Designing the Climate Observing Systems of the Future

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USGCRP, February 17, 2016

USGCRP – Climate Observations

- Prior discussion: September 16, 2015
- Major discussion points:
  - Many climate questions are observationally limited.
  - Investments in observations offer a strong monetary return to society.
  - Tools exist to prioritize and plan observations in an effective manner.
- Action Item:
  - Engage the broader community and get feedback on presented ideas.

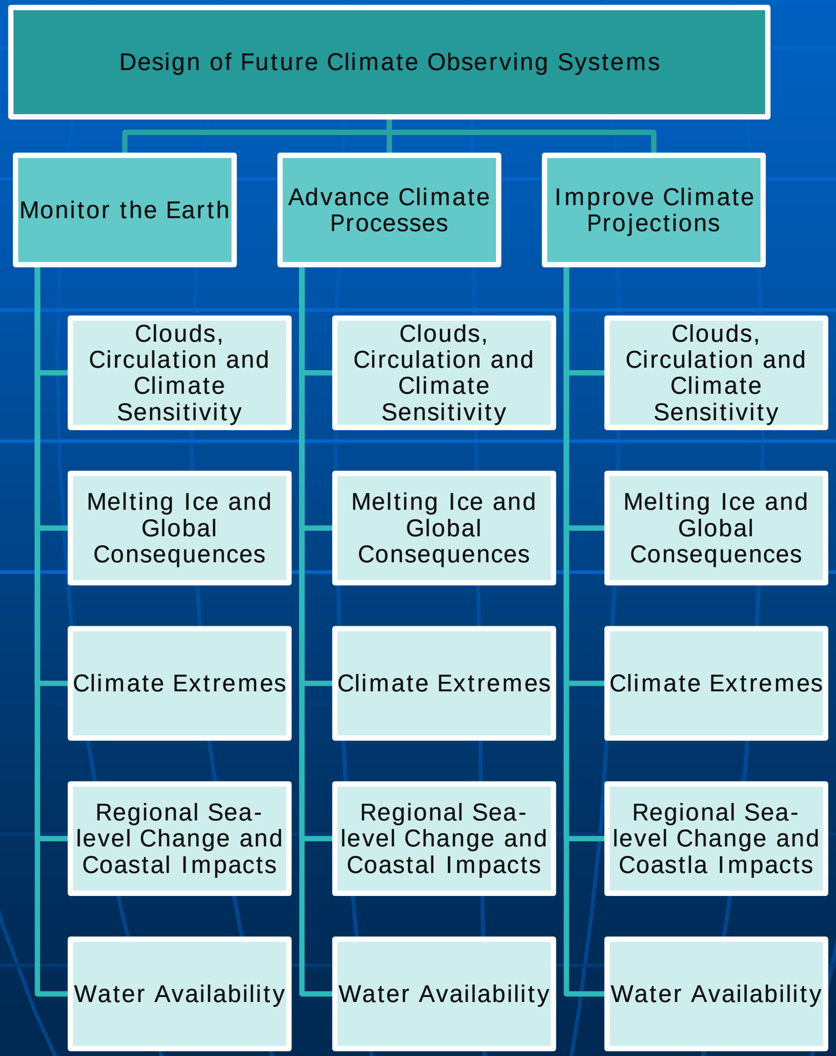
Community Engagement

- Numerous discussions, several presentations, one face-to-face meeting have taken place.
- Effort was made to reach a variety of constituents (modelers, observationalists, meteorologists, climate system analysts).
- Strong, positive feedback.
- Sense of urgency and unity.

Interaction with the Decadal Survey

- Bruce Wielicki presented the information to the first meeting of the 2017 NRC Decadal Survey (NASA/NOAA/USGS)
- Feedback has been positive
- When asked how the Decadal Survey could advocate for the critically needed additional observations and resources, Grace Hu from OMB responded:
  - more quantitative objectives
  - better understanding of return on investment

Addressing the World Climate Research Program's Grand Challenges



Formal presentation of ideas

- Presentation at AGU in Dec. (Betsy Weatherhead)
- Presentation at AMS in Jan. (Betsy Weatherhead)
- Presentation at NRC in Jan. (Bruce Wielicki)
- In all cases, feedback has been strong and people have sought out and requested further involvement.
- Next month, presentation at GCOS in Amsterdam. (Betsy Weatherhead)

AGU meeting summary highlights

- Over 20 participants.
- Strong positive desire for climate OSSEs to go forward.
- When we talk about climate observations, we are really talking about climate science.
- There is a sense of urgency to address this issue now.
- Colleagues are on board with extending WCRP's Grand Challenges as a framework.
- Independent assessment of observation needs is important for success and to avoid lost opportunity costs.
- There are a number of ongoing efforts to examine future observations; all are in agreement with need for prioritization; OSSEs are a welcome critical and objective evaluation, well suited to open peer review.
- There is opportunity to collaborate and learn lessons from the weather OSSE community.

This is an international issue as much as it is a national issue.

- Many of the national experts are involved in international coordination efforts.
- There is no reason for the US to do everything.
- Evaluation of current capabilities should include both national and international observing systems.
- Planning should take into account international plans.
- Independent observations and analysis are a key scientific approach to increasing confidence in results

Next Steps

- Continue communication with colleagues.
- Identify and quantify important climate science questions that are observationally limited.
- Evaluate current capabilities with respect to key climate science questions.
- Establish evaluation capabilities for proposed observing systems.

Next Steps within USGRP

- One day meeting with representatives from the agencies
  - Does USGCRP develop a Climate Observing System Vision document?
  - NRC Continuity report used as a value framework?
- Identify roles for individual agencies
- Identify quantified science questions
- Categorize current observations with respect to key climate questions.
- Identify current observational plans with respect to key climate questions.

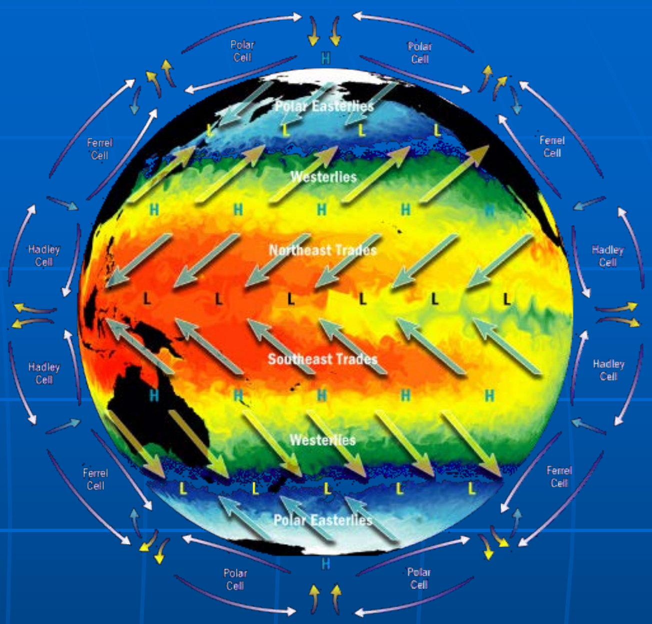
Back Up Slides

OSSEs Supporting Weather Forecasting

- Weather forecasting includes a diverse set of forecasting needs, often on the timescale of hours to months.
- Real time observations are critical, initial value prediction
- Global observations are important.
- Key questions address physics/chemistry of the Earth
- We can look a the effectiveness of different observations to address these needs.

OSSEs Supporting Climate Science

- Climate Science includes a diverse set of scientific questions, on timescales of seasons to decades to centuries



- Long-term trends are fundamental.
- Global observations are critical.
- Key questions address physics/chemistry/biology of Earth
- We can look at the effectiveness of different observations to address these questions.

