SI Traceability for Climate Measurements

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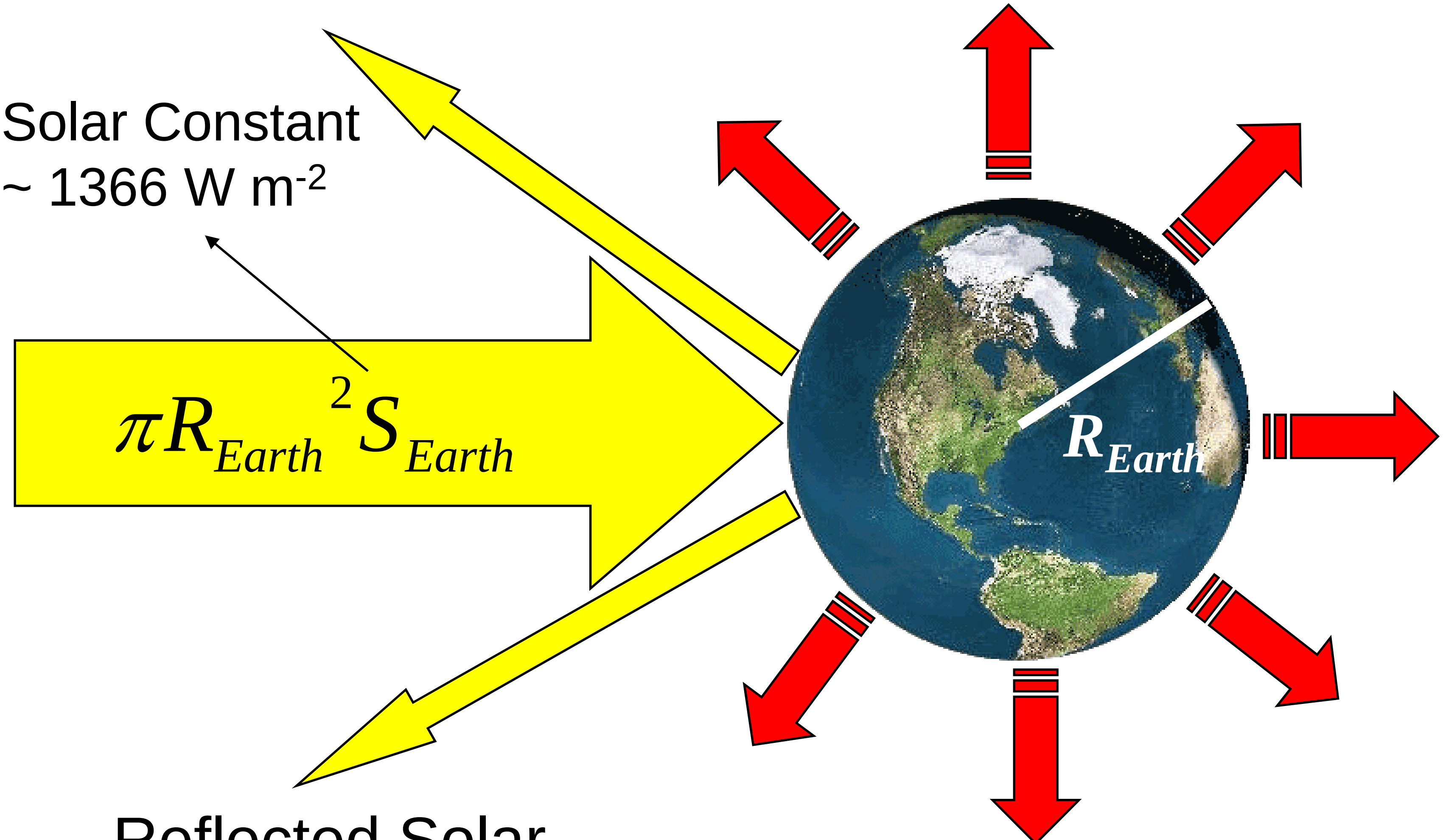
Measurement of Optical Radiation & Climate



Reflected Solar

$$\pi R_{Earth}^{\ 2} \rho_{Earth} S_{Earth}$$

~0.30

IR Thermal Emission

$$4\pi R_{Earth}^{\ 2} \sigma \varepsilon T_{Earth}^{4}$$

Two Climate Measurement Strategies

- Understand the phenomenology and have the models predict the trends
  →requires targeted measurements and high-quality models

- **Create environmental data records to determine the trends**
  → requires accurate, long-term measurements

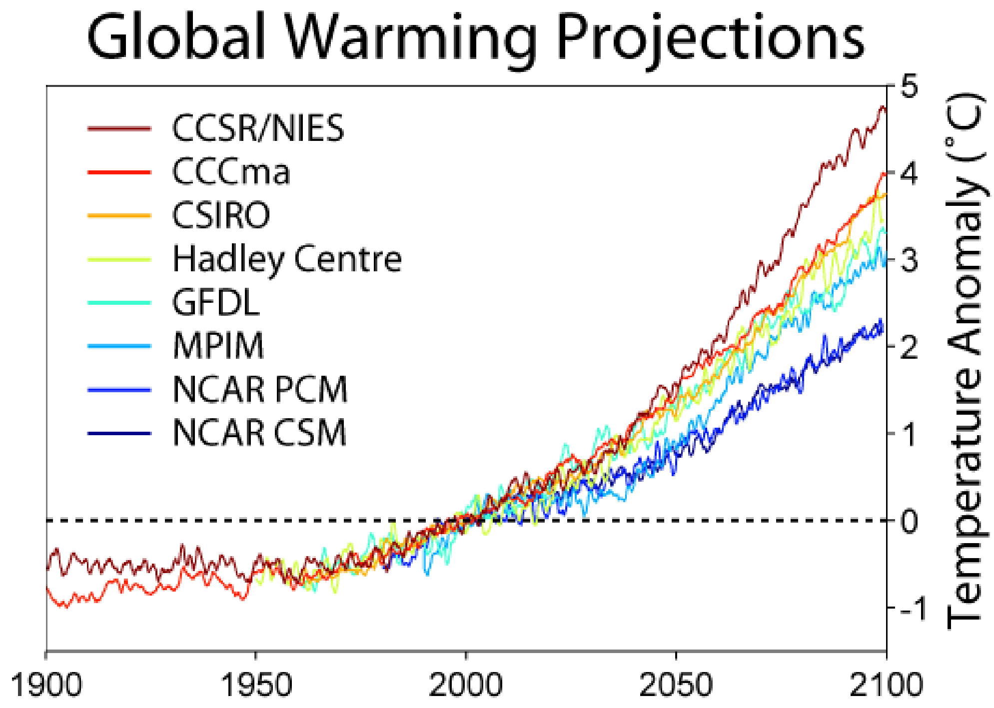
Challenge

- Lack of Accurate Models
  → Phenomenology Gaps

- Lack of Accurate Measurements
  → Over Reliance on Low-Accuracy Ground and Space-Based Weather Measurements

Claim: Climate is Done. Accurate Measurements are No Longer Necessary.

- How much and how fast?
- What is the impact?
- What are the global vs. regional differences and consequences?
- Is there a mitigation strategy?
- Is mitigation working?
- Are there unexpected new anthropogenic environmental threats?



→ *We need to get it right for policy makers*

Climate Measurements Require a New Strategy

Dedicated satellite program to provide benchmark climate-quality measurements

→Low uncertainties known throughout mission

→Reference for other satellite measurements

→Benchmark measurements for future generations

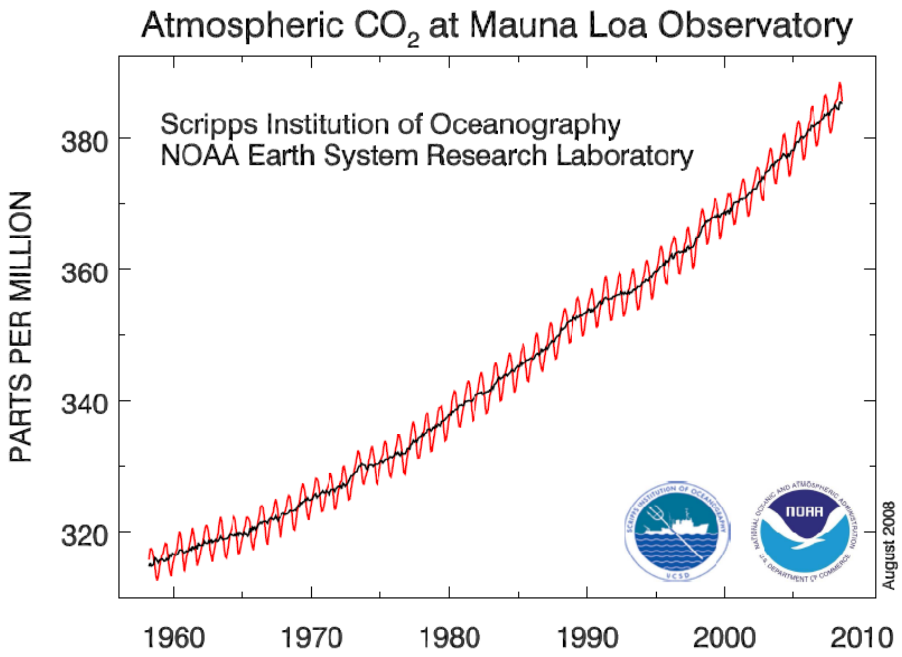
Instrument Digital Counts $\xrightarrow{f(DN,\,time)}$ Measurement Relative to SI Units

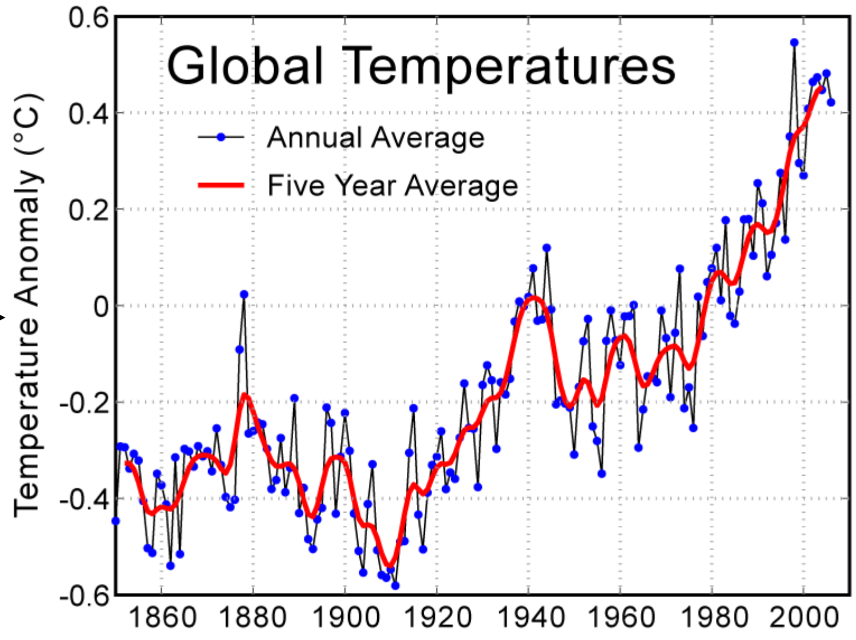
Traceability—Foundation for Accurate Measurements

