Designing the Climate Observing System of the Future

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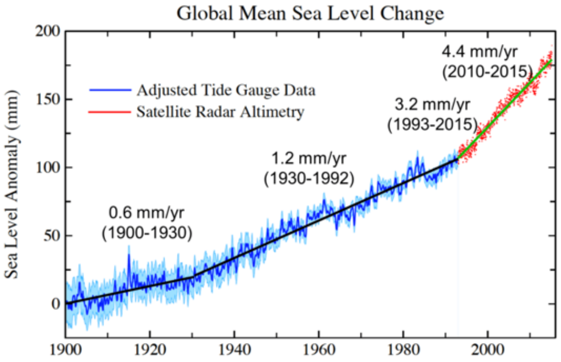
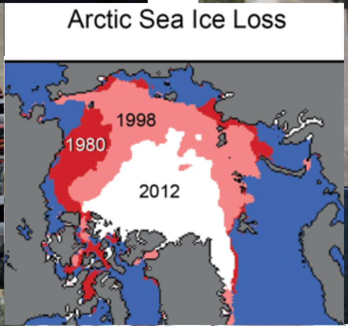
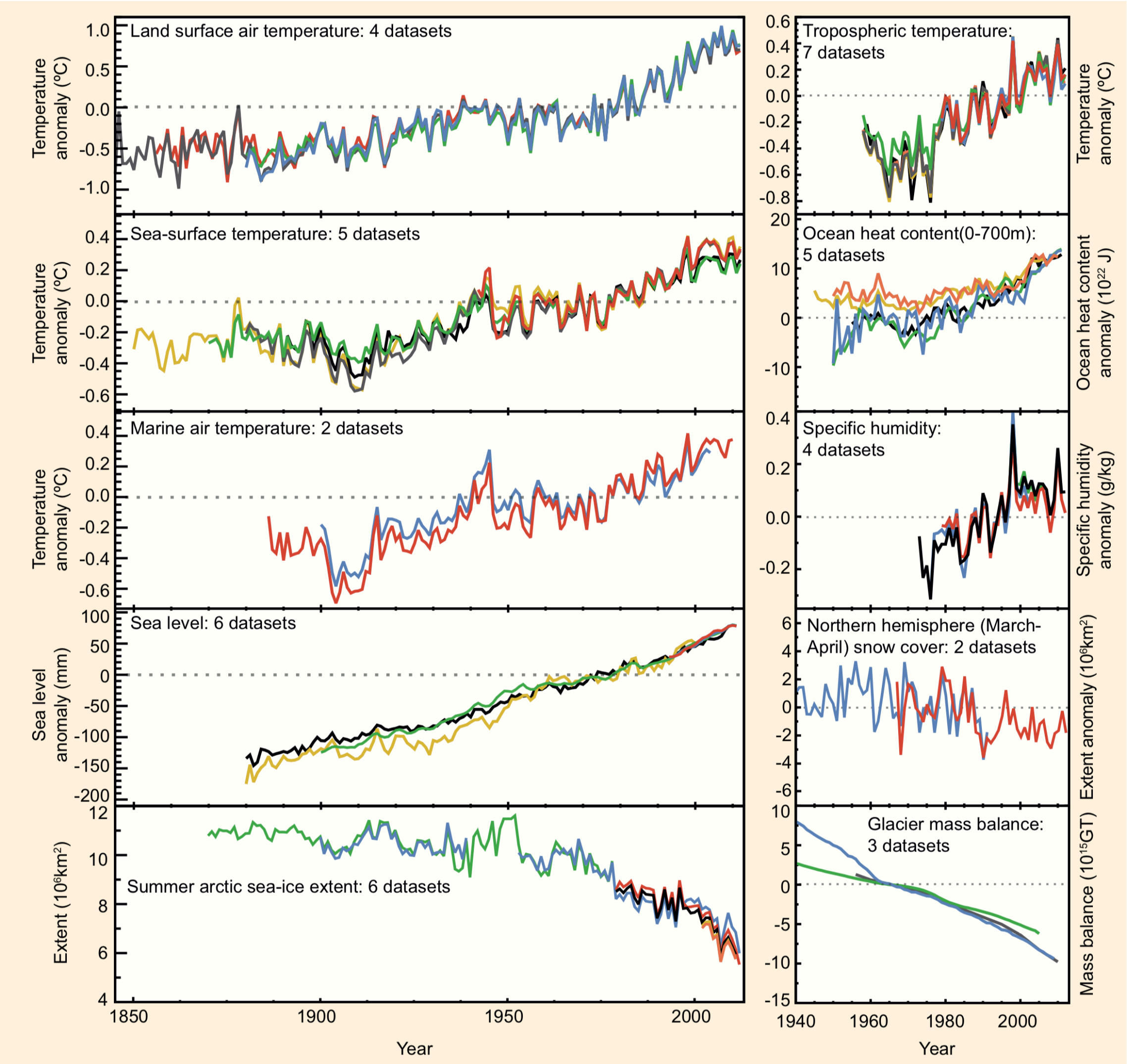
The Many Challenges of Climate Change



