CDR DEVELOPMENT PROJECT

Total and Spectral Solar Irradiance

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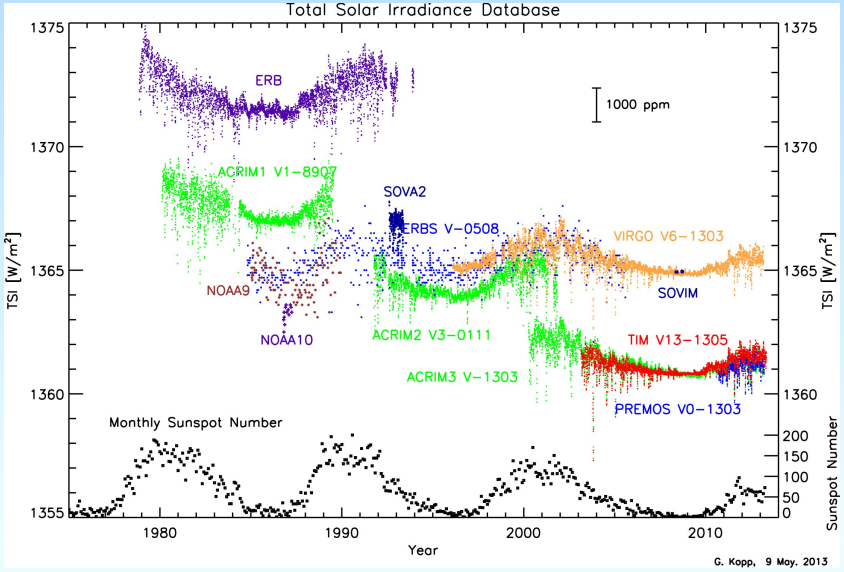
Outline

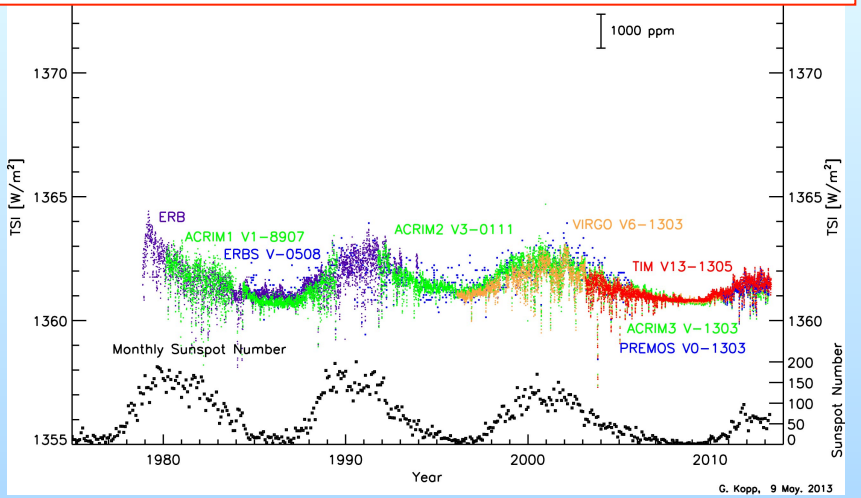
- Project Description
- Production and QA Approach
- Applications
- Schedule & Issues

Solar Irradiance CDR Development

- Solar Irradiance CDR Development Team
  - maintain several duties of the former NPOESS Operations and Algorithms Team (OAT)
  - Ensure the effective and technically robust utility of the solar irradiance CDRs
    - Collaborate with user community and other CDR Teams.
  - Ensure data stewardship of TSI and SSI through:
    - Develop the TSIS Algorithm Theoretical Basis Document.
    - CDR development from current and heritage satellite instruments.
    - Construct irradiance composites.
    - Develop related solar irradiance products and algorithms to be distributed to the broader community.
  - Enable the rapid and reliable generation of Solar Irradiance Climate Data Records following the launch of TSIS.



