Economic Value of a More Accurate Climate Observing System

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Outline

- Science is an economic investment by the public
- We will be managing Earth's climate until civilization moves elsewhere
- We have no climate observing system, nor a plan to create one. Should we invest in one? Is it worth it?
- What is the economic value of an advanced climate observing system?

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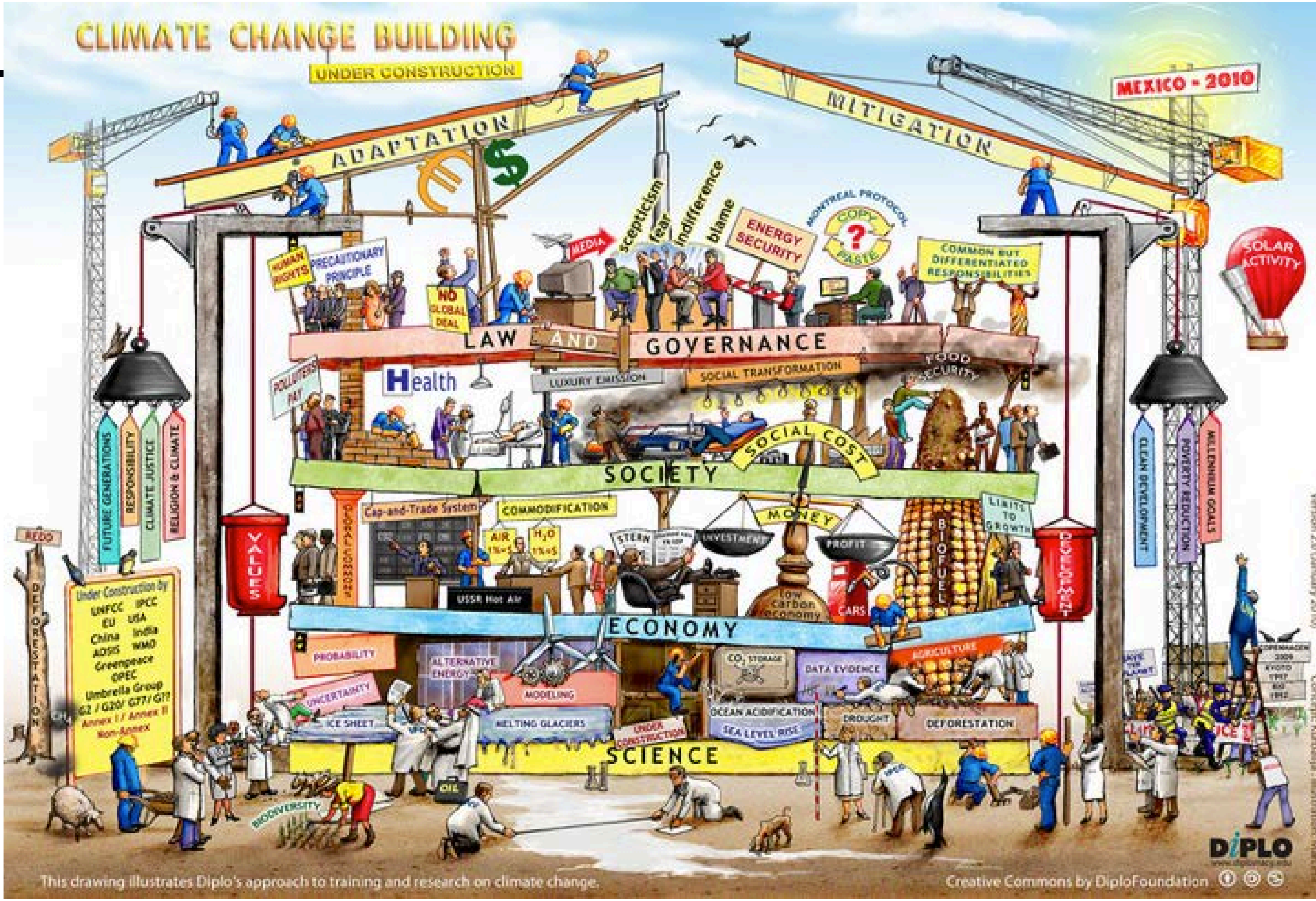
- What is the economic value of an advanced climate observing system?
- ***An initial framework suggests ~ its really big***.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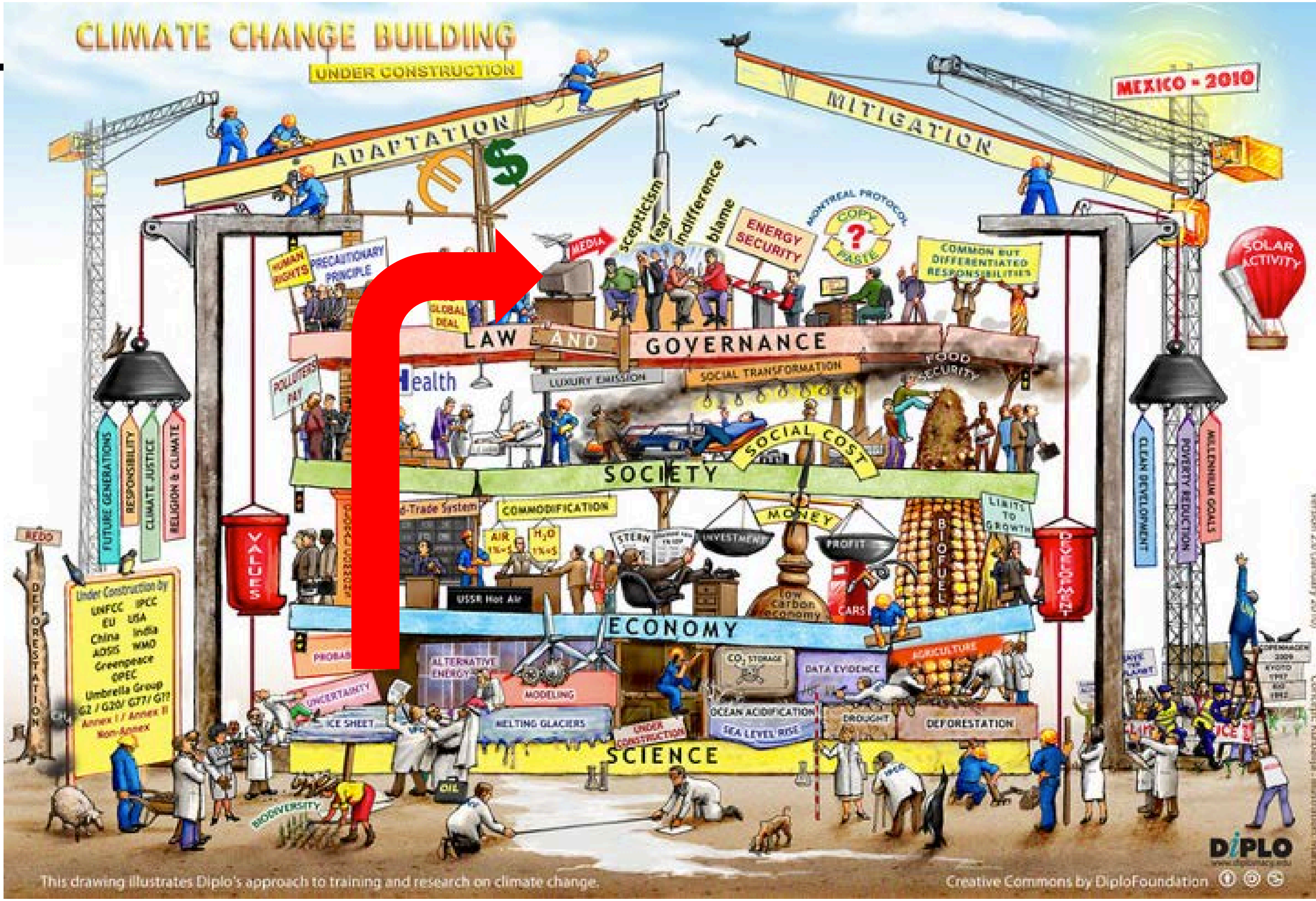