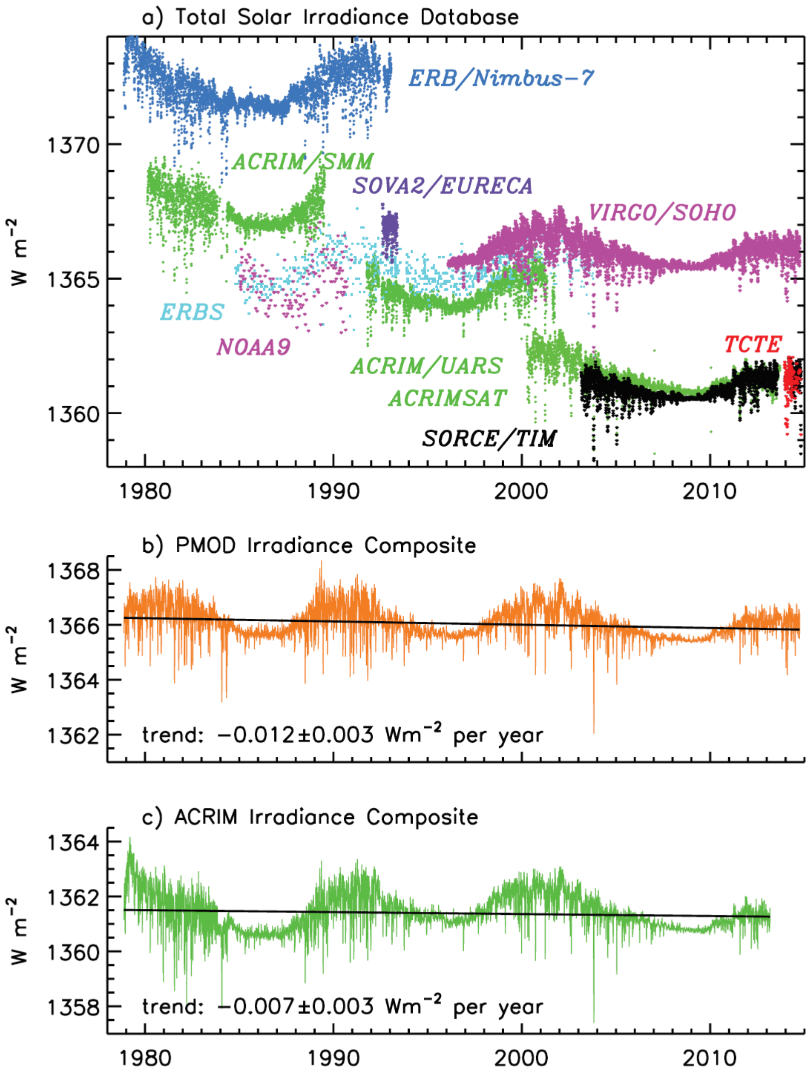


Climate Change Records, IPCC 2013



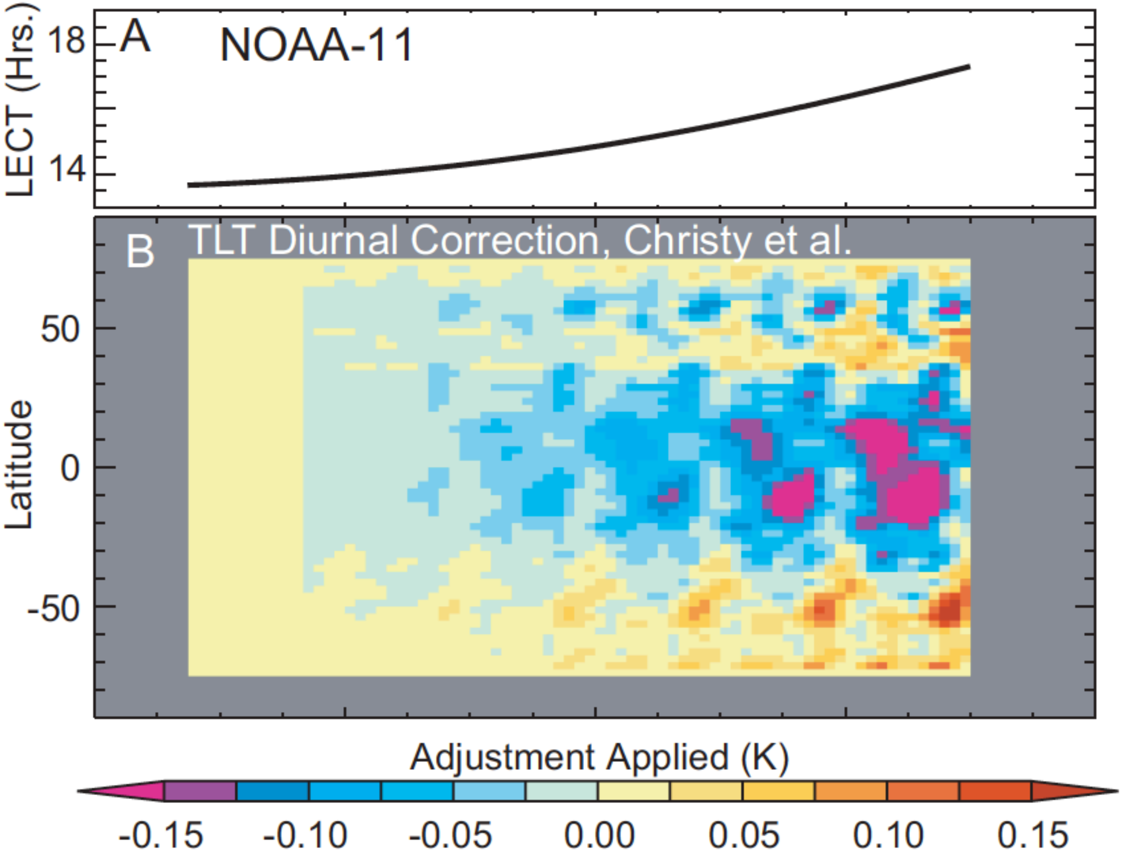
NRC Continuity Report, 2015

Changing Absolute Calibration Effects

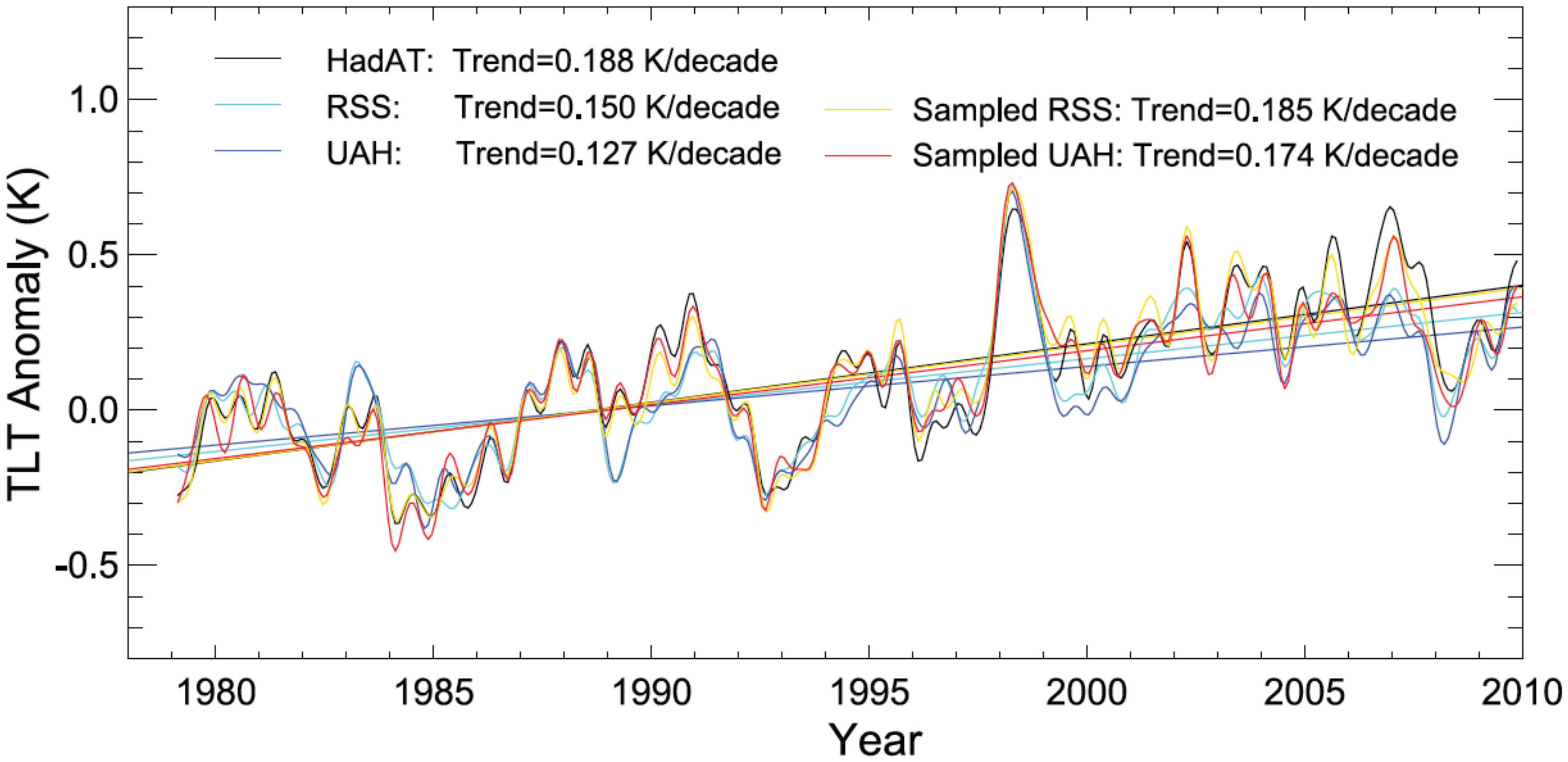


NRC Continuity Report, 2015

Changing Time Sampling Effects



NRC Continuity Report, 2015
Changing Analysis Method Effects



Why is a Climate Observing System Important?

- Climate change has very different requirements than weather observations:
  - *10 times more accuracy: 0.03K instead of 0.3K*
  - *10 times as many key variables: 50 vs 5*
  - *Prediction time scales of decades vs days*
  - *Need for independent observations and analysis to verify surprises: cannot go back in time to verify them*
  - *Observations that must maintain consistency over many decades*
    - *Much longer than space based instrument lifetimes (5-15 years)*
    - *Longer than a scientist's career*
- Climate system physical, chemical, and biological processes occur on scales that vary from millennia down to seconds, and from global down to micrometers
- The challenge of such an observing system exceeds anything humanity has attempted to date for any scientific field.

Do we have a Climate Observing System?

