Variability in Global Top-of-Atmosphere Shortwave Radiation Between 2000 And 2005

Norman G. Loeb

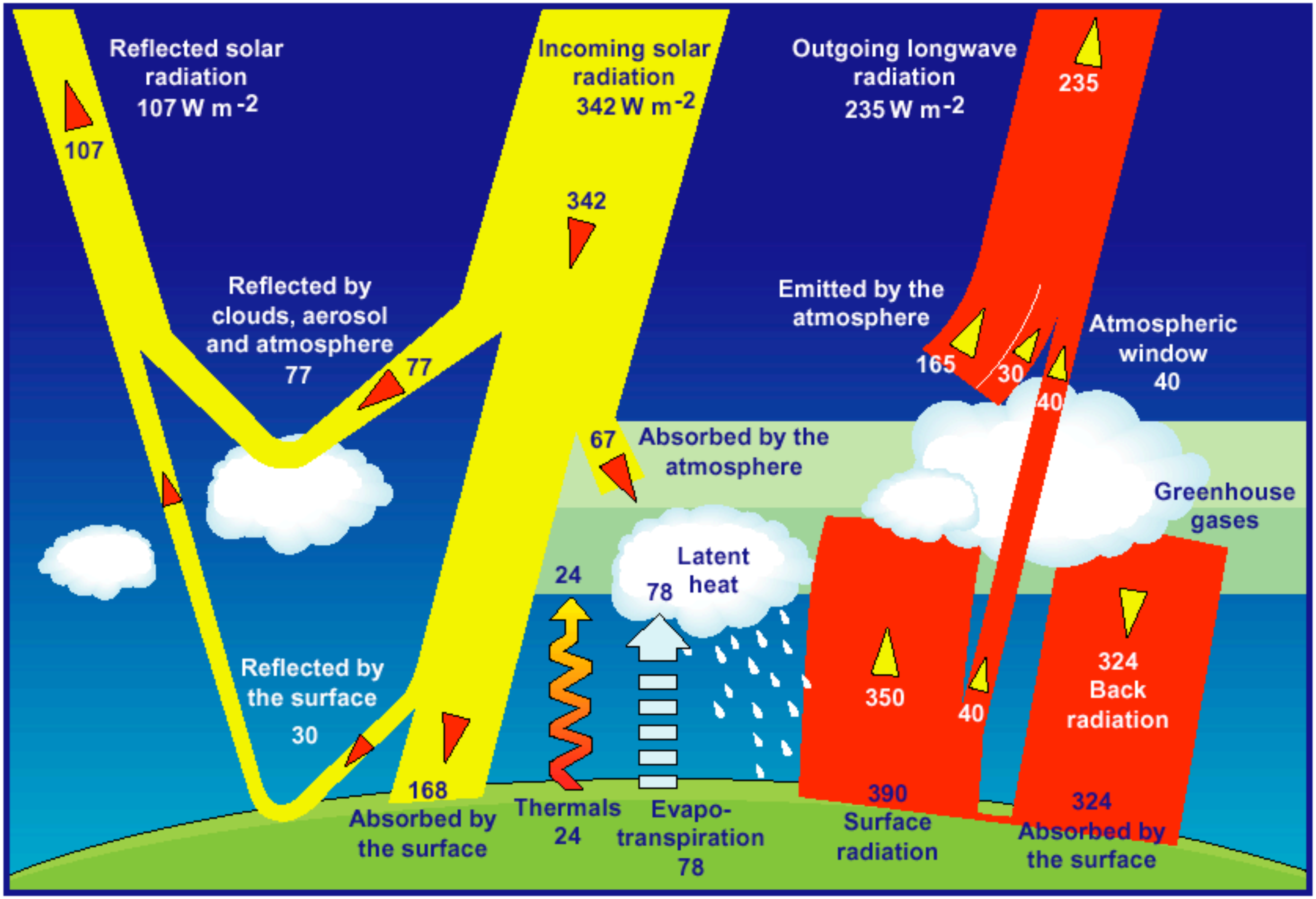
NASA Langley Research Center

Hampton, VA

Collaborators: B.A. Wielicki, F.G. Rose, D.R. Doelling

February 28th, 2007, Lunar Workshop (Tempe, AZ)

Global Radiation Budget



Monitoring the Earth’s Albedo from the Moon

- Is the Earthshine approach for monitoring the Earth’s albedo a reasonable independent check on more traditional satellite-based techniques (e.g., CERES)?
- What are the climate accuracy requirements for monitoring the Earth’s albedo?
- Can the Earthshine approach satisfy these climate accuracy requirements?

