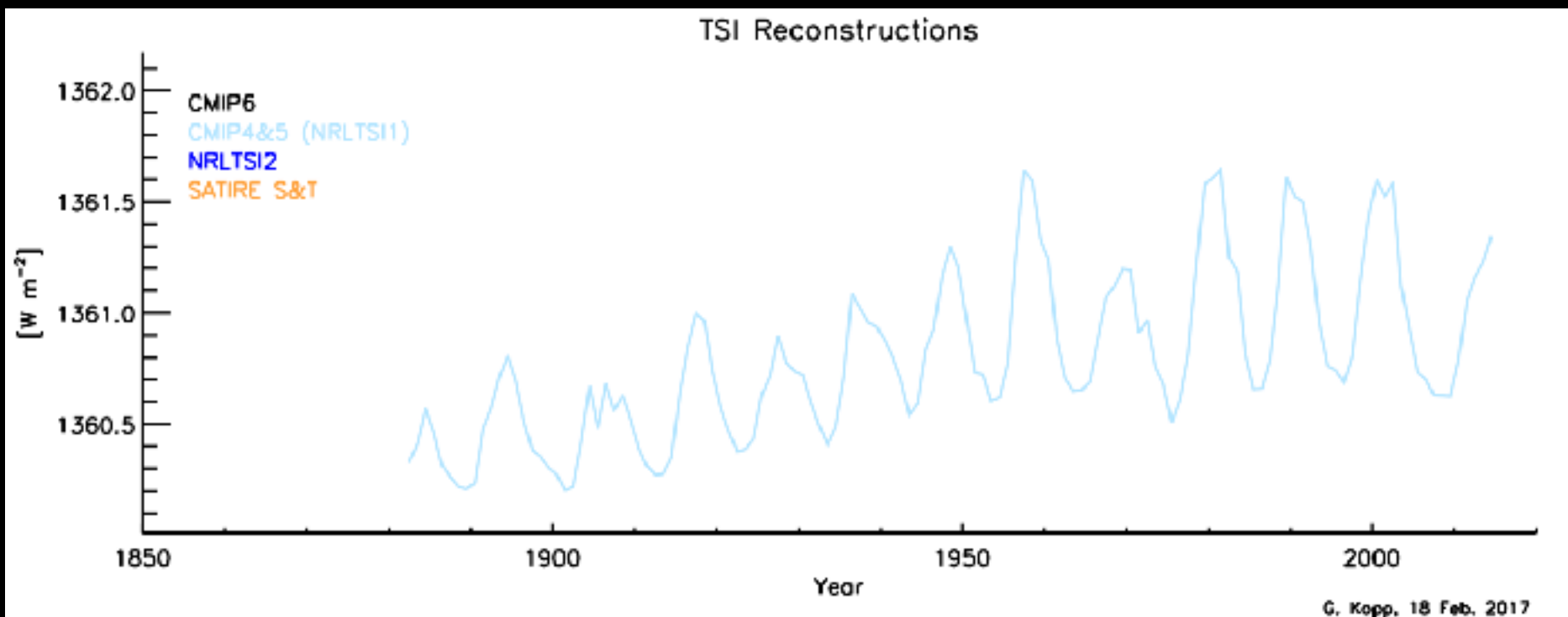


Long-term Solar Variability Based on the TSI-Measurement Record

Greg Kopp
CU/LASP & MPI/MPS

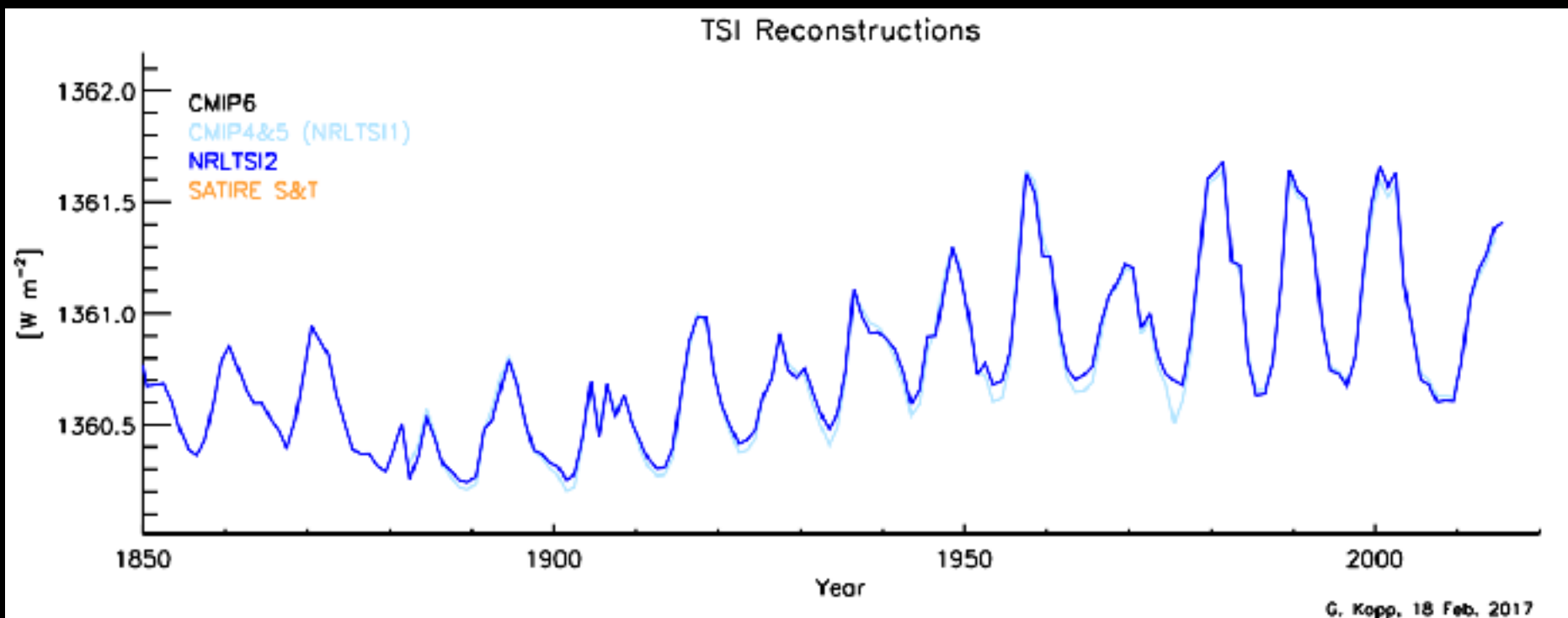
Climate Studies Depend on Solar Variability

- Coupled Model Intercomparison Project (CMIP6) TSI inputs show a large modern-era downward trend compared to CMIP5
 - May affect global-climate-model sensitivity to solar forcing



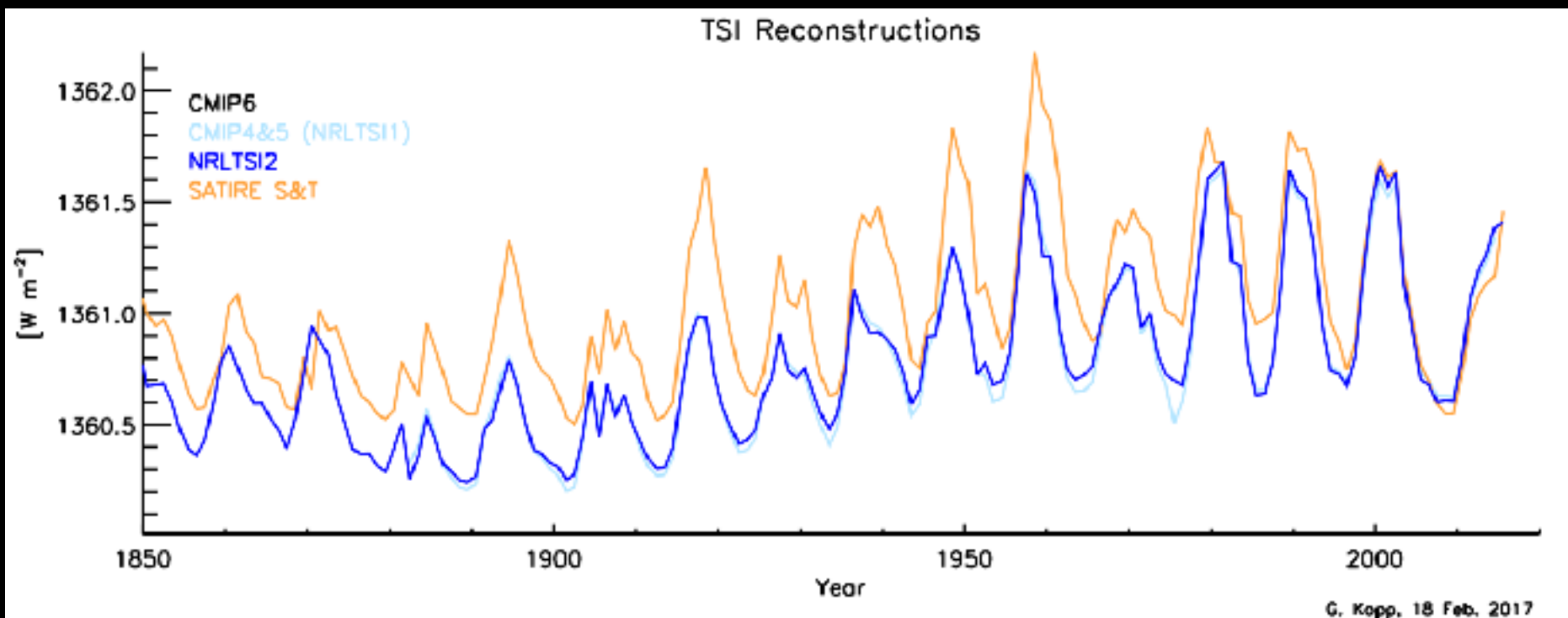
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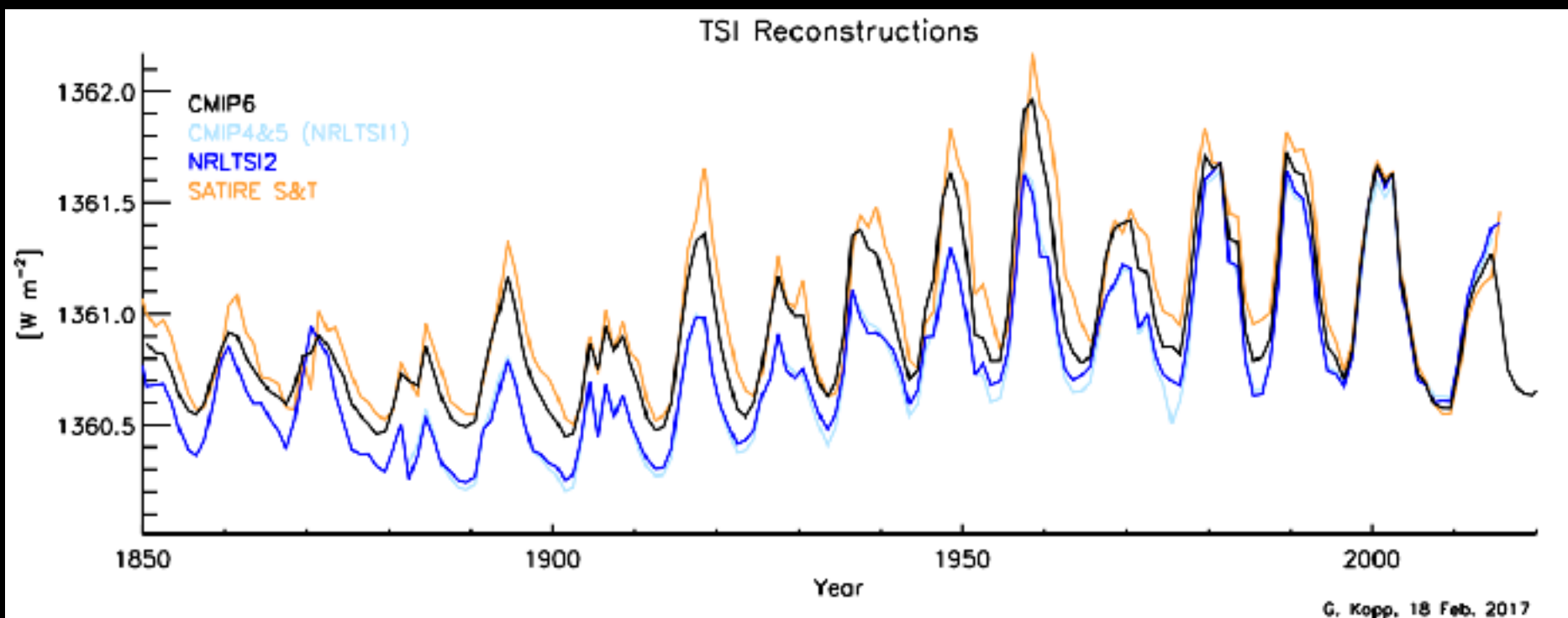
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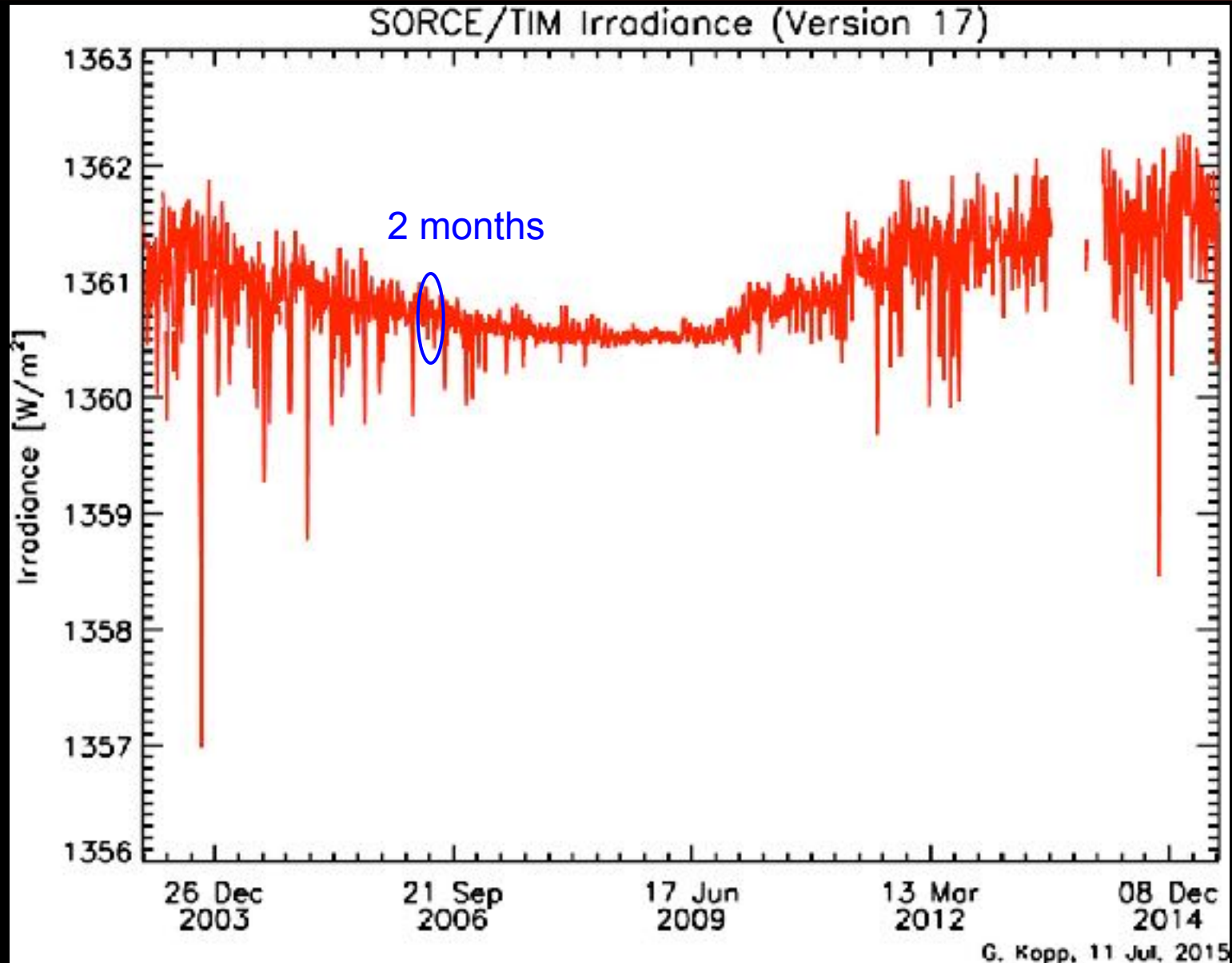