Calibration differences, chiefly internal instrument scatter are responsible for the instrument offsets. [*Kopp and Lean*, 2011]



Project Description

CDR(s) (Validated Outputs)	Period of Record	Spatial Resolution; Projection information	Time Step	Data format	Inputs	Uncertainty Estimates (in percent or error)	Collateral Products (unofficial and/or unvalidated)
Total Solar Irradiance	1978 – present	N/A	1 day	SORCE: ASCII and IDL save, and HDF5. Similar data formats are planned for TSIS. LASP will also produce in NetCDF4, and conform to CDRP data and metadata requirements.	Raw satellite sensor telemetry data; composites from individual sensor level 3 irradiance data. TSI: ERB, ACRIM-I,II,&III, ERBS, SOVA, VIRGO, PREMOS, and TIM, SORCE Mg II index product, NGDC sunspot data SSI: SIM, SOLSPEC, SCIAMACHY, SORCE Mg II index product, NGDC sunspot data	0.01-0.035%	N/A
Solar Spectral Irradiance	2002-present	N/A	1 day			0.2-1%	N/A

Production Approach: TSI/SSI

- Converting from Instrument signal to irradiance follows a "Measurement Equation Approach"

$$\mathcal{E}_\lambda(\lambda_s) = \frac{\mathcal{P}_{\mathrm{ESR}}(\lambda_s)}{A_{slit} \cdot \int \alpha_\lambda \cdot T_\lambda \cdot \phi_\lambda \cdot S(\lambda, \lambda_s)\, d\lambda}$$

ESR detected power

Aperture area

ESR Absorptance

prism transmission

slit diffraction

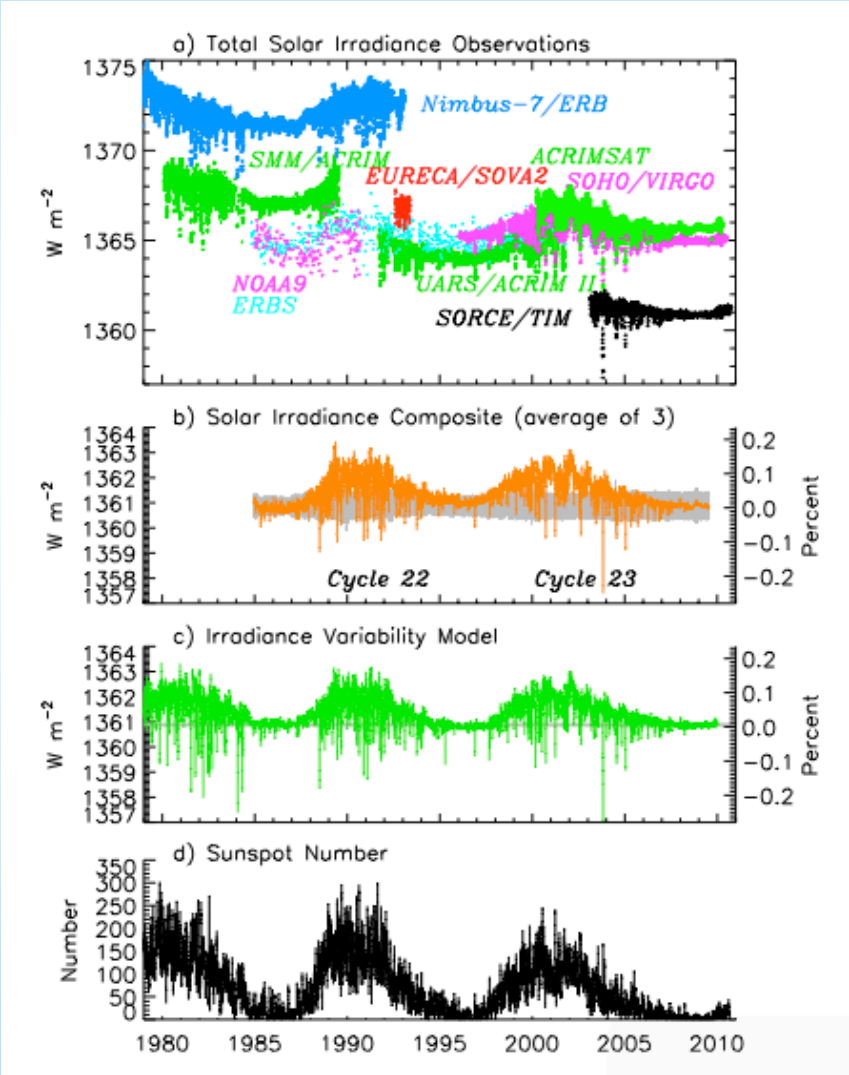
instrument function

Measurement equation for the SIM instrument

- Measurement and characterization/calibration of all terms on the right-hand-size of equation are performed
  - shutter waveform factor, entrance aperture/slit, bolometer absorption, equivalence ratio, loop gain, diffraction correction, prism transmission, exit slits, instrument function convolution, photodiode radiant responsivity…

