

# *The TSI Instruments – What's Old, What's New, and What's Next*

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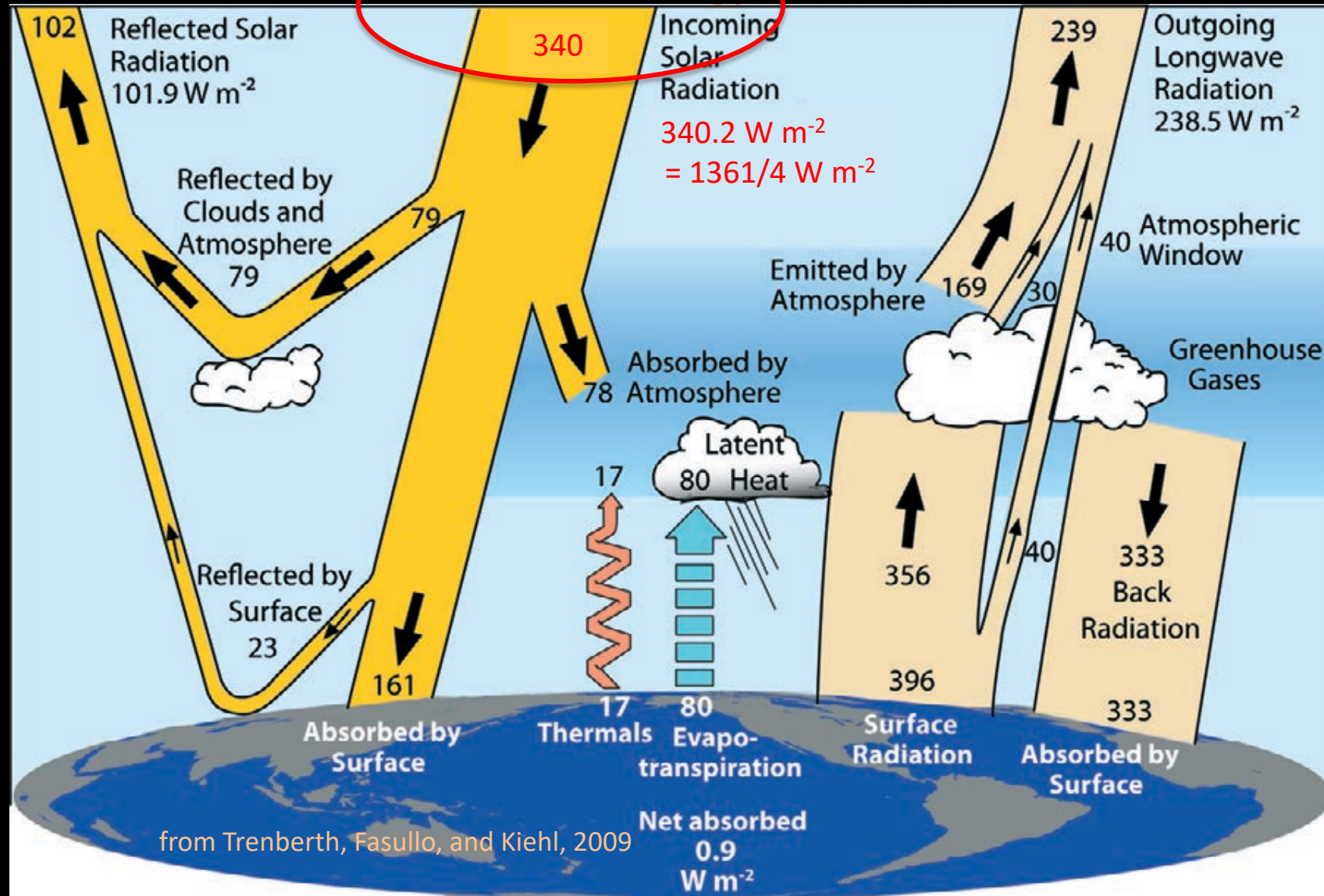


# Total Solar Irradiance Is *Nearly* All of the Earth's Energy Input

Shortwave

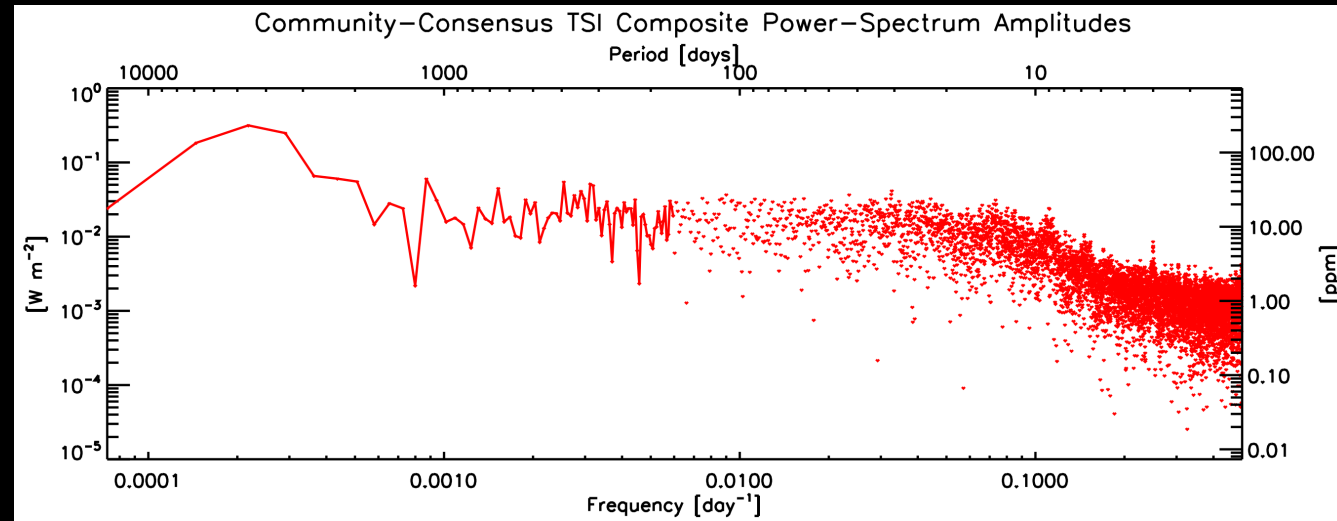
Total Solar Irradiance

Infrared



# What Are the Timescales of TSI Variability?

- 0.01% over minutes
- < 0.3% over a few days
  - Short duration causes negligible climate effect
- 0.1% over 11-year solar cycle
  - Detectable effect on climate
- 0.05 - 0.3% over centuries (unknown)
  - Direct effect on climate (Maunder Minimum and Europe's Little Ice Age)
- $10^{-10}$ /yr on evolutionary timescales