Clouds, Radiation and Climate

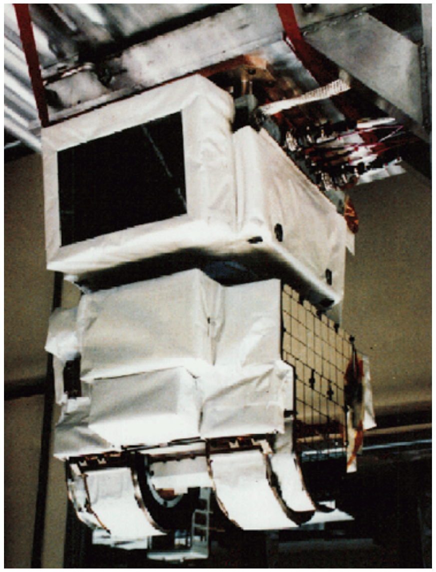
- The largest uncertainty in global climate sensitivity over the next century is cloud feedback.
- A global cloud feedback can amplify or dampen global warming.
- Global cloud feedback has been shown to be linear in changing cloud radiative forcing (CRF) (Soden and Held, 2006). This implies that changes in net CRF are directly related to climate sensitivity.
- The forcing attributed to increasing greenhouse gases in the next few decades is +0.6 W m^{-2} $decade^{-1}$, equivalent in magnitude to a change of -0.002 $decade^{-1}$ in global albedo.
- To constrain cloud feedback to 50%, a stability of **0.3 Wm^{-2} $decade^{-1}$** is required (**0.001 $decade^{-1}$ in global albedo**).

Observing the Earth's Global Radiation Budget

All methods that attempt to observe the Earth's radiation budget suffer from errors due to one or more of the following:

- Instrument calibration (absolute and relative)
- Spectral sampling
- Spatial sampling
- Angle sampling
- Temporal sampling