Production Approach: TSI Composite CDR

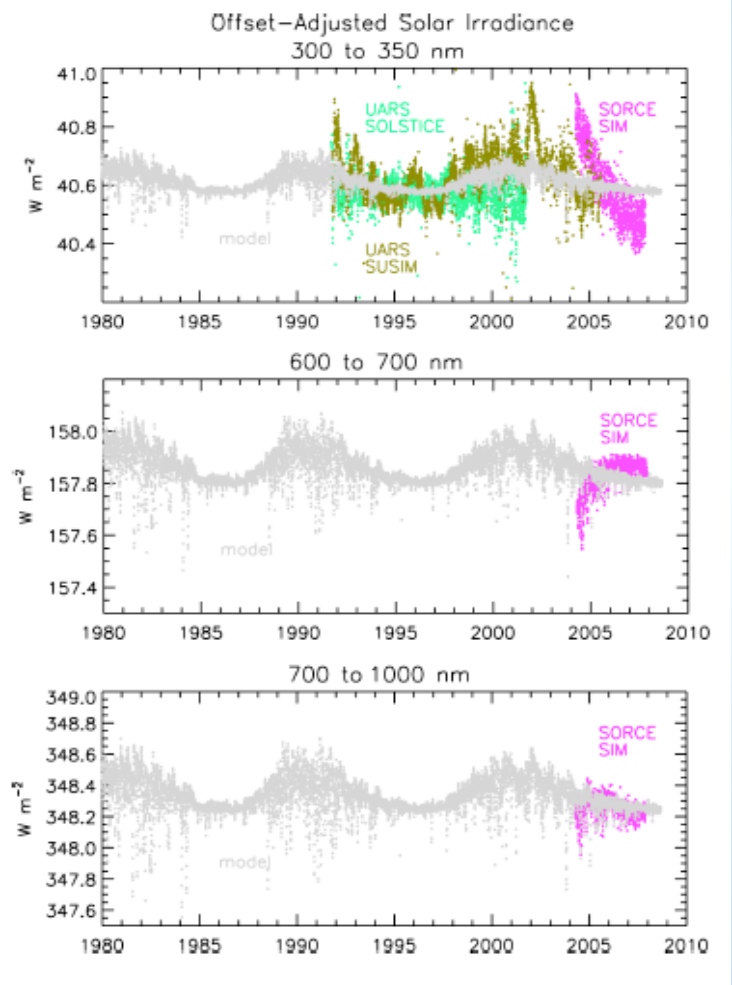
- An empirical model [*Lean et al.*, 2005] determines the net effect of opposing influences by sunspot darkening and faculae brightening to solar irradiance variability. Necessary steps include:
  - Align absolute scales of individual radiometers.
  - Input 1: Use daily SORCE Mg II index product (or other) as a proxy for facular signal.
  - Input 2: Daily projected sunspot area from NGDC sunspot record.
  - Relative proportions of sunspot & faculae are determined using a linear scaling with coefficients determined by multiple regression of the two inputs against current SORCE TIM observations to create daily TSI variability.



Kopp and Lean, 2011

Production Approach: SSI Model

- NRL SSI model uses same two inputs (daily sunspot area and Mg II index) as TSI irradiance model [*Lean et al.*, 2000; ; *Lean & Woods*, 2009; *Thullier et al.*, 2013 *submitted to Solar Physics*]. Additional or different steps include:
  - Scaling coefficients determined by multiple regression against UARS SOLSTICE observations for NRLSSI Version 1 and from SORCE SIM & SOLSTICE for NRLSSI Version 2 (and from solar theory for irradiance > 400 nm).
  - For SSI, the scaling coefficients are separate from those for TSI and provided for each 1 nm bin from 120-100000 nm.
  - SSI model is internally consistent with TSI (i.e. TSI is calculated daily, independent of SSI, and the integral of SSI verified to add to the TSI).