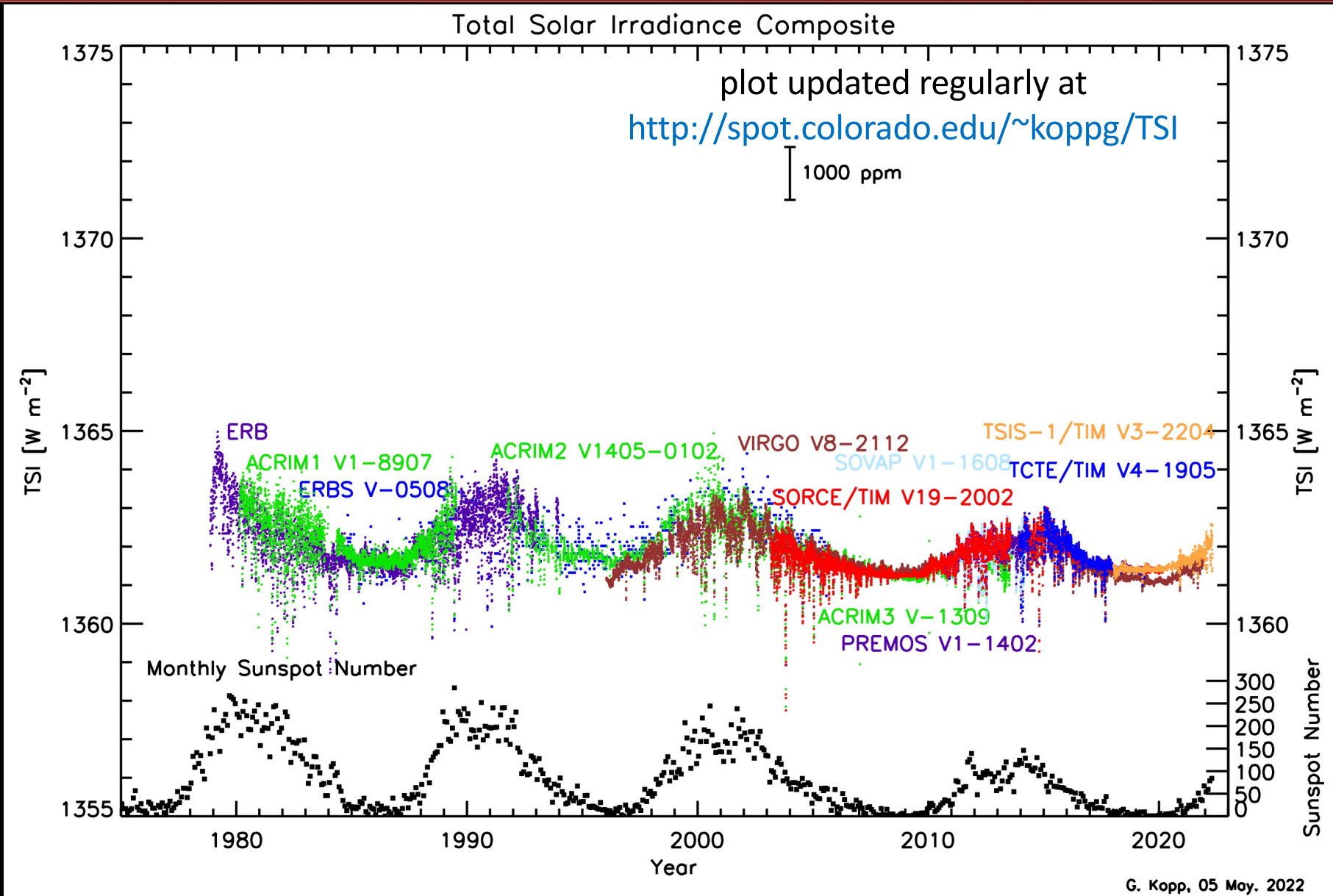


[values are peak-to-peak amplitudes]

- An unequivocal link between climate change and TSI has been established
  - Magnitude of natural climate forcing needs to be known for setting present and future climate policy regulating anthropogenic forcings

