Separating Forcing from Feedback with Phase Space Analysis -or- (Do Cloud Changes Cause Temperature Changes… or the Other Way Around?)

Roy W. Spencer
William D. Braswell
The University of Alabama in Huntsville

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<u>Ultimate Goal</u>:

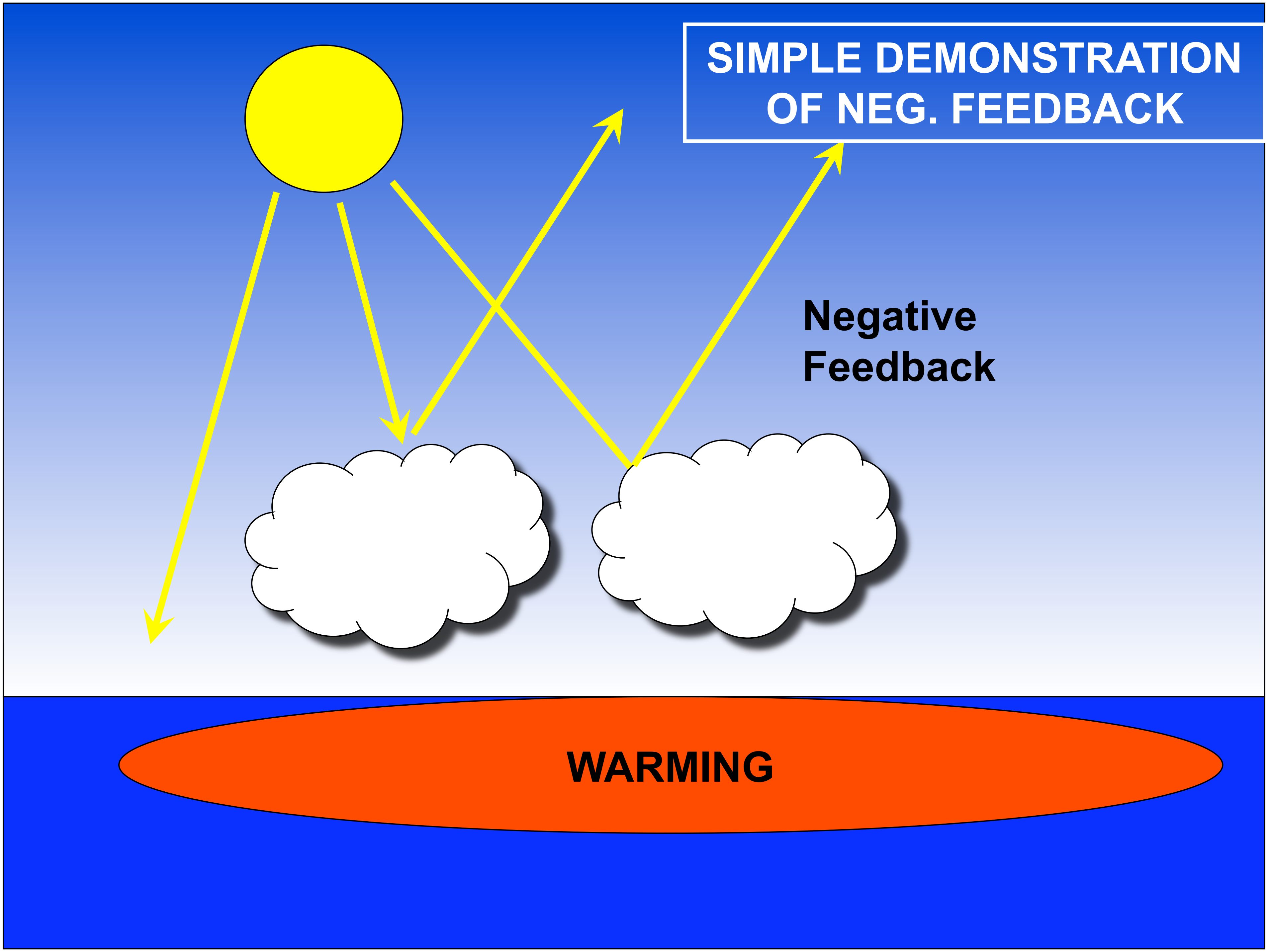
Diagnose Climate Sensitivity (Feedbacks) from Satellite Data

WHY?…because FEEDBACKS determine whether manmade global warming will be a catastrophe… …or barely measurable.

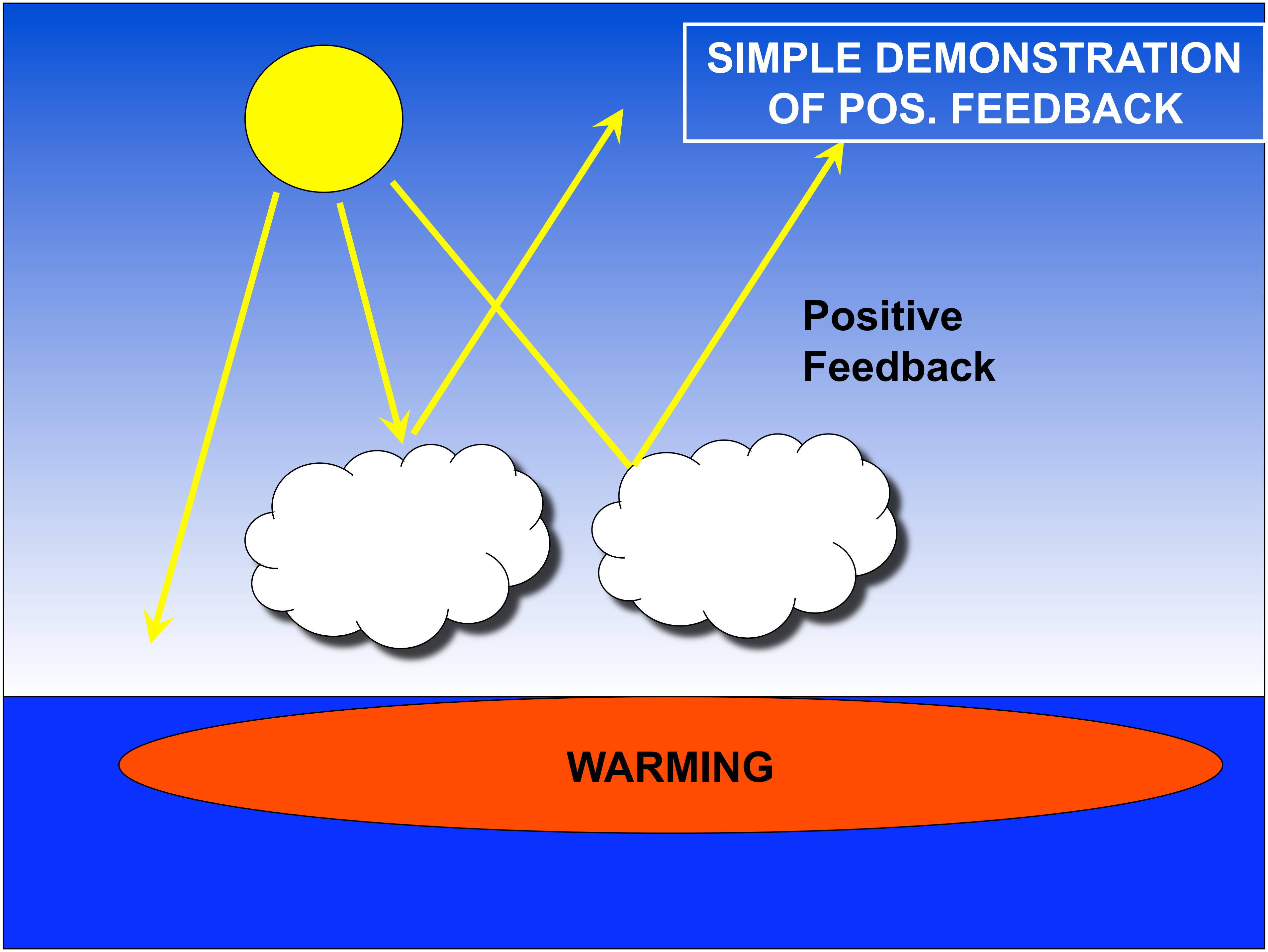
⇒Largest uncertainty is cloud feedbacks,
<u>especially due to low clouds (IPCC, 2007)</u>
(Will warming cause low clouds to increase or decrease?)

