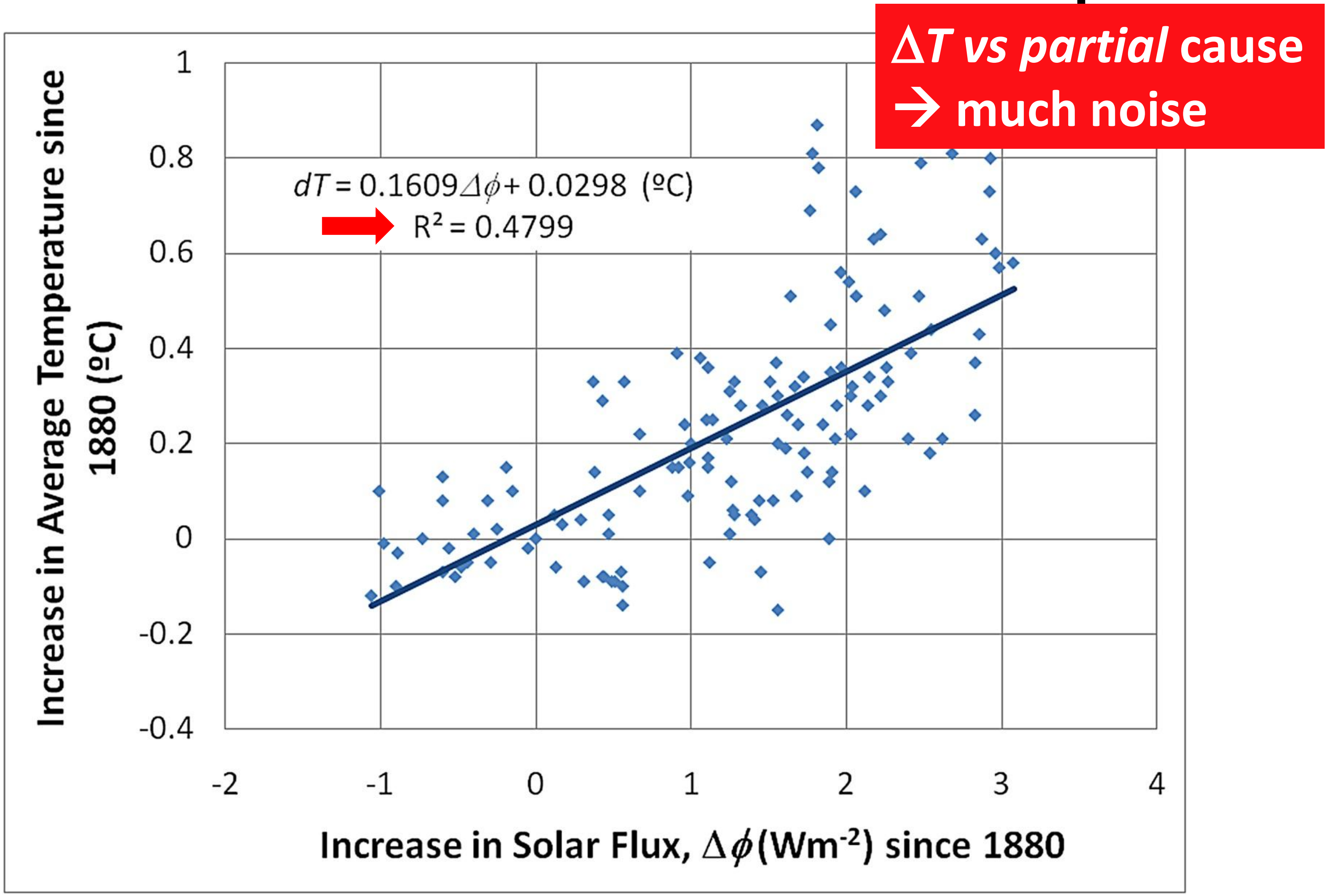
$$\Delta T \text{ versus } \ln\left(C / C_0\right)$$

- It’s a little harder to dope out which is cause and which is effect, because two entirely different phenomena lead to the same *form* of equation
- We should *expect* to find a direct proportion.
- How to interpret slope?