# The Current Total Solar Irradiance Record

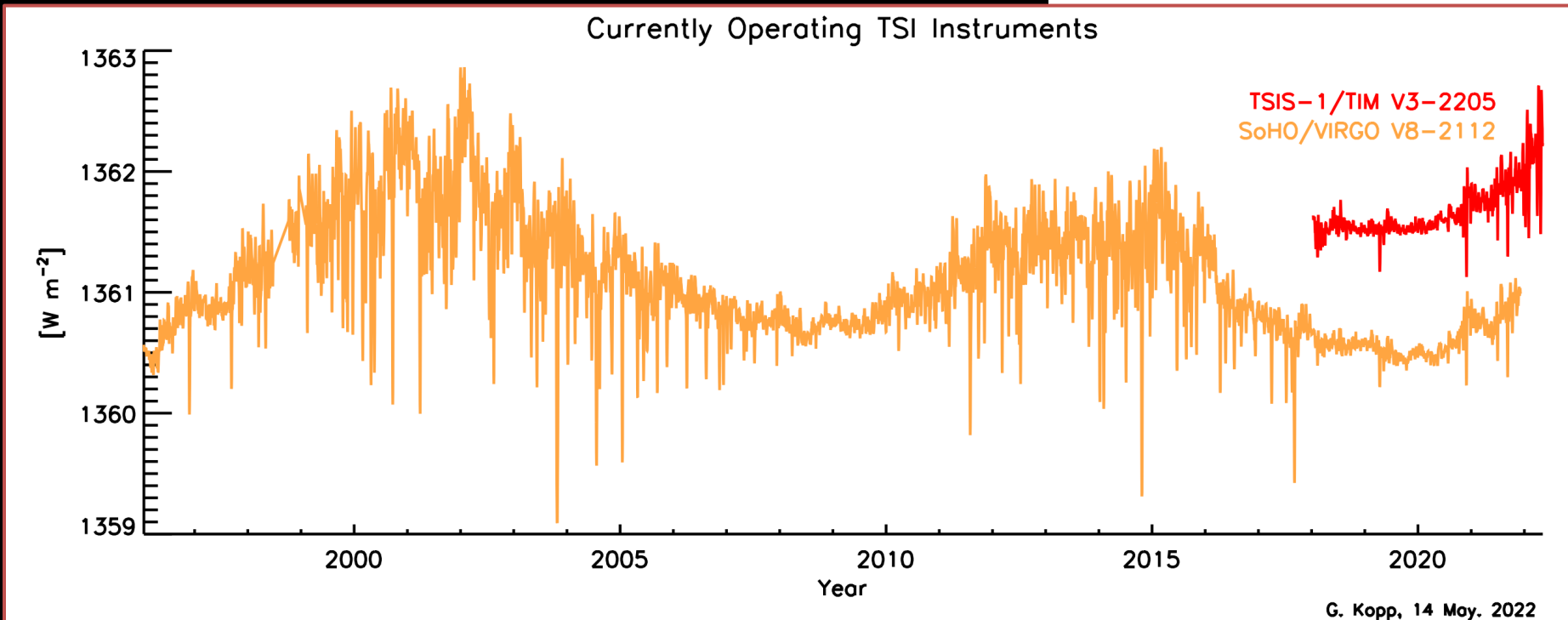
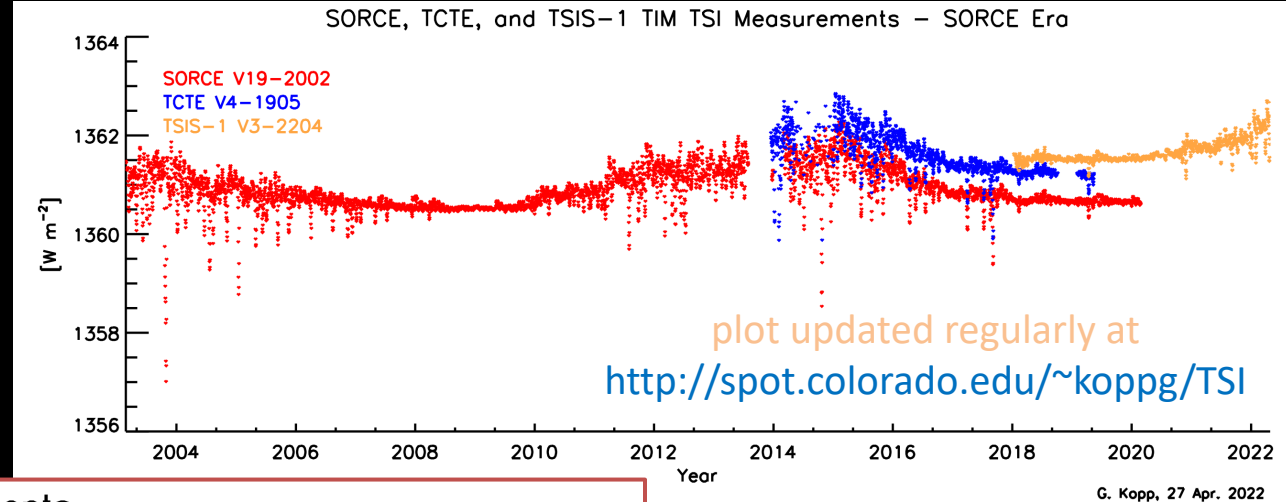
- The uninterrupted, 44-year-long spaceborne TSI record includes contributions from more than 15 NASA, ESA, and NOAA instruments
  - The record continues to rely on continuity and stability
  - Improvements have been made to absolute accuracy





# Current Total Solar Irradiance Measurements

- TSIS-1 and VIRGO continue to provide data
- NorSat-1/CLARA (data not released)
- FY-3E (data not released)



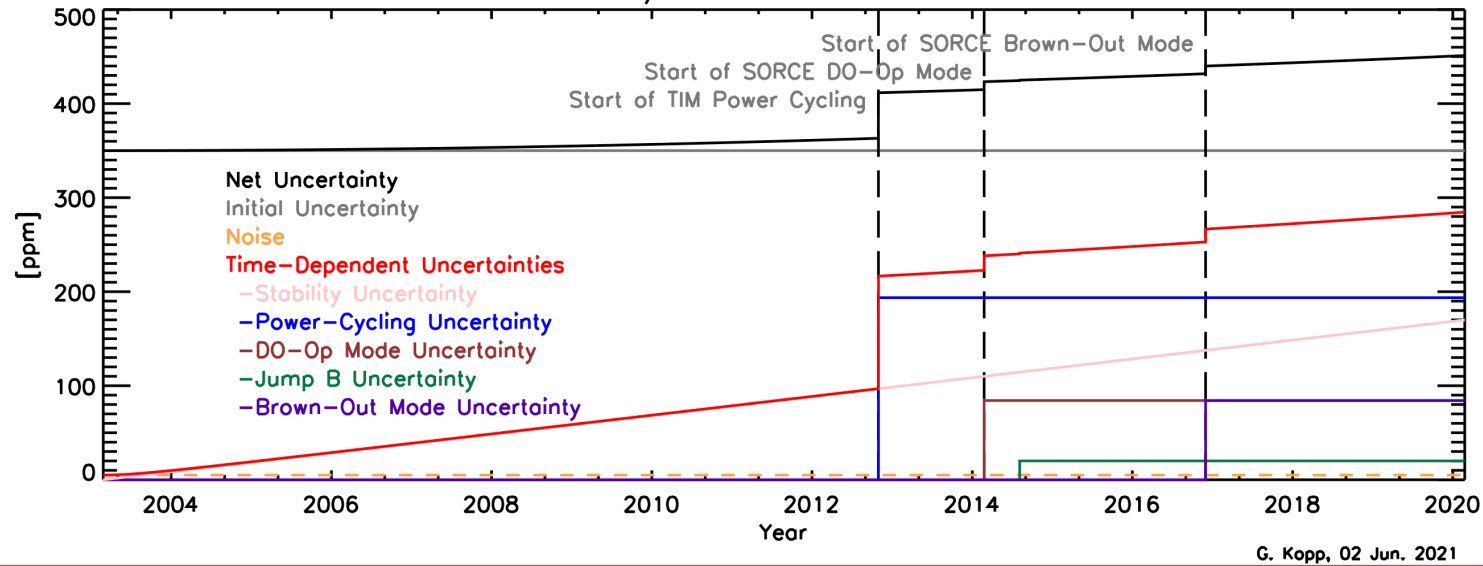
# Chronological Summary of Instrument Data and Data Quality

Instrument	Version	Begin Date	End Date	Years of Data	% Daily Values	Short-Term Uncertainty
NIMBUS7	NIMBUS7	17-Nov-1978	24-Jan-1993	14.19	86.80%	0.110
ACRIM1	V1-8907	16-Feb-1980	14-Jul-1989	9.41	90.10%	0.229
ERBS	V-0307	24-Oct-1984	30-Jul-2003	18.76	10.70%	0.057
ACRIM2	V1405-0009	22-Jul-1992	2-Sep-2000	8.12	92.90%	0.089
VIRGO	V8-2112	18-Jan-1996	5-Dec-2021	25.88	97.70%	0.042
VIRGO	V6-1805	28-Jan-1996	2-May-2018	22.26	97.50%	0.042
ACRIM3	V-1309	5-Apr-2000	17-Sep-2013	13.45	96.10%	0.032
SORCE/TIM	V19-2002	25-Feb-2003	25-Feb-2020	17.00	94.70%	0.028
PREMOS	V1-1402	27-Jul-2010	11-Feb-2014	3.55	90.00%	0.033
TCTE/TIM	V4-1905	16-Dec-2013	15-May-2019	5.41	83.50%	0.050
TSIS-1/TIM	V3-2205	11-Jan-2018	6-May-2022	4.31	86.90%	0.026