Property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties (VIM, 6.10)

Based on the SI
International System of Units

High Quality Measurements more Readily Accepted



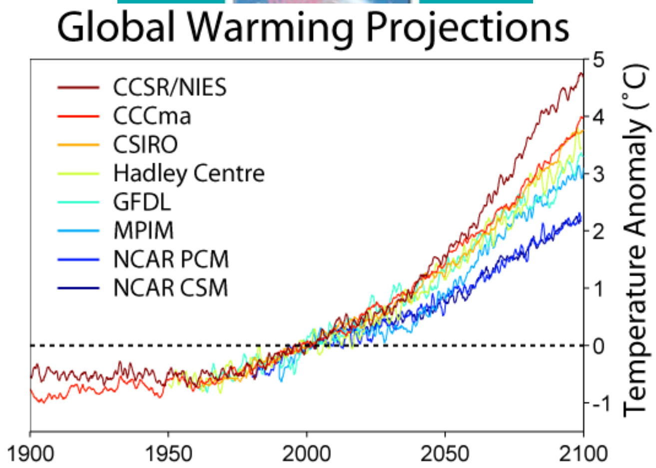


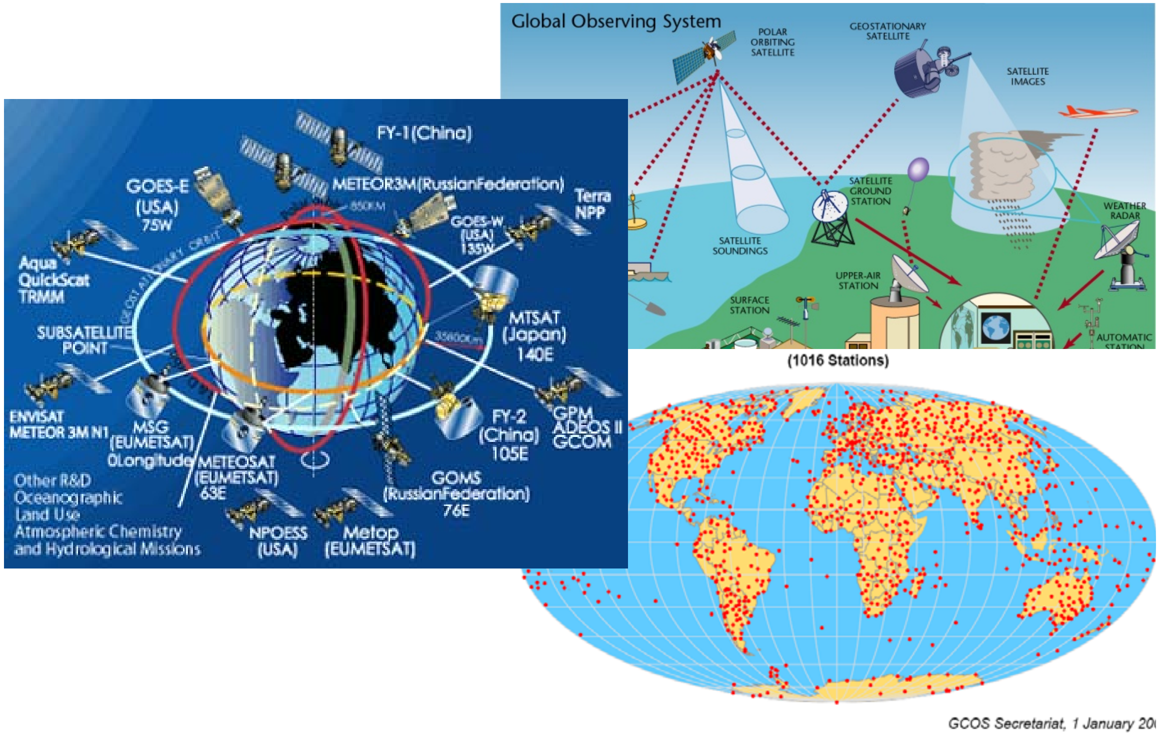
…very high confidence that the global average net effect of human activities since 1750 has been one of warming…

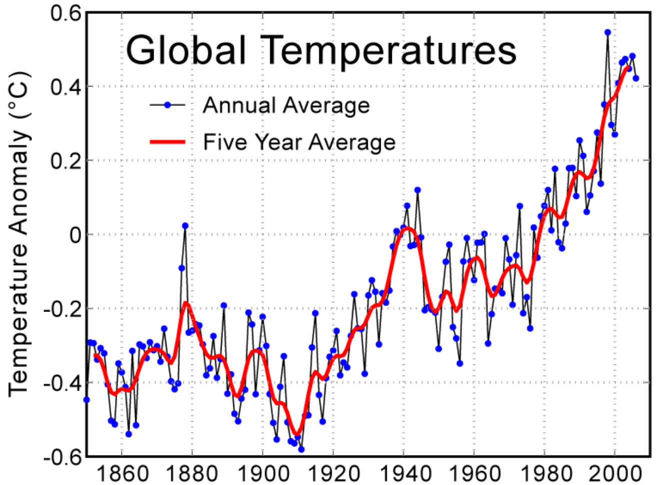
Intergovernmental Panel on Climate Change (IPCC)

Climate Measurements Require SI Traceability with Low Uncertainties

- Comparability on climate-change scales
- Comparability to fundamental physical models
- Comparability across generations
- Comparability across borders & organizations
- Comparability across instrument/measurement types

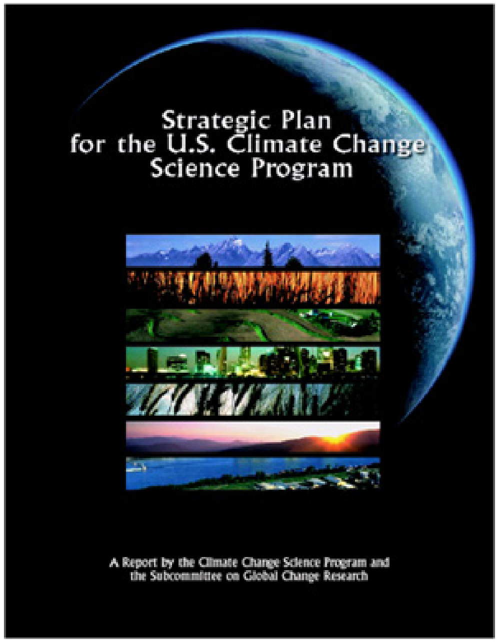






Traceability Requirement Recognized by Climate Research Community

… *Instrument calibration, characterization, and stability become paramount considerations. Instruments must be tied to national and international standards such as those provided by the National Institute of Standards and Technology (NIST)...*



Traceability of What?

<u>Raw Instrument Counts</u>

Calibrate Against the SI → Traceability to SI Established

<u>Fundamental Climate Data Records</u>
→Spectral or Band-Averaged Radiances

Combine with Ancillary Data and a Model → Traceability to SI Broken→

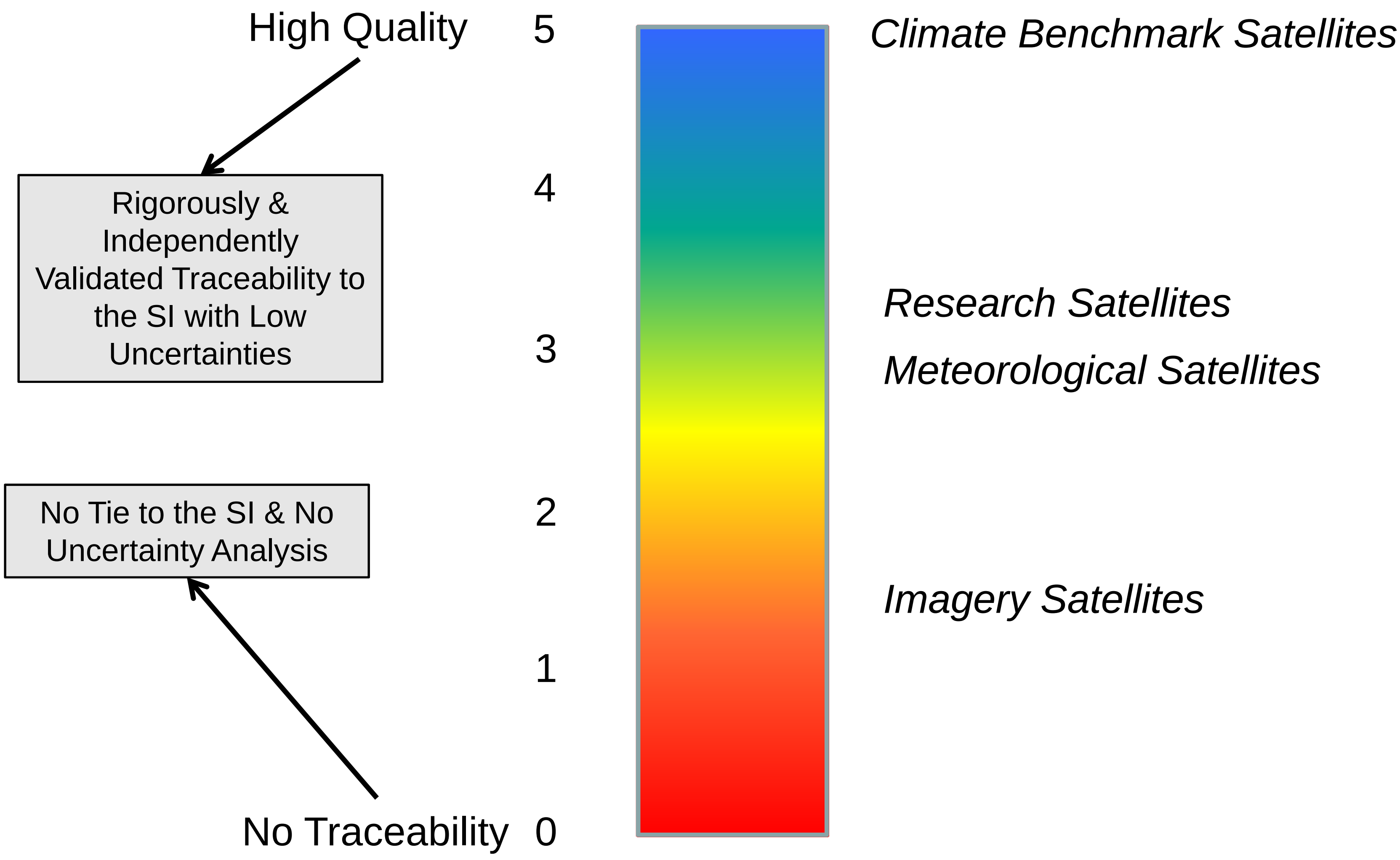
- Uncertainties of Ancillary Data Unknown
- Model Uncertainty Unknown
- Model Poorly Defined Physically