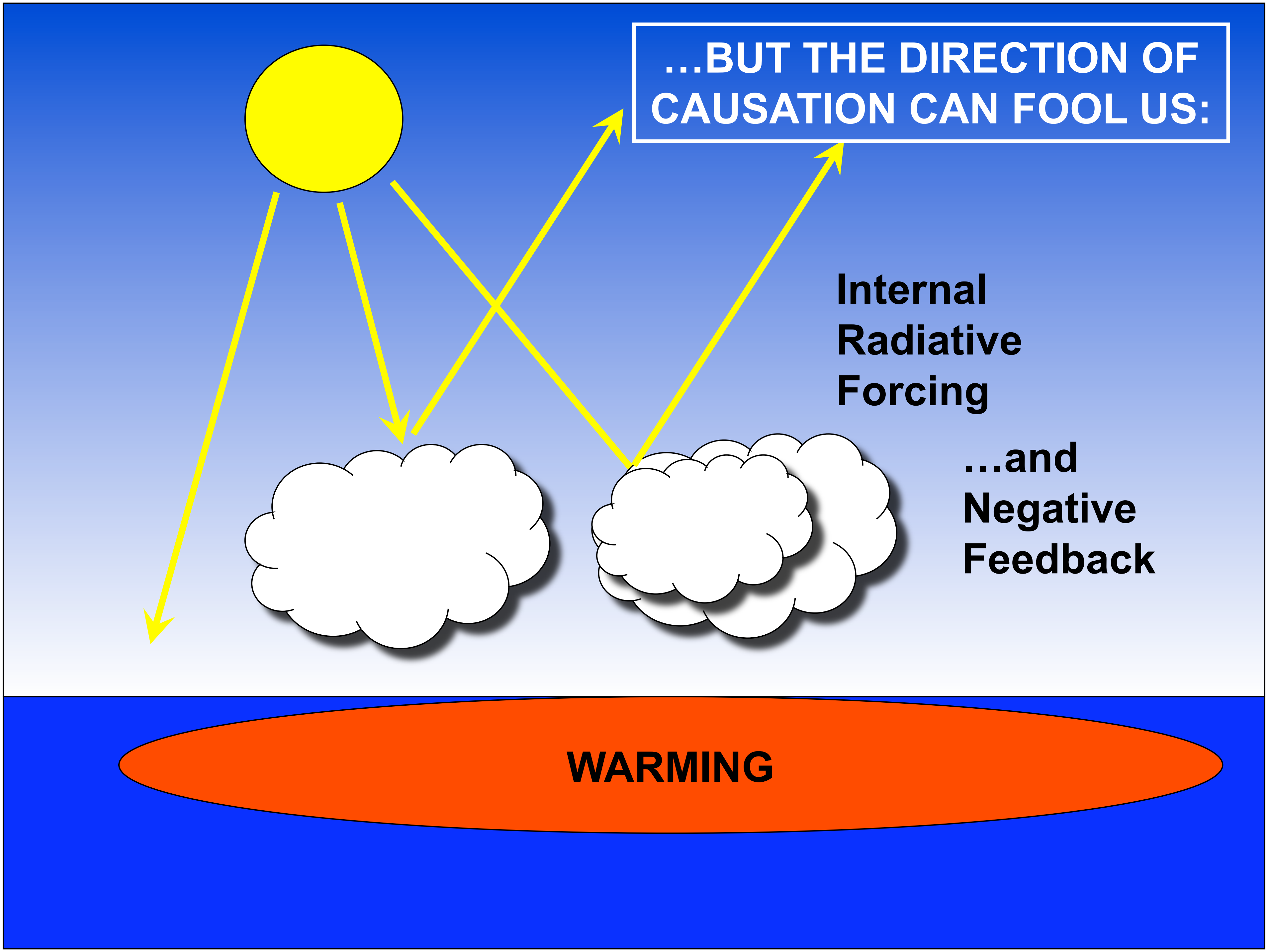
Spencer & Braswell (2008 *J. Climate*) showed that climate sensitivity is probably being overestimated because natural cloud variations causing temperature variations “looks like” positive feedback…

=> How serious is this problem?
=> How to more accurately diagnose feedbacks?



SIMPLE DEMONSTRATION
OF NEG. FEEDBACK
Negative
Feedback
WARMING


SIMPLE DEMONSTRATION OF POS. FEEDBACK
Positive Feedback
WARMING


…BUT THE DIRECTION OF CAUSATION CAN FOOL US:
Internal Radiative Forcing
…and Negative Feedback
WARMING

The Conundrum

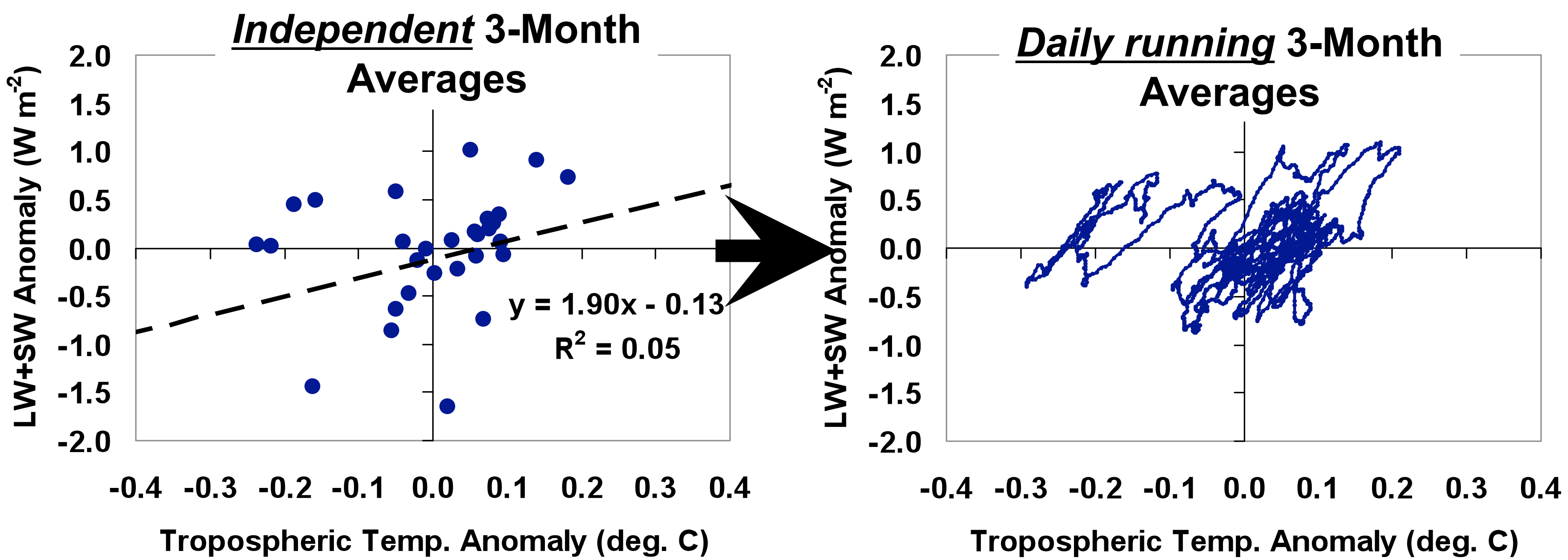
- What do satellite <u>*TOA radiative flux*</u> vs. <u>*T*</u> variations have to do with Feedbacks?

<u>SATELLITE DATA</u>

Terra CERES TOA LW+SW Flux vs.
AMSU5 (~tropospheric T) Anomalies
(60N-60S oceans, ES4 Edition2, Rev1, Mar. 2000-Aug. 2007)