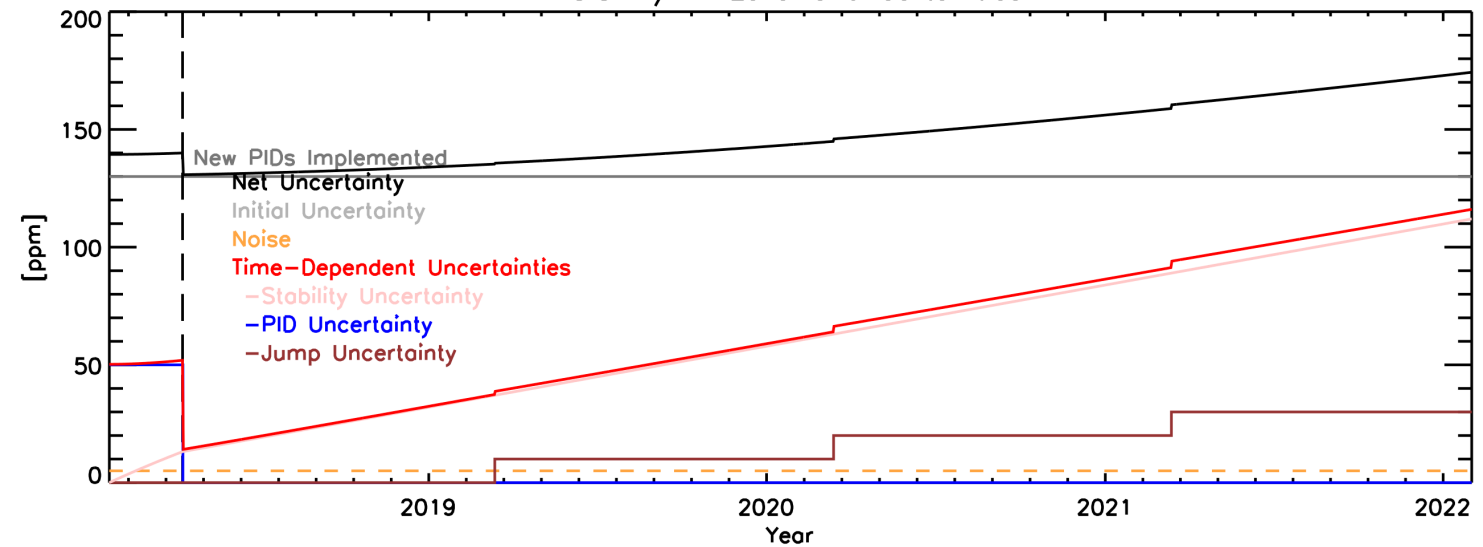
# TIM Time-Dependent Uncertainties Are Provided With Data

SORCE/TIM Level 3 Uncertainties



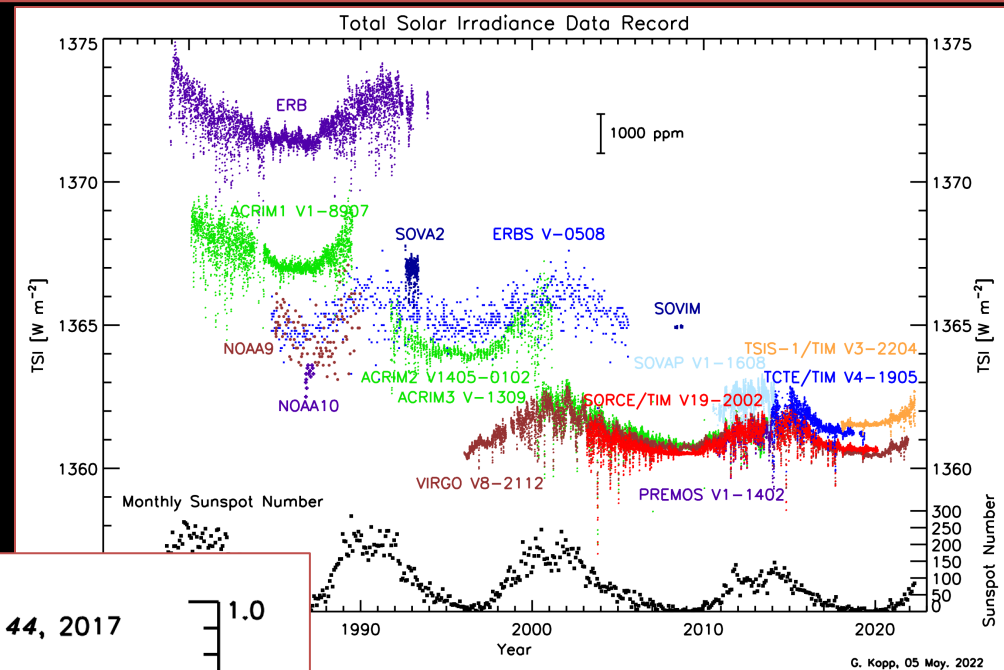
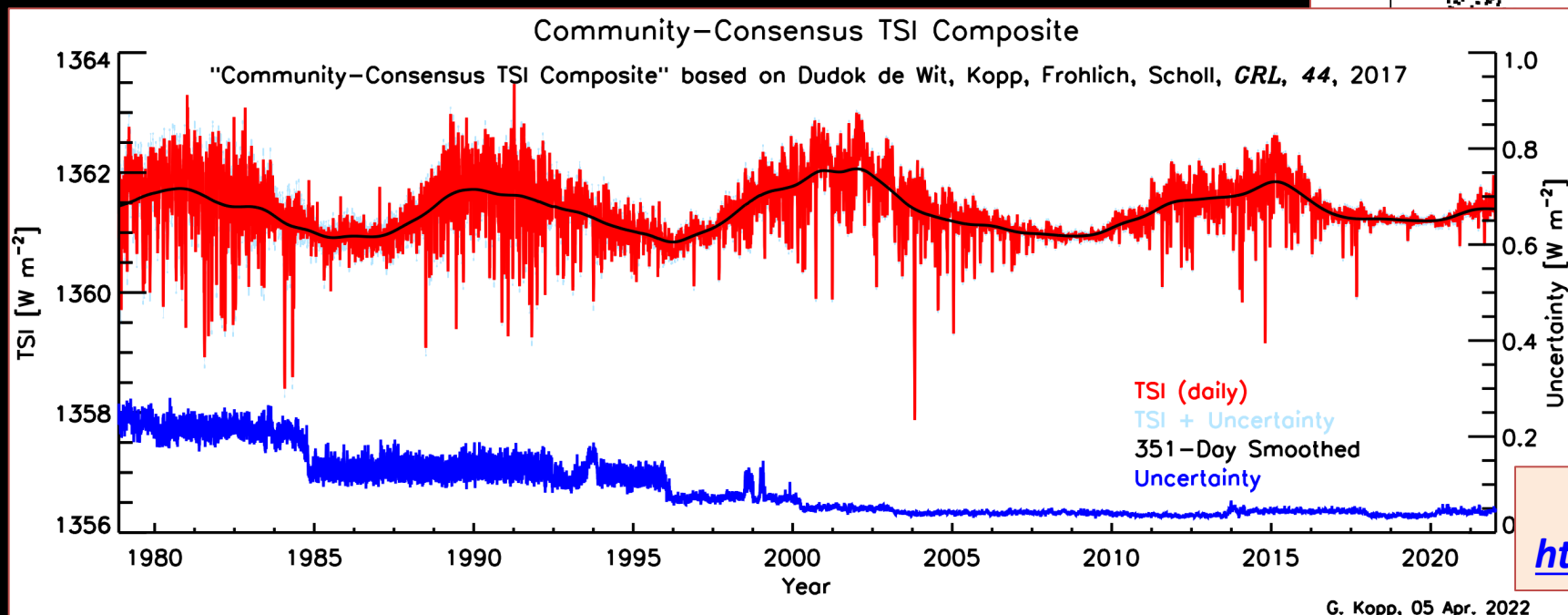
Reflect estimates of on-orbit effects

