The Future of Radiation Budget Observations for Climate Change

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14th Conference on Atmospheric Radiation

Boston, July 8, 2014

Tony Slingo on Climate Research, 1989

One of Tony's concerns is that current interest in global climate change might backfire if research doesn't progress quickly enough.

"Governments want results," he says. "Politicians tend not to be interested in long-term research. What I think Needs doing now is more research, but that doesn't buy votes."

From NCAR Staff Notes interview with Tony Slingo, 1989

25 Years Later …

25 Years Later …

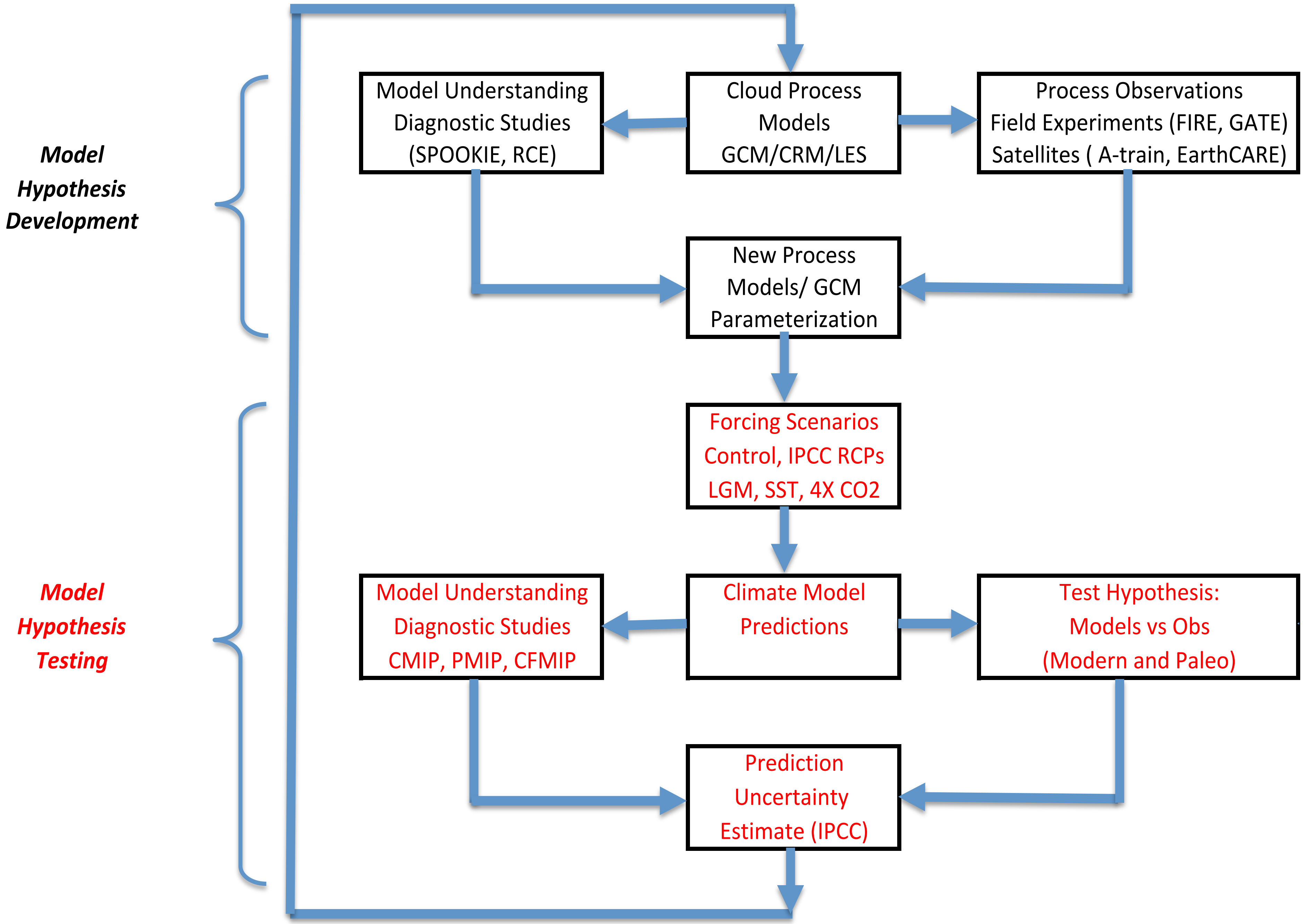
25 Years Later … More urgent, but …

- Lack of a climate observing system (vs. weather)
  - Climate is 10x the variables and 10x the accuracy of weather.

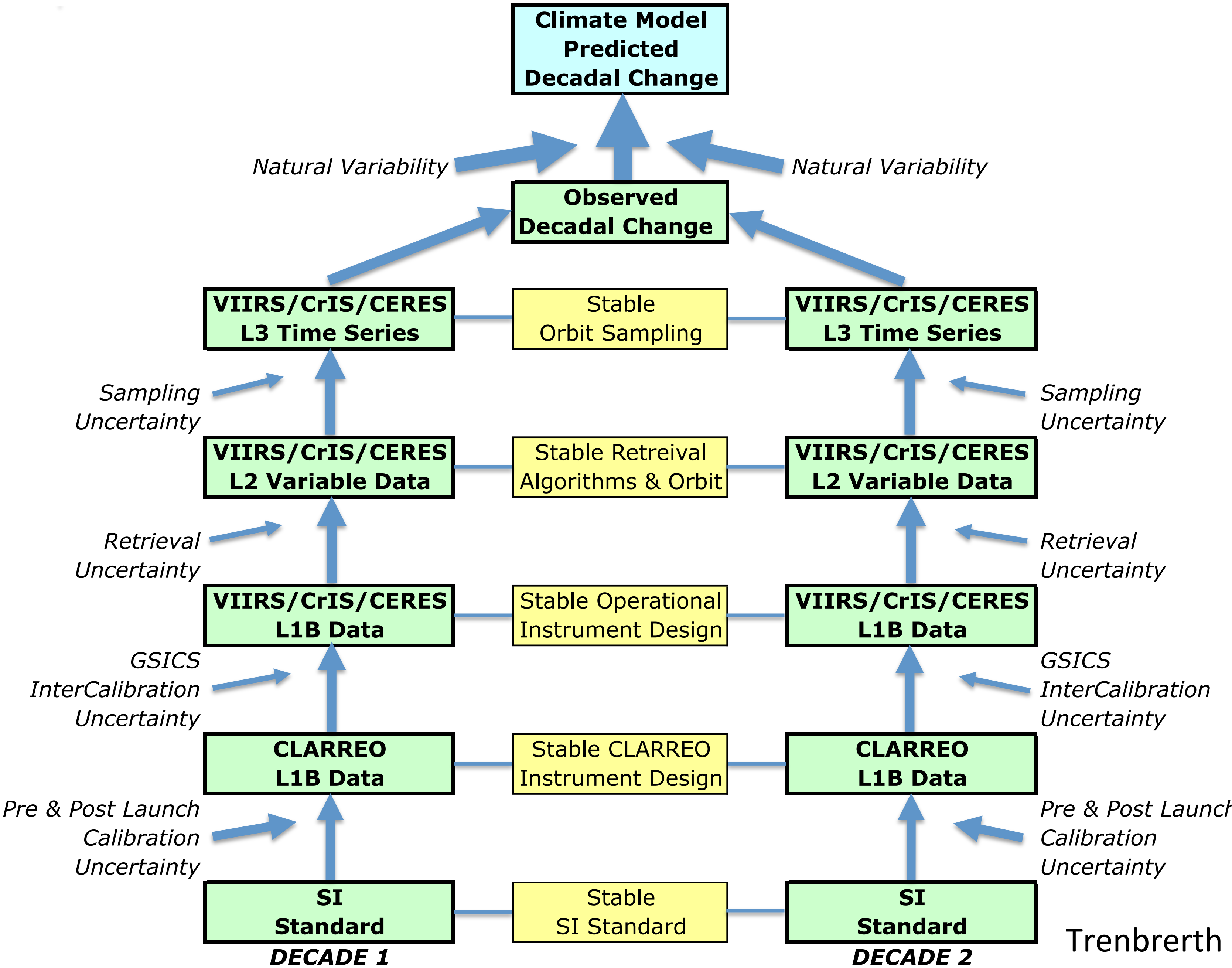
- Struggles to get sufficient resources for climate modeling