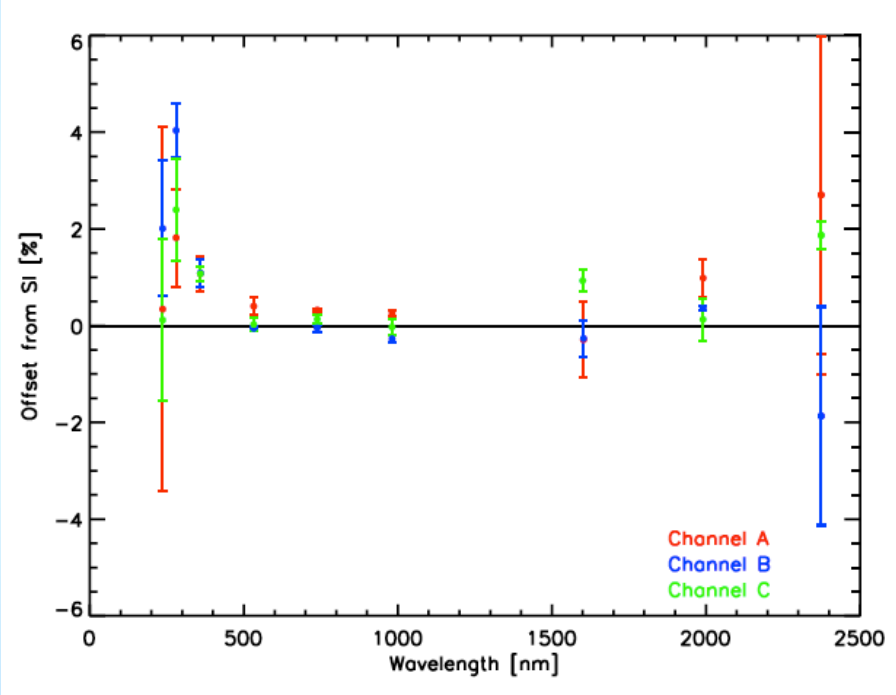


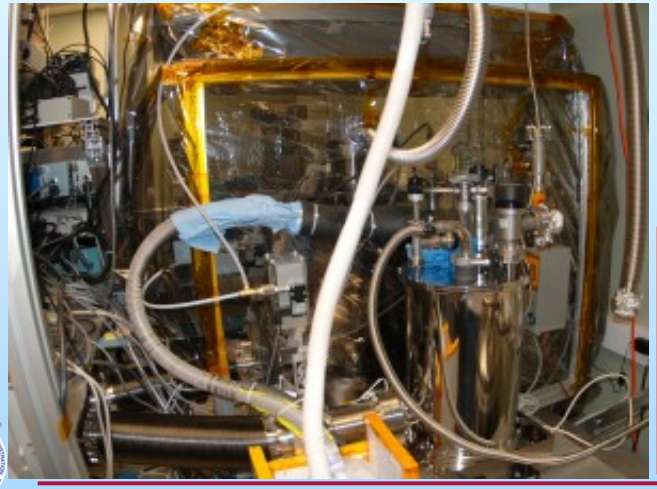
Comparisons of measured SSI to model output derived by scaling sunspot blocking and proxies of facular variability [*Lean and Woods, 2009*].

Validation & Quality Assurance: TSIS TSI & SSI

1. Calibration & Characterization
   - The TSIS instruments are "absolute sensors".
   - Overall measurement uncertainty is a root sum square error of the individual uncertainties.
   - End-to-end validation.

