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

Bruce Wielicki and Yolanda Shea, NASA Langley
Roger Cooke, Resources for the Future

CALIPSO-CloudSat
Ten-Year Progress Assessment and Path Forward

June 8-10, 2016
Paris, France
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
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
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
Even a perfect observing system is limited by natural variability.

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., *Climate Policy*, 2015, ISSN: 1469-3062
VOI Estimation Method

BAU Emissions

Climate Sensitivity

Climate Change

Economic Impacts
VOI Estimation Method

BAU Emissions

Climate Sensitivity

Climate Change

Economic Impacts

Fuzzy Lens #1: Natural Variability Uncertainty

Fuzzy Lens #2: Observing System Uncertainty

Societal Decision
VOI Estimation Method

BAU Emissions → Climate Sensitivity → Climate Change → Economic Impacts

Fuzzy Lens #1: Natural Variability Uncertainty
Fuzzy Lens #2: Observing System Uncertainty

Societal Decision → Reduced Emissions → Climate Sensitivity → Reduced Climate Change → Reduced Economic Impacts
VOI Estimation Method

- BAU Emissions
- Climate Sensitivity
- Climate Change
- Economic Impacts

Fuzzy Lens #1:
- Natural Variability Uncertainty

Fuzzy Lens #2:
- Observing System Uncertainty

Societal Decision

Climate Science VOI

Reduced Emissions

Climate Sensitivity

Reduced Climate Change

Reduced Economic Impacts
VOI Estimation Method

BAU Emissions
Climate Sensitivity
Climate Change
Economic Impacts

Fuzzy Lens #1
Natural Variability Uncertainty

Fuzzy Lens #2
Observing System Uncertainty

Societal Decision
Reduced Emissions
Climate Sensitivity
Reduced Climate Change
Reduced Economic Impacts

Climate Science VOI

Emissions Reduction Costs
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.
Run 1000s of economic simulations and then average over the full IPCC distribution of possible climate sensitivity

<table>
<thead>
<tr>
<th>Discount Rate</th>
<th>Improved Climate Observations VOI (US 2015 dollars, net present value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5%</td>
<td>$17.6 T</td>
</tr>
<tr>
<td>3%</td>
<td>$11.7 T</td>
</tr>
<tr>
<td>5%</td>
<td>$3.1 T</td>
</tr>
</tbody>
</table>

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*

<table>
<thead>
<tr>
<th>Discount Rate</th>
<th>Improved Climate Observations VOI (US 2015 dollars, net present value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5%</td>
<td>$17.6 T</td>
</tr>
<tr>
<td>3%</td>
<td>$11.7 T</td>
</tr>
<tr>
<td>5%</td>
<td>$3.1 T</td>
</tr>
</tbody>
</table>

**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)

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

Shea et al 2016, submitted to J. Climate
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)

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

Shea et al 2016, submitted to J. Climate
Cloud Top Effective Temperature (60S – 60N Avg)

11 μm Calibration Uncertainty (95% Conf.)

Perfect: 0.00K
Dash: 20%+Perf.: 0.06K
0.20K
0.30K
0.40K
V: 0.54K
M: 0.68K

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
- 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

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:

\[
U_a = (1 + \sum f_i^2)^{1/2}, \text{ where } f_i^2 = \sigma_i^2 \tau_i / \sigma_{\text{var}}^2 \tau_{\text{var}}
\]

for linear trends where \( s \) is standard deviation, \( \tau \) is autocorrelation time, \( \sigma_{\text{var}} \) is natural variability, and \( \sigma_i \) 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:

\[
U_t = (1 + \sum f_i^2)^{1/3}
\]

Degradation in time to detect trends is only \( \frac{2}{3} \) of degradation in accuracy.
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?