<u>Lack of Rigor</u>

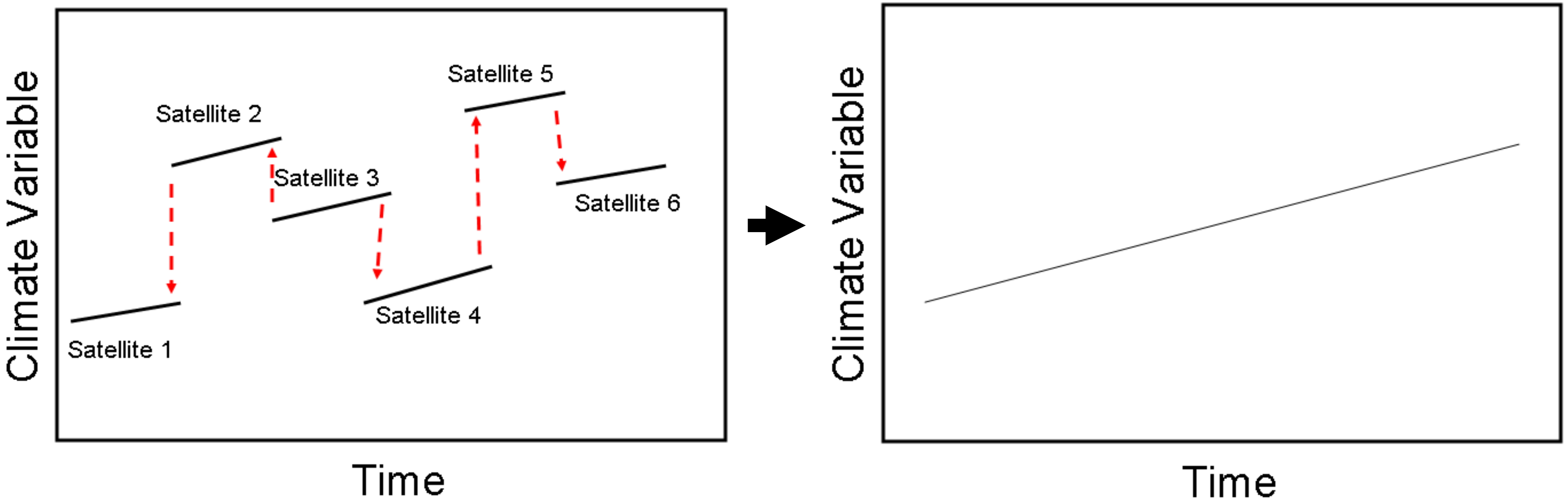
<u>Essential Climate Variables</u>
Aerosol Optical Properties, Cloud Properties, Ocean Chlorophyll, Sea Surface Temperature, Surface Reflectance, etc.

Quality of Traceability Claim

Quality of Traceability Claim for Radiances



Claim: Sensor is Stable So Accuracy/Traceability is Secondary

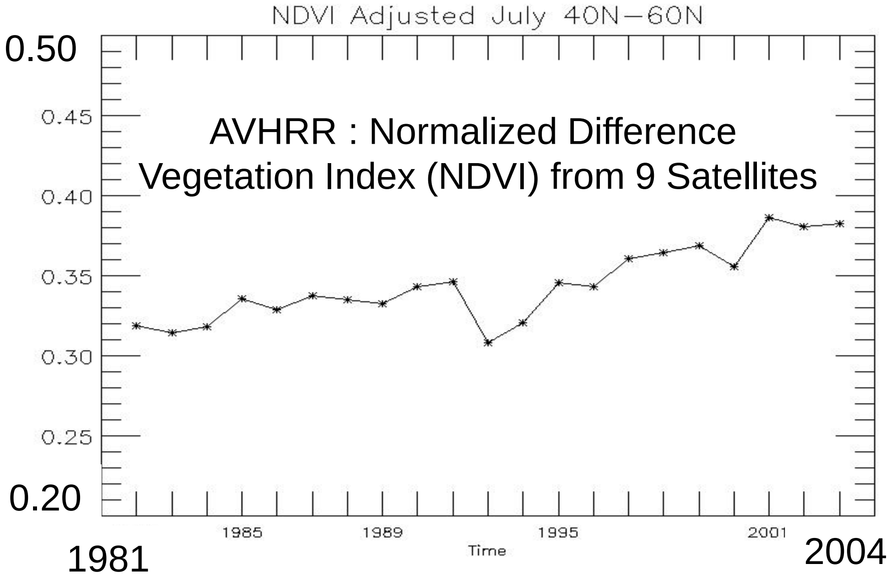


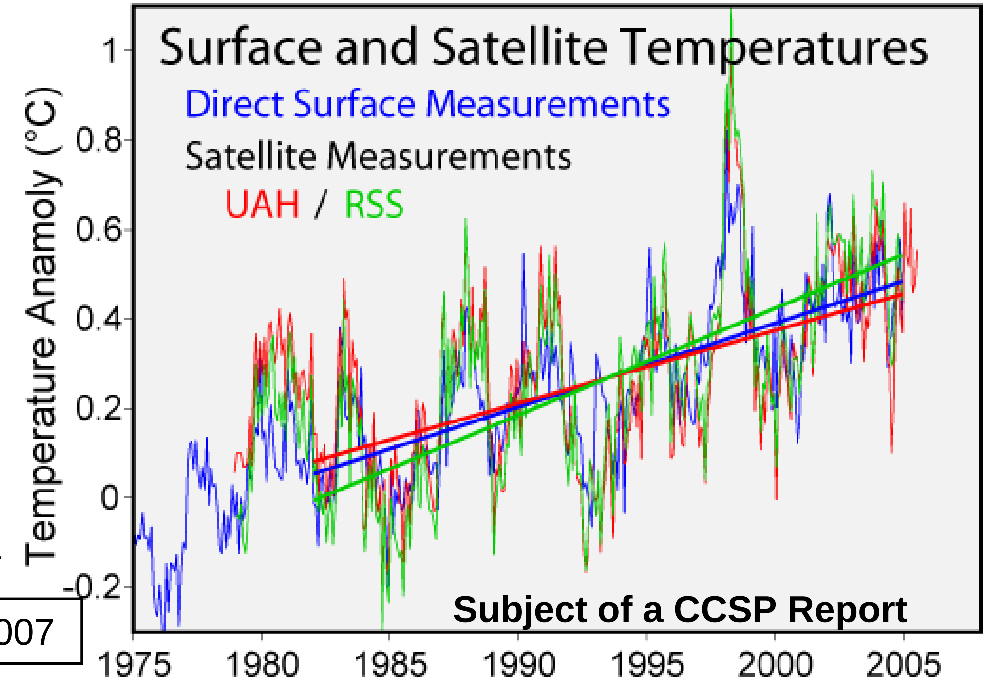
Issues

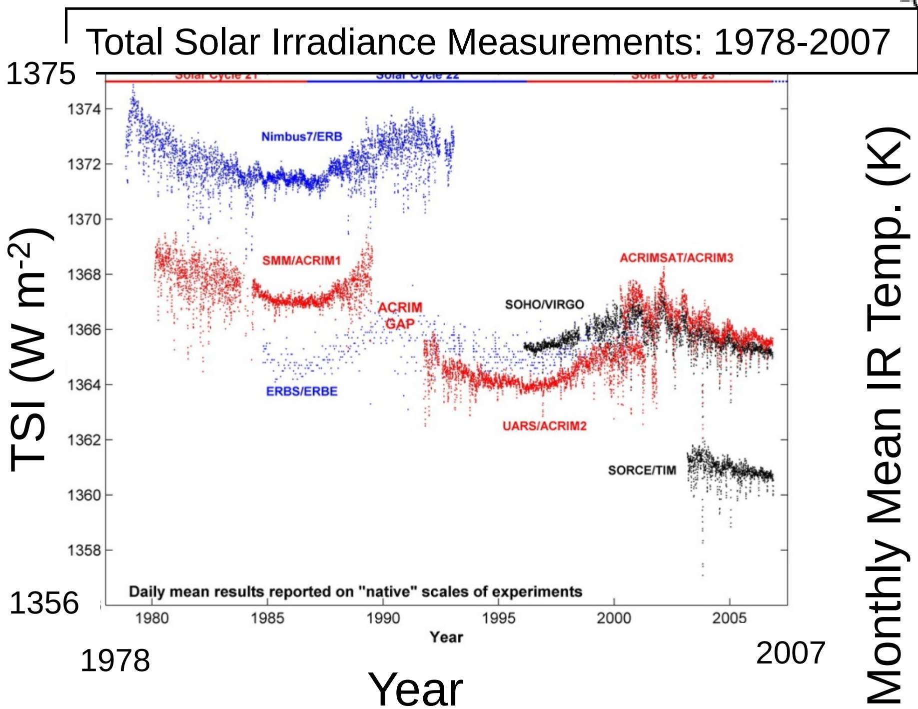
- Absolute scale?
- Common sensor drift?
- Uncertainties?
- Need sensor overlap