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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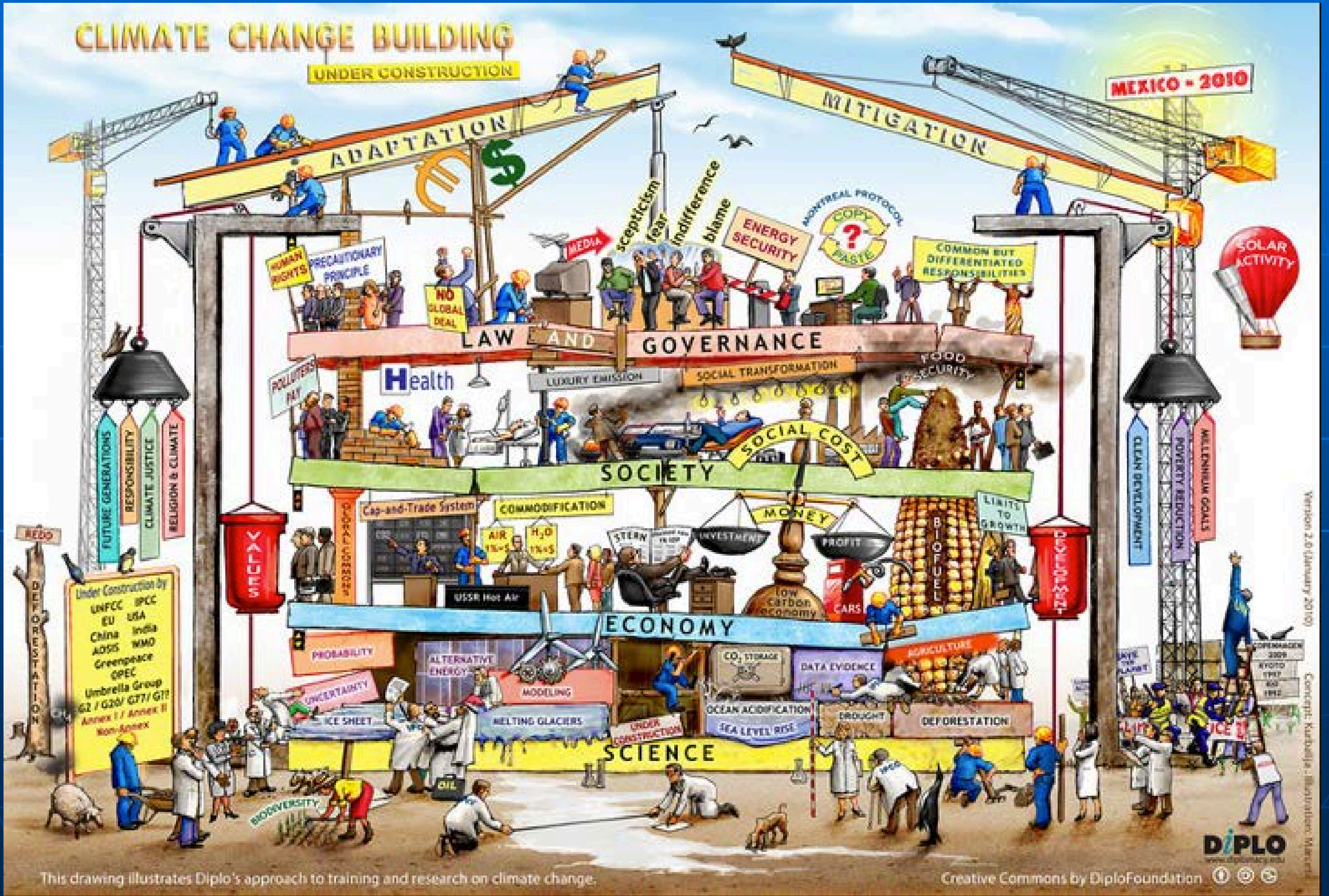
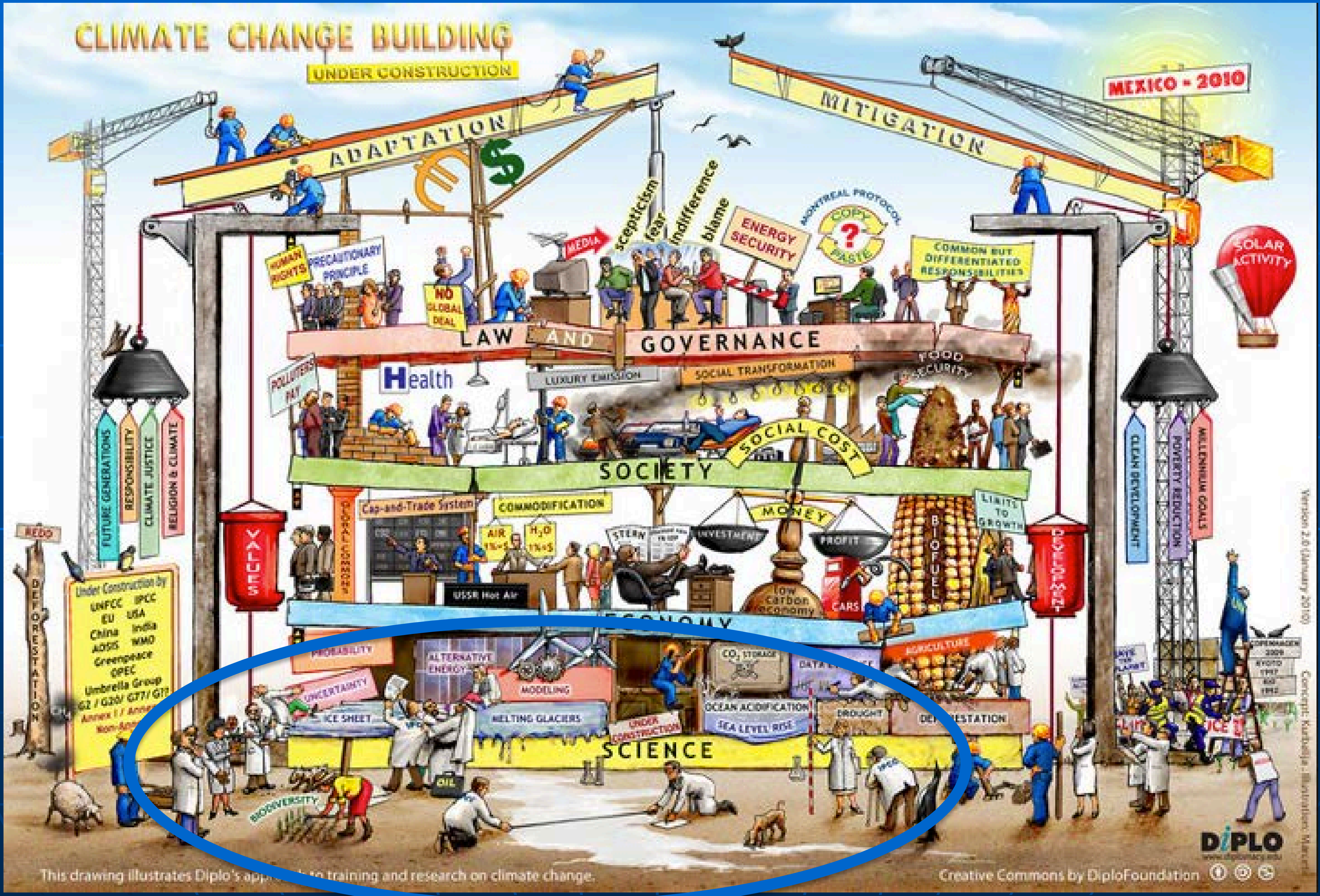
35 Years Later …



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.
- Struggle 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

A New Paradigm

1. Quantified Objectives
2. Gaps and Synergies
3. COSSE Measurement Requirements
4. Cost and Likelihood of Success
5. Societal Value

Quantified Science Objectives

- Examples:
  - Narrow uncertainty in climate sensitivity by a factor of 2
  - Determine the rate of sea level rise to 0.2 mm/yr (95% conf)
  - Measure the expansion of the tropics to within 15 km/decade
  - Determine ozone trends to within 1%/decade (95% conf)
  - Determine Total Solar Irradiance trends to 10 ppm/yr
  - Determine global ocean heat storage to within 0.1 Wm^{-2} for 10 yr averages and 0.2 Wm^{-2} for annual average.
  - Determine Eastern half of CONUS carbon fluxes to within 15% of global annual flux.
  - Determine Greenland and Antarctic ice sheet mass loss to within 0.1 mm/yr of sea level rise equivalent.

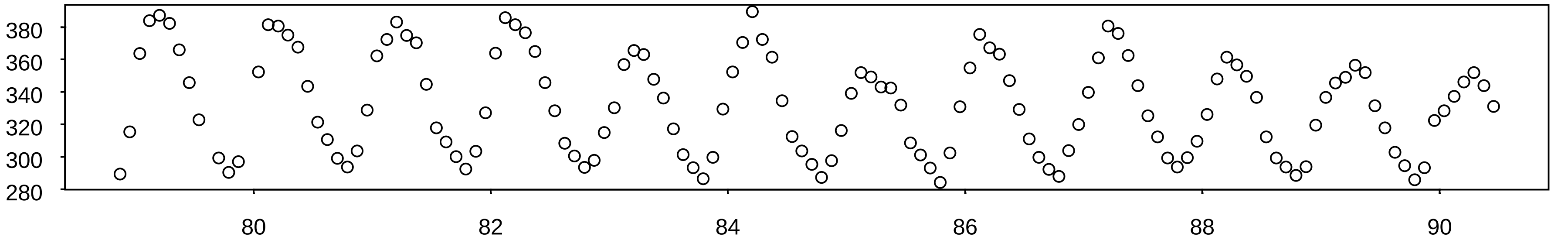
- Rate the importance of each quantified climate science objective (using economic impact, science impact, etc): *USGCRP, NRC*

Climate Observation Simulation System Experiments (COSSEs)

- We can simulate the value of proposed observing systems to their ability to address climate science needs.
- We can use natural variability on appropriate time scales to understand the power of a system to address a testable hypothesis.
- We can control four parameters in our observing systems:
  - What we measure
  - Where we measure
  - How frequently
  - How accurately
- Choices on all four of these issues affect our ability to effectively address scientific questions.

