Climate Sensitivity: the Role of Long Term Lidar and Radar Cloud Observations

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Roger Cooke, Resources for the Future

CALIPSO-CloudSat
Ten-Year Progress Assessment and Path Forward

June 8-10, 2016
Paris, France

Charney Report, 1979

Concerning Anthropogenic Climate Change:

"In order to address this question in its entirety, one would have to peer into the world of our grandchildren, the world of the twenty-first century."

Foreword by Vern Suomi

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35 Years Later …

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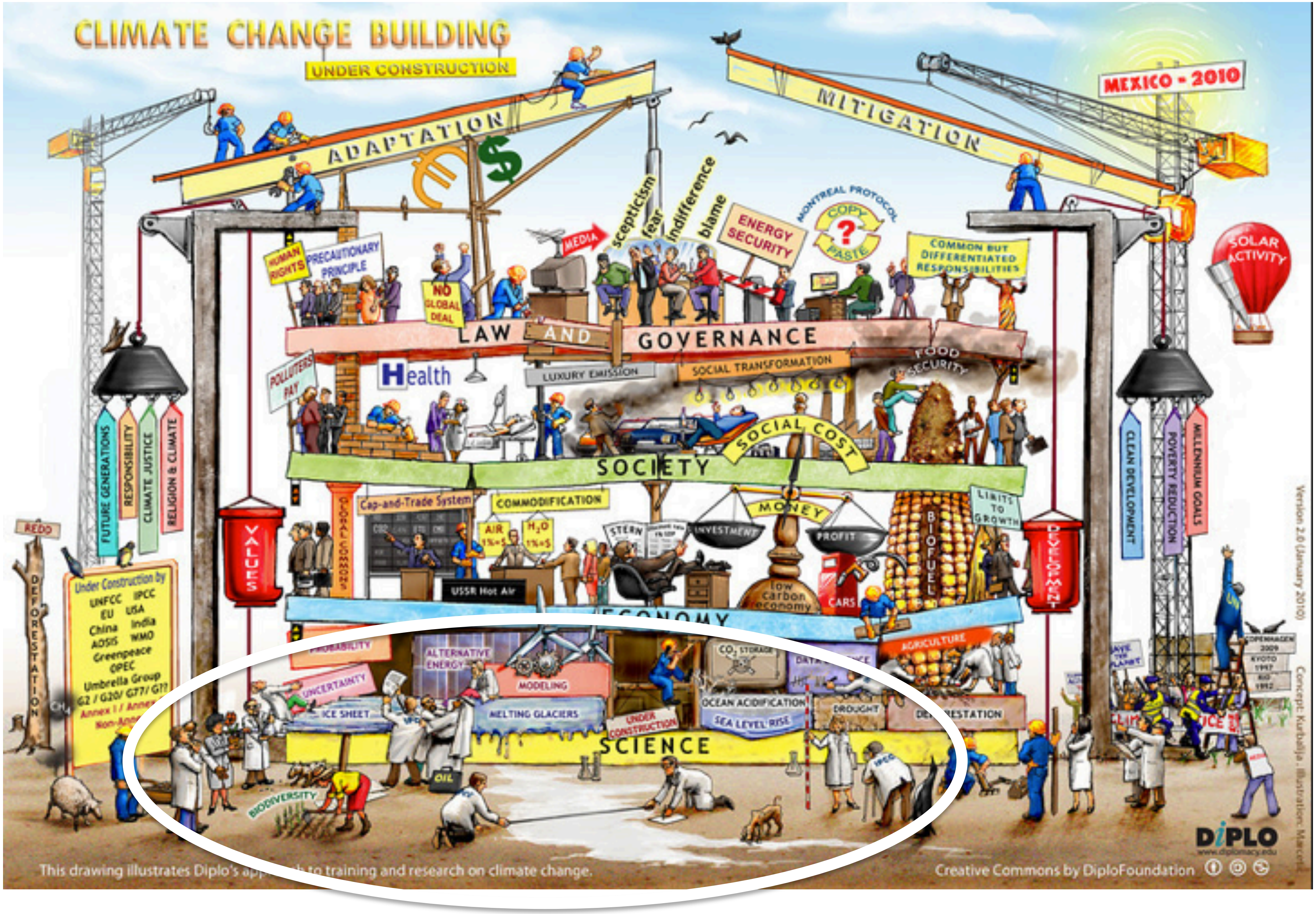
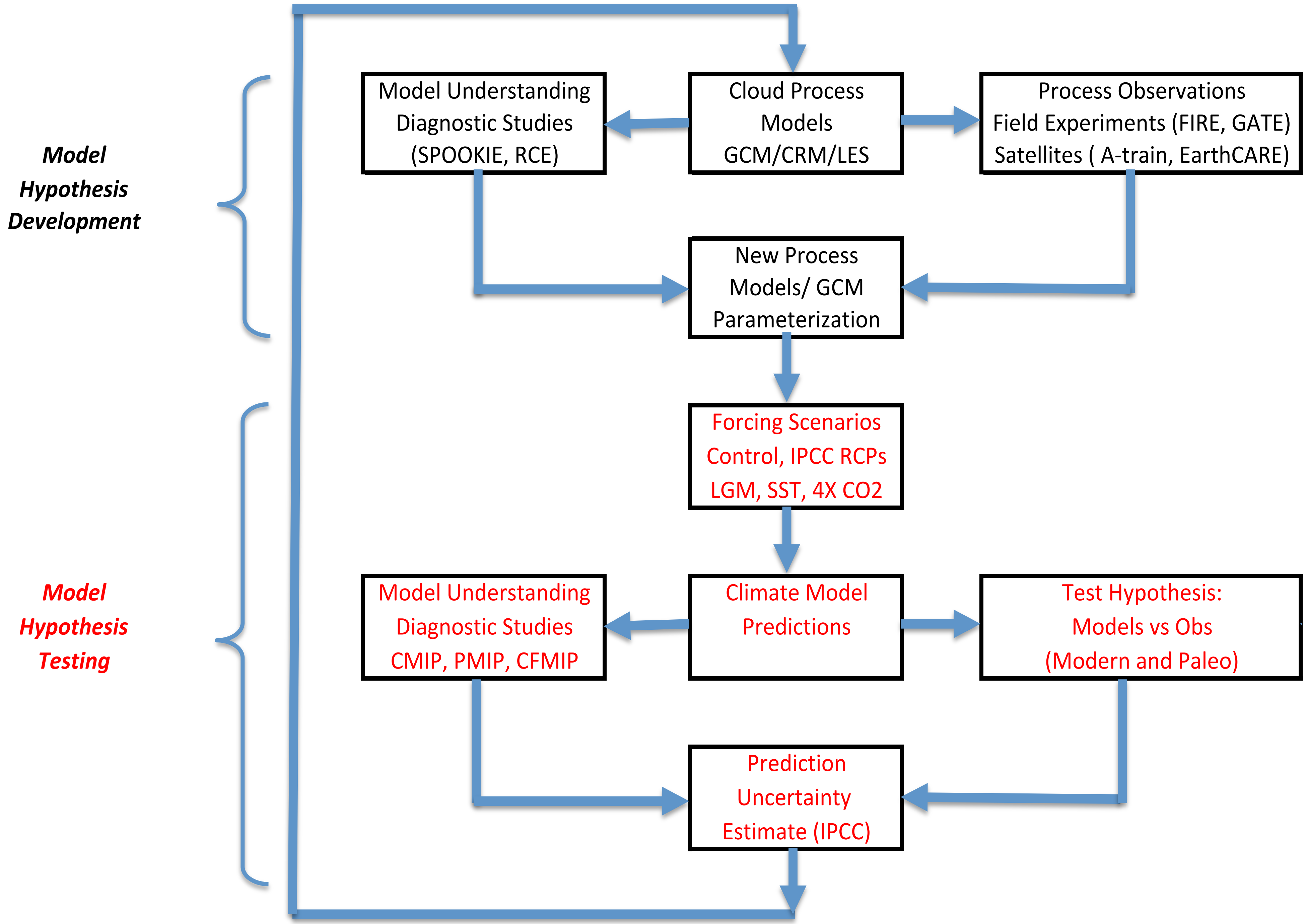


