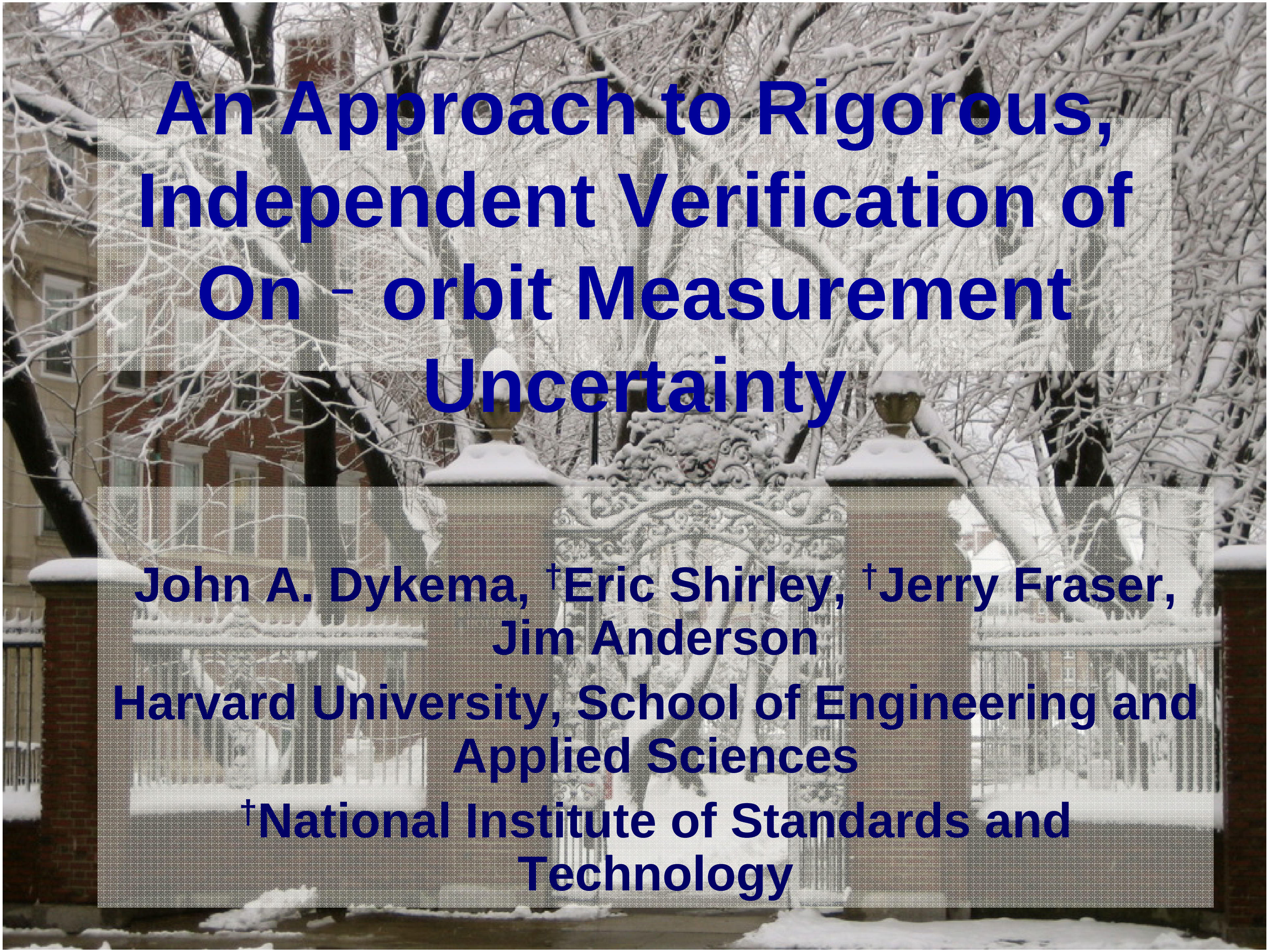


An Approach to Rigorous, Independent Verification of On – orbit Measurement Uncertainty