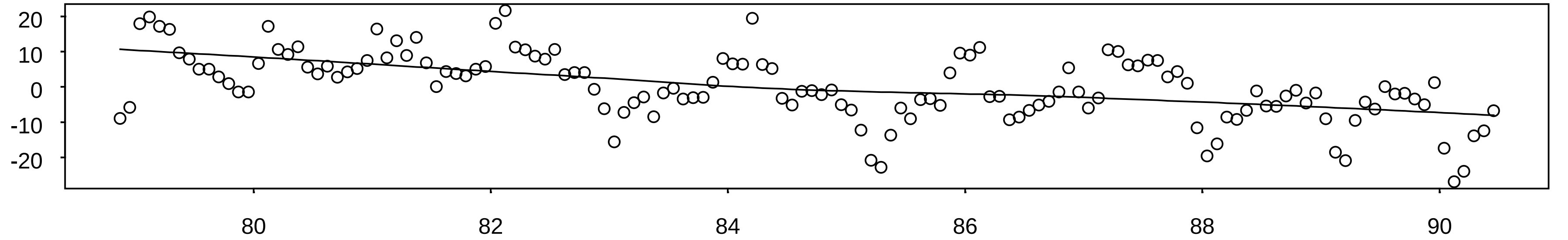
SBUV OZONE TOTAL COLUMN OZONE - 40N

Original Monthly Averaged Data

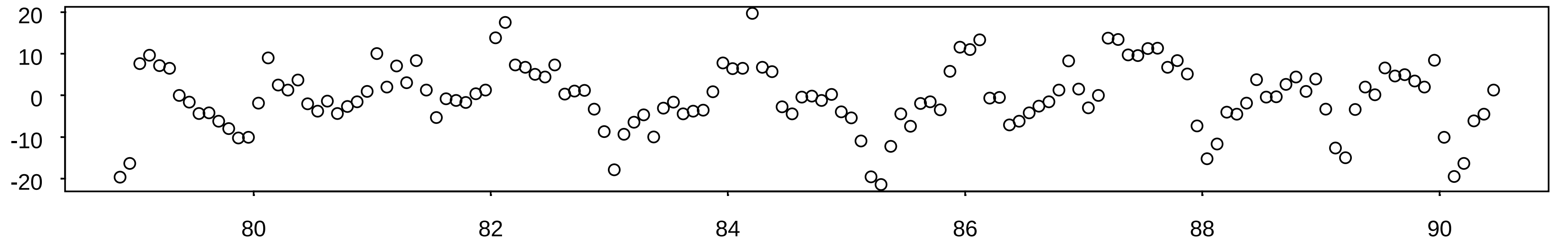


Weatherhead Fri Nov 2 11:48:50 2001

Monthly Means Removed, Lowess Line Fit Superimposed

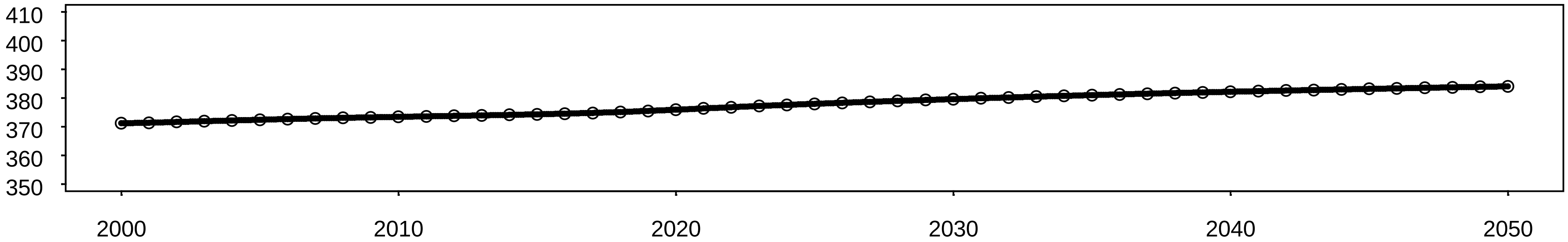


Residuals From Lowess Line Fit

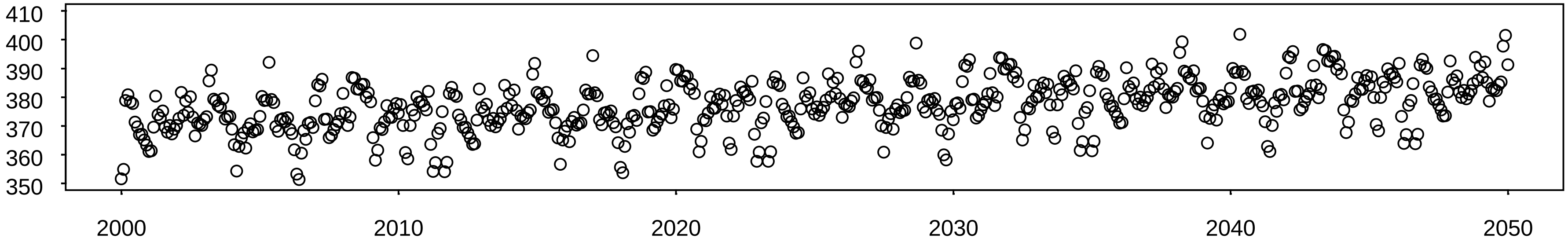


GSFC 2d Predictions with SBUV Residuals of Total Col. Ozone (d.u.) 40N

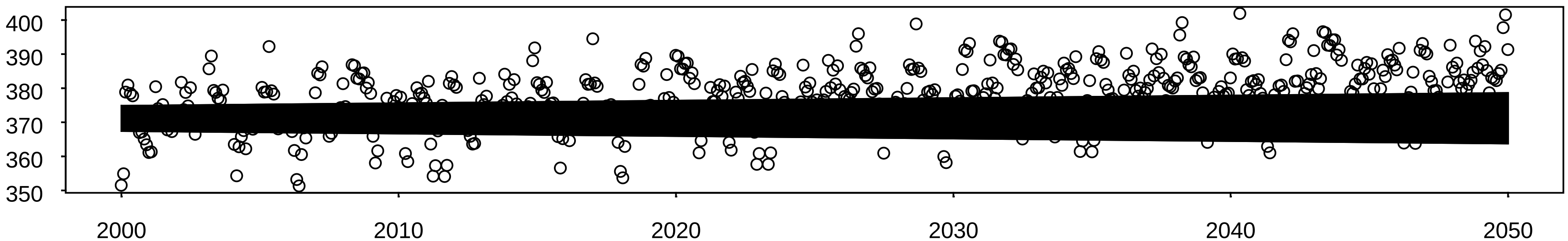
GSFC Predictions - without climate change