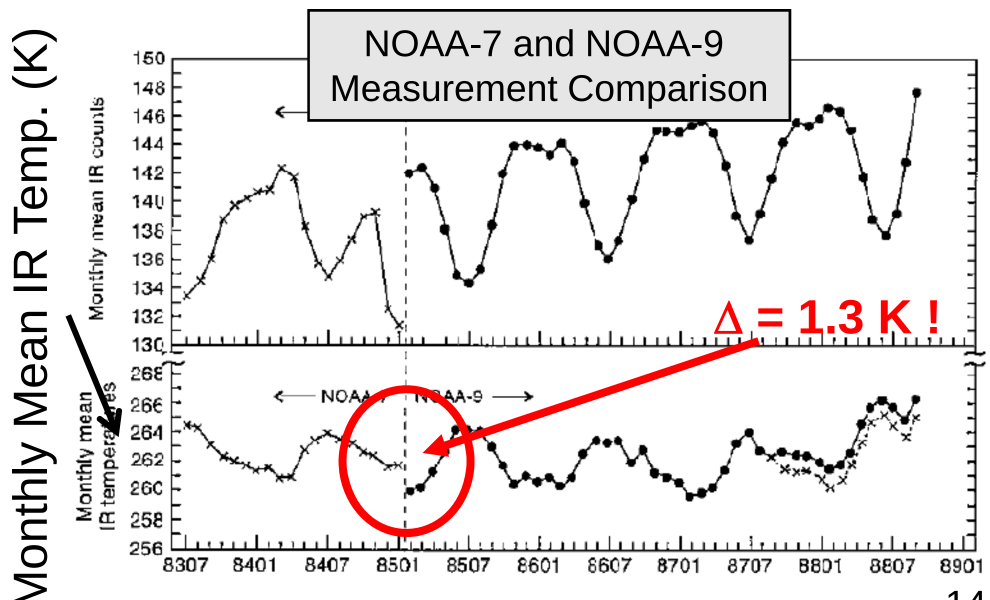
→Need SI-based references at beginning, end, & in the middle

Claim Raises Eyebrows







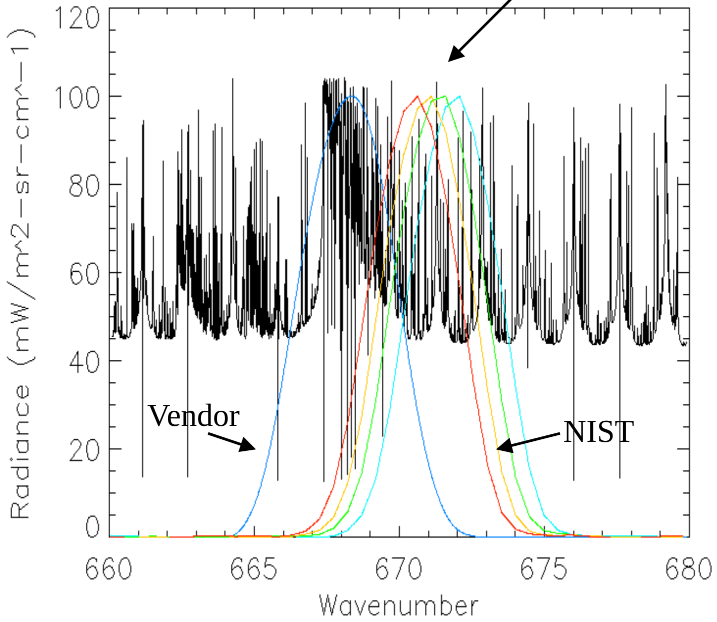


Comparisons through Satellite Overlaps Reveal Issues

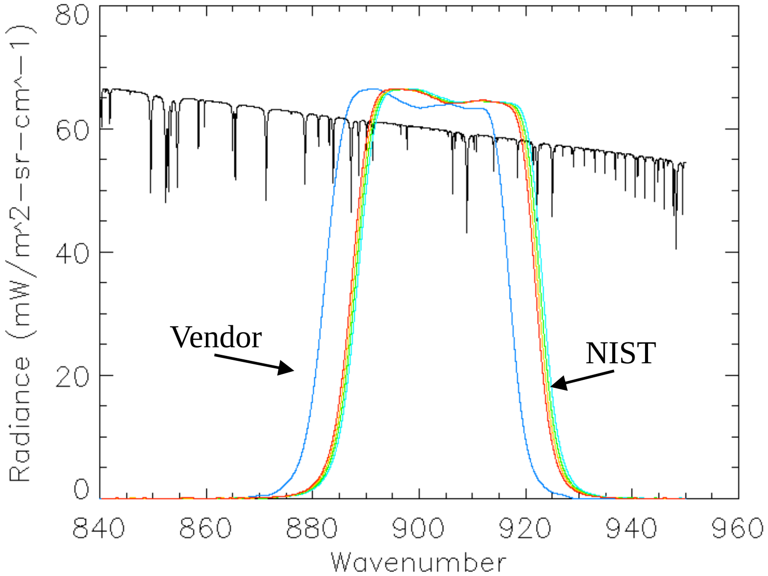
High Resolution Infrared Radiation Sounder (HIRS) on the NOAA-14 & 15 Polar-Orbiting Operational Environmental Satellites (POES)

Stratospheric T sensitive to filter center wavelength

HIRS 15 μm CO_2 Q-branch (stratospheric T)



HIRS 11 μm window (surface T)

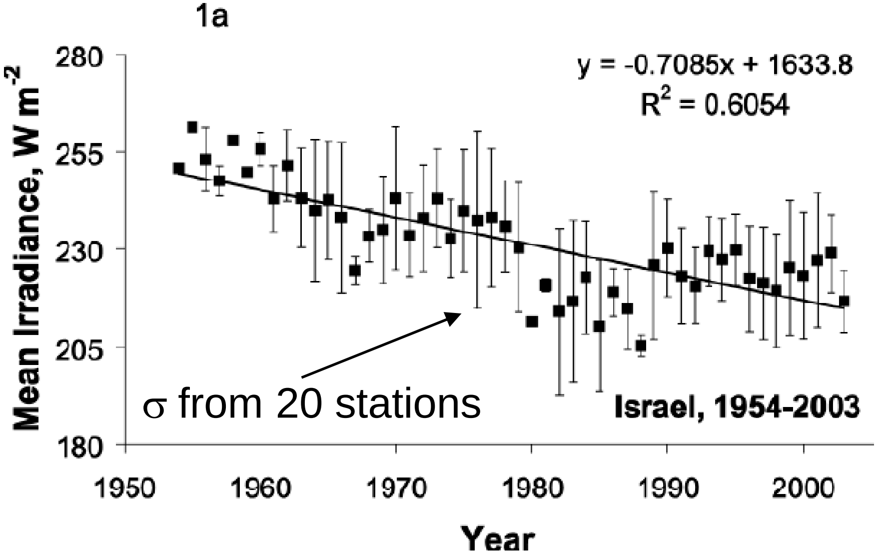


➔ $\Delta T > 10$ K

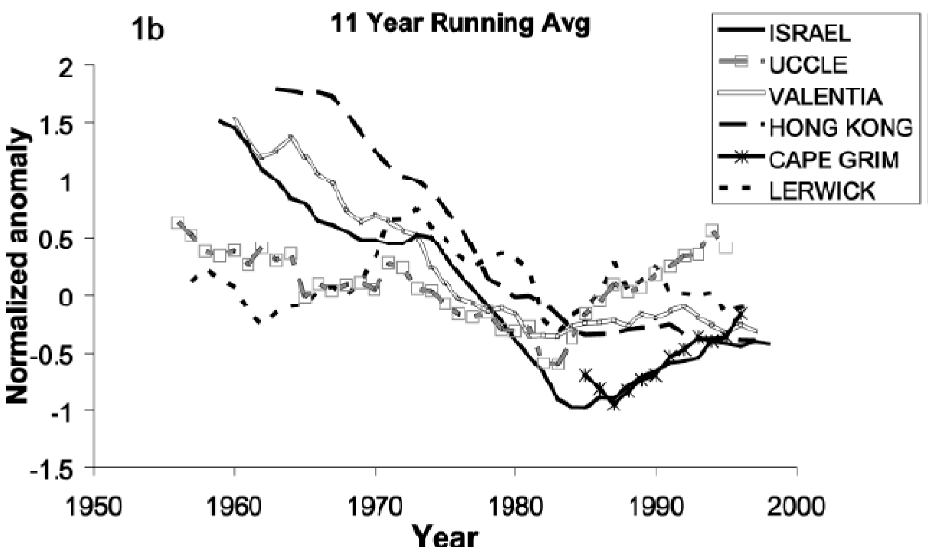
➔ ΔT up to 0.5 K

CAL/VAL Issues Also Affect Ground-Based Measurements

- Solar dimming?
- Aerosols, calibration, or both?
- Regional variation or calibration?



G. Stanhill, Eos ***88****, 58 (2007)*

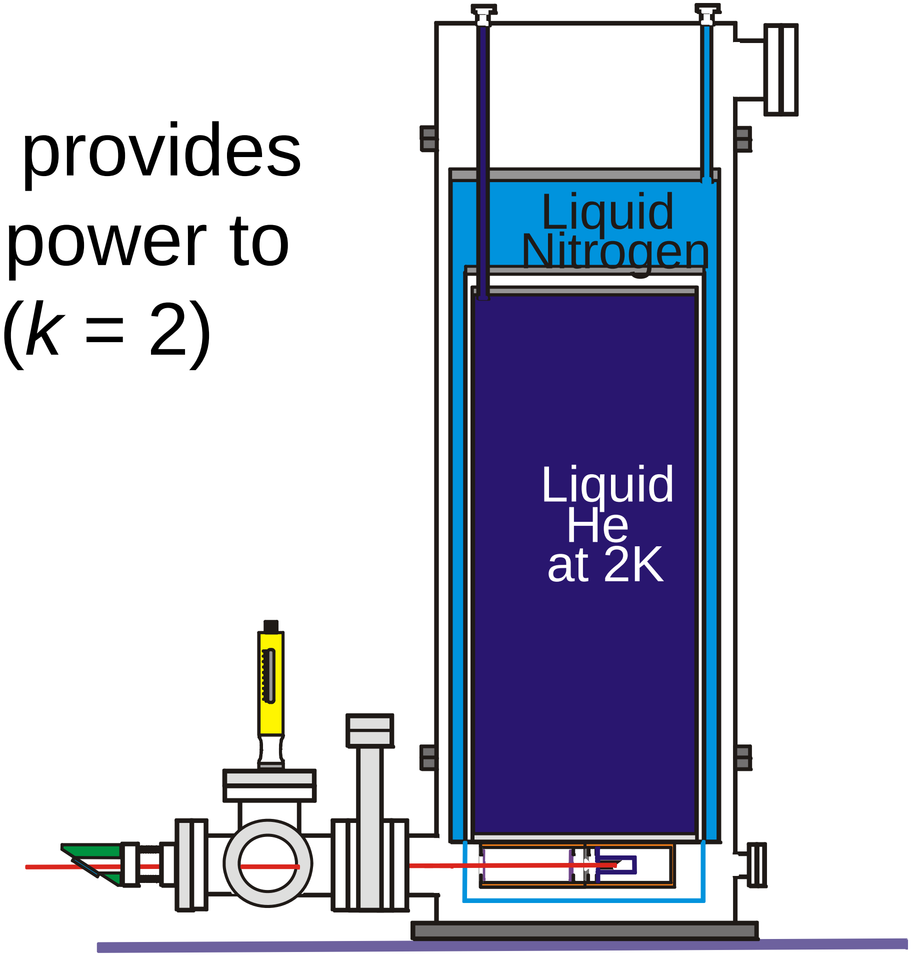


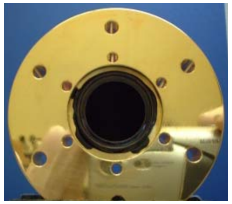
The National Measurement Laboratory (NMI) Model for Traceability