TSIS-1/TIM Level 3 Uncertainties



# Community-Consensus TSI Composite

- Supported by TSI community
- Uses all available instrument data
- Uses an unbiased statistical approach
- Scale-wise weightings smooth gaps and transitions
- Scale normalized by weighting instrument accuracies
- Provides time-dependent uncertainties



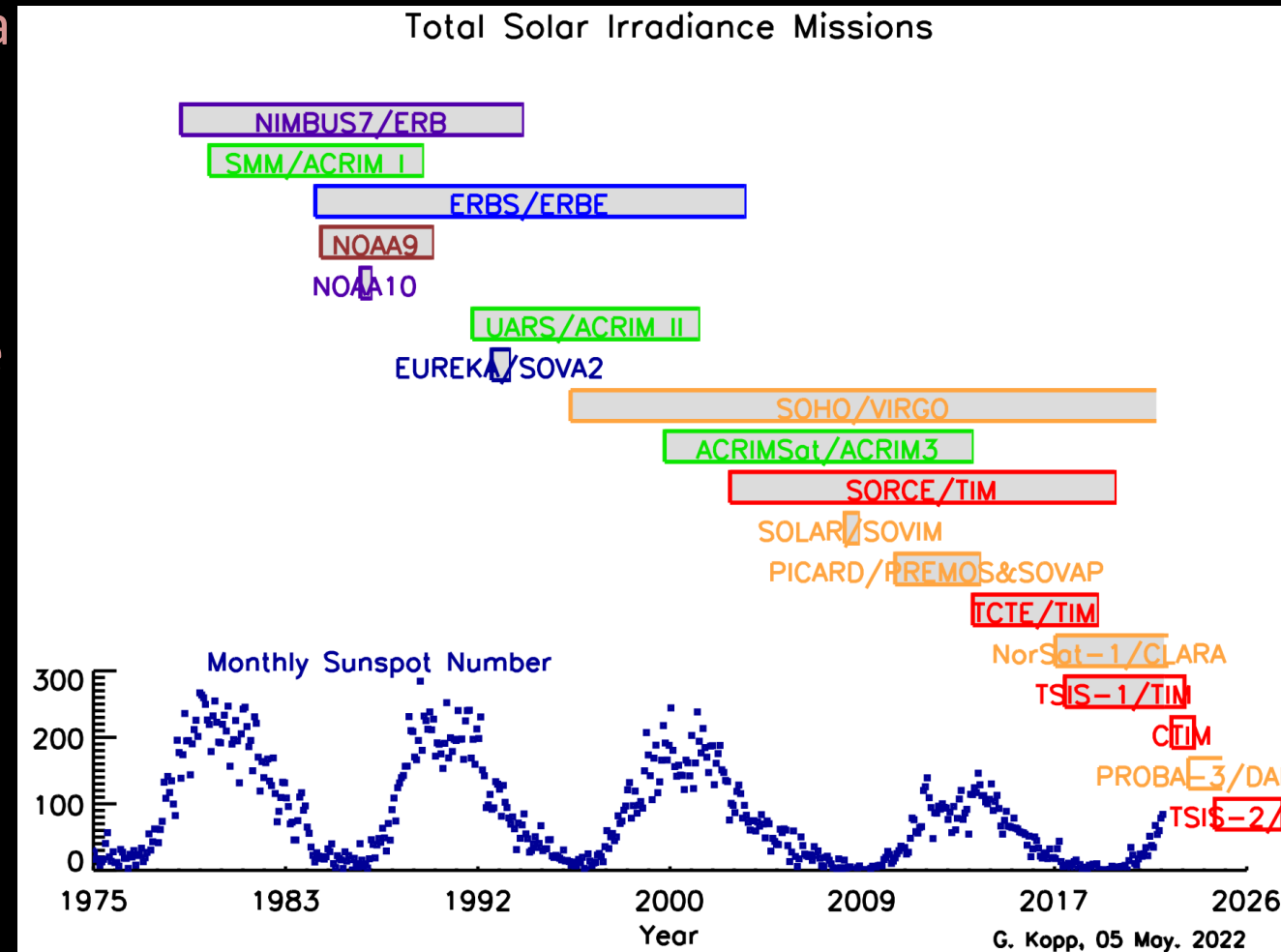
*This composite continues  
to be updated to include  
new data*

*Data and plots available at:*  
<http://spot.colorado.edu/~kopp/TSI>



# Future Solar-Irradiance Measurement Plans

- TSIS-1 and VIRGO continue to provide data
- Data from the NorSat-1/CLARA and FY-3E may become available in the future
- The Compact TIM (CTIM), a CubeSat TSI instrument, will be ready for launch in late June 2022
- The PROBA-3/DARA is planned for launch in 2023
- TSIS-2, a rebuild of the TSIS-1, is being prepared for an Aug. 2024 launch



plot updated regularly at  
<http://spot.colorado.edu/~kopp/TSI>

## Compact Total Irradiance Monitor Flight Demonstration

PI: Dave Harber, CO-Is LASP: Greg Kopp, Peter Pilewskie, NIST: Michelle Stephens, John Lehman