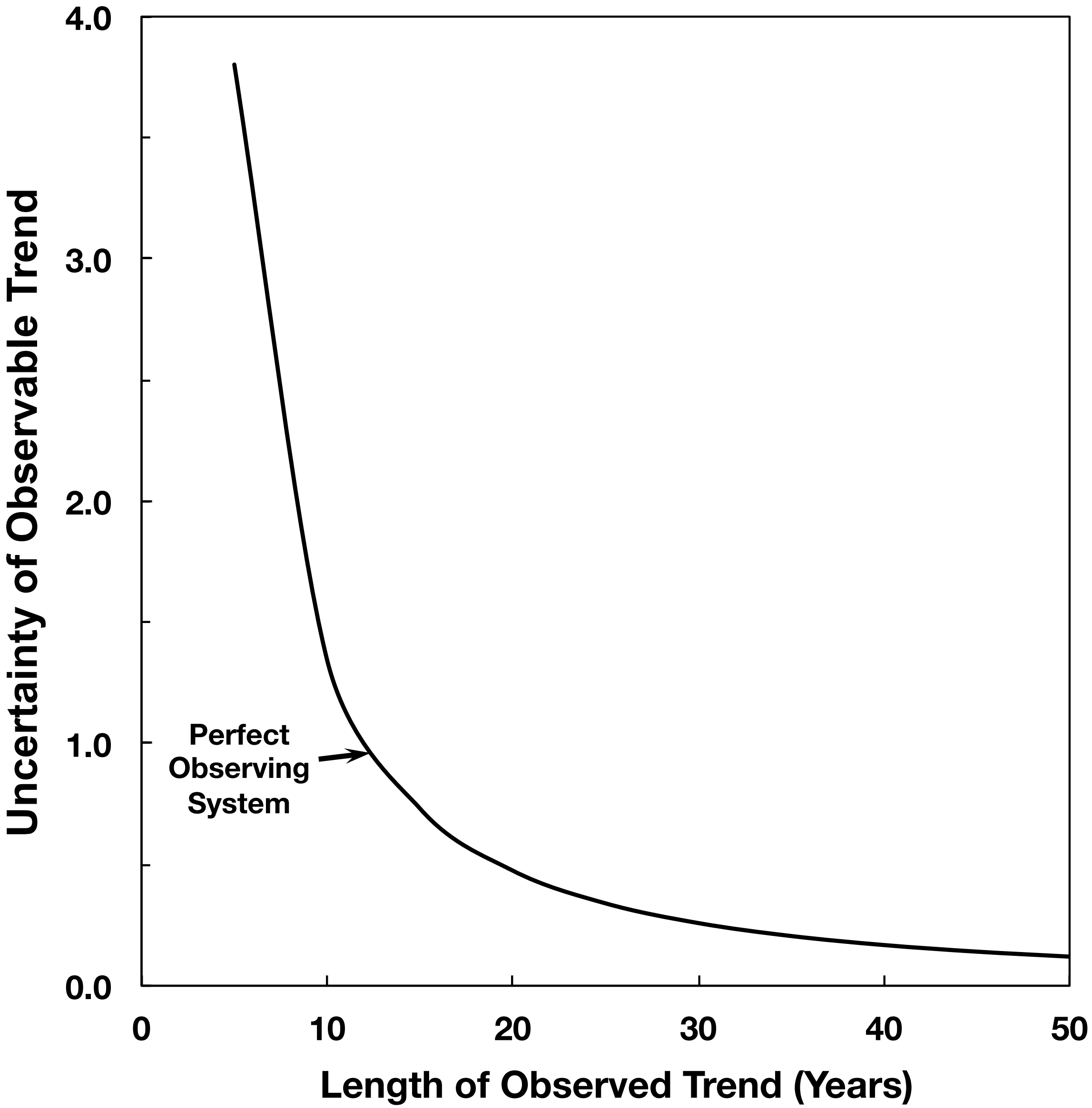
35 Years Later … More urgent, but …

- 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)