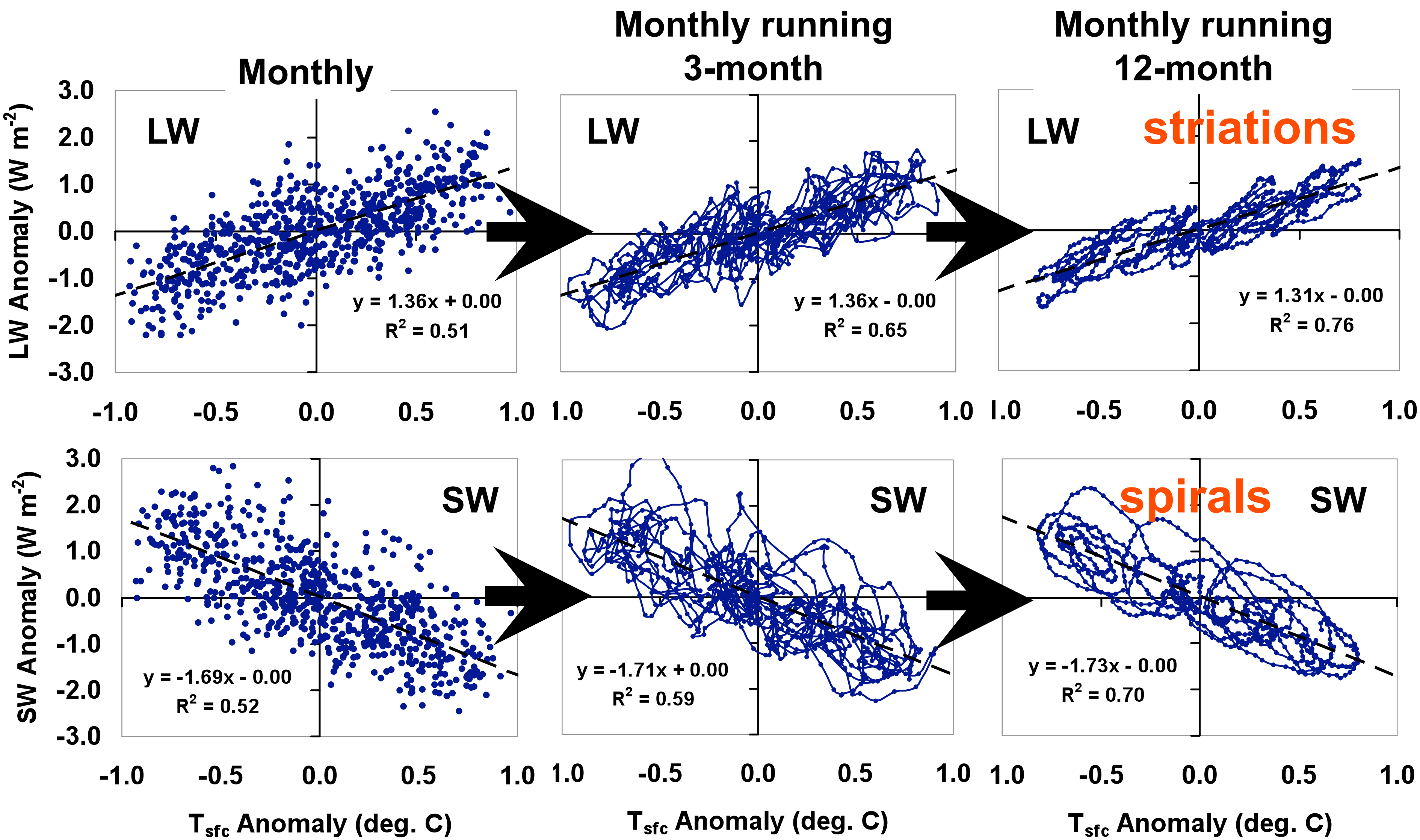
Data are typically poorly correlated…

..“phase space” plots reveal Linear Striations & Spirals/Loops



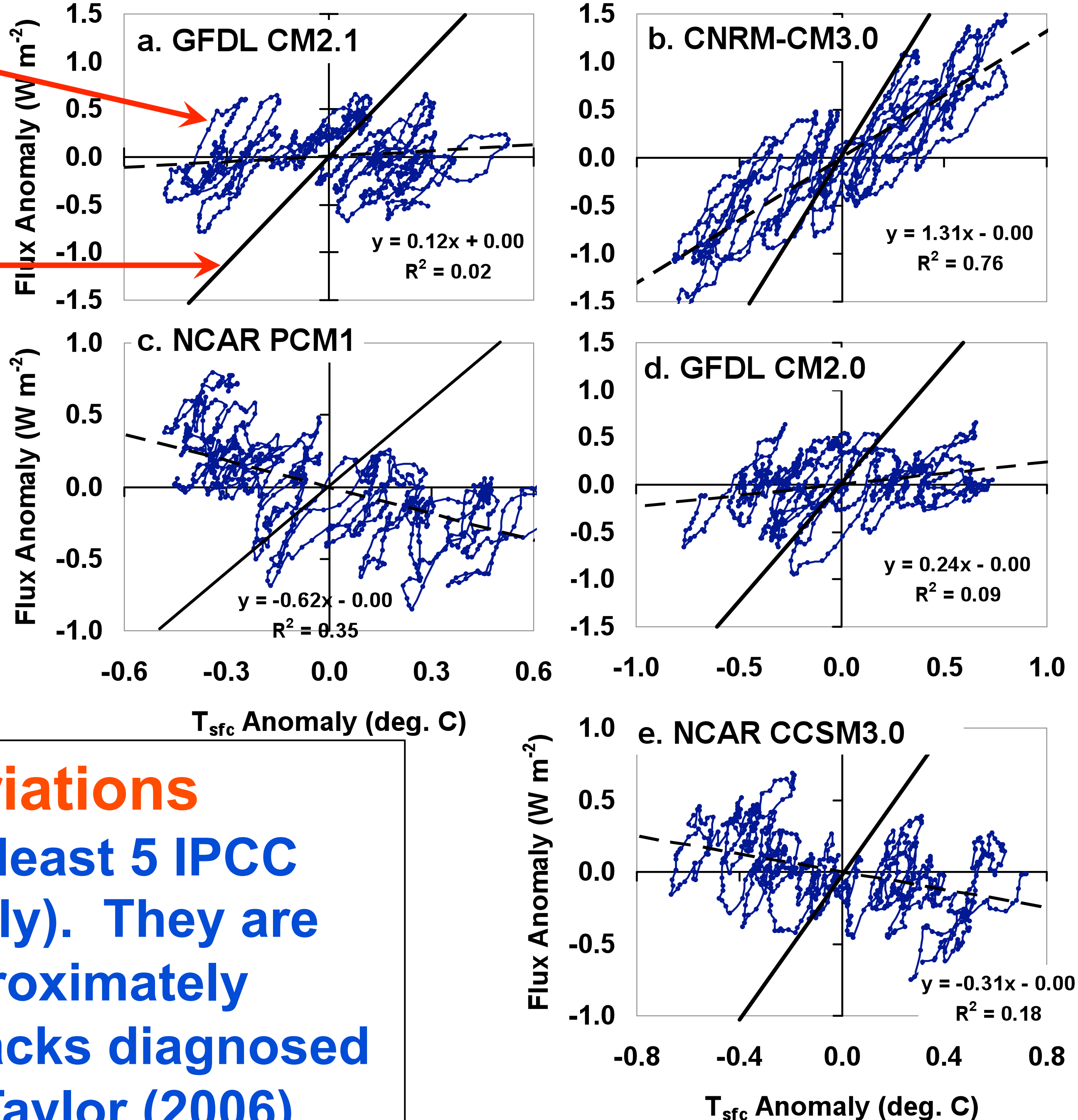
IPCC AR4 Climate Model

CNRM-CM3.0 (global, 60-yr integration, +1%CO2/yr to CO2 doubling)



linear striations

Model FB response to anthropogenic GHG forcing (Forster & Taylor, 2006)



linear striations

are seen in at least 5 IPCC models (LW only). They are aligned approximately along the Feedbacks diagnosed by Forster & Taylor (2006)

The Explanation
for spirals & striations:

A combination of 3 processes:

Time-varying, ***internal radiative forcing*** of temperature causes *spirals* (mostly in SW, so prob. low clouds).

Time-varying, ***internal NON-radiative forcing*** of temperature (fluctuations in ocean⇔atm heat flux) plus ***linear feedback*** upon temperature causes *striations*.

A Simple Model of Global T *Variability*:

(Spencer & Braswell, 2008 *J. Climate* [thanks to Isaac Held, *pers. comm.*])

CERES measures a combination of these 3 (not just feedback)

Bulk heat capacity (ocean mixed layer depth)

$$C_p(d\Delta T/dt) = f(t) + N(t) + S(t) - \lambda\Delta T$$

***external* radiative forcings (anthro.; volcanoes; solar)**

***internal* radiative forcings (non-FB vars. in clouds, mostly)**

internal NON-radiative forcings (vars. in ocn => atm heat flux)

Feedback

Model was run at monthly time resolution for 20 years:
C_p equivalent to a 50 m deep “swamp” ocean
for 5 different cases.

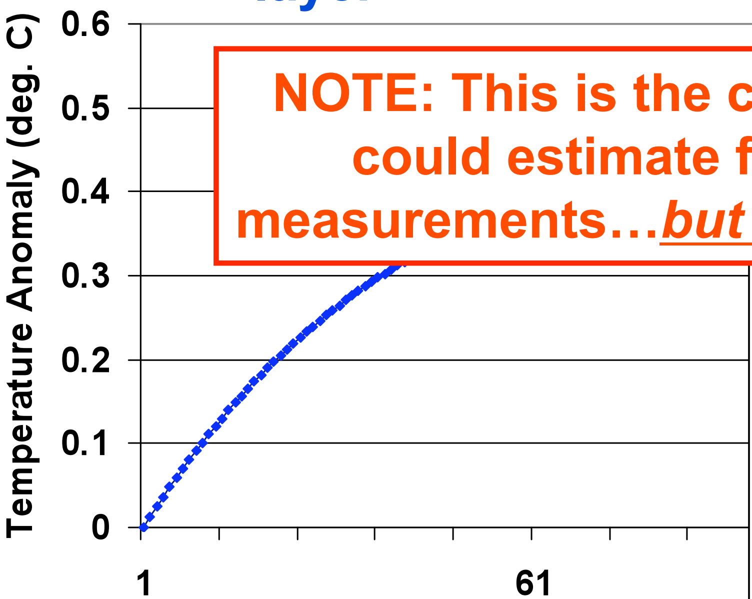
Case 1) The 'Original' Anthro. Global Warming Example:

(instantaneous, *constant* radiative forcing [Gregory et al., 2004])

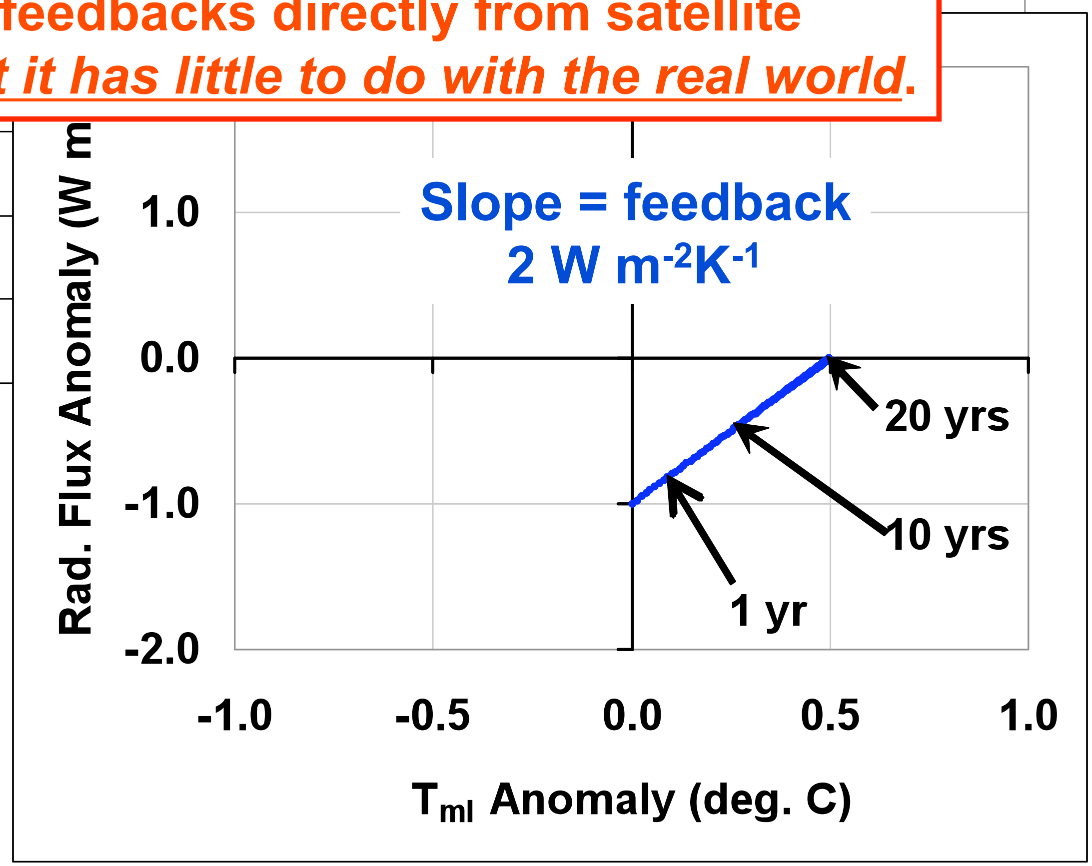
50 m mixed layer → $C_p(d\Delta T_{ml}/dt) = f - \lambda\Delta T$

f: 1 W m^{-2}

λ: 2 W m^{-2}K^{-1}



NOTE: This is the case that fooled us into thinking we could estimate feedbacks directly from satellite measurements…*but it has little to do with the real world*.