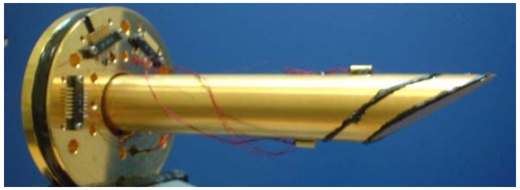
- Measurements are Based on Well-Defined Physical Quantities
- Measurements are Compared among NMIs
- Measurements are Compared to Independent Approaches
- Uncertainty Claims are Rigorous and Validated
- Methods are Documented in Quality Systems and in Peer-Reviewed Publications
- Research is Undertaken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

NIST Optical Measurements are Traceable to the Electrical Watt through the Primary Optical Watt Radiometer (POWR)

- POWR provides optical power to 0.01% (k = 2)



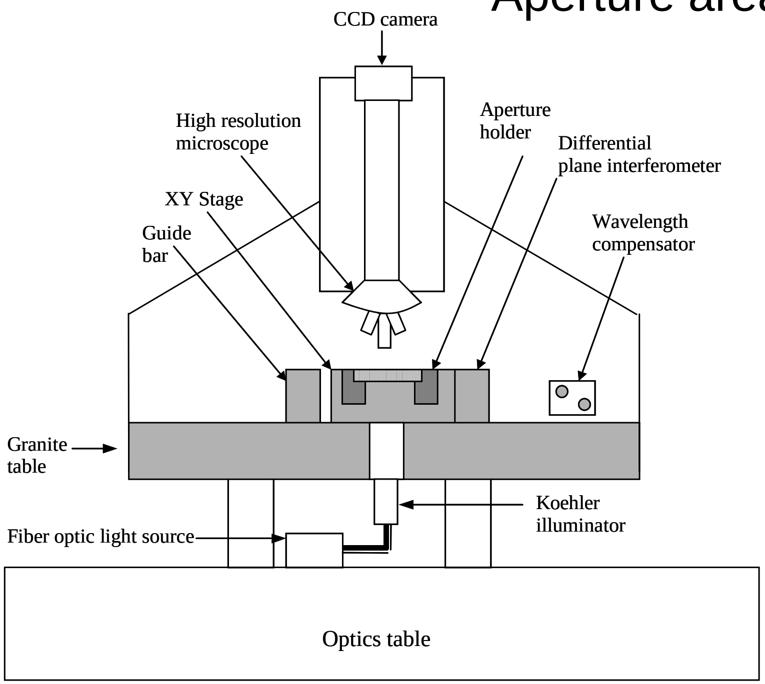


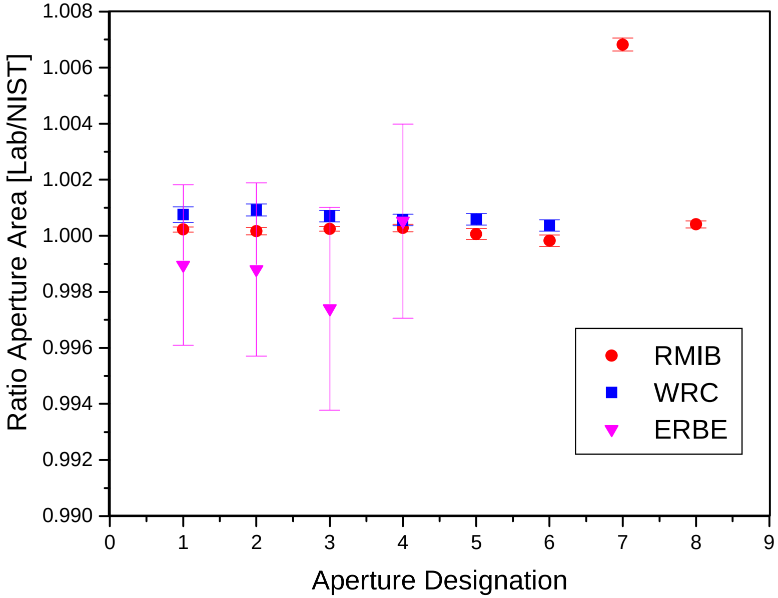


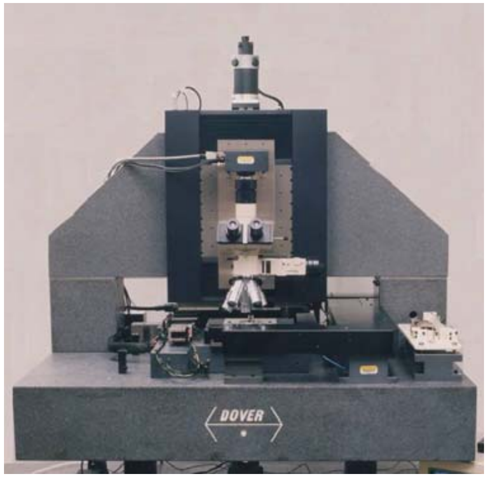
Jeanne Houston
Joe Rice

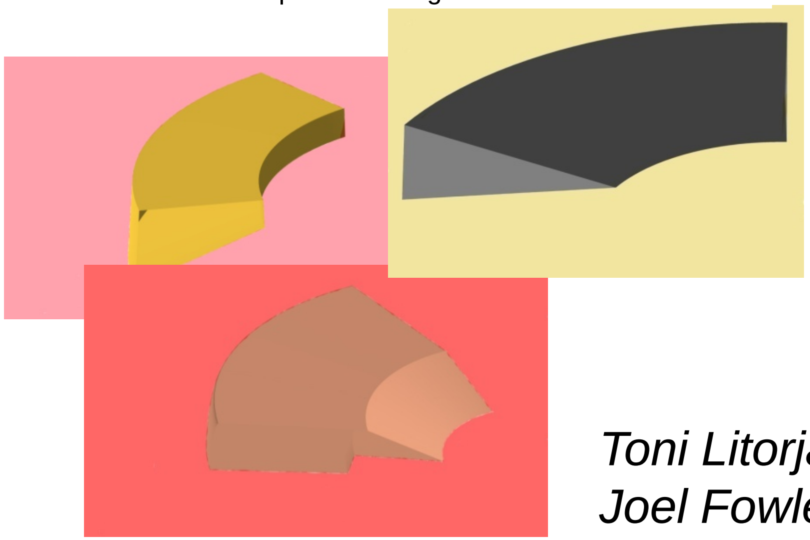
…and to the Meter through Aperture Area Measurements Performed by the Absolute Aperture Area Measurement Facility...

Aperture area to better than 0.01%





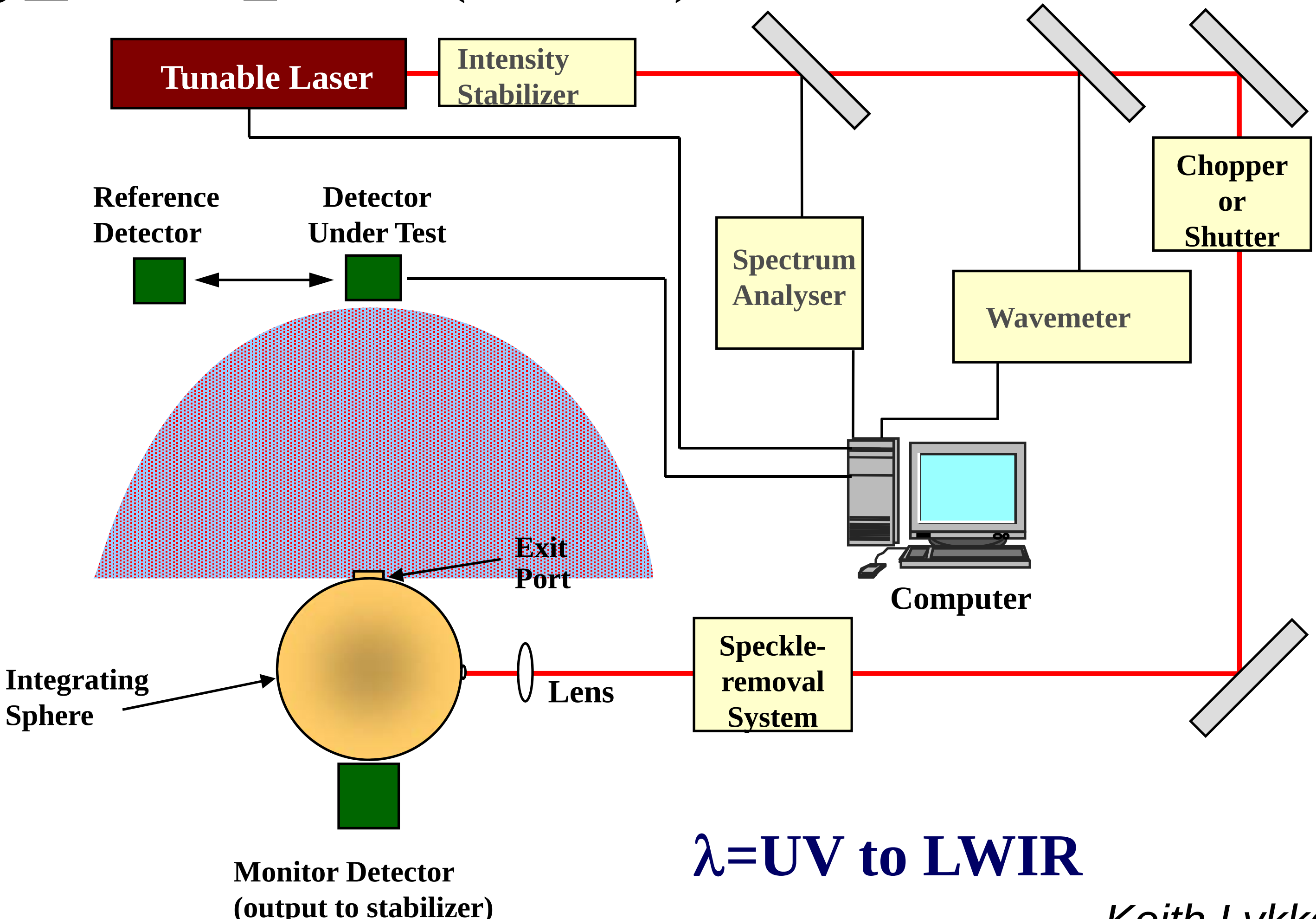




Toni Litorja
Joel Fowler

with the aid of SIRCUS

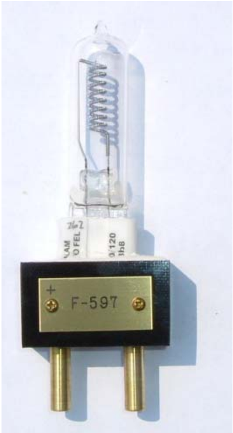
Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources (SIRCUS)