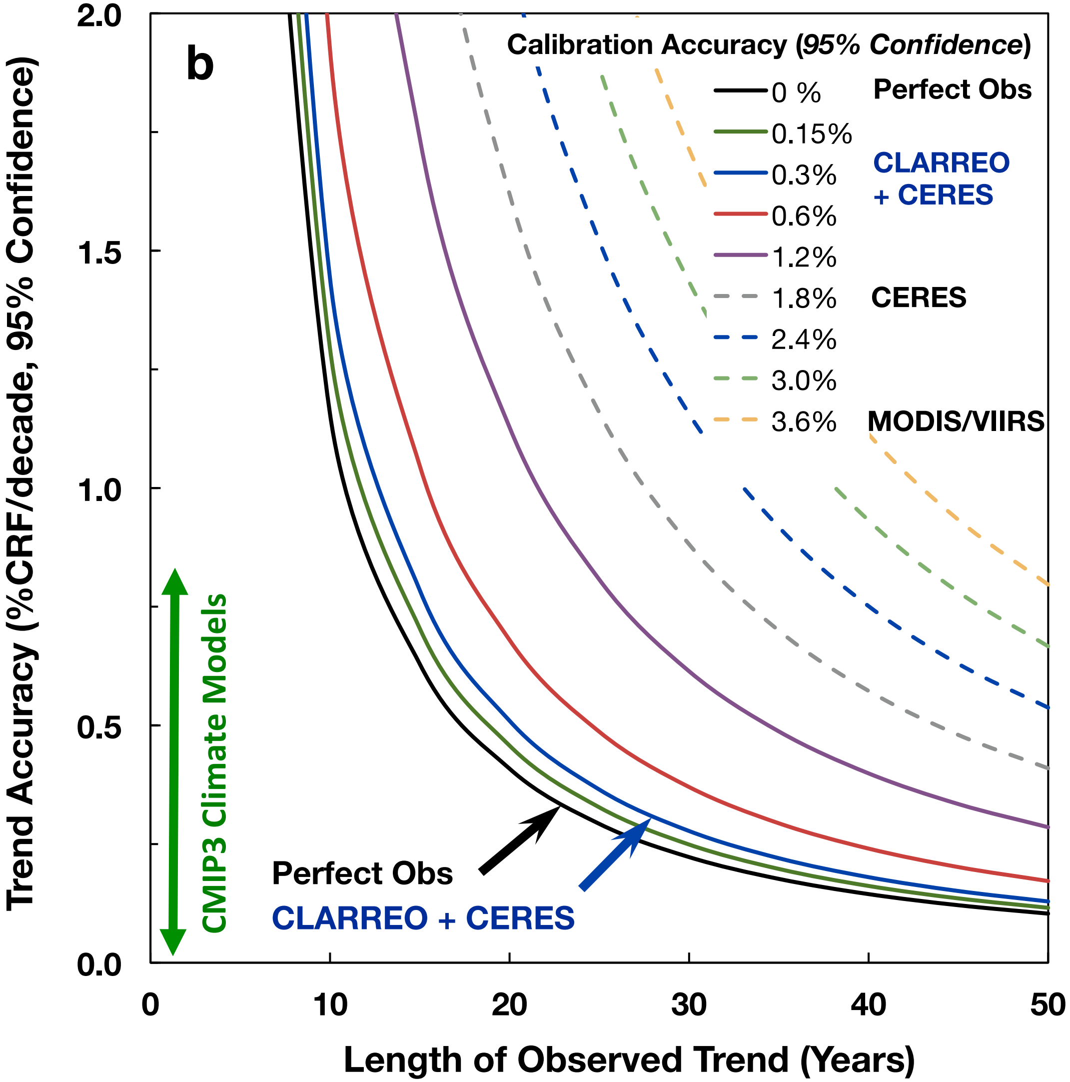
Accuracy Requirements of the Climate Observing System



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



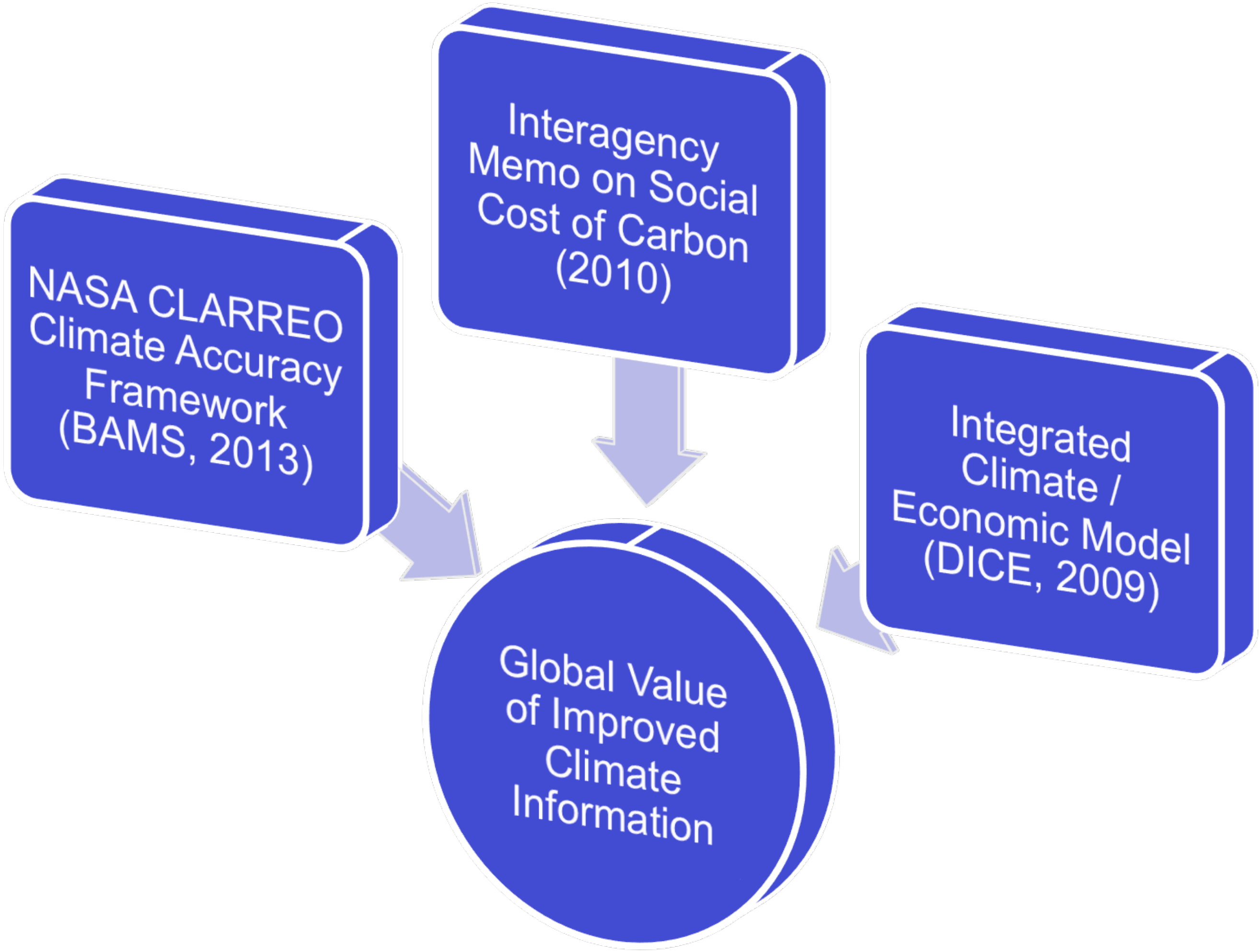
Climate Sensitivity Uncertainty is a factor of 4 (IPCC, 90% conf) which =*factor of 16 uncertainty in climate change economic impacts*

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*

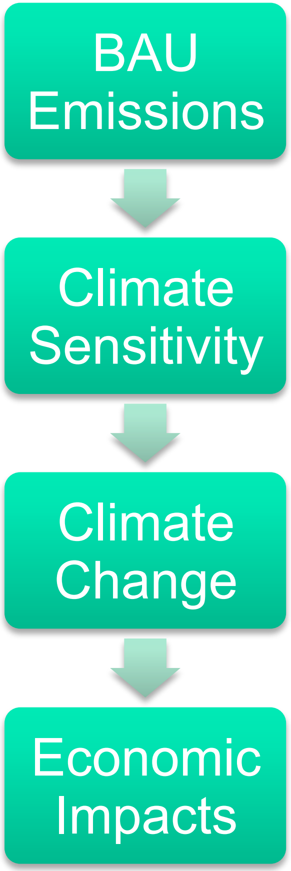
Wielicki et al. 2013, Bulletin of the American Meteorological Society

What is the right amount to invest in climate science?