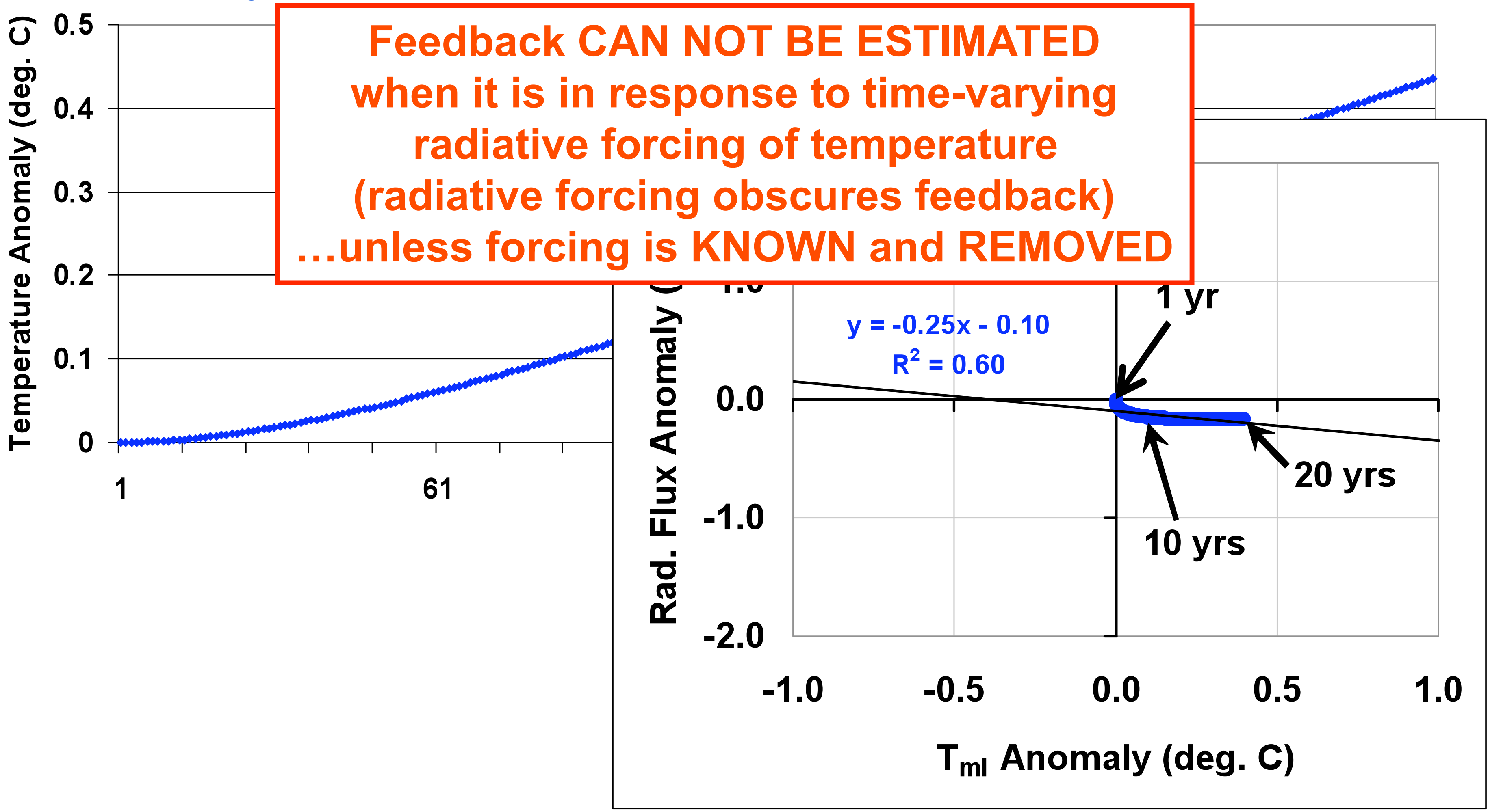
Case 2) "More Realistic" Anthro. Global Warming Example:

(*transient* radiative forcing, [Forster & Taylor 2006])

$$C_p(d\Delta T_{ml}/dt) = f(t) - \lambda\Delta T$$

- C_p: 50 m mixed layer
- $f(t)$: 0.5 W m^{-2}/decade
- λ: 2 W $m^{-2}K^{-1}$

Feedback CAN NOT BE ESTIMATED when it is in response to time-varying radiative forcing of temperature (radiative forcing obscures feedback) …unless forcing is KNOWN and REMOVED



3) Transient Rad. Forcing + Random NON-Rad. Forcing ("Feedback Stripes")

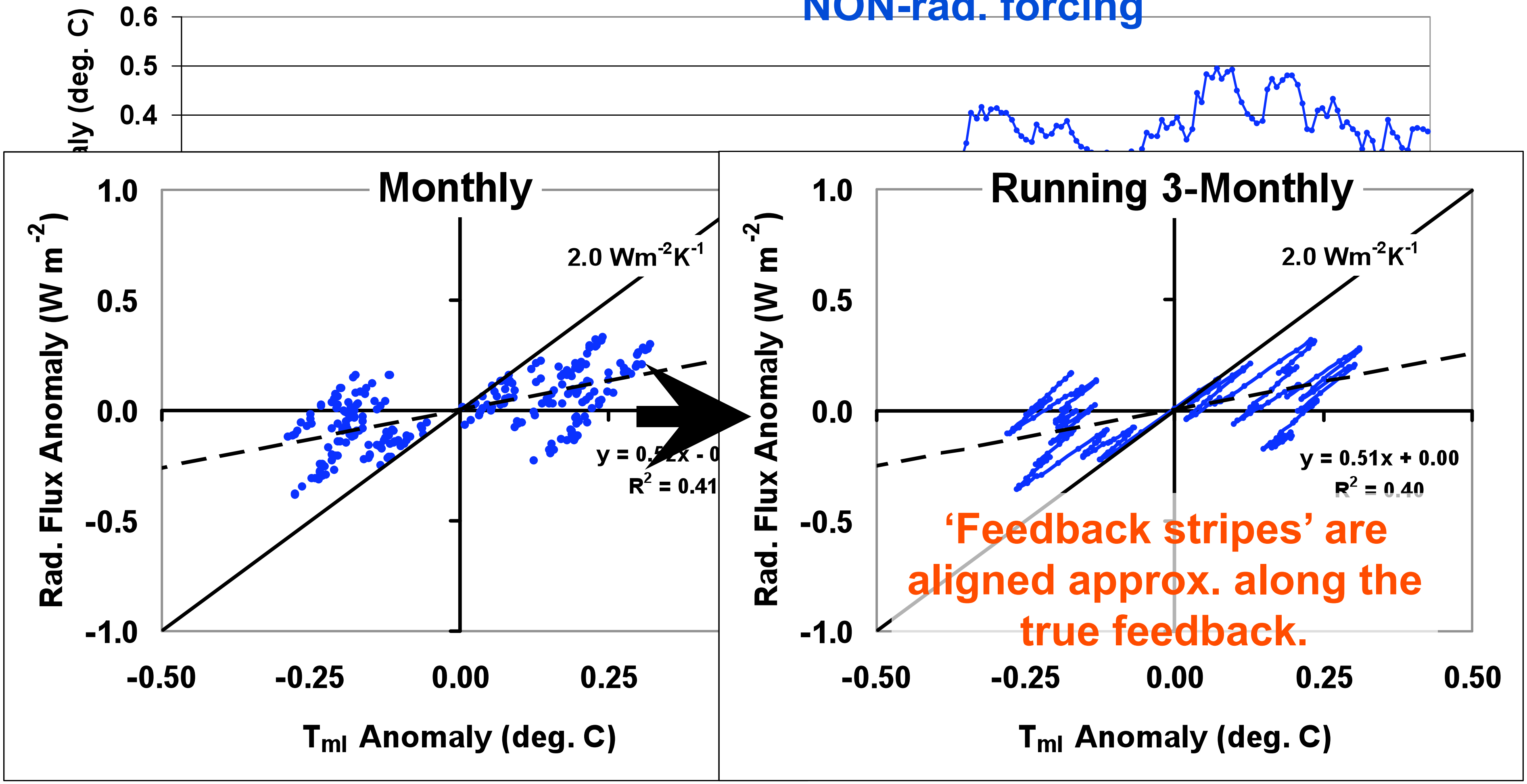
$$C_p(d\Delta T_{ml}/dt) = f(t) + S(t) - \lambda\Delta T$$

50 m mixed layer → C_p

0.5 W m^{-2}/decade → $f(t)$

Random NON-rad. forcing → $S(t)$

2 W m^{-2}K^{-1} → λ



4) Transient Rad. Forcing + Random Rad. Forcing:
("Radiative Forcing Spirals")