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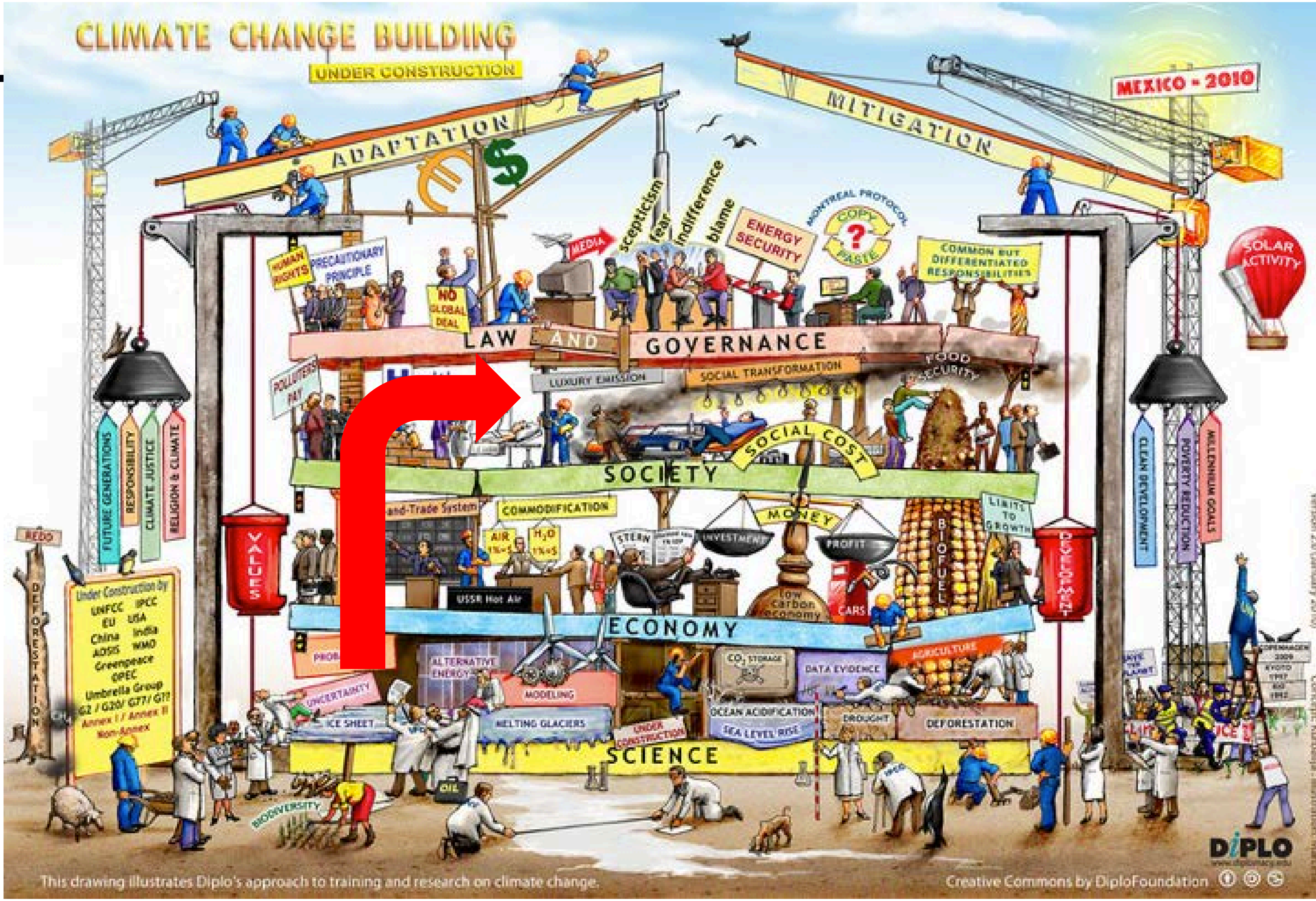
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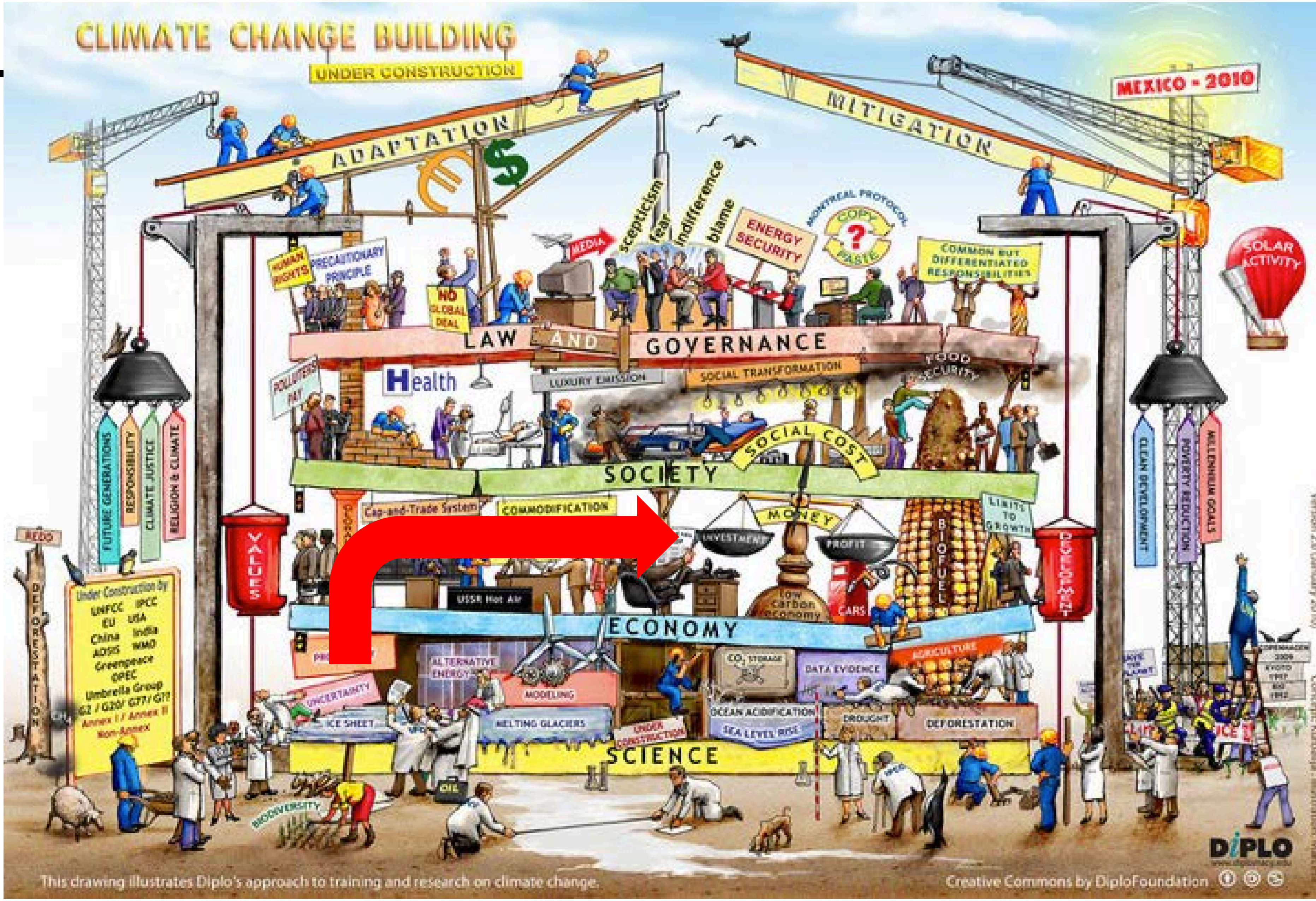

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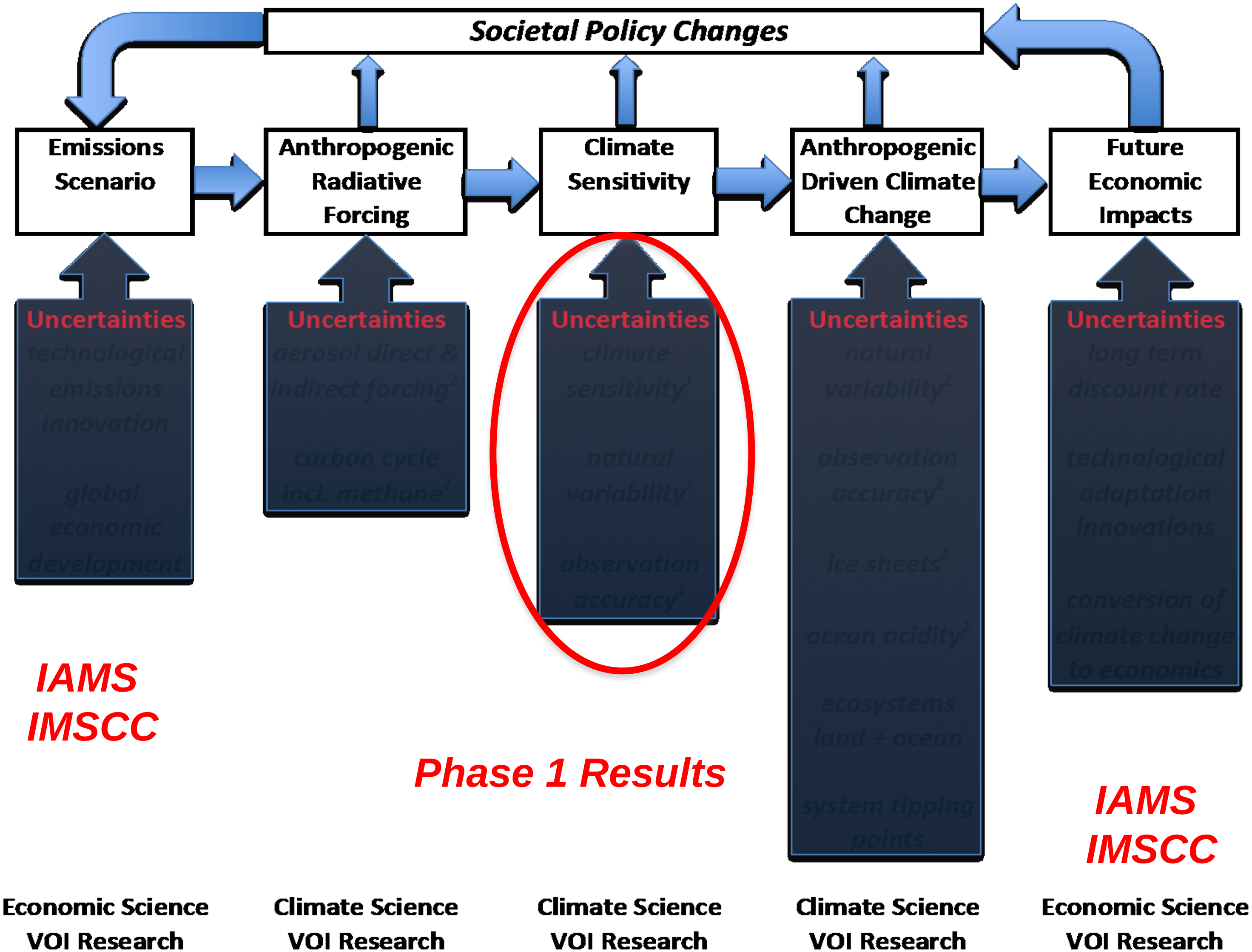
What is the Economic Value of Climate Science?