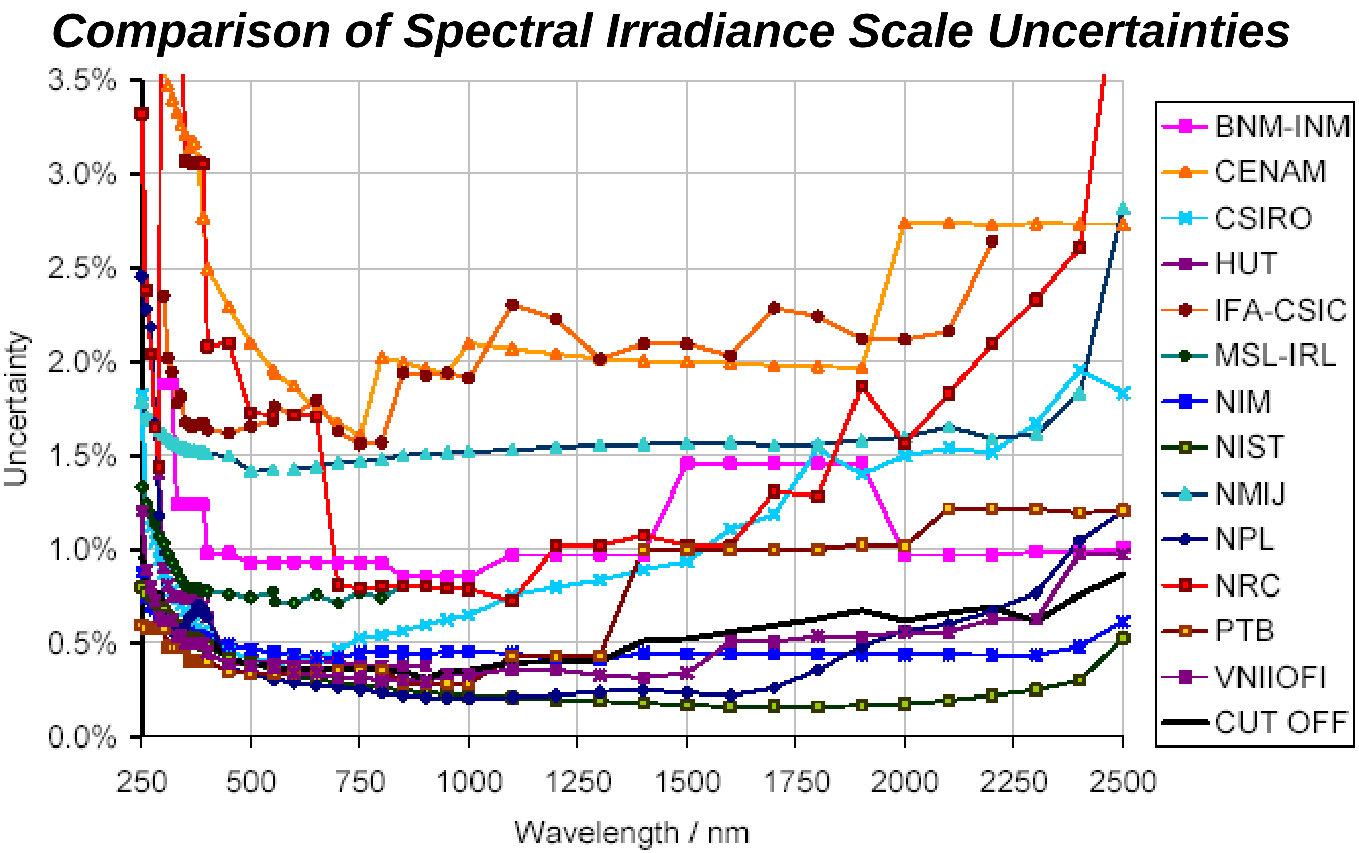


λ=UV to LWIR

Keith Lykke
Steve Brown
George Eppeldauer

...and Validated Through International Comparisons

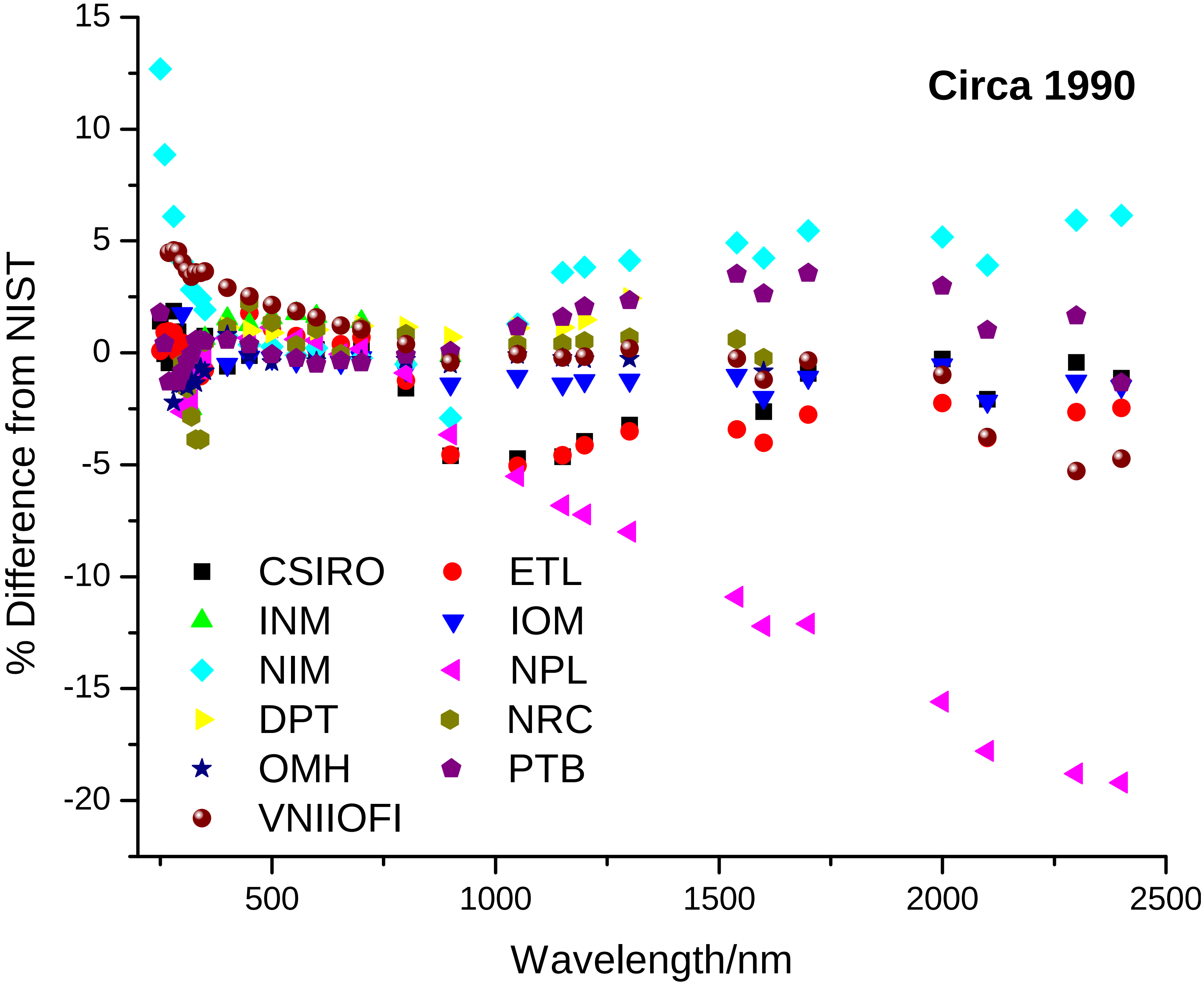




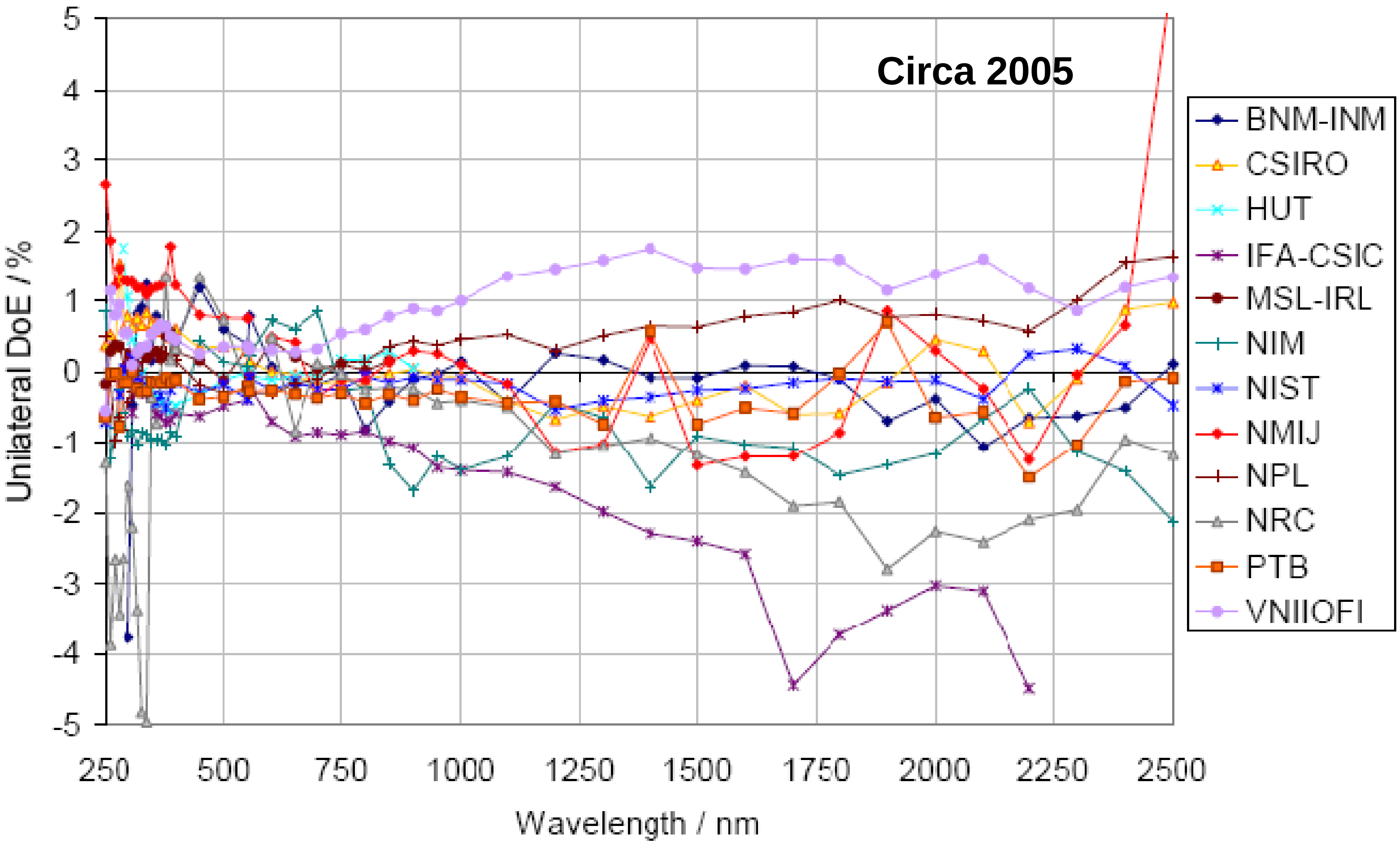
- Lowest uncertainties in the world
- Many NMI's use NIST irradiance standards, including Singapore, S. Korea, New Zealand, Poland, Austria, Sweden, Hungary, Canada, Mexico, Netherlands, & South Africa