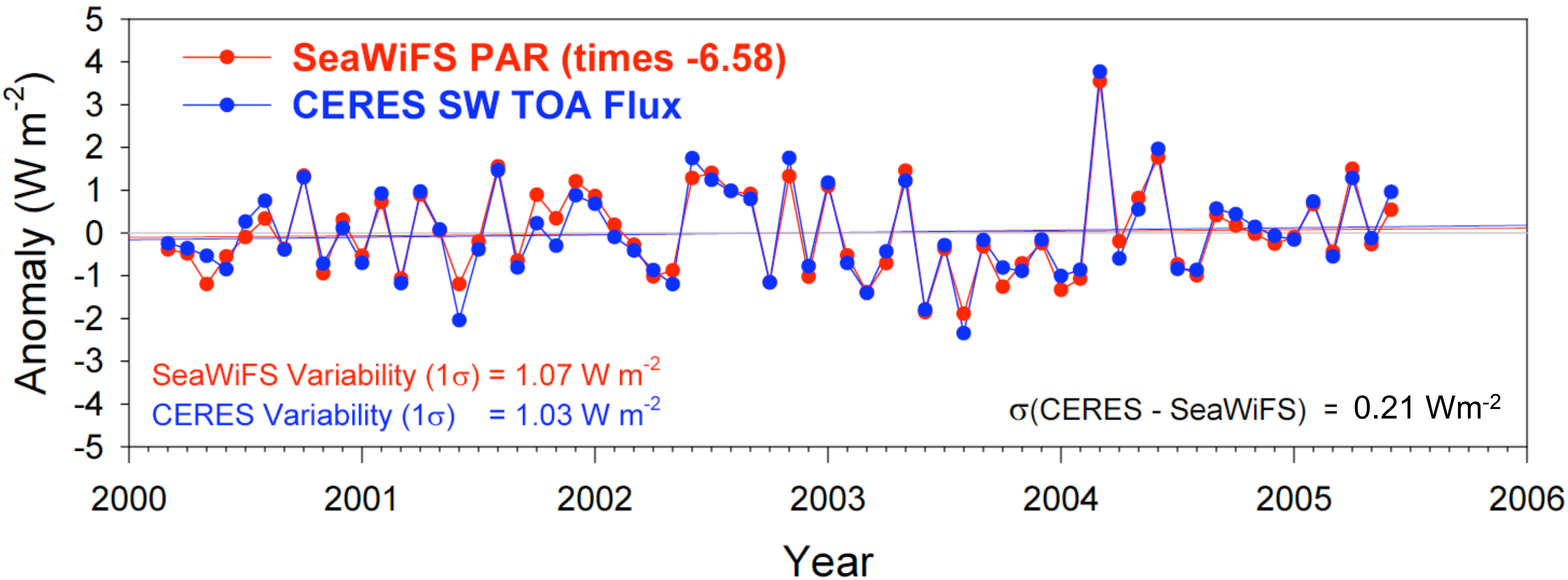
CERES Measurements



- 5 Instruments on 3 Satellites (TRMM, Terra, Aqua) for diurnal and angular sampling.
- 3 Channels per instrument:
  - <u>Shortwave</u> (0.2-4.0 μm) – Reflected solar radiation
  - <u>Total</u> (0.2-100 μm) – Earth emitted radiation by subtracting SW
  - <u>Window</u> (8-12 μm) – Thermal infrared emission