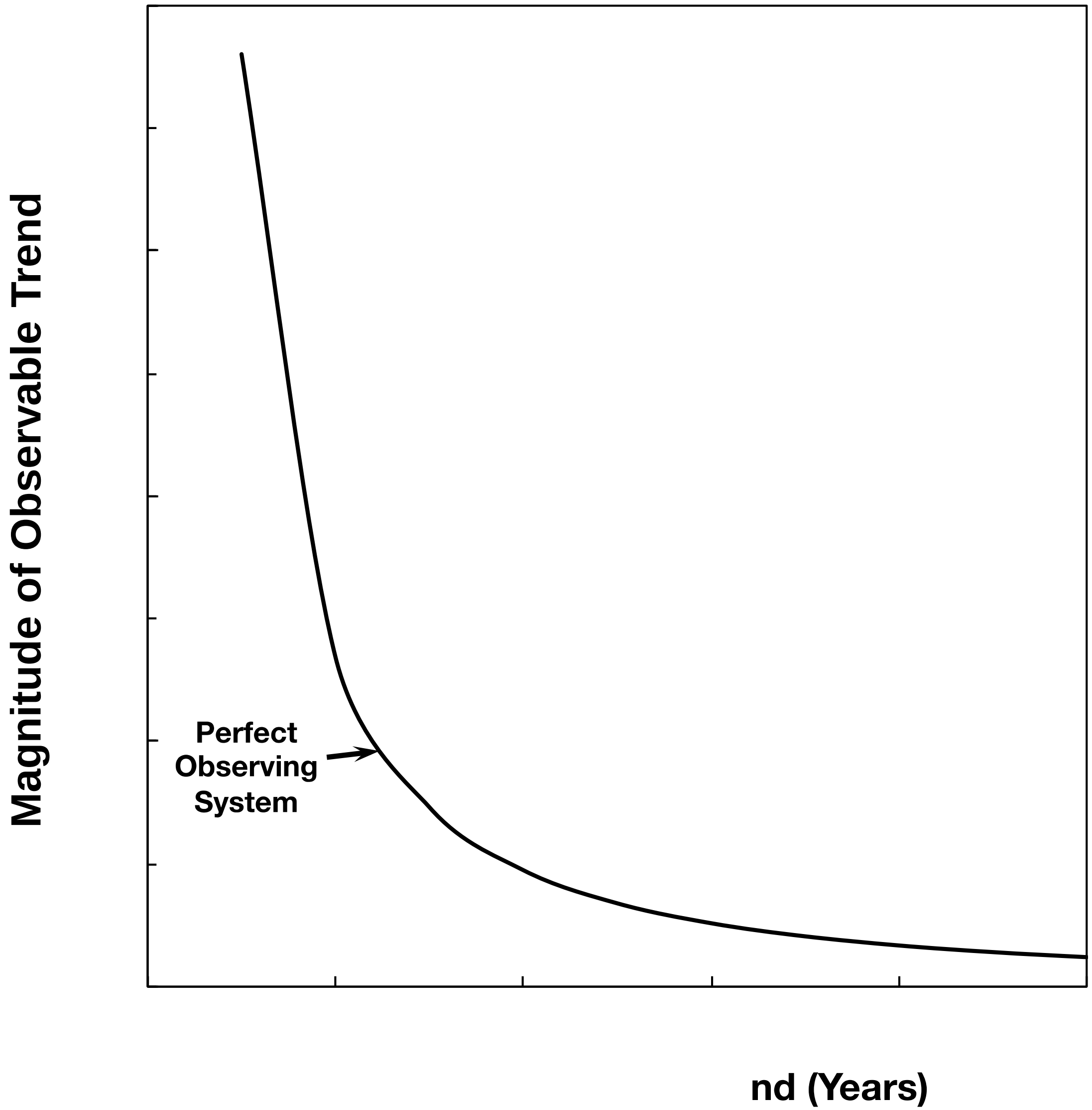
- We have a few traceable estimates of the economic value of weather prediction
- Climate scientists often say that the results from their research ***"will inform societal decisions with trillion dollar impacts"***
- But is this statement verified and traceable in any way?
- How could we quantify an economic value to climate science?
  - Climate change science value exists decades into the future
  - That value has to be treated as a risk/benefit economic analysis
  - Rigorous analysis must take into account the uncertainties in both climate science, economic impacts, policy
- Science value and economic frameworks are potentially valuable for strategic planning of the Earth observing system, as well as communicating what we do and its value to society

