The Science, Relevance, and Improvements of NOAA's Upcoming TSIS

Greg Kopp, Peter Pilewskie, and Erik Richard

LASP / Univ. of Colorado

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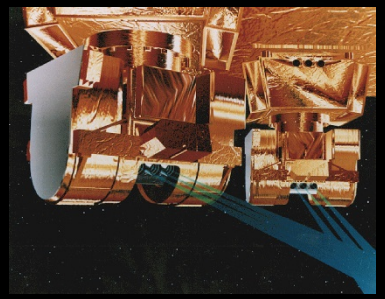
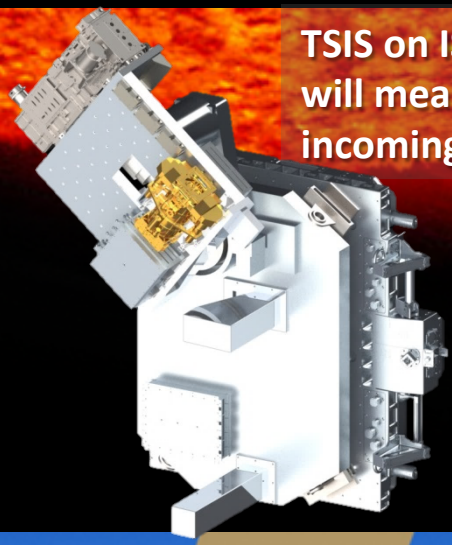
Climate Studies Require Accurate Long-term Energy Balance Measurements

Clouds and Earth's Radiant Energy System (CERES) measures reflected and emitted energy

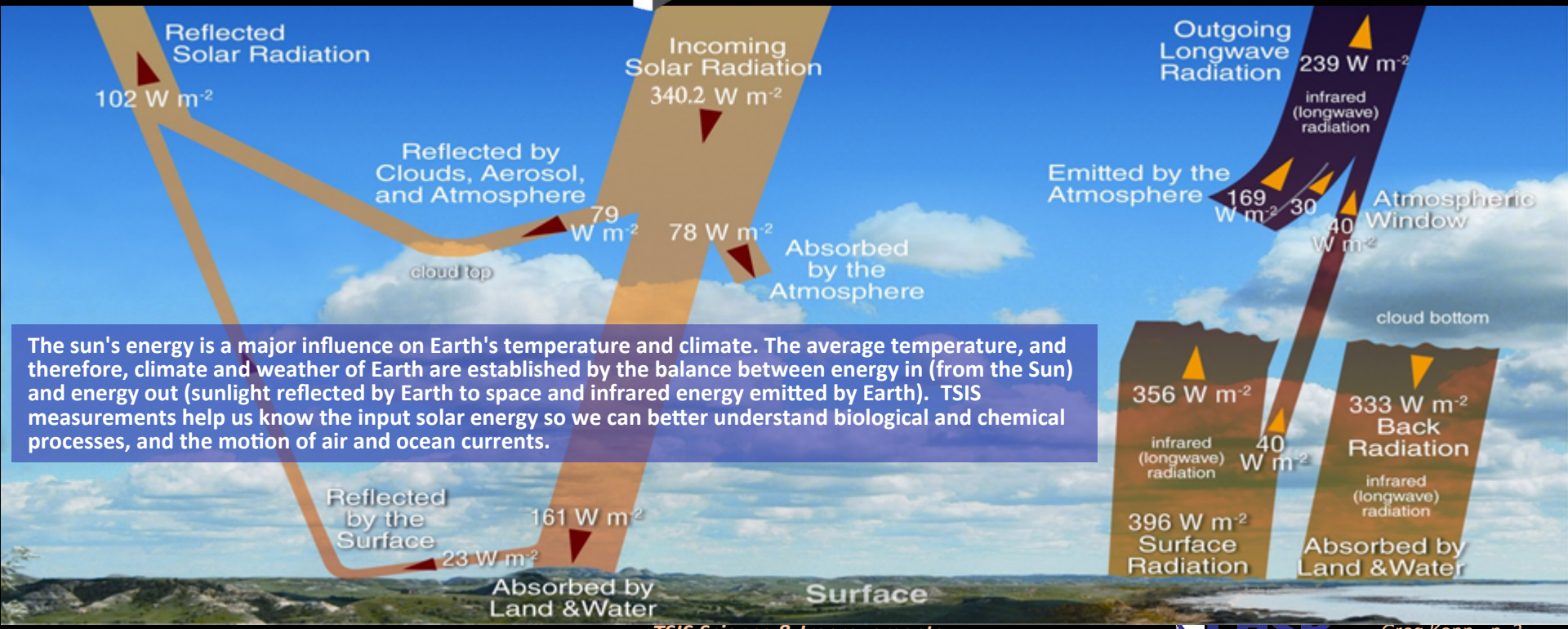




TSIS on ISS will measure the incoming energy

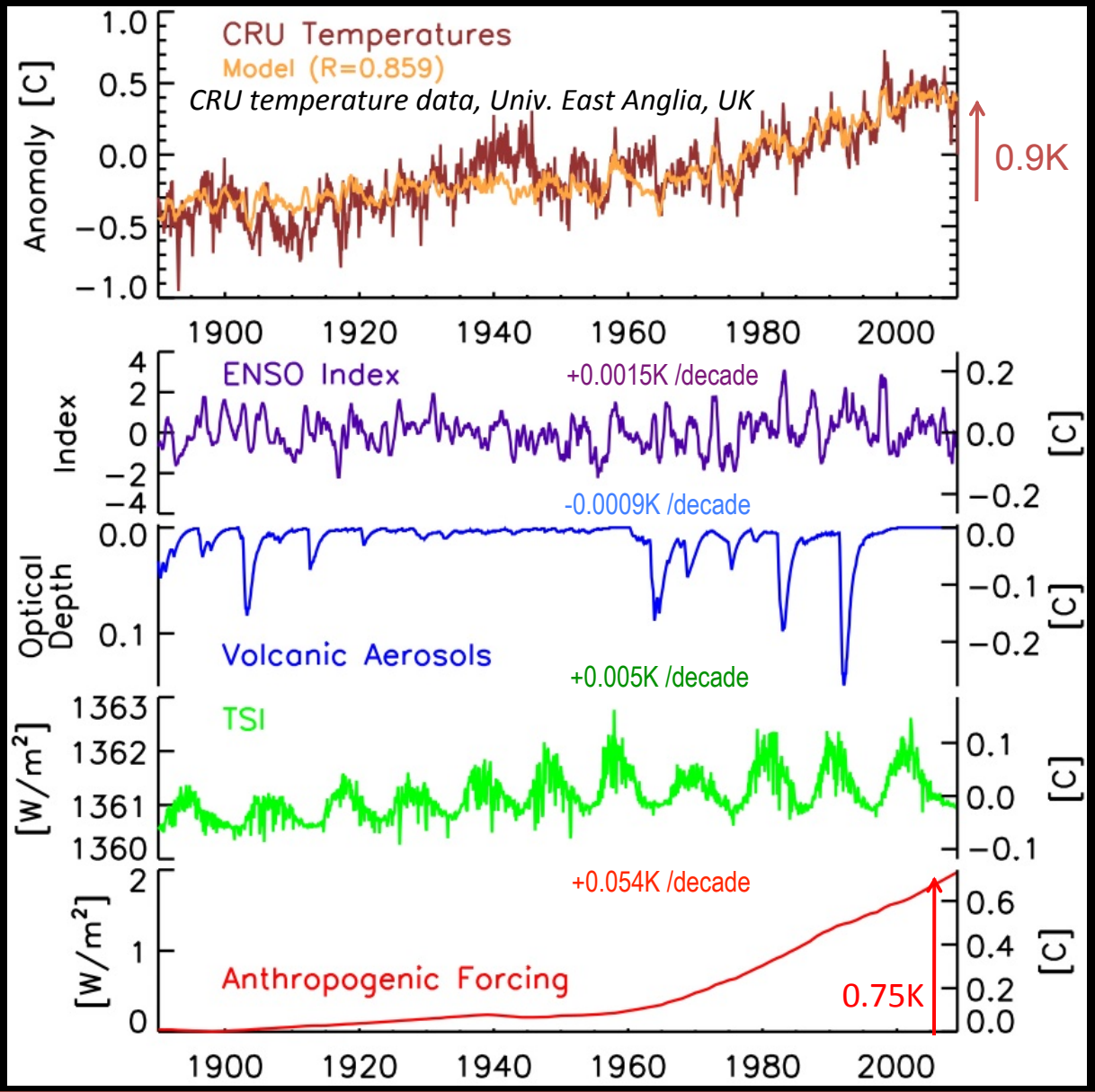
TSIS: Total and Spectral Solar Irradiance Sensor

NASA recently awarded the new Radiation Budget Instrument (RBI) to continue reflected and emitted energy measurements



The sun's energy is a major influence on Earth's temperature and climate. The average temperature, and therefore, climate and weather of Earth are established by the balance between energy in (from the Sun) and energy out (sunlight reflected by Earth to space and infrared energy emitted by Earth). TSIS measurements help us know the input solar energy so we can better understand biological and chemical processes, and the motion of air and ocean currents.