Climate Studies Depend on Solar Variability

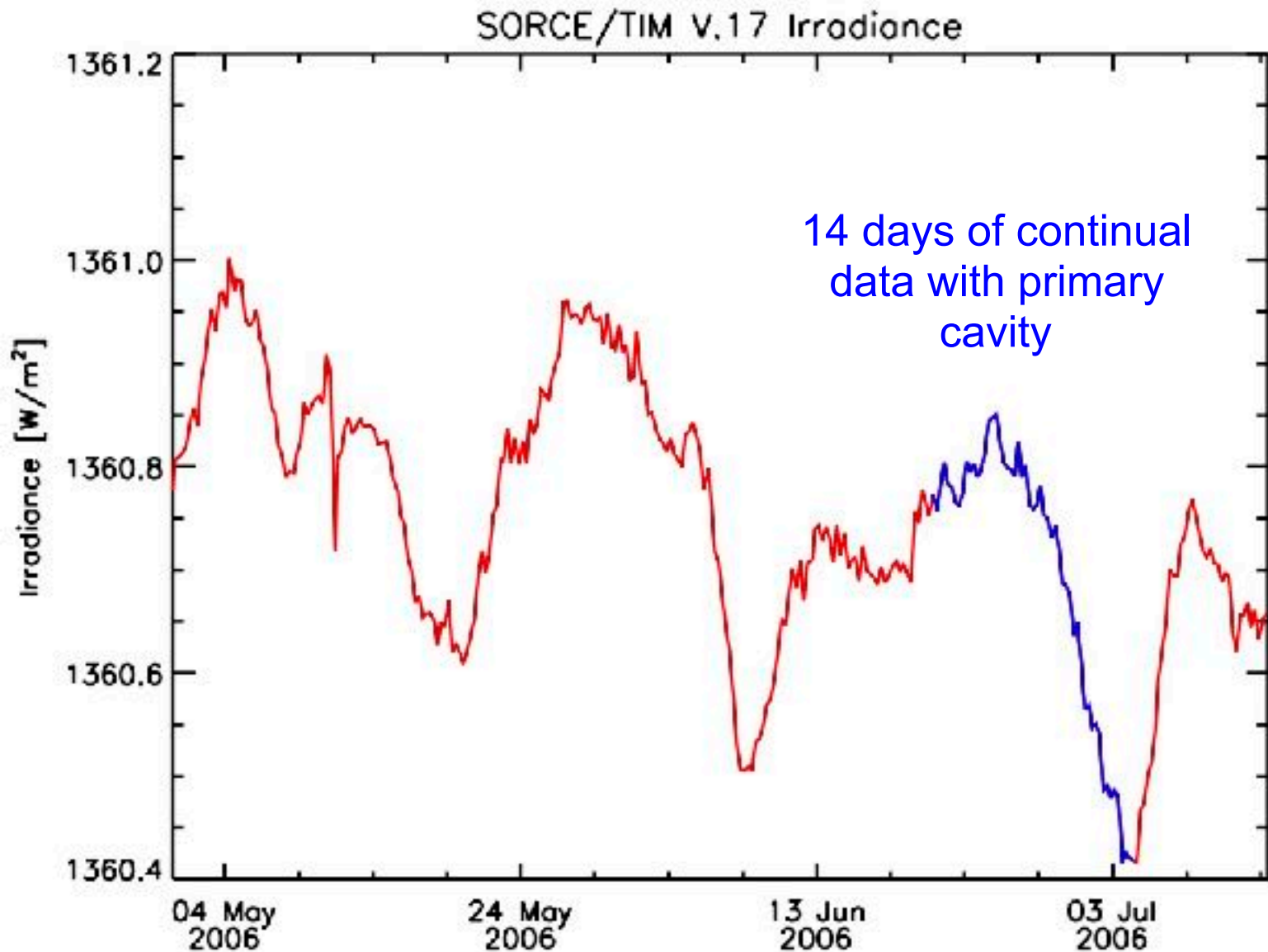
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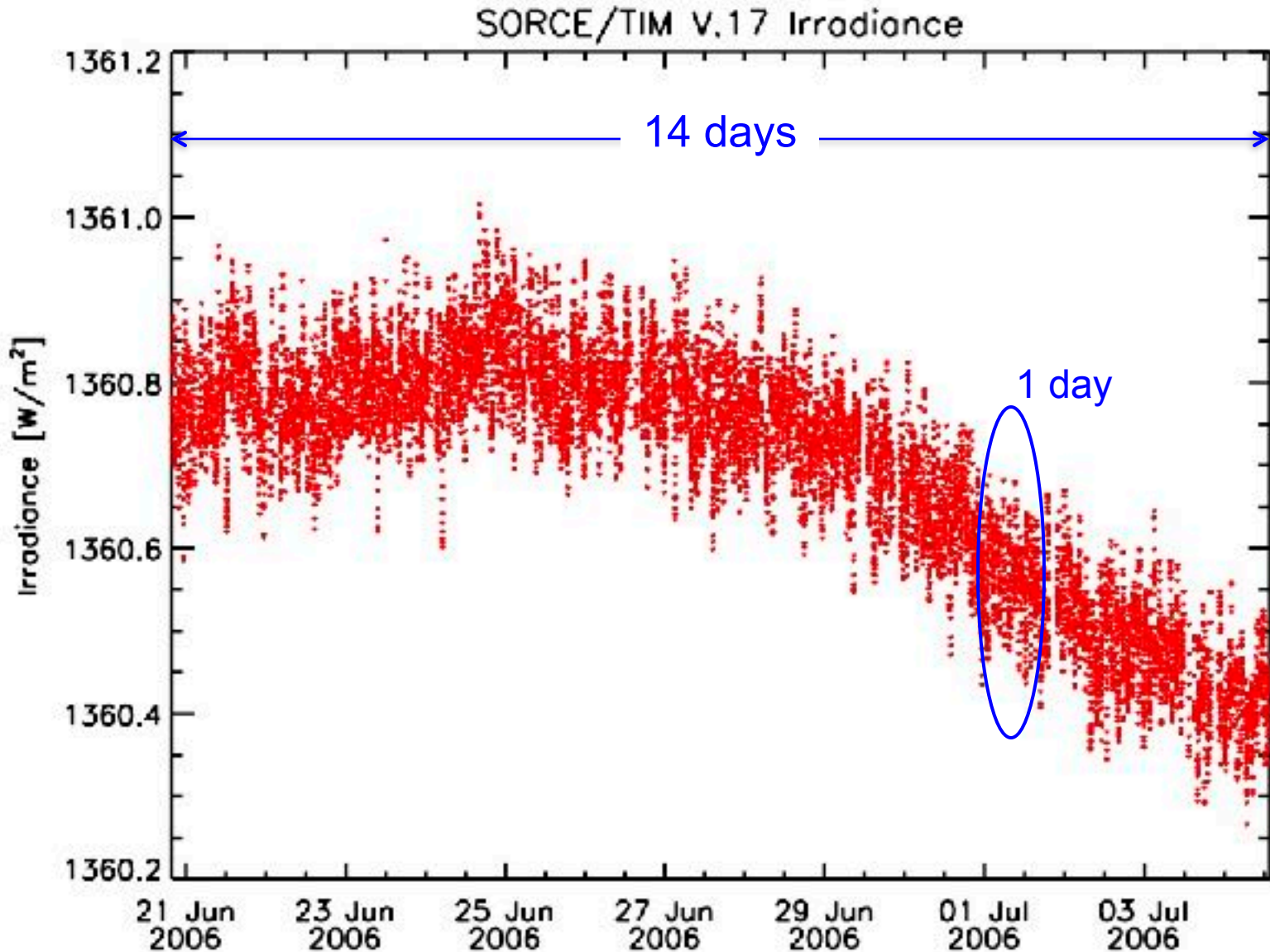
SORCE/TIM TSI Record