John A. Dykema, [†]Eric Shirley, [†]Jerry Fraser, Jim Anderson

Harvard University, School of Engineering and Applied Sciences

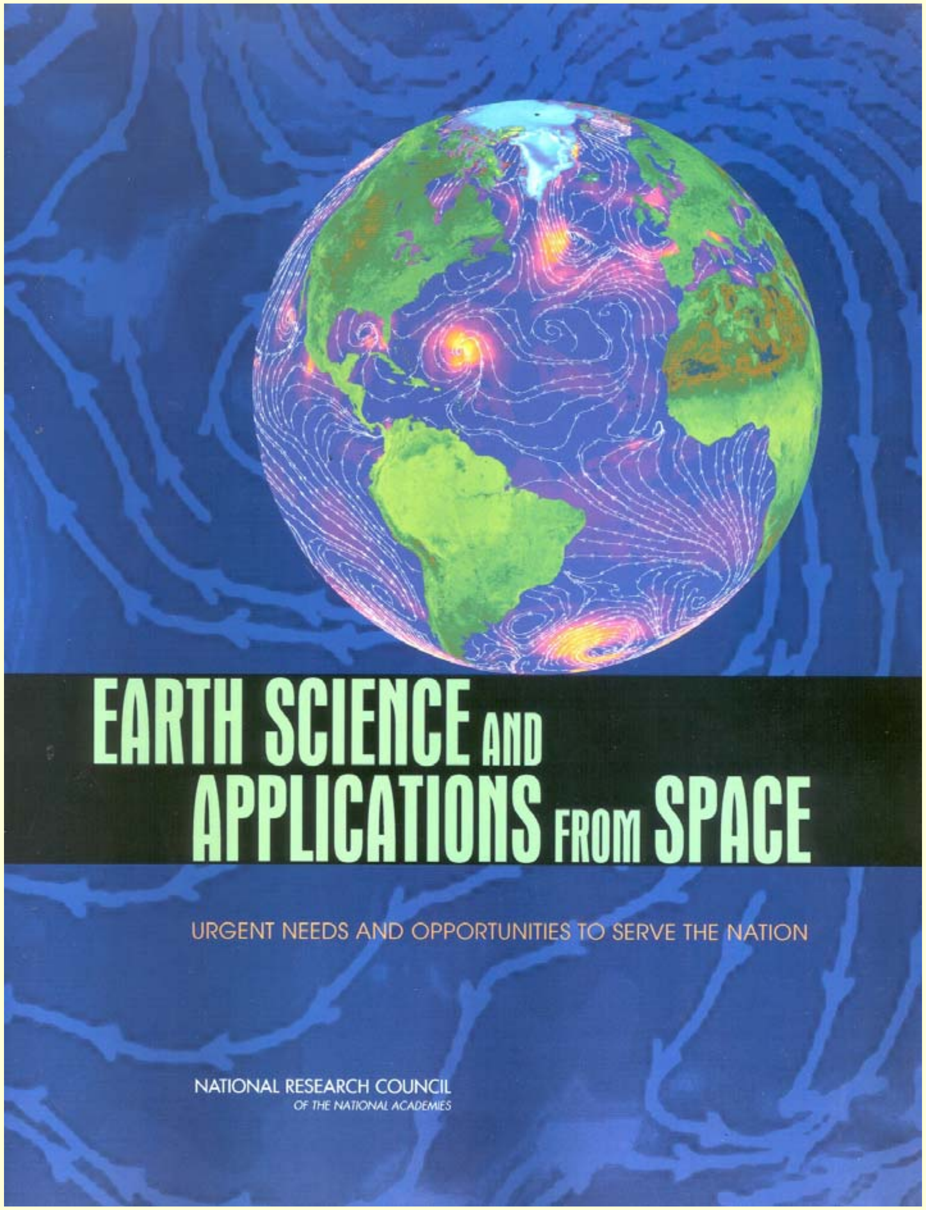
[†]National Institute of Standards and Technology

VISION

A healthy, secure, prosperous and sustainable society for all people on Earth

"Understanding the complex, changing planet on which we live, how it supports life, and how human activities affect its ability to do so in the future is one of the greatest intellectual challenges facing humanity. It is also one of the most important for society as it seeks to achieve prosperity and sustainability."