- Science questions typically qualitative not quantitative
  - Understand and explore vs rigorous hypothesis testing
  - Leads to intuitive “Seat of the Pants” requirements
  - After > 30 years of climate research: time to improve

- *What is the right amount to invest in climate science?*
  - Requires link of science to economics
  - Requires thinking outside narrow disciplines
  - Requires arguing for climate science, not our own science

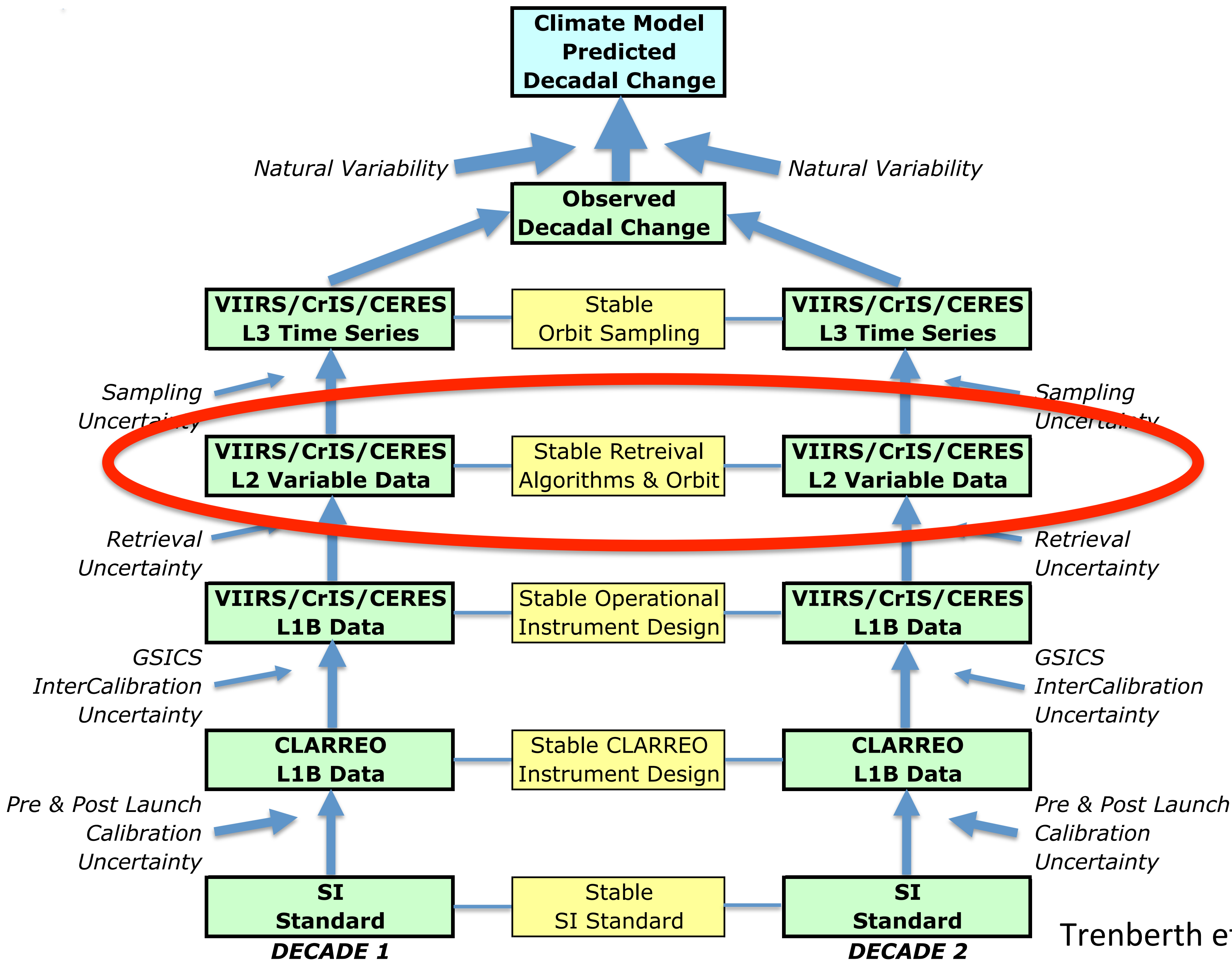

Model
Hypothesis
Development
Model Understanding
Diagnostic Studies
(SPOOKIE, RCE)
Cloud Process
Models
GCM/CRM/LES
Process Observations
Field Experiments (FIRE, GATE)
Satellites (A-train, EarthCARE)
New Process
Models/ GCM
Parameterization
Forcing Scenarios
Control, IPCC RCPs
LGM, SST, 4X CO2
Model
Hypothesis
Testing
Model Understanding
Diagnostic Studies
CMIP, PMIP, CFMIP
Climate Model
Predictions
Test Hypothesis:
Models vs Obs
(Modern and Paleo)
Prediction
Uncertainty
Estimate (IPCC)

