Climate Change Accuracy: Observing Requirements and Economic Value

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2015 Sun-Climate Symposium:

"Multi-Decadal Variability in Sun and Earth during the Space Era"

Savannah, GA

November 10-13, 2015

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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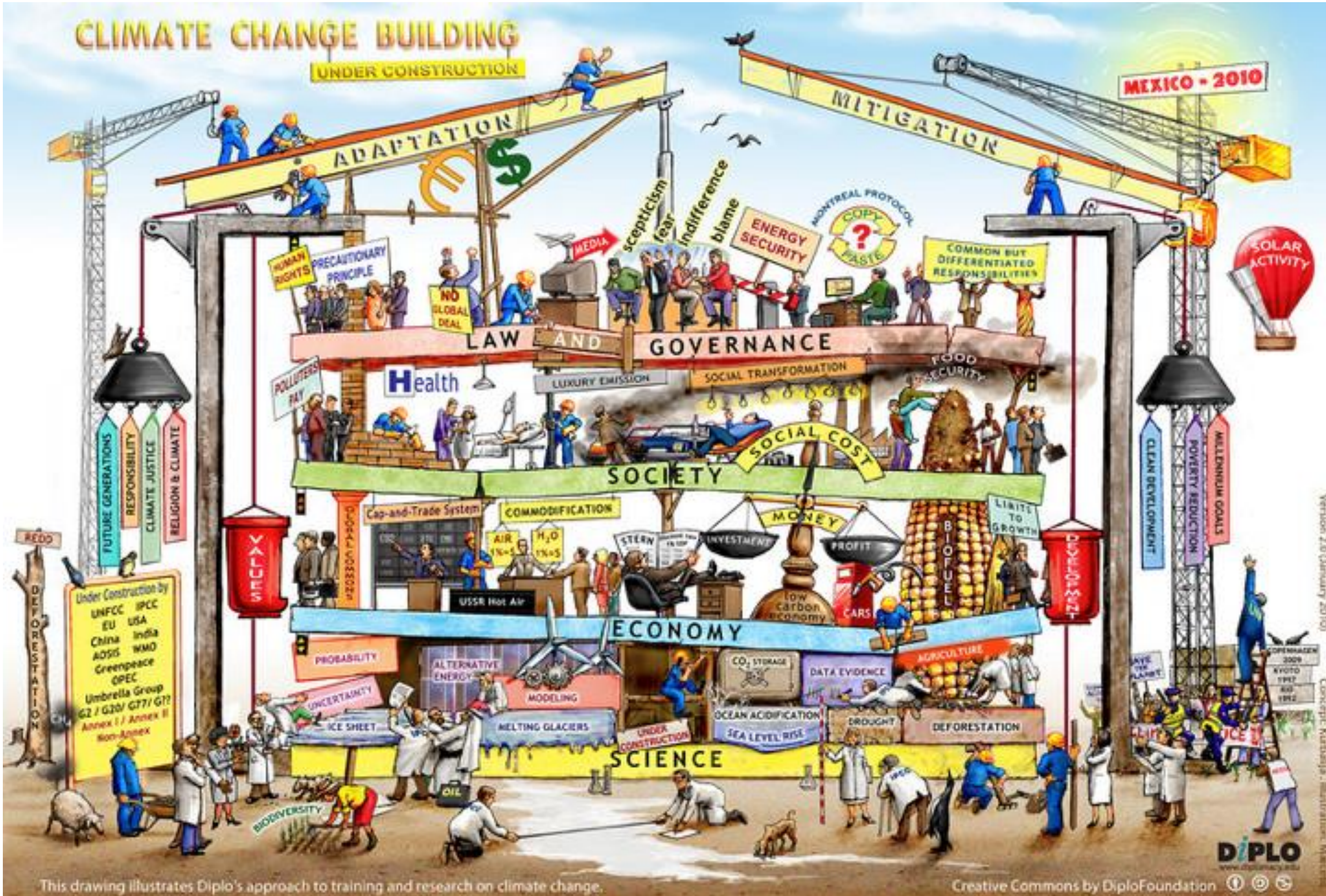
Foreword by Vern Suomi