- ***No. Nor do we currently have any committed plan to build one***
- We do have many documents that discuss the shortcomings in our current observations used for climate change research and monitoring
  - Strategy Towards and Architecture for Climate Monitoring from Space (Dowell et al. 2013, CEOS/CGMS/WMO report)
  - The Global Observing System for Climate: Implementation Needs (WCRP GCOS, 2016)
  - Simmons et al. 2016: Observation and integrated Earth-system science: A roadmap for 2016–2025 (COSPAR)
  - Designing the Climate Observing System of the Future (Weatherhead et al. 2017, AGU Earth’s Future)
  - 2017 Earth Science and Applications Decadal Survey (U.S. National Academy of Sciences), including over 30 quantified and prioritized climate science objectives (Chapter 10, Appendix B).
    - Critical observations missing for 80% of “Most Important” climate science objectives, 71% of “Very Important” objectives, 47% of “Important” objectives
    - ***Critical observations missing for ~ 2/3 of all climate science objectives***

Climate Change Detection Time: Perfect Observations

$$\Delta t_P = \sqrt[3]{12 s^2 \sigma_{var}^2 \tau_{var} / m^2}$$

Δt	time to detect the trend
m	trend magnitude
s	statistical confidence level ***(s = 2 ~ 95% confidence),***
σ^2_{var}	variance of natural variability
τ_{var}	autocorrelation time of natural variability

NRC Continuity Report, 2015

Climate Change Detection Time: Imperfect Observations

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

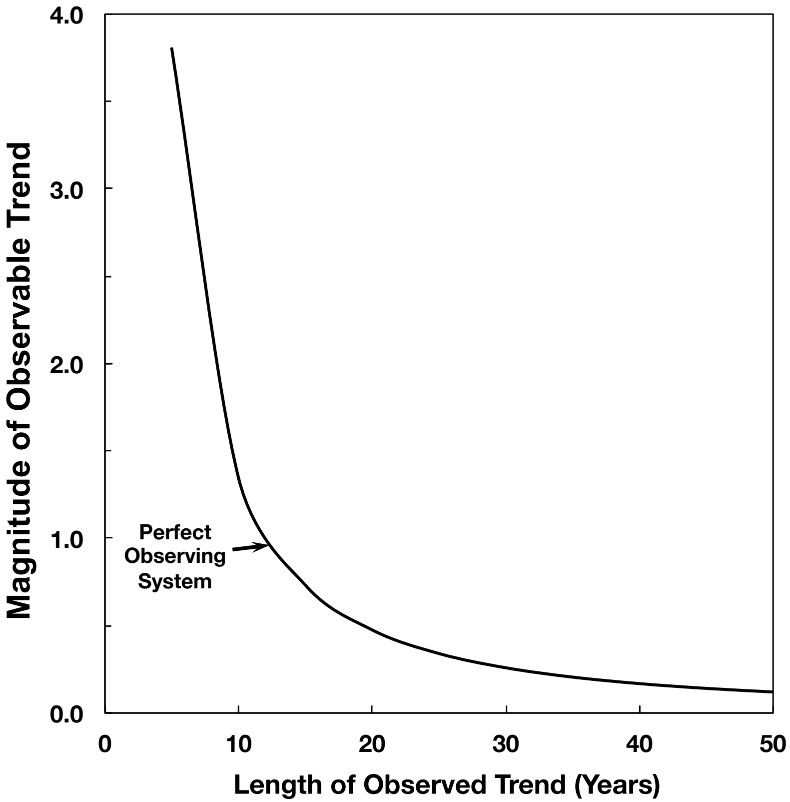
σ^2_{cal}, and τ_{cal} characterize instrument calibration uncertainty,

σ^2_{sam}, and τ_{sam} characterize time/space sampling uncertainty,

σ^2_{alg}, and τ_{alg} characterize analysis algorithm uncertainty

NRC Continuity Report, 2015

Accuracy Requirements of the Climate Observing System

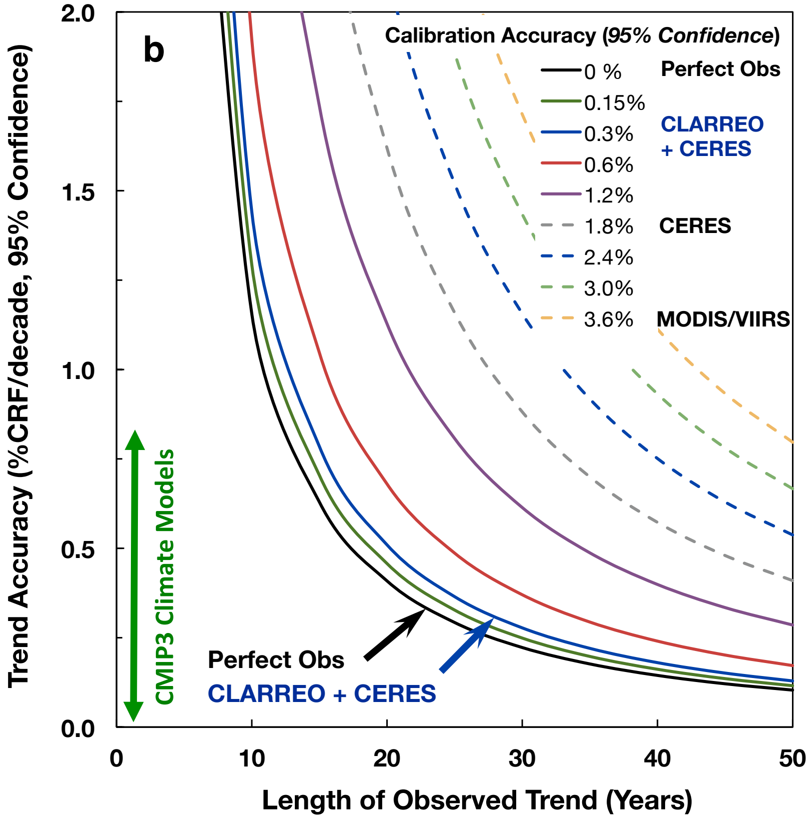


The length of time required to detect a climate trend caused by human activities is determined by:

- *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 intercalibration 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

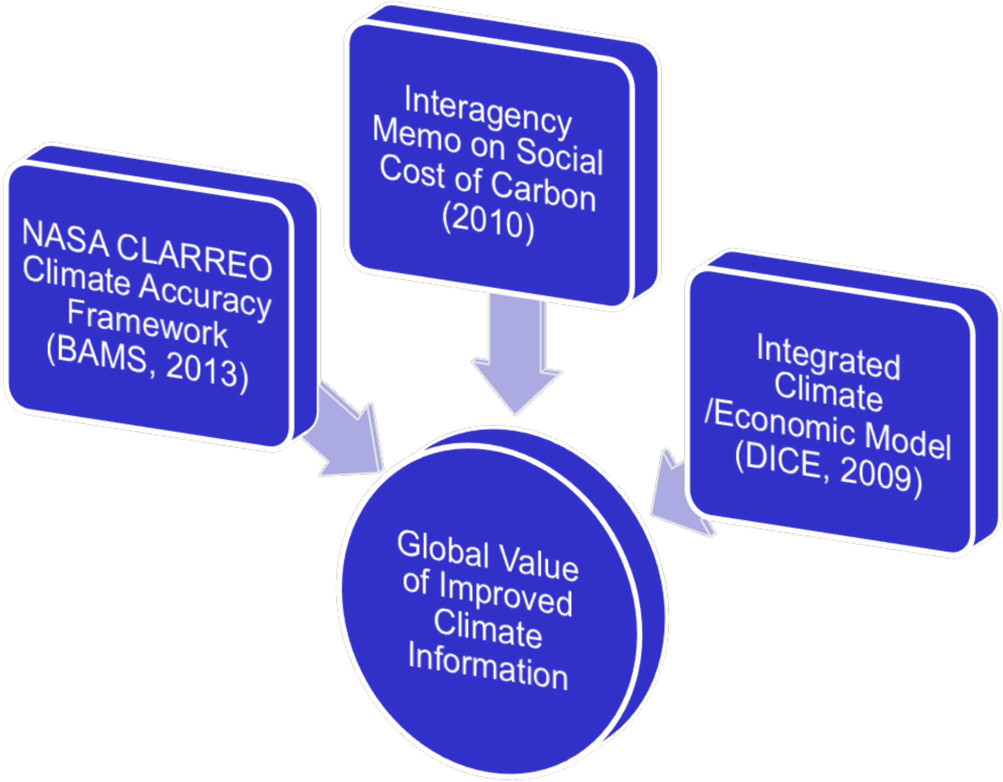
Examples of Needed Climate Observation Improvements

- Independent Observations (e.g. observation techniques and systems)
- Independent Observation Analysis (methods, analysis groups)
- Much more complete set of observations (critical observations missing from 2/3 of all climate science objectives in 2017 National Academy Decadal Survey): 50 essential climate variables vs. 5 weather variables.
- Sufficient absolute accuracy traceable to SI standards to successfully handle data gaps, and to determine instrument calibration drifts over years to decades
- Accuracy requirements for instrument accuracy, space/time sampling accuracy, retrieval accuracy to eliminate long delays in observing climate change trends
- Quantified climate science objectives based on major national and international reviews and reports (e.g. IPCC, WCRP, USGCRP, Academy of Sciences)
- See NRC Continuity Report, Nov. 2015 and Weatherhead et al. 2018 (AGU Earth's Future) for further details on quantitatively designing a climate observing system.

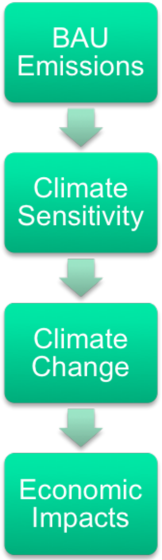
Economics: The Big Picture

- World GDP today ~ $85 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.

What is the right amount to invest in climate science?