NRC



Strategic Choices Driven by Society's Need for Decision Structures

Decision Structures in Service to Society for:

- Climate Policy
- Energy Policy
- Human health
- Water resources
- Weather and severe storms
- Solid Earth hazards
- Land use, Ecosystems, Biodiversity

Required Forecasts:

- Rate of Sea Level Rise
- Airborne and water borne toxicity
- Rainfall, river flow, ground water, snow pack
- Regional temperatures, hurricane intensity, optical properties of atmosphere
- Earthquakes, volcanoes, tsunamis

Critical Observations to Specifically Test Forecast Credibility

- Nitrate, sulfate, organics, heavy metal effluents globally
- Index of refraction, absolute spectrally resolved radiance, solar irradiance
- Surface deformation

Prioritization Process

The prioritization process for mission selection involved eight criteria used to set relative rankings:

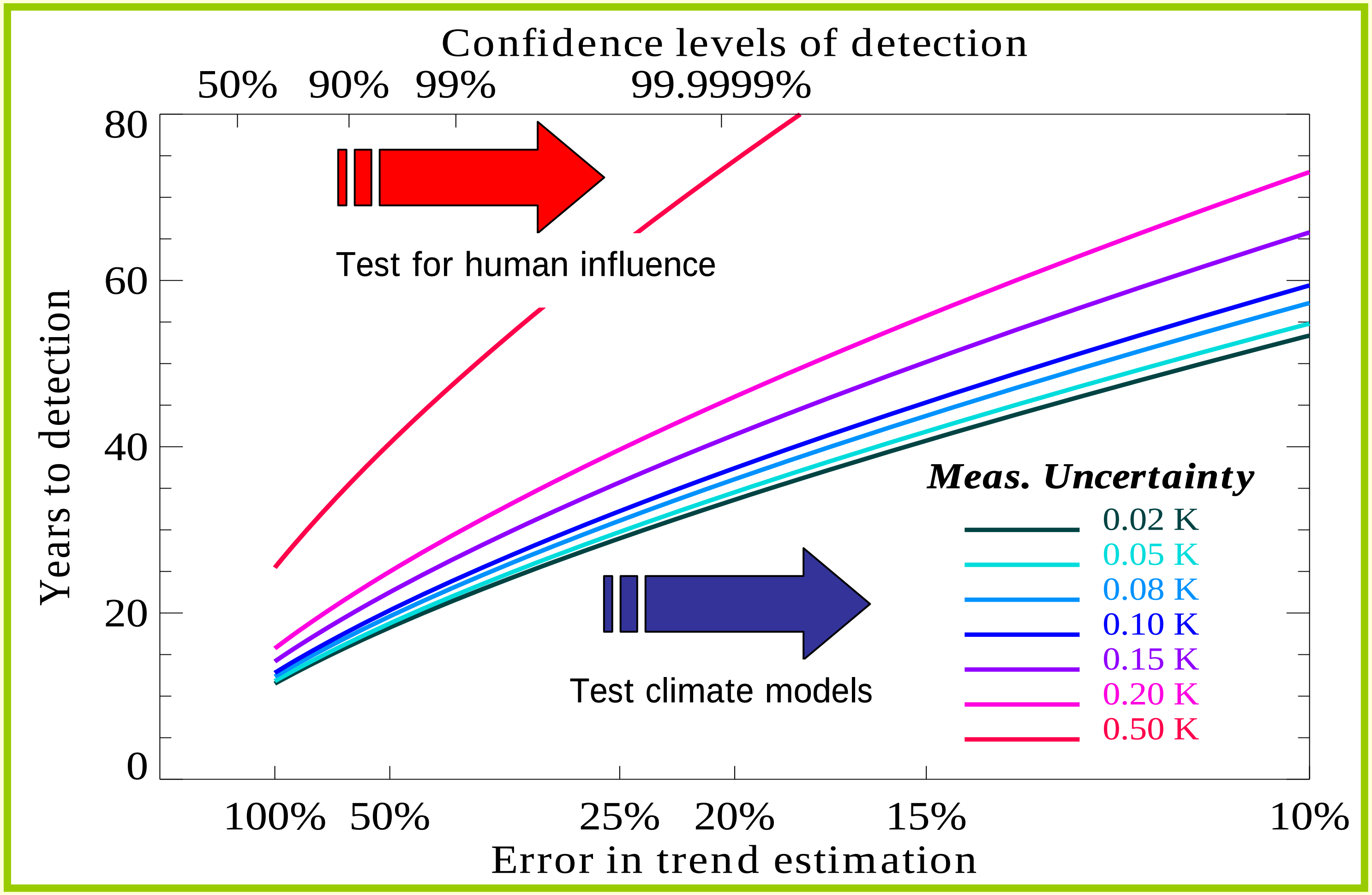
1. Contribution to the most important scientific questions facing Earth sciences today (scientific merit, discovery, exploration)
2. Contribution to applications and policy making (societal benefits)
3. Contribution to long-term observational record of the Earth
4. Ability to complement other observational systems, including national and international plans
5. Affordability (cost consideration, either total costs for mission or costs per year
6. Degree of readiness (technical, resources, people)
7. Risk mitigation and strategic redundancy (backup of other critical systems)
8. Significant contribution to more than one thematic application or scientific discipline