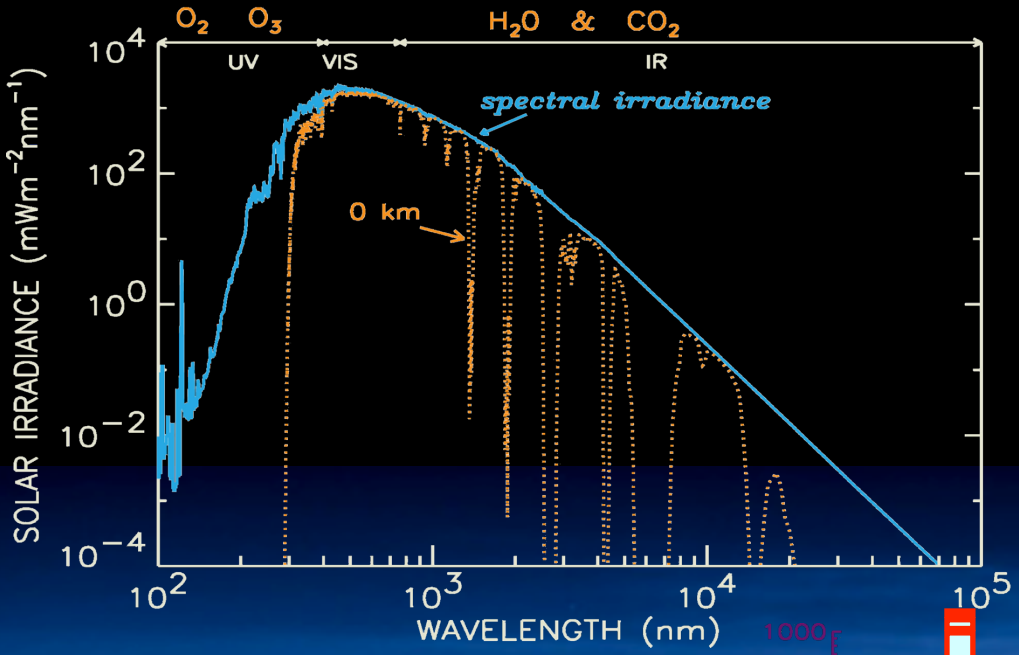
Climate Change Depends on Solar Variability



Decompositions of historical and recent global surface temperatures give consistent individual natural and anthropogenic components:

Natural components account for <15% of warming since 1890

Atmospheric Response Is Wavelength Dependent

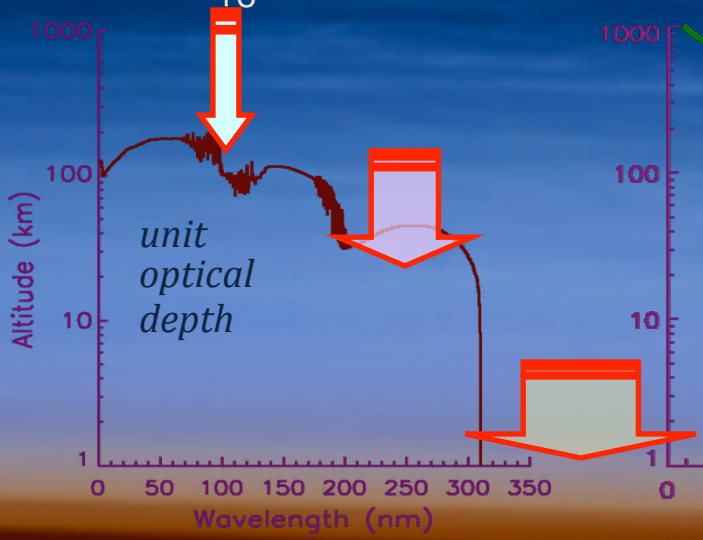


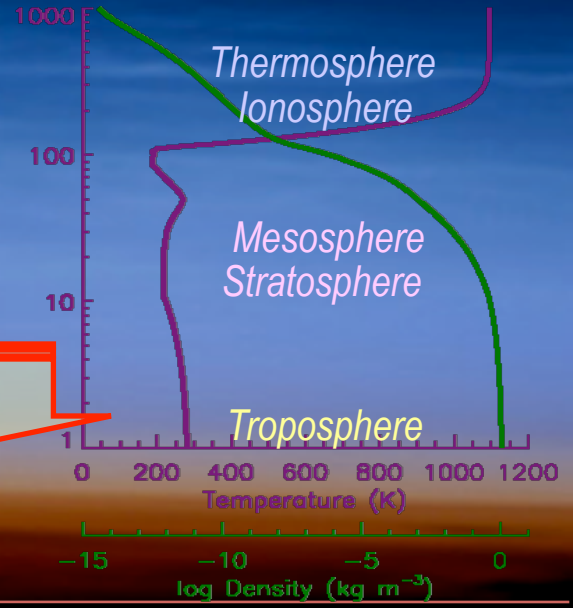
NOAA's TSIS measures both *total solar irradiance* (TSI) and *spectral solar irradiance* (SSI) with improved accuracies and stabilities