GSFC Predictions with SBUV Lowess Residuals

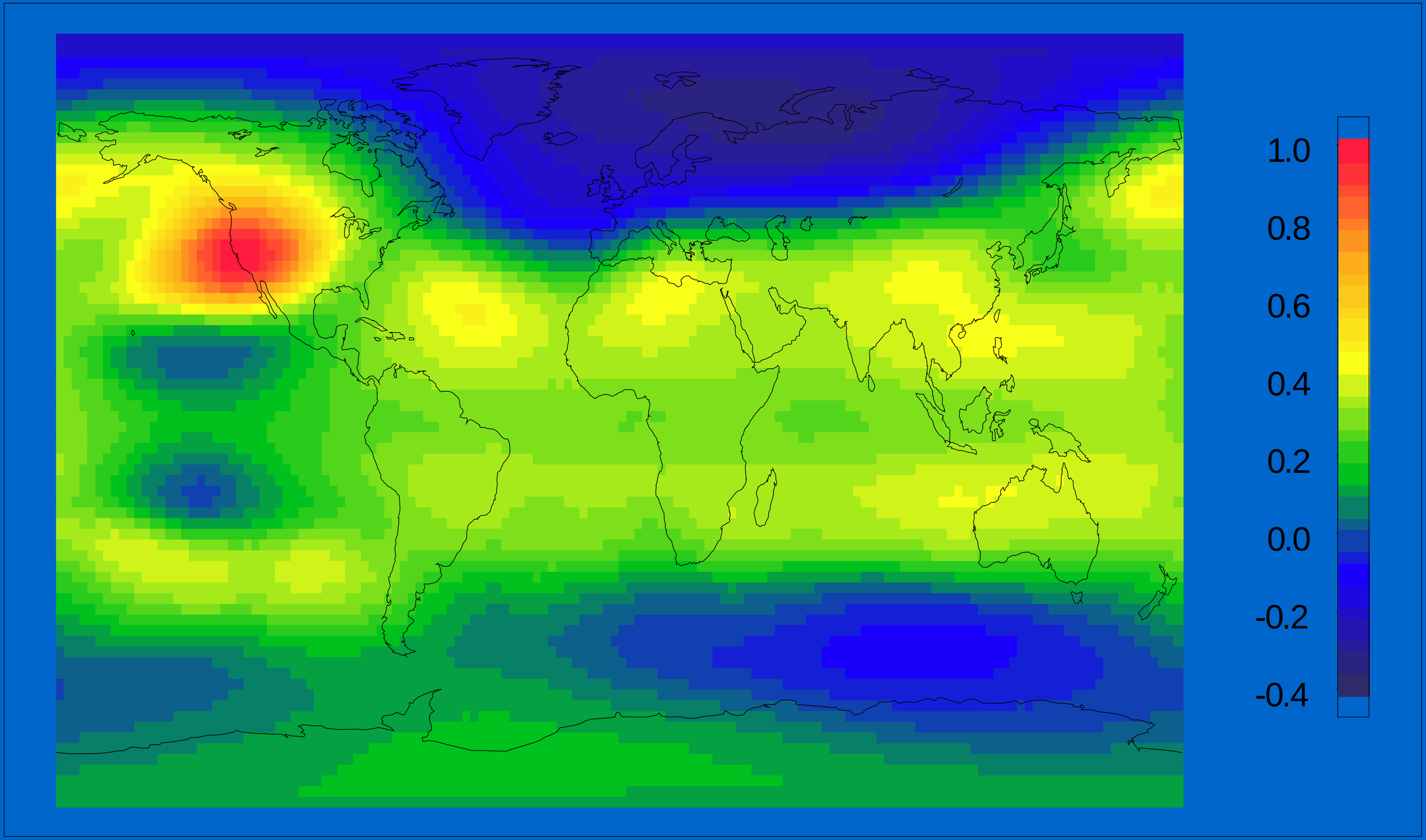


with +-1% error plus +-1% drift

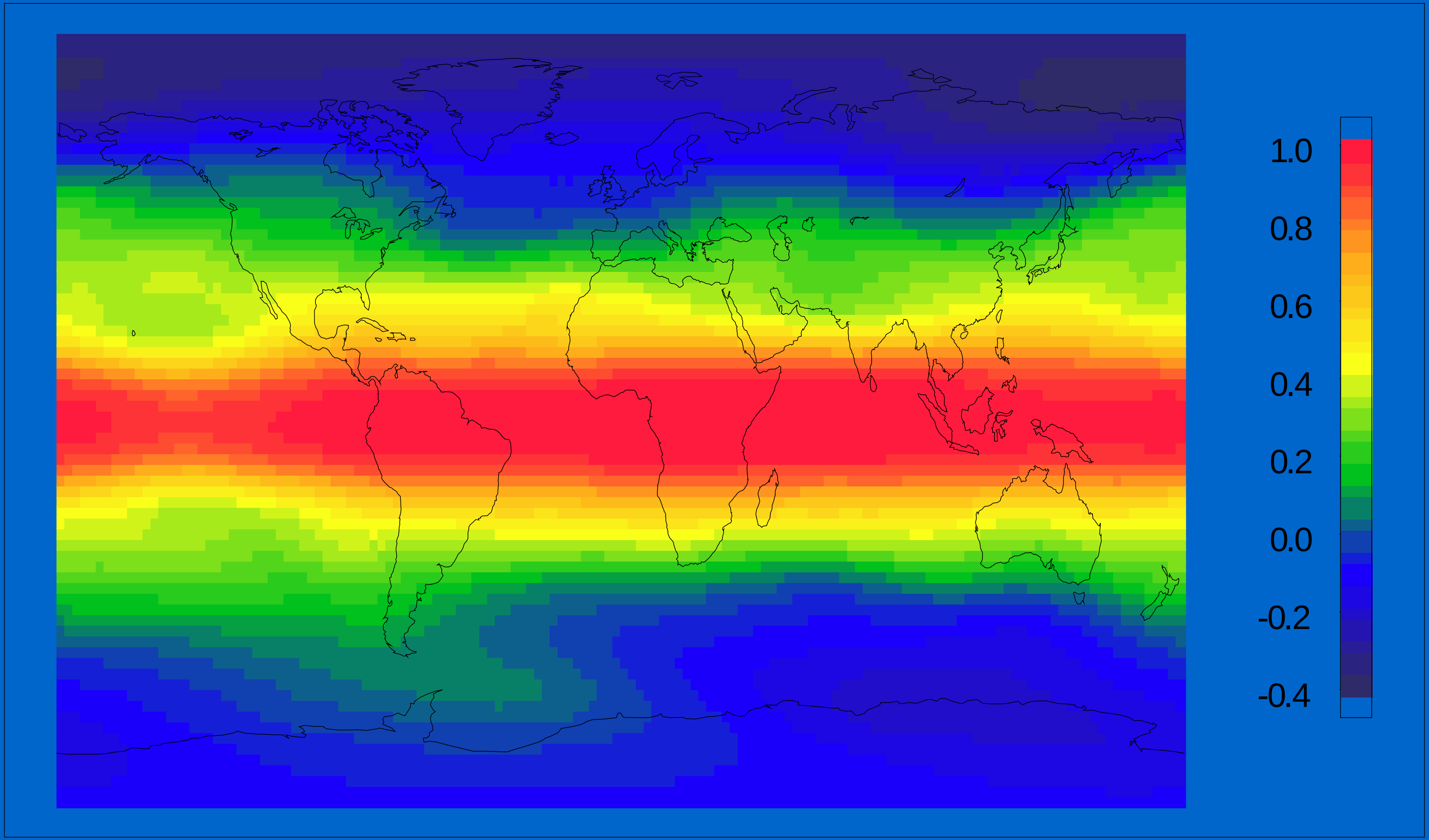


Weatherhead Fri Nov 2 11:53:23 2001

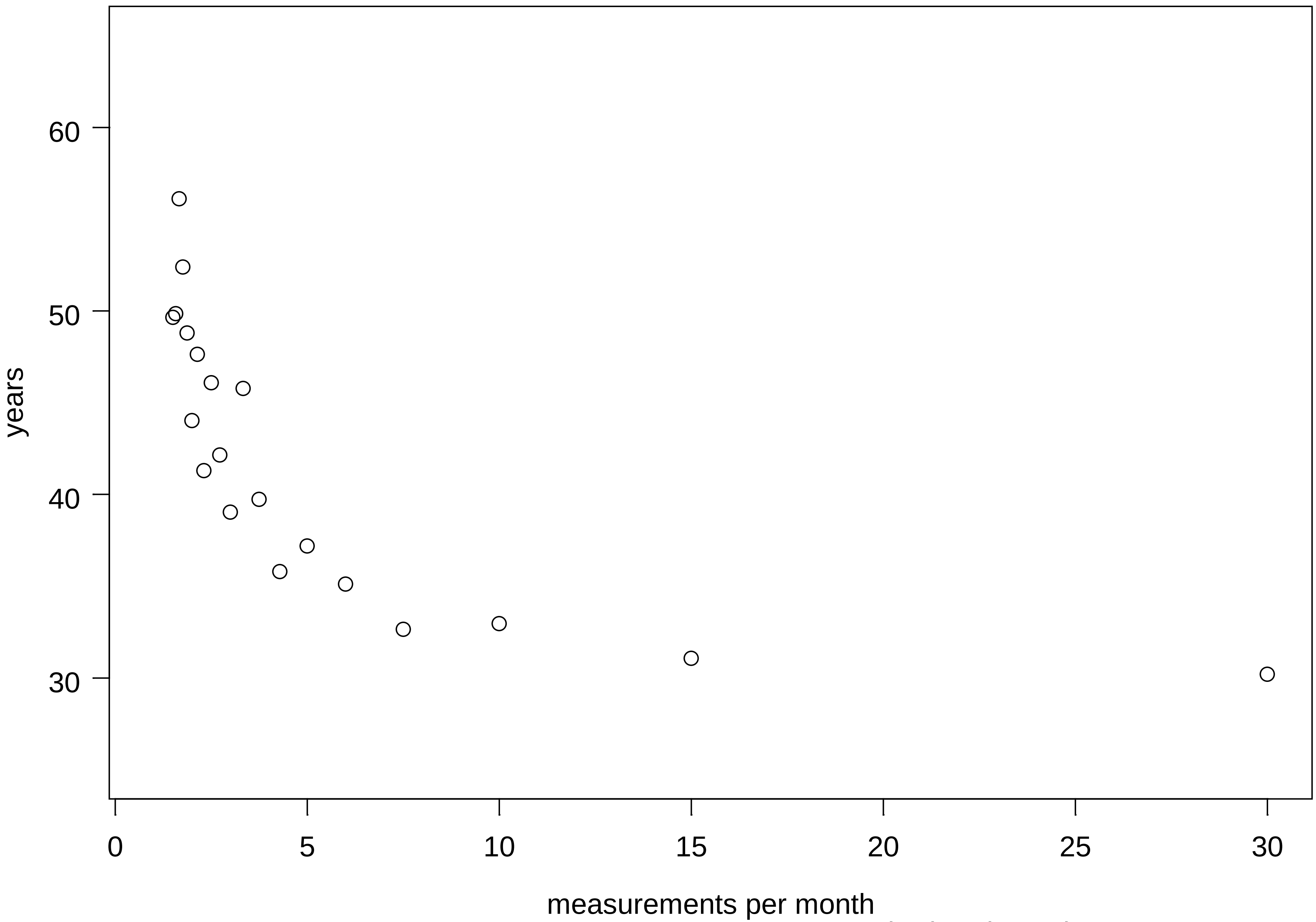
MSU Channel 4
Correlation with S.F.