Accuracy of Climate Change Observations & Predictions



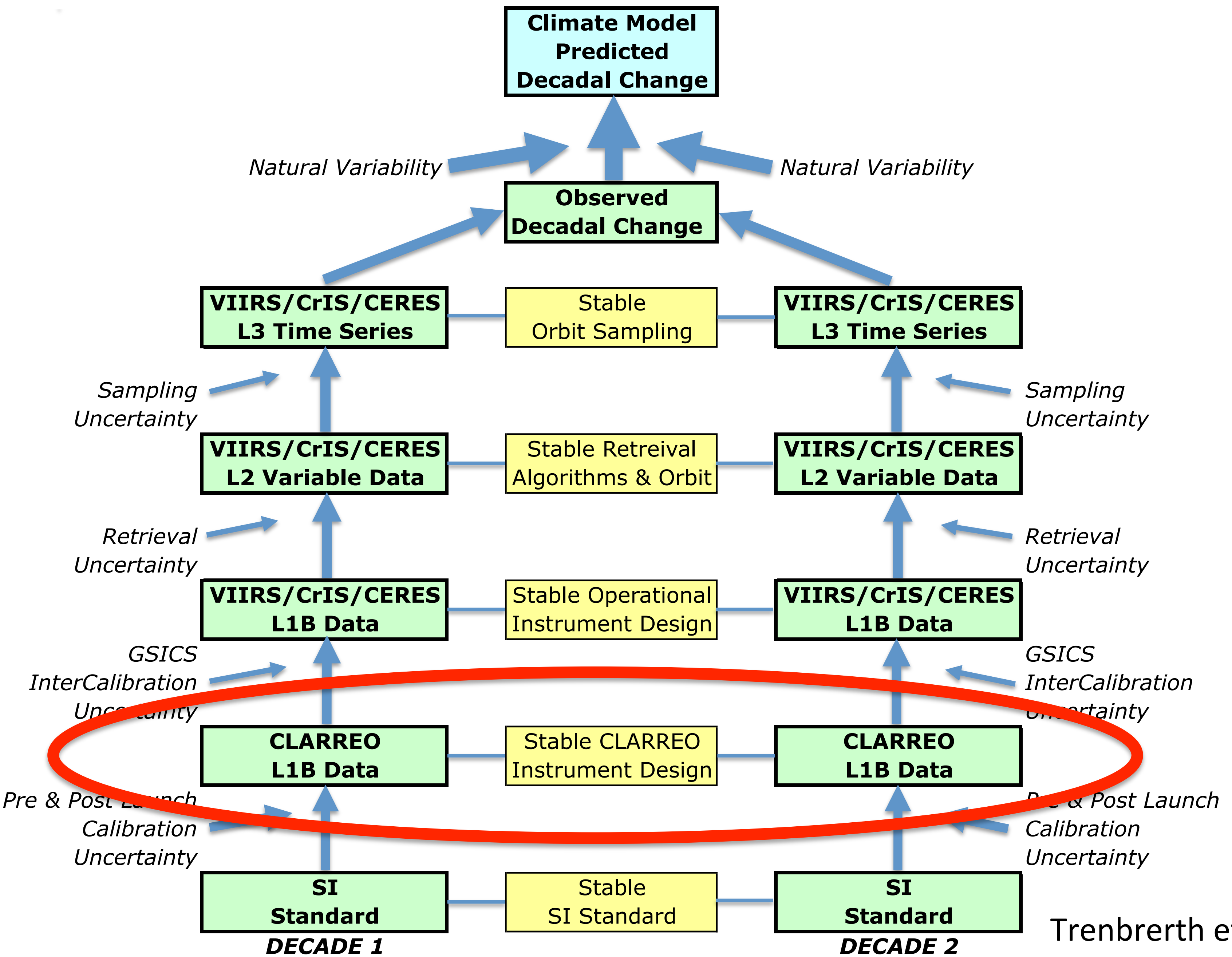
Trenbrerth et al. 2013

Accuracy of Climate Change Observations & Predictions



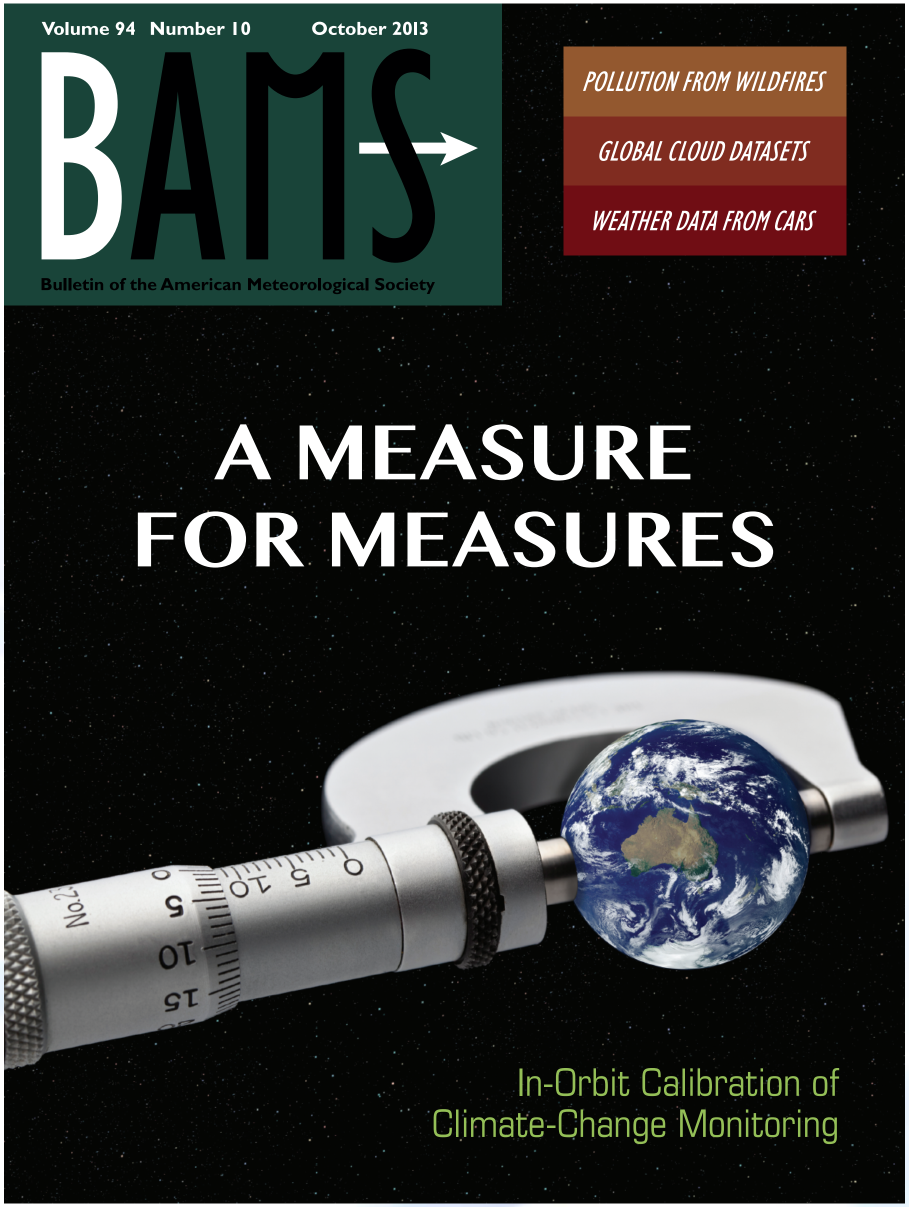
Trenberth et al. 2013

Accuracy of Climate Change Observations & Predictions



Trenbrerth et al. 2013

BAMS October, 2013



ACHIEVING CLIMATE CHANGE ABSOLUTE ACCURACY IN ORBIT

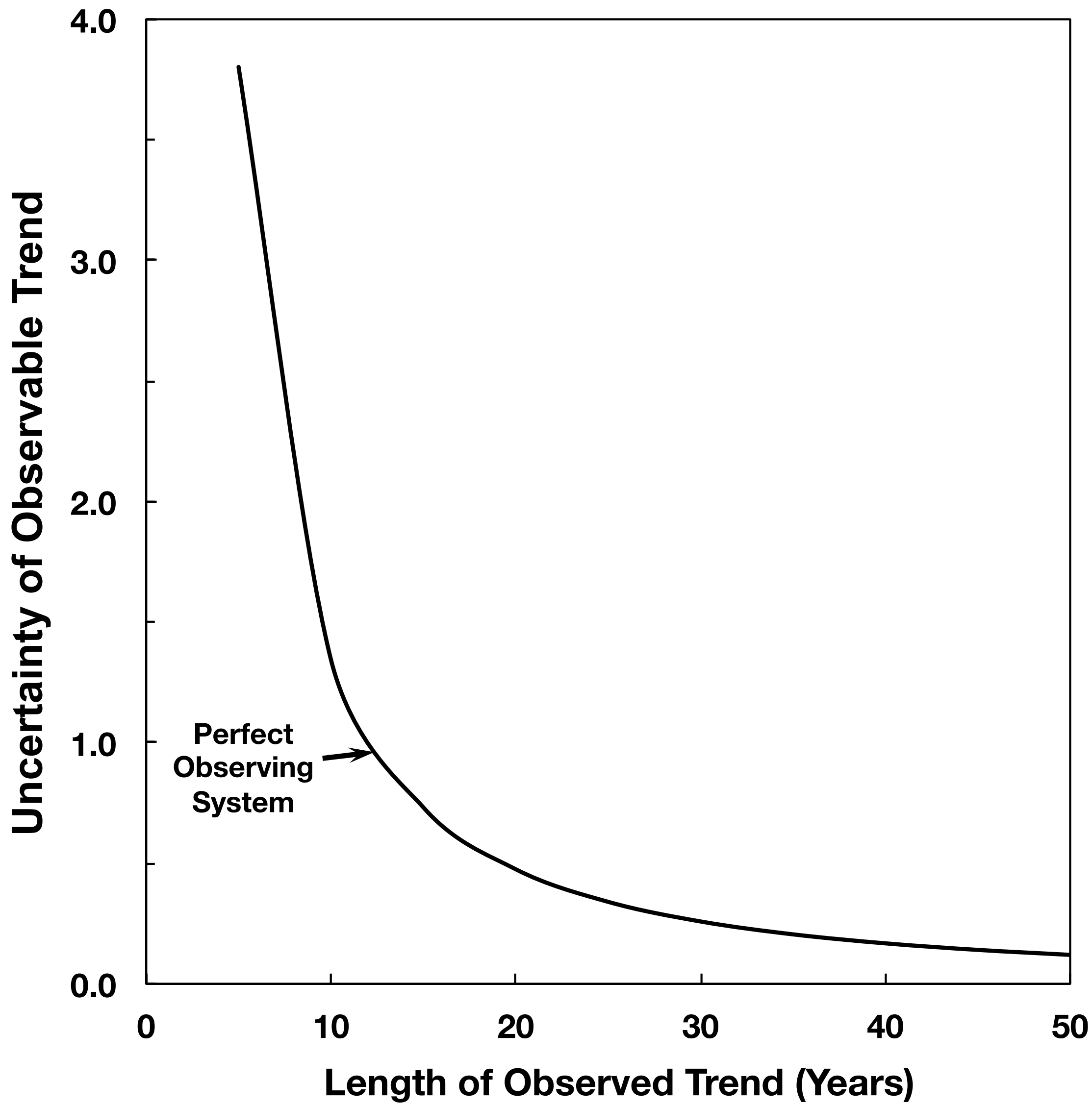
BY BRUCE A. WIELICKI, D. F. YOUNG, M. G. MLYNCZAK, K. J. THOME, S. LEROY, J. CORLISS, J. G. ANDERSON, C. O. AO, R. BANTGES, F. BEST, K. BOWMAN, H. BRINDLEY, J. J. BUTLER, W. COLLINS, J. A. DYKEMA, D. R. DOELLING, D. R. FELDMAN, N. FOX, X. HUANG, R. HOLZ, Y. HUANG, Z. JIN, D. JENNINGS, D. G. JOHNSON, K. JUCKS, S. KATO, D. B. KIRK-DAVIDOFF, R. KNUTESON, G. KOPP, D. P. KRATZ, X. LIU, C. LUKASHIN, A. J. MANNUCCI, N. PHOJANAMONGKOLKIJ, P. PILEWSKIE, V. RAMASWAMY, H. REVERCOMB, J. RICE, Y. ROBERTS, C. M. ROITHMAYR, F. ROSE, S. SANDFORD, E. L. SHIRLEY, W. L. SMITH SR., B. SODEN, P. W. SPETH, W. SUN, P. C. TAYLOR, D. TOBIN, AND X. XIONG

With its unprecedented accuracy, the Climate Absolute Radiance and Refractivity Observatory substantially shortens the time to detect the magnitude of climate change at the high confidence level that decision makers need.