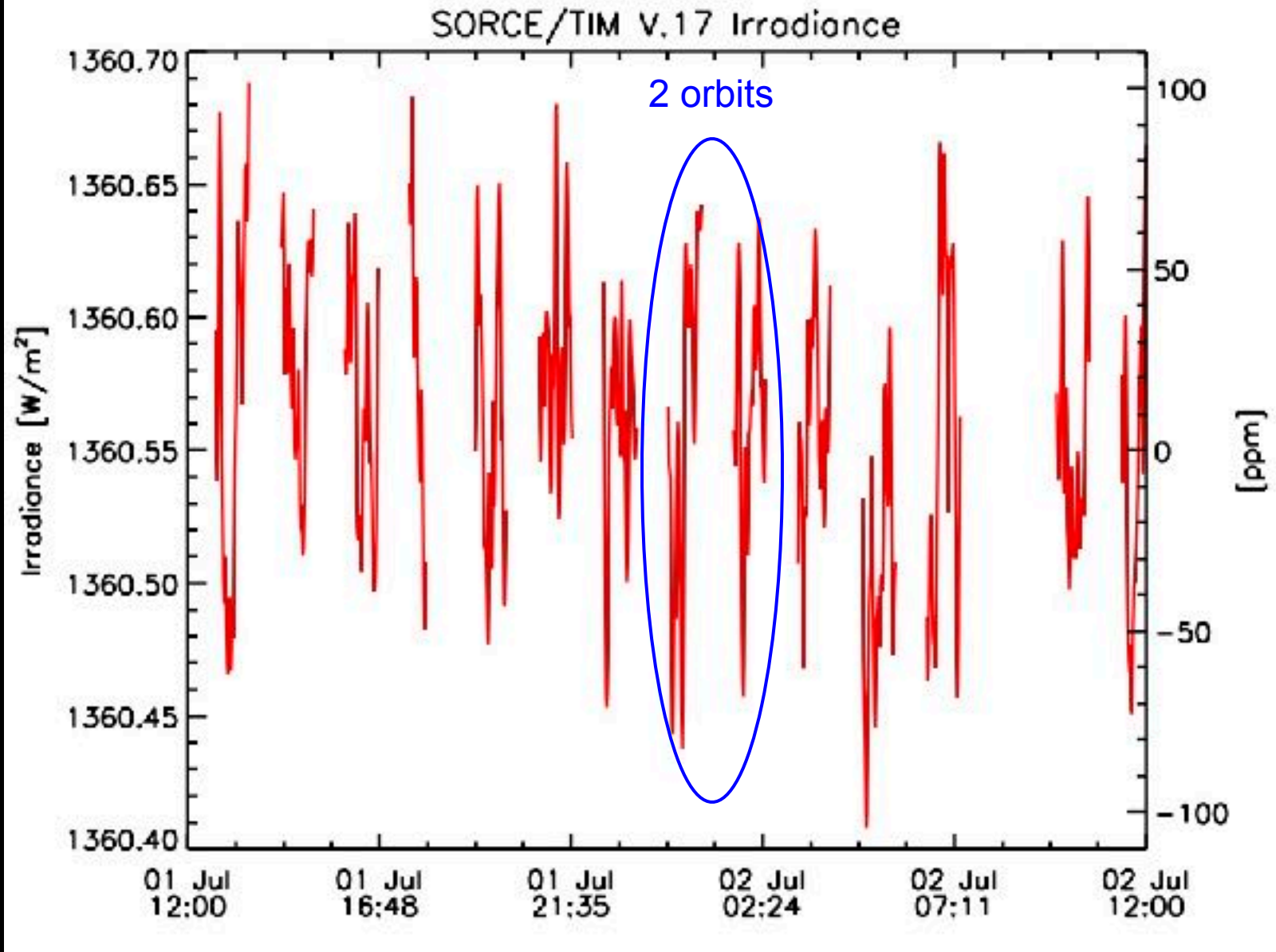
SORCE/TIM TSI Record – 2 Months



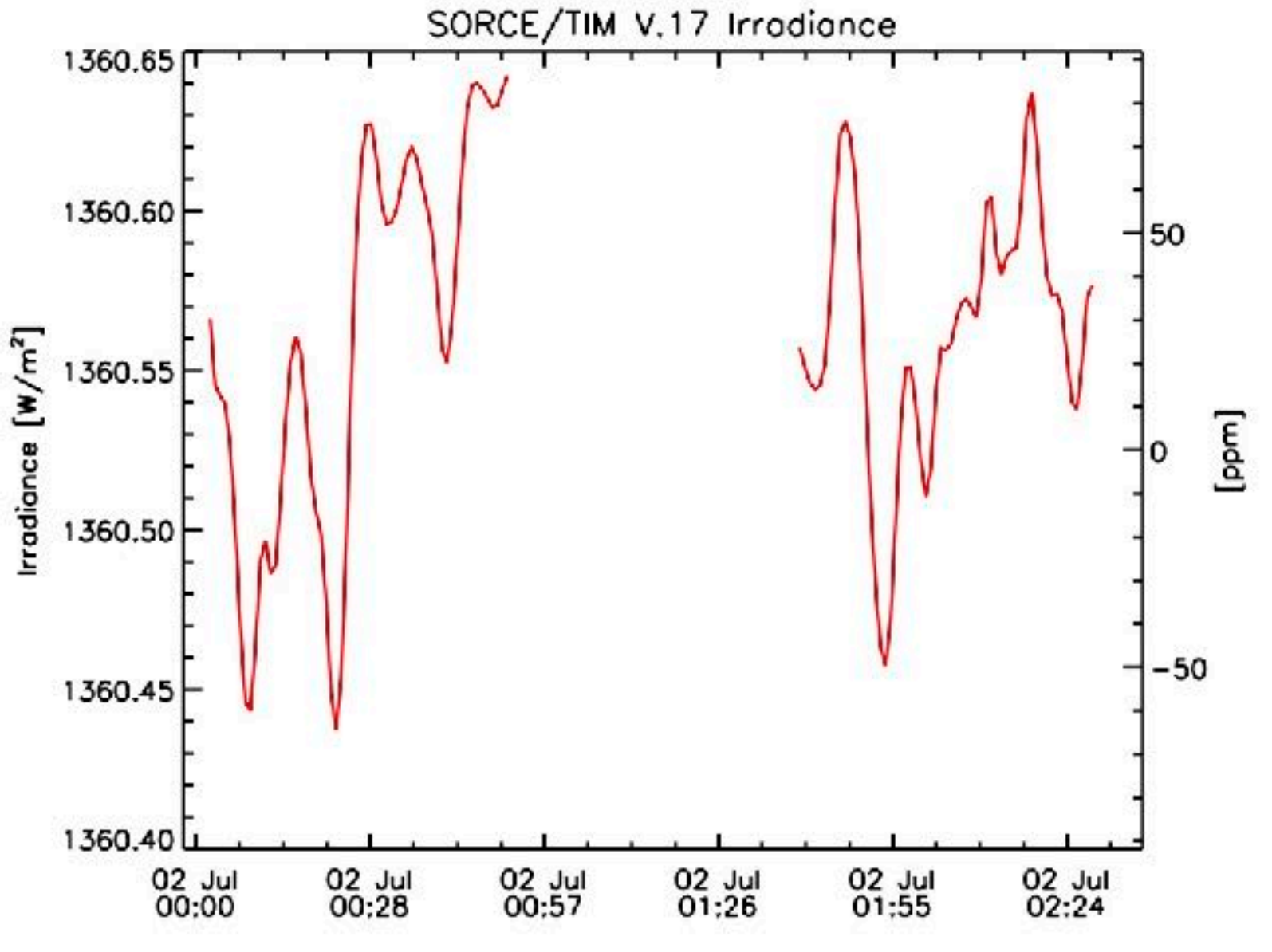
SORCE/TIM TSI Record – 2 Weeks



SORCE/TIM TSI Record – 1 Day



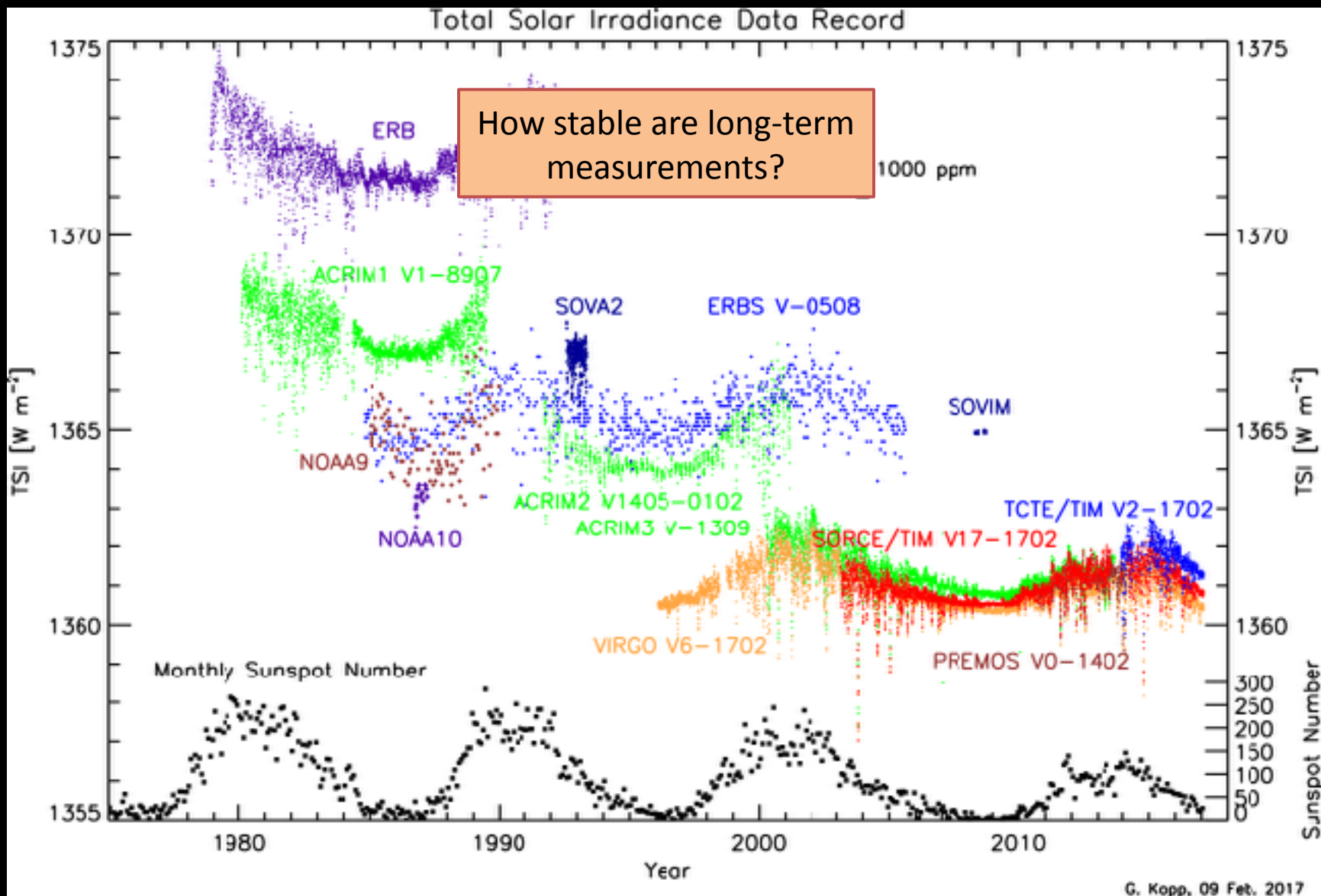
SORCE/TIM TSI Record – 2 Orbits



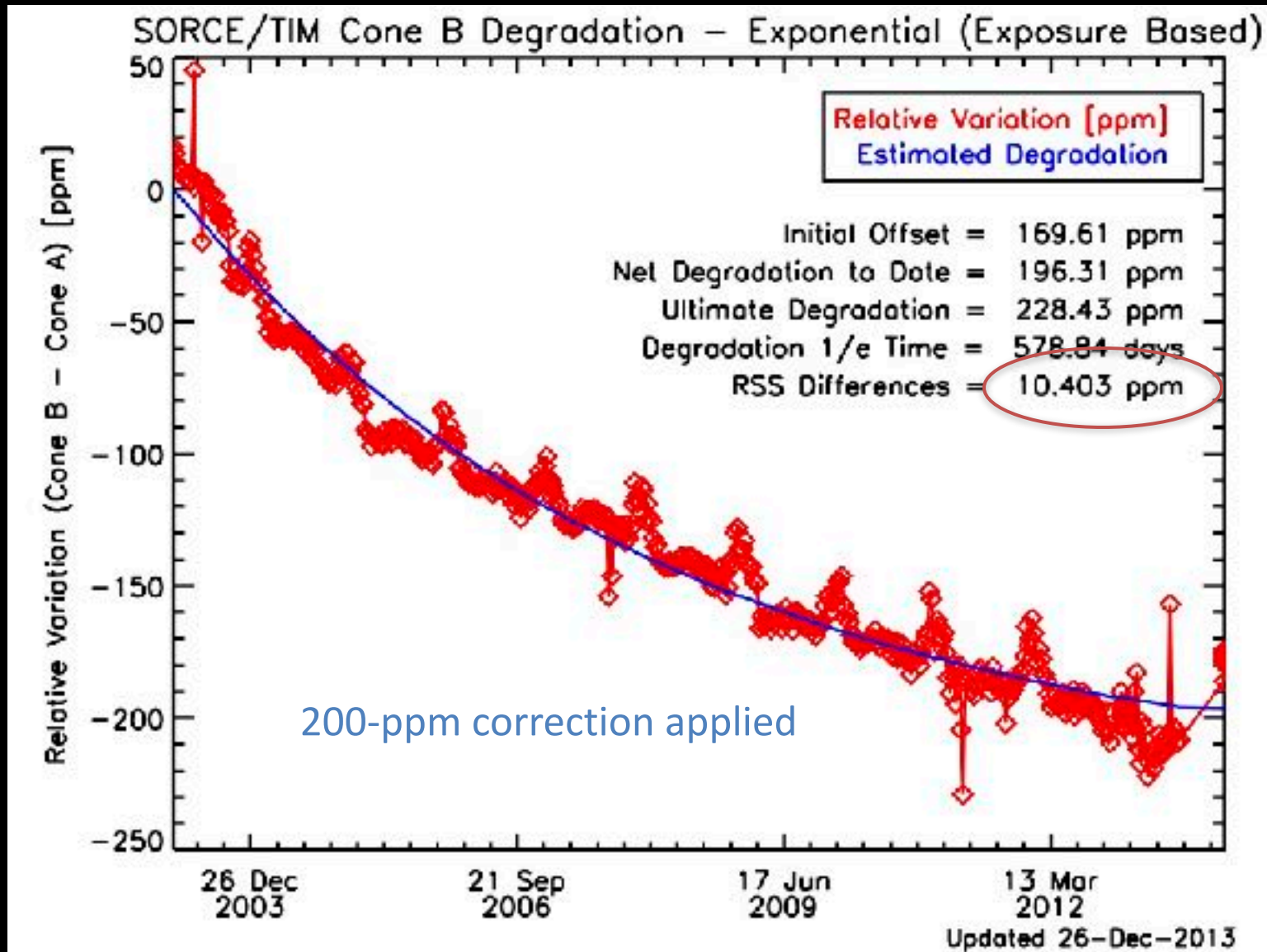
Timescales of TSI Variability

- Minutes 0.01%
- Days <0.3%
- Solar Cycle 0.1%
- Century ???
- Evolutionary (MS) 10^{-10} / yr