35 Years Later …



35 Years Later …

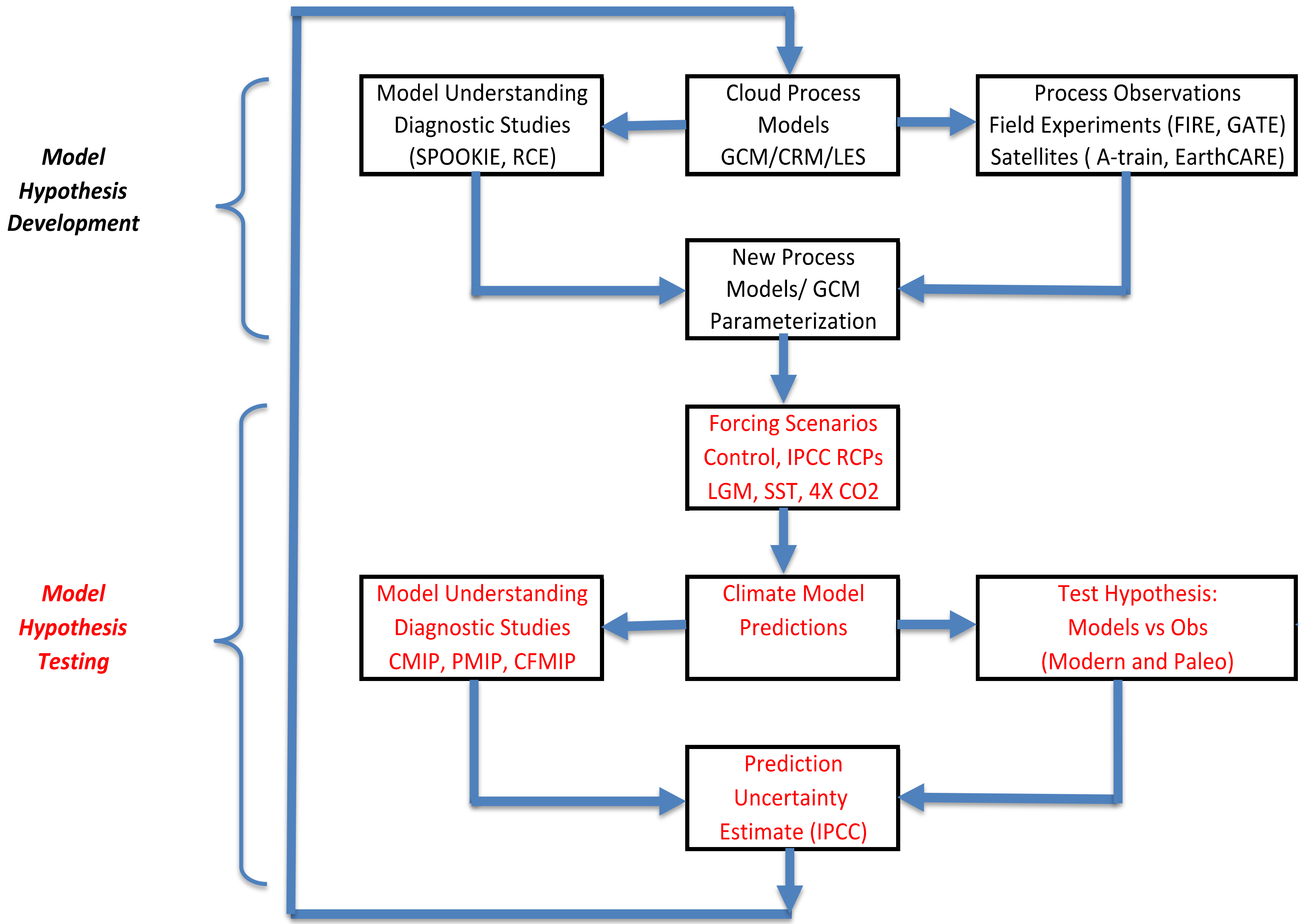
35 Years Later … More urgent, but …

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

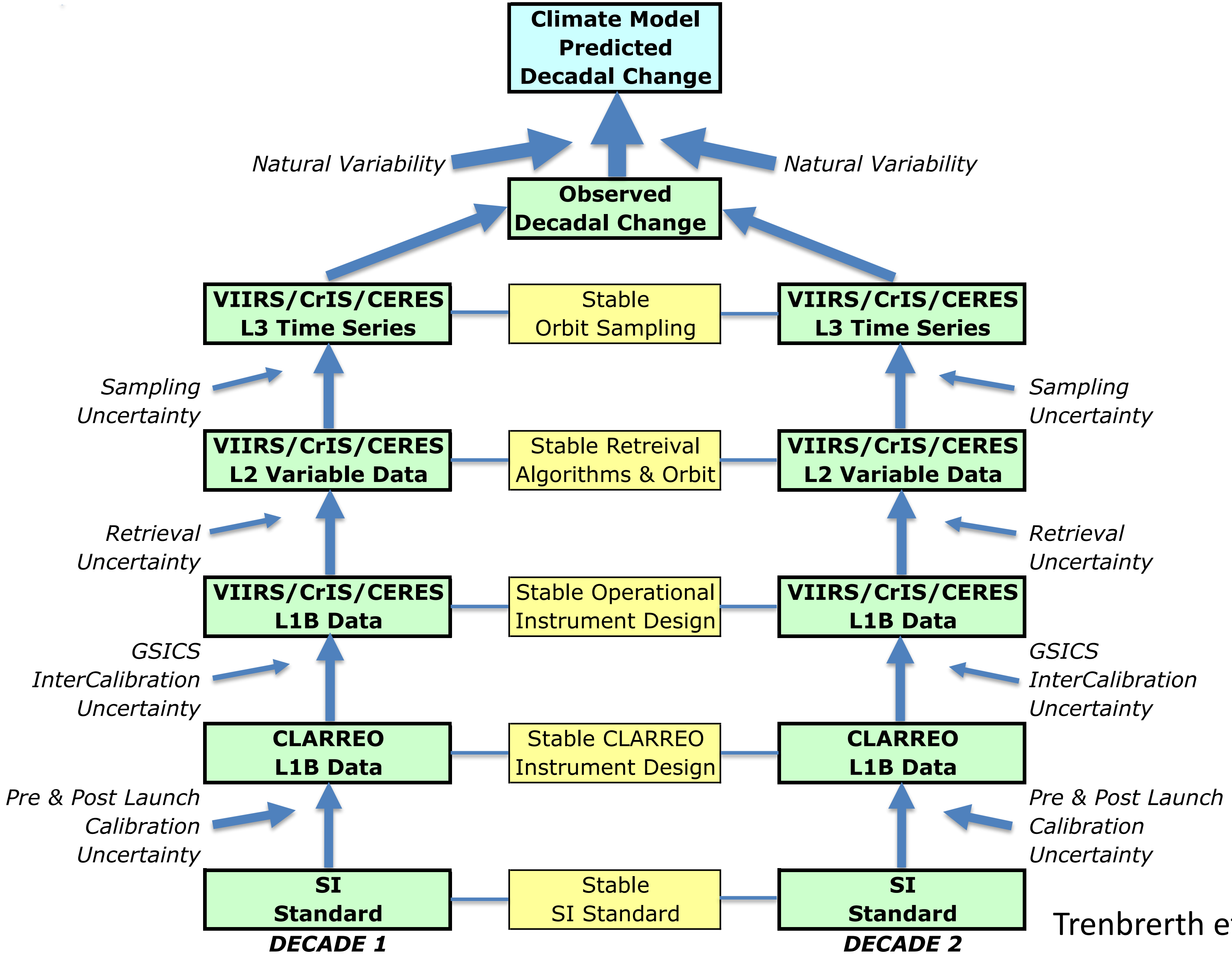
- Struggles to get sufficient resources for climate modeling

- 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

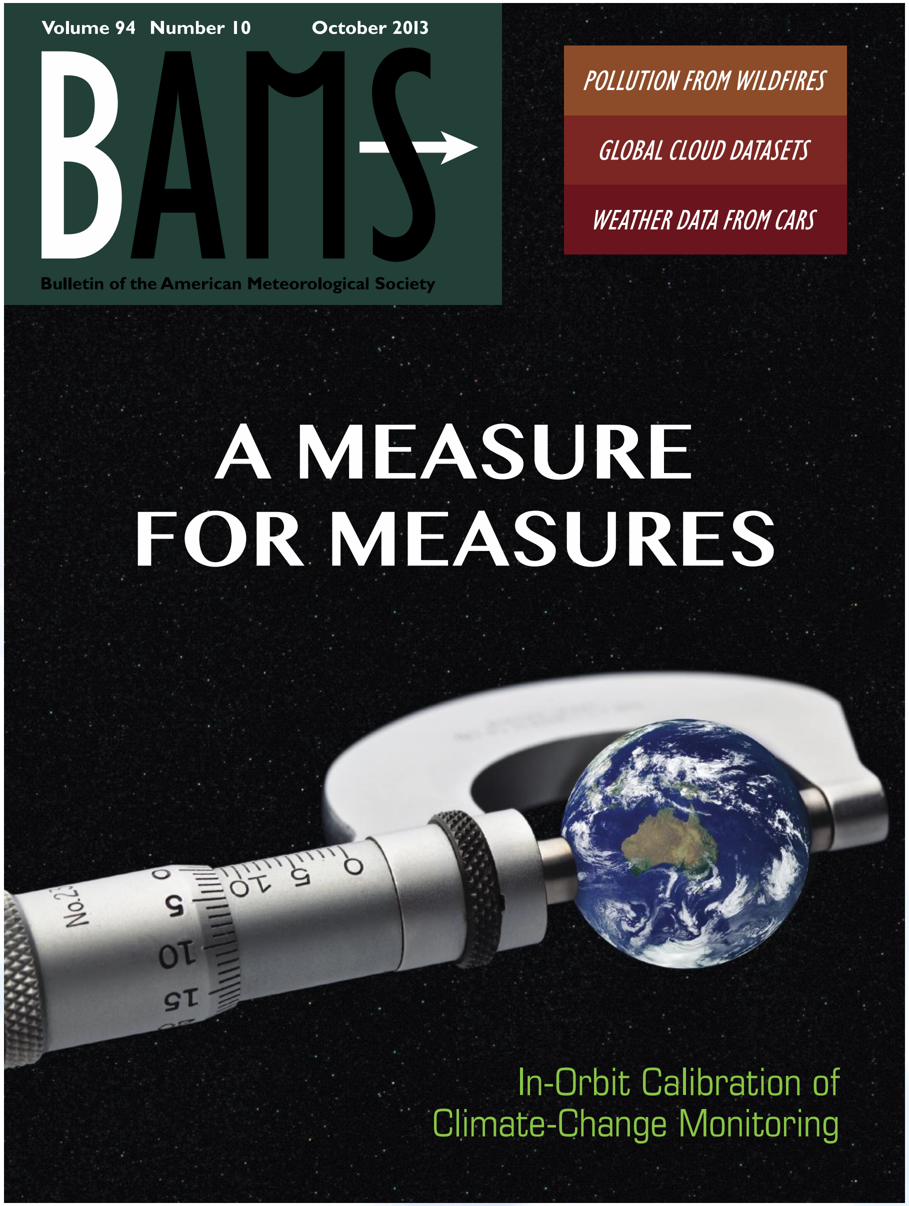

Model Understanding
Diagnostic Studies
(SPOOKIE, RCE)
Cloud Process
Models
GCM/CRM/LES
Process Observations
Field Experiments (FIRE, GATE)
Satellites (A-train, EarthCARE)
Model
Hypothesis
Development
New Process
Models/ GCM
Parameterization
Forcing Scenarios
Control, IPCC RCPs
LGM, SST, 4X CO2
Model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