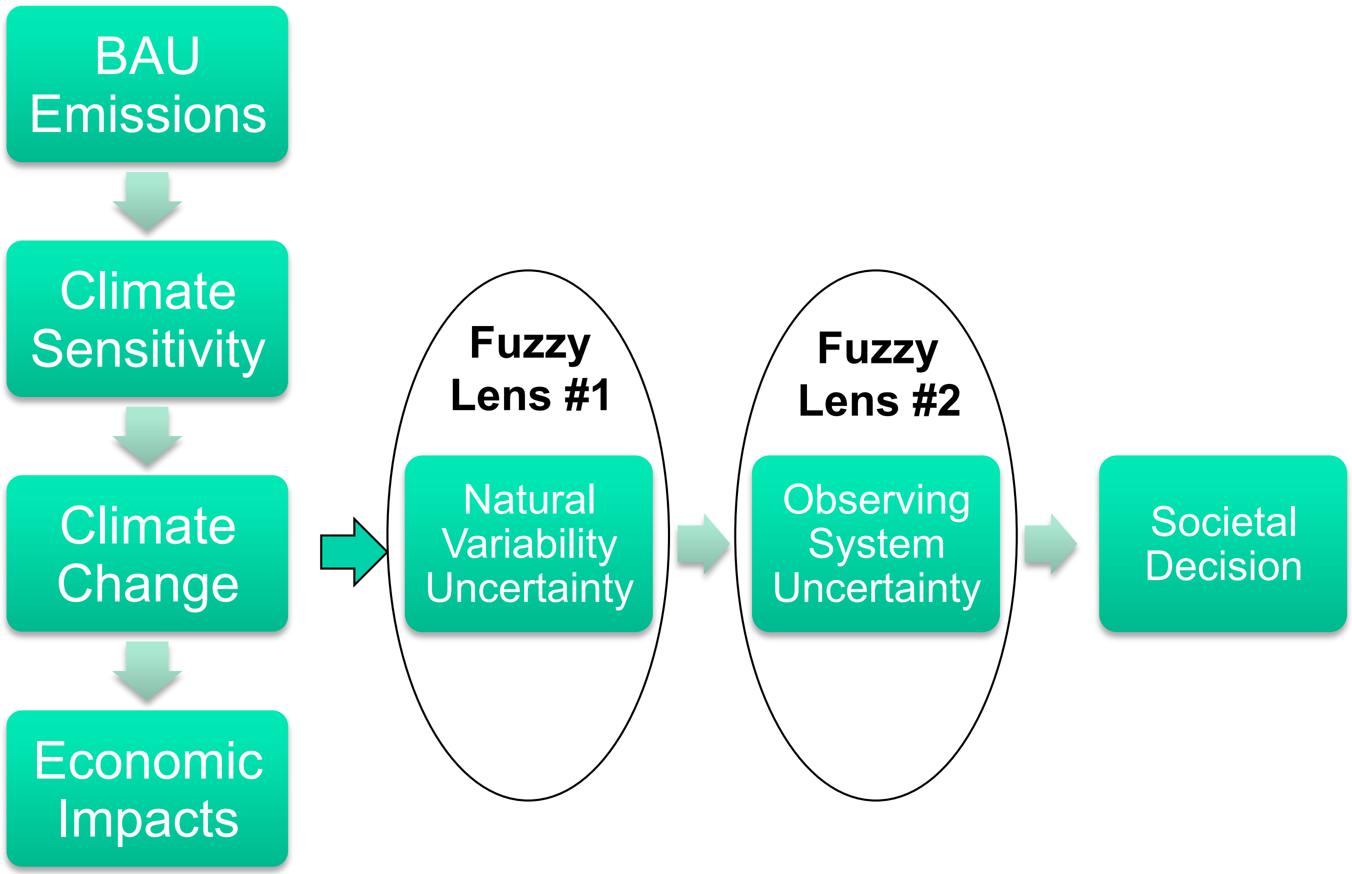


Cooke et al., Journal of Environment, Systems, and Decisions, 2014, paper has open and free distribution online: doi:10.1007/s10669-013-9451-8.
Cooke et al., Climate Policy, 2015, ISSN: 1469-3062