Current TSI-Measurement Record



Degradation Corrections Critical for Stability

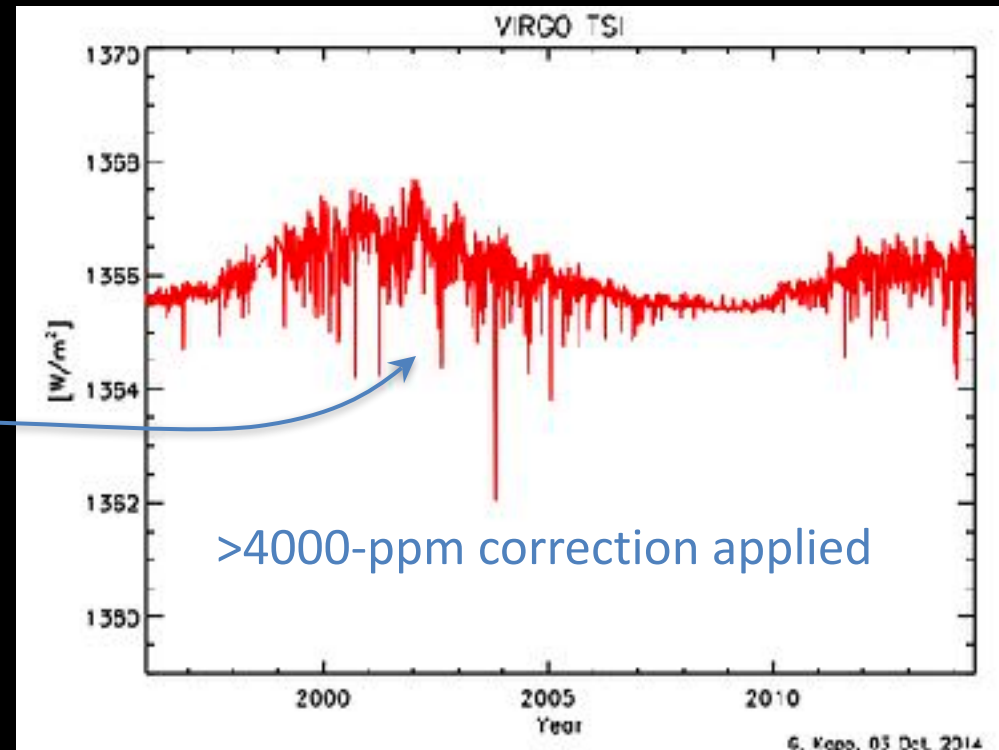
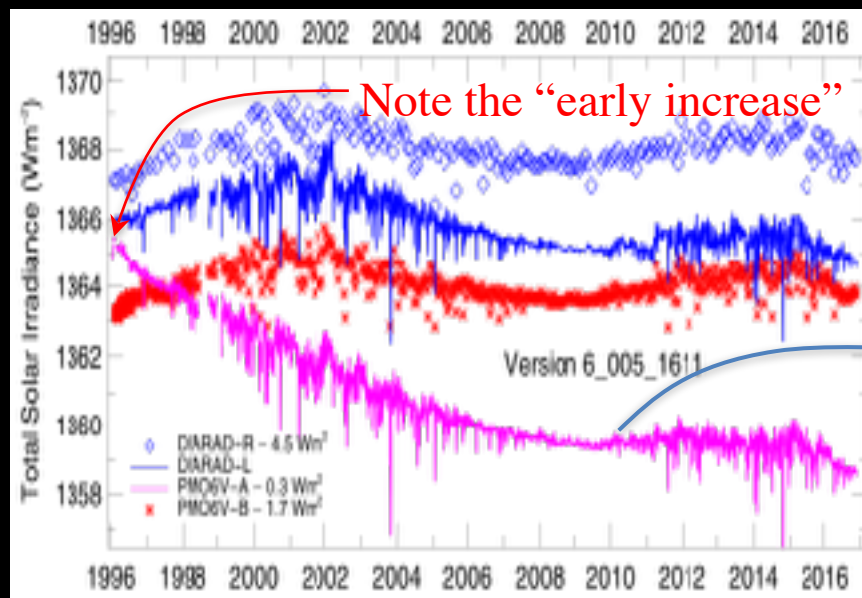


Degradation Corrections Critical for Stability

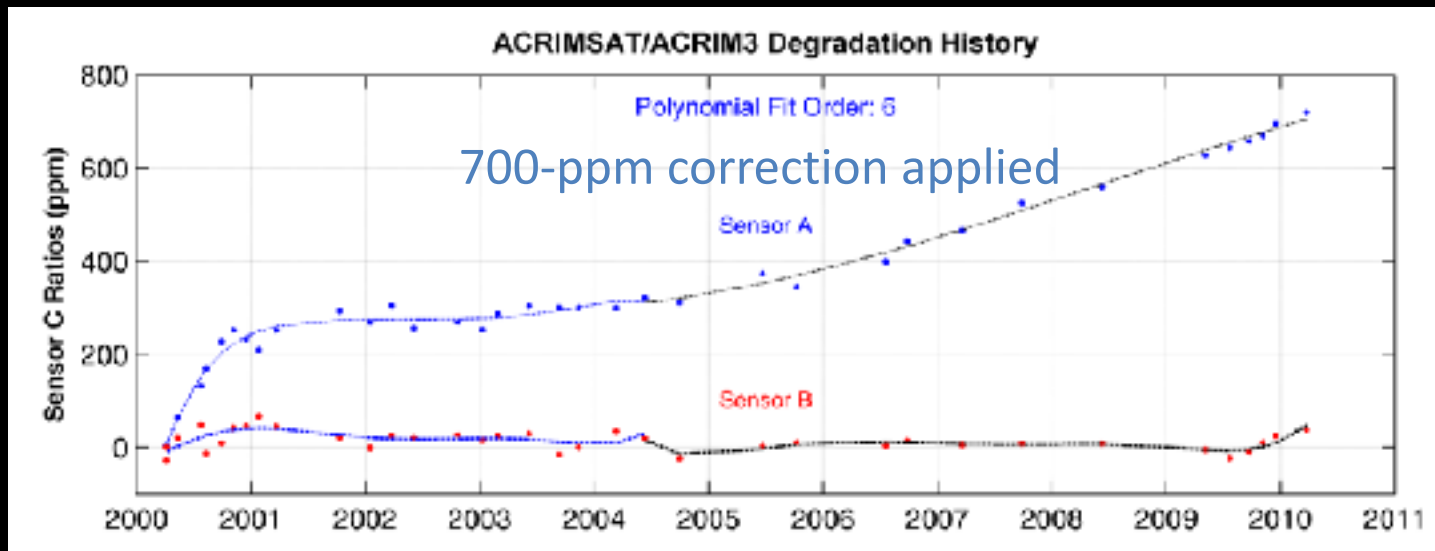
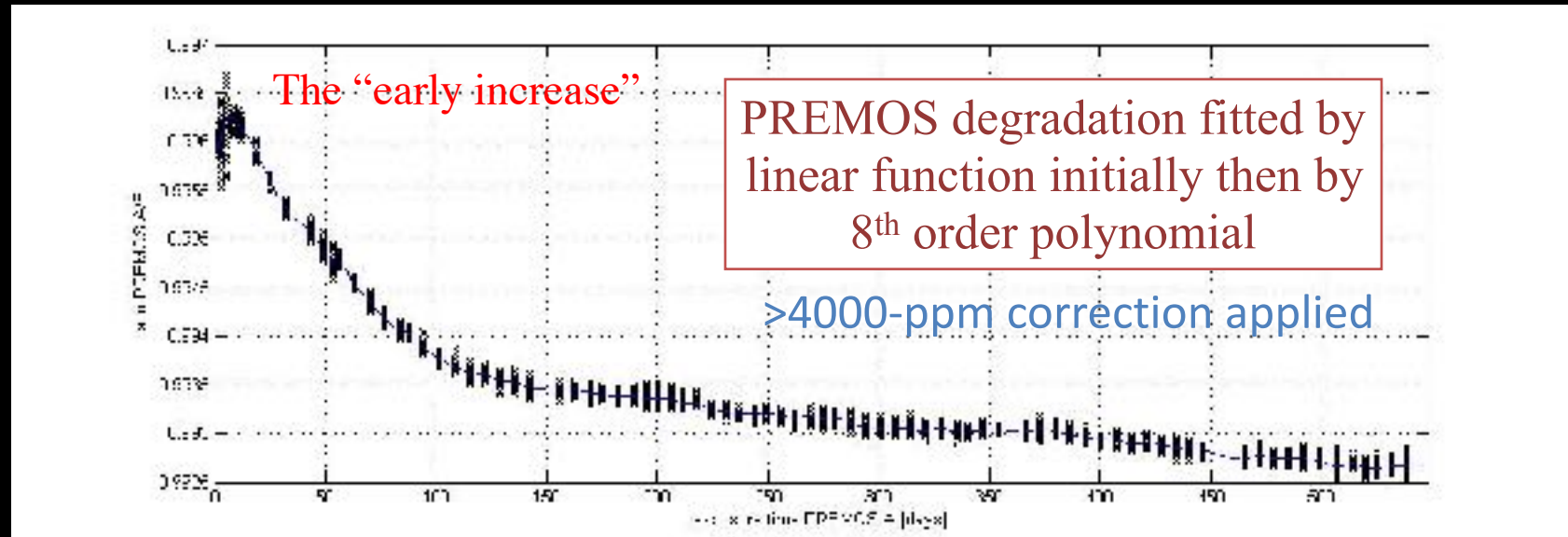
- Larger intrinsic degradation likely also has larger correction-uncertainties
 - Level 1 VIRGO data demonstrate level of variations of individual channels

Level 1 Data (all 4 channels)

Level 2 Data (VIRGO)