Value of Information Estimation Method



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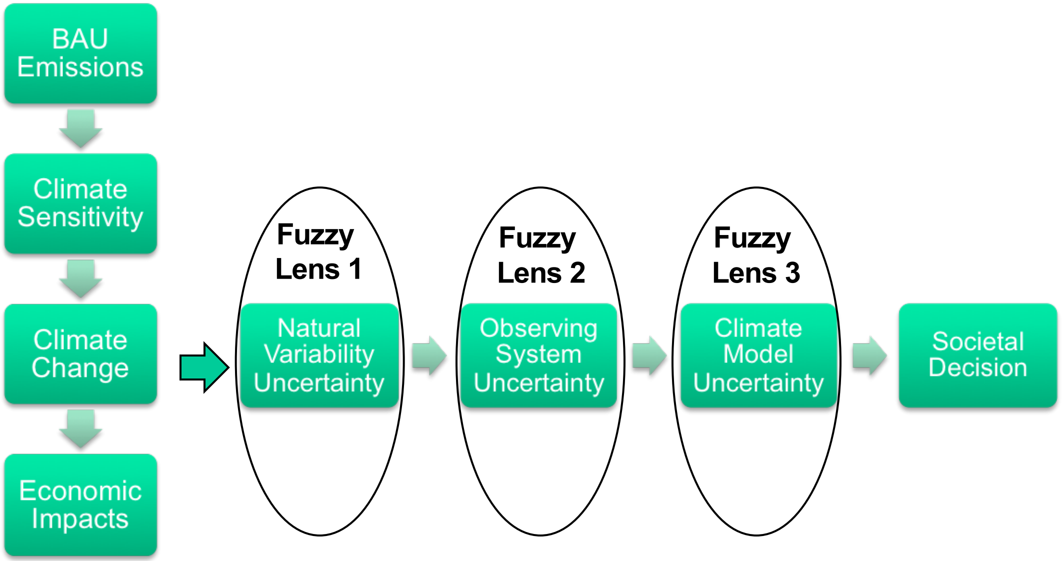

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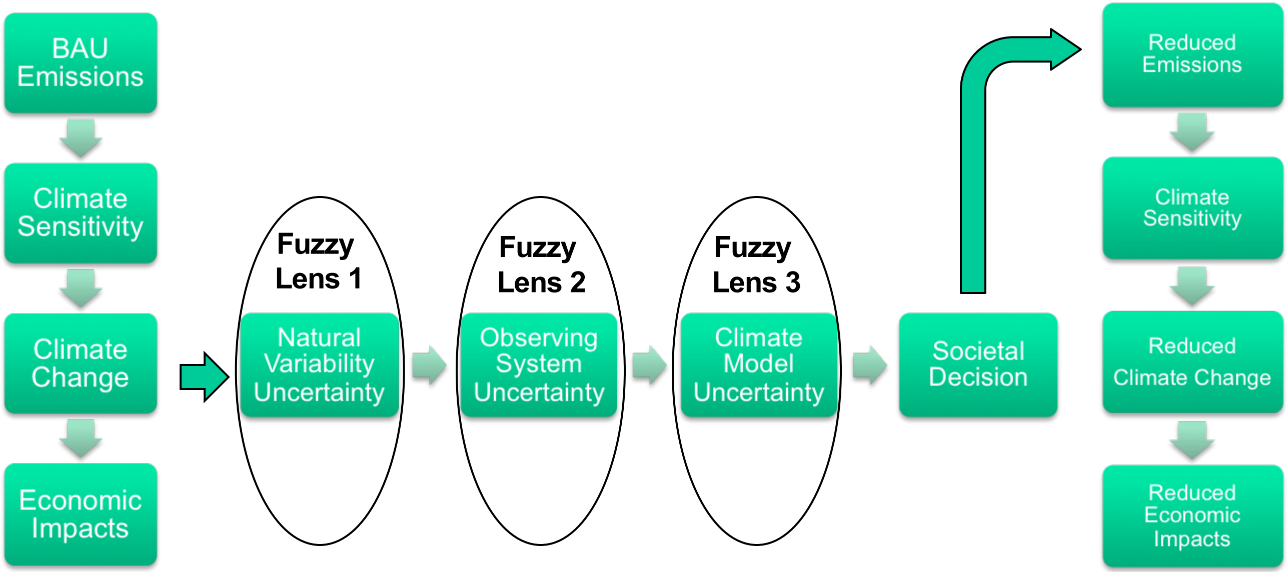

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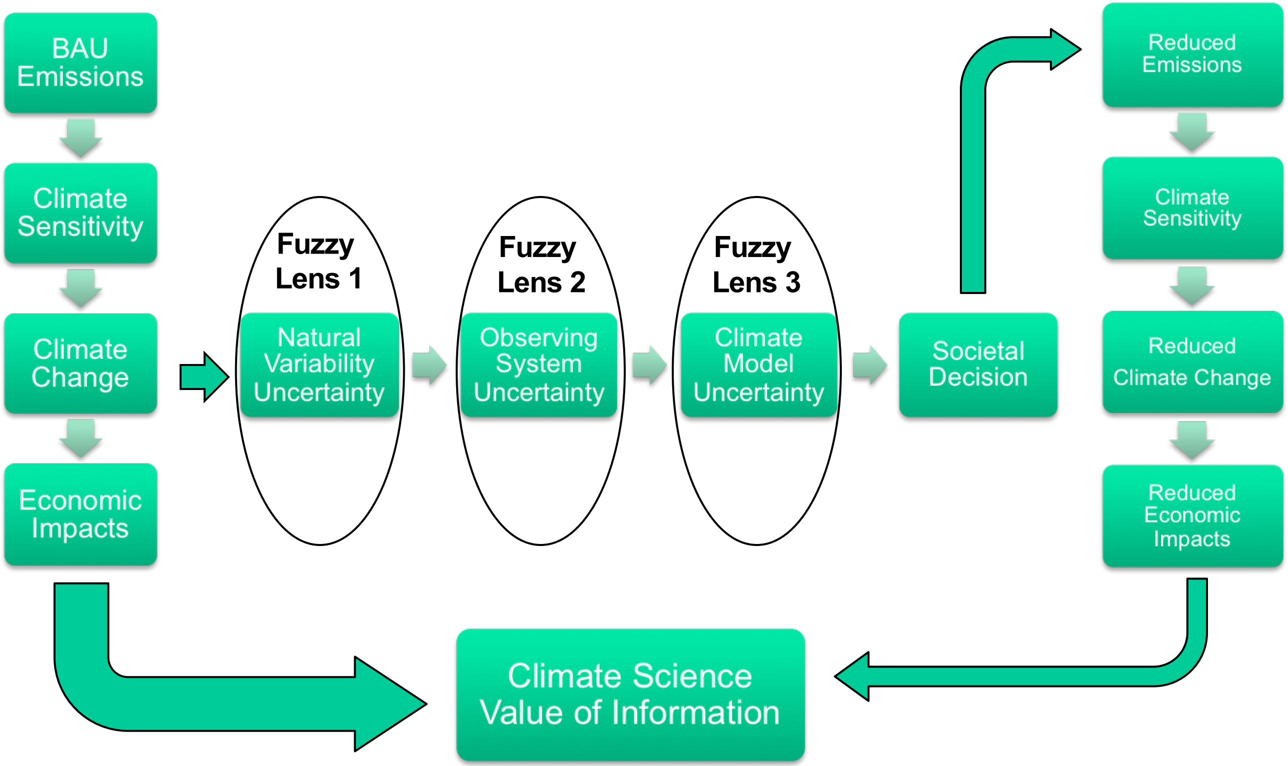