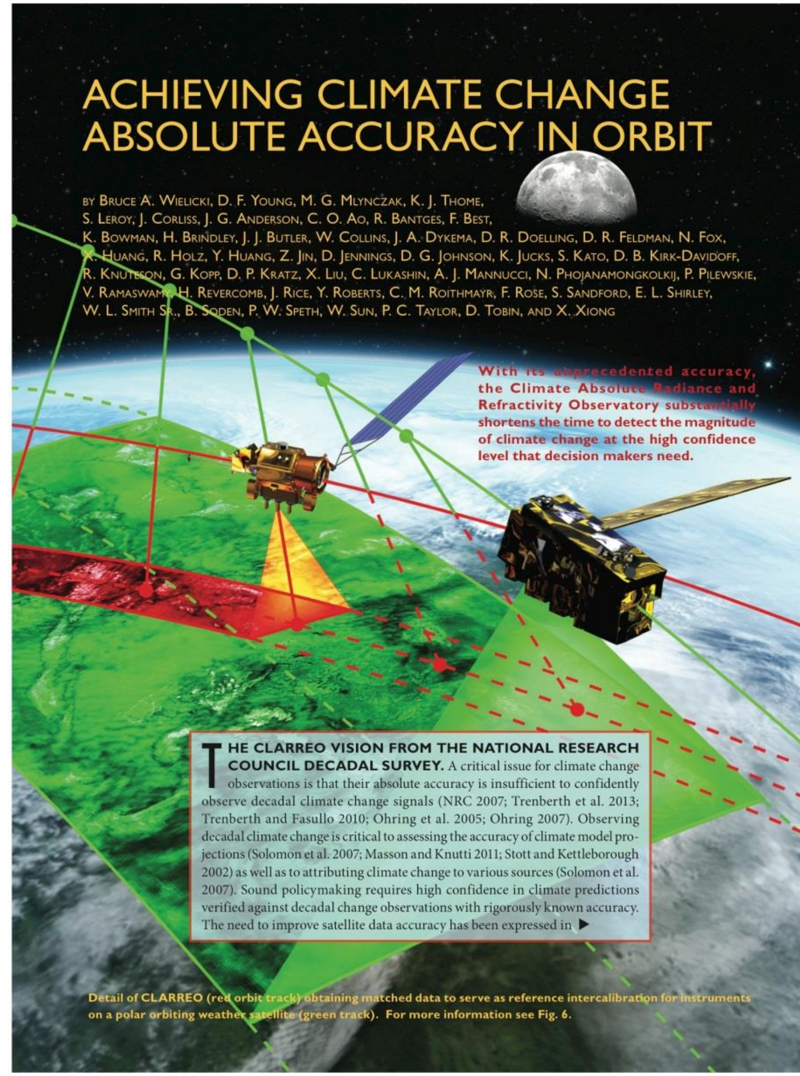
Accuracy of Climate Change Observations & Predictions



Trenbrerth et al. 2013

BAMS October, 2013





ACHIEVING CLIMATE CHANGE ABSOLUTE ACCURACY IN ORBIT

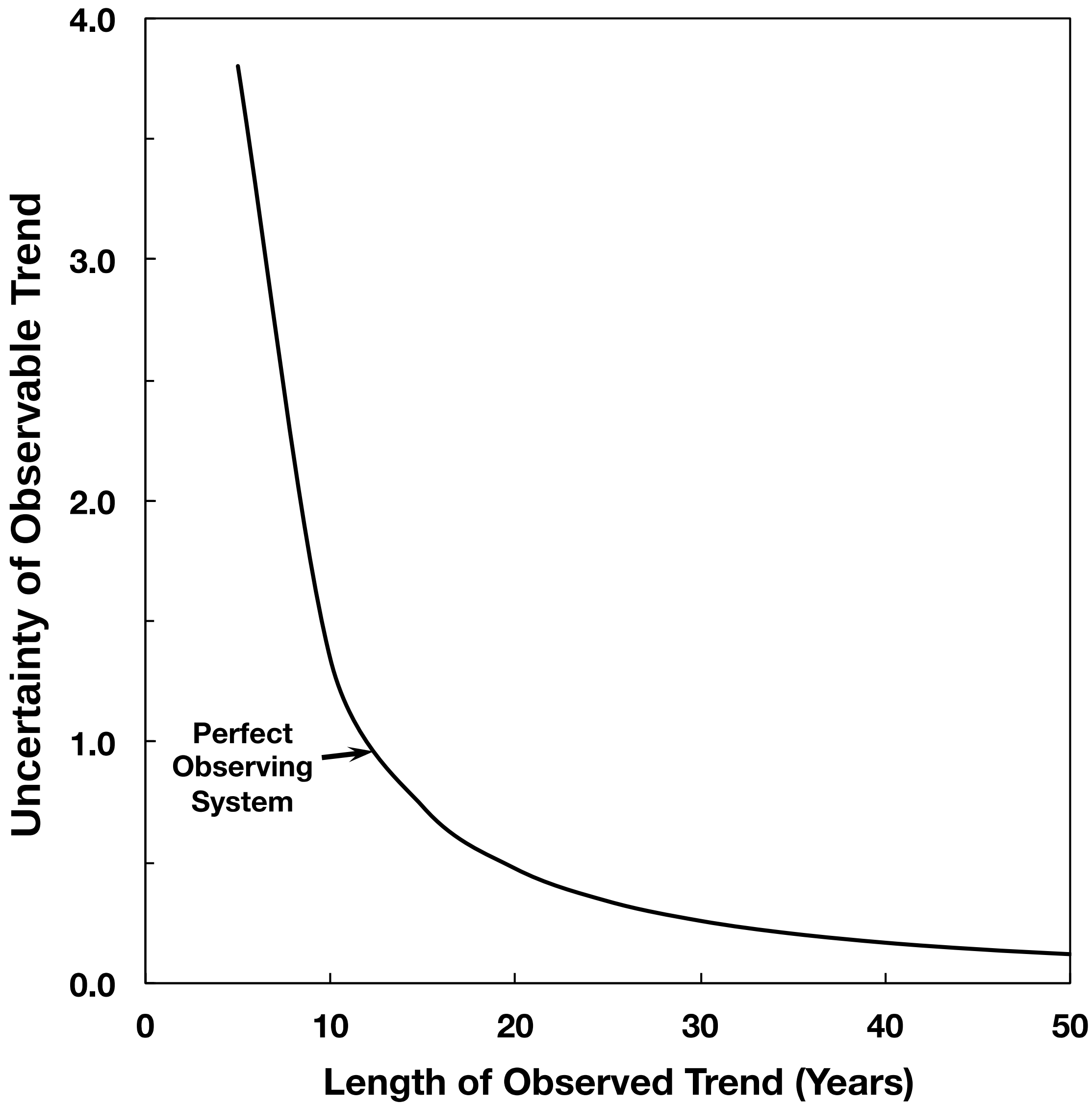
BY BRUCE A. WIELICKI, D. F. YOUNG, M. G. MLYNCZAK, K. J. THOME, S. LEROY, J. CORLISS, J. G. ANDERSON, C. O. AO, R. BANTGES, F. BEST, K. BOWMAN, H. BRINDLEY, J. J. BUTLER, W. COLLINS, J. A. DYKEMA, D. R. DOELLING, D. R. FELDMAN, N. FOX, X. HUANG, R. HOLZ, Y. HUANG, Z. JIN, D. JENNINGS, D. G. JOHNSON, 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.