NRC DS and CLARREO

- “a long-term global benchmark record of critical climate variables that are accurate over very long time periods, can be *tested for systematic errors* by future generations, are unaffected by interruption, and are *pinned to international standards*”
- CLARREO science team:

- High information content
- High accuracy, proven on-orbit
- Sampling errors in time, angle, space lower than climate noise

Robust Uncertainty Estimate *Critical* to Mission Success



Dykema et al.: Robust On-Orbit Uncertainty, Calcon 2009

Uncertainty Estimates are Historically Optimistic

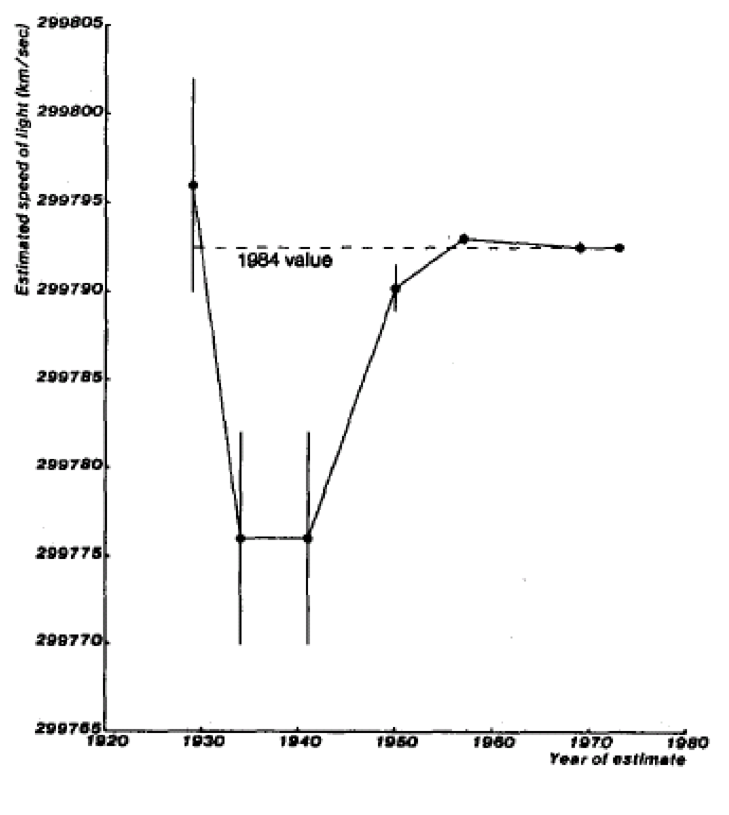
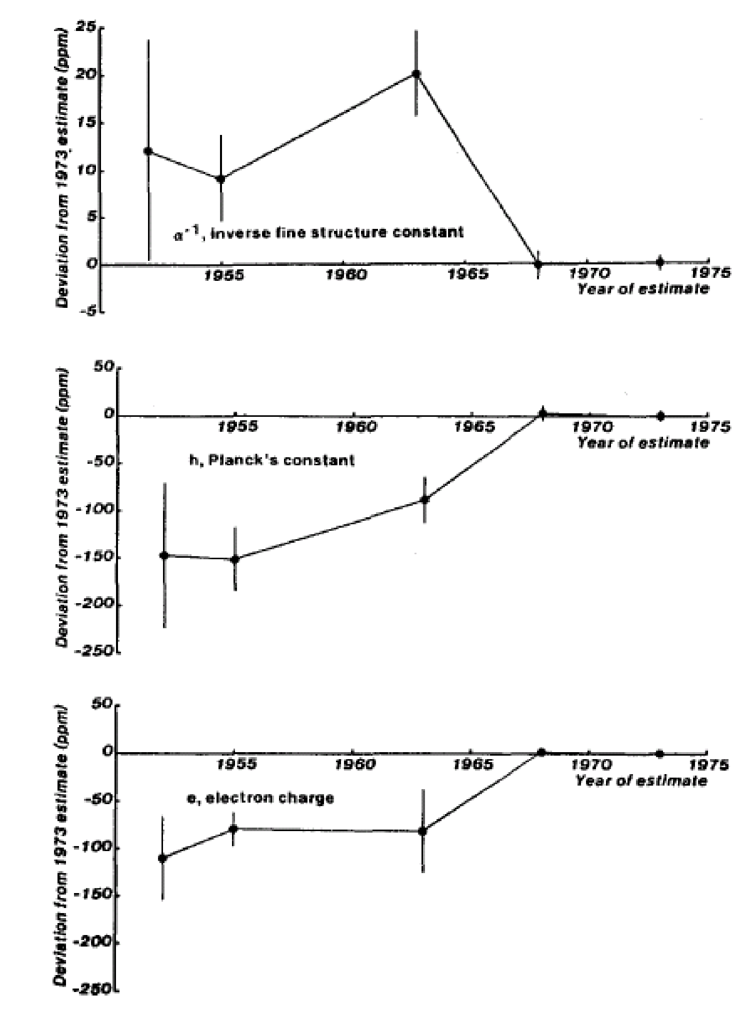


Fig. 2. Recommended values for the velocity of light; 1929–1973.