MSU Channel 4
Correlation with lat=0 and long=0



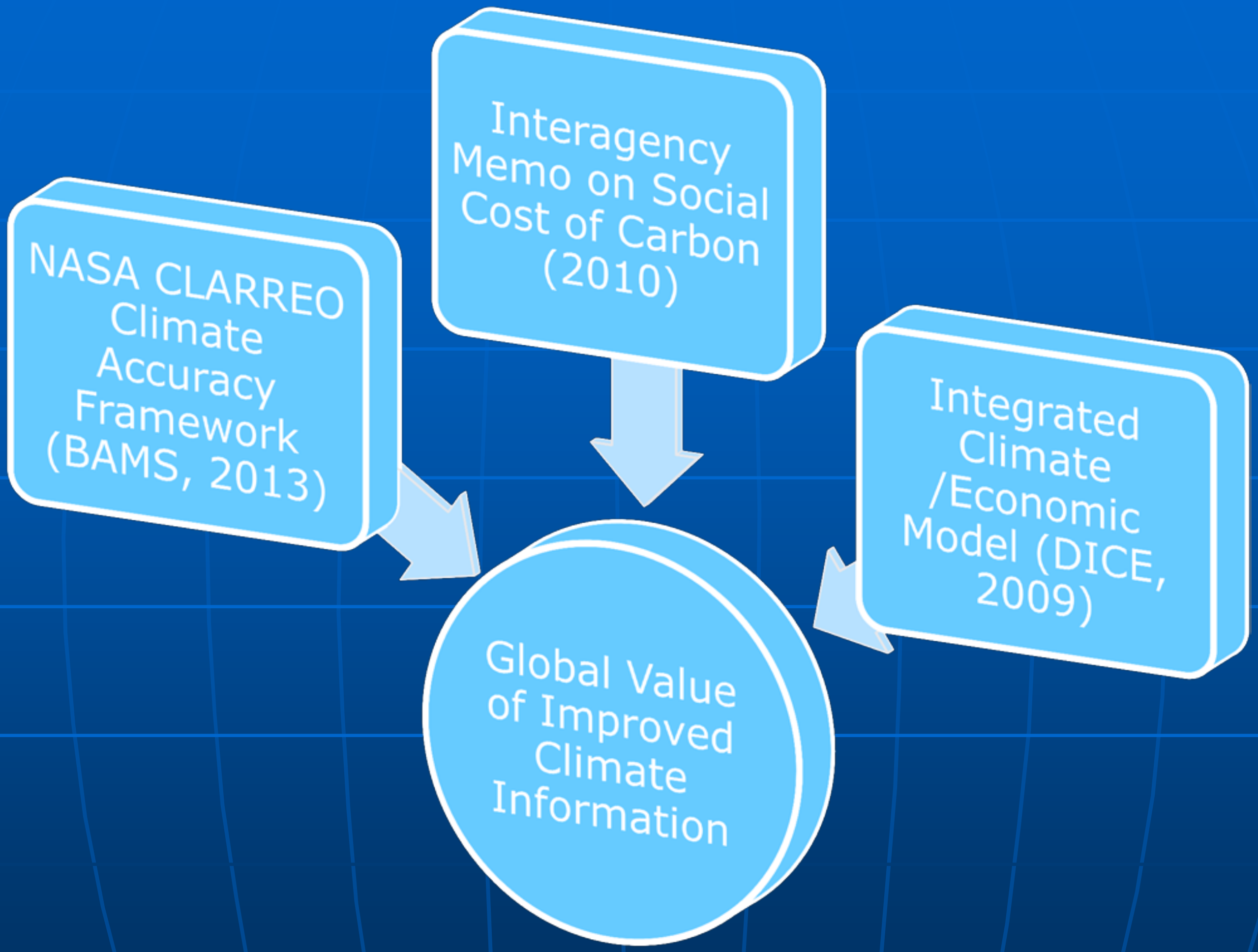
Years to Detect 0.2 degrees per Decade
Dulles 0Z 500 mb



CLIMATE OSSEs CAN ESTIMATE SUCCESS OF PROPOSED OBSERVING SYSTEMS

- What, where, when and how accurate can all be addressed in a climate OSSE.
  - Trend assessment
  - Process studies
  - Improved climate models
- Realistic variability and appropriate measurement uncertainty all need to be addressed objectively.
- Current ad hoc OSSEs can result in overpromising and wasted investments.

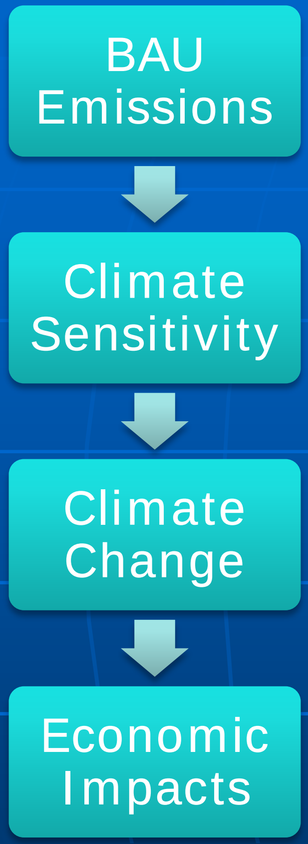
What is the right amount to invest in climate science?



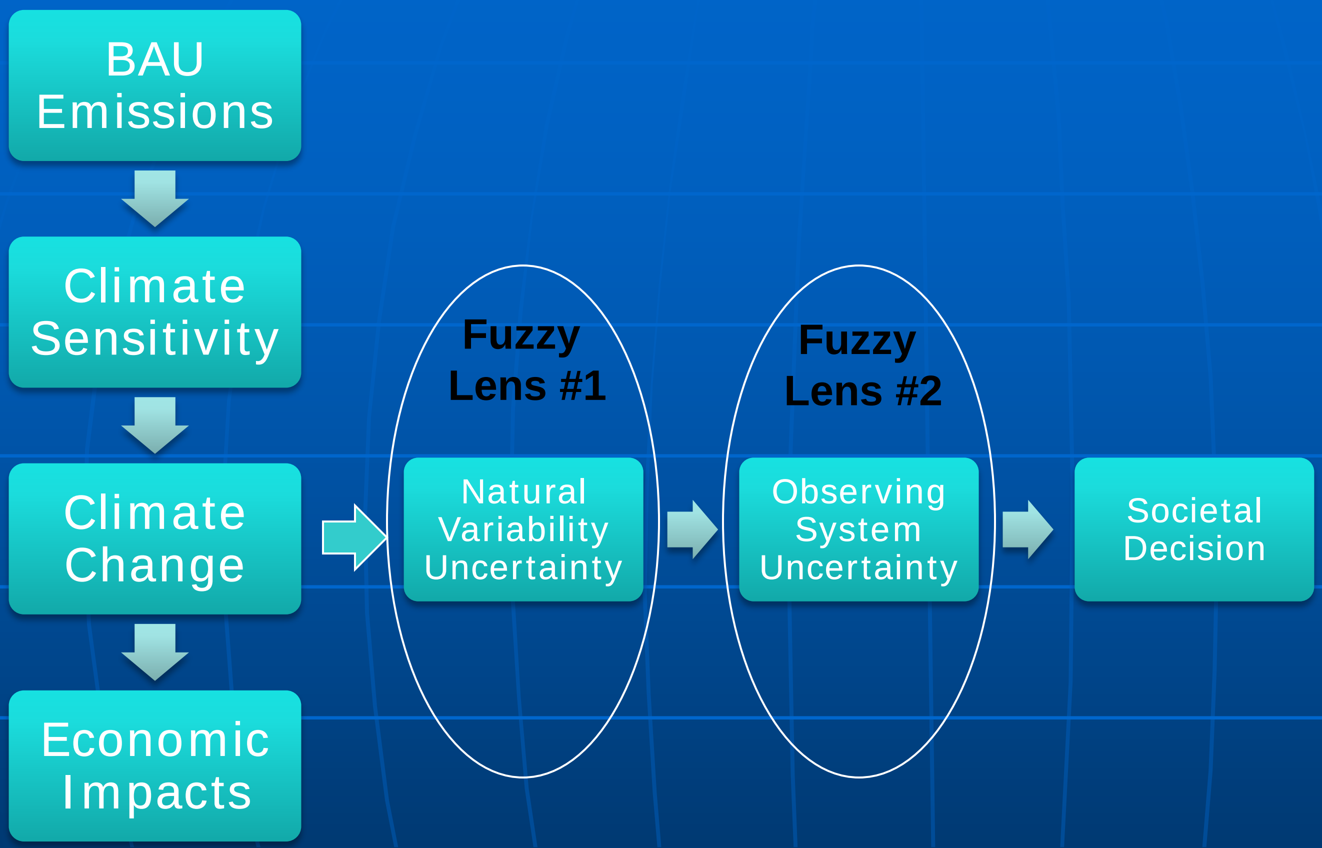
Cooke et al., Journal of Environment, Systems, and Decisions, July 2013, paper has open and free distribution online: doi:10.1007/s10669-013-9451-8
Cooke et al., 2015, Journal of Climate Policy