$$C_p(d\Delta T_{ml}/dt) = f(t) + N(t) - \lambda\Delta T$$

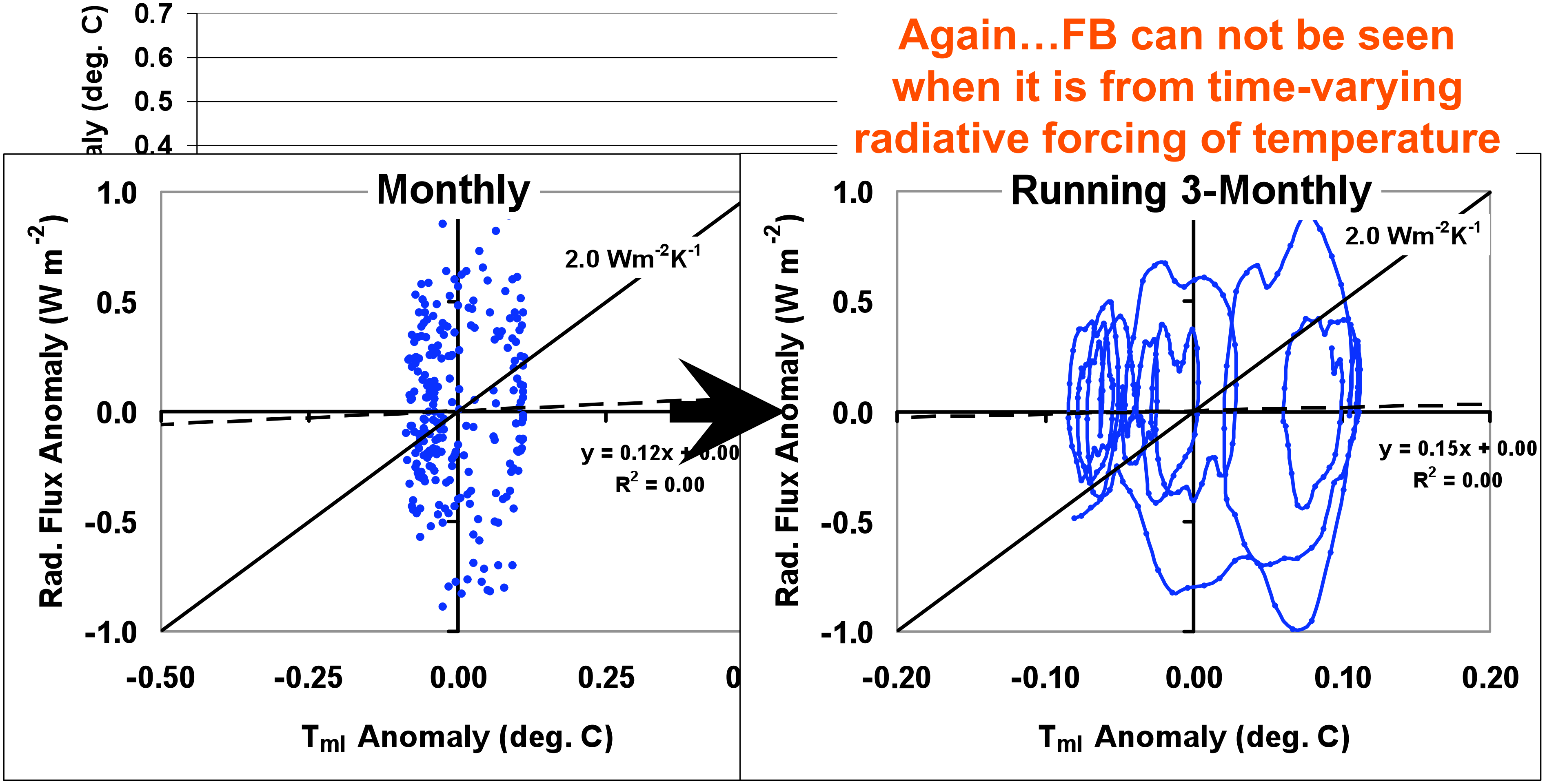
50 m mixed layer

0.5 W m^{-2}/decade

Random Rad. 12-mon smooth

2 W $m^{-2}K^{-1}$

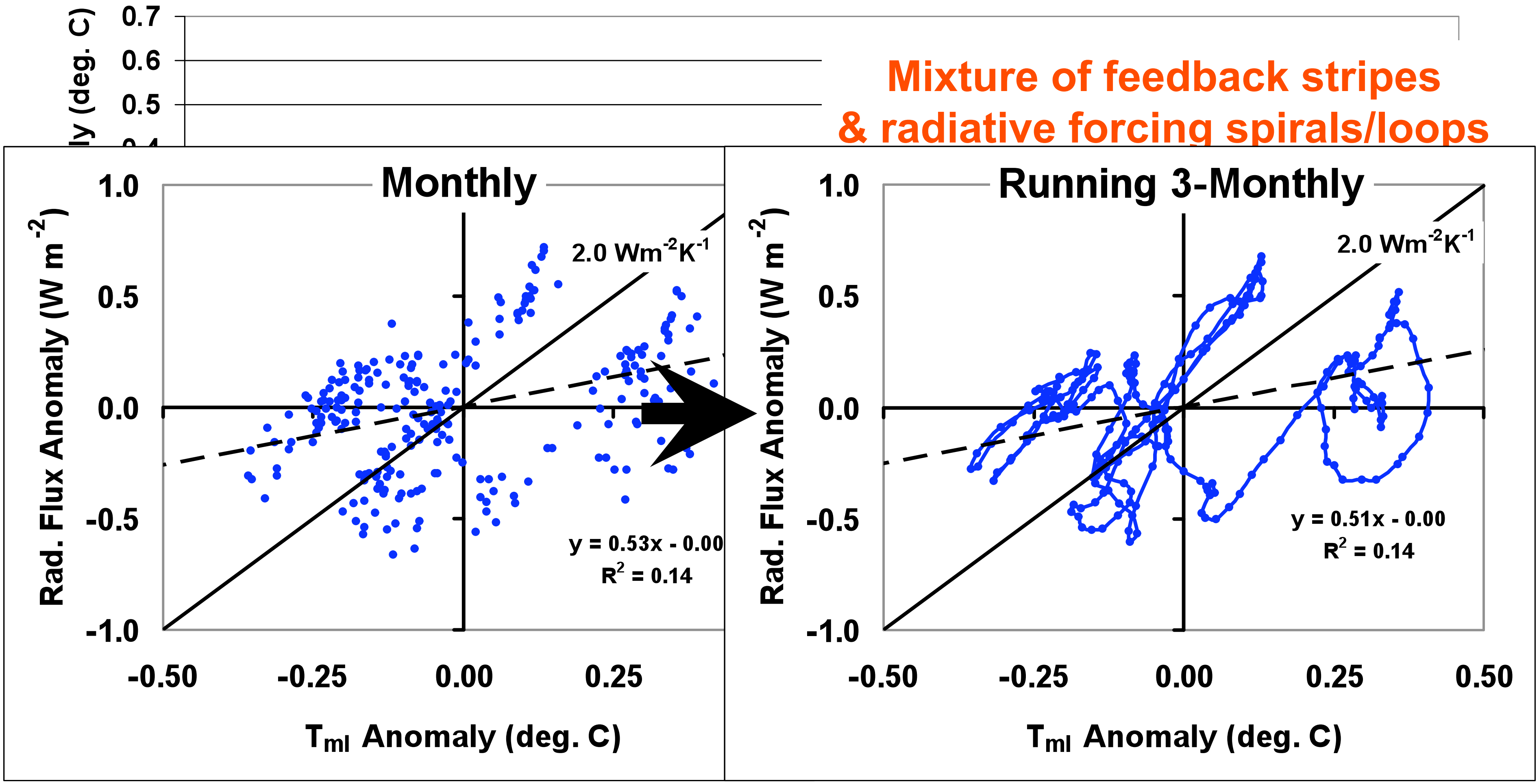
Again…FB can not be seen when it is from time-varying radiative forcing of temperature



5) Transient Rad. + Random Rad. + Random non-Rad. Forcing (mixture of spirals/loops and stripes)

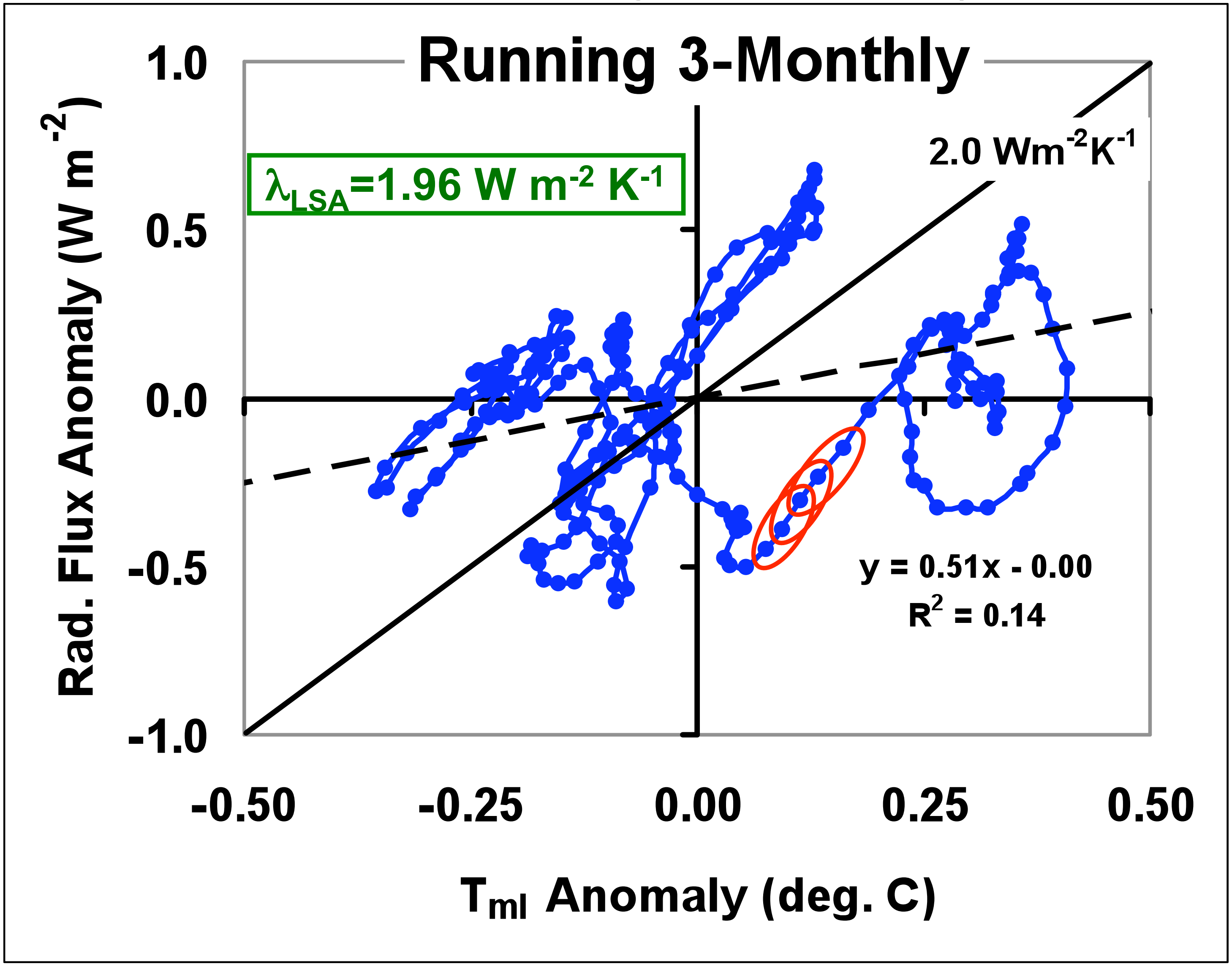
$$C_p(d\Delta T_{ml}/dt) = f(t) + S(t) + N(t) - \lambda\Delta T$$