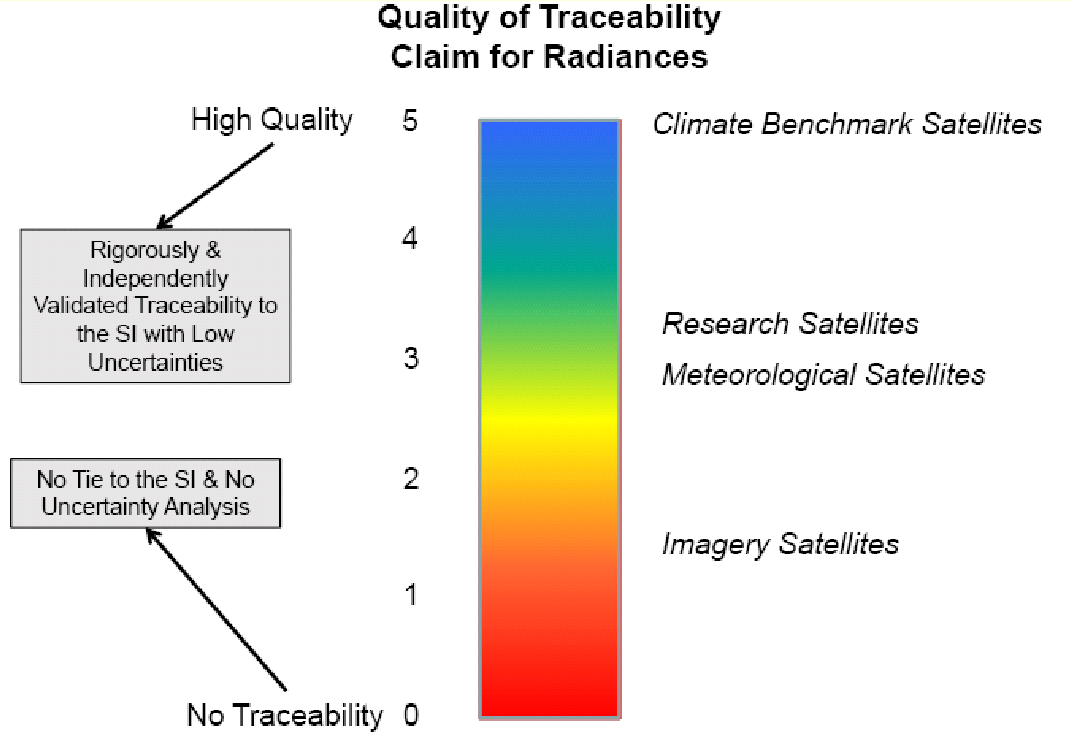
from Henrion and Fischhoff, 1986, Am. J. Phys.

What is *SI Traceability*?

- *SI traceability* is conferred by a chain of comparisons, each of stated uncertainty, back to a recognized SI standard
- CLARREO needs to:
  - have uncertainty low enough for decadal science *and*
  - needs to prove that biases (systematic error) that specify this uncertainty are within tolerances

SI Traceability and CLARREO

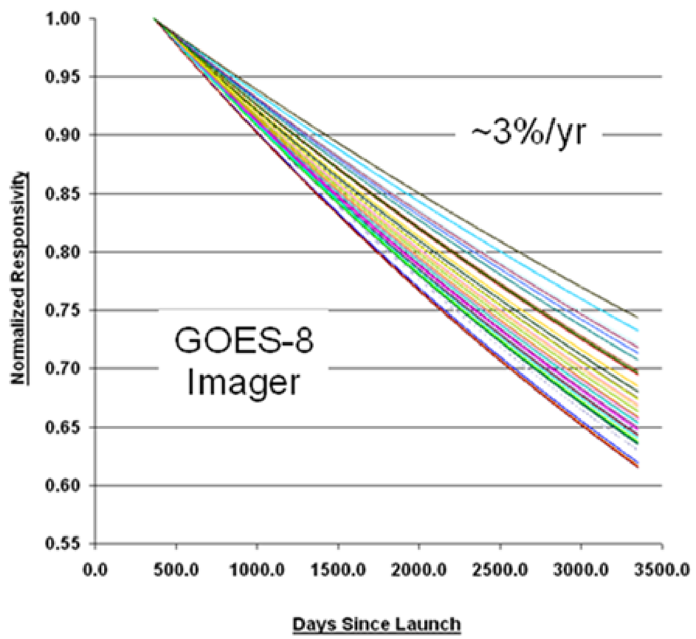
- Jerry Fraser, Raju Datla, et al. (NIST) have introduced the idea of strength of SI traceability claim
- We would recognize that CLARREO requires robust traceability to achieve its ambitious science goals