Interdisciplinary Integration of Climate Science and Economics

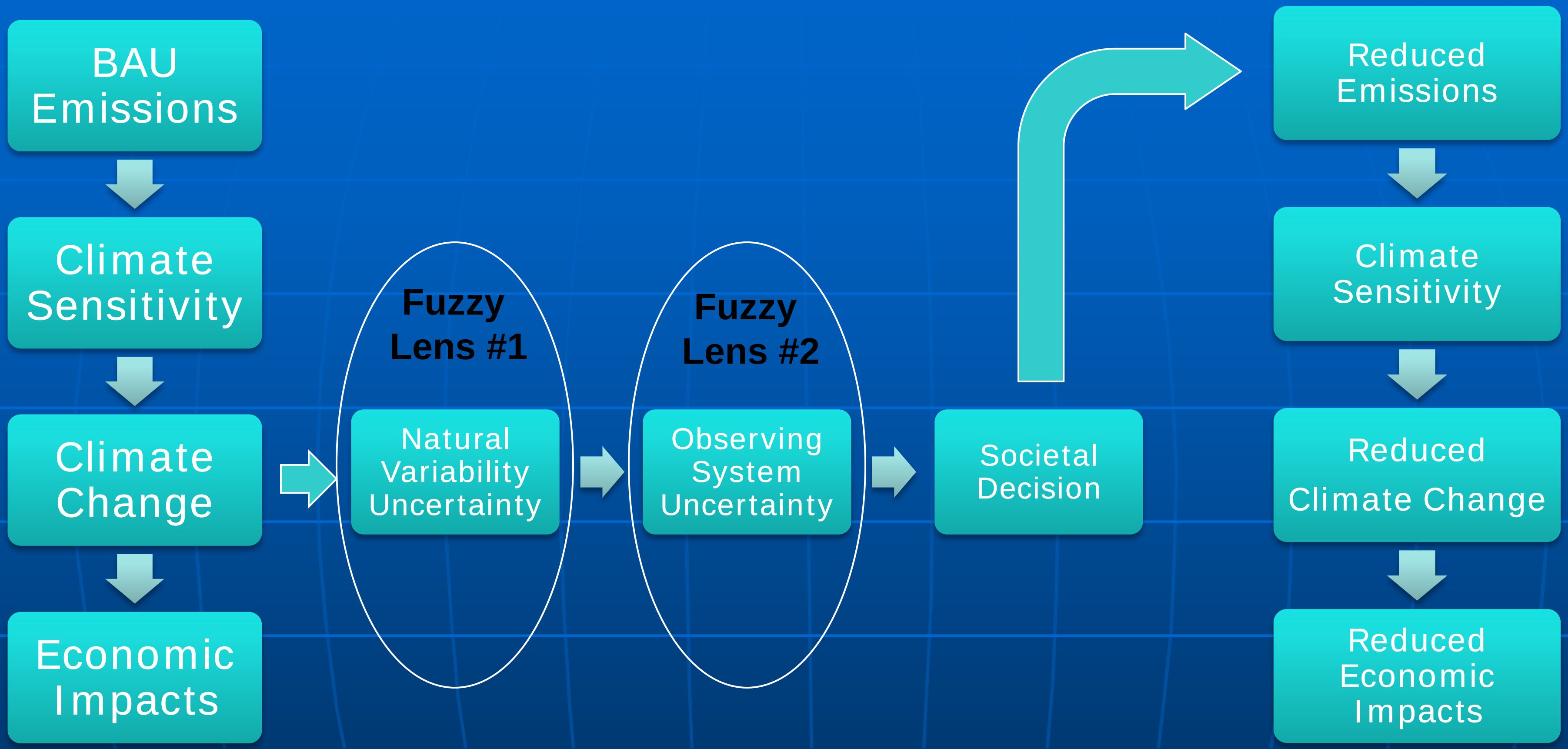
VOI Estimation Method



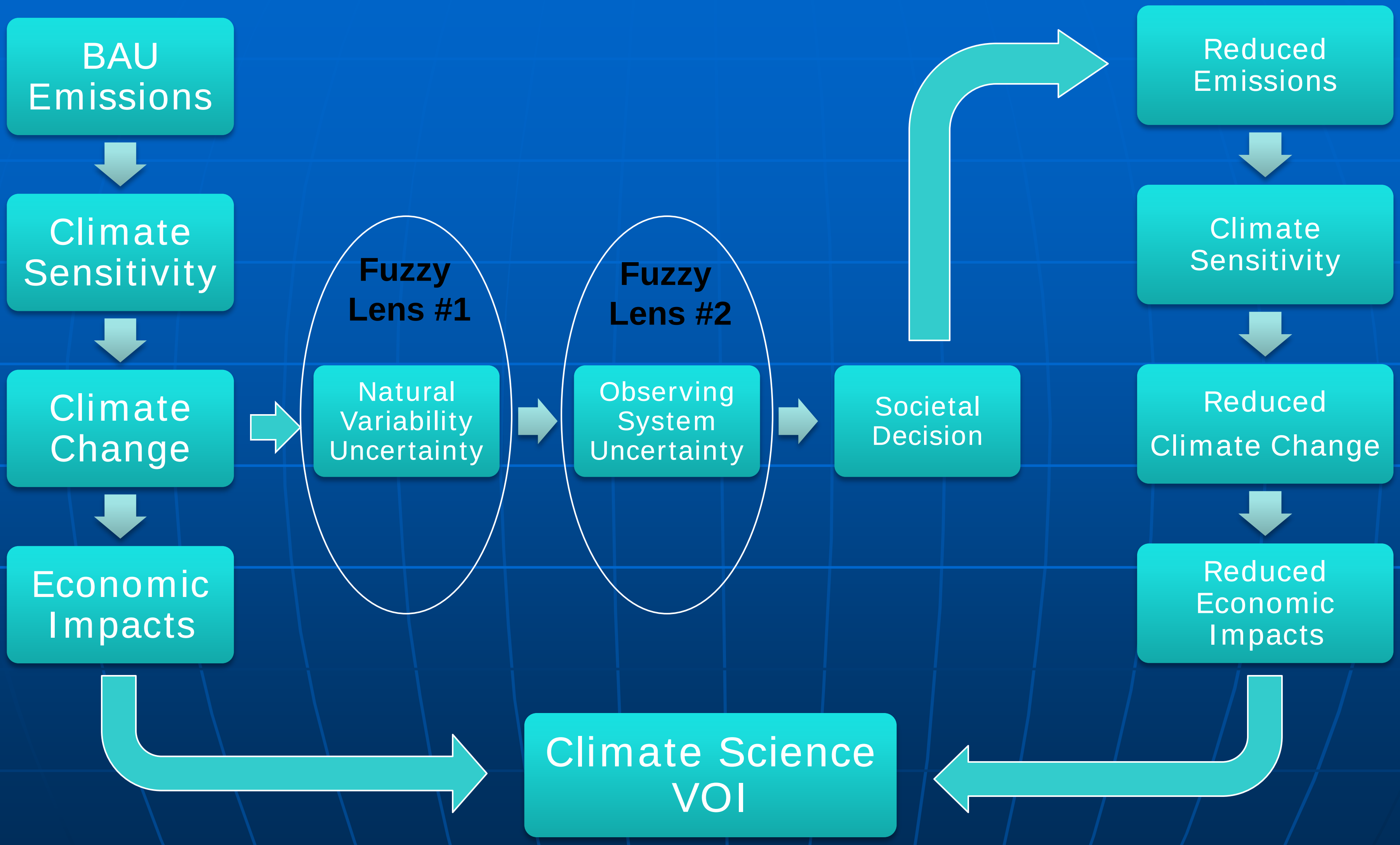
VOI Estimation Method



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 (NPV)

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

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2.5%	$17.6 T
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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

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
  - Full spatial coverage (lat, long and vertical)
  - Appropriate temporal resolution
- Economic Value of Improved Climate Observations and Models
  - See J. Env. Sys. Decisions paper for example: broadly applicable

Summary

Lack of appropriate observations = delayed knowledge.

We lack a climate observing system capable of testing climate predictions with sufficient accuracy, spatial coverage, temporal resolution and 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.

We know how to evaluate proposed observing systems, but it takes time and investments. COSSEs need to be objective.

It's time to invest in an advanced climate observing system.