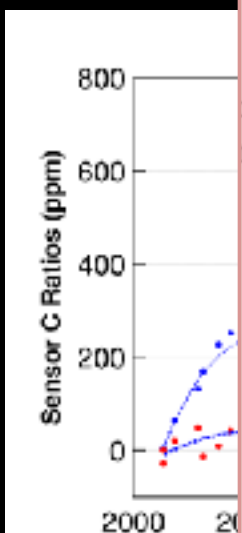
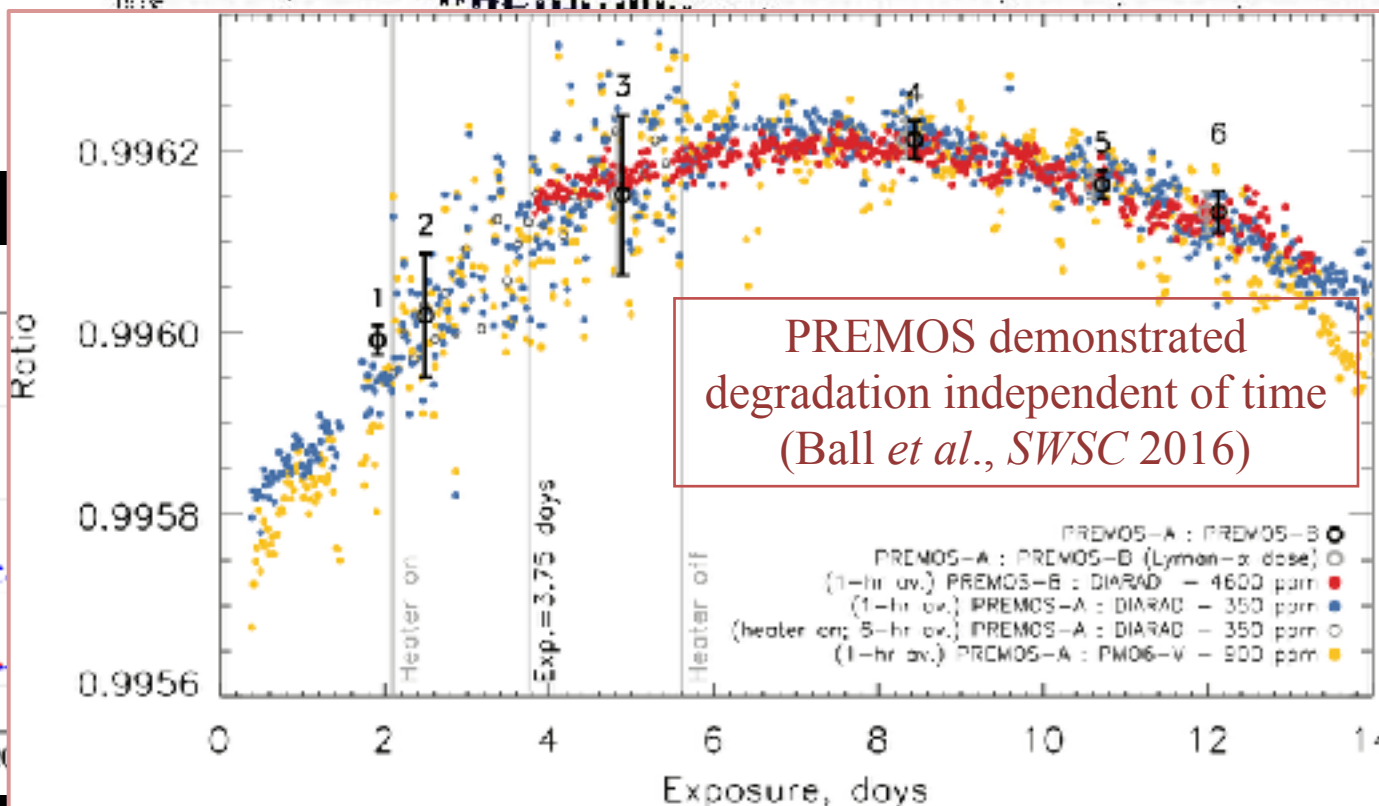
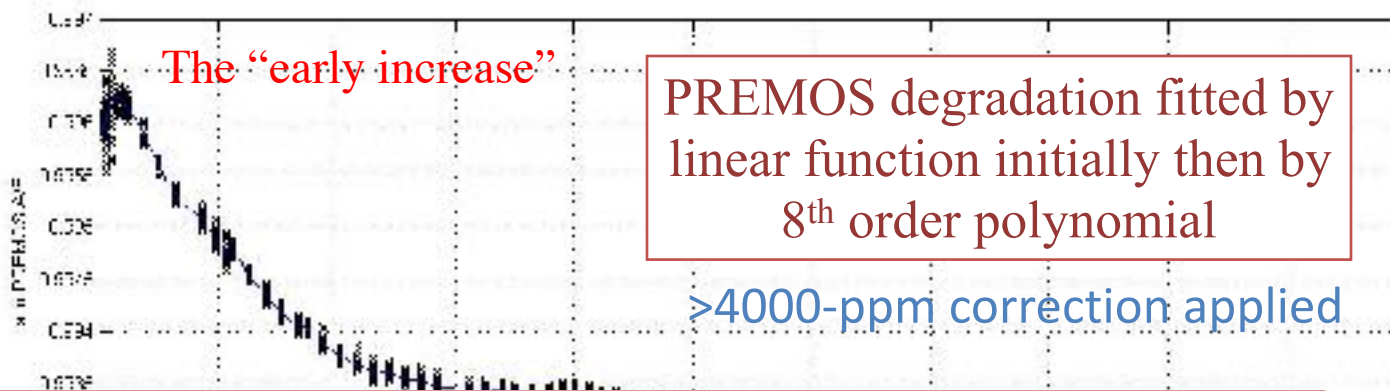


Degradation Corrections Critical for Stability



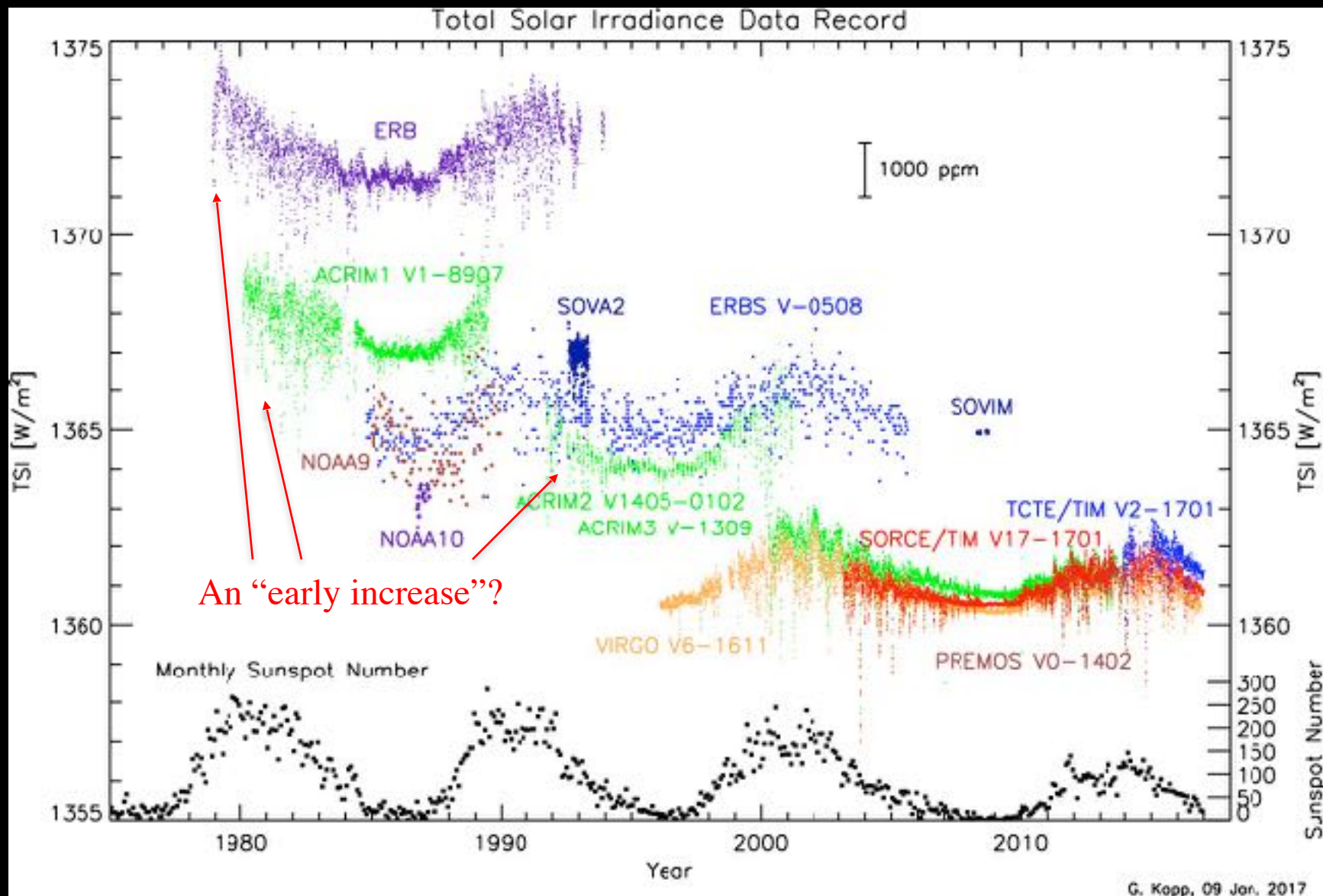
ACRIM3 degradation fitted by 6th order polynomial

Degradation Corrections Critical for Stability

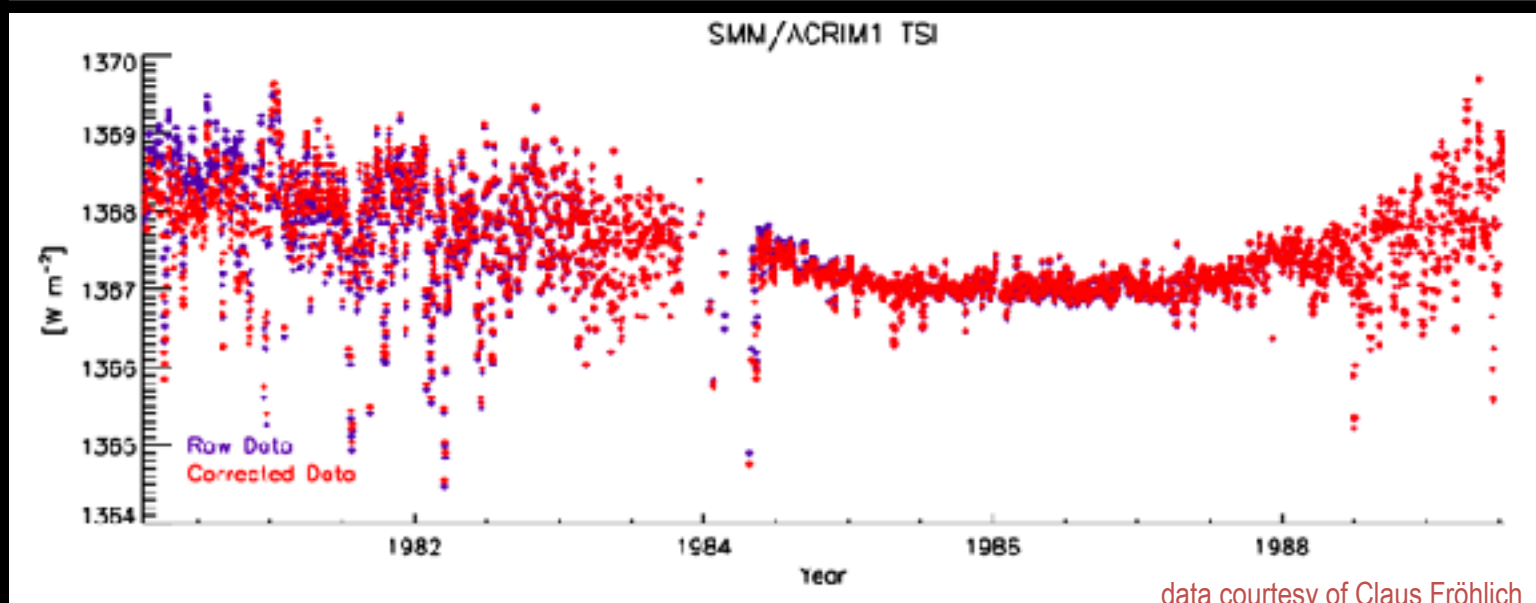
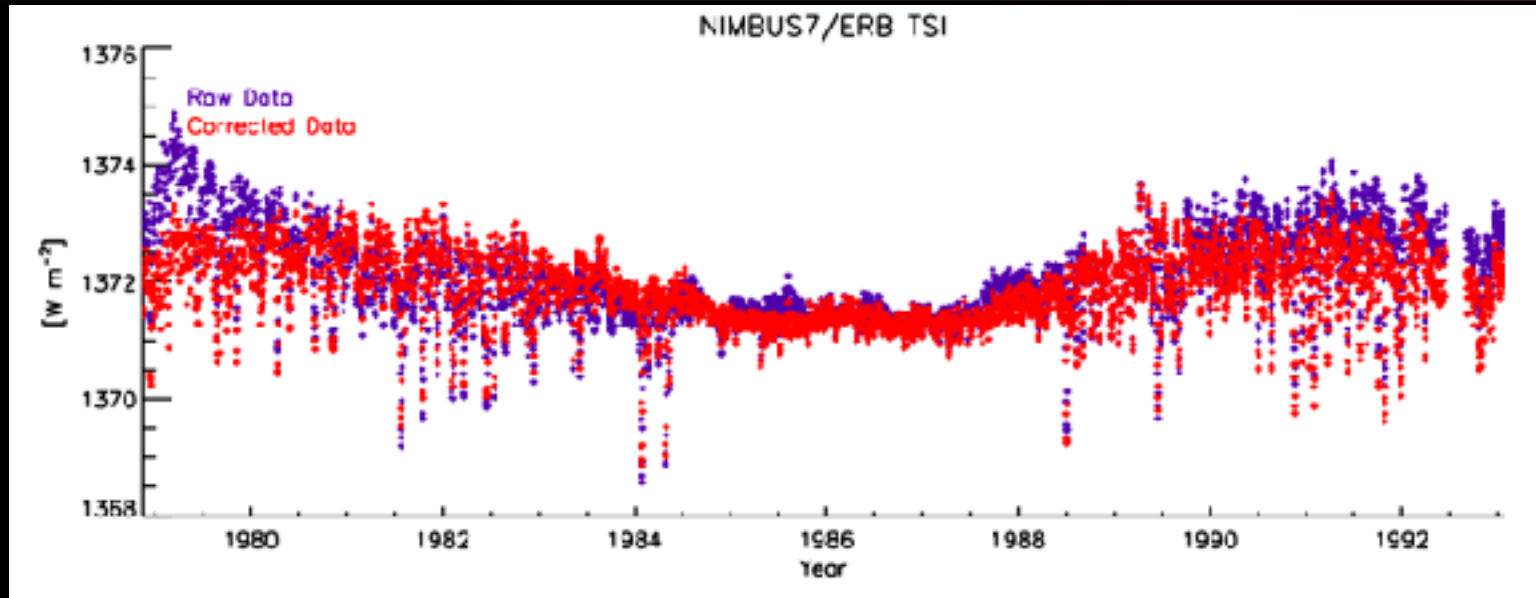