A CubeSat-based Total Solar Irradiance Instrument

### Goals

- Match TSIS-1, TSIS-2/TIM performance using an 8-channel 6U-CubeSat TSI instrument
- Demonstrate measurement performance via 1-year of solar observations

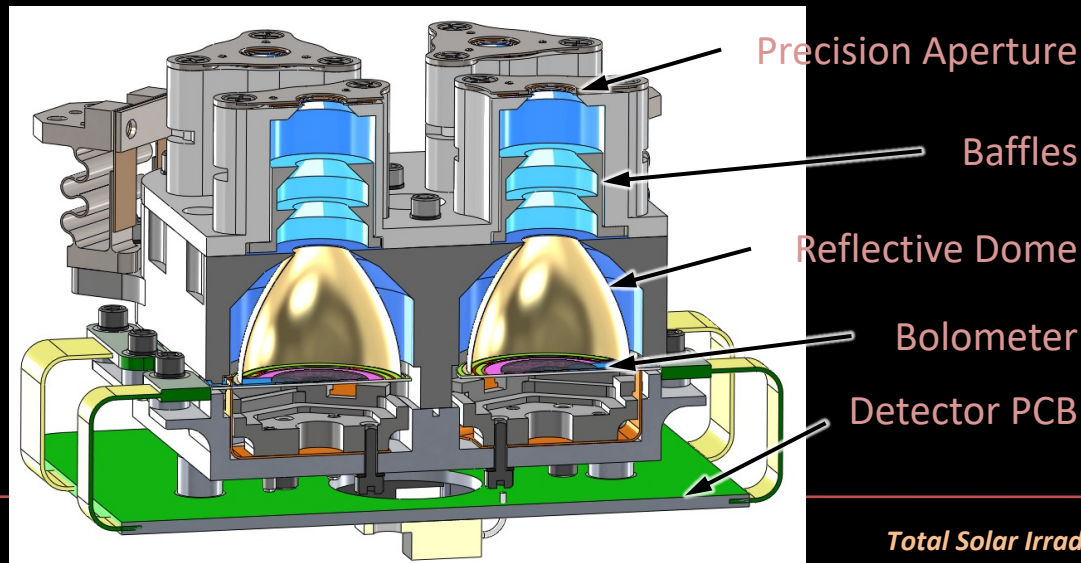
### Technology

- Detectors: Vertically-aligned carbon nanotube optical absorber on silicon substrates
- Precision apertures: Silicon ion-etched