THE CLARREO VISION FROM THE NATIONAL RESEARCH COUNCIL DECADAL SURVEY. A critical issue for climate change observations is that their absolute accuracy is insufficient to confidently observe decadal climate change signals (NRC 2007; Trenberth et al. 2013; Trenberth and Fasullo 2010; Ohring et al. 2005; Ohring 2007). Observing decadal climate change is critical to assessing the accuracy of climate model projections (Solomon et al. 2007; Masson and Knutti 2011; Stott and Kettleborough 2002) as well as to attributing climate change to various sources (Solomon et al. 2007). Sound policymaking requires high confidence in climate predictions verified against decadal change observations with rigorously known accuracy. The need to improve satellite data accuracy has been expressed in ▶

Detail of CLARREO (red orbit track) obtaining matched data to serve as reference intercalibration for instruments on a polar orbiting weather satellite (green track). For more information see Fig. 6.

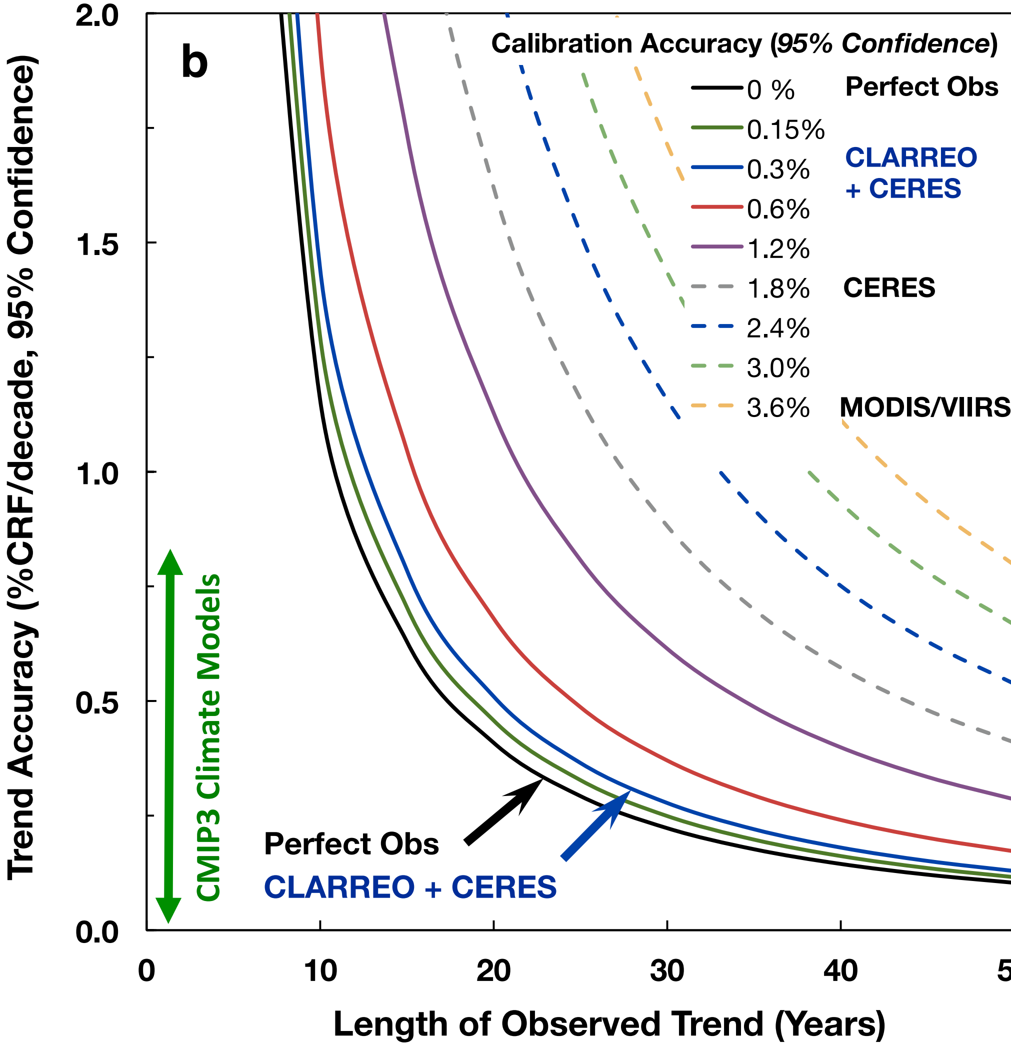
Accuracy Requirements of the Climate Observing System



The length of time required to detect a climate trend caused by human activities is determined by:

- *Natural variability*
- *The magnitude of human driven climate change*
- *The accuracy of the observing system*

Reflected Solar Accuracy and Climate Trends



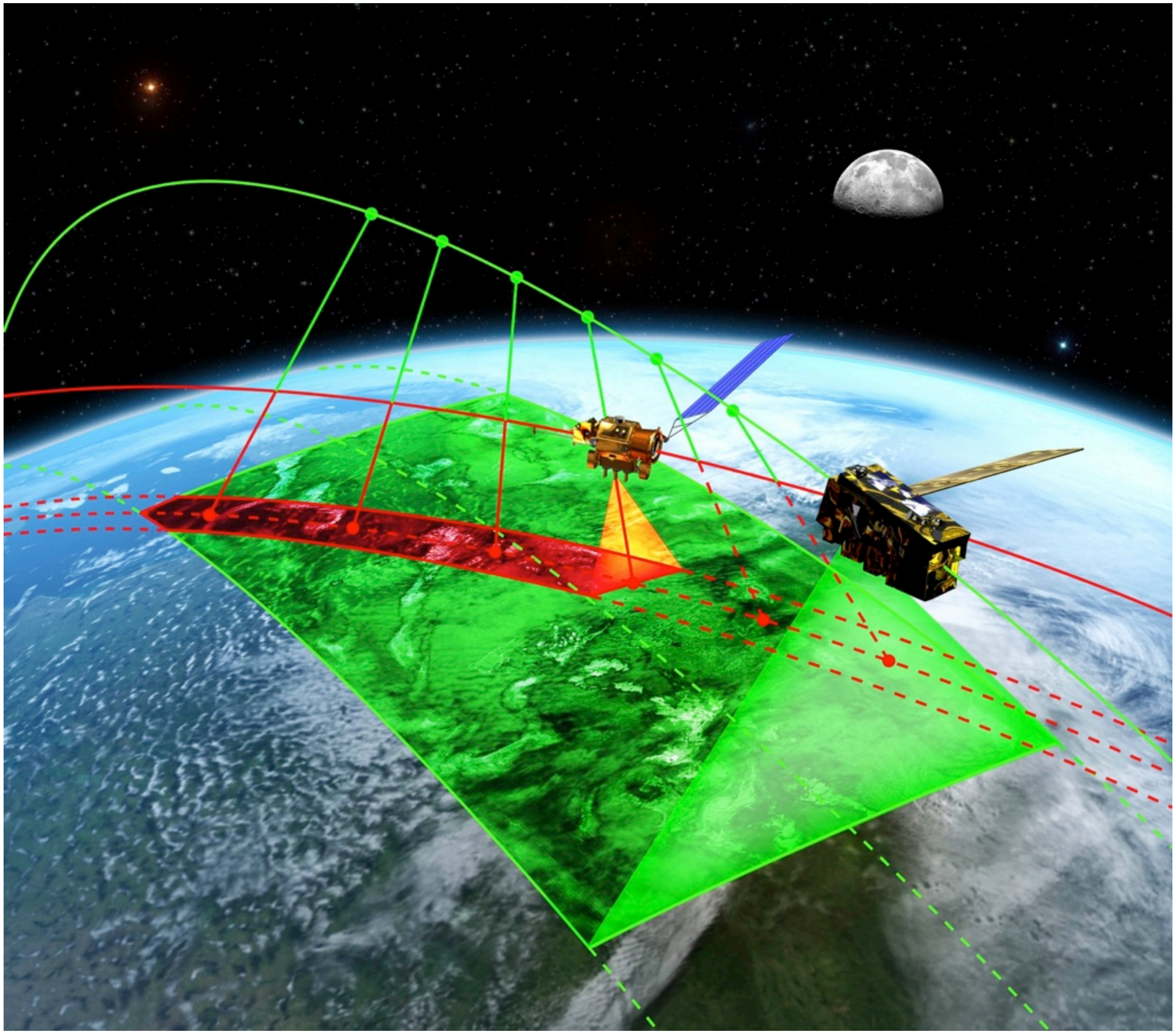
Climate Sensitivity Uncertainty is a factor of 4 (IPCC, 90% conf) which =*factor of 16 uncertainty in climate change economic impacts*