TSIS SIM to Cryogenic Radiometer Comparison: Preliminary Results

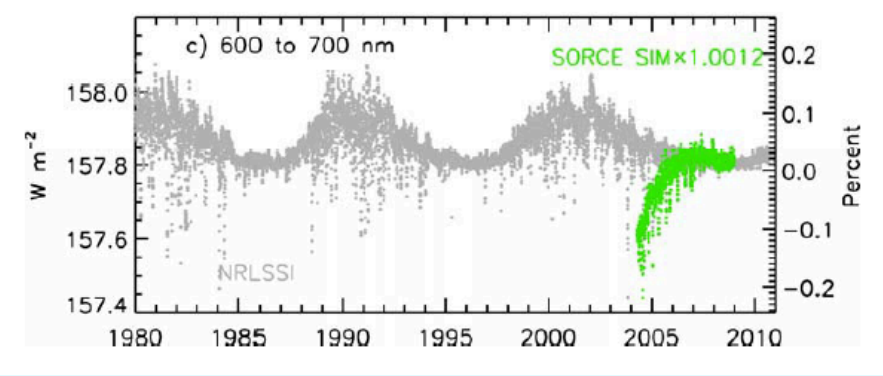




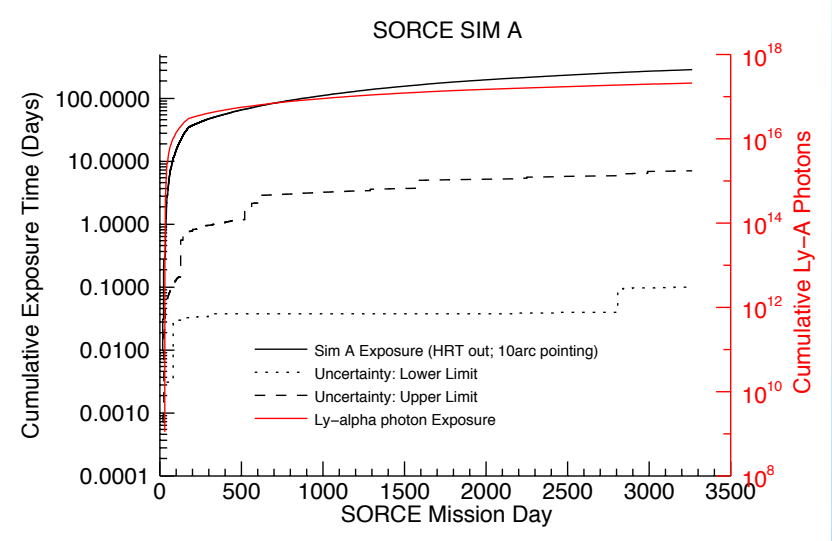
The TSI Radiometer Facility (TRF) and Spectral Radiometer Facility (SRF) at LASP tie irradiance comparisons to a NIST L-1reference cryogenic radiometer at power levels typical of the Sun and under flight-like vacuum conditions.

Validation & Quality Assurance: TSIS TSI & SSI

2. On-orbit degradation correction.
3. Comparisons with other data sets and models of solar irradiance
4. New research focus areas involve investigation of solar exposure and degradation of SORCE SIM.
   - Comprehensive accounting of solar exposure time and potential differences between solar exposure time and photon "dose".
   - Bayesian-like methodologies for propagating measurement and exposure uncertainties, and allowing for the possibility of "recovery" in degradation.



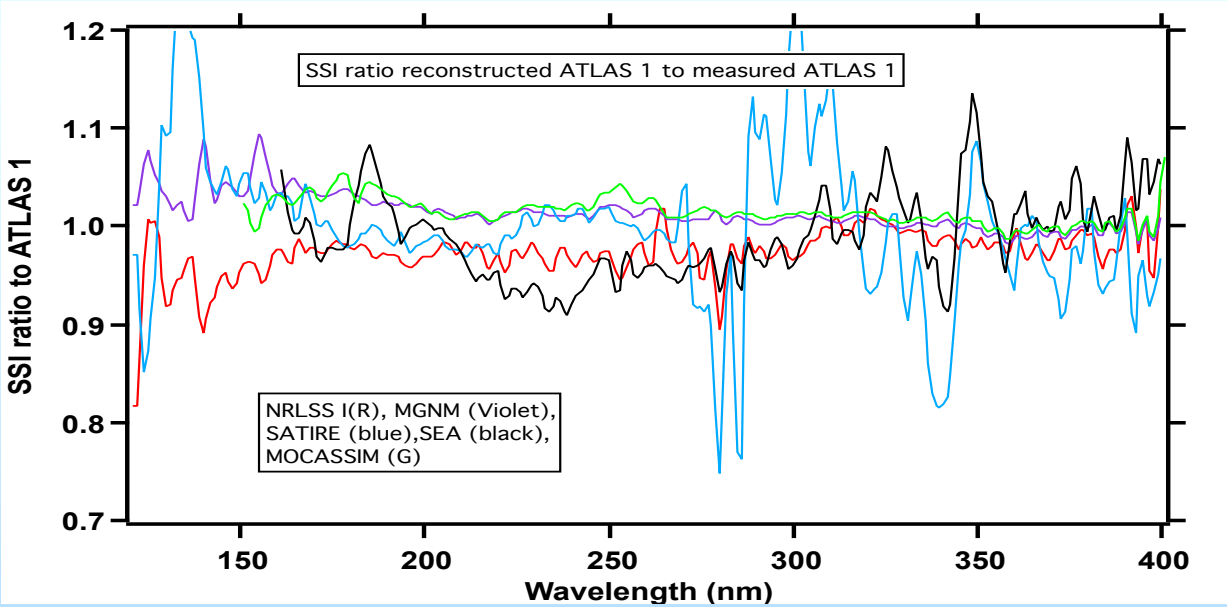
SORCE SIM data shows out-of-phase behavior at different wavelengths and 3-5x greater variability in the UV compared to models. [Lean and DeLand, 2012].