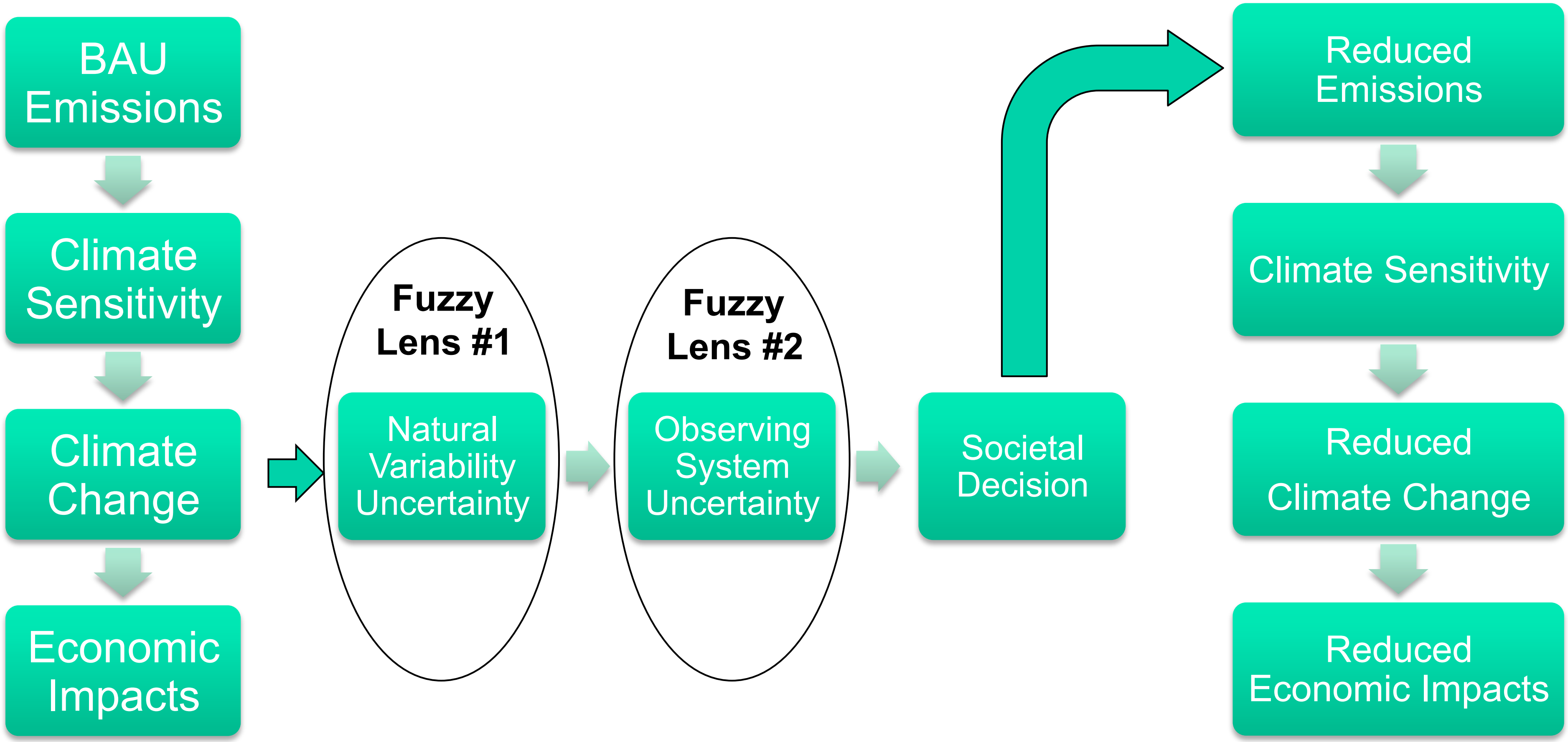
VOI Estimation Method



VOI Estimation Method



VOI Estimation Method



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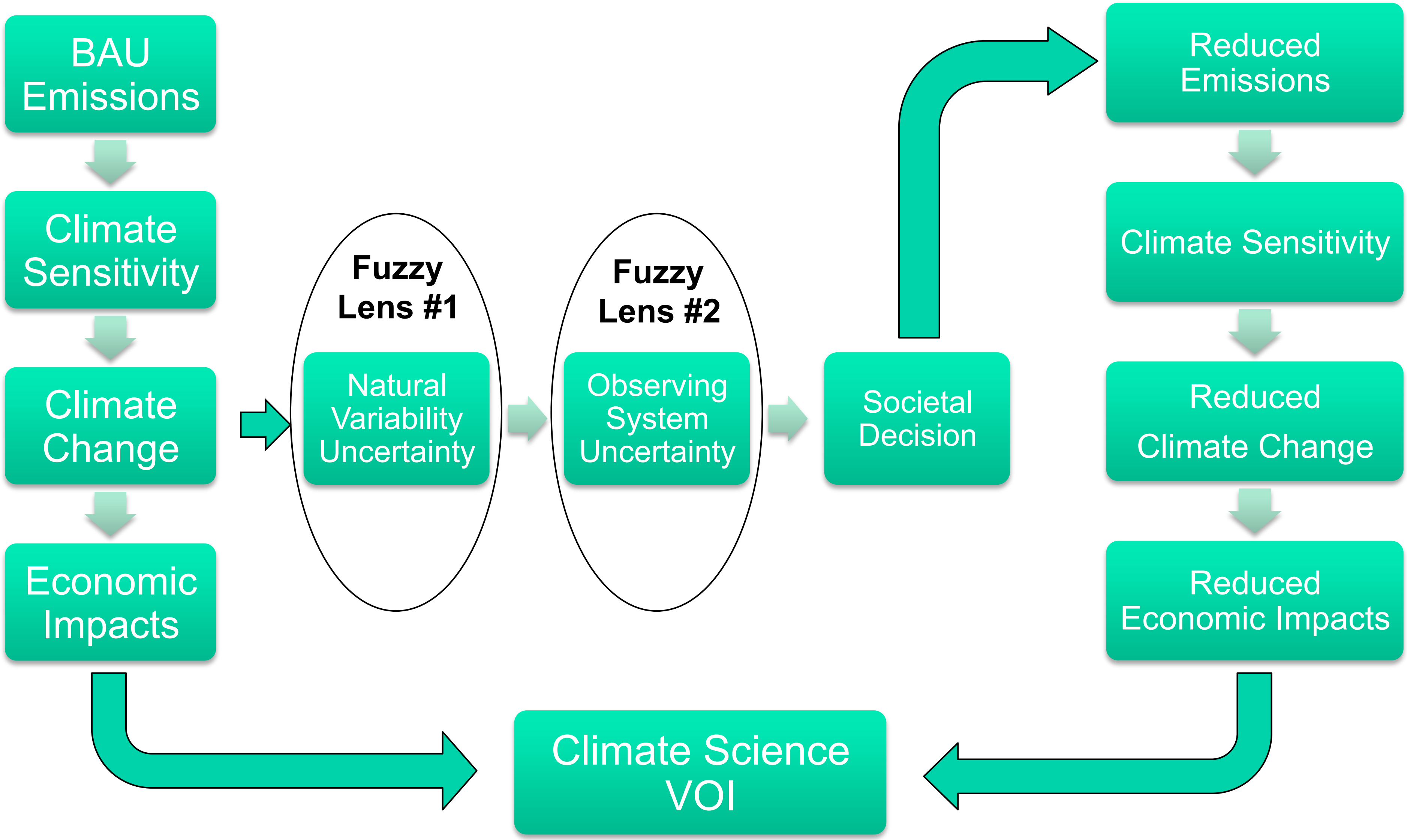

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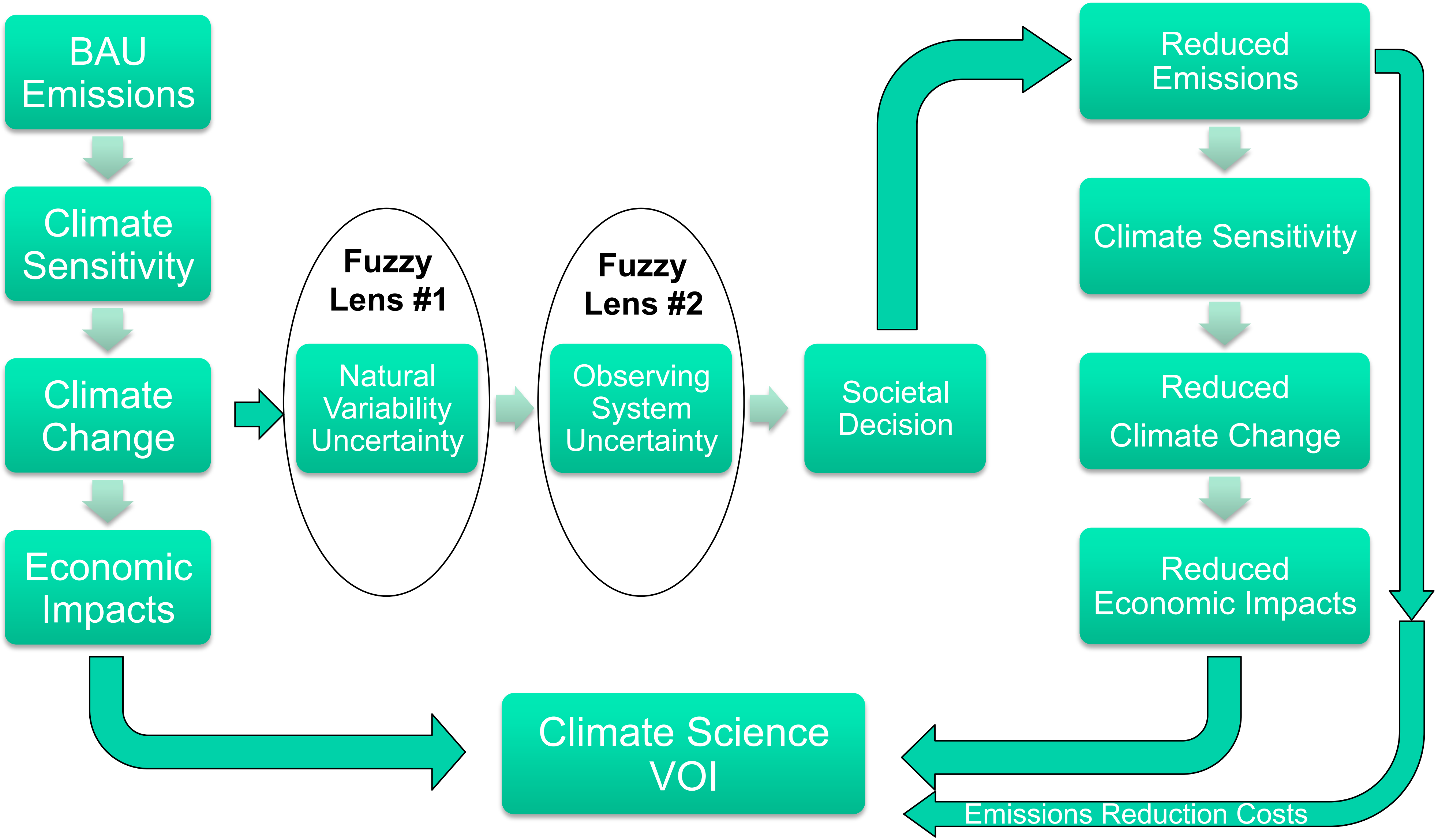