- C_p: 50 m mixed layer
- $f(t)$: 0.5 W m^{-2}/decade
- $S(t)$: random
- $N(t)$: random, 12-mon smoother
- λ: 2 W $m^{-2}K^{-1}$

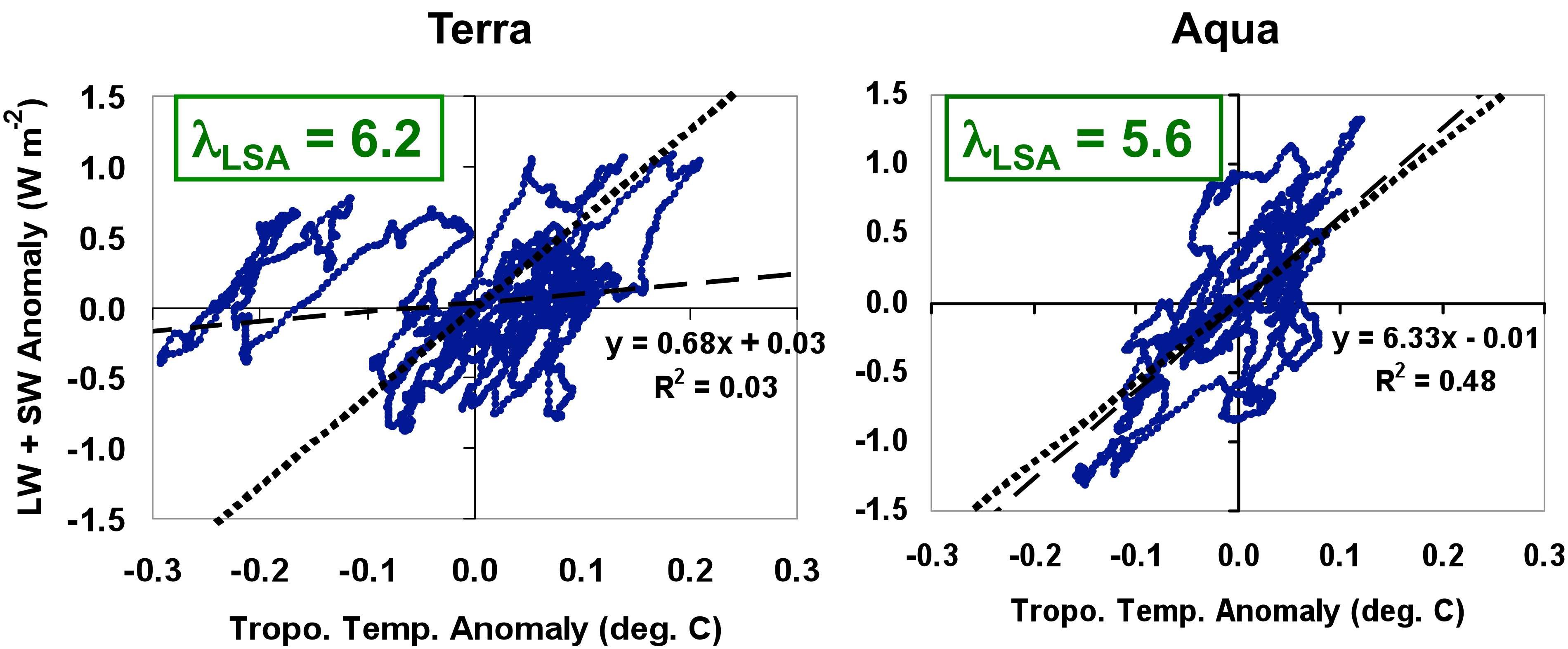


Local Slopes Analysis

Average of all local regression slopes computed on subintervals of the data (e.g. regression on every 3-month interval throughout time series)



Terra & Aqua Global Oceanic LW+SW
LSA Total Feedback Parameter of ~6.0 W m^{-2} K^{-1}



The ACCURACY of feedback diagnosis depends upon ratio of stochastic radiative [*N*(t)] to stochastic non-radiative forcing [*S*(t)] (Spencer & Braswell, 2008 *J. Climate*)

(that is, 'feedback stripes' can be obscured by 'radiative forcing spirals')

Error in Feedback Can Be Computed EXACTLY… *IF* you know the time-varying radiative forcing & temperature.

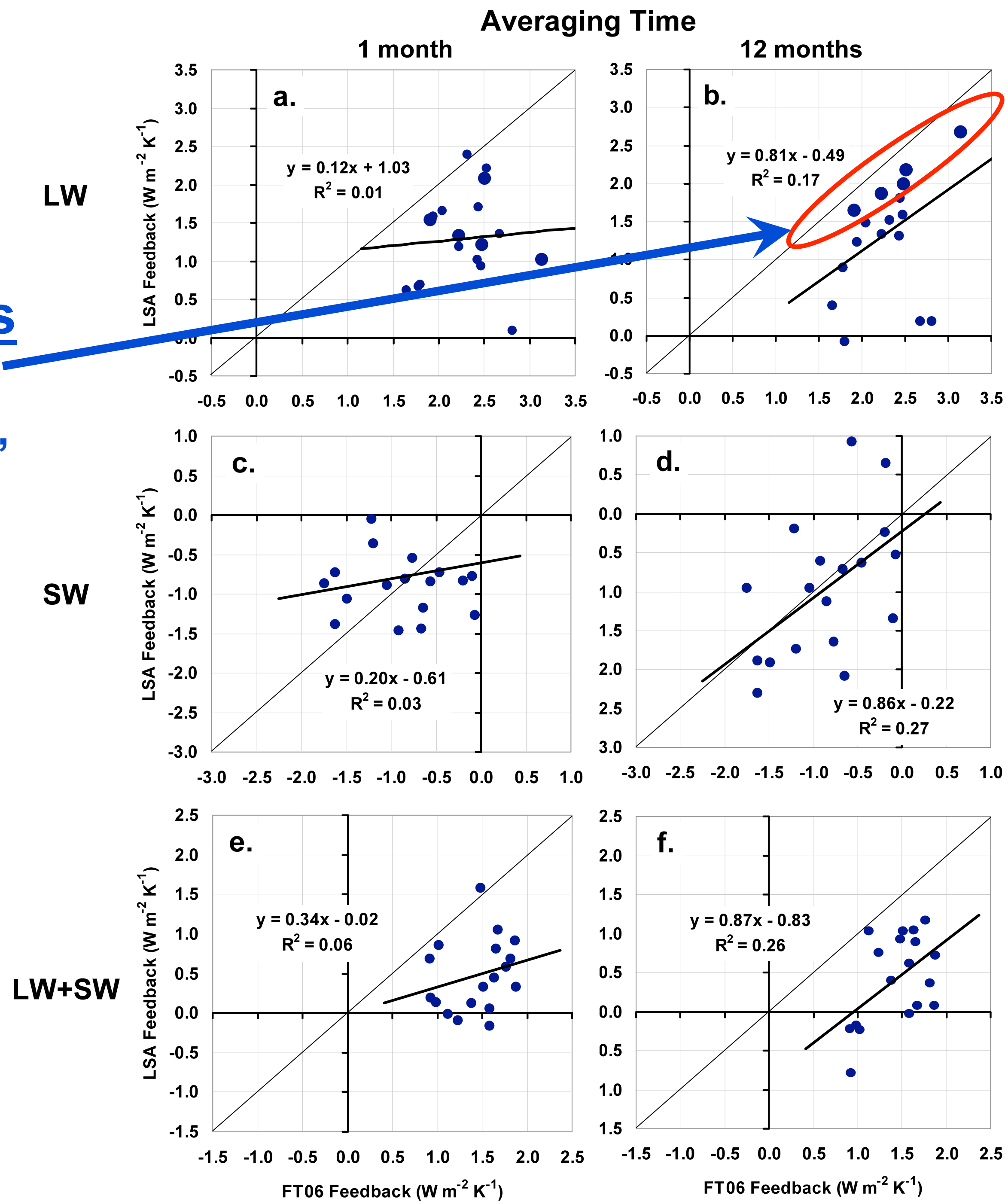
(Isaac Held => Spencer & Braswell, 2008 J. Climate)

$$\lambda_{err} = -\Sigma[N(t)T(t)] \,/\, \Sigma T(t)$$

LSA on 18 IPCC Models

When feedback stripes are visible **in IPCC AR4 Models, Local Slopes Analysis provides a good estimate of those Models' Feedback Response to Long-term Radiative Forcing**

(as diagnosed by Forster & Taylor, 2006 *J. Climate*)



Major Conclusions

- The forcing/feedback paradigm of climate variability is valid
  - spirals and stripes seen in IPCC models & sat. data
- Global avg. satellite TOA fluxes are a combination of forcing *and* feedback
  - the presence of one contaminates the estimation of the other (NOT new…Forster & Gregory, 2006; Forster & Taylor, 2006)
  - Local Slopes Analysis of sat. data results in $\lambda \sim 6$ W m^{-2} K^{-1}
  - Satellite FB results of Forster & Gregory (2006) from ERBS are probably biased low
- There is NO WAY (that I know of) to diagnose radiative feedback in response to unknown amounts of time-varying radiative forcing (e.g. natural cloud variations)
  - (the feedback signal is almost totally obscured by the forcing)
- Local Slopes Analysis provides a more accurate diagnosis of feedback **IF** sufficient non-radiative forcing of temperature exists (feedback stripes)
  - IPCC models are known to be deficient in their production of intraseasonal oscillations (only 5 IPCC models revealed obvious feedback stripes, in LW only)