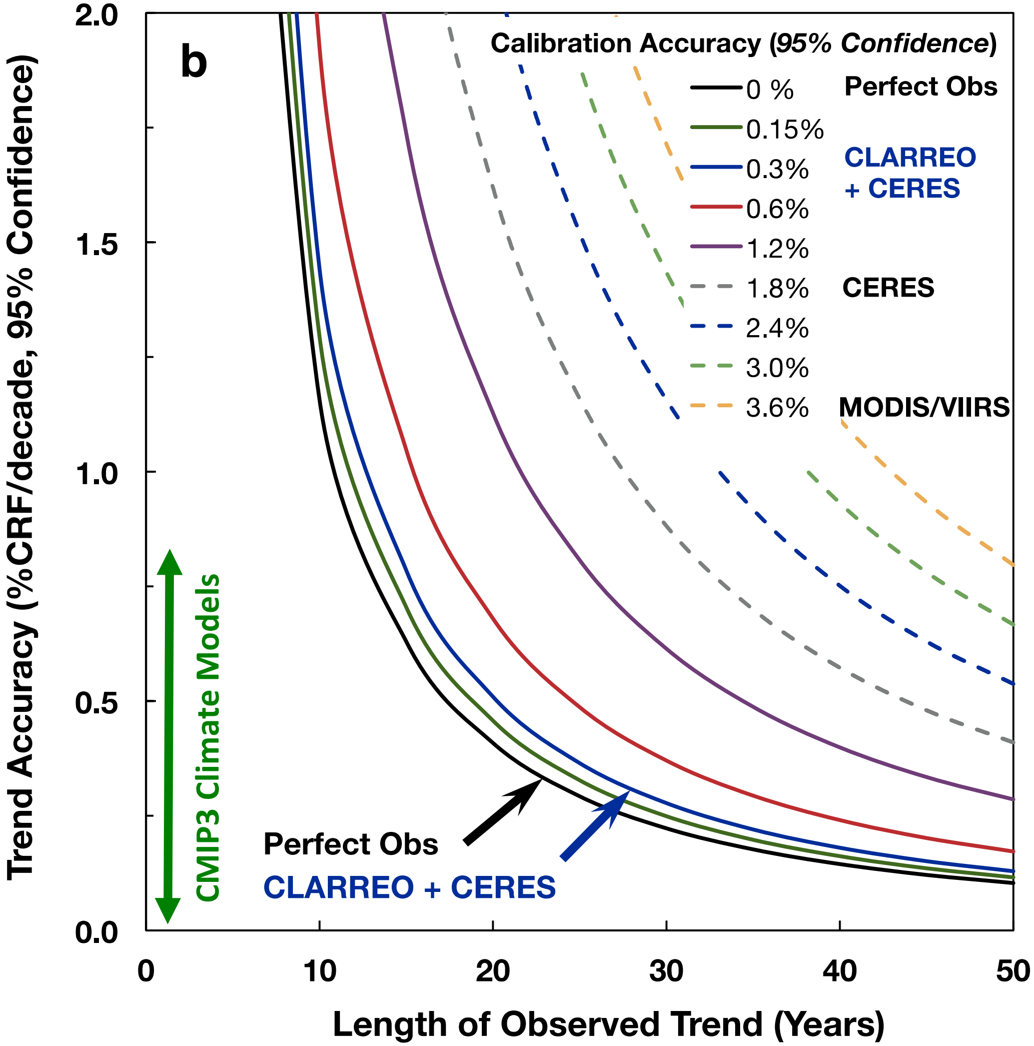
Accuracy Requirements of the Climate Observing System



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



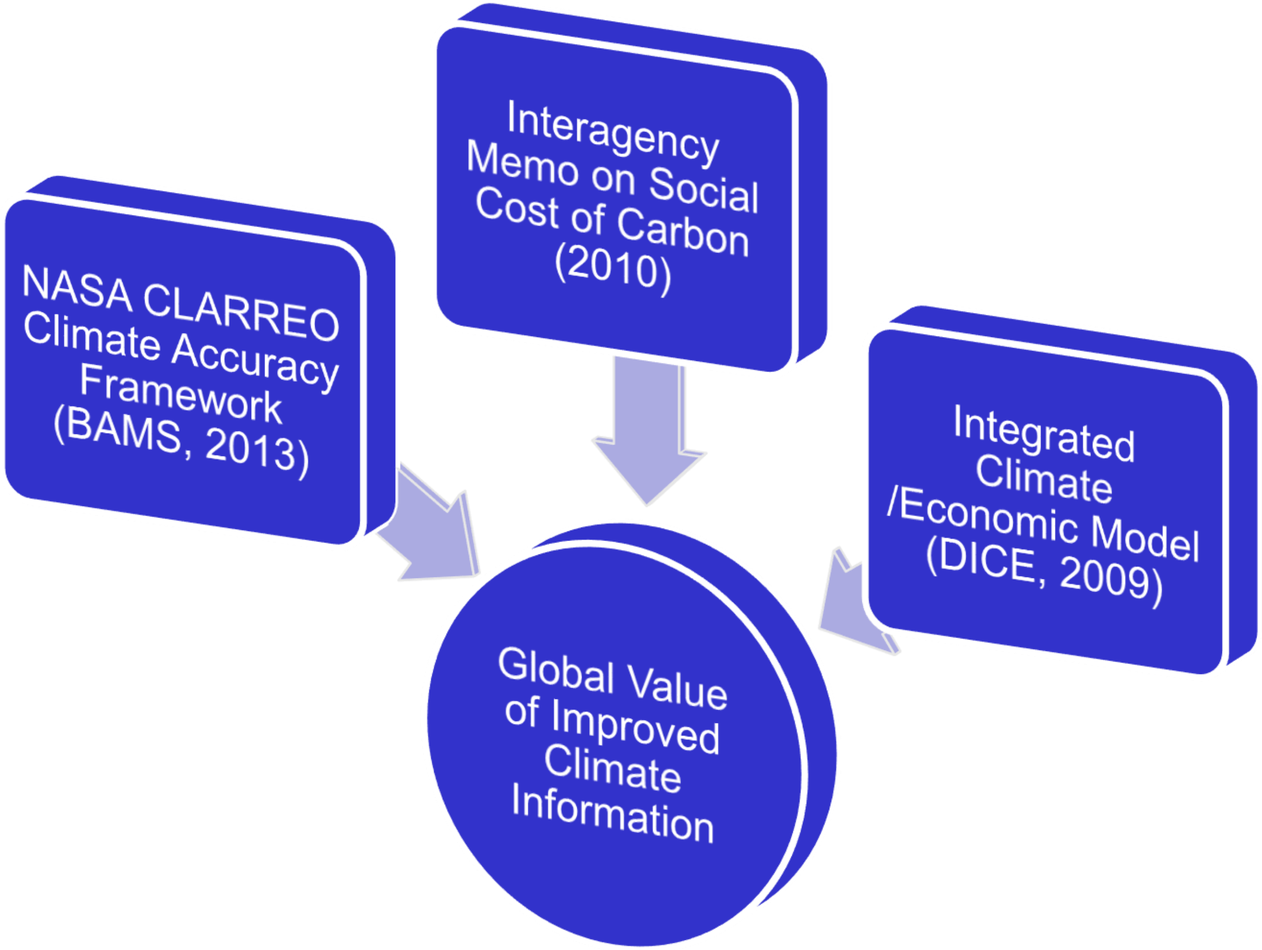
Climate Sensitivity Uncertainty is a factor of 4 (IPCC, 90% conf) which =*factor of 16 uncertainty in climate change economic impacts*

