Traceability and Quality Issues

Bruce Wielicki
NASA Langley Research Center

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Existing TSI Composites Lack Needed Stability

Need stability uncertainties <10 ppm/year
Composite Choice Is Critical for Climate Researchers


“We estimate that the Sun could account for as much as 69% of the increase in Earth's average temperature, depending on the TSI reconstruction used.”

courtesy of P. Pilewskie, LASP, Sun and Climate Symposium, Nov 2015
The History of Progression to Lower TSI Values

Life was pretty good...
The History of Progression to Lower TSI

Total Solar Irradiance Data Record

...until SORCE launched in Jan. 2003

G. Kopp, 19 Nov. 2014
The History of Progression to Lower TSI

How socially driven is science?
Traceability and Quality

• We currently typically rely on stability and overlap of space based climate observations
  – Climate change signals are small and difficult to verify
  – Consistency of multiple systems all of which lack climate accuracy is weak evidence for climate change signals. Leads to moderate not high confidence. True of most climate variable records. The classical exception: 60 year SI traceable CO$_2$ record at Mona Loa.

• SI Traceability and accuracy in orbit must replace stability and overlap as primary source of confidence in climate observations given the large political and economic challenges

• Independent observations and independent uncertainty analysis is key to standards, traceability, and quality: analogous to metrology lab standards: but this doubles cost

• Must observe and determine evolution of climate not evolution of observing system.

• Also greatly improves interoperability of networks of systems with lower accuracy: constellations, multinational, multi source
Detection of Anthropogenic Trends

• Fuzzy Lens #1: natural variability of the climate system limits even perfect observations

• Fuzzy Lens #2: observing system uncertainty (calibration, stability, sampling, algorithm, reprocessing, data availability: including fundamental instrument calibration data)

• A climate observing system is designed to reduce the effect of observing system uncertainty to levels much less than natural variability levels (i.e. factor of 2 to 3 smaller). Beyond that is the point of diminishing returns.

• A very good metric for climate observing system accuracy is the delay in time to detect trends versus a perfect observing system (NRC Continuity, 2015): 0 yrs = 100%, 30 yrs = 0%.

• Economic value of narrowing uncertainty in future climate change by ~ 15 years is ~ $10 Trillion U.S. dollars for the world (Cooke et al. 2014, 2015).

• Tripling all global climate research investment (obs, modeling, analysis) would return $50 per $1 invested. Lose $650B per year of delay.

• Higher accuracy of trends = Much higher economic value
Critical Areas to Improve Traceability

• Key advances needed in on orbit SI traceability of calibration (SI) and retrieval algorithms (ALG)
  – Reflected solar narrowband radiometers and spectrometers (SI)
    • Degradation in orbit due to contamination of optics/diffusers (factor of 5 to 10)
  – Reflected solar broadband radiometers (0.3-3.5μm) (SI), factor of 5-10
  – Spectral Solar Irradiance (SI) factor of 5 to 10
  – Lunar Spectral Irradiance (SI) factor of 10 to 20
  – Infrared narrowband radiometers and spectrometers (SI) factor of 5
  – Broadband infrared radiometers (3.5 to 100μm) (SI) factor of 5
  – Microwave passive radiometers (SI) factor of 10
  – Precipitation Radar (ALG, SI) factor of 10
  – Aerosols (ALG, Polarization, SI) factor of 5
  – RO below 5km and above 25km (ALG)
  – Cloud Radar (ALG?, SI?) factor of ? TBD
  – Biomass SAR (ALG?, SI?) factor of ? TBD
  – Ice Sheet SAR dynamics: TBD
Areas with Acceptable Traceability

- Lidar cloud height for top layer, and total cloud fraction.
- Lidar ice sheet elevation
- Sea level altimetry
- Gravity for ice sheet mass
- Passive total cloud fraction if cloud optical thickness > 1 and field of view is ~ 300m or less
Use of Current Technology to Improve Traceability: *available but not yet deployed*

- CLARREO/TRUTHS spectrometers: full spectrum of reflected solar and infrared observations (320nm to 2300nm, 5μm to 50μm) serve as SI traceable metrology lab in orbit for 30 to 40 sensors: GSICS anchor
- Higher accuracy SSI: 0.2% (1 sigma), TSIS on ISS in 2017
- Higher accuracy Lunar spectral irradiance (CLARREO/TRUTHS)
- Use of CALIPSO backscatter lidar to monitor cloud top height/fraction: no firm observing plans past EarthCARE
- Use of wind lidar beyond ADM-Aeolus
- Multi-wavelength high spectral resolution depolarization lidar (e.g. EarthCARE, ACE) for cloud, aerosol, ocean biomass
- Multi-wavelength doppler radar for precipitation, snow
- Multi-wavelength polarization SAR: biosphere, cryosphere
- Higher accuracy metrology standards 1 to 5μm and 15 to 100μm
- More rigorous statistical analysis of potential data gaps depending on instrument and spacecraft design life, age, and launch schedules: $P_{\text{gap}}(t)$
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
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 = \textit{Changes in SW CRF/decade (y-axis of figure)}