Learning From Noise

- What Would Noise Be Like if …
  - You plotted Atmospheric Pressure (effect) at Times Square versus water flow in the Rio Grande (putative cause)?
    - All noise, no trend
  - You plotted Quantity of O_2 consumed (effect) versus Quantity of CH_4 consumed (cause) in combustion experiments?
    - No noise, all trend
  - You plotted Earth's temperature rise (effect) versus increase in solar flux (*partial* cause)?
    - A trend & some noise. Have a look.

Solar in Cause-Effect Graph



What do *you* expect for the *Shape* and the *Noise*?

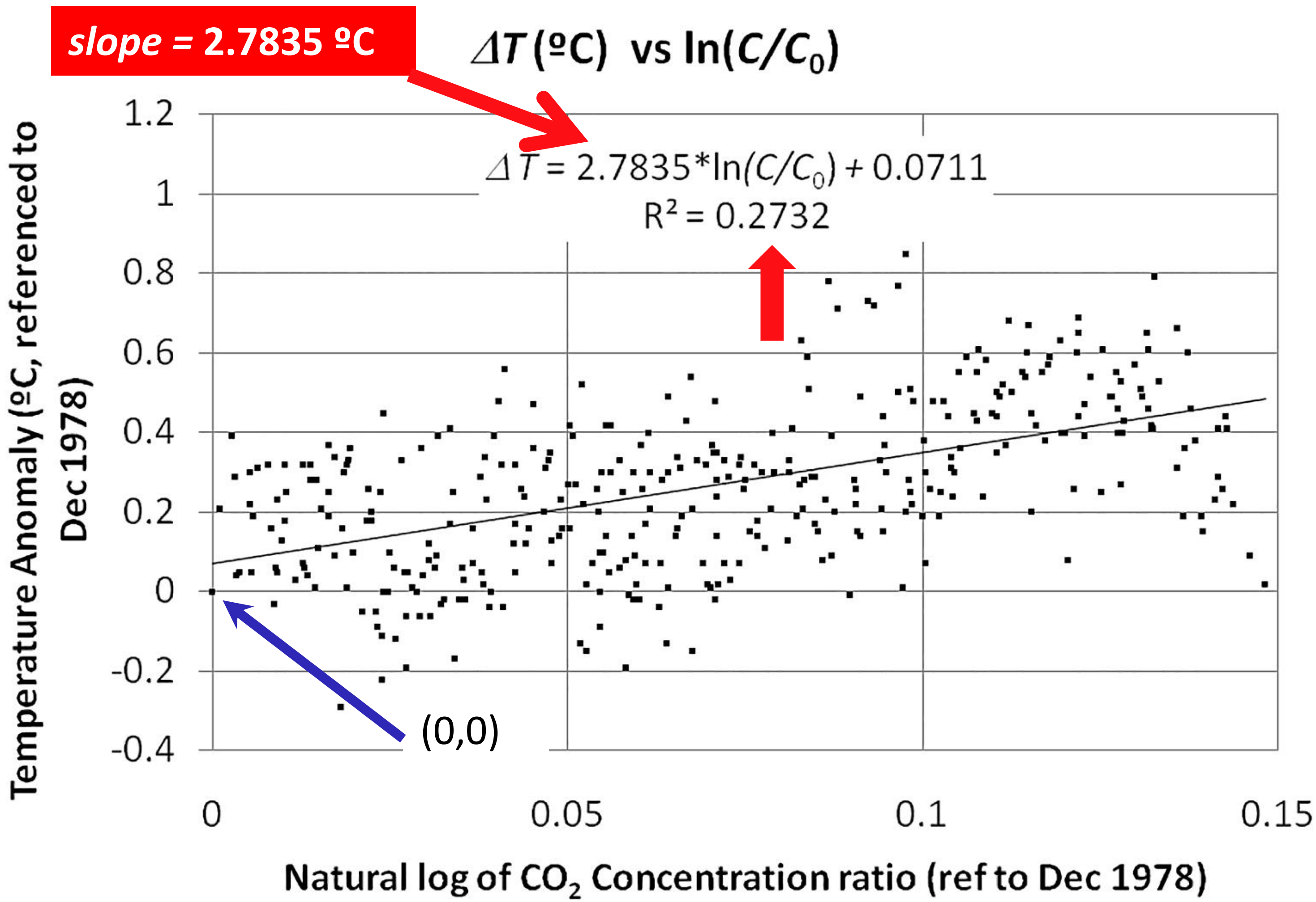
- Plot ΔT versus $\ln(C / C_0)$ using *data* (as opposed to computer output)
  - Shape:
    - Hockey stick? Direct Proportion? Asymptotic curve? Parabolic rise? No discernible shape?
  - Noise
    - Little noise ($R^2 > 0.8$) ?
    - Considerable noise ($0.3 < R^2 < .7$) ?
    - Very high noise ($R^2 < 0.2$) ?