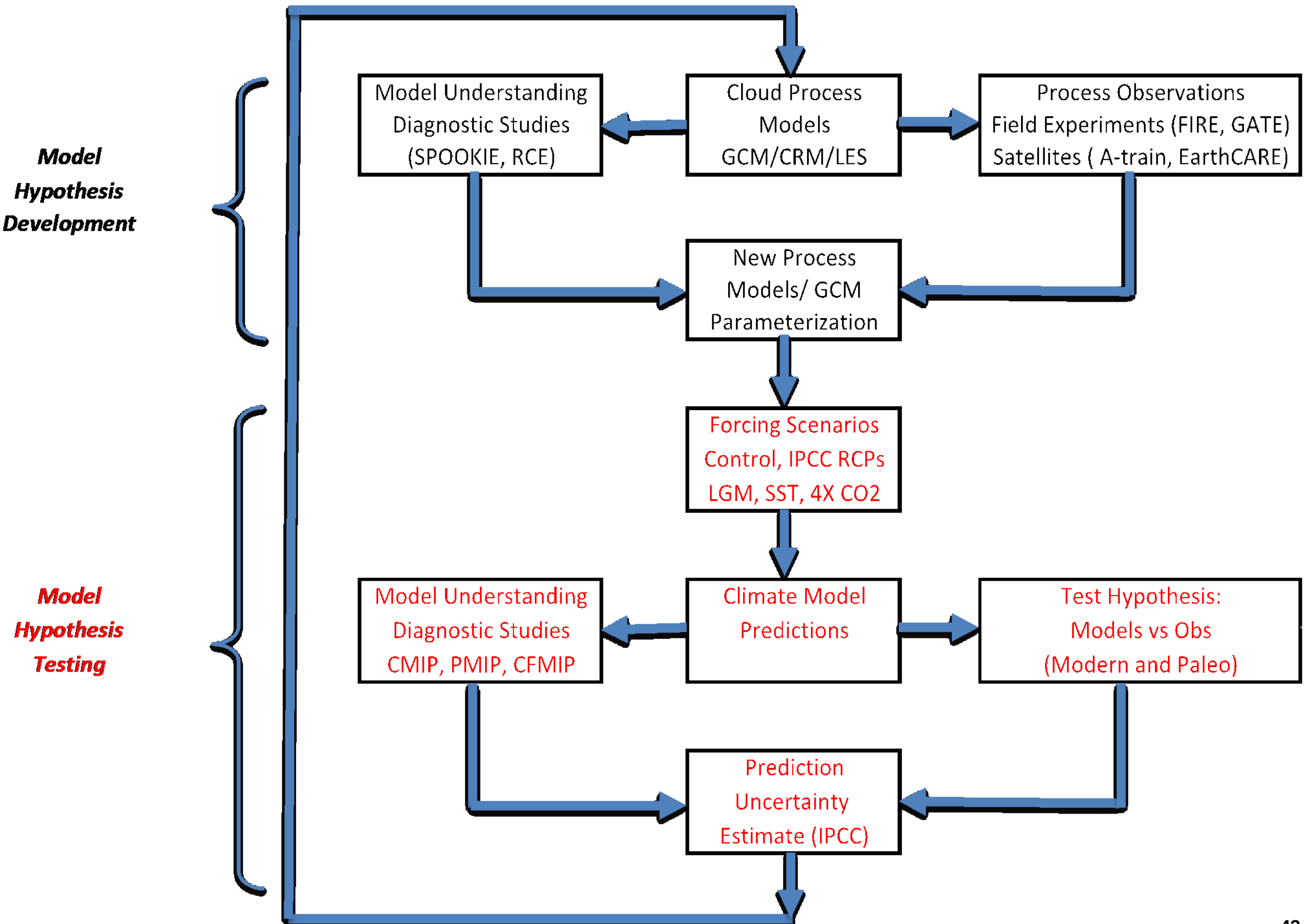
BACK-UP SLIDES

Possible Next Steps

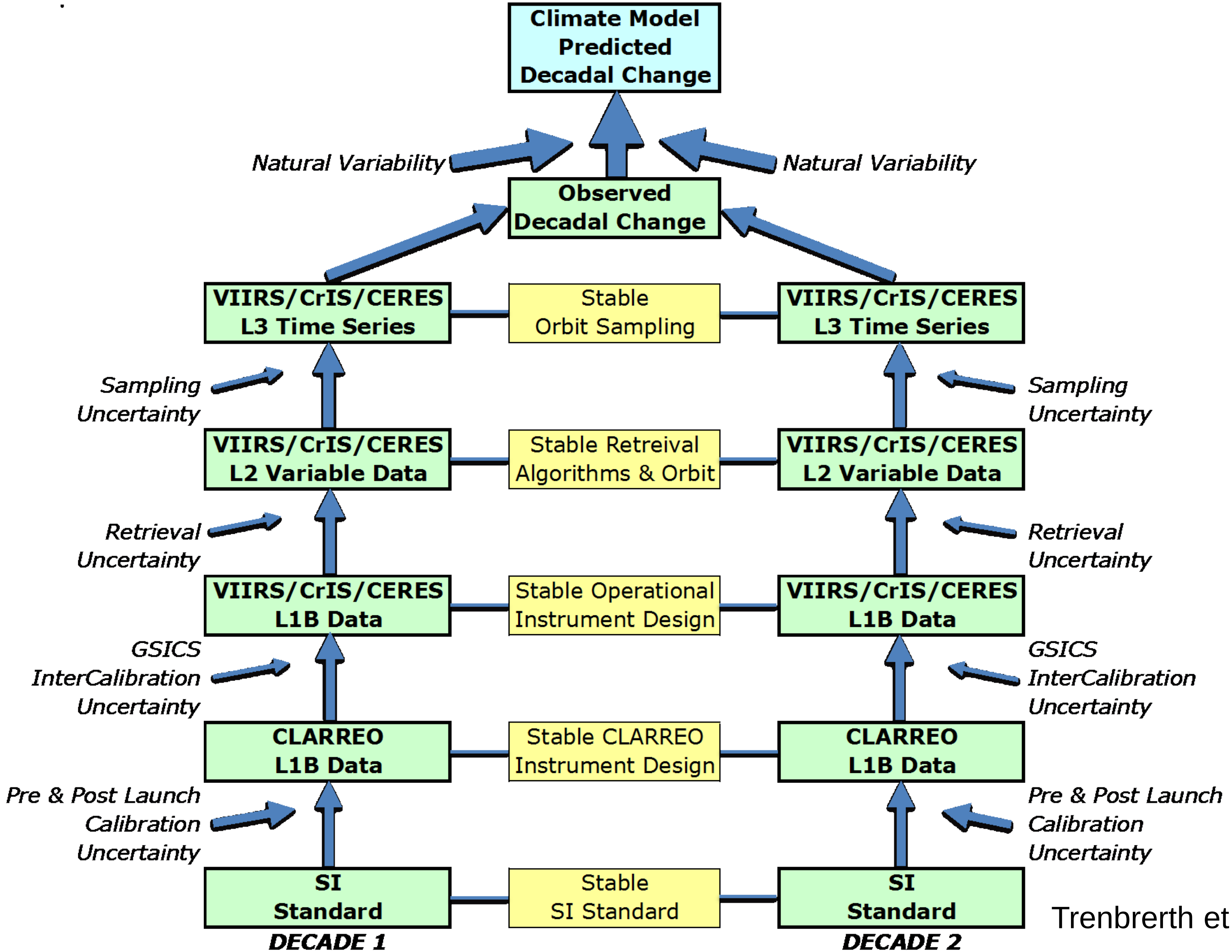
- Task 1: 18 months. Summary documents for any proposed or testable hypotheses/goals that are identified as highest priorities will be posted for review. Meetings with relevant parties and reports will be carried out in conjunction with existing programs to develop quantified science objectives as hypothesis tests or goals and prioritization of the objectives.
- Task 2. Part 1. 9 months. Development of a website with dynamic links to existing reports and studies on observational climate needs and COSSEs. This task includes a system for maintaining the information in the website.
- Task 2. Part 2. 18 months Determination of gaps and synergies of existing observations and future planned observations with the quantified science objectives developed in Task 1..
- Task 3: 36 to 60 months. Design and funding of COSSE groups to evaluate proposed observing systems. COSSE groups can either be funded via a proposal system or established by agencies as additions to existing weather or other OSSE efforts. Improve COSSE tool development during Task 1.
- Task 4: 36 months. Given the large number of potential measurements, an extended period of time would be required for the agencies to evaluate cost and success probabilities for measurement approaches.