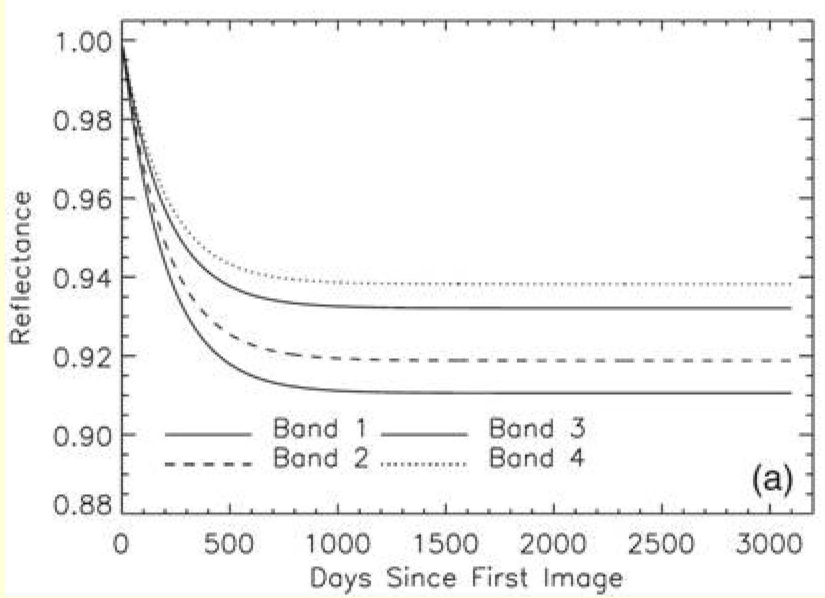


Dykema et al.: Robust On-Orbit Uncertainty, Calcon 2009

On-orbit degradation poses major challenge

NOAA's weather satellites monitor stars to track optical system deterioration on orbit.