Economics: The Big Picture

- World GDP today ~ $80 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	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 (NPV)

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

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Advanced Climate Observing System:

Return on Investment: $50 per $1

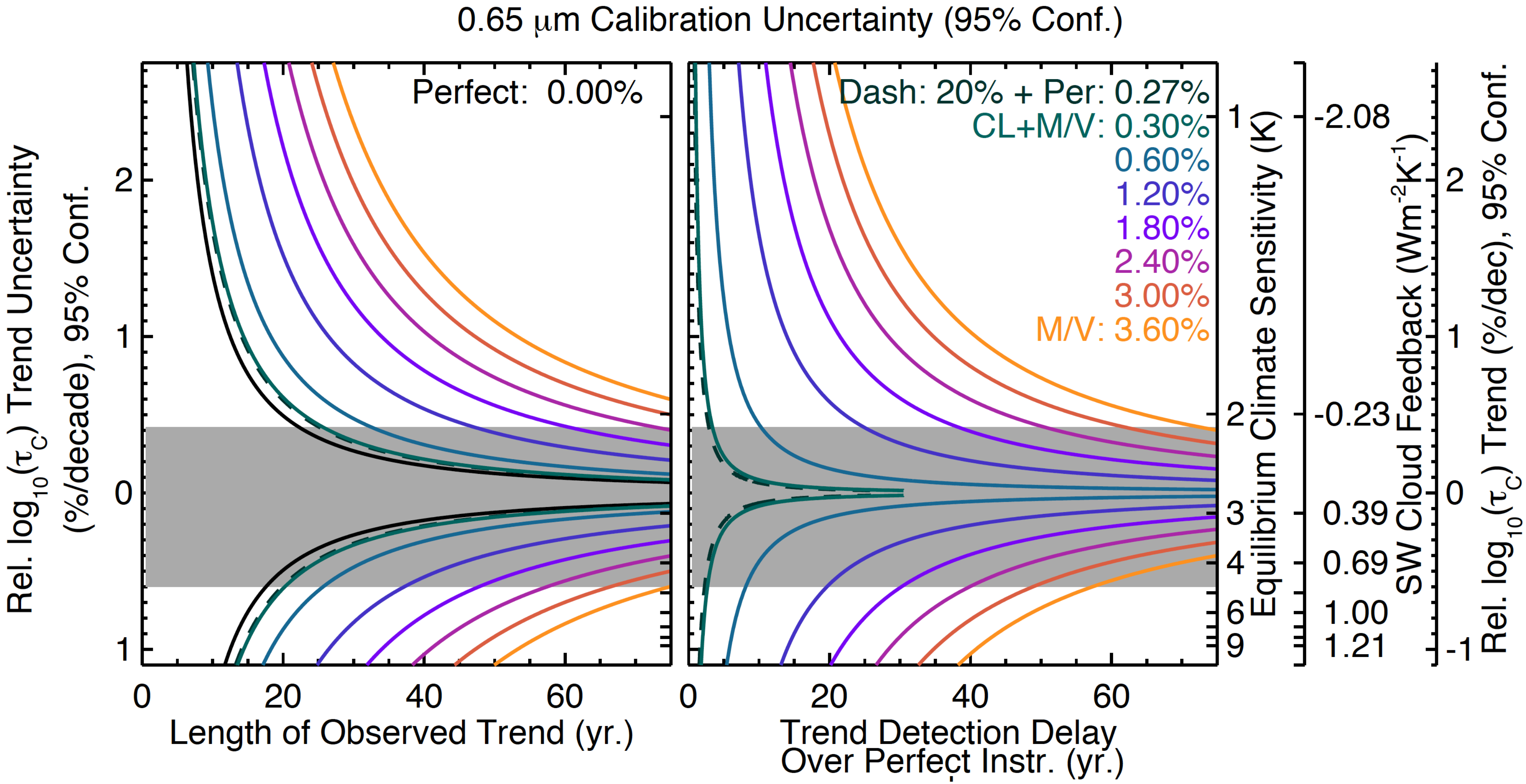
Cost of Delay: $400B per year

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

Cloud Feedback Observations Needed

- **Radiation Budget Cloud Radiative Forcing Decadal Change:** *Integral constraint on cloud feedback (e.g. Soden et al. 2008)*
- **Cloud Property Decadal Change: Cloud Fraction, Height, Temperature, Optical Depth, Phase, Particle Size:** *Bottoms up constraint on cloud feedback (e.g. Zelinka et al. 2012, 2013)*
- **Global, zonal, what resolution for regional? 1000km? 3000km?**
- **10 years of CALIPSO and CloudSat data can be used to examine the advantages vs MODIS or VIIRS or AIRS/CrIS/IASI cloud properties**
- **Examples for MODIS calibration requirement study (Shea et al., submitted to J. Climate)**