Climate Sensitivity Uncertainty = Cloud Feedback Uncertainty = Low Cloud Feedback = *Changes in SW CRF/decade (y-axis of figure)*

Higher Accuracy Observations = CLARREO reference intercal of CERES = *narrowed uncertainty 15 to 20 years earlier*

Wielicki et al. 2013, Bulletin of the American Meteorological Society

Calibration Reference Spectrometers (IR/RS) for Global Climate, Weather, Land, Ocean satellite instruments



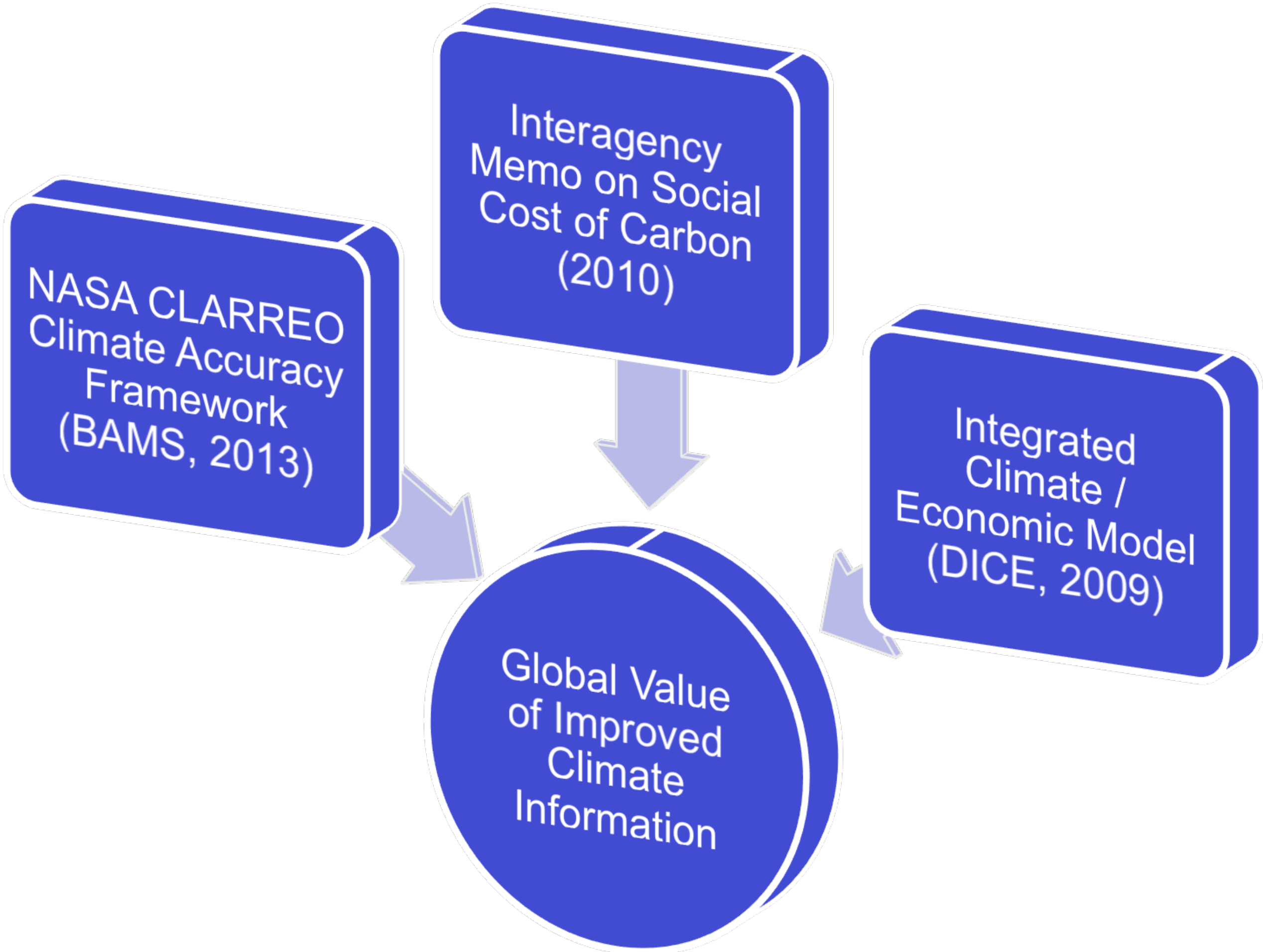
Provide spectral, angle, space, and time matched orbit crossing observations for all leo and geo orbits critical to support reference intercalibration

Endorsed by WMO & GSICS (letter to NASA HQ)

Calibrate Leo and Geo instruments relevant to climate sensitivity:
- JPSS: VIIRS, CrIS, CERES
- METOP: IASI, AVHRR
- Geostationary imagers/ sounders

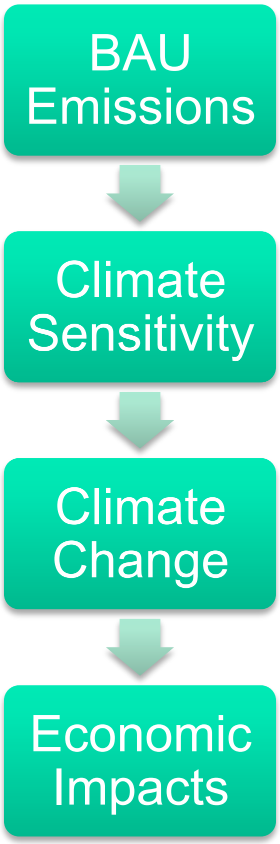
CLARREO Provides "NIST in Orbit": Transfer Spectrometers to SI Standards

What is the right amount to invest in climate science?