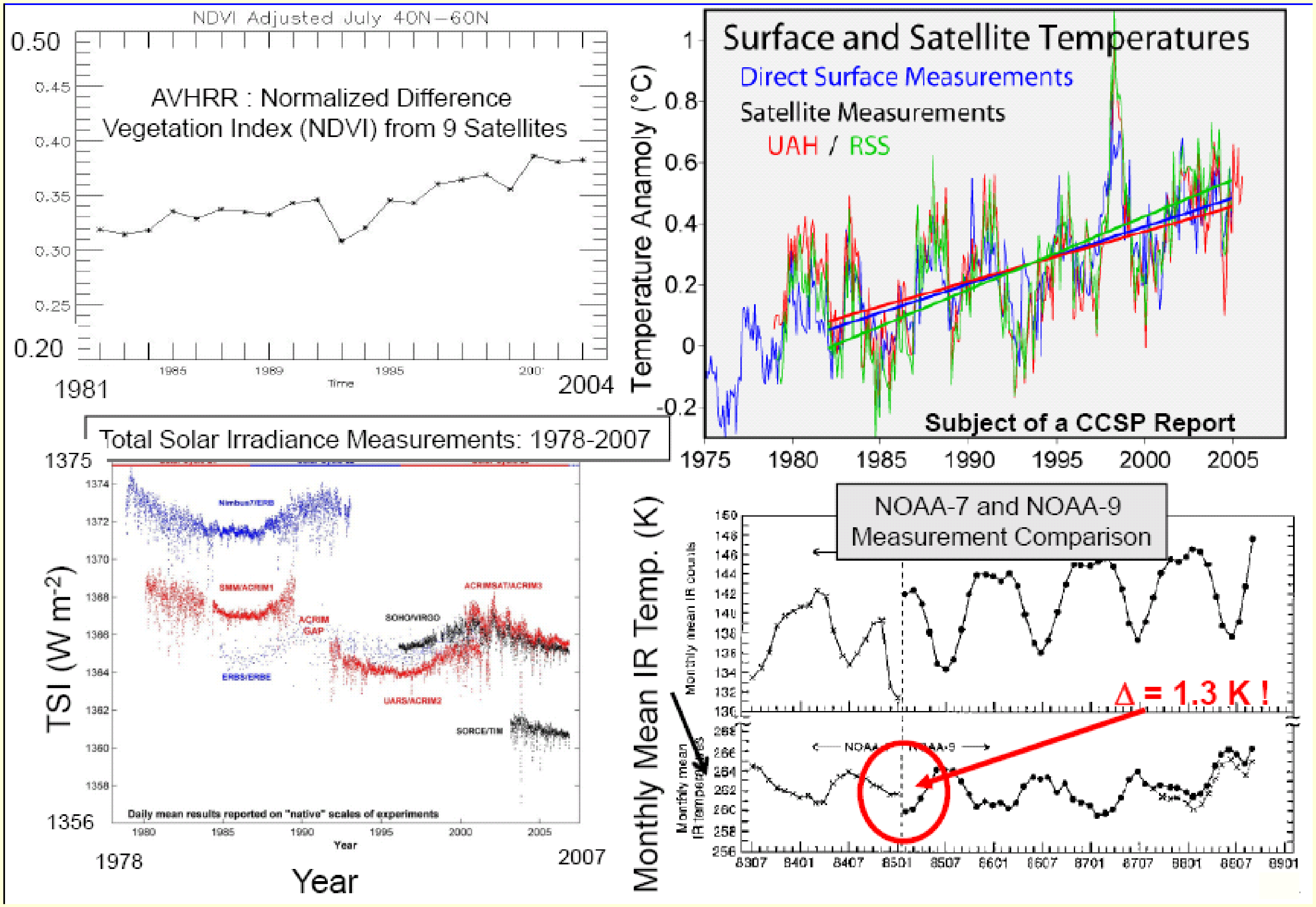


Dykema et al.: Robust On-Orbit Uncertainty, Calcon 2009

Benefits of traceability

- Greater credibility with broader natural sciences community
- Established framework for systematically evaluating uncertainty, Comparability across borders and institutions, and over time
- Programmatic benefits: relaunch on event of failure, relaxing requirement for overlap, and overall temporal coverage

Implications of lack of traceability



Dykema et al.: Robust On-Orbit
Uncertainty, Calcon 2009

From Jerry Fraser, NIST

The National Measurement Institute (NMI) Model for Traceability

- Measurements are Based on Well-Defined Physical Quantities
- Measurements are Compared among NMIs
- Measurements are Compared via Independent Approaches
- Uncertainty Claims are Rigorous and Validated
- Methods are Documented in Quality Systems and Peer-Reviewed Publications
- Research is Undertaken to Lower Uncertainties
- Fundamental Scales are Realized Periodically

GCOS Monitoring Principles

GCOS provides 10 additional principles for satellite climate monitoring beyond the 10 developed for in situ observations.

These principles cover:

- Temporal sampling including continuity,
- Production, validation, and dissemination of data products, and
- Achieving robust long-term calibration.

Those relevant to calibration (14,15 and 20) are summarized thusly:

14. Rigorous pre-launch instrument calibration against an international radiance scale should be ensured.

15. On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored.

20. Random errors and time-dependent biases should be identified.

Metrological Interpretation

- Sensor calibration should be based on reproducible physical properties
- The uncertainty analysis closely tied to the best analogs among primary laboratory standards
- All sources of measurement bias quantified against recognized standards, as identified starting with the sensor measurement equation
- Wherever possible, implement an independent physical test for each individual uncertainty source
- Optical systems selected to permit unambiguous uncertainty analysis
- The uncertainty analysis should rest on an open and continuing investigation of sensor performance
- Laboratory calibration activities mimic on-orbit environment and target characteristics
- Independent tests of the performance of the complete sensor provide the highest quality claims of traceability

•Superior quality of traceability claim is essential for decadal climate objectives, both scientific and societal

•Transparent, research-informed approach to sensor critical evaluation required to realize benefits of NMI practices for remote sensing