wavelengths < 120 nm
0.003±0.001 Wm^{-2}

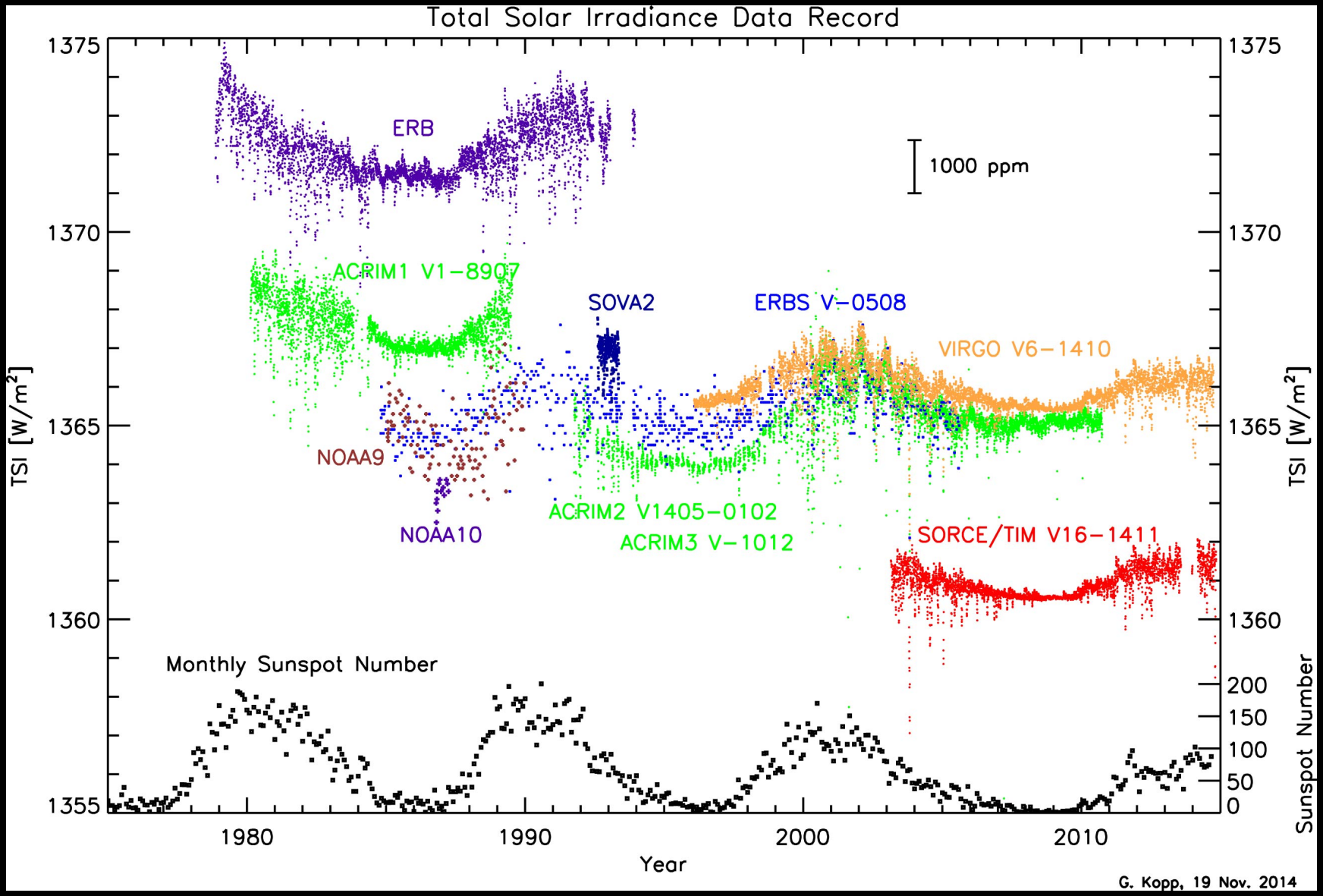
wavelengths 120-300 nm
14.9±0.1 Wm^{-2}

wavelengths > 300 nm
1346 ± 0.5 Wm^{-2}

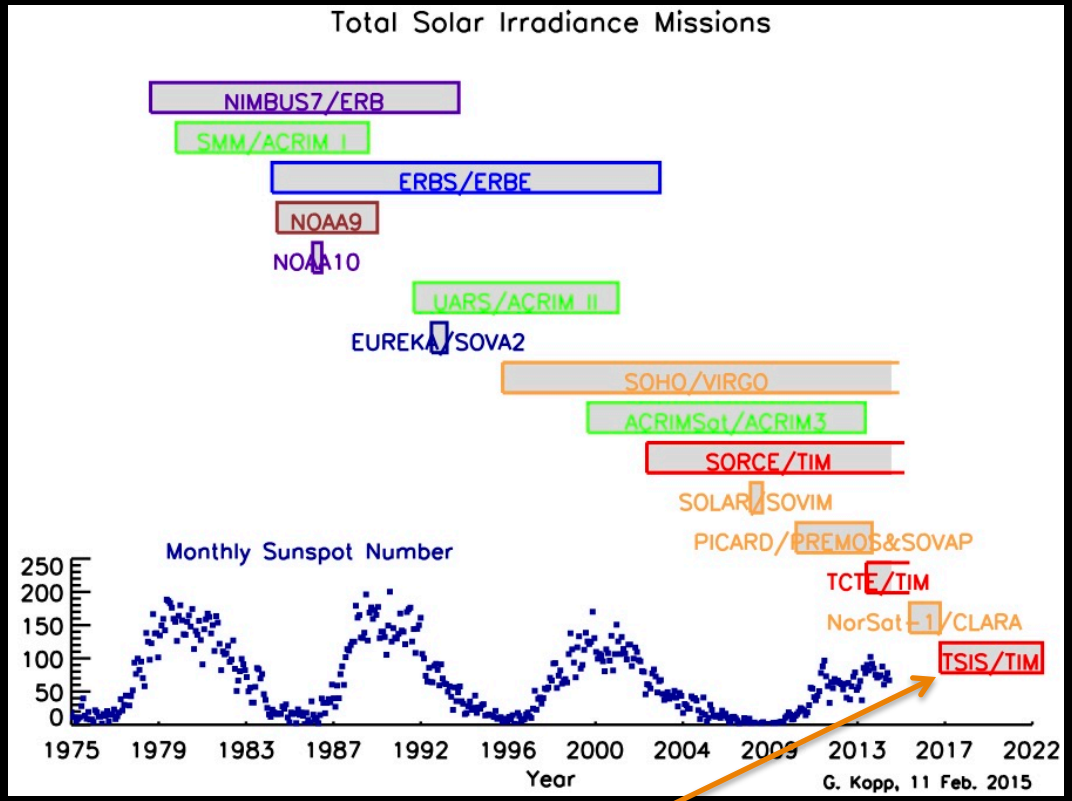


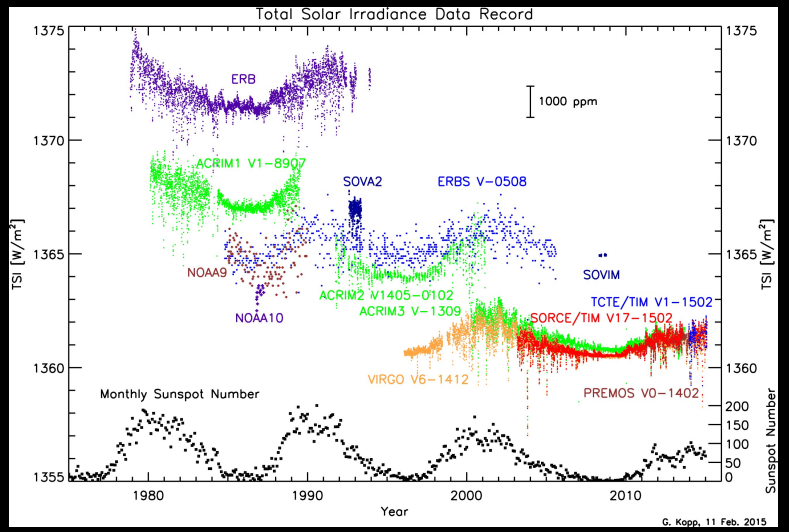


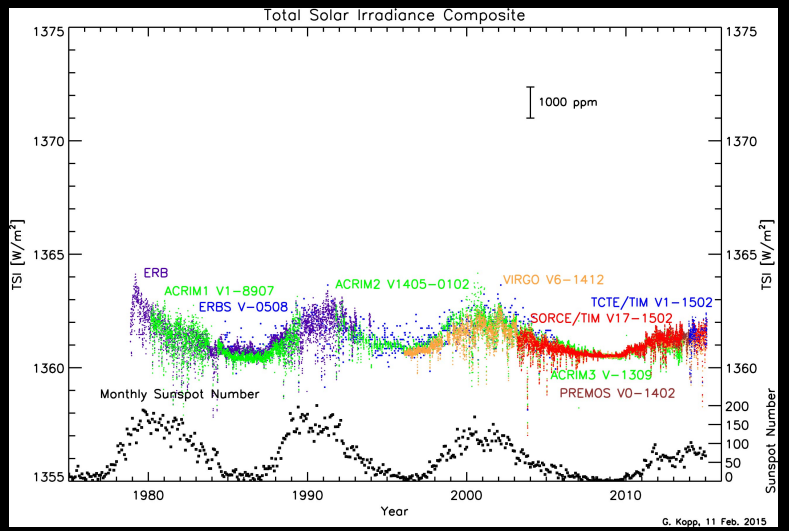
Solar Irradiance Data Record Requires Continuity