Requires a combination of climate science and economics expertise

Value of Climate Science Observations



Accuracy Requirements of the Climate Observing System



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

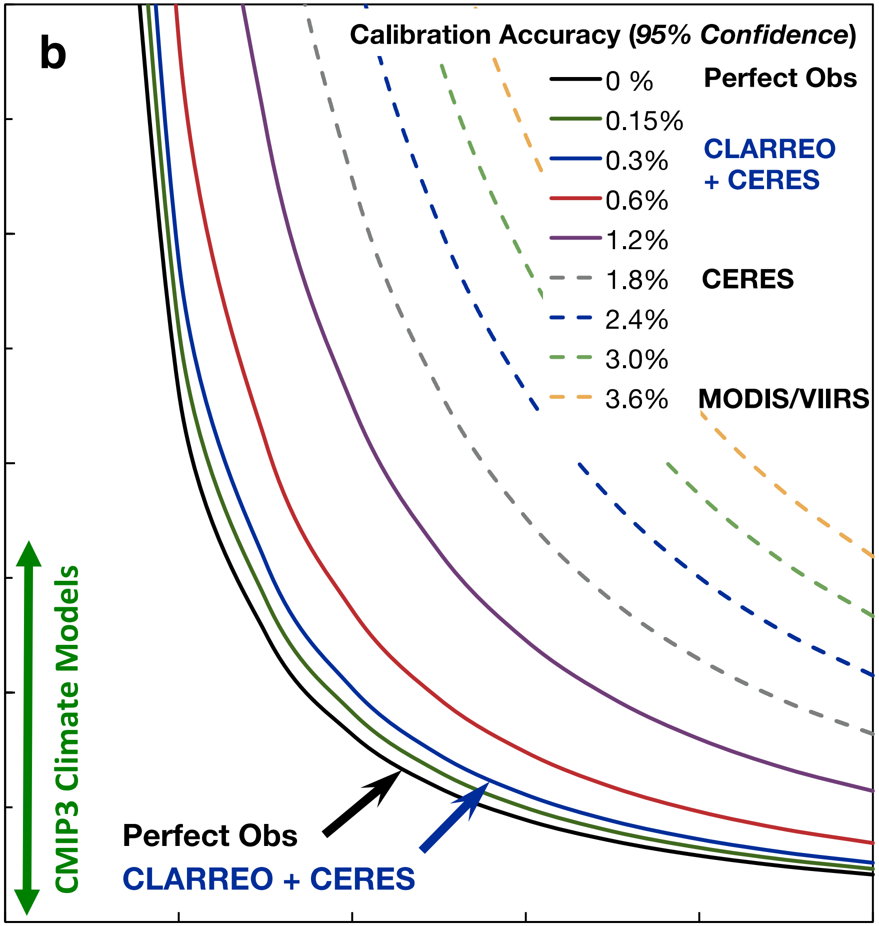
•Natural variability

•The magnitude of human driven climate change

•The accuracy of the observing system

Even a perfect observing system is limited by natural variability

Reflected Solar Accuracy and Climate Trends



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

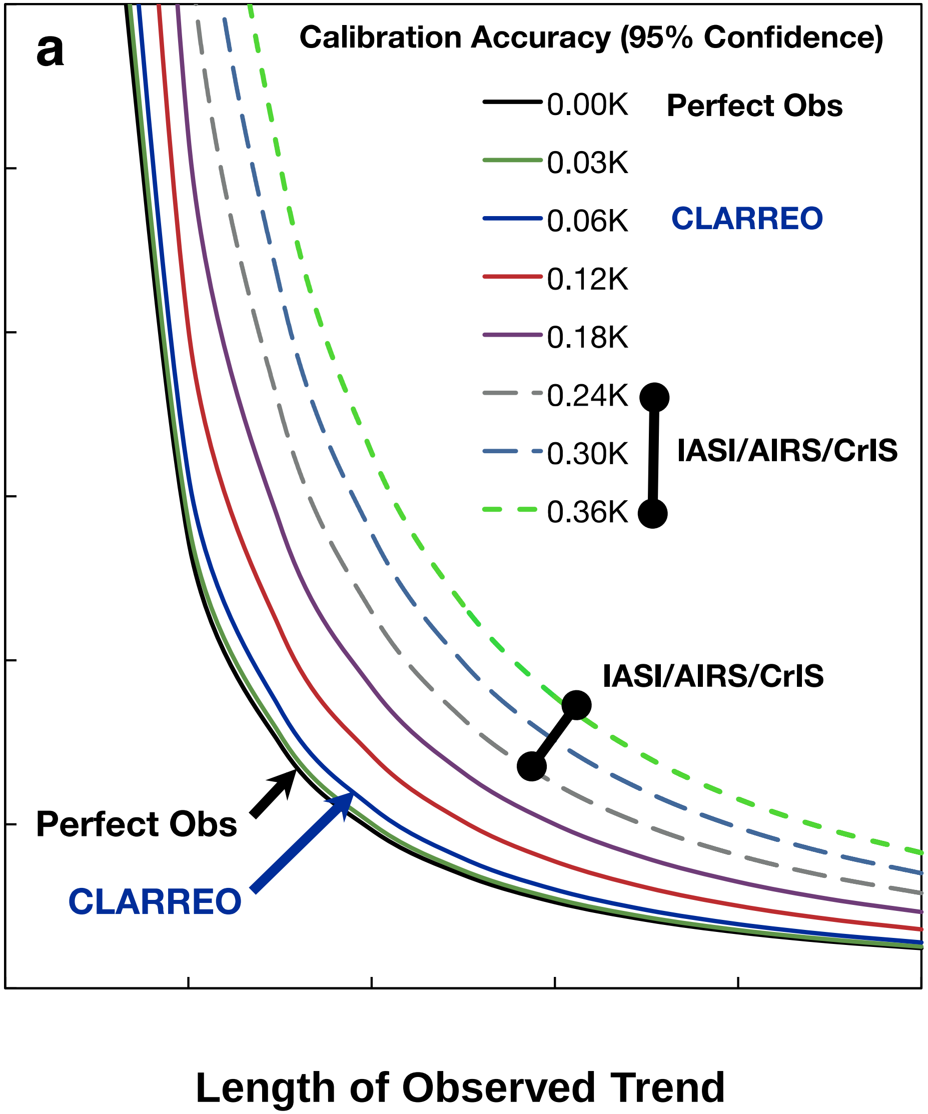
Climate Sensitivity Uncertainty = Cloud Feedback Uncertainty = Low Cloud Feedback = *Changes in SW CRF/decade (y-axis of figure)*

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

High accuracy is critical to more rapid understanding of climate change

Infrared Accuracy and Climate Trends

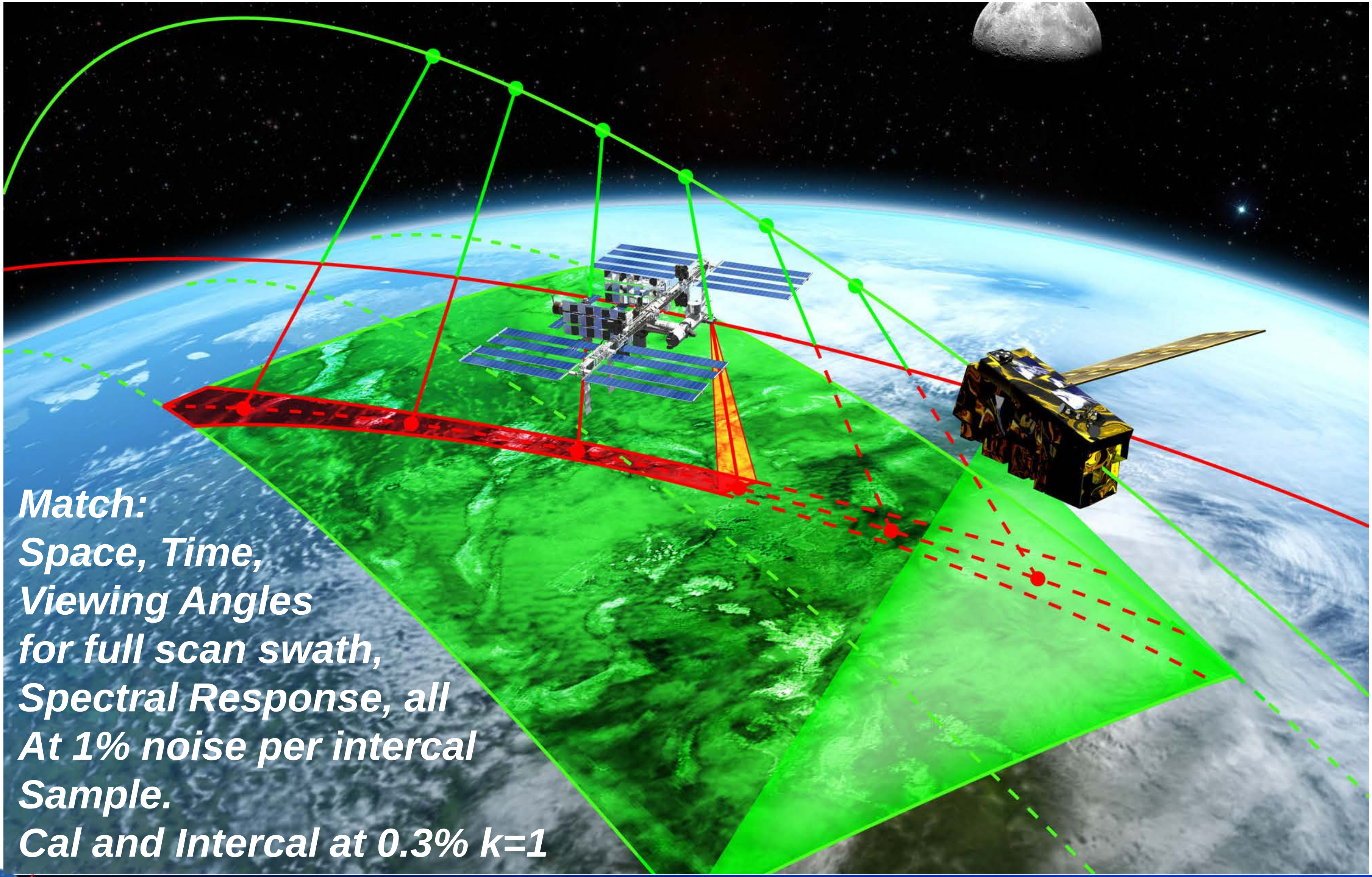


IPCC next few decades temperature trends: 0.16C to 0.34C varying with climate sensitivity

An uncertainty of half the magnitude of the trend is ~ 0.1C. Achieved 15 years earlier with CLARREO accuracy.

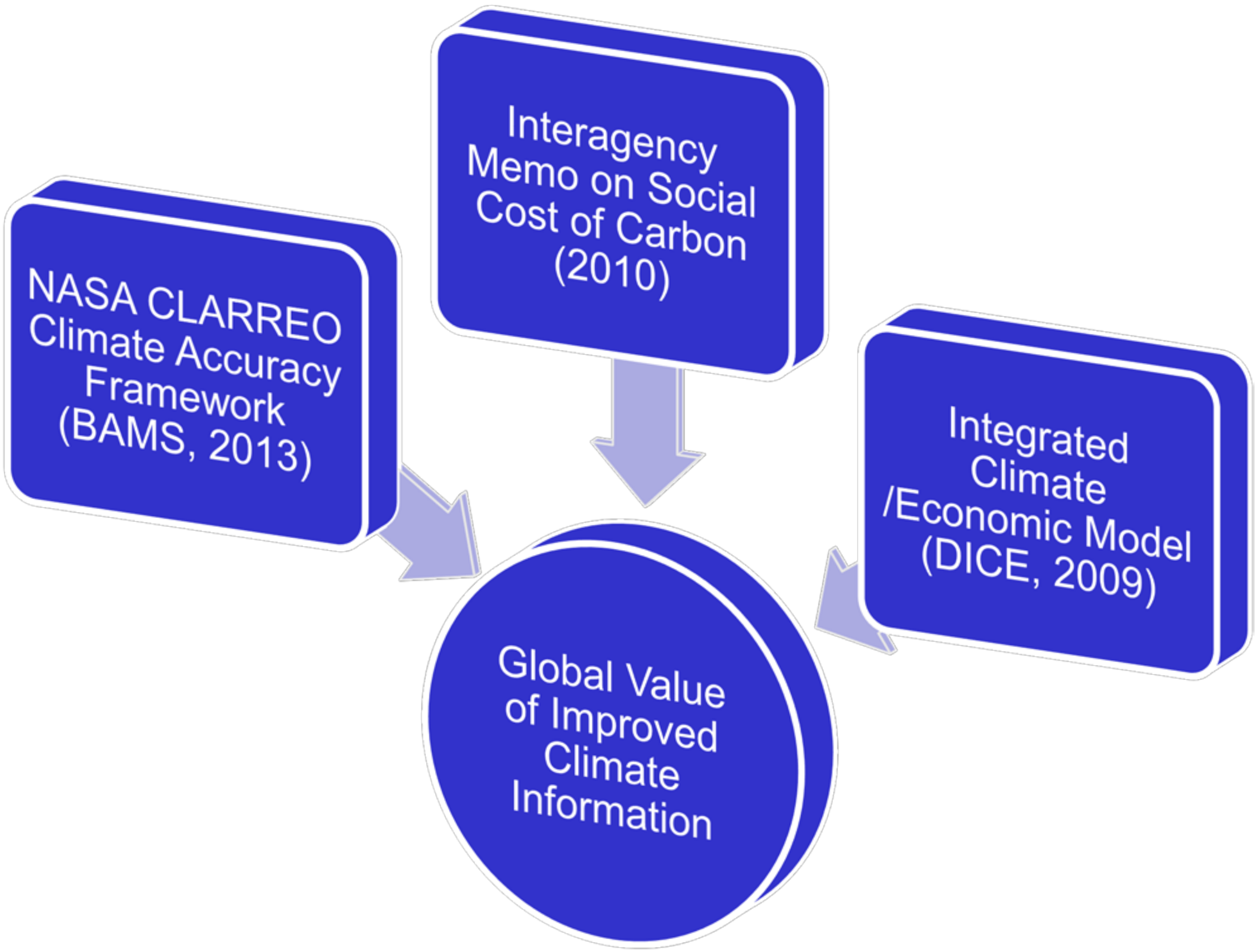
High accuracy is critical to more rapid understanding of climate change