RIM3
tion fitted
th order
nomial

Current TSI-Measurement Record



“Early Increase” Corrections Applied



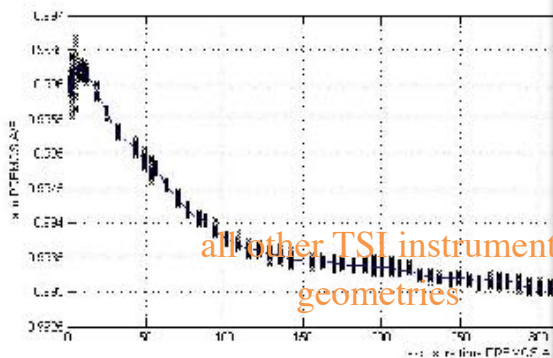
data courtesy of Claus Fröhlich

Diffraction & Scatter Erroneously Increase Signal

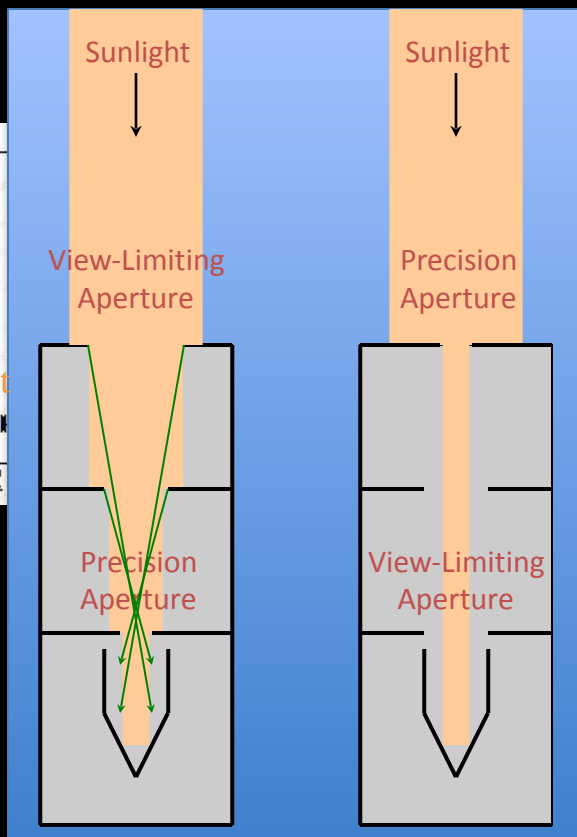
All instruments except the TIM put primary aperture close to the cavity

The “early increase”

My conjecture...



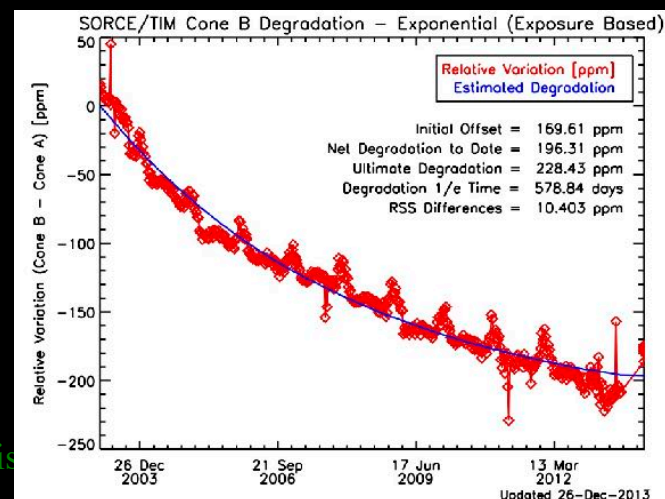
Measured increases due to uncorrected scatter/diffraction are surprisingly large



Additional light allowed into instrument can scatter into cavity

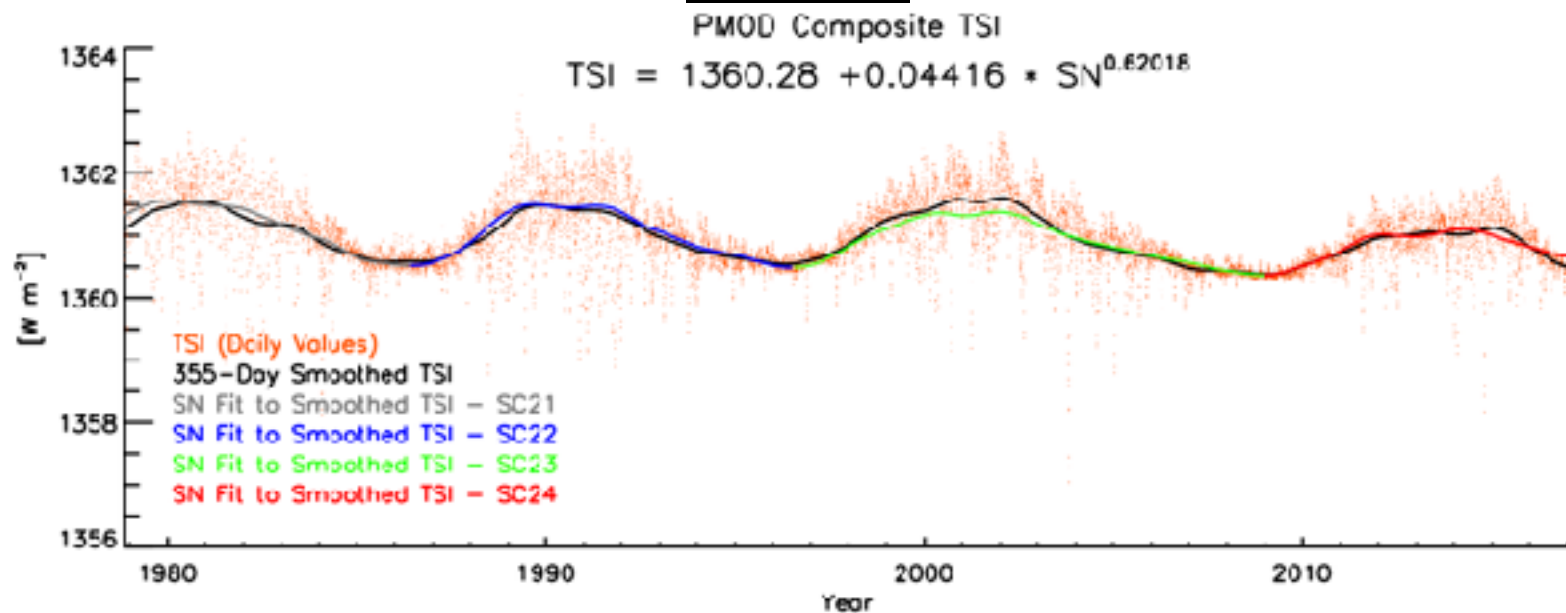
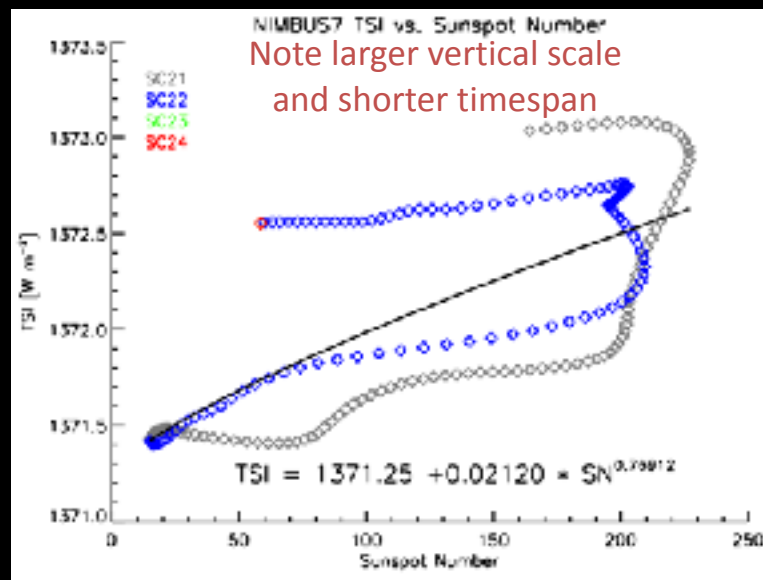
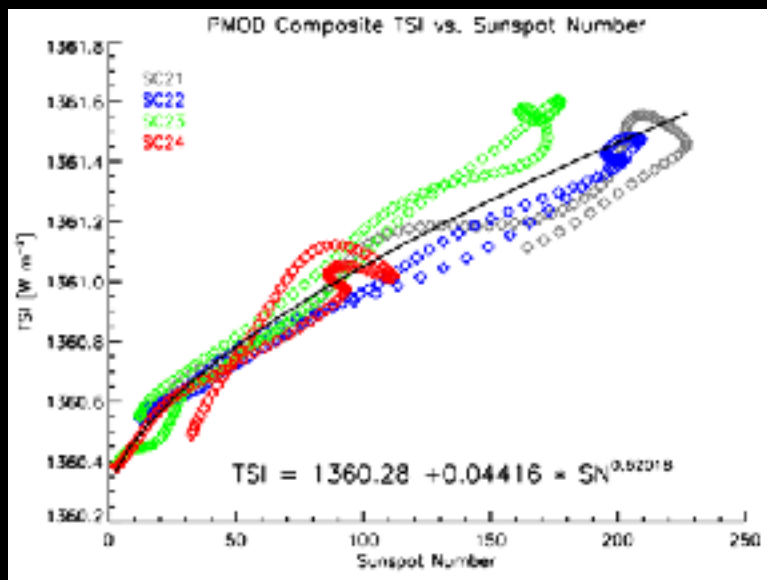
Majority of light is blocked before entering instrument

TIM geometry

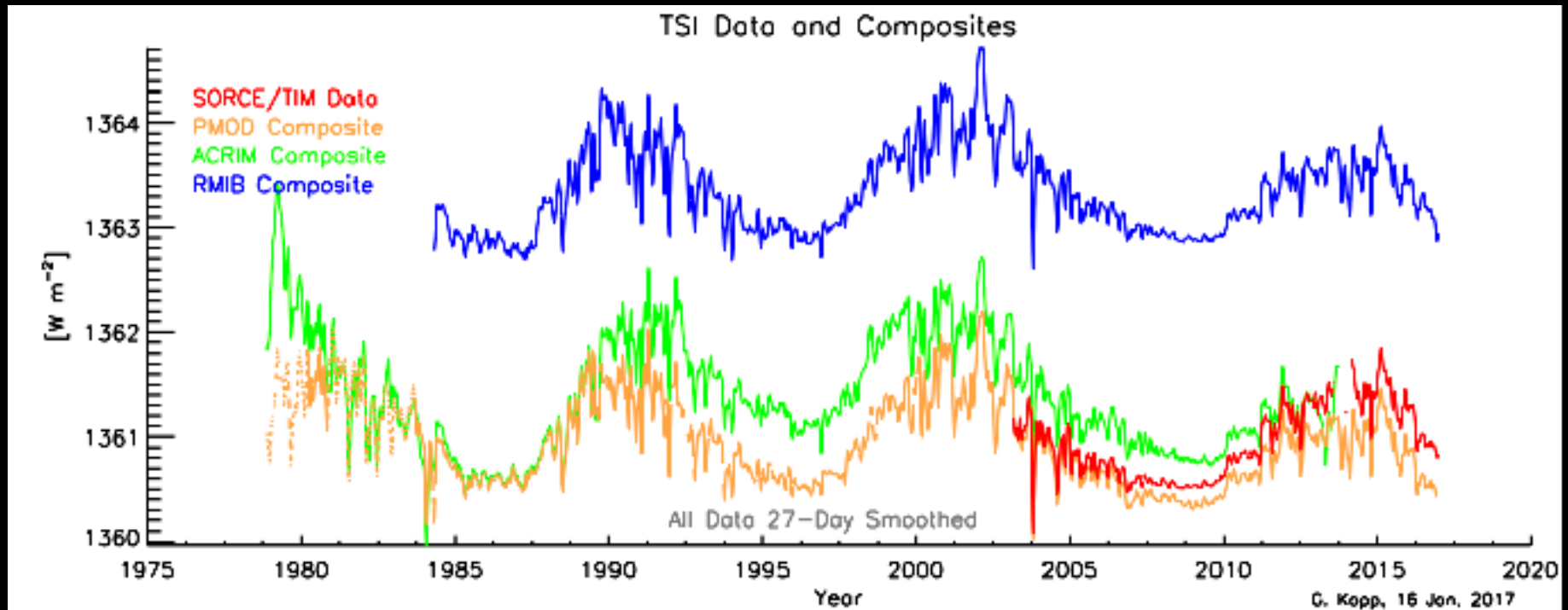


Instrument	Increase
PREMOS-1	0.10%
PREMOS-3	0.04%
VIRGO2	0.15%
ACRIM-3	0.51%
SOVAR	0.20%