Solar Data Record Relies on Stability & Continuity





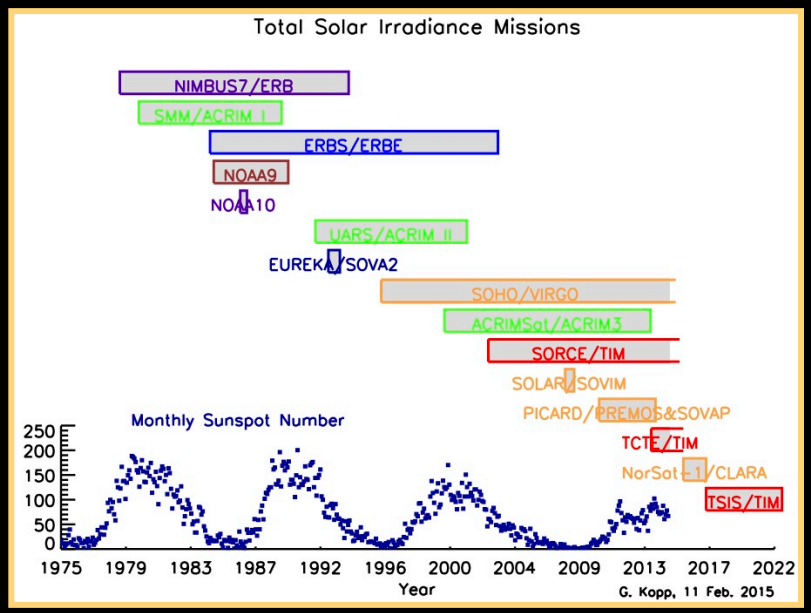


NOAA's TSIS is intended to maintain long-term continuity with improved accuracy and stability

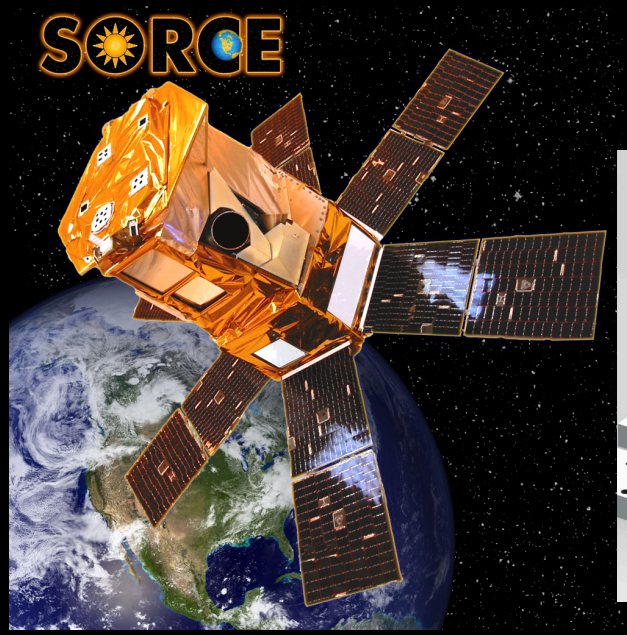
TSI plots updated regularly at:
http://spot.colorado.edu/~koppg/TSI/

NOAA's TCTE Currently Maintaining TSI Continuity

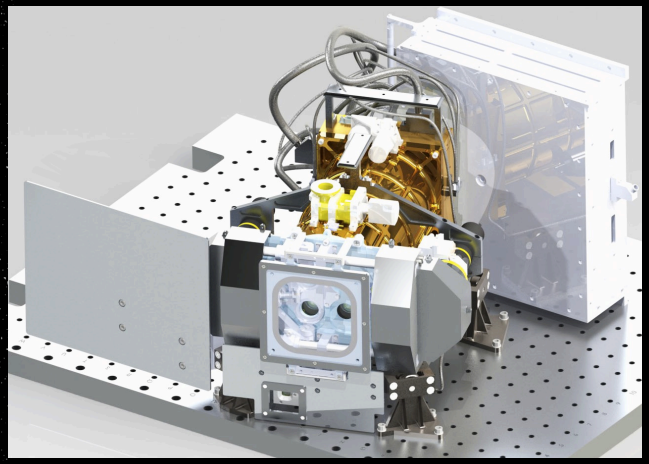
- SORCE (SOlar Radiation and Climate Experiment)
  - 5-year mission launched Jan. 2003
- TCTE (TSI Calibration Transfer Experiment)
  - Launched 19 Nov. 2013
- ISS/TSIS (2017) and CLARA (2015)