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

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: doi:10.1007/s10669-013-9451-8

VOI Estimation Method

BAU Emissions

↓

Climate Sensitivity

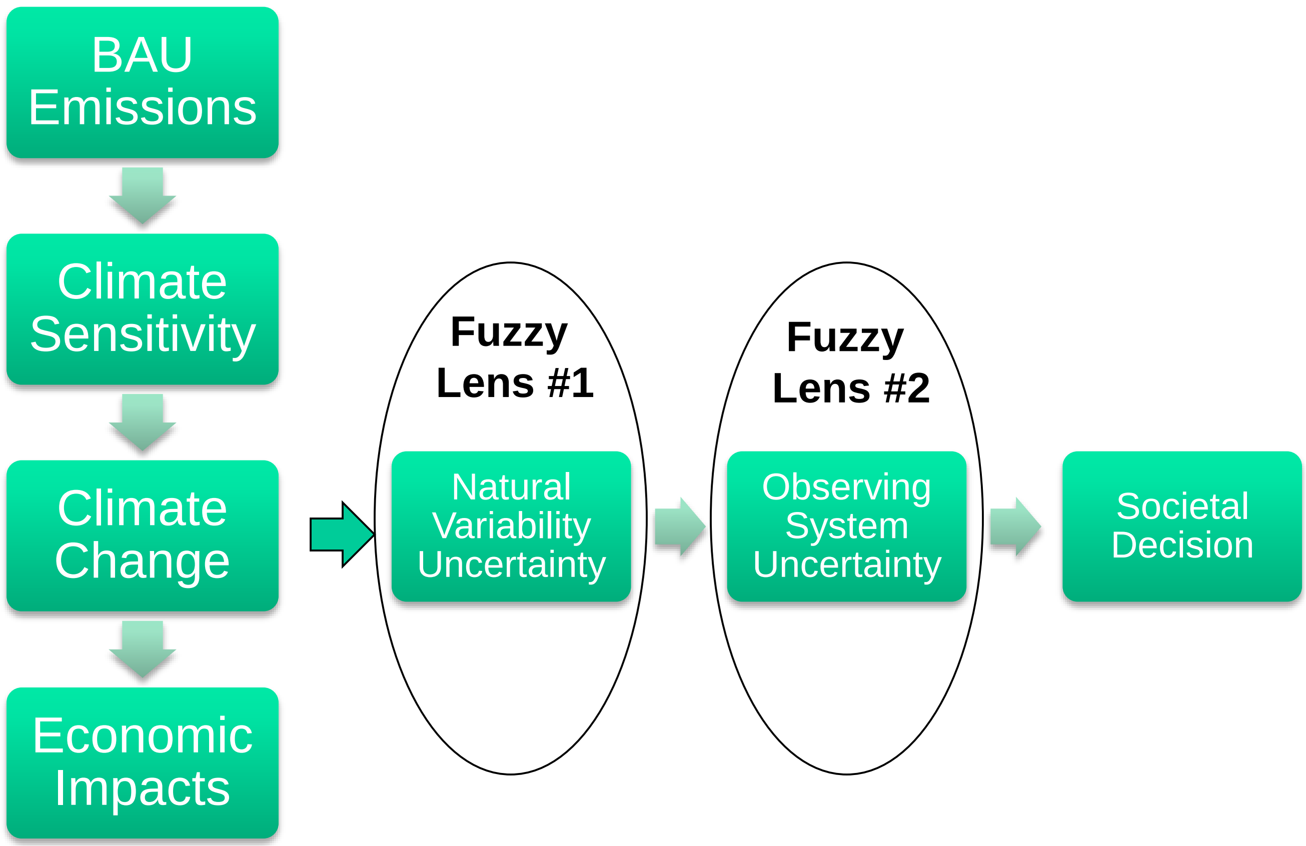
↓

Climate Change

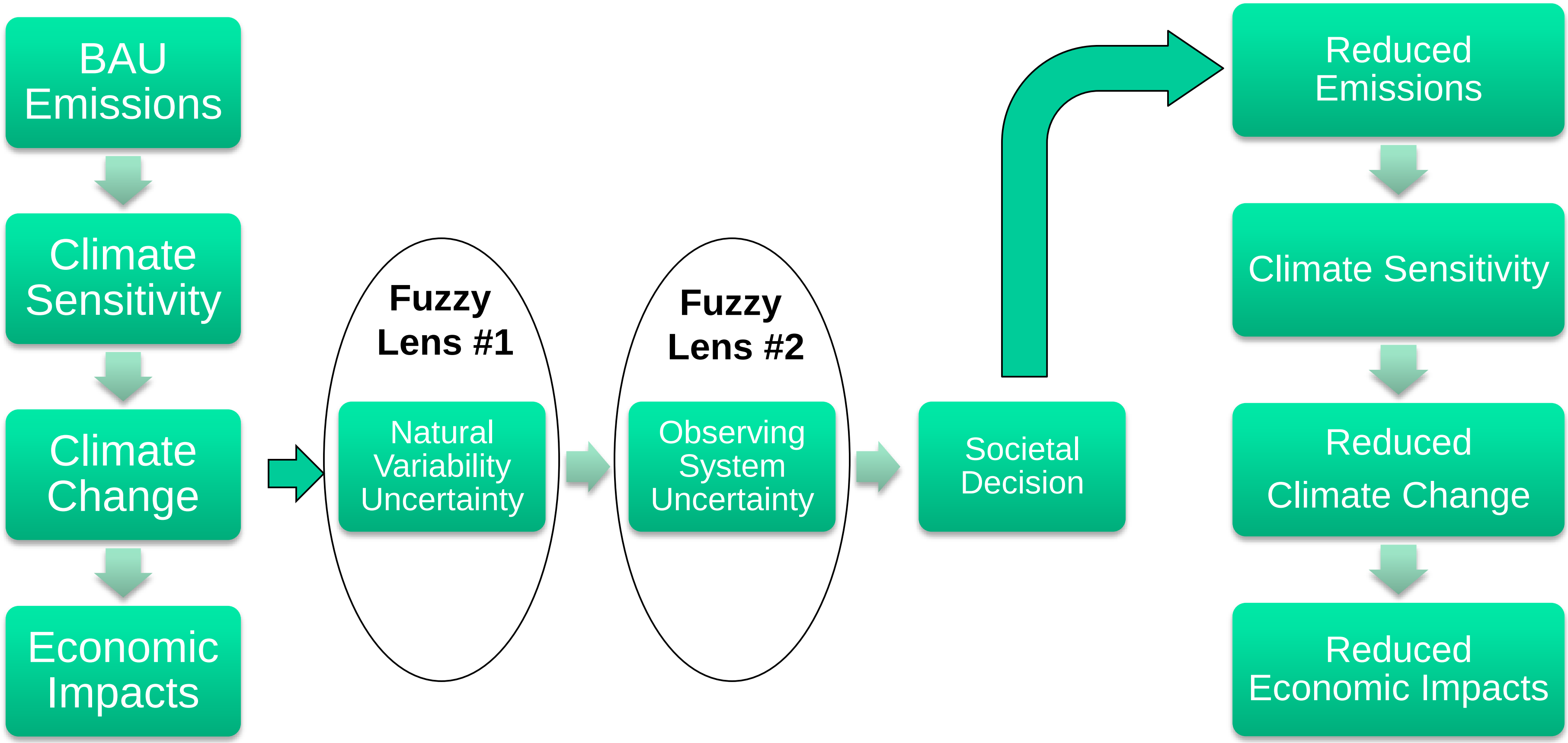
↓

Economic Impacts

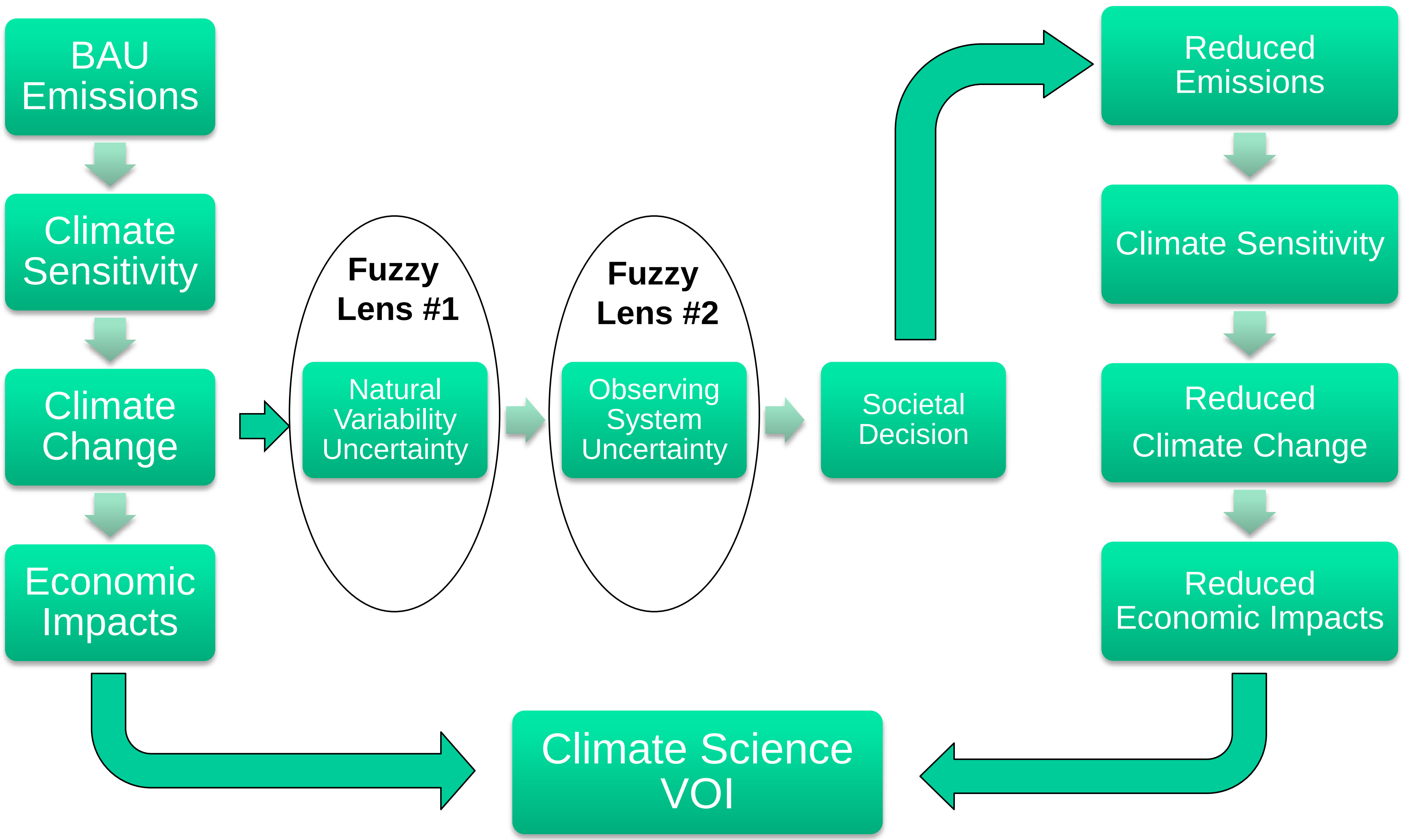
VOI Estimation Method



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 (NPV)

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

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

Advanced Climate Observing System:

Return on Investment: $50 per $1

Cost of Delay: $650B per year

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

Climate Observations: No Long Term Plan

- Global Satellite Observations without long term commitments
  - Radiation Budget (e.g. CERES)
  - Gravity (ice sheet mass) (e.g. GRACE)
  - Ice Sheet Elevation (e.g. ICESAT/Cryosat)
  - Sea Level Altimetry (e.g. JASON)
  - Sea surface Salinity (e.g. Aquarius)
  - Cloud and Aerosol Profiles (e.g. CALIPSO/Cloudsat, EarthCARE)
  - Precipitation (e.g. GPM, CloudSat/EarthCARE)
  - Soil Moisture (e.g. SMAP)
  - Ocean surface winds (e.g. QuickSCAT)
  - Carbon Source/Sinks (e.g. OCO)
  - Methane/Carbon Monoxide (MOPPIT)
  - In orbit Calibration References (e.g. CLARREO)
- Surface and In-situ observations have similar issues

How would we design a Climate Observing System?