Data Sources for Atm. Temp & CO_2

- # 1 December 1978 to present:
  - Temperature anomaly measured by satellite
  - Mauna Loa measurements of CO_2
- # 2 (130-year span)
  - NASA-GISS temperature from http://data.giss.nasa.gov/gistemp/tabledata/GLB.Ts+dSST.txt
  - NASA-GISS CO_2 concentration from http://data.giss.nasa.gov/modelforce/ghgases/Fig1A.ext.txt

Data set #1

Satellite data since 1979



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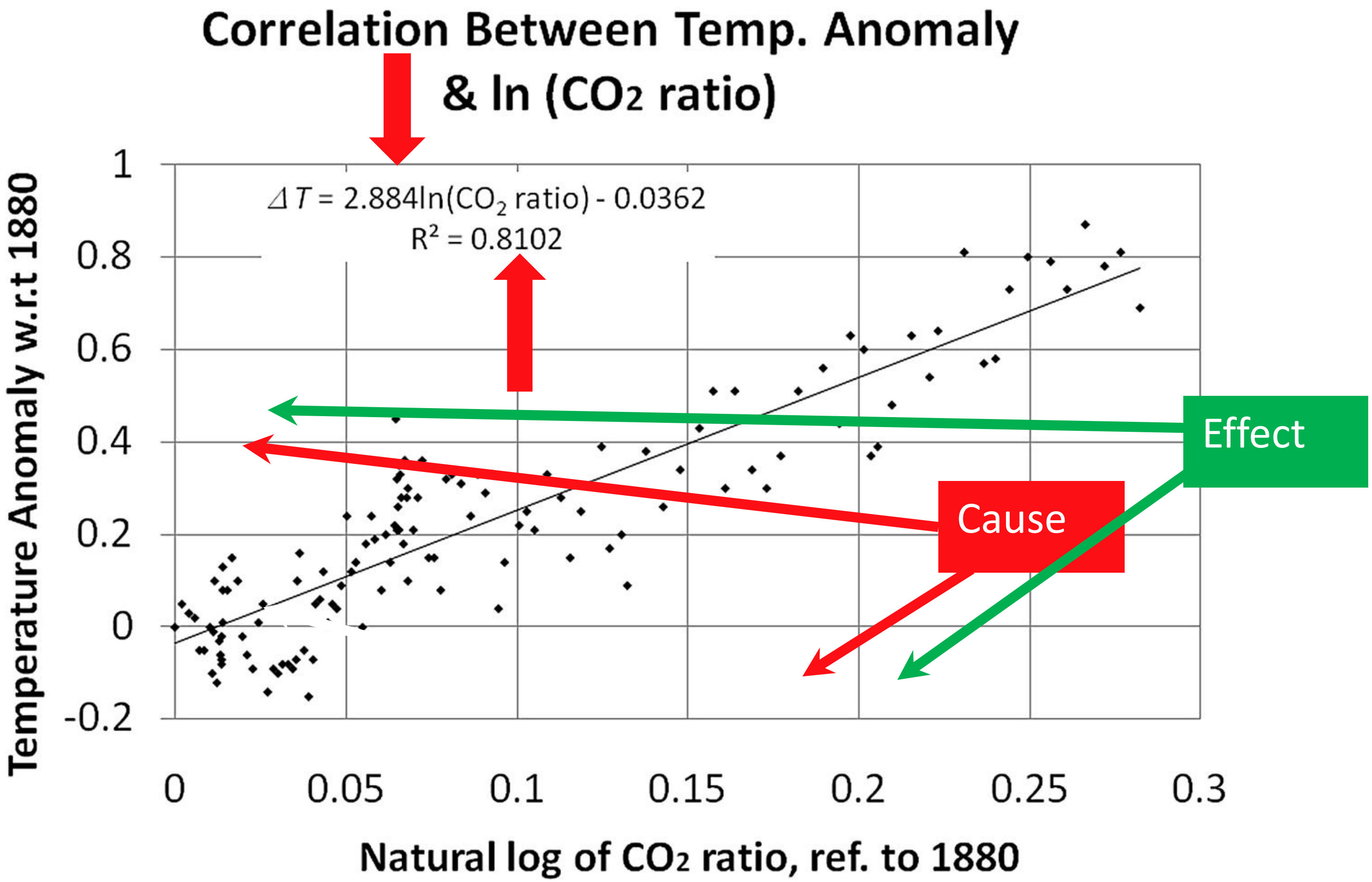
NASA data, 1880-present