CLARREO Pathfinder on ISS (2021)

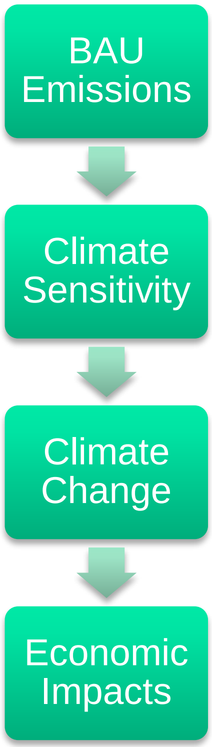


CLARREO Pathfinder Phase A began in 2016

What is the right amount to invest in climate science?



Value of Information Estimation Method



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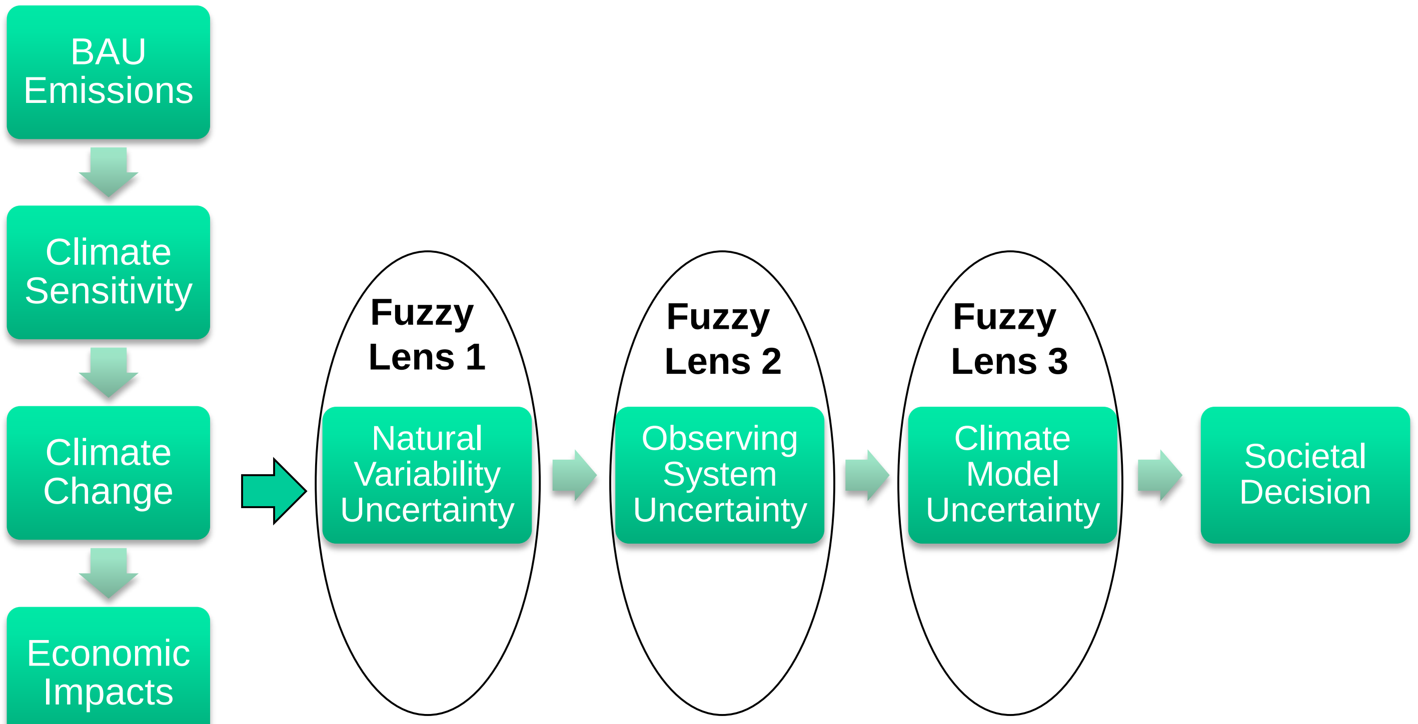

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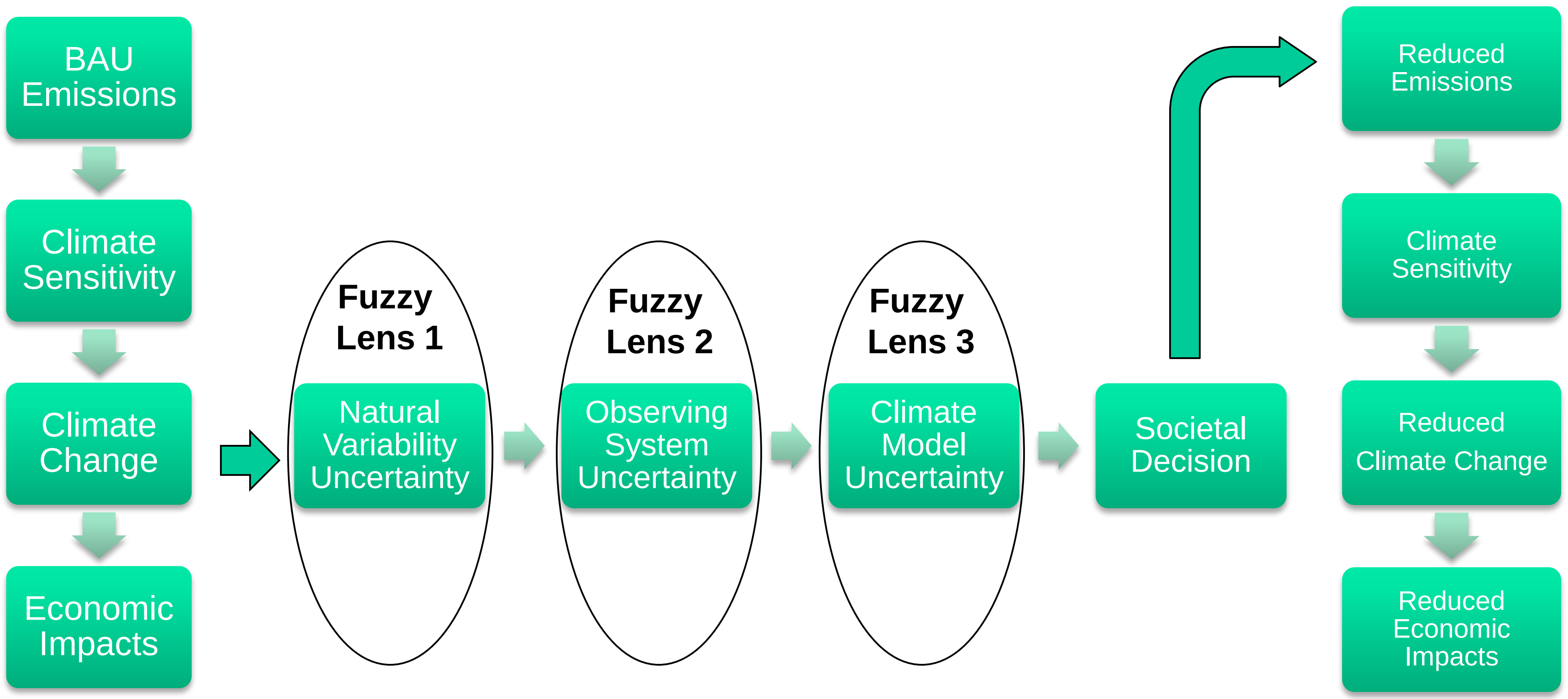