- Global coverage each day (Terra and Aqua)
- Coincident Cloud and Aerosol Properties from MODIS/VIRS
- CERES Aqua in Formation with CALIPSO and CloudSat
- 7 years of CERES Terra; 4.5 years CERES Aqua

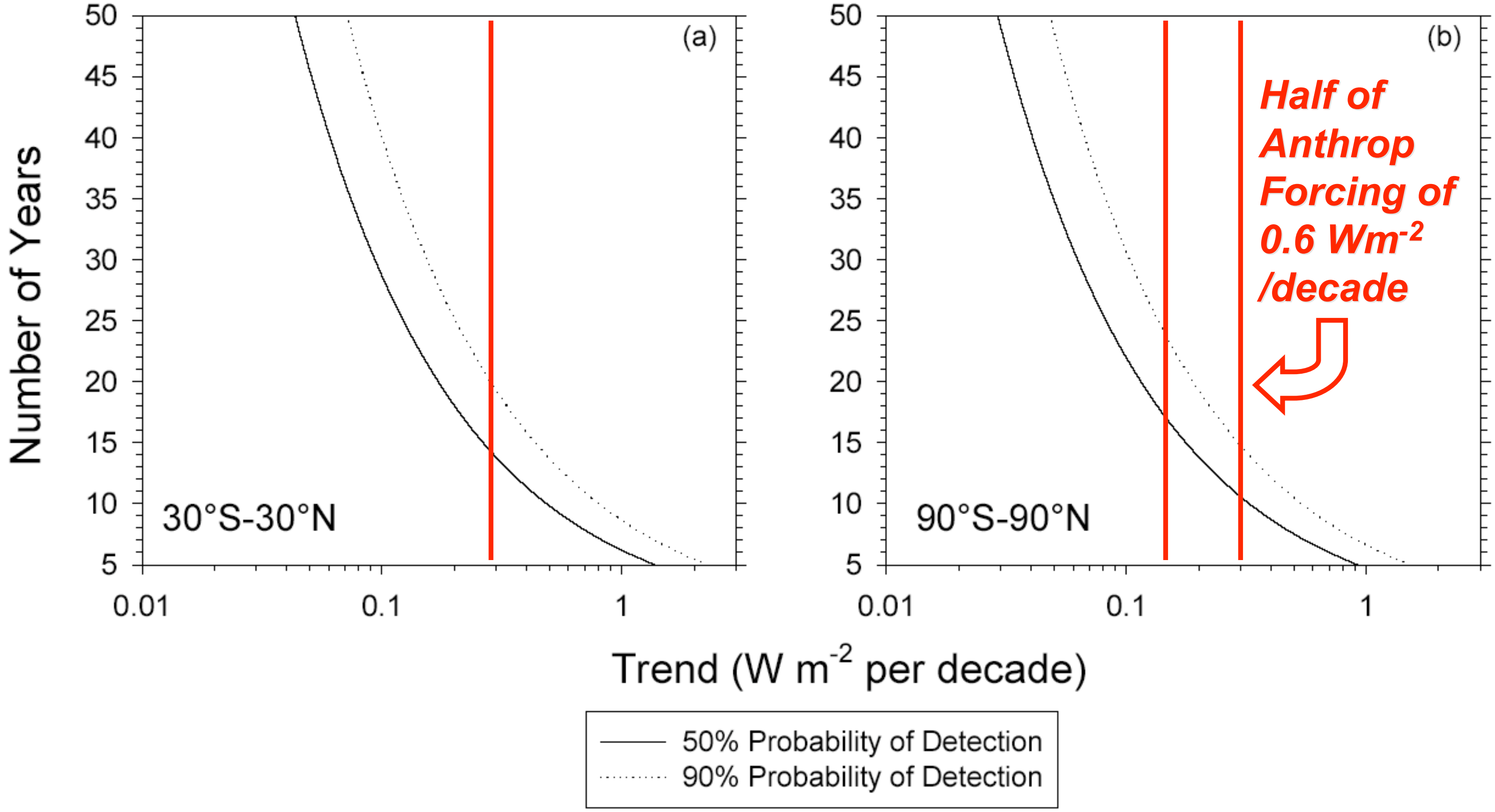
SeaWiFS PAR and CERES FM1 Ed2B_rev1 SW TOA Flux Anomaly (Ocean; 30°S-30°N)