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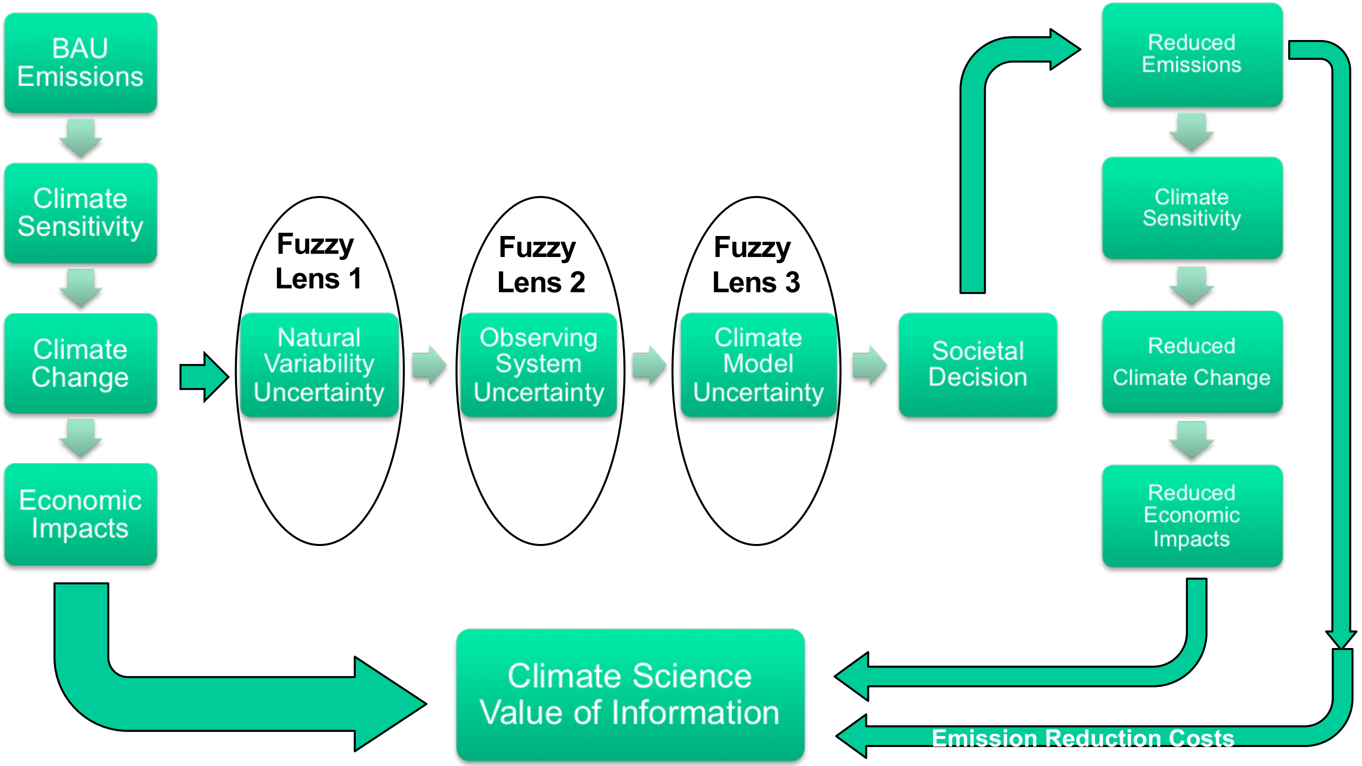


VOI vs. Discount Rate

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:
~ $8B/yr worldwide (triple current investments)
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