Comparisons to Sunspots Indicate Differences

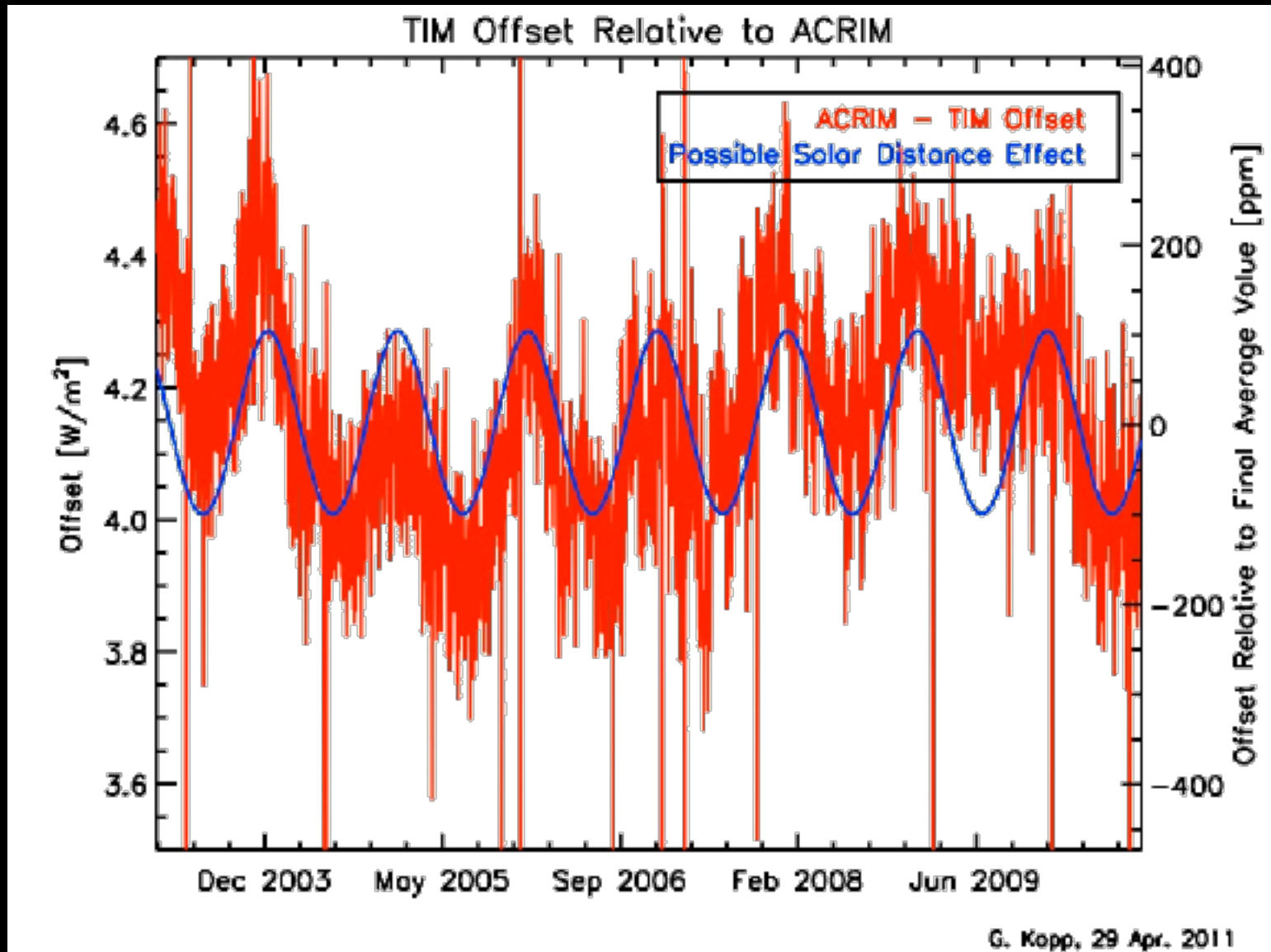


Data Should Likely Be Corrected for Early Increase

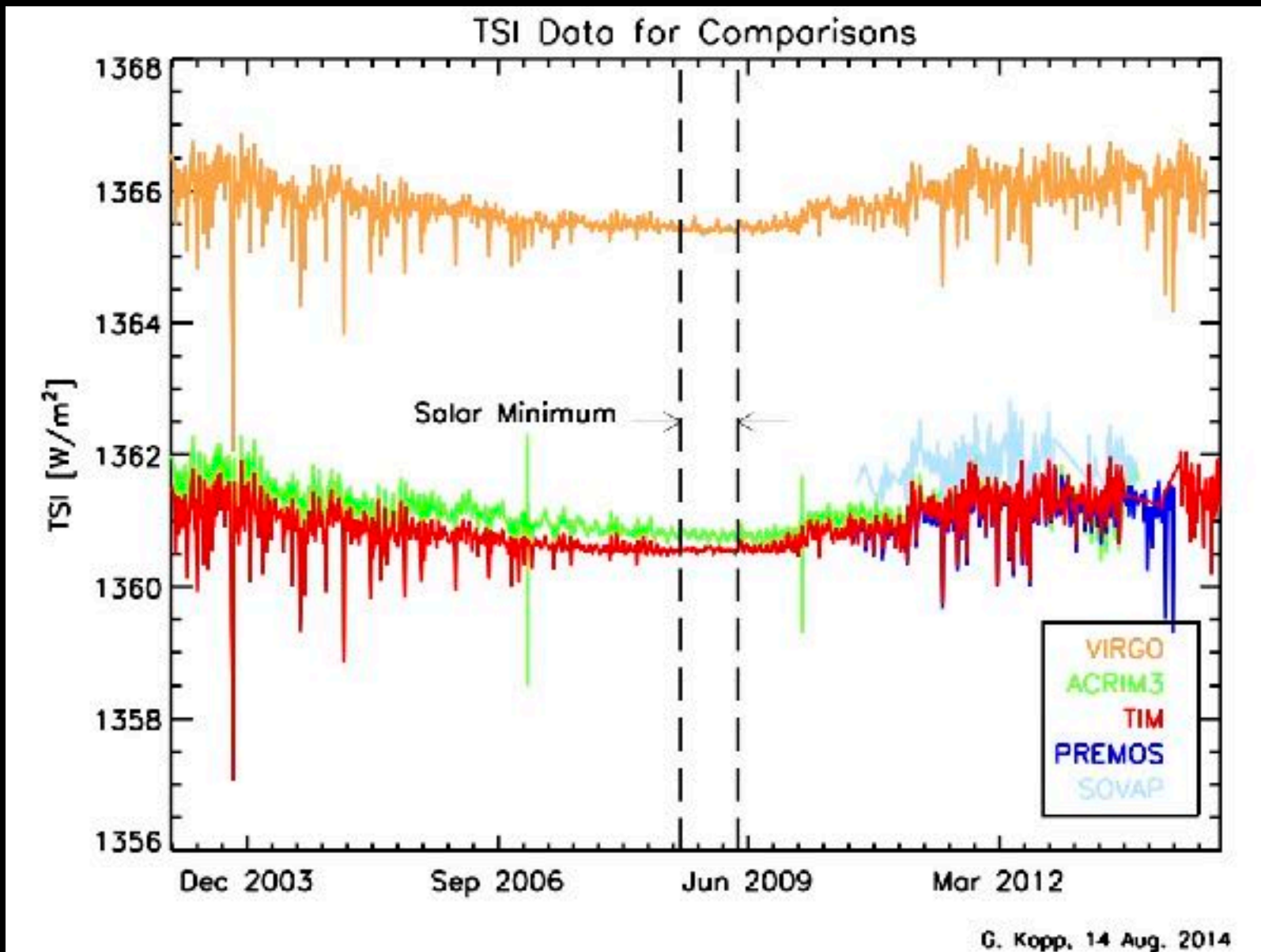


- How stable are composites?
 - Depends on the data upon which they are based

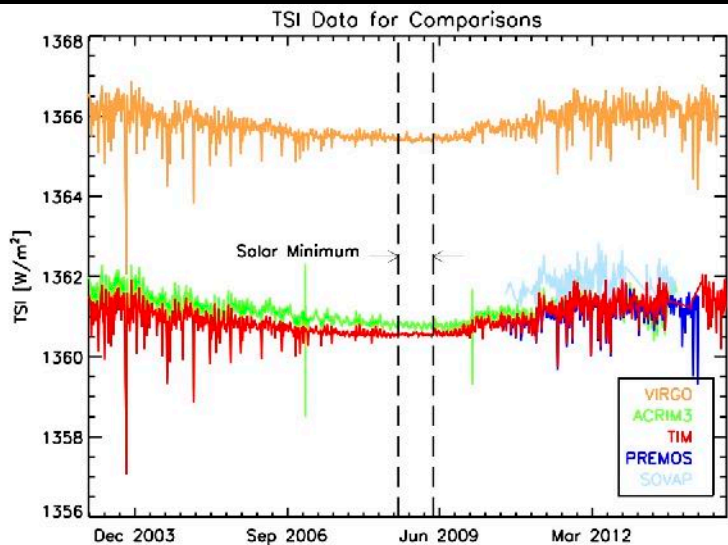
ACRIM Annual Signal of ~ 200 ppm



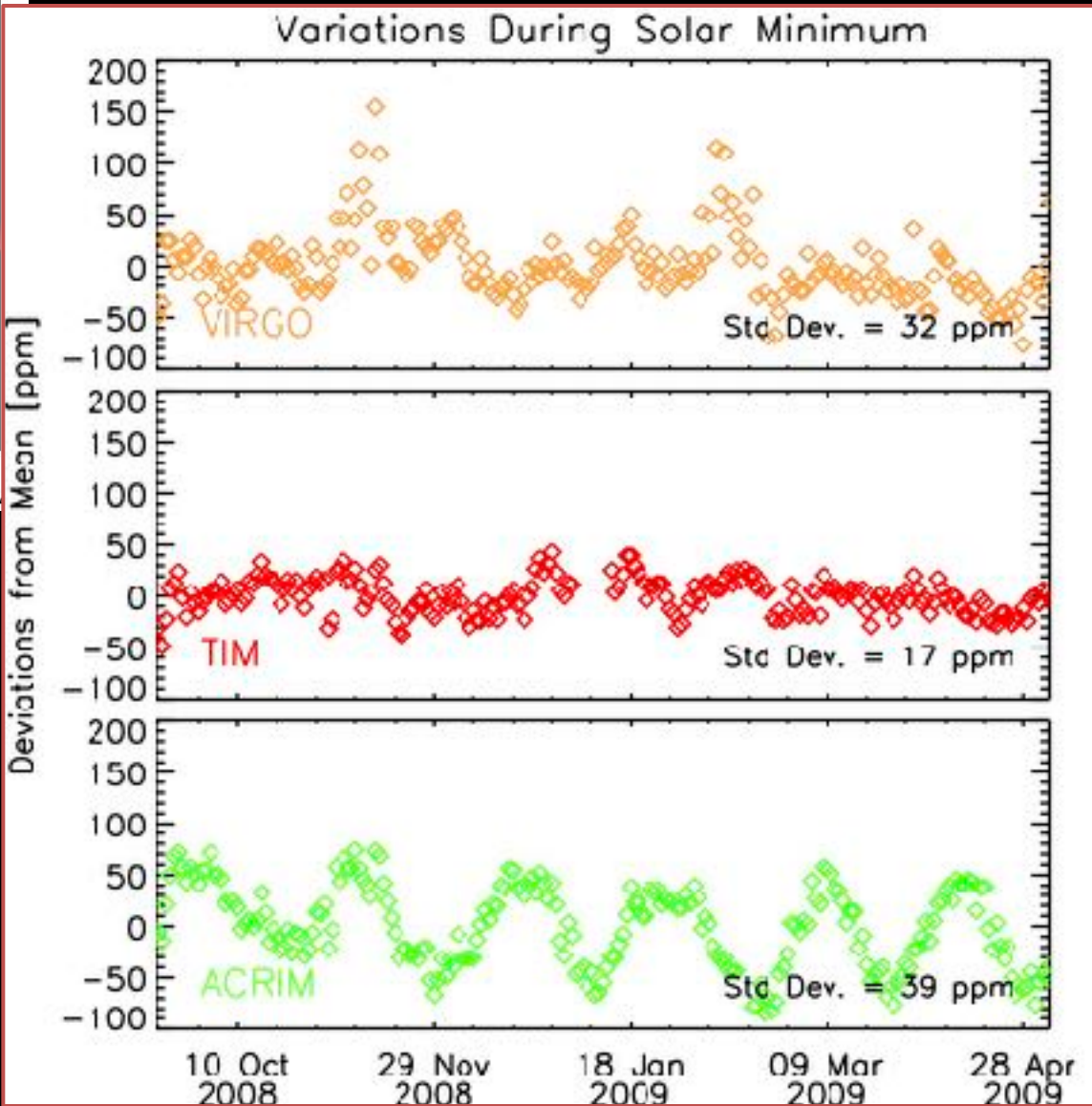
Instrument Data Comparisons Can Indicate Artifacts