Shows consistent calibration stability at < 0.3 Wm^{-2} per decade (95% conf)
Unfortunately only works for tropical mean ocean (nband vs bband issues)
Regional trends differ by +2 to -5 Wm^{-2}/decade SeaWiFS vs CERES

Loeb et al. 2007, J. Climate

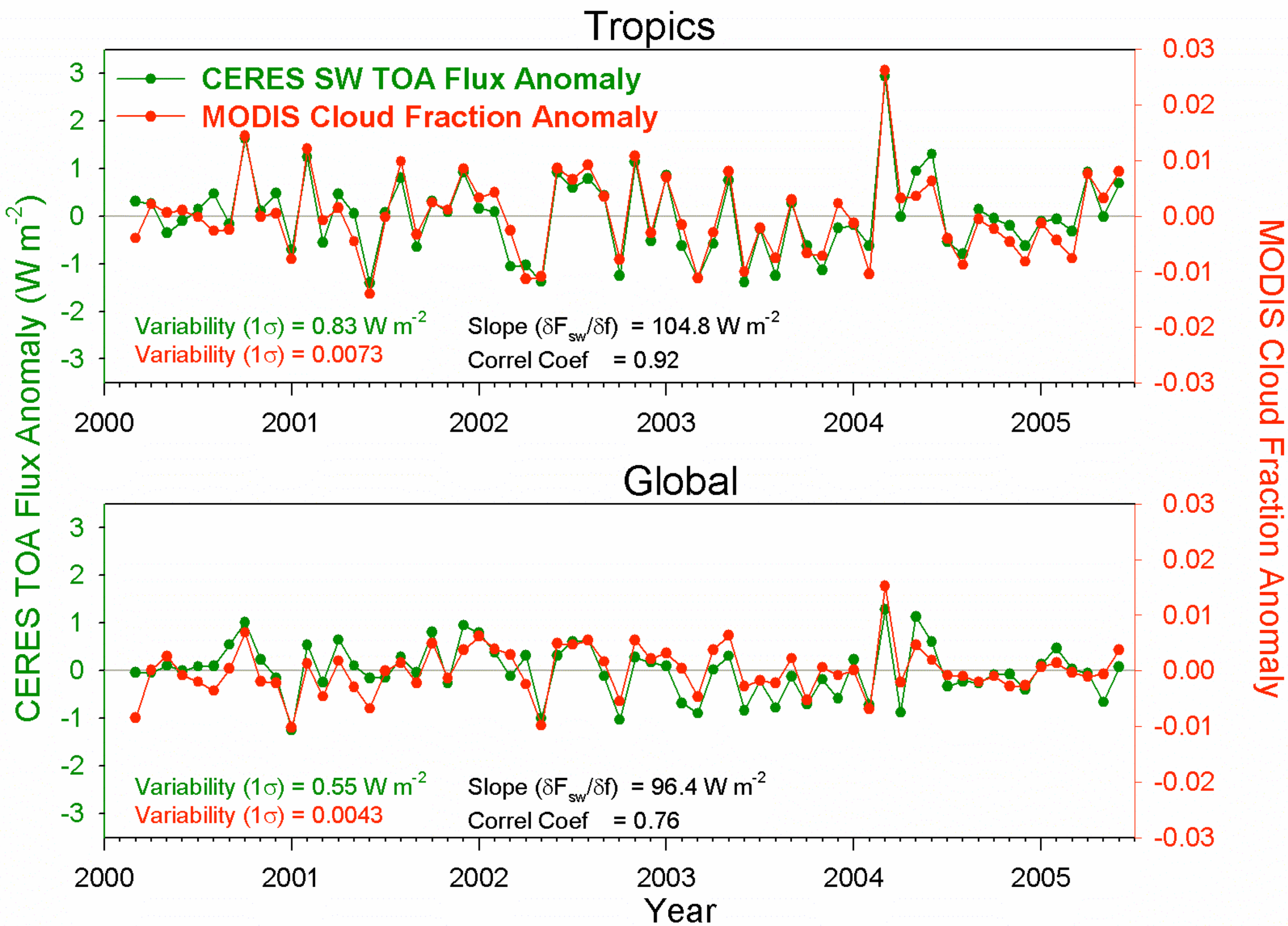
Using CERES to Determine Length of Climate Data Record Needed to Constrain Cloud Feedback