***slope* = 2.884 ºC *cf* 2.7835 in satellite data**



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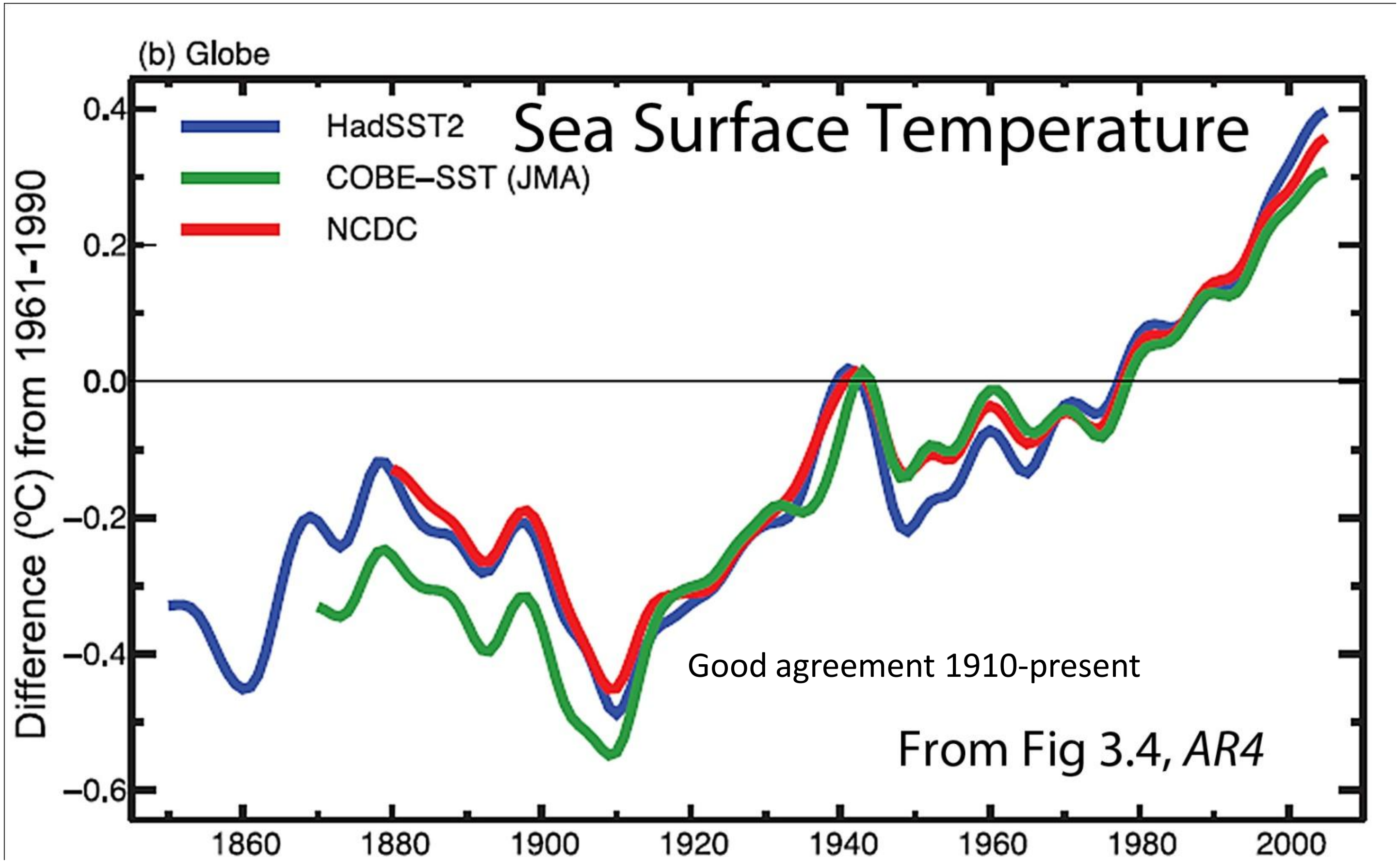
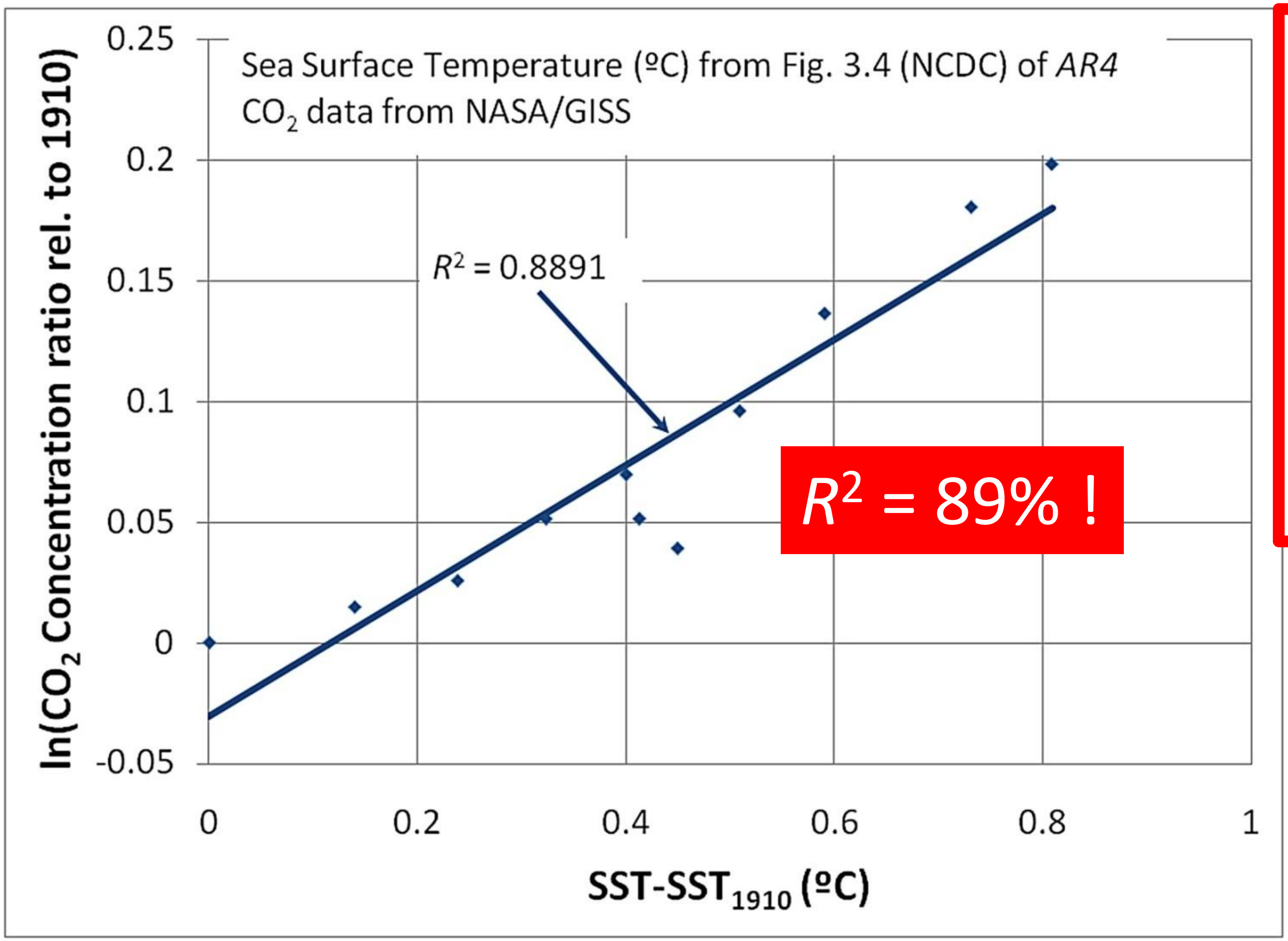
Global SST Data from *AR4*