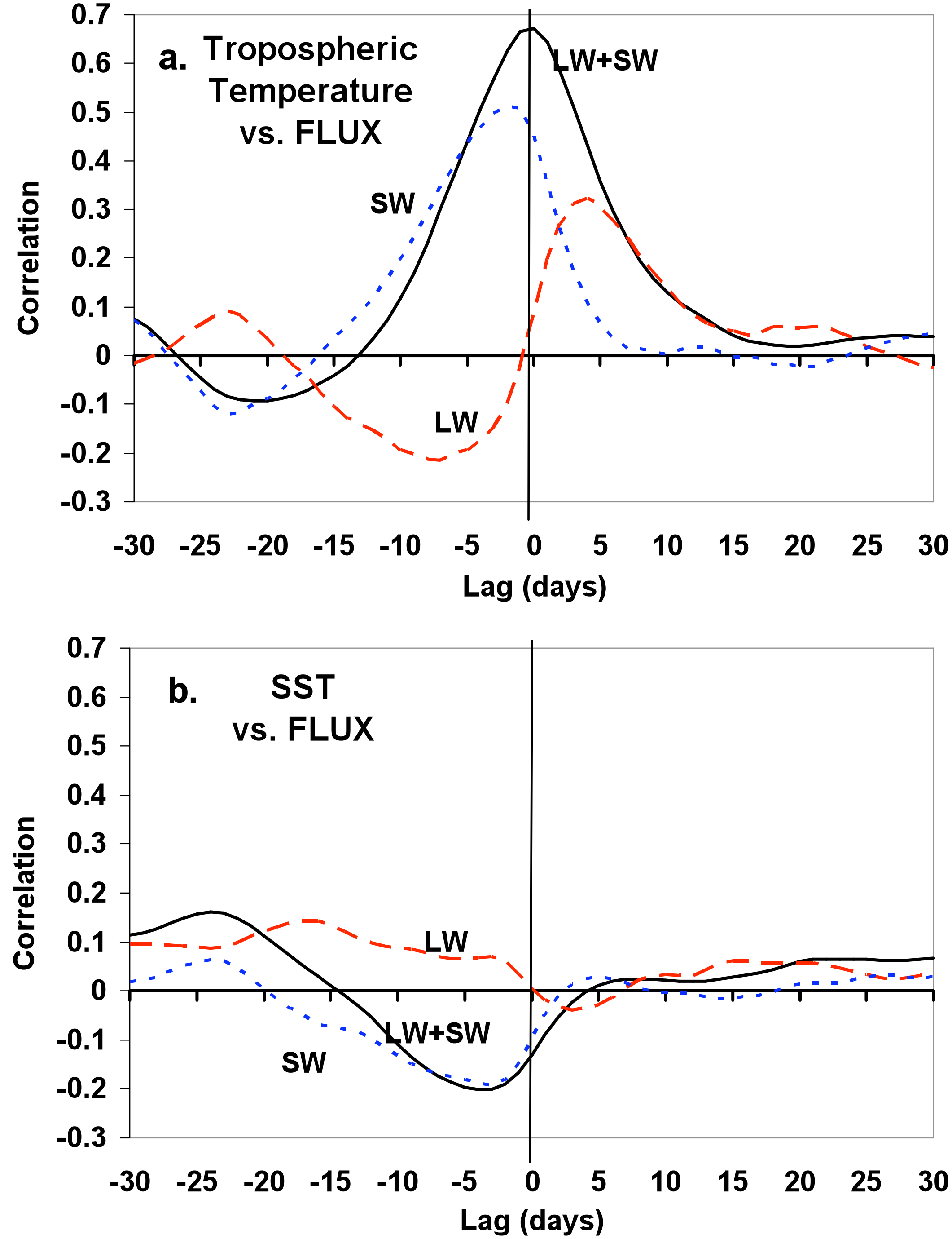
Major Speculation

- **Climate models are *too sensitive* because they have been built and validated assuming that the observed co-variations between radiative fluxes and temperature have been due to *feedback alone*.**
  - **This will lead to an overestimate of climate sensitivity, because clouds causing temperature change will *always* look like positive feedback**

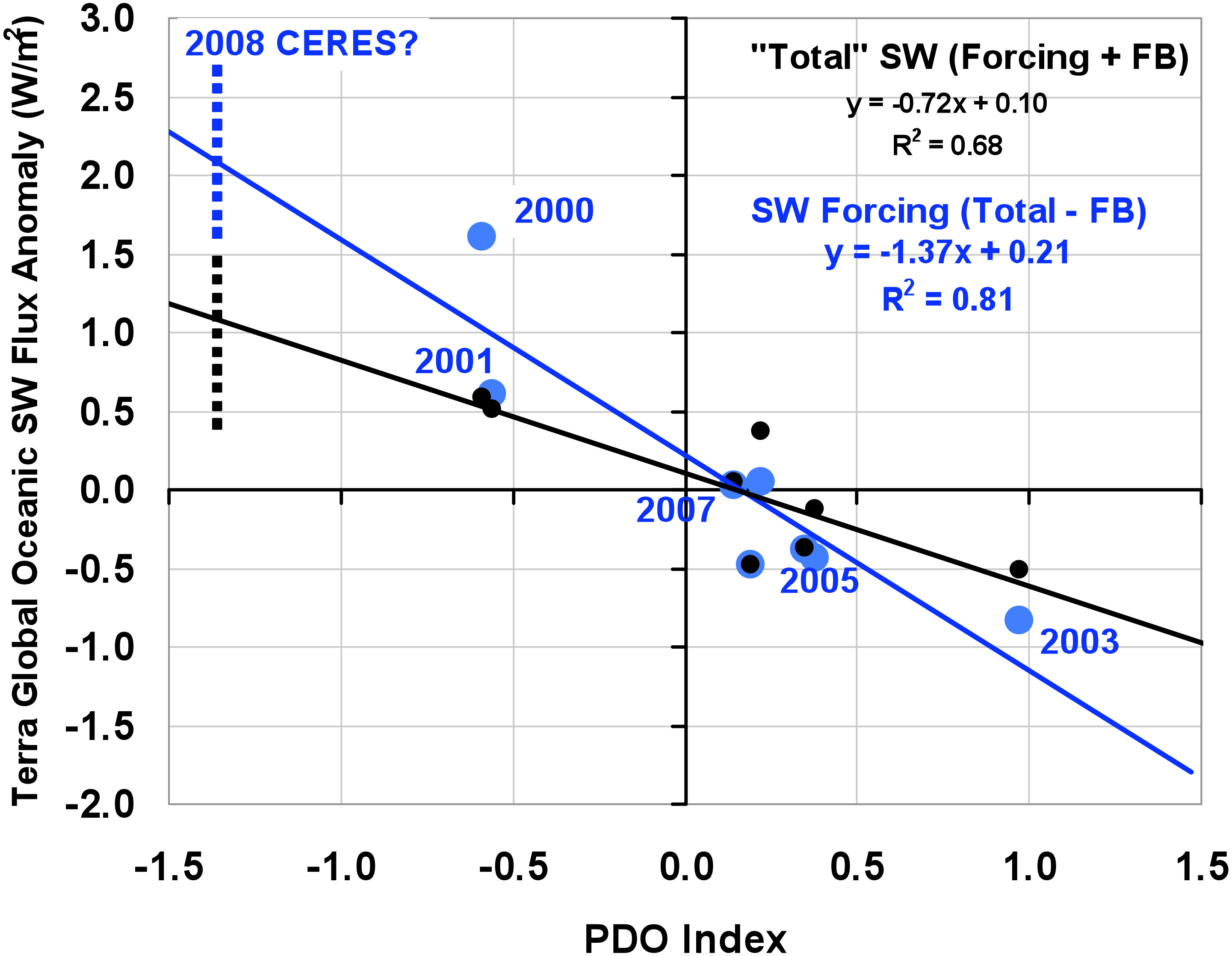
    (e.g. fewer low clouds causing warming "looks like" positive feedback if you assume causation in the wrong direction)

Backup Slides

CERES Flux Anomalies are more closely correlated with <u>tropospheric temperature</u> than with <u>SST</u>

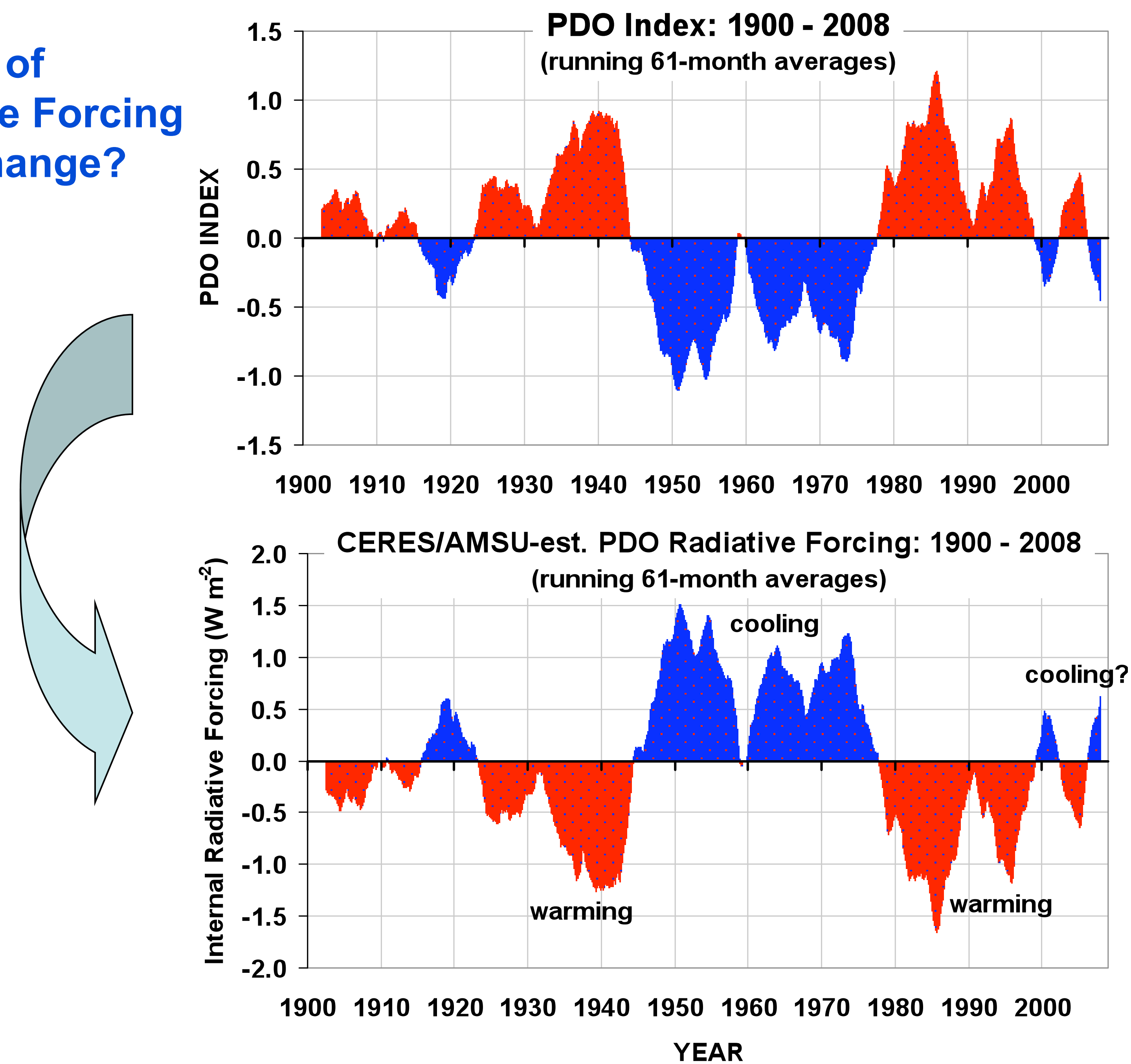


AMSU5 Feedback–Corrected (5.2 W m^{-2} K^{-1}) CERES SW Anomaly suggests The Pacific Decadal Oscillation (PDO) causes Internal Radiative Forcing of -1.37 Wm^{-2} per PDO Index