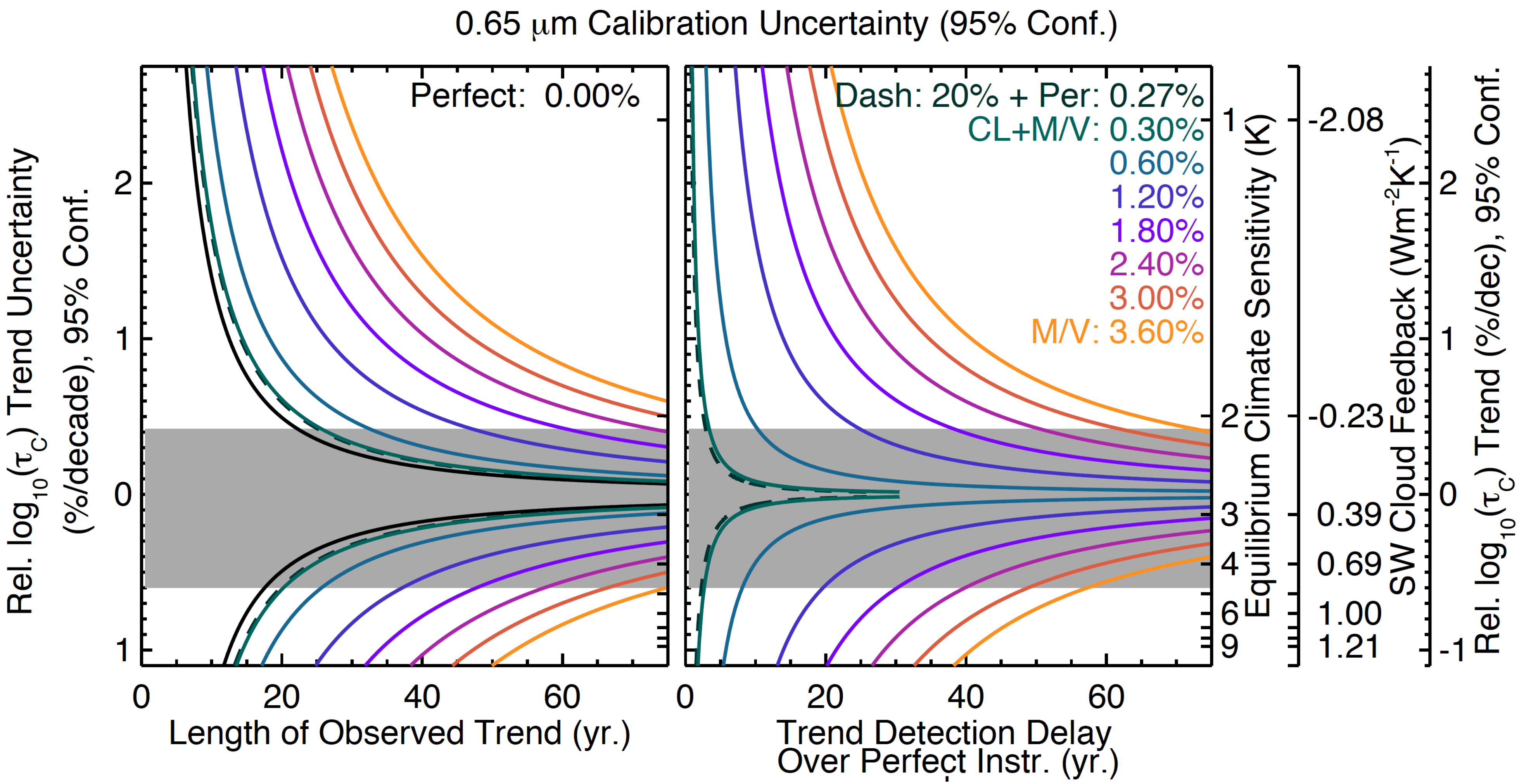
Cloud Optical Depth (60S – 60N Avg)



Shea et al 2016, submitted to J. Climate

To hold delay of information to 5 years: ~ 0.3% accuracy at 95% confidence

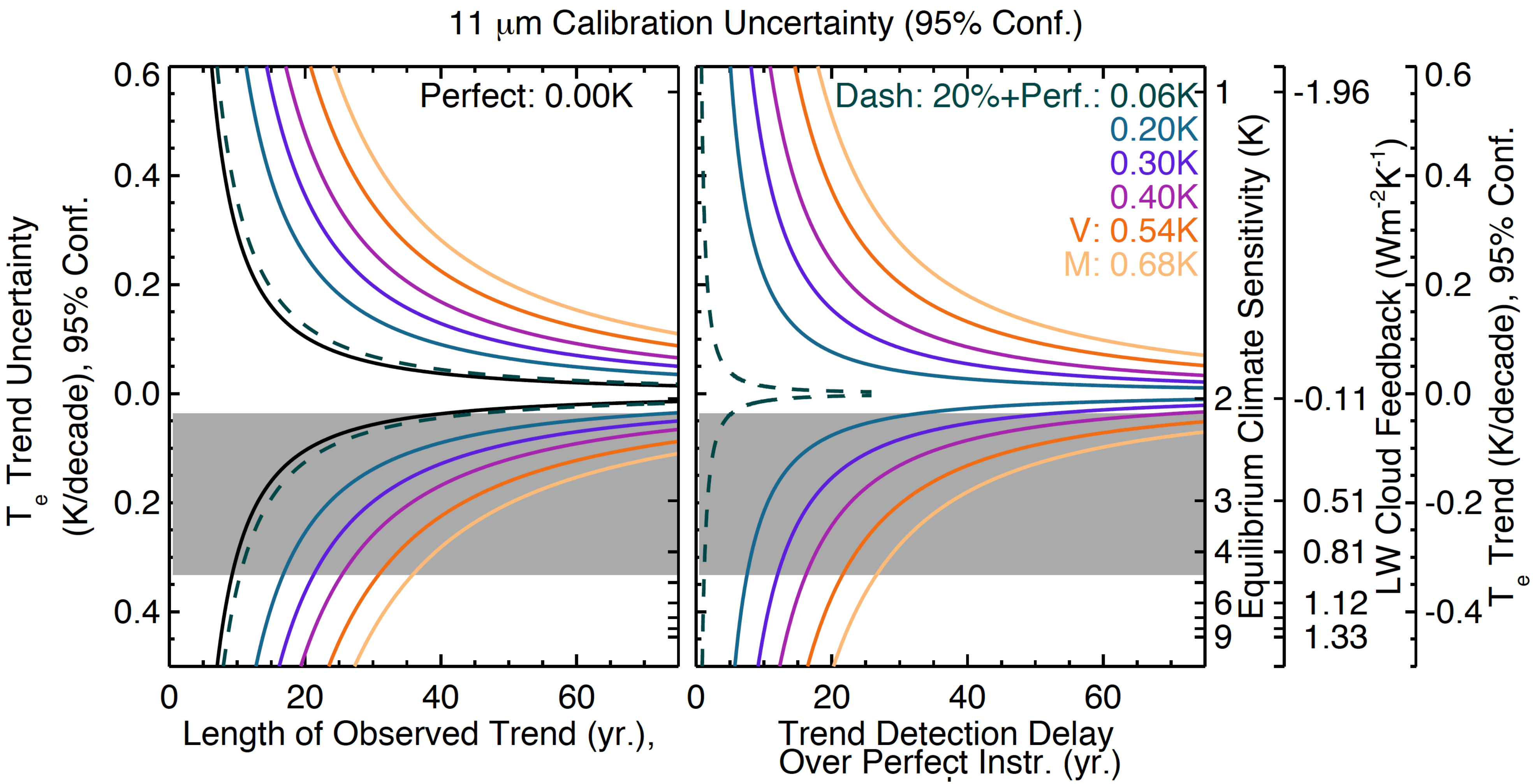
Cloud Optical Depth (60S – 60N Avg)



What would the answer be for lidar aerosol optical depth if used to constrain aerosol radiative forcing?