but not SSI



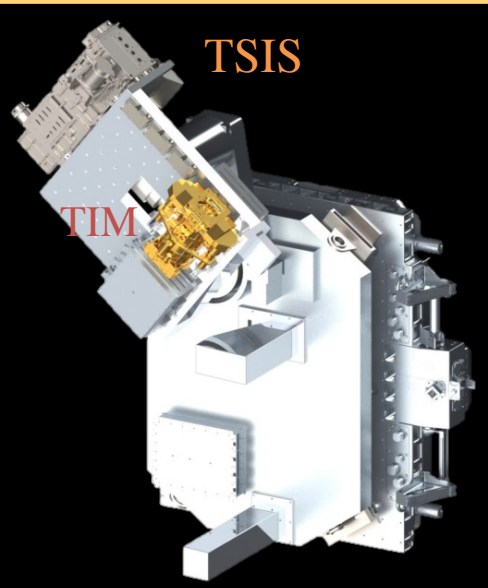
TCTE/TIM



TSIS

SIM

TIM

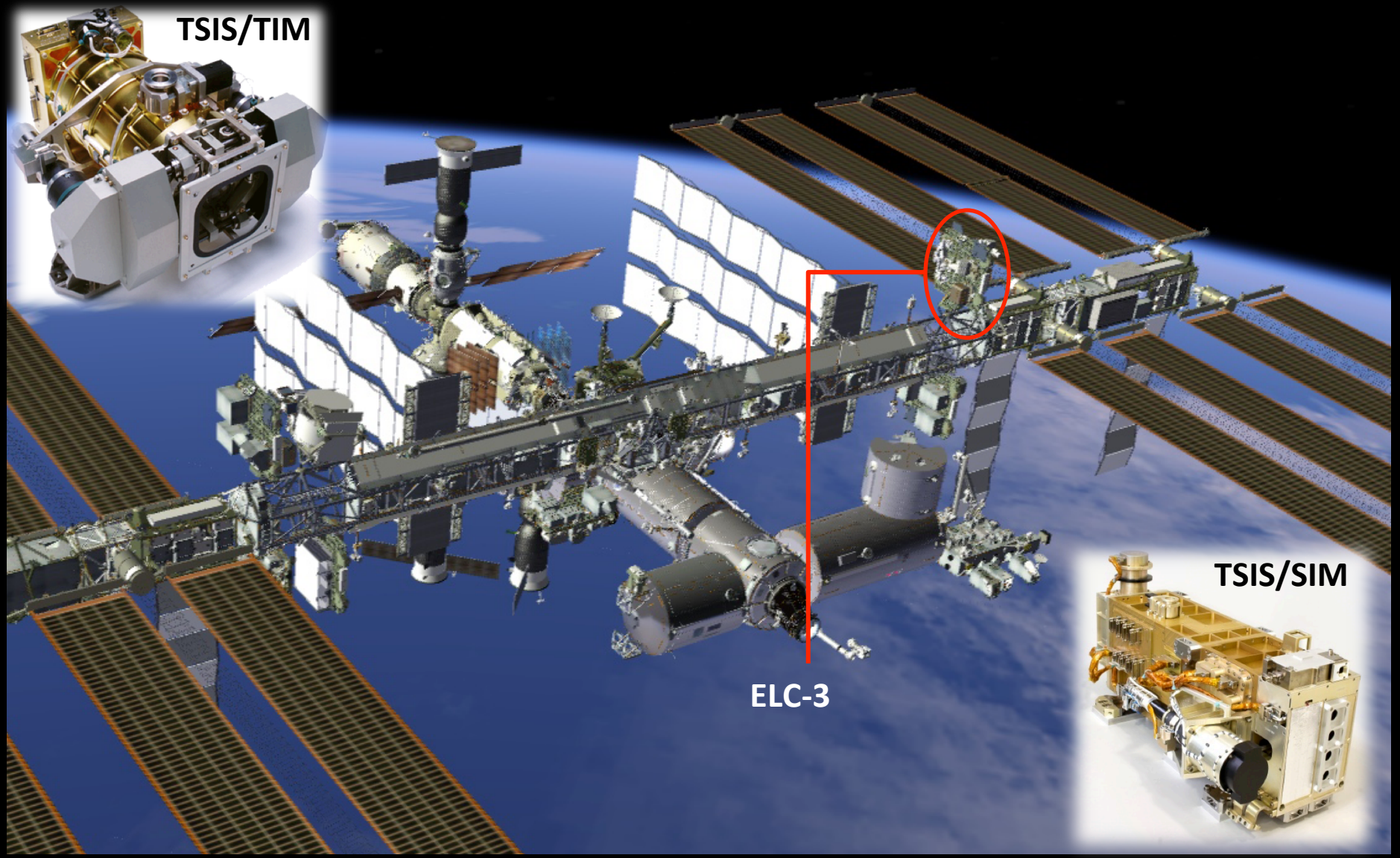


TSIS History

- 1998: TSIS selected for NPOESS as a series providing continuity
- 2006: TSIS de-manifested following the Nunn-McCurdy Review
- 2008: TSIS re-manifested to fly on NPOESS C1
- 2010: NOAA-NASA Joint Polar Satellite System (JPSS) Free-flyer replaces NPOESS; division of JPSS established
- 2011: JPSS not funded in FY11
- 2012: JPSS Free-Flier 1 established for TSIS, SARSAT, and ADCM
- 2013: Polar Free-Flier (PFF) separated from JPSS
- 2014: PFF not funded in FY14; TSIS-2 (and other climate sensors) transferred to NASA; ISS implementation for TSIS-1 approved; SIDAR (Solar Irradiance, Data, and Rescue) established (and already abolished?)
- 2015: ISS/TSIS-1 transferred to NASA in FY16 (President's budget)

TSIS-1 on ISS's External Payload Attachment Site

TSIS-1 approved for deployment in August 2017 on Express Logistics Carrier ELC-3



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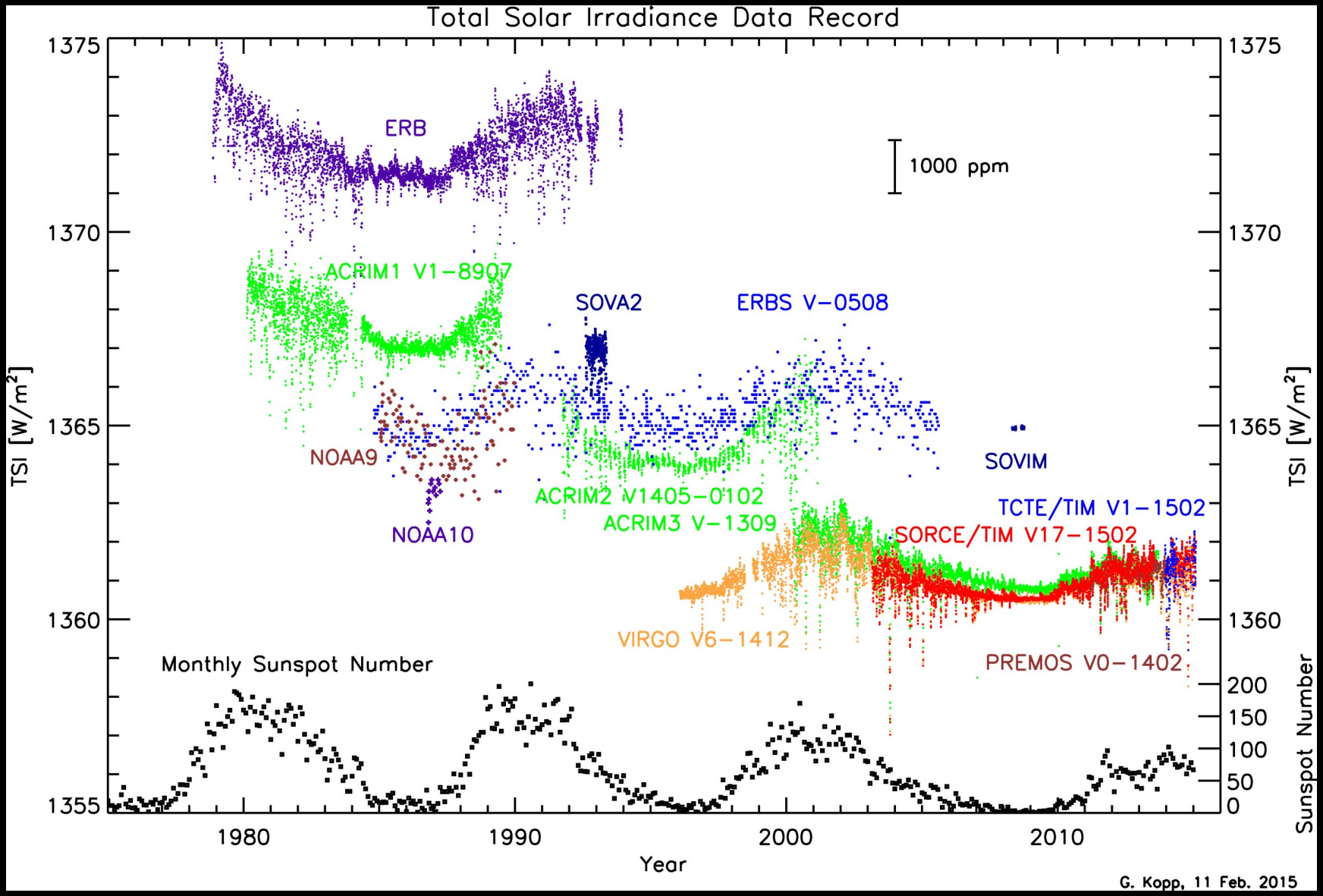