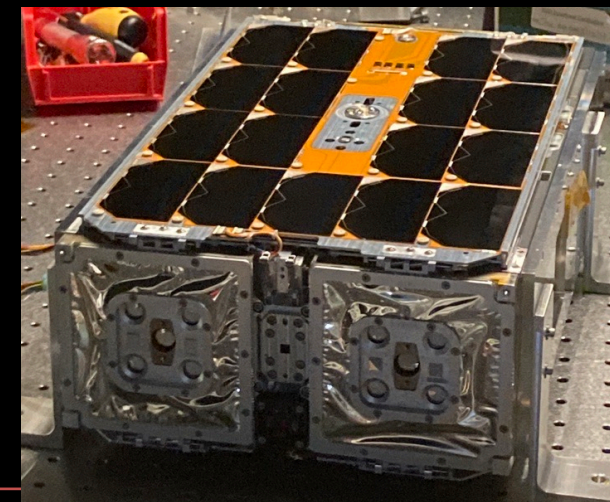
### Launch

- NET June 29<sup>th</sup> on STP-28A launched by Virgin Orbit

### CTIM Detector Head Cross-Section



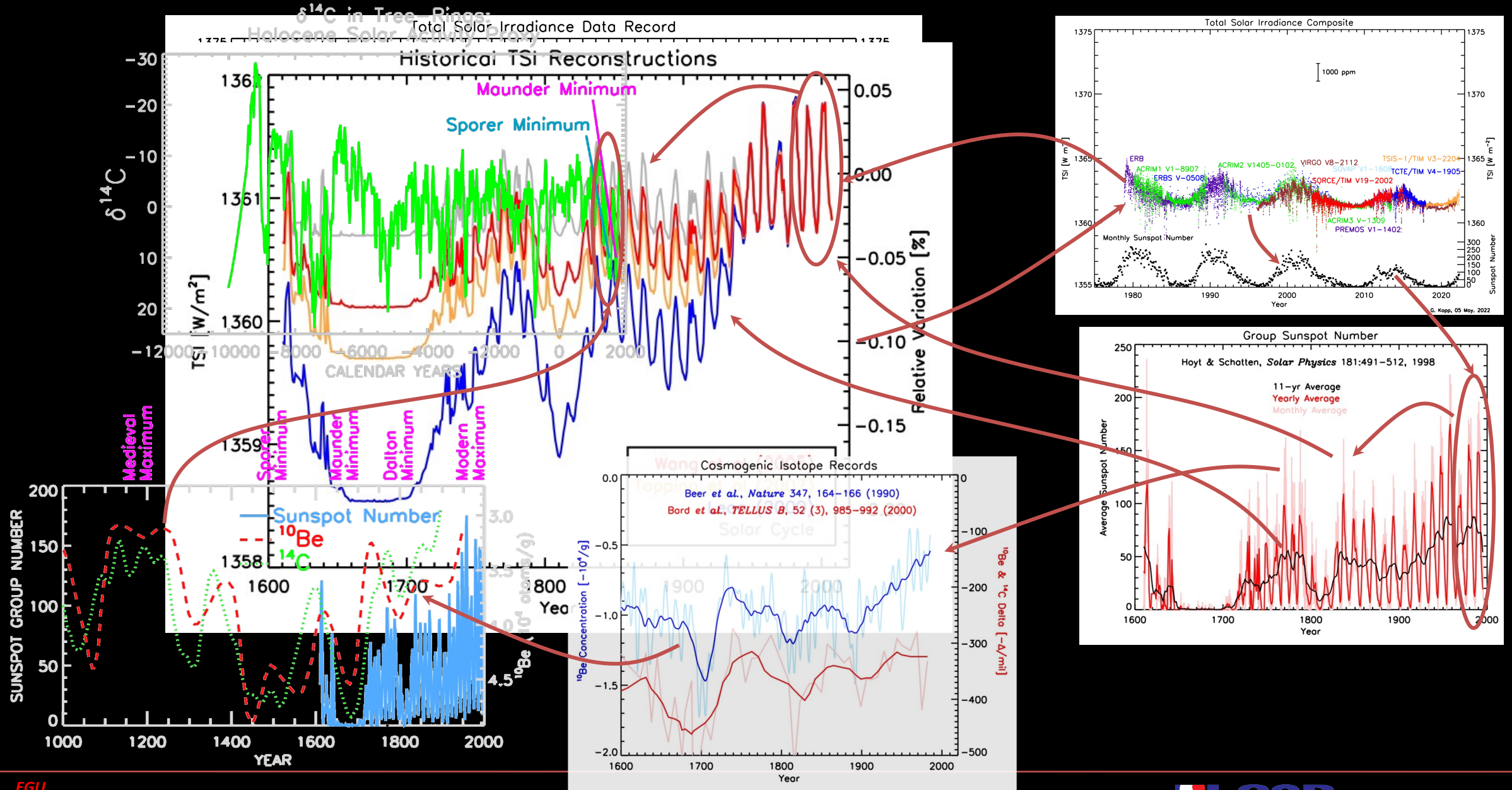
### Integrated CTIM-FD CubeSat



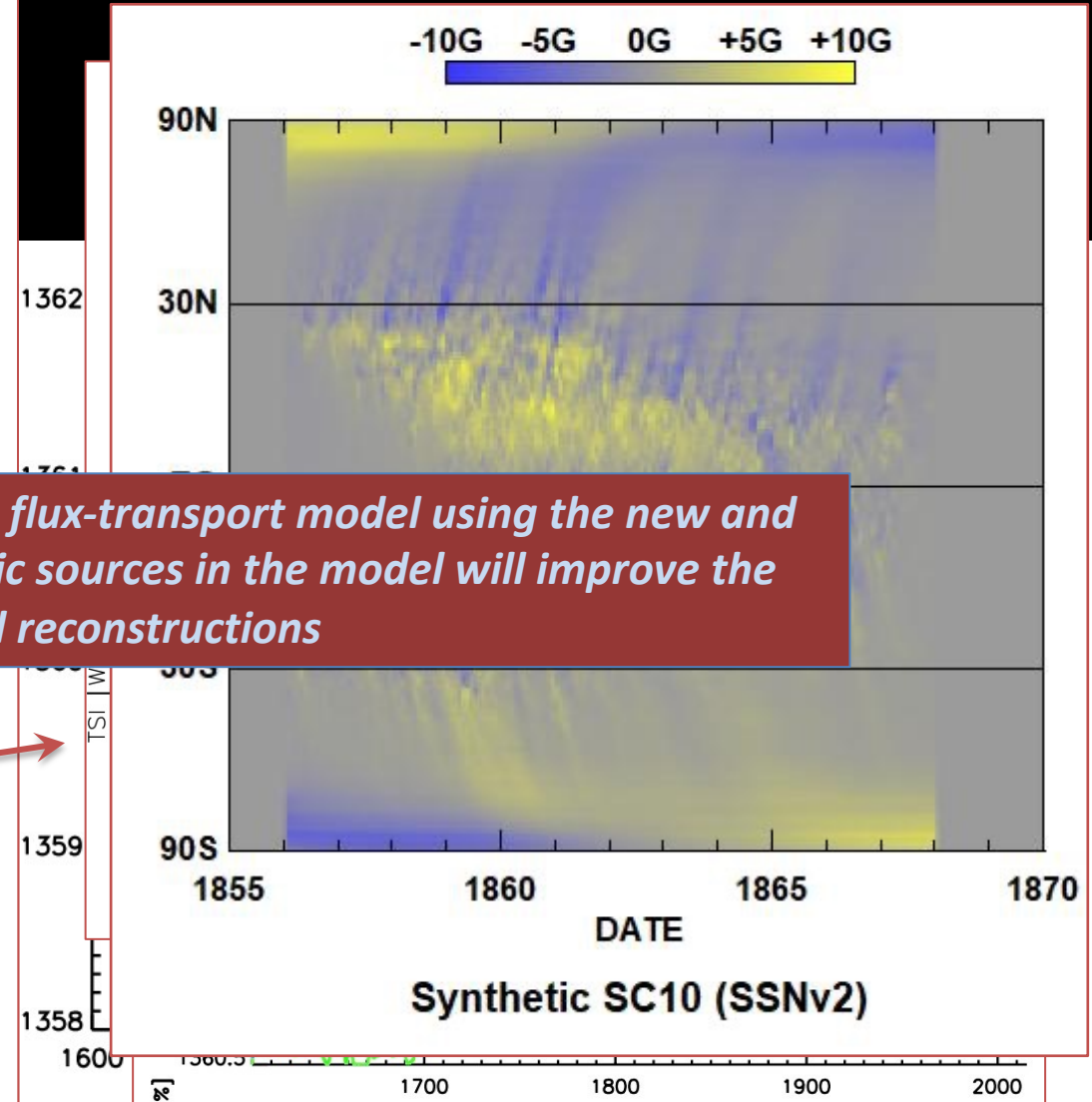
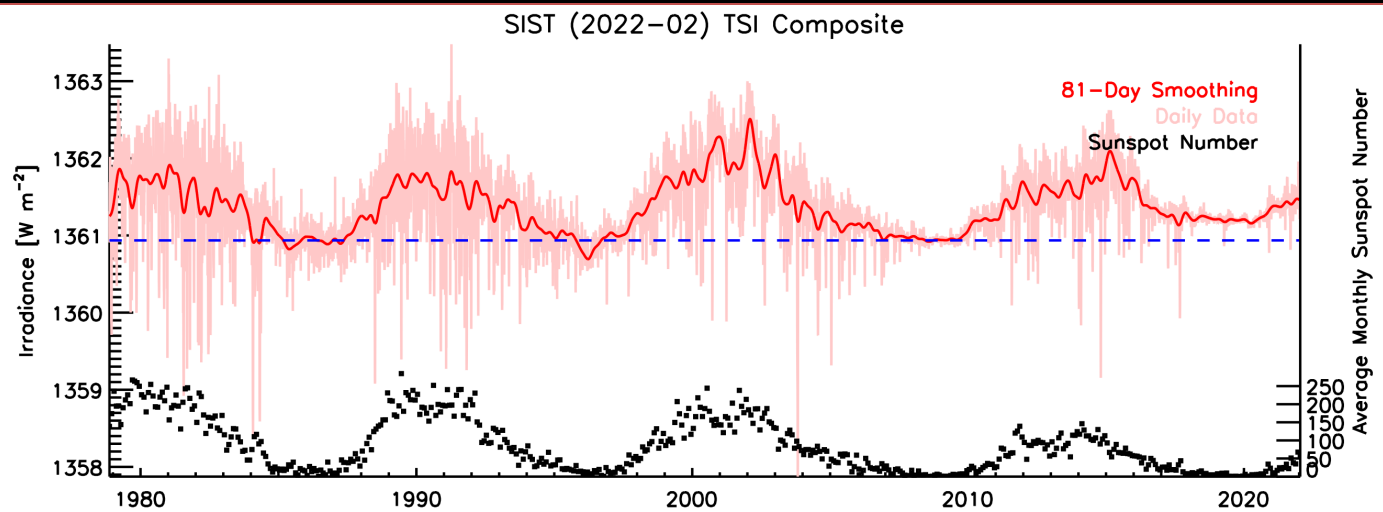
Total Solar Irradiance