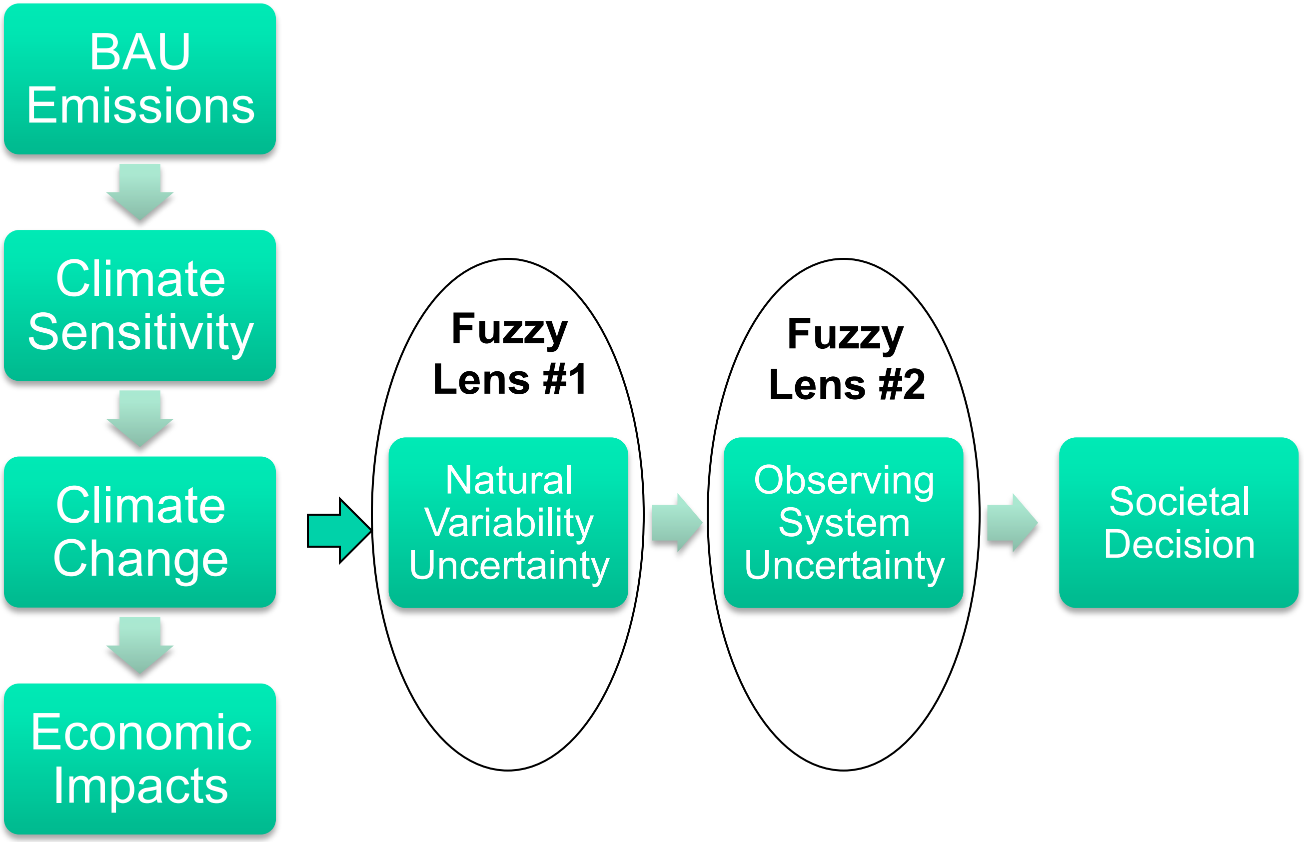


Cooke et al., Journal of Environment, Systems, and Decisions, July 2013, paper has open and free distribution online.