Converting from Solar Exposure Time to Photon "Dose"

Validation & Quality Assurance: Models of SSI

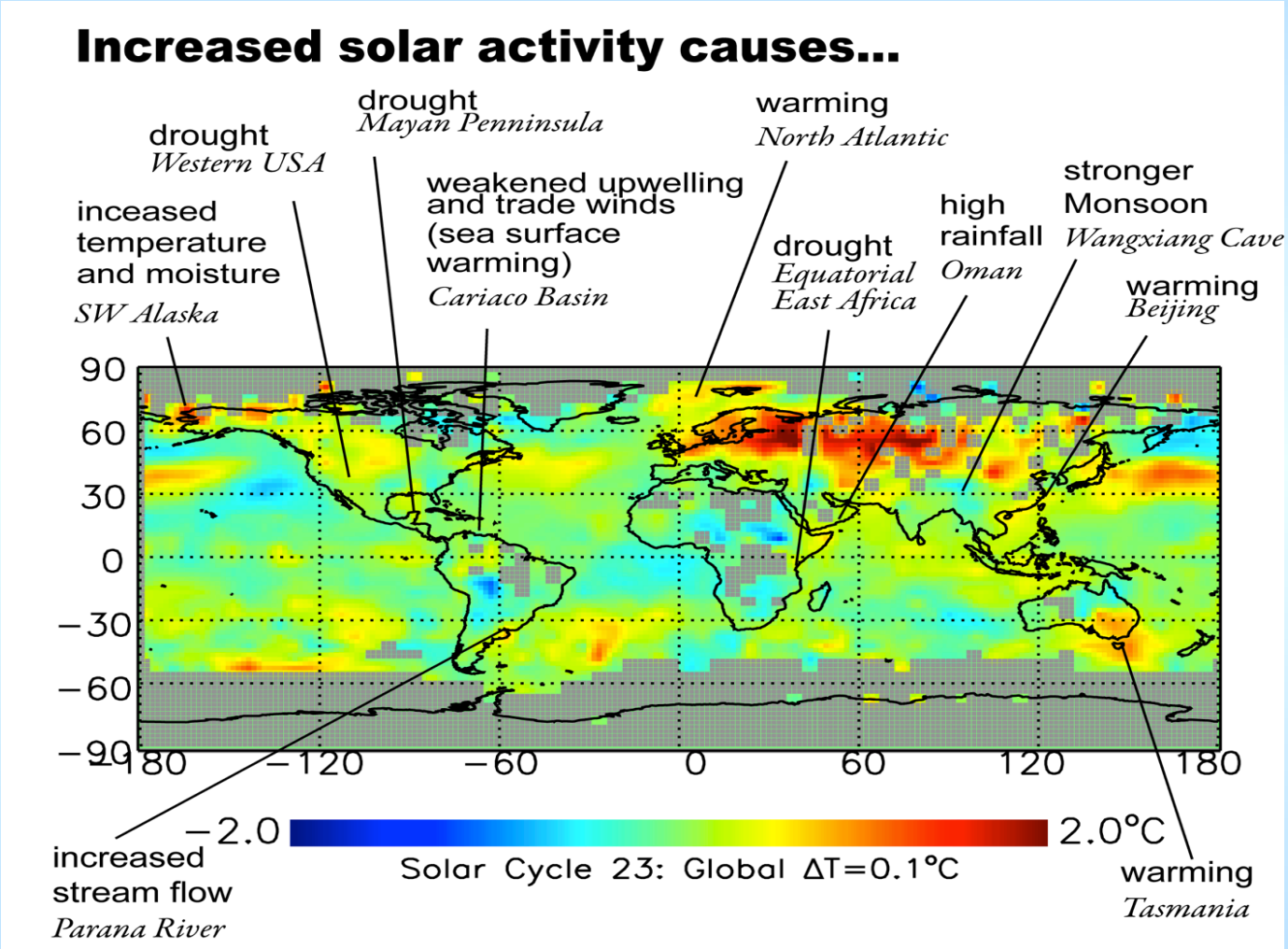
- Comparisons of modeled SSI variability with revised/ reanalyzed SORCE SIM data.
- Systematic comparison among models and observations of SSI variability.