Given climate variability, 15 to 20 years is required to first detect climate trends at cloud feedback level with 90% confidence, and 18 to 25 years to constrain to +/- 25% in climate sensitivity

Loeb et al. 2007, J. Climate

CERES Shortwave TOA Reflected Flux Changes: Ties to Changing Cloud Fraction

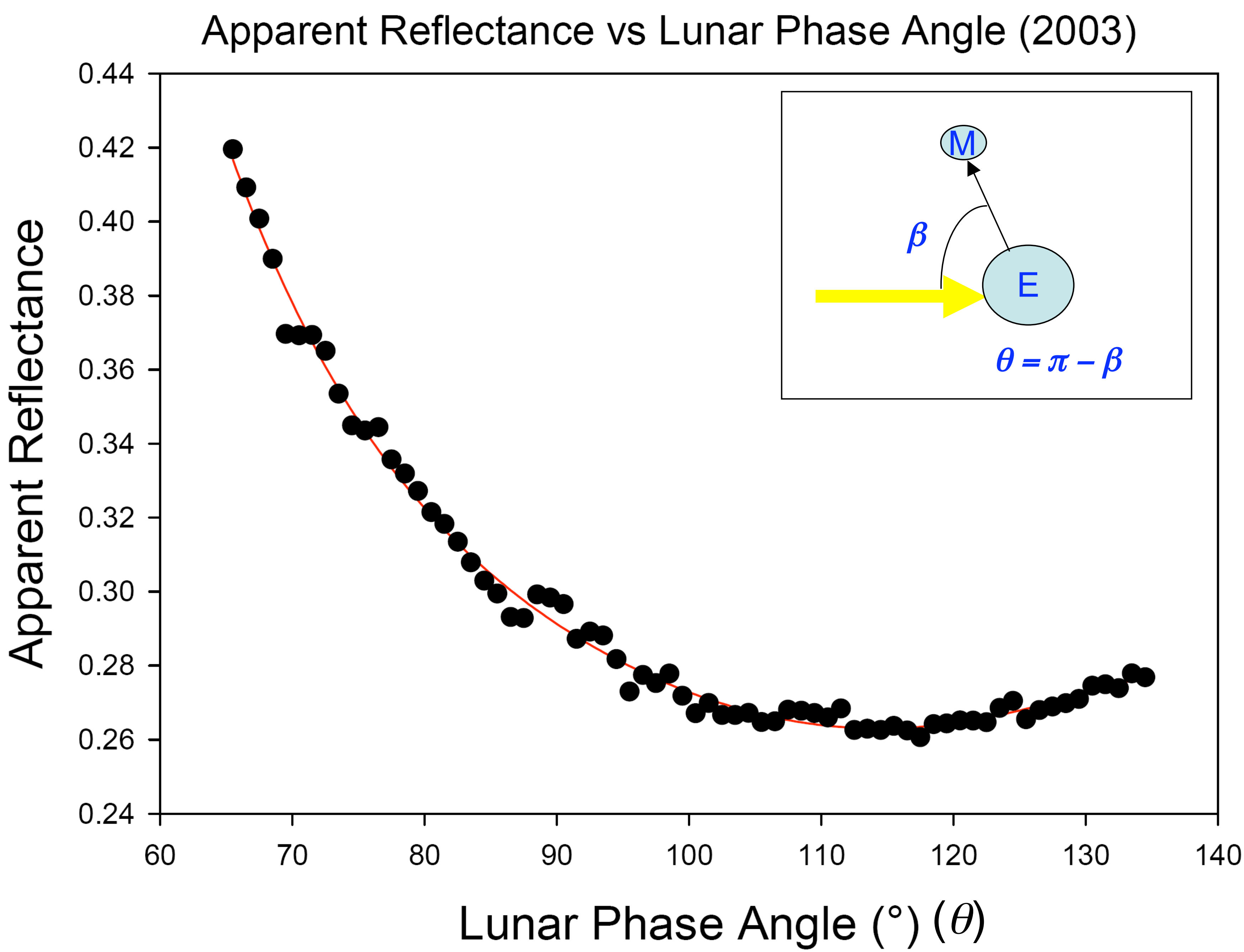


Unscrambling climate signal cause and effect requires complete parameter set at climate accuracy, e.g. for forcing/response energetics: radiation, aerosol, cloud, land, snow/ice, temperature, humidity, precipitation