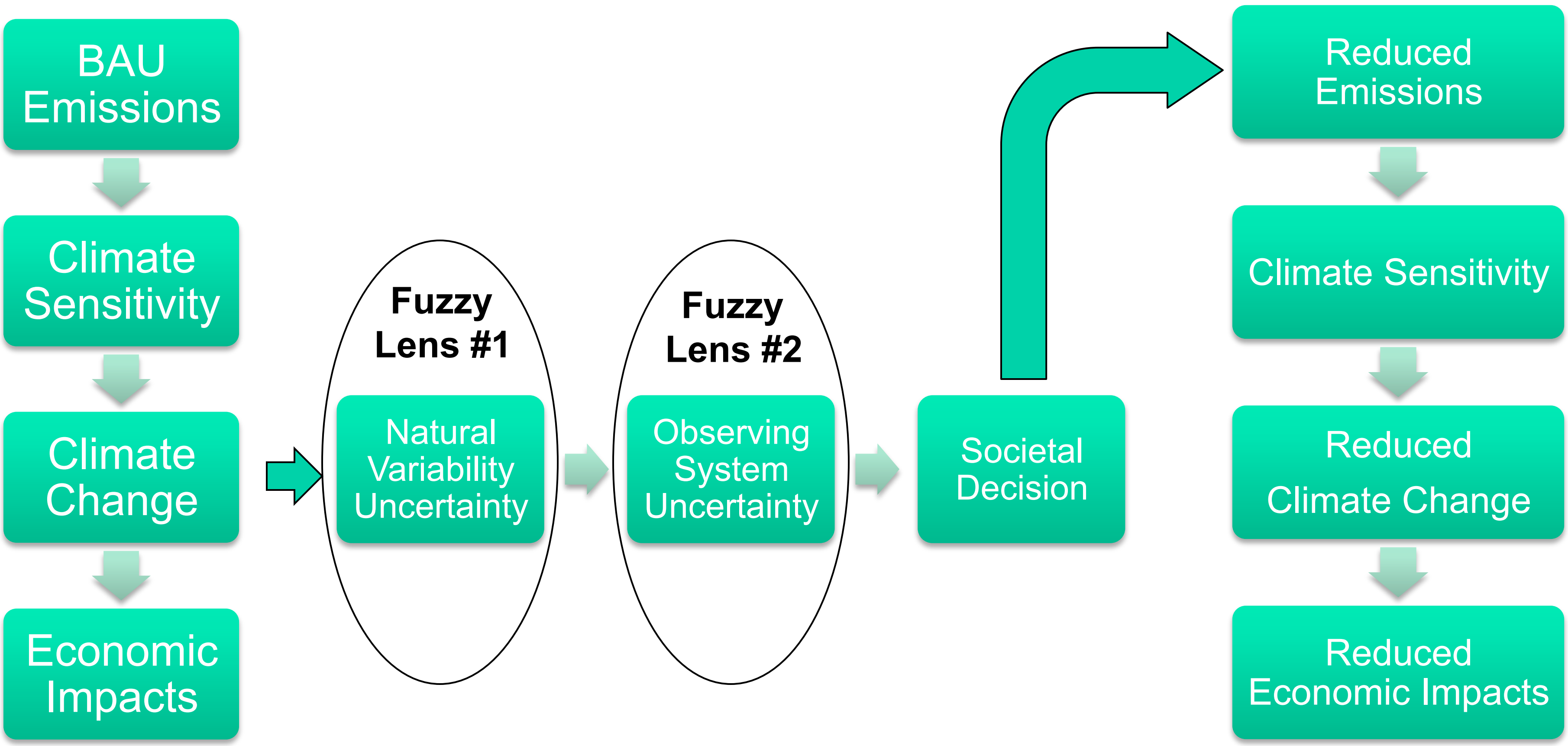
VOI Estimation Method



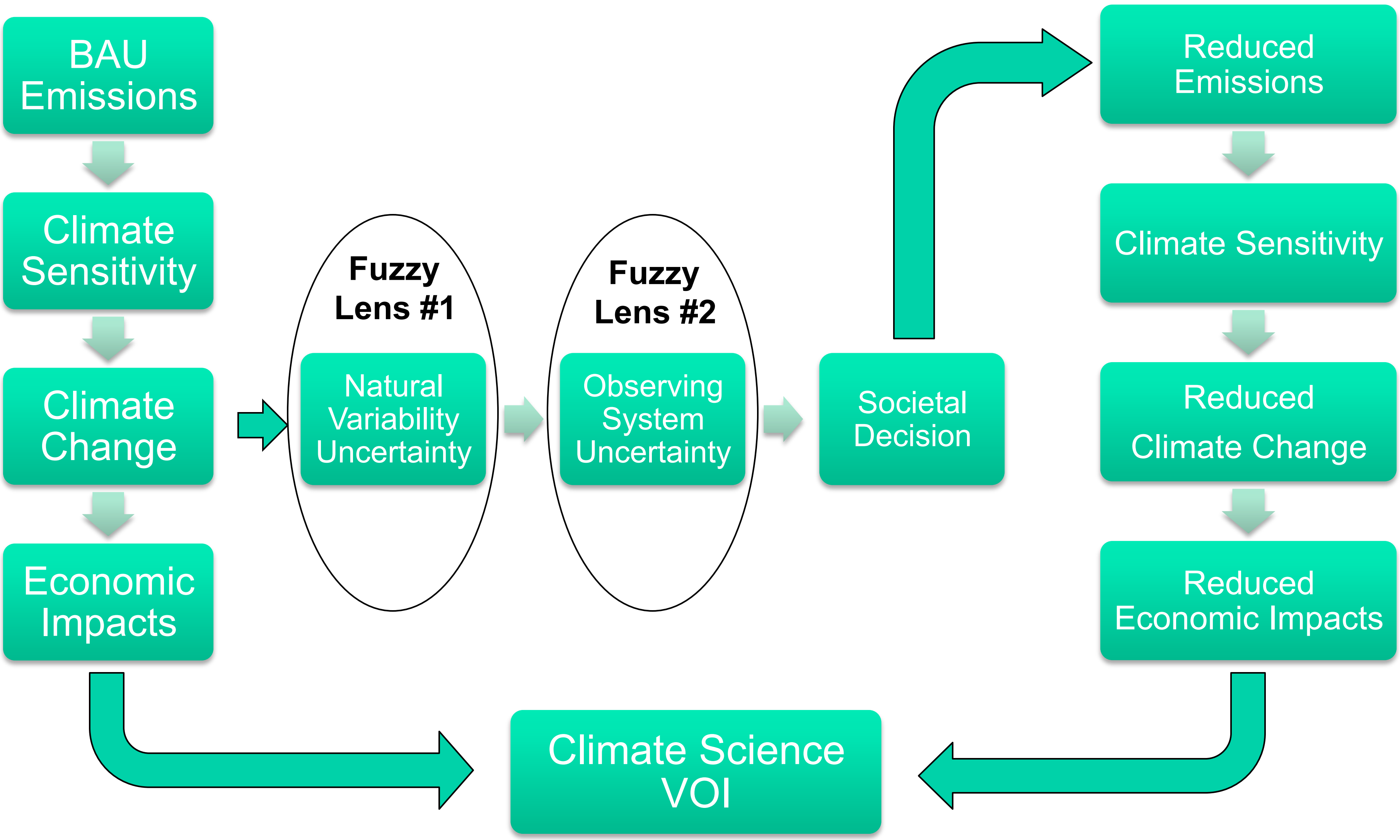
VOI Estimation Method



VOI Estimation Method



VOI Estimation Method



Economics: The Big Picture

- World GDP today ~ $70 Trillion US dollars
- Net Present Value (NPV)
  - compare a current investment to other investments that could have been made with the same resources
- Discount rate: 3%
  - 10 years: discount future value by factor of 1.3
  - 25 years: discount future value by factor of 2.1
  - 50 years: discount future value by factor of 4.4
  - 100 years: discount future value by factor of 21
- Business as usual climate damages in 2050 to 2100: 0.5% to 5% of GDP per year depending on climate sensitivity.

VOI vs. Discount Rate

Run 1000s of economic simulations and then average over the full IPCC distribution of possible climate sensitivity

Discount Rate	CLARREO/Improved Climate Observations VOI (US 2015 dollars, net present value)
2.5%	\$17.6 T
3%	\$11.7 T
5%	\$3.1 T

Additional Cost of an advanced climate observing system:
~ \$10B/yr worldwide
Cost for 30 years of such observations is ~ \$200 to \$250B in NPV
For a payback ratio of ~ \$50 per \$1 invested

Even at the highest discount rate, return on investment is very large

Suggested Directions

- Quantitative Science Questions
  - Hypothesis Tests not “improve and explore”, think Higgs Boson
- Observing System Simulation Experiments (OSSEs)
  - Improve observing system requirements
  - Move from “base state” to “climate change” climate model tests
  -
- Higher Accuracy Observations for Climate Change
  - See BAMS paper for example: broadly applicable
- Economic Value of Improved Climate Observations and Models
  - See J. Env. Sys. Decisions paper for example: broadly applicable
- Remember Tony Slingo’s Nature 1990 paper: a very early attempt at a climate “OSSE” for clouds and radiation: “Sensitivity of the Earth’s radiation budget to changes in low clouds”.

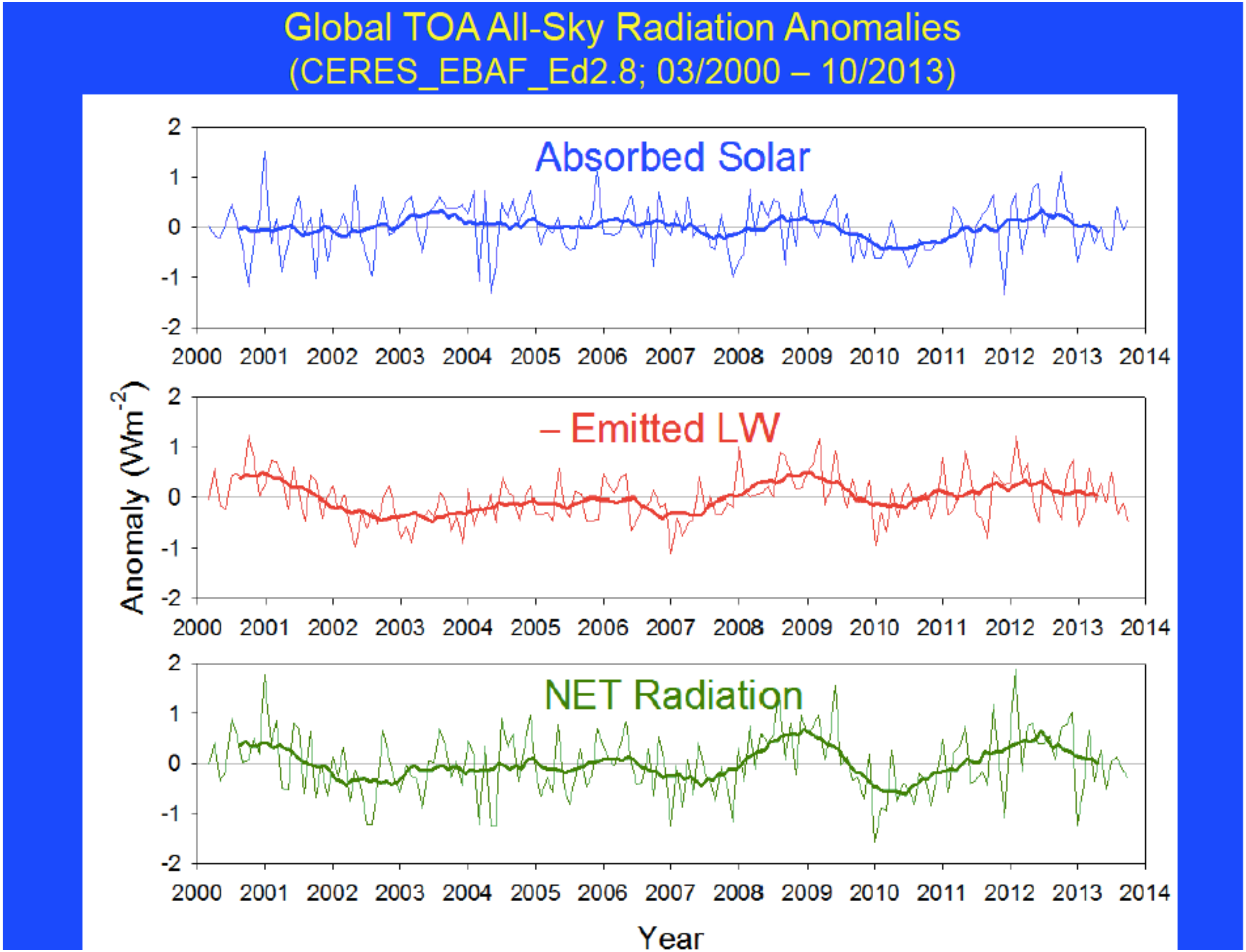
Backup Slides

Example Radiation Science Questions

- Can we narrow uncertainty in climate sensitivity by a factor of 3 below that in AR5?
- Can we narrow uncertainty in anthropogenic aerosol forcing by a factor of 3 below that in AR5?
- Can we close the surface energy balance (radiative/latent/sensible) from the current 15 W/m^2 to 5 W/m^2?
- Can we understand short term and long term fluctuations in the rate of warming and global heat budget to within 0.1 Wm^{-2} at global annual scales?
- Given large arctic changes: are clouds increasing or decreasing arctic change rates? (determine within 25% of snow/ice feedbacks)
- Spectrally verify the Far-Infrared water vapor greenhouse effect and water vapor feedback (accuracy consistent with question 1)

Reducing Uncertainty

- **Climate Science Uncertainty =>**
  - Climate Modeling Diagnostics & Hypothesis Tests (e.g. CMIP)
  - Process Modeling Diagnostics & Hypothesis Tests (CRM, LES)
  - *Model OSSEs for Observation Requirements (rarely done)*
  - *Field Experiments Observation Requirements (loosely done)*
  - Satellite Observation Process Retrieval Requirements (well done, focus on instantaneous retrieval needs and accuracy/ precision)
  - *Satellite Climate Change Observation Requirements (loosely done, ad hoc for calibration, sampling, retrieval algorithms)*
  - *Combined Satellite, Surface, In-situ, Aircraft Observation Requirements (typically adhoc discussions of what is currently available to cobble together)*
  - **Shortcomings are all symptoms of the lack of a planned rigorous climate observing system and the modeling to define its requirements**