Charles Gibson & Howard Yoon

Example Intercomparison: Spectral Irradiance



Example Intercomparison: Spectral Irradiance

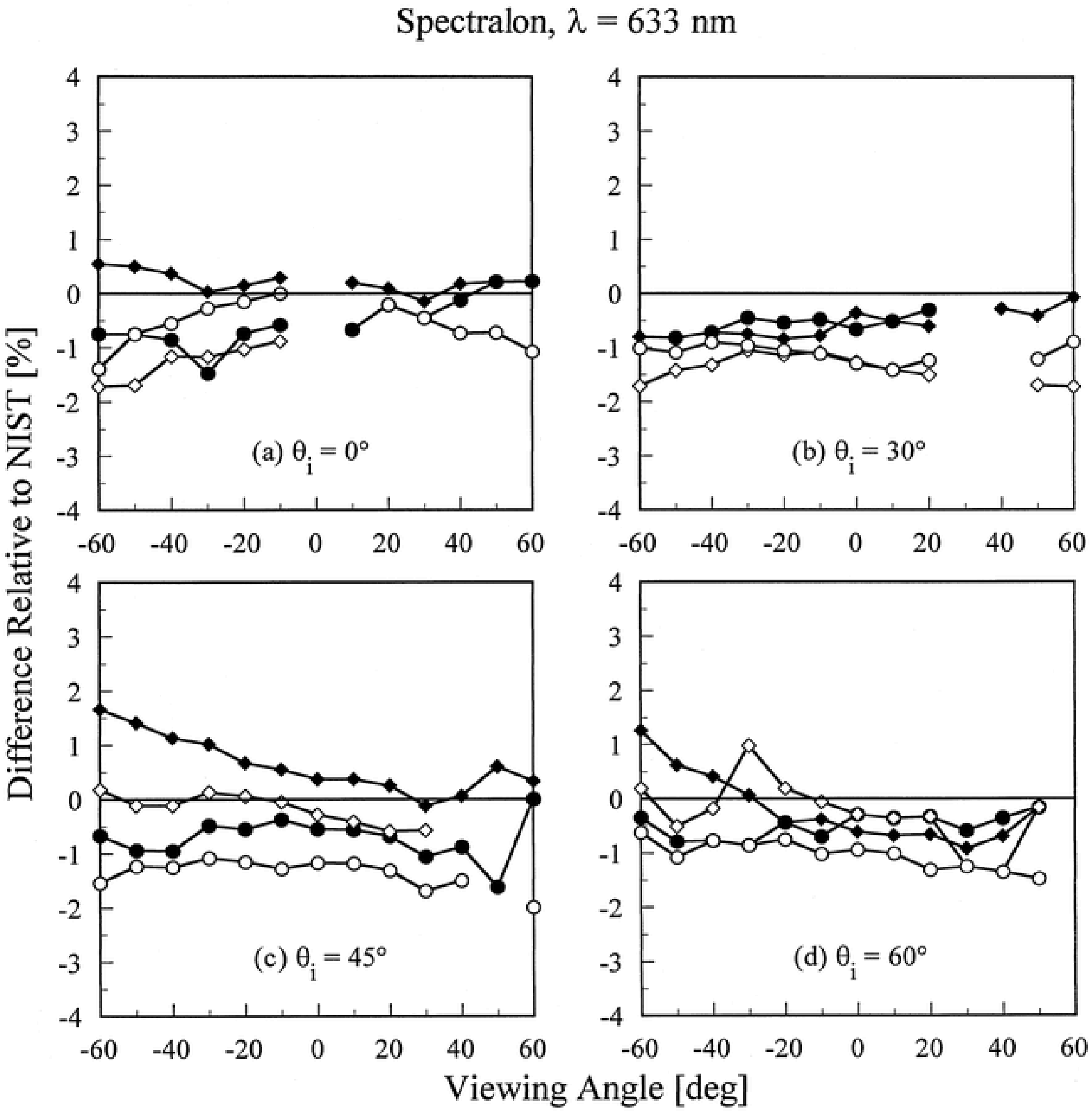


Intercomparisons: SIMBIOS Ocean Color Radiometric Scales

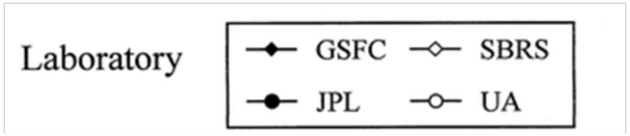
Laboratory	**Primary Calibration Source**
NRL Optical Sensing Section	FEL
NASA Code 920.1 Calibration Facility	FEL NIST
Wallops Flight Facility (NASA)	Non FEL Irradiance Standards
Moss Landing Marine Laboratory	Integrating Sphere NIST
Scripps	Integrating Sphere
Biospherical Instruments	FEL NIST
UCSB	FEL NIST
U. South Florida	Integrating Sphere
University of Miami	FEL
Satlantic	FEL

The Second SIMBIOS Radiometric Intercomparison (SIMRIC-2), March – November 2002,
Meister *et al*., NASA/TN-2002-210006, Vol. 2, Aug. 2003

BRDF Intercomparison: Pressed PTFE



MODIS Diffuser

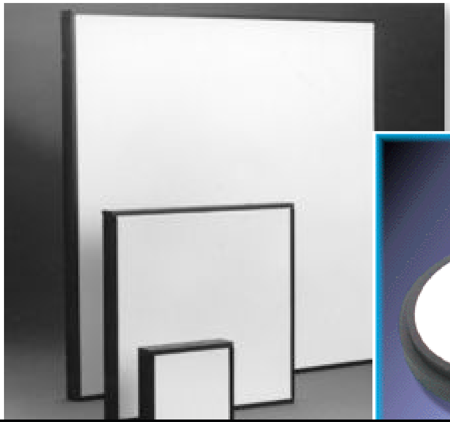


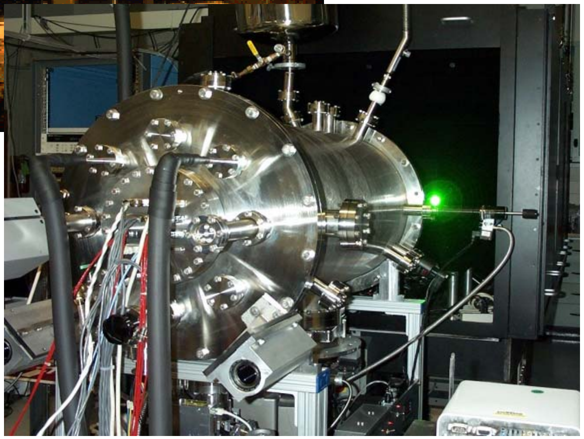
E.A. Early, et al., J. of Atmos. and Ocean. Tech. **17**, 1077–1091 (2000)

NIST's Highly Accurate Radiometric Scales Are Disseminated through Calibration Services

Calibration Services and Standard Reference Materials Include--

- Reflectance Standards (PTFE Plaques) [*David Allen, Maria Nadal*]
- Spectral Irradiance Source Standards (FEL and Deuterium Lamps) [*Charles Gibson, Howard Yoon*]
- Spectral Radiance Source Standards (Integrating Spheres, Blackbodies, Plaque/FEL Combination) [*Charles Gibson, Sergey Mekhontsev, Ben Tsai*]
- Detector/Radiometer Absolute/Relative Spectral Responsivity Standards (Si Photodiodes) [*Tom Larason, Jeanne Houston*]