Higher Accuracy Observations = CLARREO reference intercal of CERES = \textit{narrowed uncertainty 15 to 20 years earlier}

\textit{Wielicki et al. 2013, Bulletin of the American Meteorological Society}
Calibration Reference Spectrometers (IR/RS) for Global Climate, Weather, Land, Ocean satellite instruments

Provide spectral, angle, space, and time matched orbit crossing observations for all leo and geo orbits critical to support reference intercalibration

Endorsed by WMO & GSICS

Calibrate Leo and Geo instruments relevant to climate sensitivity: e.g.
- JPSS: VIIRS, CrIS, CERES
- METOP: IASI, AVHRR
- Geostationary imagers/sounders (all)
- Landsat, SPOT, MSI
Global Satellite Observations (WMO)
Global Satellite Observations (WMO)
CLARREO Instruments and Orbit

• Orbit: Baseline 600 km altitude 90 degree orbit, Pathfinder tech demo: ISS orbit (51 degree)

• Reflected Solar Spectrometer:
  – 320 – 2300 nm contiguous spectrum, 4 nm sampling, 8 nm resolution
  – 0.3% SI traceability on orbit (95% confidence)
  – 300 m field of view, 100 km swath
  – 2-axis gimbal pointing to provide intercal angle matching for full swath: increases intercalibration sampling 100X vs SNO approach.
  – Verify for other instruments: offset, gain, nonlinearity, polarization dependence, including scan angle dependence

• Infrared Interferometer
  – 200 to 2000 cm\(^{-1}\) contiguous spectrum, 0.5 cm\(^{-1}\) unapodized resolution
  – 0.07K SI traceability on orbit (95% confidence)
  – 25 to 100 km nadir fov, 1 sample every 200 km along the orbit track
  – Verify for other instruments: offset, gain, nonlinearity

• Small calibration focused instruments: ~ 50 kg, ~ 50 W
Areas in Need of Technological Development

• Advances in metrology standards/methods for passive microwave
• Advances in metrology standards/methods for lidar backscatter
• Advances in metrology standards/methods for radar backscatter
• Advances in higher vertical resolution water vapor profiles including in the boundary layer (DIAL lidar, water vapor absorption line RO)
• Advances in higher power, multifrequency, Doppler radar (e.g. precipitation and snow beyond GPM)
• Advances in higher power lidar for atmospheric composition, wind, cloud, aerosol (lidar type varies)
Areas in Need of Technological Development

• Advances in defining Quantitative Earth Science Objectives (QESOs). See the NRC Continuity 2015 report. Examples:
  – Narrow the uncertainty in equilibrium climate sensitivity by a factor of 2
  – Determine the acceleration of sea level rise to 1mm/yr/decade (1 sigma)
  – QESOs are needed to more rigorously tie societal benefits and research goals to observing system design

• Advances in developing climate change OSSEs to better understand the relationship of QESOs to climate observing system requirements.
  – Weather is great at using OSSEs and OSEs, climate is not. Initial value vs boundary condition. See NRC 2012: Quantifying uncertainty in complex models

• Advances in better understanding of the relationship of more accurate climate observations to societal economic value (e.g Cooke et al. 2014, 2015)
Summary

• Traceability and Quality remain critical issues for climate observations
• Traceability and Quality would enable more effective operational observations (interoperability, evolution)
• A wide range of technological advances are ready to apply to the challenge
• A wide range of technological development could be envisioned
• The 2040 Vision forward needs to capture:
  – No current designed and committed climate observing system exists
  – The economic value of higher accuracy climate obs is huge: ~ $10 Trillion U.S., Return on investment of $50 to $1. (3% discount rate)
  – Methodology advances needed to design a climate observing system:
    • Quantified Science Objectives, climate OSSEs, Quality (uncertainty) requirements defined, Success Probability and Cost trades (see NRC Continuity Report, 2015)
“I skate to where the puck is going to be, not to where it has been”

(Wayne Gretsky: when asked to explain the secret of his success)
“I skate to where the puck is going to be, not to where it has been”

We need to skate from a Climate Observing System toward a Climate Change Observing System
Relevant References

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