Global TOA All-Sky Radiation Anomalies
(CERES_EBAF_Ed2.8; 03/2000 – 10/2013)
Absorbed Solar
– Emitted LW
NET Radiation
Anomaly (Wm-2)
Year
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014
2 1 0 -1 -2

Trend in Annual Mean CERES All-Sky TOA Flux by Latitude (2000-2012)

Reflected SW

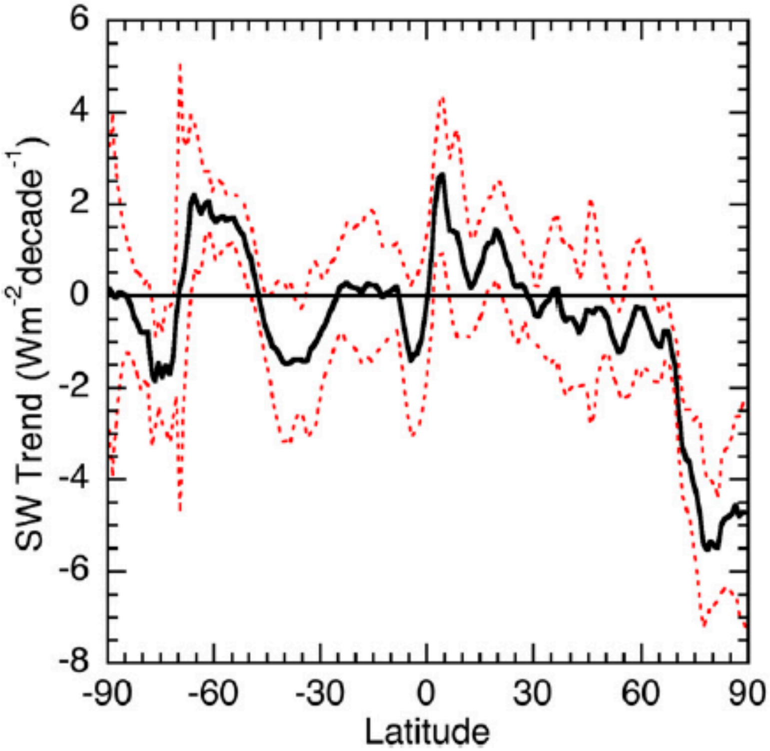


FIG. 1. Trend in reflected shortwave computed from annual-mean data and plotted as a function of latitude. The solid line shows the linear trend difference over the period 2000–12 for the zonal- and annual-mean reflected shortwave. The dashed lines show the 5% and 95% confidence levels.

Outgoing LW

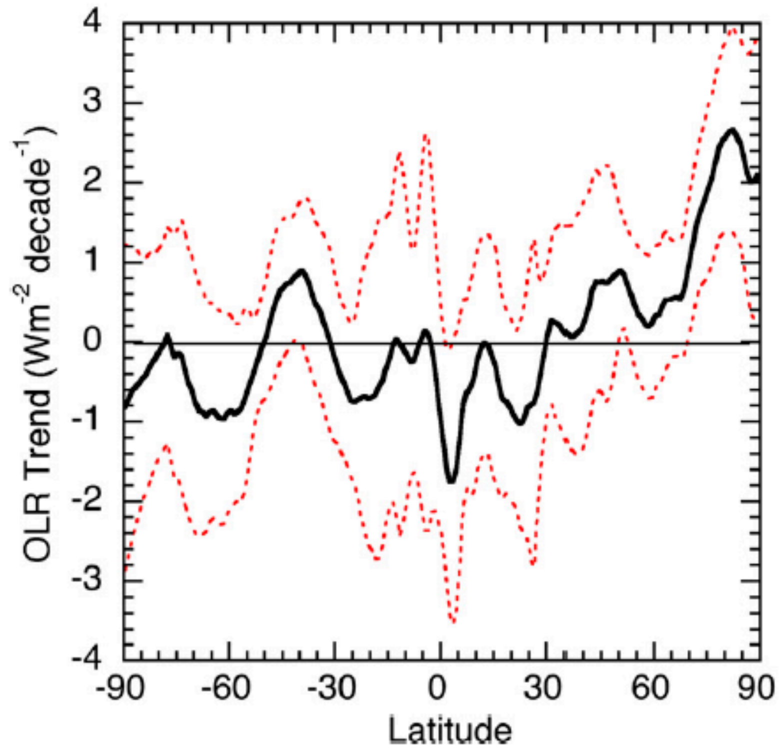
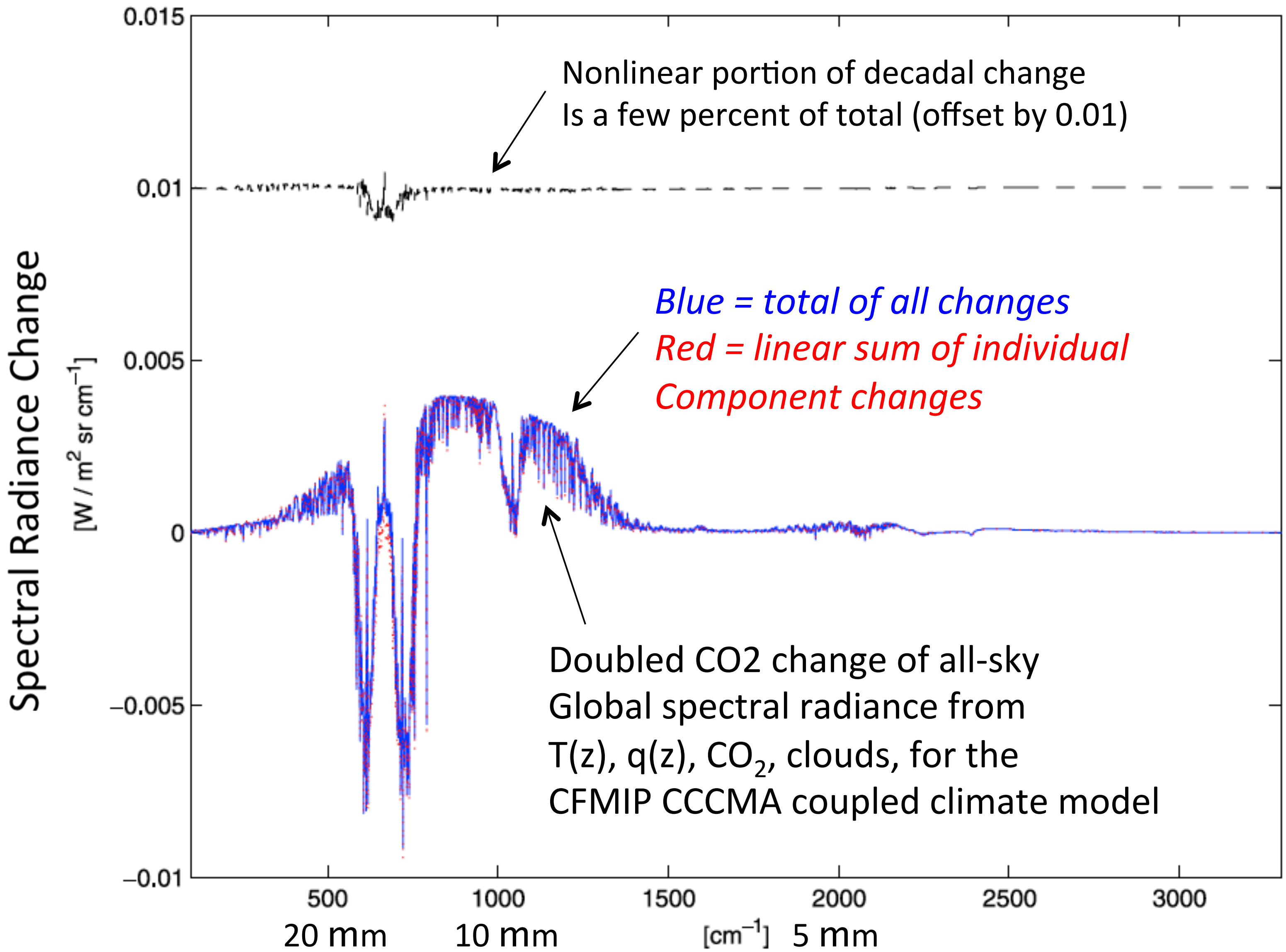


FIG. 11. As in Fig. 1, but for OLR.

Hartmann and Ceppi, JCLIM, 2014

Spectral Decadal Change is Linear



Huang et al. 2010

similar linearity found for decadal change of reflected solar spectra Jin et al., 2010

Let there be light.