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

Results and Sensitivity to Assumptions

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

Summary

- The world continues to march toward an uncertain climate future
- We continue to lack a designed and committed climate observing system
- The cost of providing such a system might require tripling current investment levels globally for up to an additional $8 Billion U.S. dollars per year.
- A new climate observing system could reduce uncertainties 15 to 20 years sooner than current observations
- Total value of such a system to the world estimated at $5 to $20 Trillion U.S. dollars
- Return on Investment of such a system estimated at 25 to 100:1
- Return on Investment exceeds that for weather observations (currently 6:1 in the U.S.)
- U.S. investments in climate observations and research have stagnated since 1994, over 24 years (USGCRP annual reports inflation adjusted)

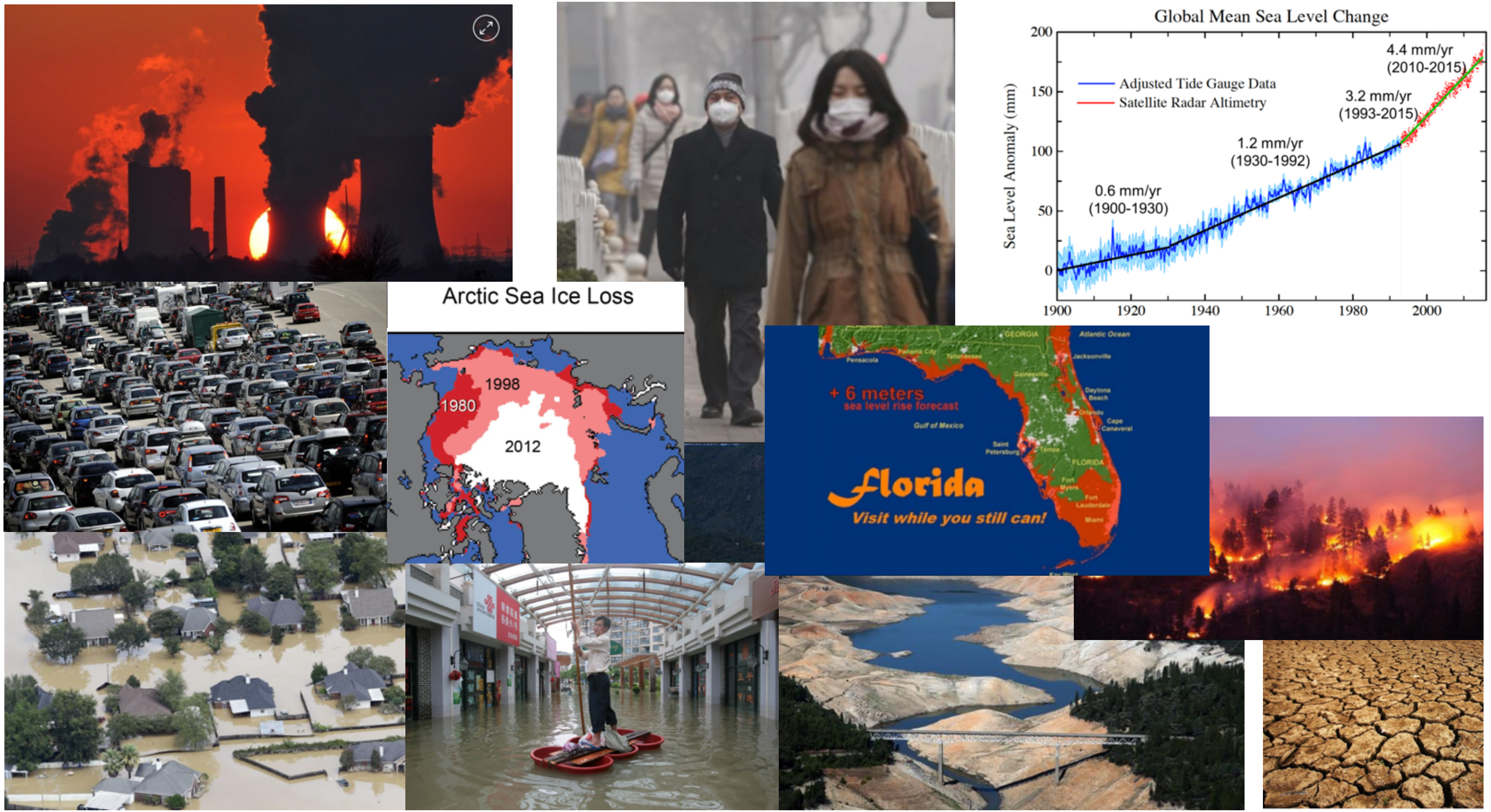
Summary

- Even large uncertainty in the economic value (e.g. factor of 5) leave the conclusion unchanged*:*
  - *Return on Investment of a new climate observing system would range from 10:1 to 250:1*

- *Cost of delay in building such a system is estimated at $250 to $500 Billion/yr.*
  - *Cost to provide a new climate observing system estimated at $8 Billion/yr.*
  - *This cost is about 3% of the $250 Billion/yr current investments in carbon emission reductions.*

- *A new climate observing system would be one of the most cost effective investments society could make to provide a stable economic future*.

A climate observing system will help...



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.*

- Chepfer, et al., 2018: The Potential of a Multi-Decade Space-borne Lidar Record to Constrain Cloud Feedbacks. J. Geophys. Res

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

- Cooke, R. M., A. Golub, B. A. Wielicki, M. Mlynczak, D. Young, and R. R. Baize, 2019: Monetizing the Value of Measurements of Equilibrium Climate Sensitivity Using the Social Cost of Carbon. Accepted: *Enivonmental Monitoring and Assessment*

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.

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