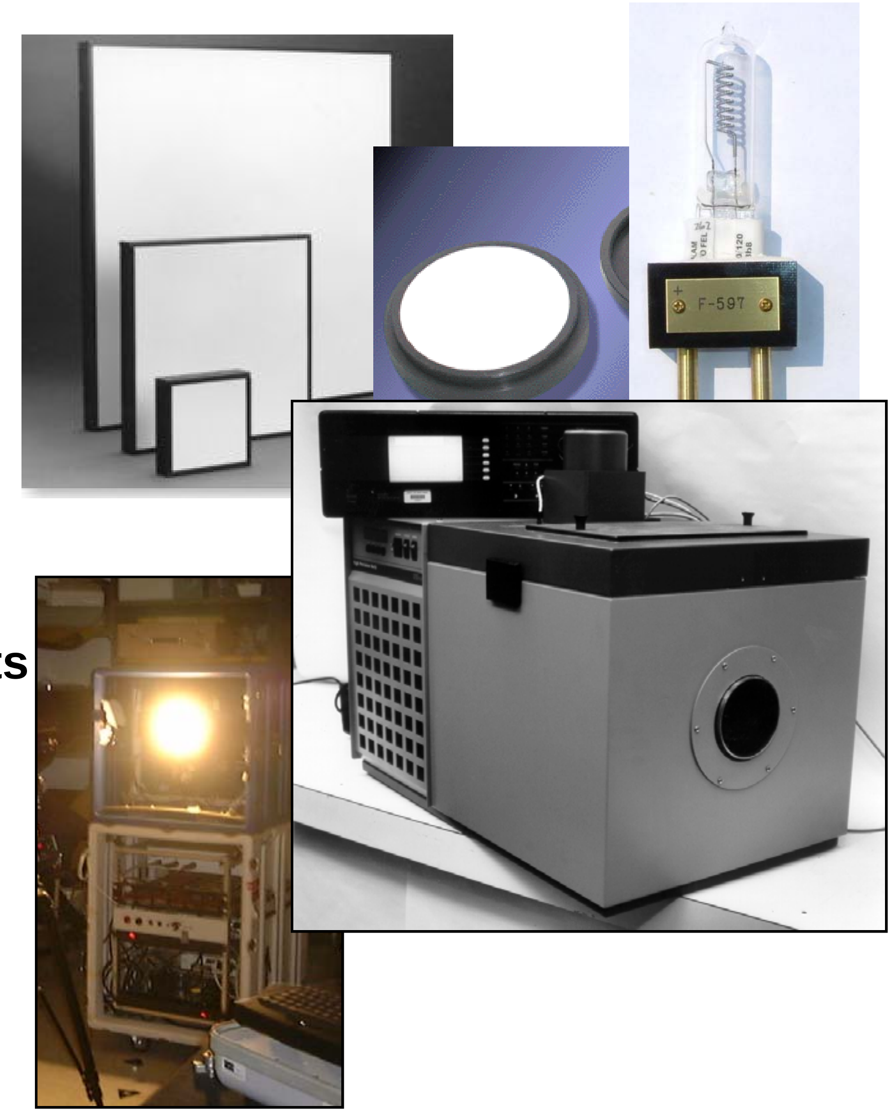




Climate Measurement Requirements Challenge
NIST Disseminated Standards

Climate community typically realizes

- Spectral Reflectance to 2 %
- Spectral Radiance to 2%
- Radiance Temperature 100 mK



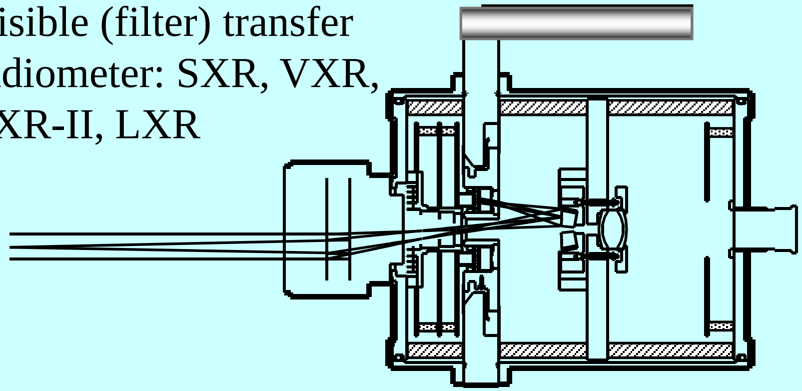
Compare with Stated Climate Requirements

Variable	Accuracy	Stability
Surface Albedo	1 %	0.2 %
Sea-Surface Temperature	100 mK	40 mK

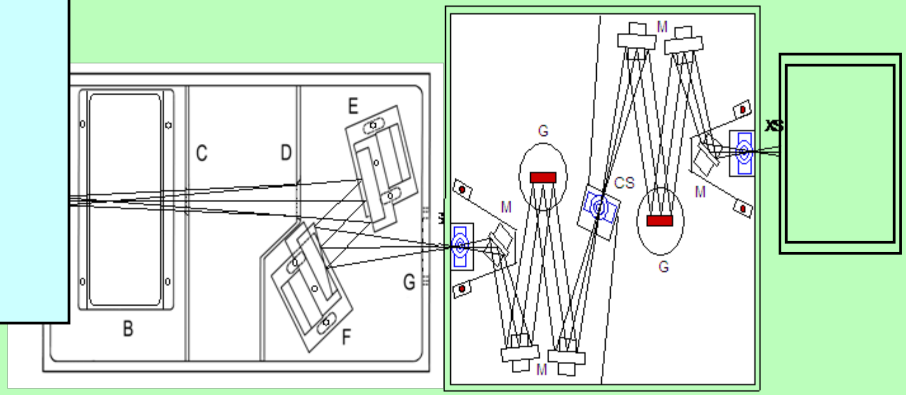
New NIST Effort Needed to Allow Calibrations to meet Climate Requirements

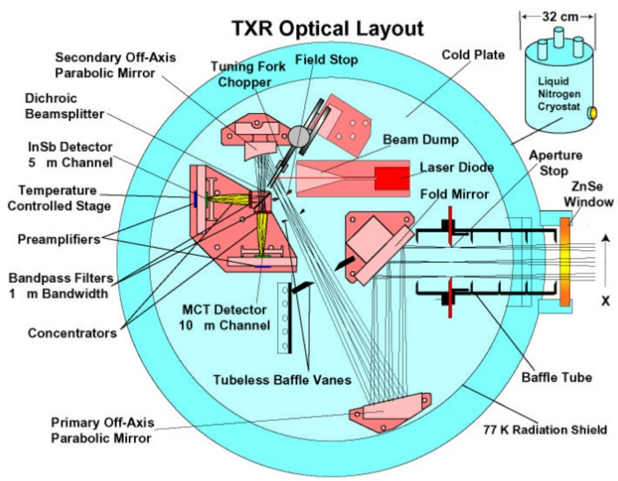
Validation: Transfer Radiometers

Visible (filter) transfer radiometer: SXR, VXR, SXR-II, LXR

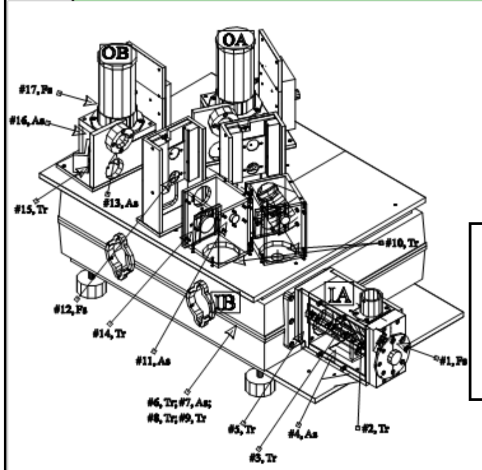


Short-Wave Infrared Transfer Radiometer (SWIXR)





Thermal Infrared Transfer Radiometer (TXR)



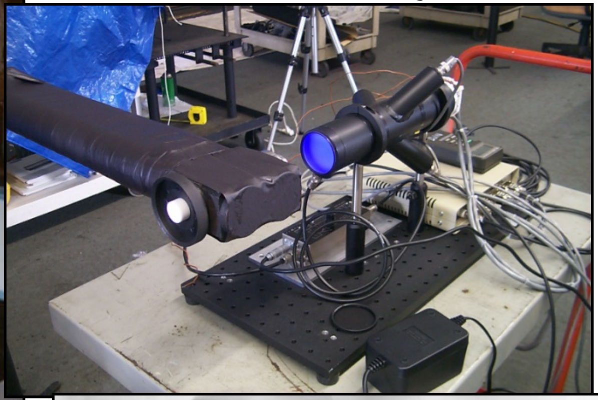
Fourier-Transform Thermal Infrared Transfer Radiometer (FTXR)

Carol Johnson
Steve Brown
Joe Rice

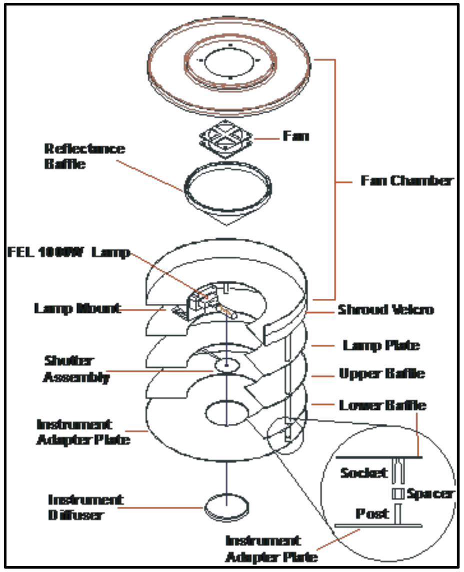
Validation: Transfer Sources

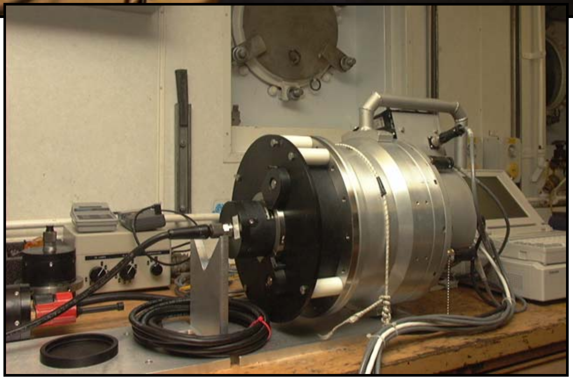
NIST Portable Radiance (NPR) Source

Blue LED Field Stability Source



UV Field Source Calibrator





SeaWiFS Quality Monitor (SQM)

Water Bath Blackbody Source

Carol Johnson
Joel Fowler
Ted Early
David Allen
Ping Shaw

Agencies Partner with NIST to Help Meet Measurement Requirements

National Aeronautics and Space Administration
Goddard Space Flight Center

USGS
science for a changing world

UV NET

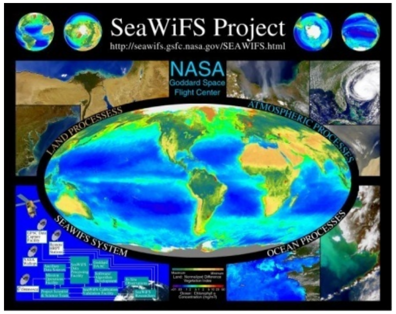
NOAA
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

Triana

GOES-R

National Polar-orbiting Operational Environmental Satellite System
NPOESS
Three Agencies One Mission

USDA UV-B Monitoring Program



Earth Sciences Systems Program Office
EOS
Earth Observing System

Carol Johnson
Steve Brown
Joe Rice

Conclusions

The NMI Model Works!

Acknowledgements

Steve Brown
Carol Johnson
Joe Rice

David Allen
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