Comparison of SSI models to measurements: Ratio of the ATLAS 1 reconstructions by models to the original ATLAS 1 [*Thullier et al*., 2013 *submitted*].

Users & Applications

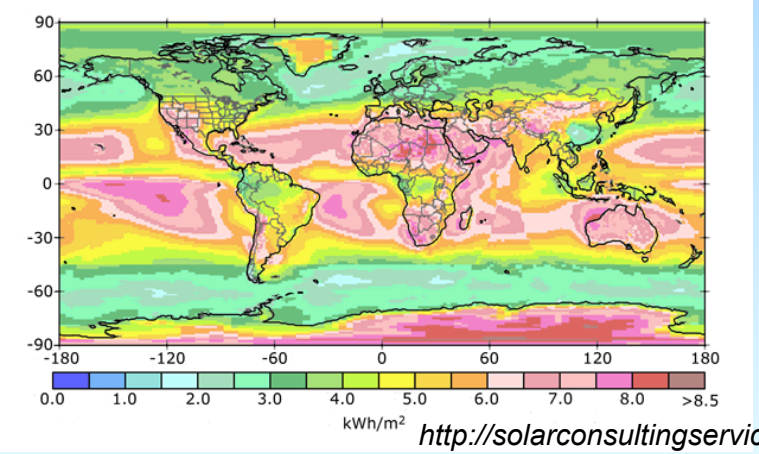
Global Summary of various relationships between solar activity and climate



Map is derived from analysis of the current surface temperature record, taking into account ENSO, volcanic influences, anthropogenic influences, and solar variability (as in [*Lean, 2010*]).

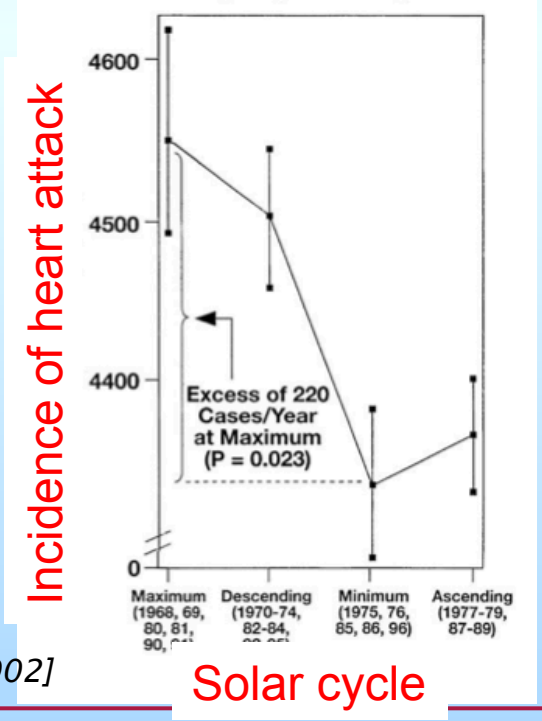
Users & Applications

- CDR development teams for energy budget (CERES/ERB), ozone, and temperature remote sensing
- Modelers of global climate, stratospheric processes, and stratospheric climate
  - require solar spectral irradiance as top-of-atmosphere boundary condition (i.e. not sufficient to use just TSI)
- Renewable Solar energy community
  - solar irradiance variability is used to test and improve PV cell technology and guide large solar energy projects (to supply electricity to utility companies).
- Heliobiology
  - Do conditions on the Sun and in Earth's magnetosphere affect human health?



http://solarconsultingservices.com

Daily-average direct normal irradiance (*DNI*): the solar "resource" available from the Sun to a collection device.