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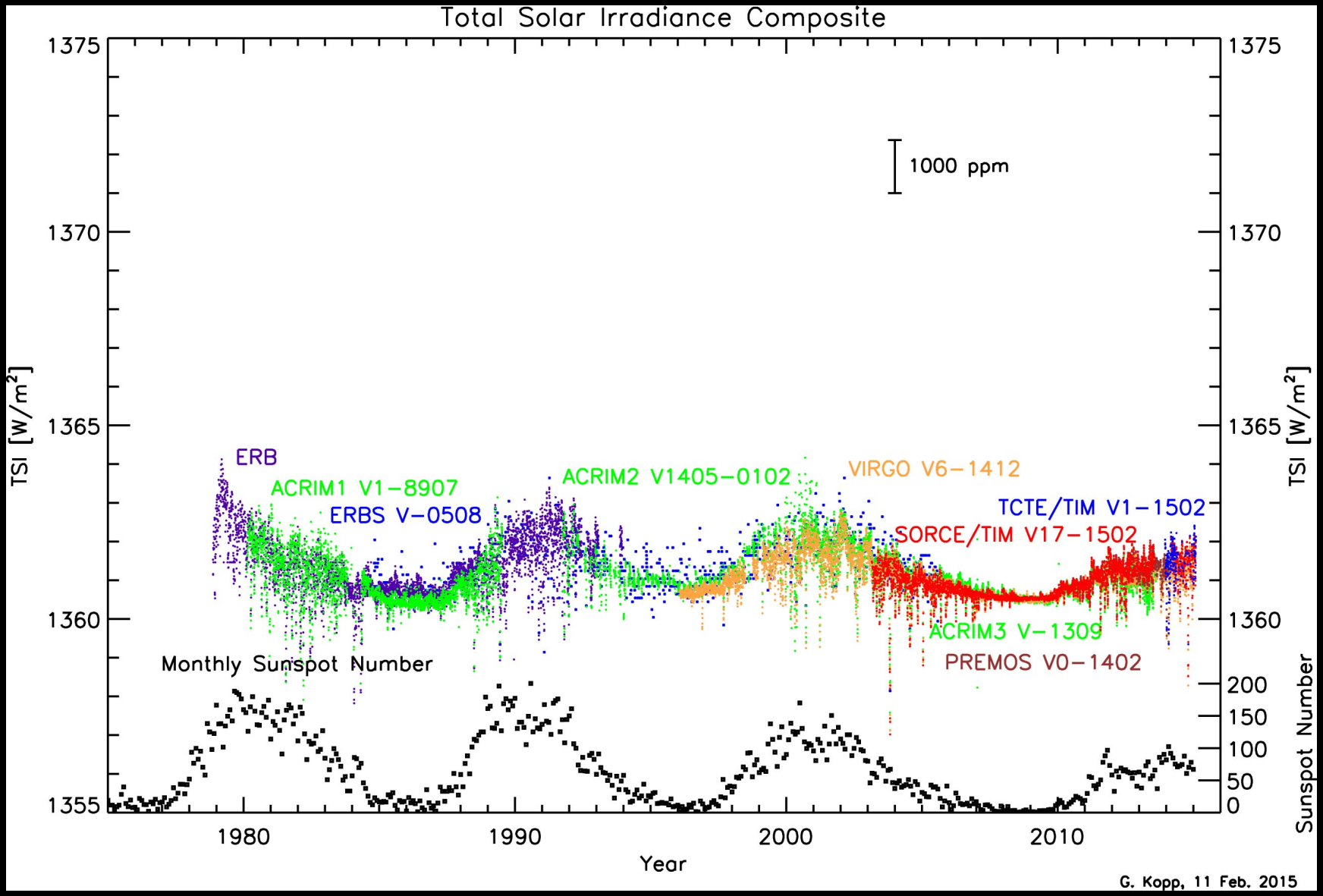
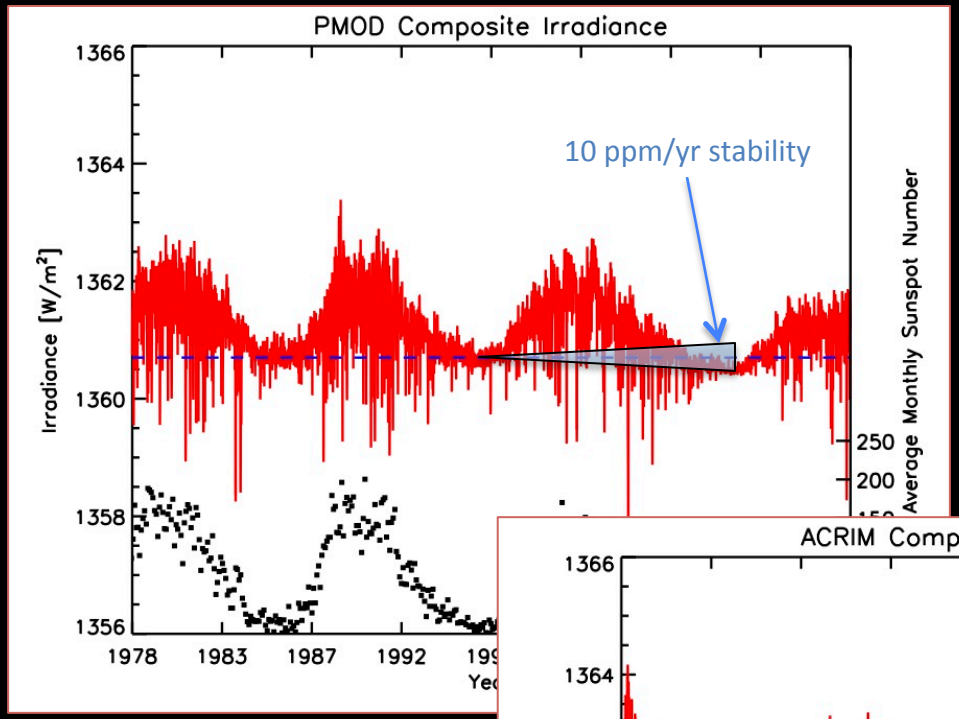
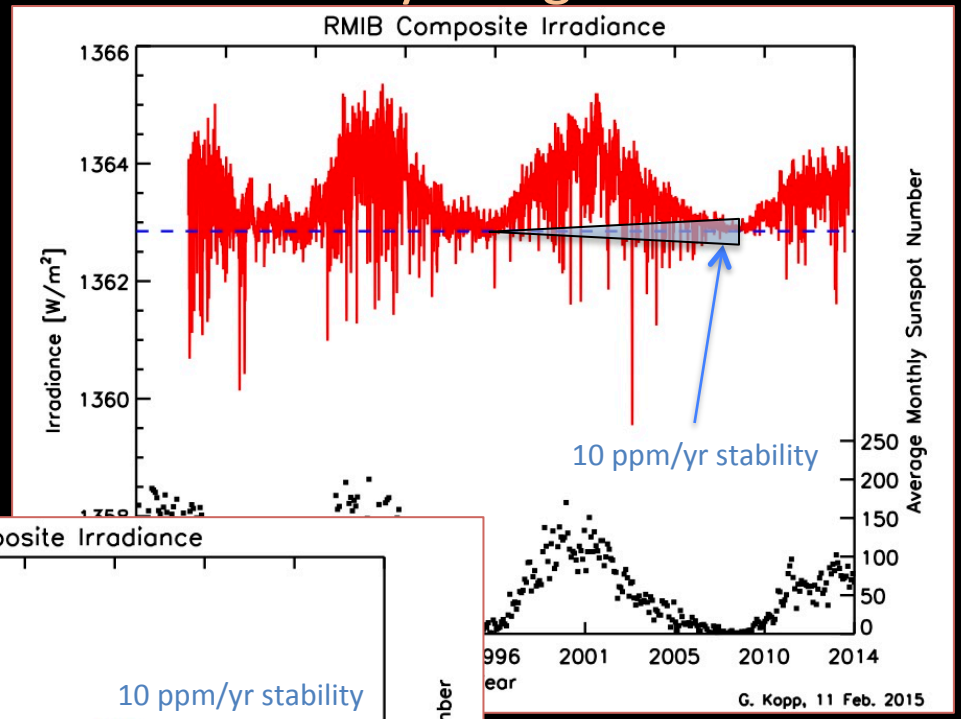
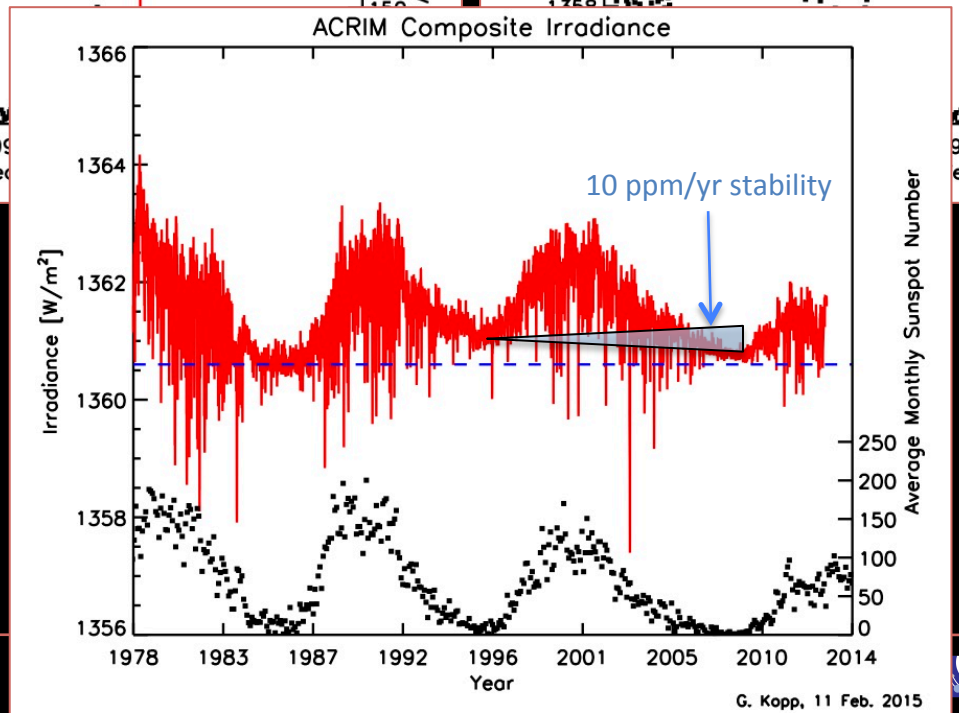