Loeb et al. 2007 GRL

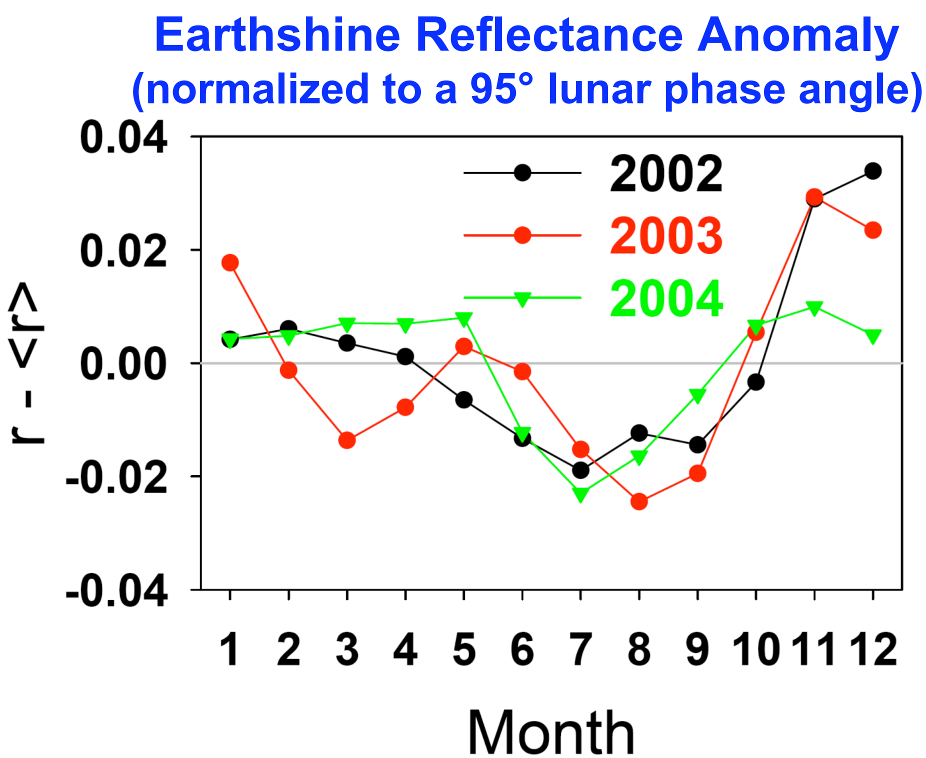
Earthshine Simulations Using CERES

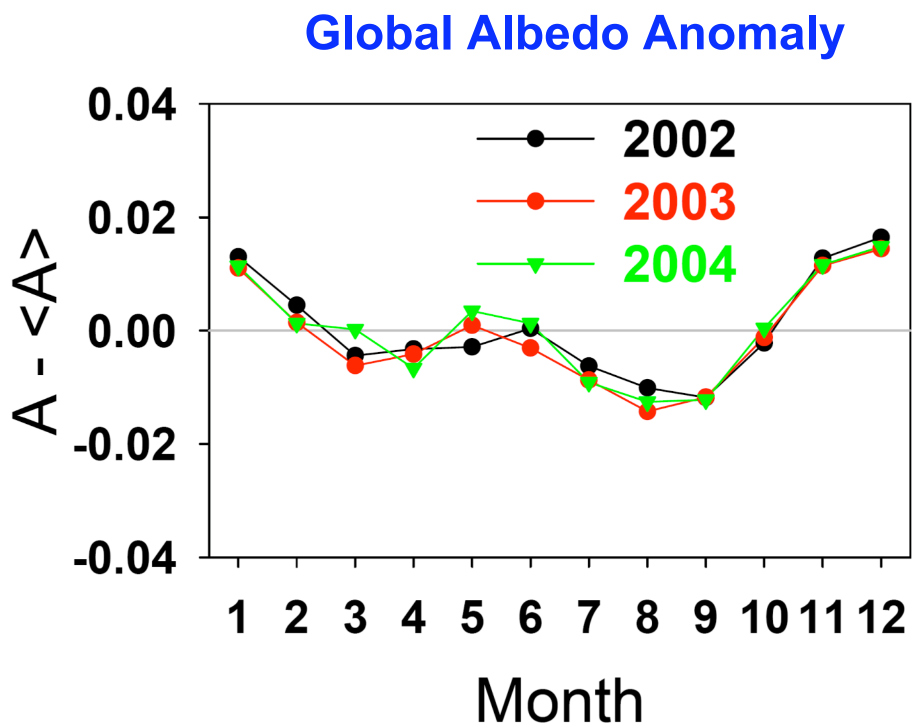
- Simulate the Earth's reflectance as it would appear from an observer on the moon viewing Earthshine.
- Assuming no changes in scene properties between the CERES and Earthshine measurement times, simulate the reflectance contributions from all points on the Earth that contribute to Earthshine:
  - Use the CERES ADMs to transform the observed reflectance at the CERES viewing geometry to that corresponding to the sun-earth-moon viewing geometry at the Earthshine observation time.
  - Integrate the reflectances over the lunar viewing geometry to determine the total Earthshine reflectance intercepted by the moon.
  - Only observations with a lunar phase angle between 65° and 135 ° are considered (consistent with ground-based Earthshine approach).
  - Reflectance at every time-step is adjusted to a common lunar phase angle of 95°.



Apparent Reflectance vs Lunar Phase Angle (2003)
0.44
0.42
0.40
0.38
0.36
0.34
0.32
0.30
0.28
0.26
0.24
Apparent Reflectance
60
70
80
90
100
110
120
130
140
Lunar Phase Angle (°) (θ)
M
β
E
θ = π − β