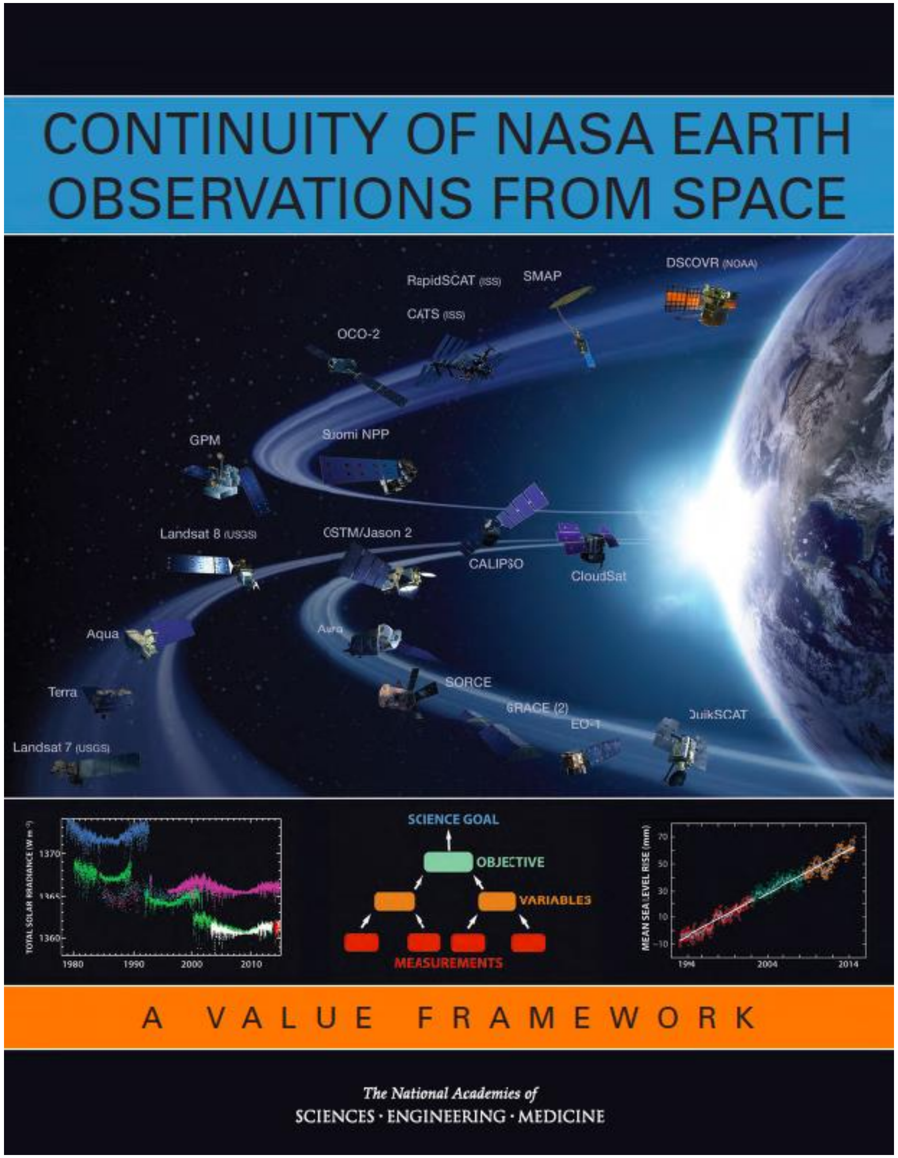
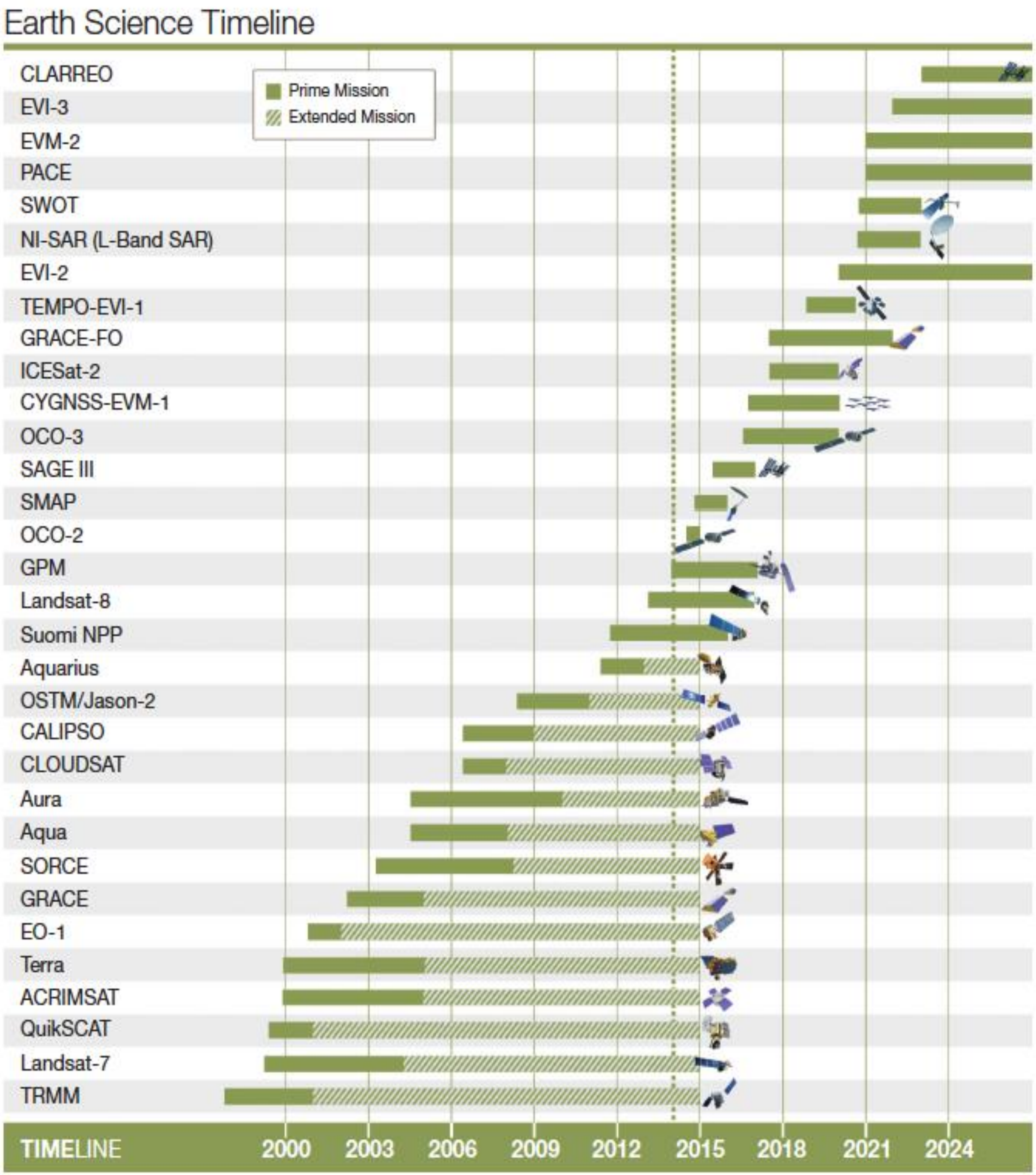


Figure 4.4 Summary of Earth Science Missions



Design a Climate Observing System:

What missions?
What measurements?
How accurate?
Independent obs?
How long?
What cost?
U.S. & International?

Definition of Continuity

- **Finding:** *Continuity of an Earth measurement exists when the quality of the measurement for a specific quantified science objective is maintained over the required temporal and spatial domain set by the objective. The quality of a measurement is characterized by its combined standard uncertainty, which includes instrument calibration uncertainty, repeatability, time and space sampling, and data systems and delivery for climate variables (algorithms, reprocessing, and availability)—each of which depends on the scientific objective*.