Existing Instruments Lack Needed Stability

- Trend detection between TSI minima is currently marginal

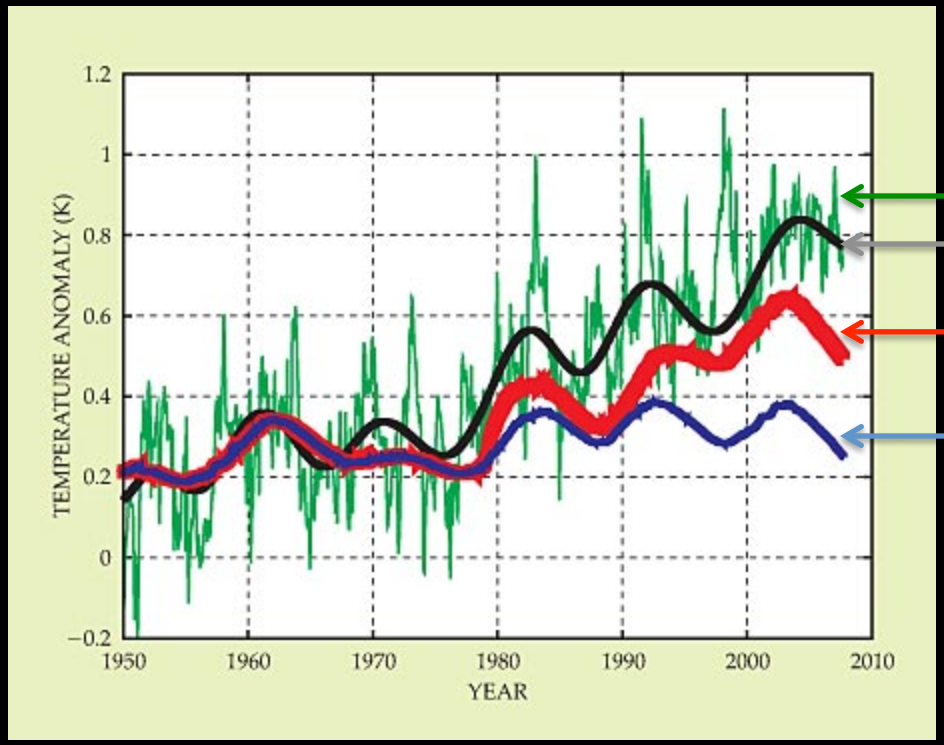






Composite Choice Is Critical for Climate Researchers

To Avoid Misleading



Global Surface Temperature anomalies

Filtered Global Surface Temperatures

Solar Reconstruction #1

Willson & Mordvinov, *GRL*, 2003

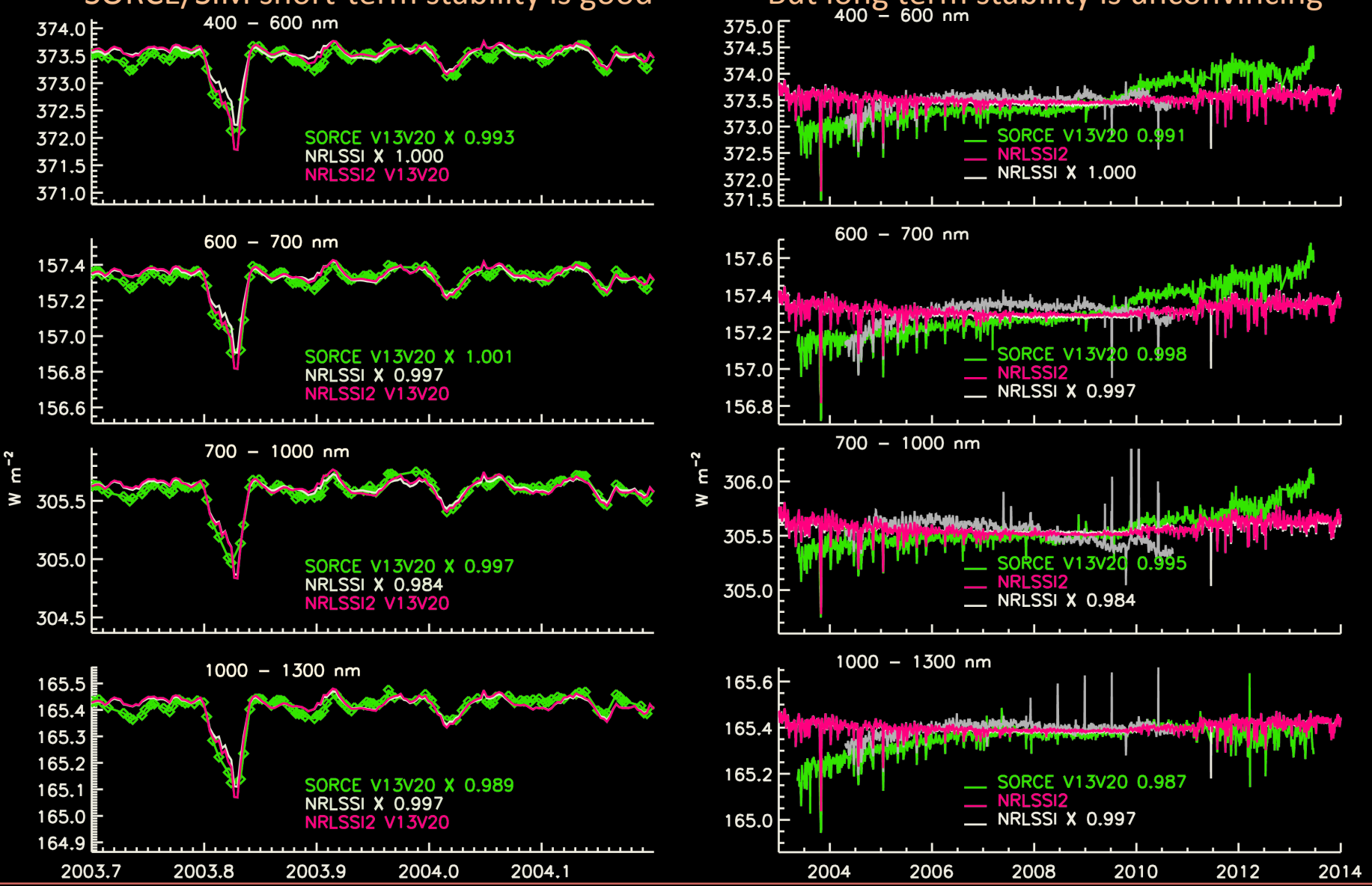
Solar Reconstruction #2

Fröhlich and Lean PMOD composite

Scafetta and West, *Physics Today*, 2008

"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."*

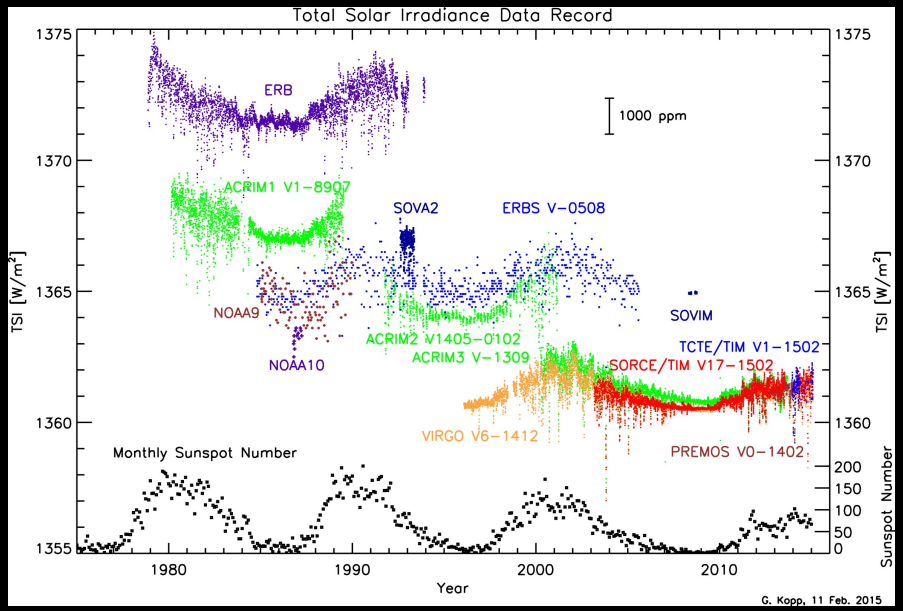
Existing Instruments Lack Needed Stability