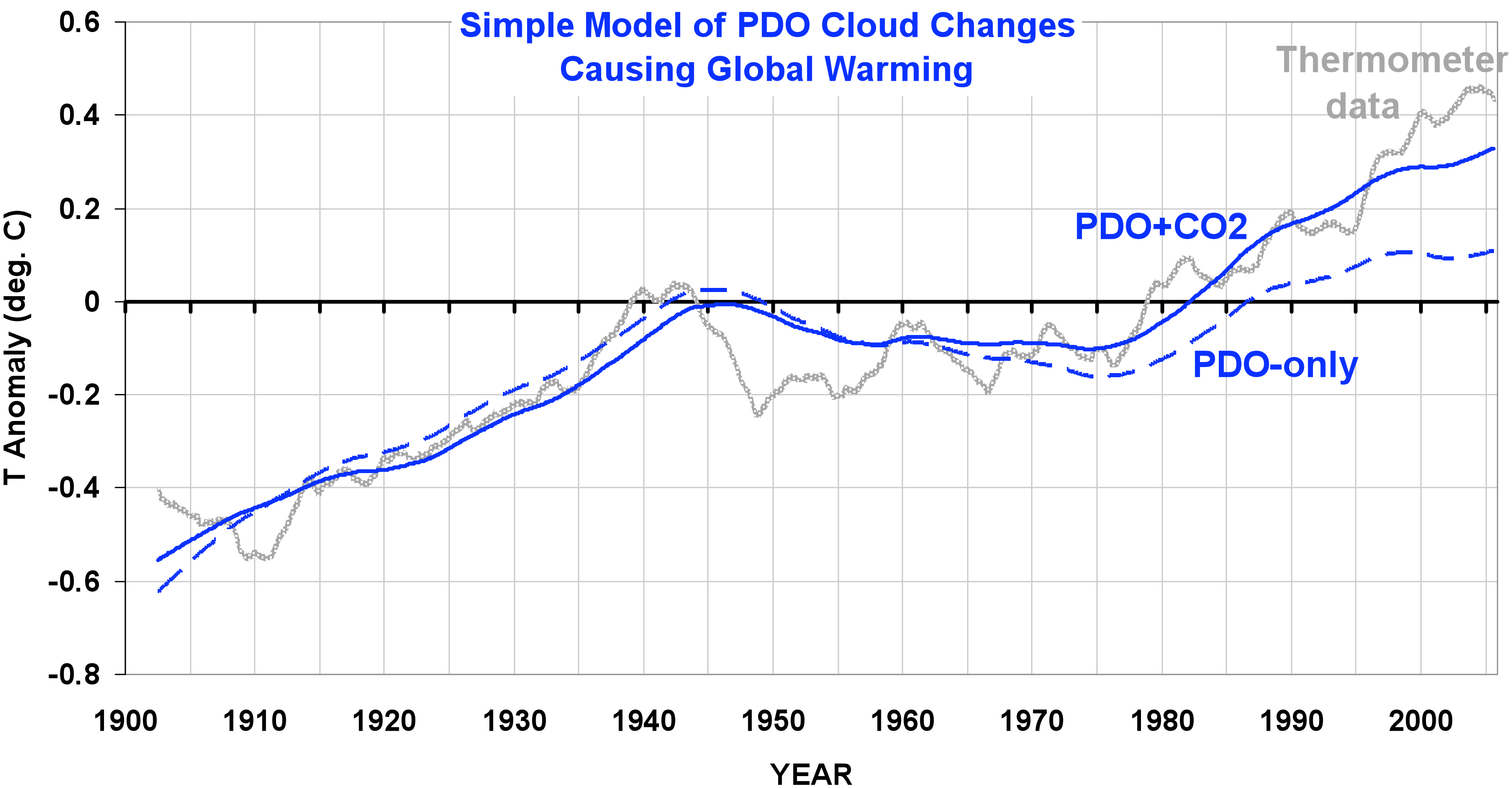
Evidence of Internal Radiative Forcing Of Climate Change?

$-1.37\ W/m^2$ per unit PDO Index



PDO Can explain 3/4 of 20th Century Warming…

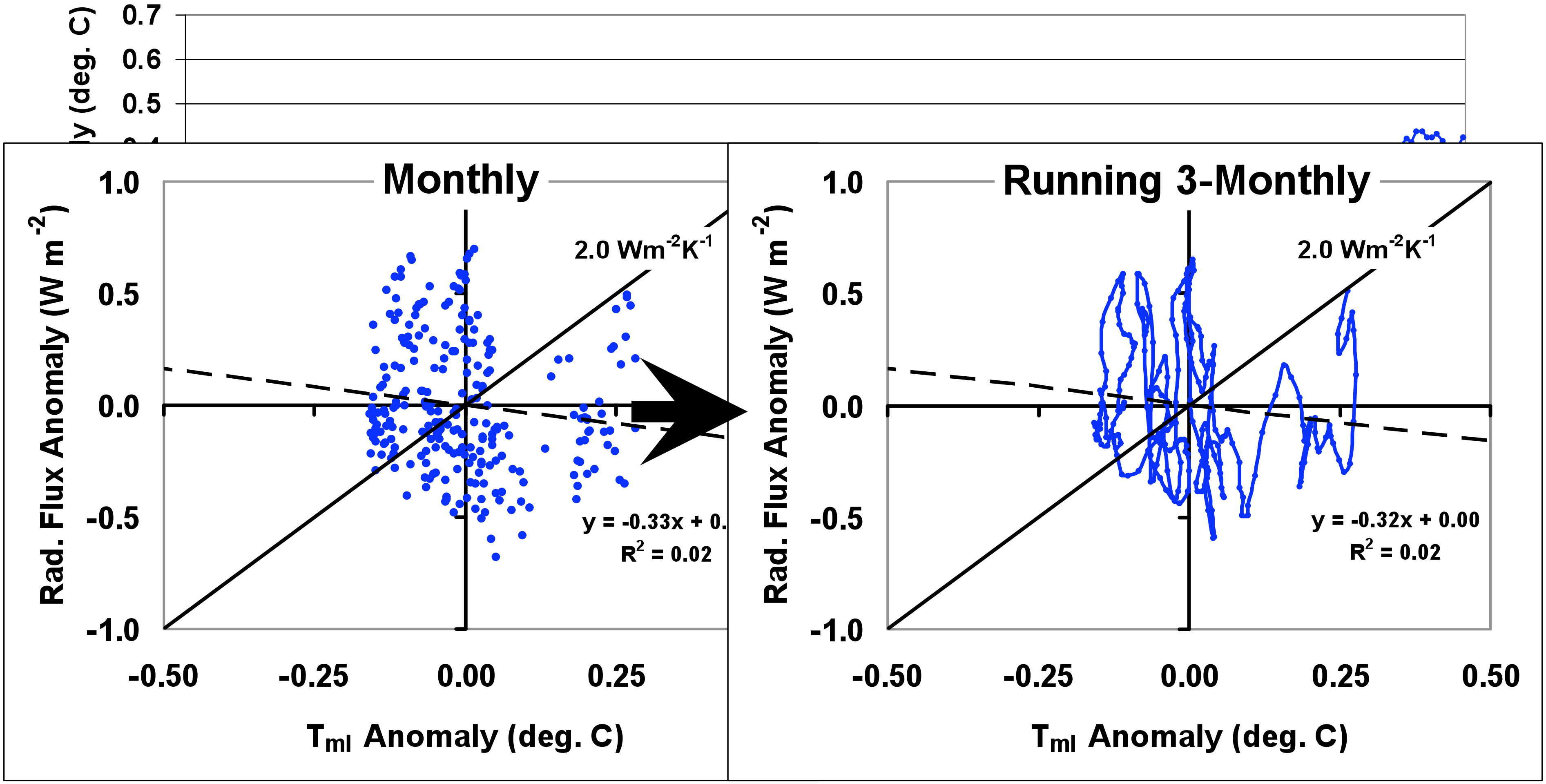
…IF a simple computerized climate model gets to "choose" the relationship between the PDO and cloud cover variations (& that choice just happens to match satellite observations!)



Change 50 m to 100 m mixed layer depth (transient forcing does not have to produce a positive slope)

$$C_p(d\Delta T_{ml}/dt) = f(t) + S(t) + N(t) - \lambda\Delta T$$

- 50 m mixed layer → C_p
- 0.5 W m^{-2}/decade → $f(t)$
- Random non-rad. → $S(t)$
- Random rad., 12-mon smoother → $N(t)$
- 2 W m^{-2}K^{-1} → λ



Change λ=2 W m^{-2} K^{-1} to 6 W m^{-2} K^{-1} (approximates behavior of satellite data)

$$C_p(d\Delta T_{ml}/dt) = f(t) + S(t) + N(t) - \lambda\Delta T$$

50 m mixed layer

0.5 W m^{-2}/decade

Random Non-rad.

Random rad., 12-mon smoother

6 W m^{-2}K^{-1}