Quantified Earth Science Objective

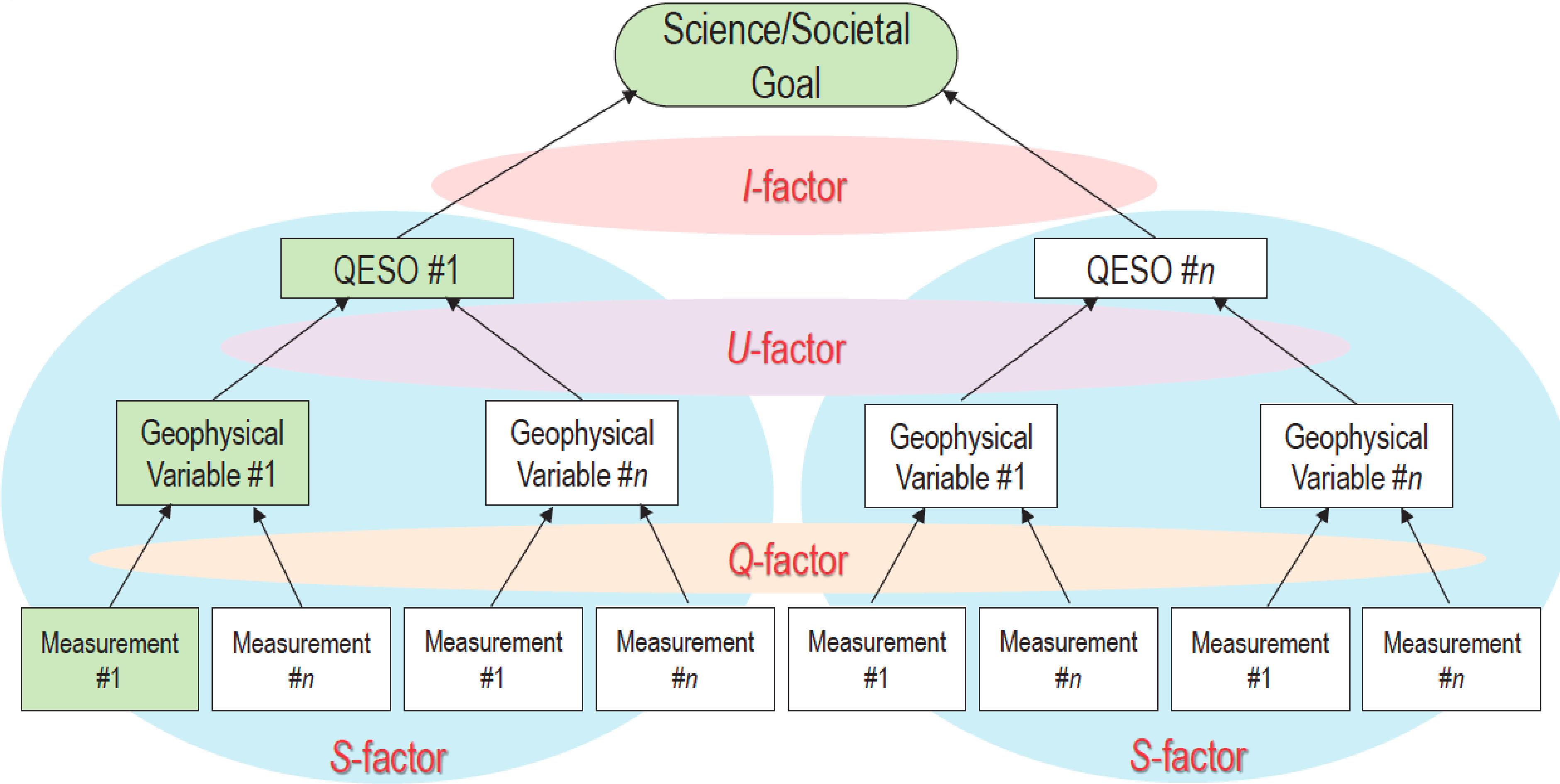
- The notion of a quantified Earth science objective (QESO) is the starting point for the recommended decision framework.
- A well-formulated QESO would be directly relevant to achieving an overarching science goal of the ESD and allow for an analytical assessment of how the quantified objective would help meet that science goal.
- Proposed space-based continuity measurements should be evaluated in the context of the QESO they address. The resolution, uncertainty, and repeatability of candidate measurements should all be taken into account when deciding whether a QESO is achievable.
- Examples of QESOs could be:
  - Determine the rate of global mean sea level rise to $\pm$1 mm yr^{-1} $decade^{-1}$(1σ)
  - *Narrow the Intergovernmental Panel on Climate Change Fifth Assessment (IPCC AR5) uncertainty in equilibrium climate sensitivity (ECS) (1.5 to 6° C at 90% confidence) by a factor of 2*
  - *Determine the change in ocean heat storage within 0.1 W m-2 per decade (1σ)*

Value of a Measurement for a QESO

- We identify five key characteristics that define the value of a measurement proposed in pursuit of a QESO:
  - Importance (I),
  - Utility (U),
  - Quality (Q),
  - Success Probability (S),
  - Affordability (A)
- The committee takes Value (V) to be the product of Benefit (B) and Affordability (A); it found a useful expression of B to be an unweighted product of the factors I, U, Q, and S. Thus:

$$V^* = B \times A = (I \times U \times Q \times S) \times A$$

Quantifying Value



Evaluation Factor	Value Range	Description
Importance (I)	1 – 5	Importance indicates the documented community priorities for science goals and QESOs. It represents the maximum potential benefit of a given measurement.
Utility (U)	0 – 1	Utility includes consideration of all of the key geophysical variables, and their relative contributions for addressing a QESO. It represents the percentage of a QESO that would be achieved by obtaining the targeted geophysical variable record.
Quality (Q)	0 – 1	Quality includes consideration of its uncertainty, repeatability, time and space sampling, and data algorithm characteristics relative to that required for achieving a QESO. It represents the percentage of the required geophysical variable record that would be obtained by the proposed measurement.
Success Probability (S)	0 – 1	Success Probability includes consideration of the heritage and maturity of the proposed instrument and its associated data algorithms, the likelihood of leveraging similar or complementary measurements, and the likelihood of data gaps that would adversely affect the quality of the measurement. It represents the probability that the proposed measurement would be successfully achieved.
Affordability (A)	1 – 5	Affordability of a proposed continuity measurement includes consideration of the total cost of developing, producing, and maintaining the sought-after data record.

Time to Detect Climate Change

$$\Delta t = \sqrt[3]{12s^2\left(\sigma_{\text{var}}^2\tau_{\text{var}} + \sigma_{\text{cal}}^2\tau_{\text{cal}} + \sigma_{\text{sam}}^2\tau_{\text{sam}} + \sigma_{\text{alg}}^2\tau_{\text{alg}}\right) \big/ m^2}$$

where:

Δt = time to detect an anthropogenic trend

s = detection confidence level (s=2 for 95% confidence)

σ = variance

τ = autocorrelation time scale

var = natural variability

cal = calibration uncertainty

sam = sampling uncertainty

alg = algorithm uncertainty

m = trend magnitude to detect

Example Quality Metric

TABLE 4.6 Example of the Dependence of the Quality Metric Q_2 for a Proposed Measurement on the Time Delay for Its Measurement of Climate Trends When Compared to the Time to Detect the Trend for a Perfect Observing System

Time Delay $\Delta t - \Delta t_P$ (years)	Q_2
0	1.0
5	0.83
10	0.67
15	0.50
20	0.33
25	0.16
30	0

Success Probability

$$P_s = P_{\mathrm{accu}} P_{\mathrm{sam}} P_{\mathrm{alg}} (1 - P_{\mathrm{gap}}) P_{\mathrm{mgt}}$$

where:

P_{accu} = Probability of achieving the accuracy uncertainty
P_{sam} = Probability of achieving the sampling uncertainty
P_{alg} = Probability of achieving the algorithm uncertainty
P_{gap} = Probability of a data gap with a large impact on
P_{mgt} = Probability of achieving the measurement given the management approach (e.g. Class A,B,C,D)

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 Oct 2013 paper for example: broadly applicable
- Economic Value of Improved Climate Observations and Models
  - See J. Env. Sys. Decisions paper for example: broadly applicable

Summary

Lack of accuracy = delayed knowledge

We lack a climate observing system capable of testing climate predictions with sufficient accuracy or completeness

At our current pace, its seems unlikely that we will understand climate change even after another 35 years.

We cannot go back in time and measure what we failed to observe.

Its time to invest in an advanced climate observing system

“I skate to where the puck is going to be, not to where it has been”

(Wayne Gretsky: when asked to explain the secret of his success)