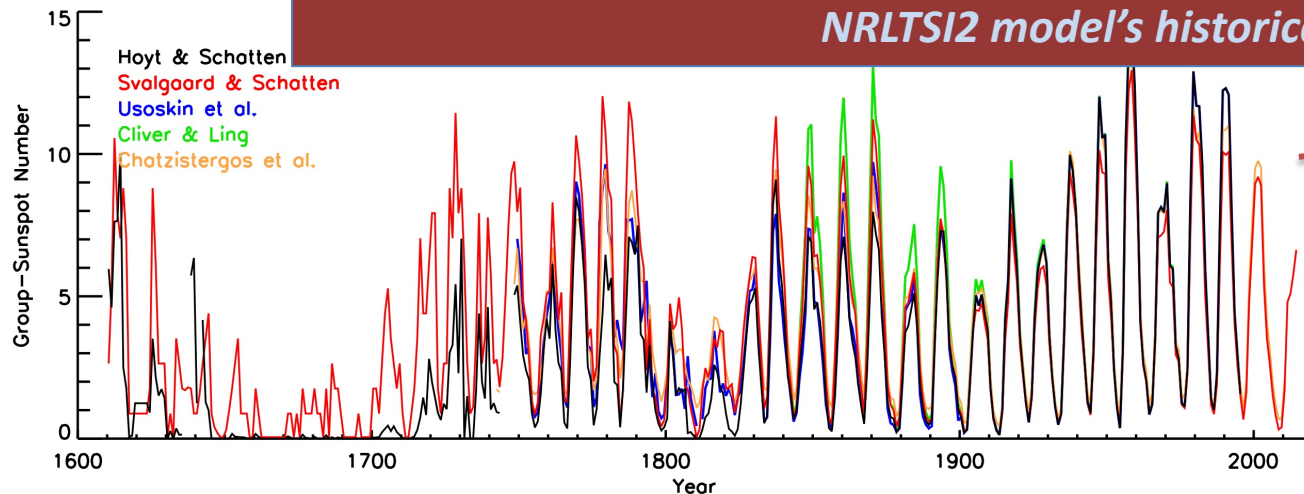
# Historical TSI Reconstructions Rely on Proxies



# Update TSI Reconstructions Using New Sunspot Records



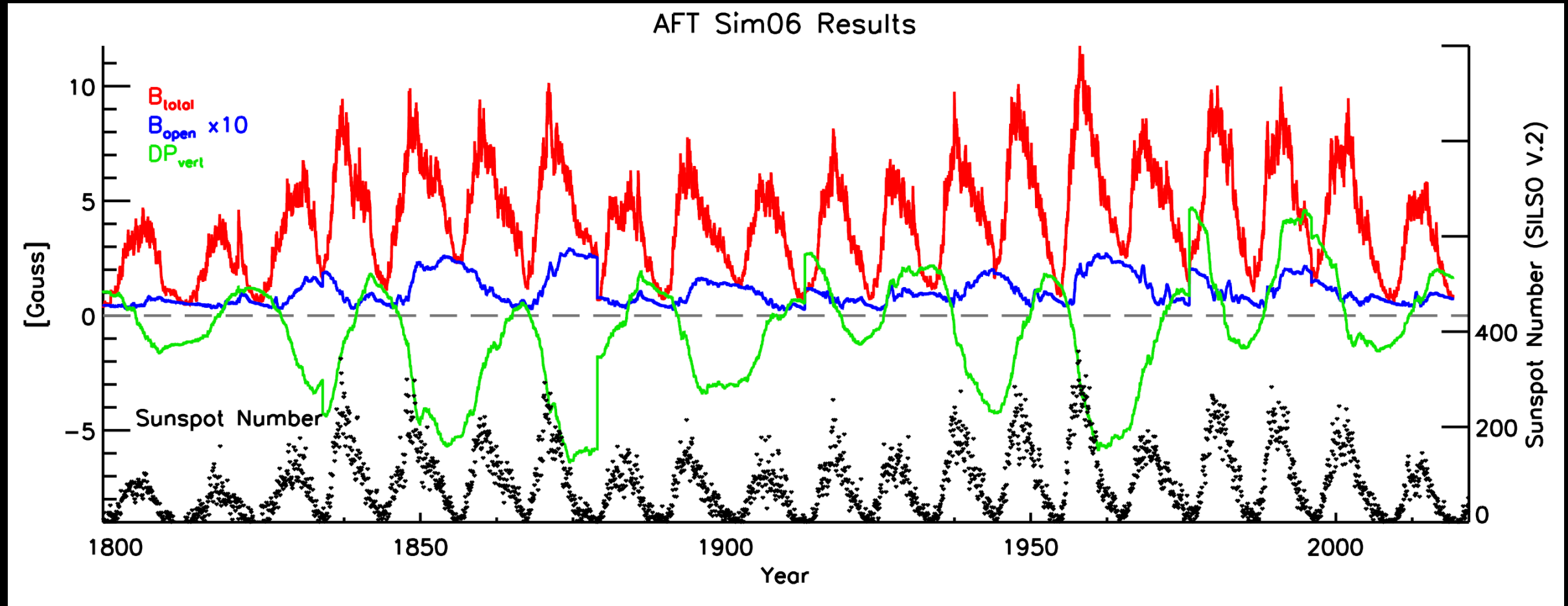
*Reevaluation of and improvements to the surface flux-transport model using the new and upcoming sunspot records to inform the magnetic sources in the model will improve the NRLTSI2 model's historical reconstructions*





# Simulating Historical Flux Maps from 1750 to Present

- Historical TSI from both the NRLTSI and the SATIRE models are being recalculated using the latest SILSO sunspot record to estimate solar forcings with this updated indicator of historical solar activity



# TSI – The Earth's Incoming Energy

- TSI provides **99.974%** of Earth's incoming energy
  - **Mean TSI at TOA:  $1361 \pm 0.5 \text{ W m}^{-2}$**
  - Accepted by IAU
- Two currently operating TSI instruments will imminently be augmented by the next-generation CTIM instrument
- “Community-Consensus TSI Composite” provides time series and updated absolute values
- Historical reconstructions being improved with AFT model results