Possible Testable Hypotheses and Goals

- **Hypothesis:** The expansion of the tropics is occurring and is directly related to climate change driving modification of the Hadley Circulation. Determine the expansion of the tropics to within 15 km/decade at 95% confidence. Example observational requirements: daily observations of temperature (+/- 0.2 degrees K), humidity (+/- 2% RH) and wind (+/- 2m/s) every 100 meters from the surface to the mid-stratosphere over the tropics (30N to 30S) for three decades. Horizontal sampling and accuracy requirements TBD using COSSE.
- **Hypothesis:** Upper tropospheric temperatures are increasing at approximately 0.2 degrees K/decade. Monitor this trend with an uncertainty of .08 K/decade (95% confidence). Observational requirements: continuous measurements of temperature (+/- 0.1 degrees K), from the boundary layer to the lower stratosphere, every 10 mb, (60N to 60S) continuously. Accuracy, vertical resolution, spatial resolution and time resolution determined using COSSE.
- **Hypothesis:** Regional fluxes of carbon from the Eastern half of CONUS is within 15% of the global carbon flux estimates on an annual basis. Observational requirements: 850 flask measurements per year across the Eastern US for a period of three year. Number of flasks determined by initial COSSE effort.
- **Goal**: Determine the change in global ocean heat storage over a decade time scale to within 0.1 Wm^{-2} and over annual time scale to 0.2 Wm^{-2}. Requires ocean vertical profile temperature and salinity measurements using a network of autonomous floats (e.g. ARGO), global ocean sea level rise, global ice mass change, global net radiative flux. Observations required for at least 50 years. Accuracy, space and time sampling requirements TBD using COSSE. .
- **Goal**: The rate of sea level rise from ice sheet loss is likely to be nonlinear and to accelerate in a warming Earth. Determine the rate of sea level rise to a global mean accuracy of 0.2 mm/yr. Observations required indefinitely. Observation requirements (sea level rise, ice sheet mass, ocean temperature and salinity profiles (thermal expansion), mountain glacier mass loss) determined using COSSEs.
- **Goal:** Measure or estimate boundary layer winds, turbulence, vertical sheer and boundary layer height. Required in support of aviation, air quality and renewable energy with a 25% improvement over current estimates for each of these parameters. Accuracy, time sampling, space sampling requirements TBD using COSSE. Importance based on analysis of economic value of improved capabilities.

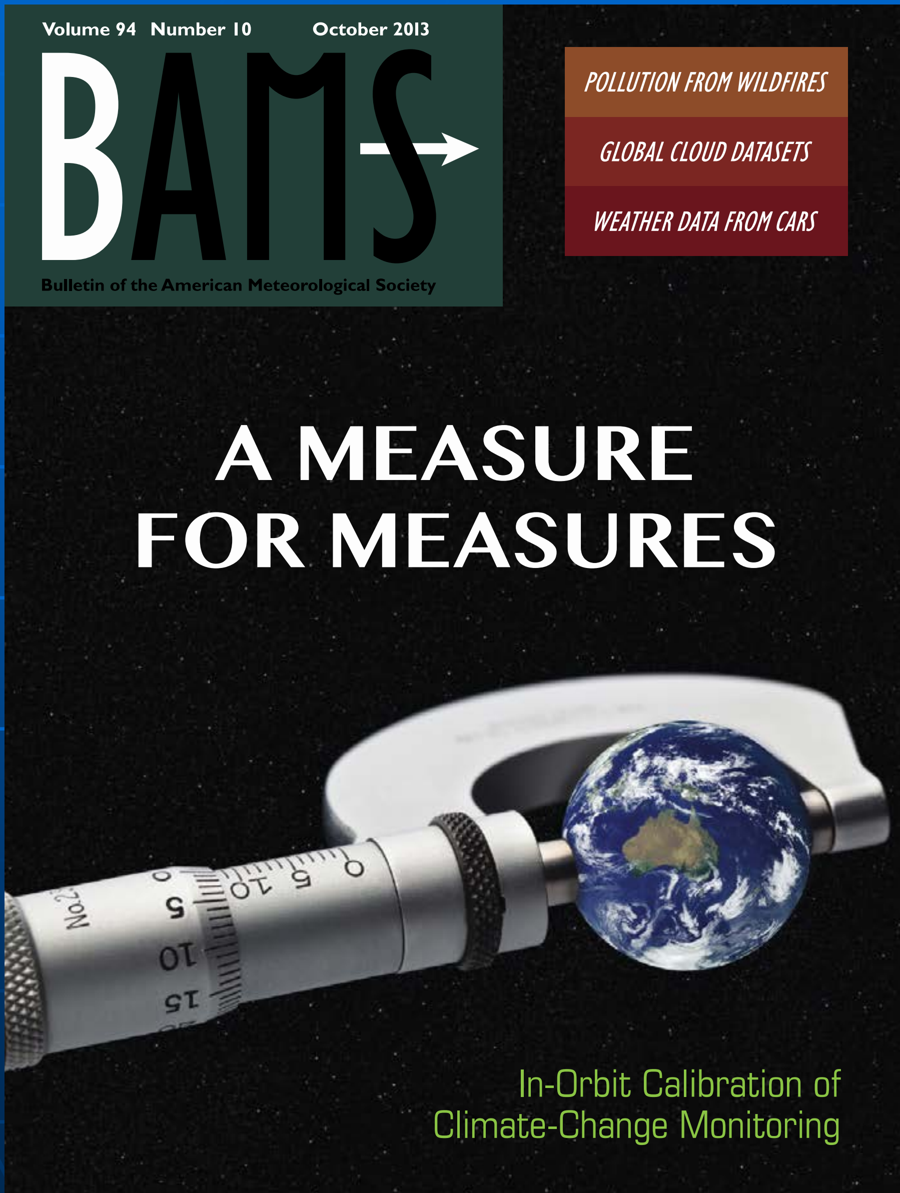

Model
Hypothesis
Development
Model Understanding
Diagnostic Studies
(SPOOKIE, RCE)
Cloud Process
Models
GCM/CRM/LES
Process Observations
Field Experiments (FIRE, GATE)
Satellites (A-train, EarthCARE)
New Process
Models/ GCM
Parameterization
Forcing Scenarios
Control, IPCC RCPs
LGM, SST, 4X CO2
Model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

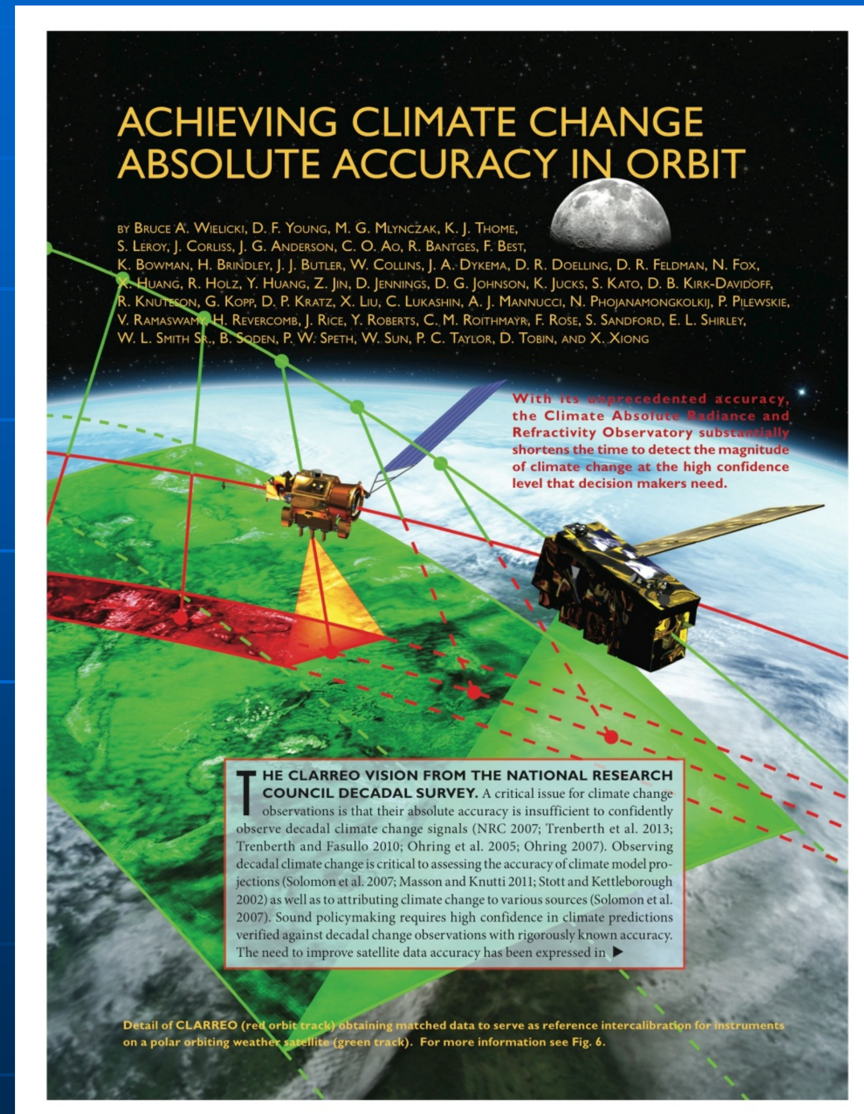
Accuracy of Climate Change Observations & Predictions



Trenbrerth et al. 2013

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.

Weather and Climate OSSEs

- Weather OSSEs can offer a range of realistic natural variability on timescales of hours – seasons.
  - Layered clouds, non-standard vertical profiles, short time scale variability all affect observing capabilities
- Weather OSSEs can offer insight into spatial and temporal sampling requirements.
- Climate OSSEs most often look at signals and timescales of longer periods.
- Radiance estimates from weather OSSEs can be directly useful to climate OSSEs.