Shea et al 2016, submitted to J. Climate

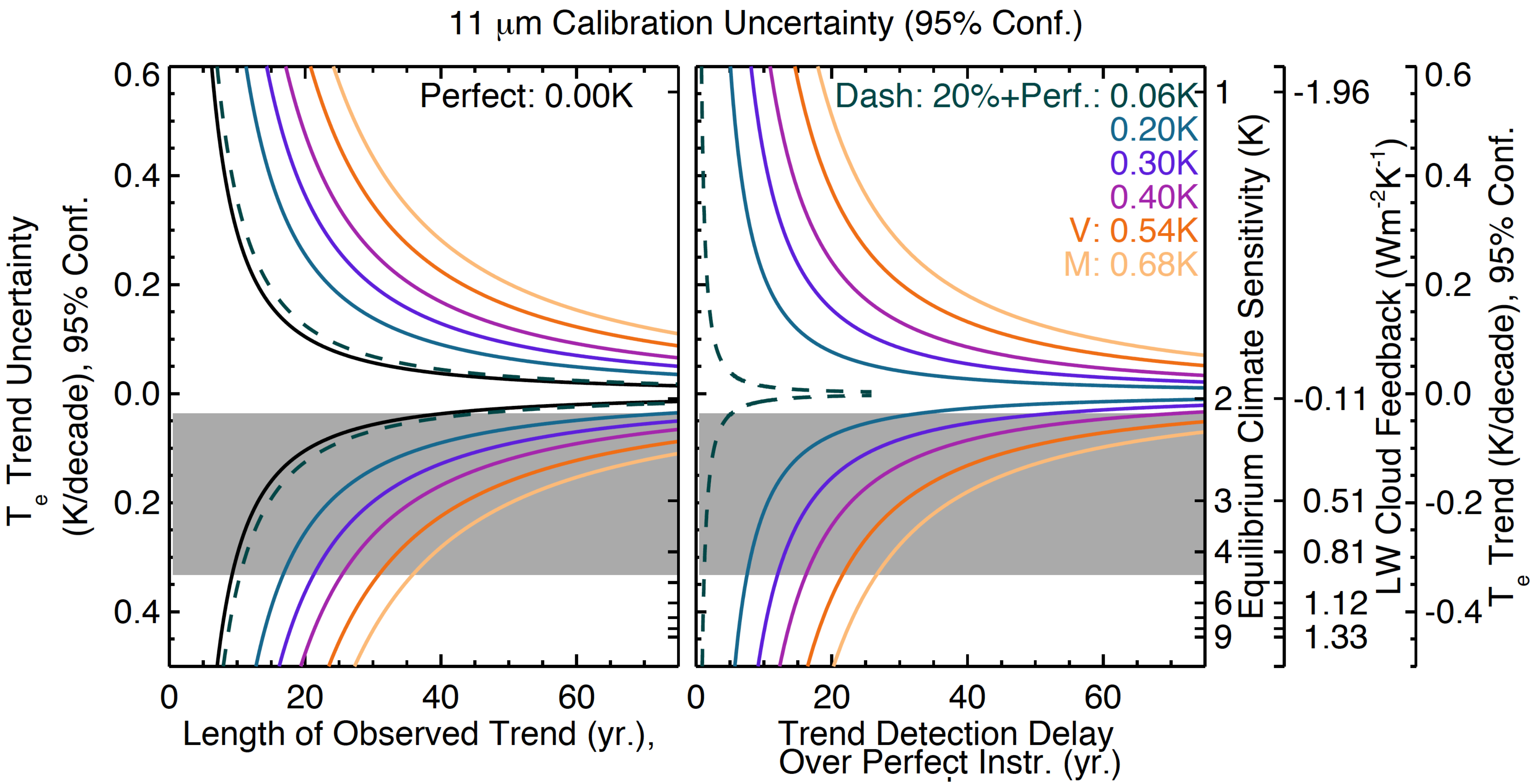
Cloud Top Effective Temperature (60S – 60N Avg)



Shea et al 2016,
submitted to J. Climate

To hold delay of information to 2 to 3 years: ~ 0.06K or 9m accuracy at 95% confidence

Cloud Top Effective Temperature (60S – 60N Avg)



Convert T_e to Altitude Accuracy: 0.06K = 9 meters

What is the accuracy of CALIPSO/CloudSat cloud height?

Shea et al 2016, submitted to J. Climate

Suggested Directions

- Quantitative Climate Science Questions
  - Hypothesis Tests not “improve and explore”, think Higgs Boson
  - See NRC Continuity report for examples (Nov, 2015)
- 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 Oct 2013 paper for example: broadly applicable
- Economic Value of Improved Climate Observations and Models
  - See Cooke et al. 2014, 2015, 2016; Hope 2015
- *What Should Cloud and Aerosol Long Term Accuracy Be?*
  - *What can Lidar and Radar provide in accuracy advances?*
  - *What can Lidar and Radar provide in improved process studies?*
- *We need a rigorous designed climate observing system!*

Backup Slides

References

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Determining the Accuracy of Decadal Change Trends and Time to Detect Trends

- A perfect climate observing system is limited in trend accuracy only by climate system natural variability (e.g. ENSO) (Leroy et al, 2008).

- Degradation of accuracy of an actual climate observing system relative to a perfect one (fractional error in accuracy, where perfect is $U_a = 1.0$) is given by:

$$U_a = (1 + \Sigma f^2_i)^{1/2}, \text{ where } f^2_i = \sigma^2_i \tau_i / \sigma^2_{var} \tau_{var}$$

  for linear trends where s is standard deviation, τ is autocorrelation time, σ_{var} is natural variability, and σ_i is one of the CLARREO error sources.

- Degradation of the time to detect climate trends relative to a perfect observing system (fractional error in detection time U_t) is similarly given by:

$$U_t = (1 + \Sigma f^2_i)^{1/3}$$

  Degradation in time to detect trends is only ⅔ of degradation in accuracy.

Decadal Change Trends

- The absolute accuracy of climate change observations is required *only at large time and space scales such as zonal annual, not at instantaneous field of view. Therefore all errors in climate change observation error budgets are determined over many 1000s of observations: never 1, or even a few.*

- Climate change requirements can be very different than a typical NASA Earth Science process mission interested in retrievals at instantaneous fields of view at high space/time resolution*, where instrument noise issues may dominate instantaneous retrievals*

- *So what accuracy relative to a perfect observing system is needed?*

Requirements focus on long term climate change