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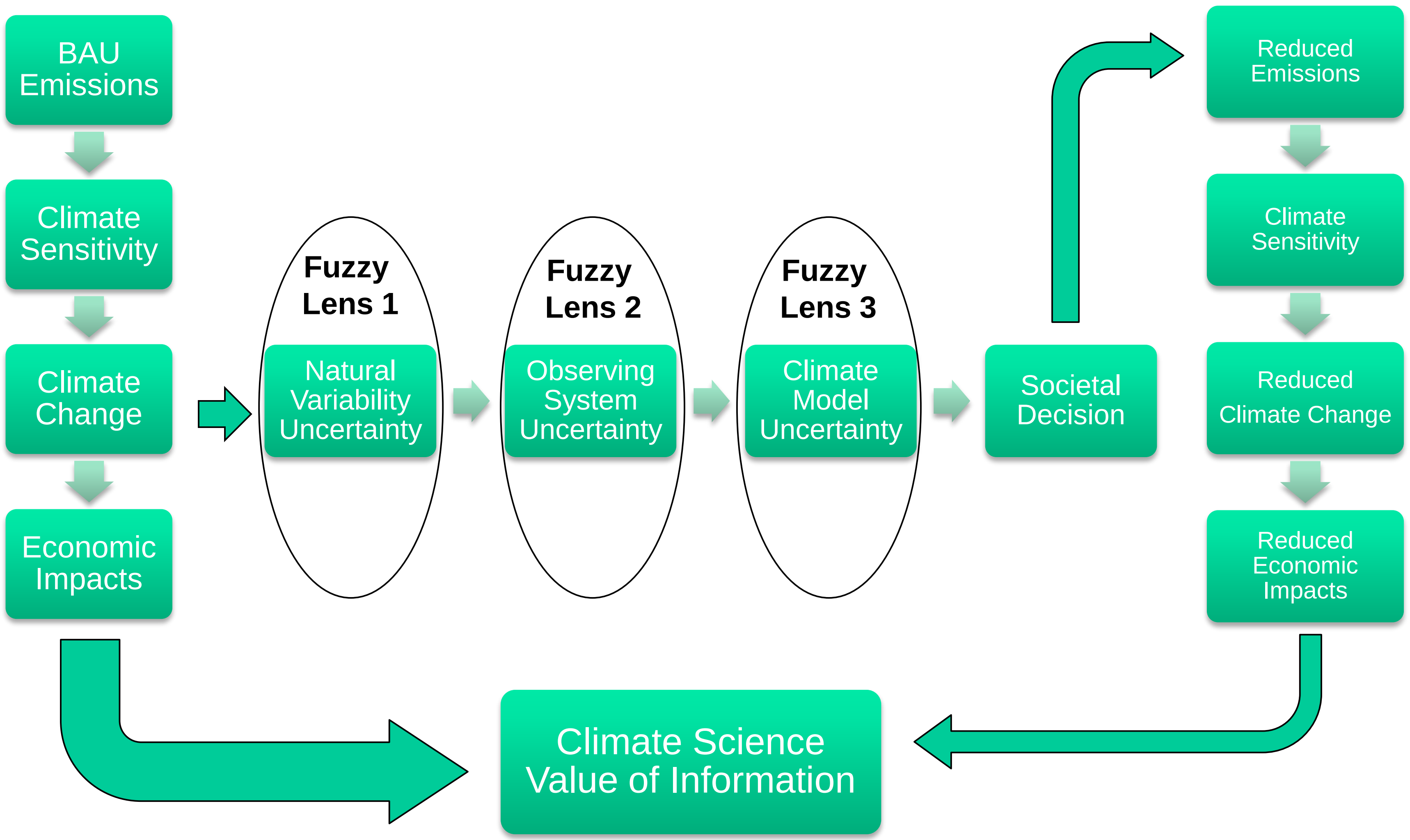

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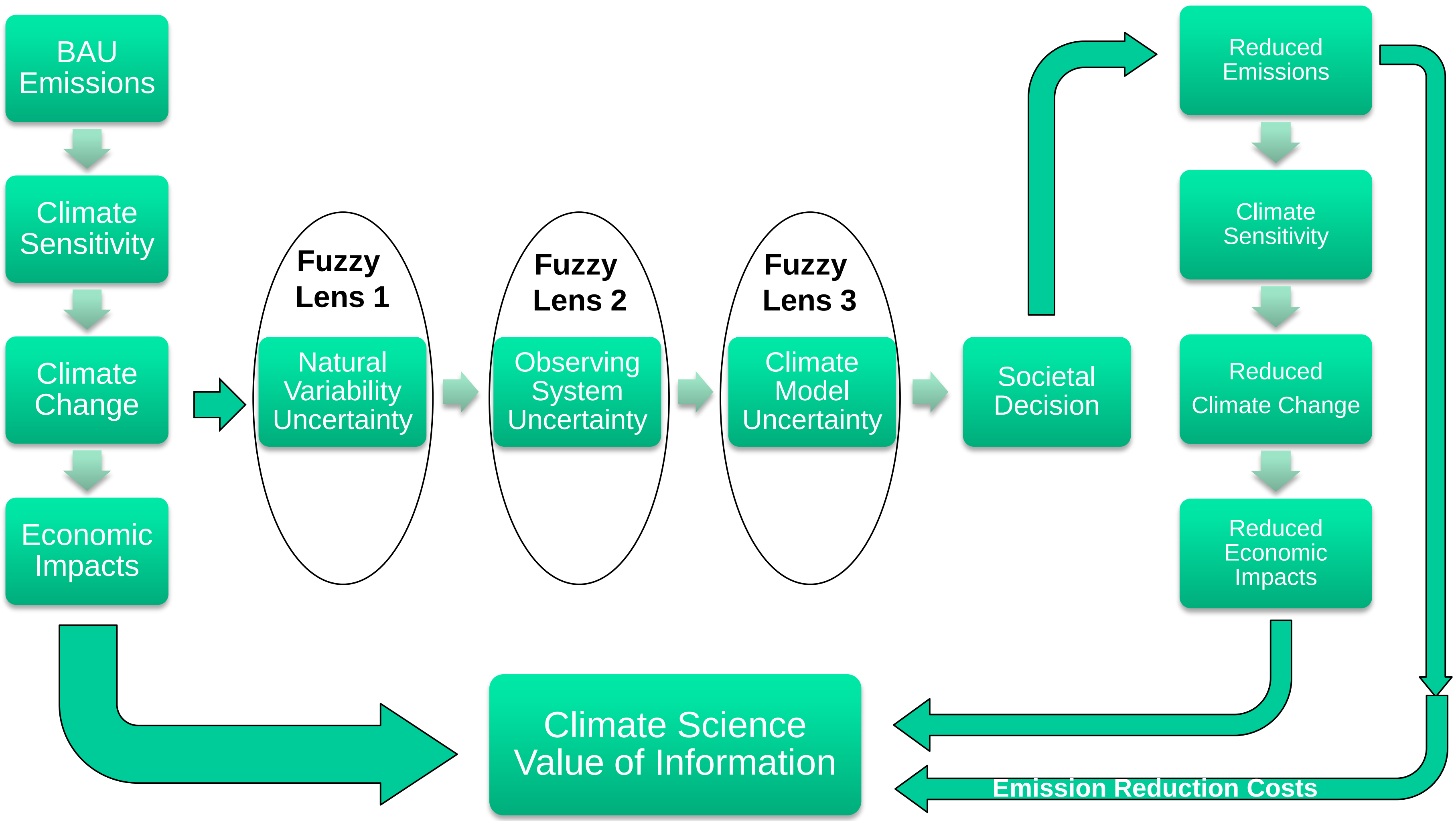

Economics: The Big Picture

- 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	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)
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3%	$11.7 T
5%	$3.1 T

Advanced Climate Observing System:

Return on Investment: $50 per $1

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

Results and Sensitivity to Assumptions

World Wide Economic Benefits

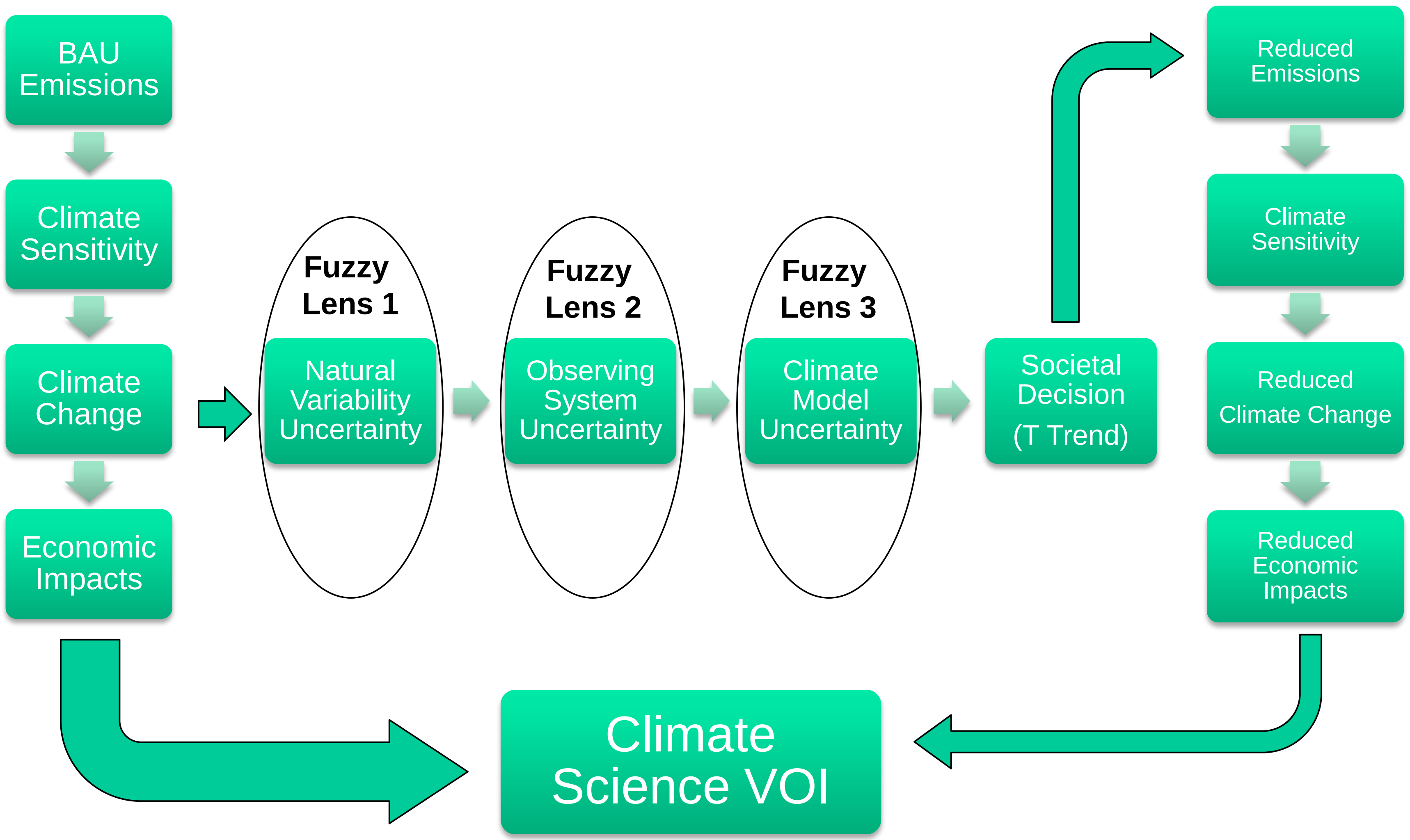
Parameter Change	CLARREO/Improved Climate Observations VOI (Trillion US 2015 dollars, NPV) 3% discount rate
Baseline*	$11.7 T
BAU => AER	$9.8 T
0.3C/decade trigger	$14.4 T
2030 launch	$9.1 T

*** Baseline uses 0.2C/decade trigger, 95% confidence in trend, BAU => DICE optimal emissions, 2020 launch**

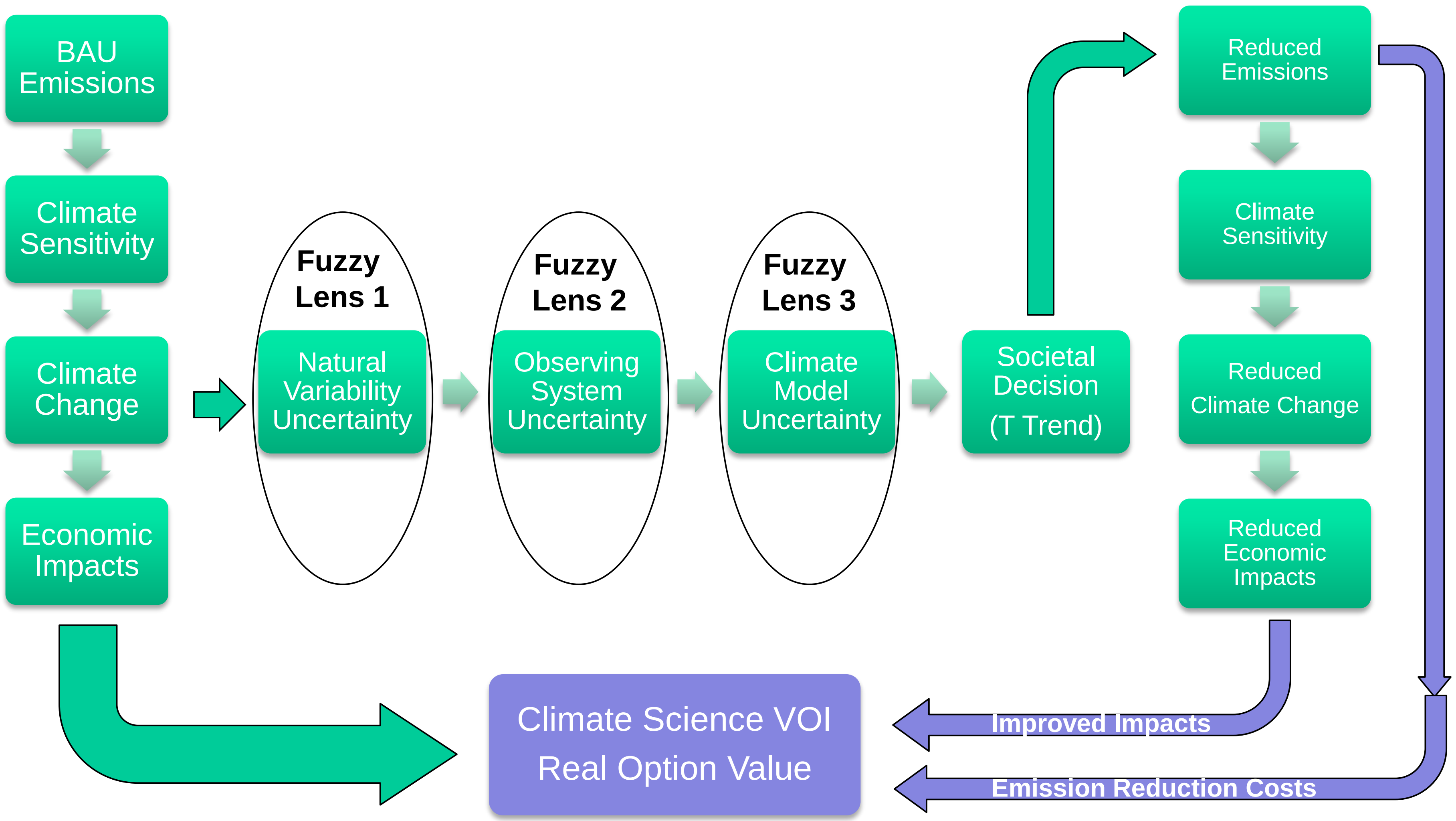
- **Delaying launch by 10 years reduces benefit by $2.6 T**

Each year of delay we lose $260B of world benefits

VOI Estimation Method: Cooke et al. 2014



VOI Estimation Method: Cooke et al. 2016a



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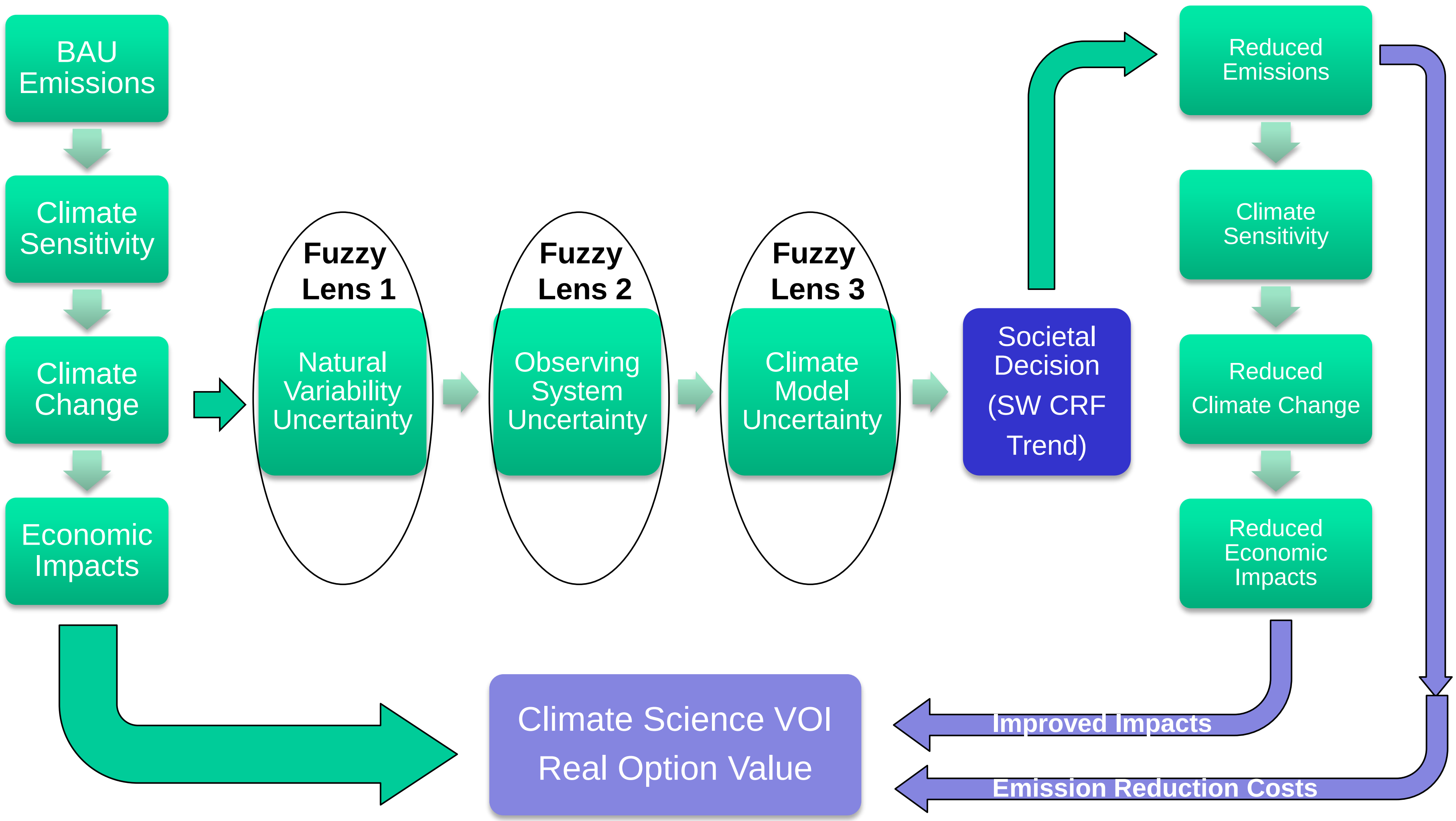