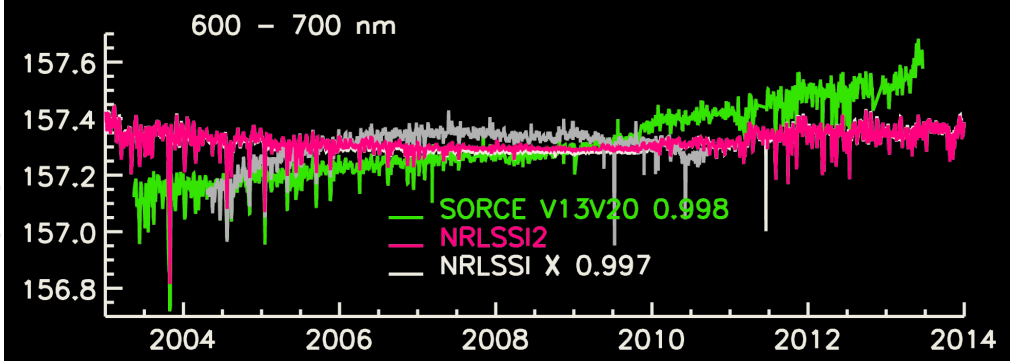


courtesy of Judith Lean, NRL

TSIS Requirements Improve Accuracy and Stability

TSIS Level 1 Threshold Performance Requirements					
Measurement	**Spectral Range [nm]**	**Spectral Resolution [nm]**	**Absolute Accuracy [ppm, 1-σ]**	**Stability [ppm/yr, 1-σ]**	**Noise [ppm, 1-σ]**
TSI total solar irradiance	total solar spectrum	N/A	100	10	10
SSI spectral solar irradiance	200-2400	2 for 200-280 nm 5 for 280-400 nm 45 for >400 nm	2000	500 for ≤400 nm 100 for >400 nm	100



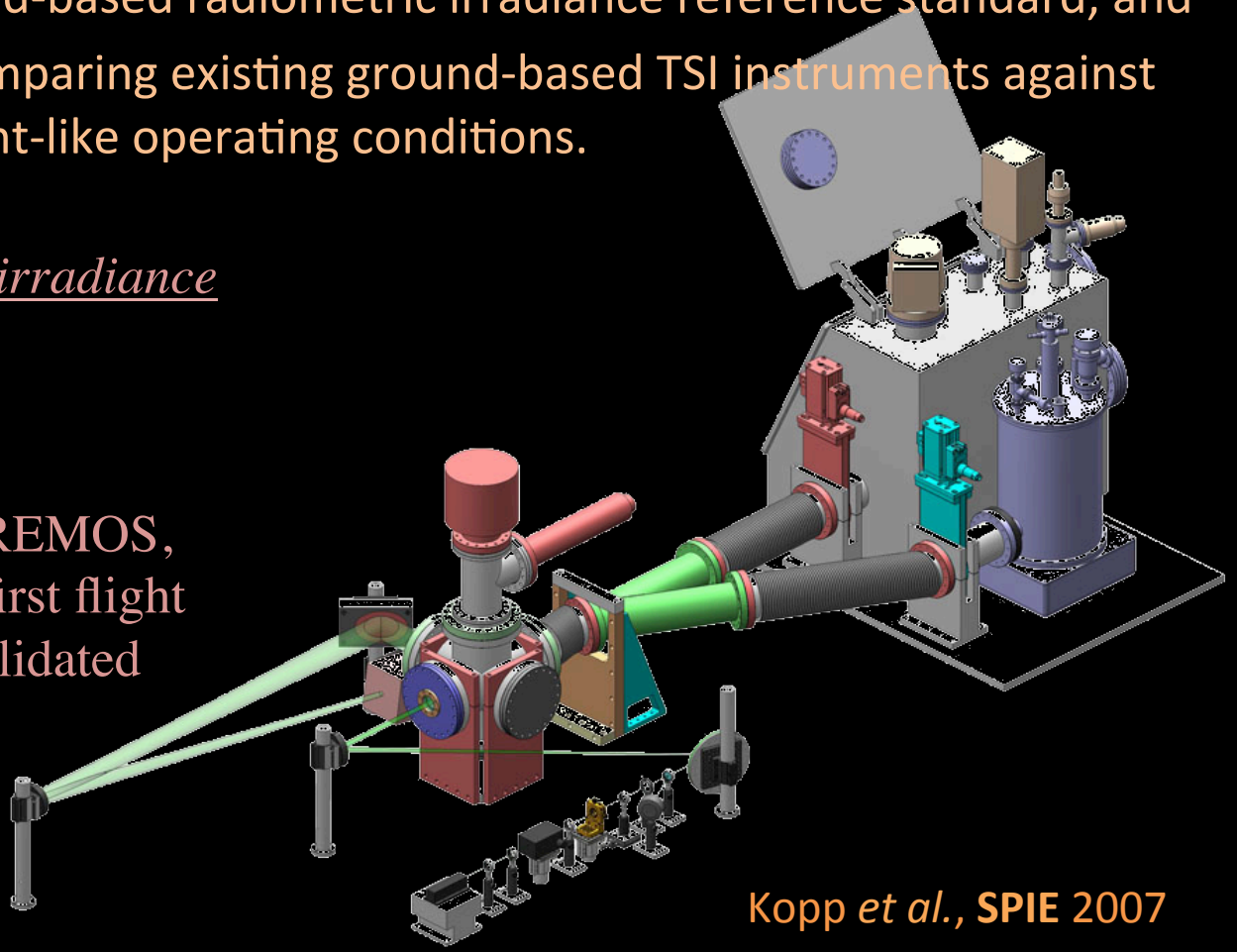


End-to-End Testing Performed on TSIS Instruments

The TSI Radiometer Facility

1. Improves the calibration accuracy of future TSI instruments,
2. Establishes a new ground-based radiometric irradiance reference standard, and
3. Provides a means of comparing existing ground-based TSI instruments against this standard under flight-like operating conditions.

- First facility to measure *irradiance*
  - at solar power levels
  - in vacuum
  - at desired accuracies
- Glory/TIM, PICARD/PREMOS, and TCTE/TIM are the first flight TSI instruments to be validated end-to-end



Kopp *et al.*, **SPIE** 2007

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- Science Rationale
  - Climate studies require accurate long-term energy balance measurements
  - Space-borne solar irradiance data record requires continuity ➔ TSIS
- JPSS/TSIS Enhancements
  - NOAA provides long-term continuity with improved accuracy and stability
- Relation to Other Data Sets
  - Continues 36-year data record from ~20 other instruments
  - Combined with ground climate records, allows climate sensitivity estimates
- Science and Technological Gaps
  - Risk of measurement data gap
  - Required measurement stability levels marginal over climate time scales
- Demonstrations
  - Current on-orbit flight instruments prove techniques and capabilities
  - End-to-end ground facilities provide calibrations/validations