Seasonal Variation in Simulated Earthshine Reflectance and CERES Global Albedo

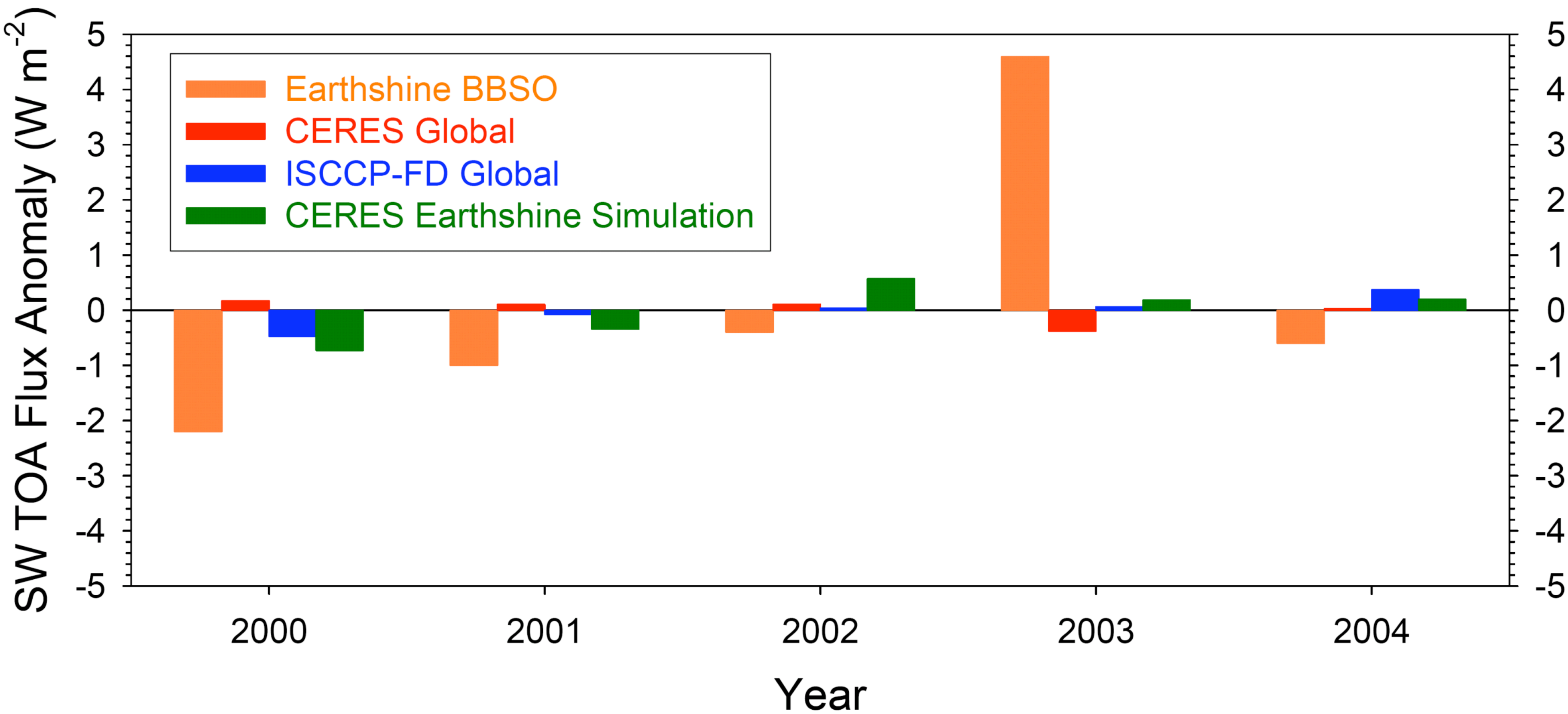




- While a seasonal cycle in Earthshine reflectance is apparent (left), it is highly variable and out-of-phase from one year to the next.

Loeb et al. 2007 GRL

Annual Mean Global SW TOA Flux Anomaly



- **The year-to-year variability is typically 4-5 times larger for simulated Earthshine reflectance compared to CERES albedo.**

- **Year-to-year variability in BBSO Earthshine reflectance is a factor of 10 larger than CERES global albedo**

Loeb et al. 2007 GRL

Sampling Issues

Instrument calibration (absolute and relative)

- Station on the moon offers advantage of regular calibration monitoring. However, dust-contamination is a concern.

Spectral sampling

- Would require broadband radiation measurements.

Angle sampling

- Restricted by sun-earth-moon geometry. Cannot measure reflectances from all angles that contribute to albedo.

Spatial sampling

- Need global coverage each day

Temporal sampling

- By restricting Earthshine to a certain lunar phase angle range, cannot get full temporal sampling needed (~15/31 days).

Earthshine approach is unlikely to achieve 0.3 Wm^{-2} $decade^{-1}$ stability requirement needed for climate science.

Combining Sun-Synchronous and Geostationary Measurements to Capture Full Diurnal Cycle of Clouds and Radiation