ln (CO_2 ratio) *vs* Δ*SST (1910-2005)*



Q: How can you explain high R^2, assuming that

(A) CO_2 is cause and SST is effect?

(B) (B) SST is cause and CO_2 is effect?

Ans:

A: CO_2 is the only thing that matters

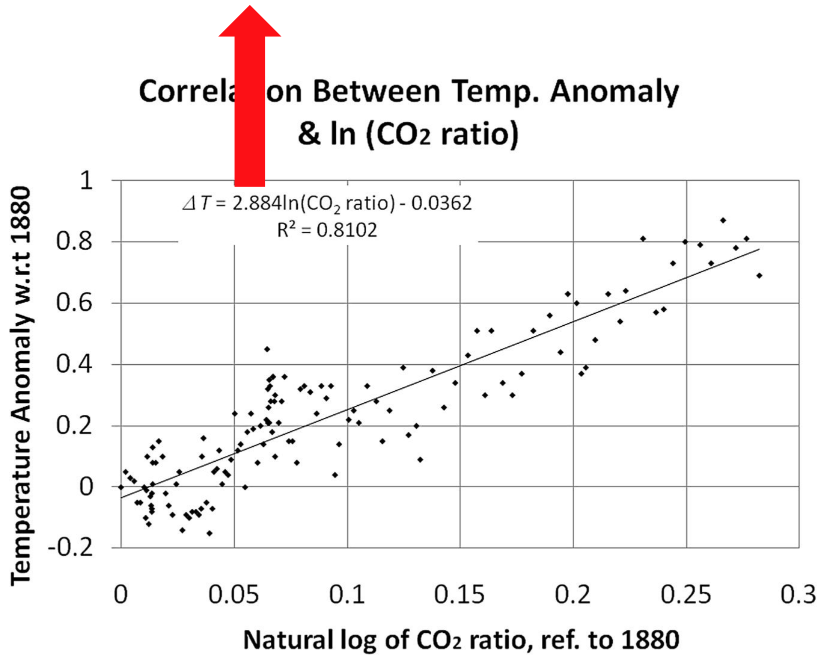
B: Only SST matters, and it makes no difference what warms the oceans

“Sensitivity” from Real Data

- Sensitivity $= \gamma * \ln(2)$
- = 2.0 ºC *providing* that *Henry’s Law doesn’t apply*
- That is, we assume incorrectly that warming water does not emit CO_2
- Therefore, 2.0 ºC is an *upper limit* to the sensitivity

Slope $= \alpha$ = 2.884 ºC

$\alpha \ln(2)$ = 2.0 ºC



Wait! We Forgot the Sun!

- Solar flux (outside the atmosphere) has increased by about 4 Wm^{-2} since 1880
- Equivalent to "forcing" of

$$1\,\mathrm{Wm}^{-2} * (1 - albedo) = 0.7\ \mathrm{Wm}^{-2}$$

- We need to correct the cause-effect graph for that (continuously variable) amount

Sensitivity < 1.66 ºC