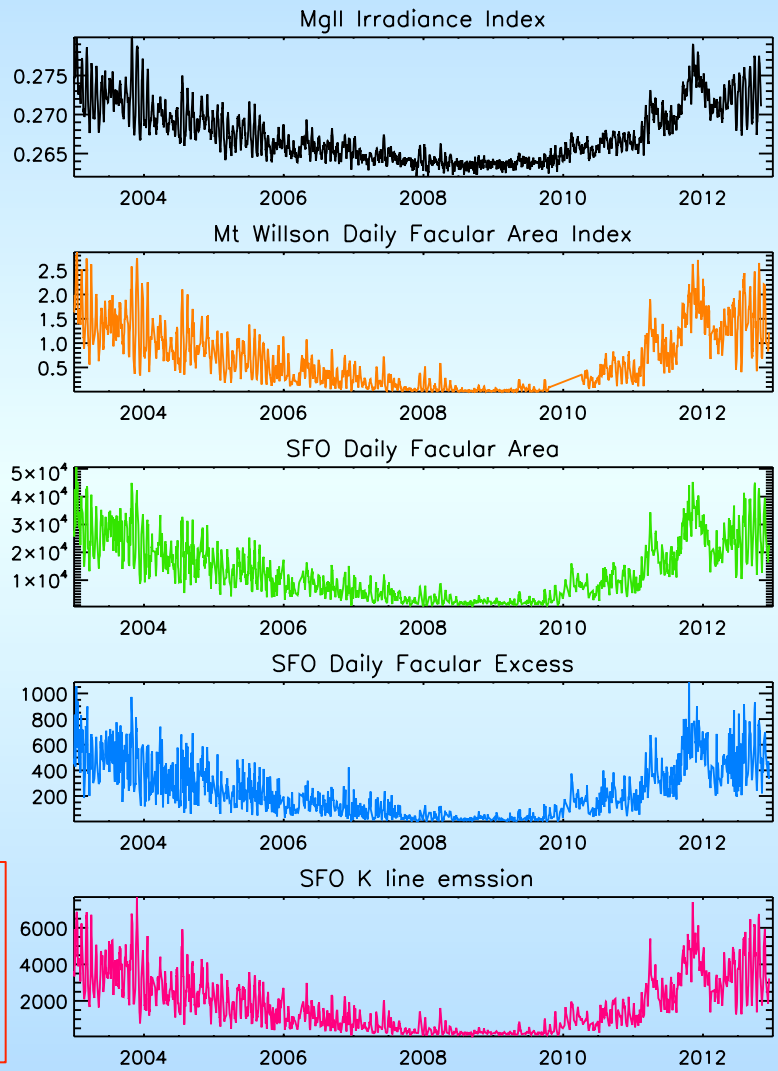
[Cornélisson et al., 2002]

Schedule & Issues

- Accomplishments over last year:
  - TSIS ATBD near completion.
    - Key sections to complete include the SIM calibration/characterization and SIM error budget table.
  - Comprehensive accounting of solar exposure & photon dose (and uncertainties).
  - Methodology in development for a Bayesian-like study of instrument degradation.
  - Scaling coefficients developed (NRLSSI V1) and in development (NRLSSI V2).
- Milestones & Schedule for solar irradiance FCDR production.
  - Implementation plan: within 45 days of award.
  - Documentation:
    - Data Flow Diagram and Maturity Matrix: within 90 days of award
    - Climate-ATBD: within 6 months of award
  - Data (to conform to CDRP data and metadata requirements):
    - Procedures for obtaining & reducing sunspot and facular indices (i.e. source code, coefficients, input time series from 1978 to current time): within 270 days of award
    - CDR data set: within 300 days of award
  - Quality Assurance:
    - Report: within 300 days of award
    - QA results: with each data set delivery (procedures for validating sunspot & facular indices)
  - CDR maintenance (time series data set updates):
    - Extending forward from end of previously delivered data set
    - Within 7-10 days of updates of the NGDC sunspot data
    - Will address errors, discrepancies, or limitations
  - Stewardship Support
    - LASP to provide access to CDR via a publically-accessible website within 2 weeks of new productions, will track quarterly data downloads, and a mechanism for users to report issues.

Schedule & Issues

- Risks or concerns
  - SSI and TSI composite record CDR requires *daily* NGDC sunspot record and Mg II index product (or other facular proxy product).
    - NOAA/NASA also make measurements of Mg II index (in case of loss of SORCE spacecraft).
  - There is a need to formally validate and quality-check these indices.
    - Currently, comprehensive but informal validation of sunspot area and Mg II index with 4-5 other time series.



Comparison of 5 different time series used as proxy indicators of facular brightening in solar irradiance models. [*Kopp and Lean Study B report*, recently submitted to NOAA].