Summary of Temperature and SW CRF Results

- Higher accuracy Temperature Trends:
  - $9 Trillion economic value
- Higher accuracy SW Cloud Radiative Forcing Trends:
  - $20 Trillion economic value
- Cost per year of delay:
  - Infrared trends: $250B/yr of delay
  - SW CRF trends: $580B/yr of delay

- Conditions:
  - 3% Discount rate (decrease/yr) on future benefits realized
  - Nominal 2020 launch of higher accuracy observations
  - 95% confidence when decision made
  - Includes cost of emission reductions and benefits of avoided climate change impacts

Summary

- SW CRF as a climate sensitivity trigger shows larger economic value than using a temperature trigger (factor of 2)
  - SW CRF decadal change signal varies more directly with climate sensitivity and over a wider range of signal
  - CLARREO reflected solar calibration advance is larger (factor of 5 to 10) than infrared (factor of 3 to 5)
  - Shorter autocorrelation time for natural variability of SW CRF: not related to the 5 year ENSO time scale as seen for temperature
- Initial next step Bayesian Net results show both the value of using multiple climate variables, as well as the value of higher accuracy observations

Caveats

- Economics estimates have large uncertainties, but they can both increase or decrease the current economic VOI costs.
- Examples that would increase economic value:
  - The following climate change costs are not included in the 2010 U.S. Social Cost of Carbon Memo:
    - *Ocean acidification,*
    - *International conflicts caused by refugees of climate change,*
    - *Species loss*
    - *Unexpected accelerations such as arctic methane or carbon dioxide greenhouse gas emissions as climate warms*
    - *Larger than expected sea level rise (e.g. recent Hansen et al 2016 paper just released on nonlinear sea level rise rates)*
- Examples that would decrease economic value:
  - Unexpected societal shift to rapidly eliminate CO_2 emissions well beyond the recent Paris agreement (factor of 2 to 4 faster reductions)
  - Unexpected early technological breakthrough in cost reduction of renewable energy (e.g. sudden factor of 4 reduction in solar, wind, battery costs by 2020)

Summary

- Current observations used for climate have an even larger economic value than those shown here: without them we would not even know climate change was happening. Current global climate science research investment ~ $4 Billion U.S. per year
- Further investments to triple this level to $12 Billion per year to build an international Climate Observing System would pay back ~ $50 for every $1 invested (NPV, 3% discount rate)
- New studies confirm these first two paper results:
  - An independent analysis by Hope et al 2015 "The $10 trillion value of better information about the transient climate response. Phil. Trans. R. Soc. A 373: 20140429. http://dx.doi.org/10.1098/rsta.2014.0429
  - A third Cooke et al paper using shortwave cloud radiative forcing trends for cloud feedback/climate sensitivity constraint as a societal decision trigger instead of temperature trends: increases VOI to about 20 Trillion. Includes carbon emissions reduction costs.

Conclusion

- Even large (factor of 5) changes in the economic analysis leave the conclusion unchanged*:*

- *Return on Investment of a New Climate Observing System would range from 10:1 to 250:1*

- *A New Climate Observing System would be one of the most cost effective investments society could make to provide a stable economic future*.

References: Climate Accuracy Requirements

- Leroy et al. 2008: Climate signal detection times and constraints on climate benchmark accuracy requirements. J. Climate, 21, 841–846. *Basic trend detection math.*

- Wielicki et al. 2013: Achieving climate change absolute accuracy in orbit. Bull. Amer. Met. Soc., 1520-1539. *CLARREO mission overview and extended trend detection math for figures in this presentation for temperature and cloud feedback*

- Shea et al: 2017: Quantifying the Dependence of Satellite Cloud Retrievals on Instrument Uncertainty. J. Climate. *Accuracy requirements for cloud physical properties including cloud algorithm impacts*

- Xu et al: 2017: Spectrally Dependent CLARREO Infrared Spectrometer Calibration Requirement for Climate Change Detection. J. Climate*.* *Temperature and Humidity profile accuracy requirements.*

- ***CLARREO and CLARREO Pathfinder Mission Web Site:*** **https://clarreo.larc.nasa.gov/**

References: Economic Value of Information

- Cooke, R., B. A. Wielicki, D. F. Young, and M. G. Mlynczak, 2014: Value of Information for Climate Observing Systems. Journal of Environment, Systems, and Decisions, *Environ Syst Decis*, 34, 98–109, DOI 10.1007/s10669-013-9451-8.

- Cooke, R., A. Golub, B. A. Wielicki, D. F. Young, M. G. Mlynczak, R. R. Baize, 2016a: Real Option Value of Earth Observing Systems. *Climate Policy*, DOI: 10.1080/14693062.2015.1110109, 16pp.

- Cooke, Roger M. Golub, Alexander, Wielicki, Bruce, Mlynczak, Martin , Young, David, Baize, Rosemary Rallo (2016b) Real Option Value for New Measurements of Cloud Radiative Forcing, RFF DP 16-19.

- Hope et al 2015 "The $10 trillion value of better information about the transient climate response. Phil. Trans. R. Soc. A 373: 20140429. http://dx.doi.org/10.1098/rsta.2014.0429

General Economics Background Information

- Nordhaus, William, 2008: A Question of Balance, Weighing the Options on Global Warming Policies. Yale Univ. Press, New Haven, 232pp.
  - Explains key concepts such as Discount Rate, Net Present Value, and Integrated Assessment Models at a general bachelors college level. Does not assume any economics background. Particularly well suited to climate change economics.
- Adams, V. et al., 2011: Analyzing the Socioeconomic Impacts of the Use of Earth Observations, A Primer. Prepared for NASA by Booz Allen, 40pp.
  - Explains a range of basic economic concepts applicable to a wide range of socioeconomic benefits of Earth Observations.
- Encourage collaboration with university economics departments: many of who will have someone already working on IPCC Working Group II and III reports
- NASA Application Program funds this type of research and has a new consortium for Earth observation economics studies led by Resources for the Future in Washington, DC.

Backup Slides

An Initial Next Step
Towards a Climate Observing System

CLARREO Pathfinder Mission Summary

- Demonstrate CLARREO calibration accuracy spectrometers (IR and RS) on International Space Station
- Nominal launch is in 2020, nominal operations 2 years
- At least one and potentially both spectrometers: final decision ~ mid-2016 (depends on final funding levels and international collaboration
- Class D low cost mission
  - Instrument design life 1 year at 85% probability, ~ 50% of achieving 4 yrs
- Demonstrate CLARREO level SI traceability in orbit
- Demonstrate CLARREO Reference Intercalibration for VIIRS, CERES, and CrIS instruments
- Take intercalibration observations for additional sensors (LEO, GEO) but Pathfinder budget only covers L0 processing for these orbit crossings
- If demonstrate success, then request funding to process full data stream and additional instrument intercalibration events, as well as nadir spectral benchmarking observations.

CLARREO Pathfinder on ISS

- Lessons learned from CLARREO Pathfinder will benefit a future CLARREO mission
  - Reduced risk
  - Demonstration of higher accuracy calibration approaches
  - Prove that high accuracy SI-traceability can be transferred to orbit
  - Show that high accuracy intercalibration is achievable
- CLARREO Pathfinder will demonstrate highest accuracy radiance and reflectance measurements from orbit
  - First on-orbit SI-traceable reflectance with uncertainty <0.5% (k=2)
  - First on-orbit SI-traceable temperature with uncertainty <0.1 K (k=3)
- Lessons learned from CLARREO Pathfinder will produce benefits across many NASA Earth Science Missions and International Missions
  - Improved laboratory calibration approaches
  - Development and testing of innovative on-orbit SI-traceable methods
  - Transfer calibration to sensors in operation at time of CLARREO Pathfinder
  - Improved lunar irradiance standard

CLARREO Pathfinder will improve accuracy across Earth Sciences

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 F_a in accuracy) is given by:

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

for linear trends where σ 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 F_t) is similarly given by:

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

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

Provides an integrated error budget across all decadal change error sources

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

Decadal Change Reference Intercalibration Benchmarks: Tracing Mission Requirements