Instrument Data Comparisons Can Indicate Artifacts

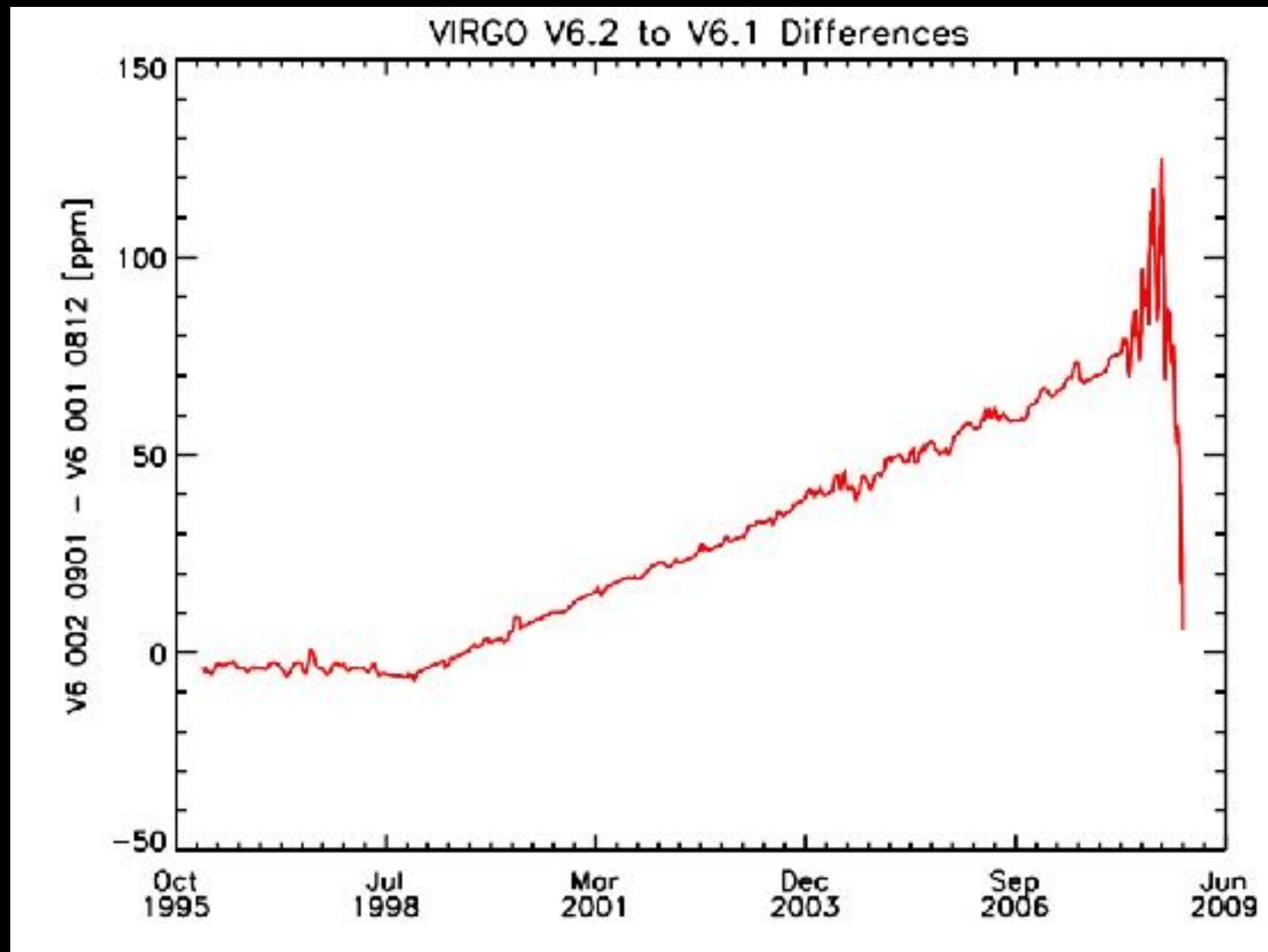


G. Kopp, 14 Aug. 2017

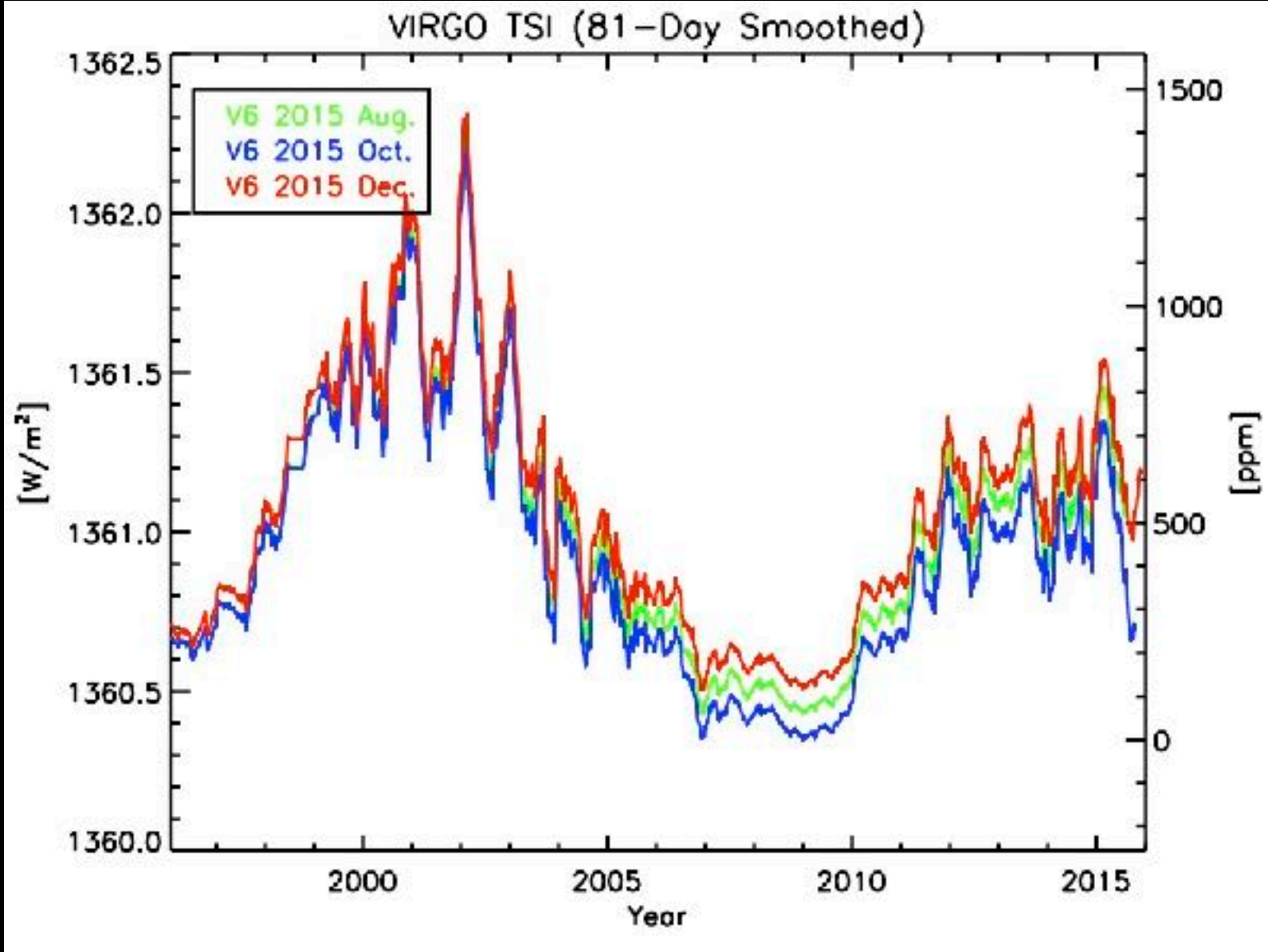


VIRGO Stability

~10 ppm/yr claimed

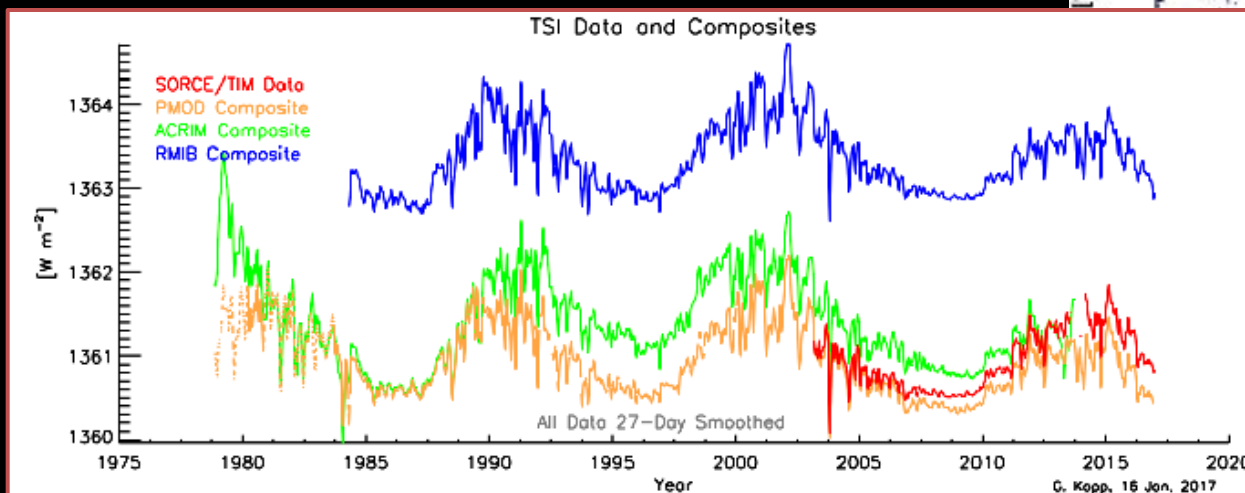
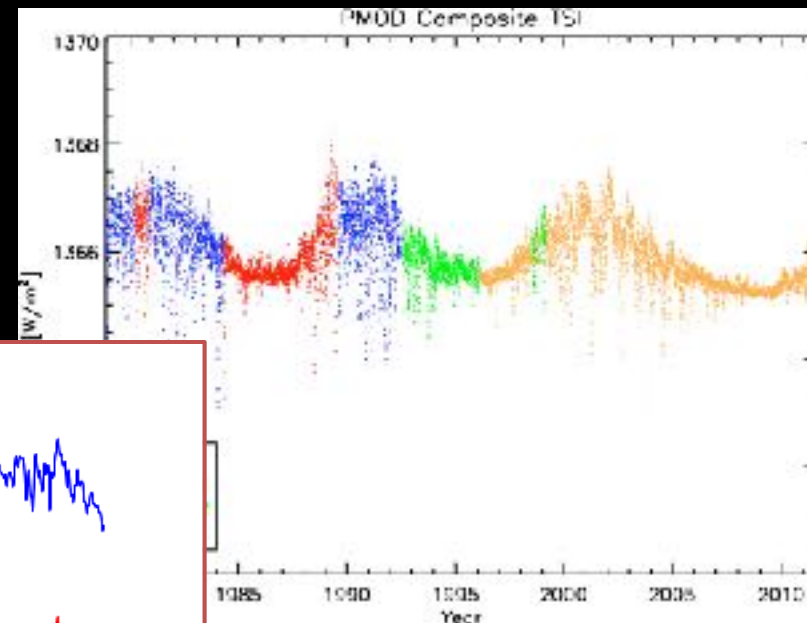
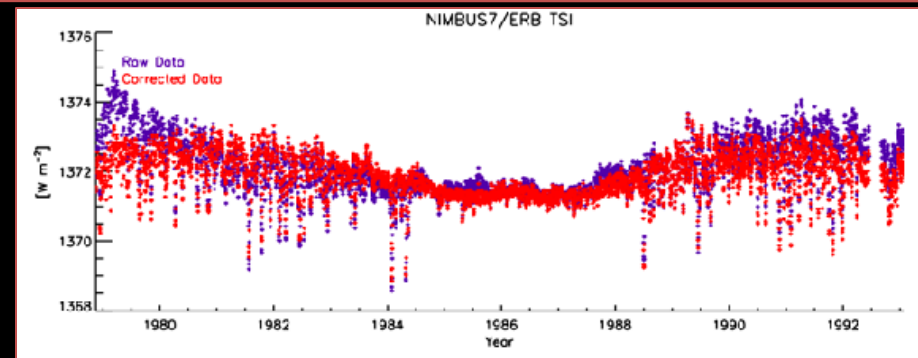


Recent VIRGO Data Indicate Stability Uncertainties



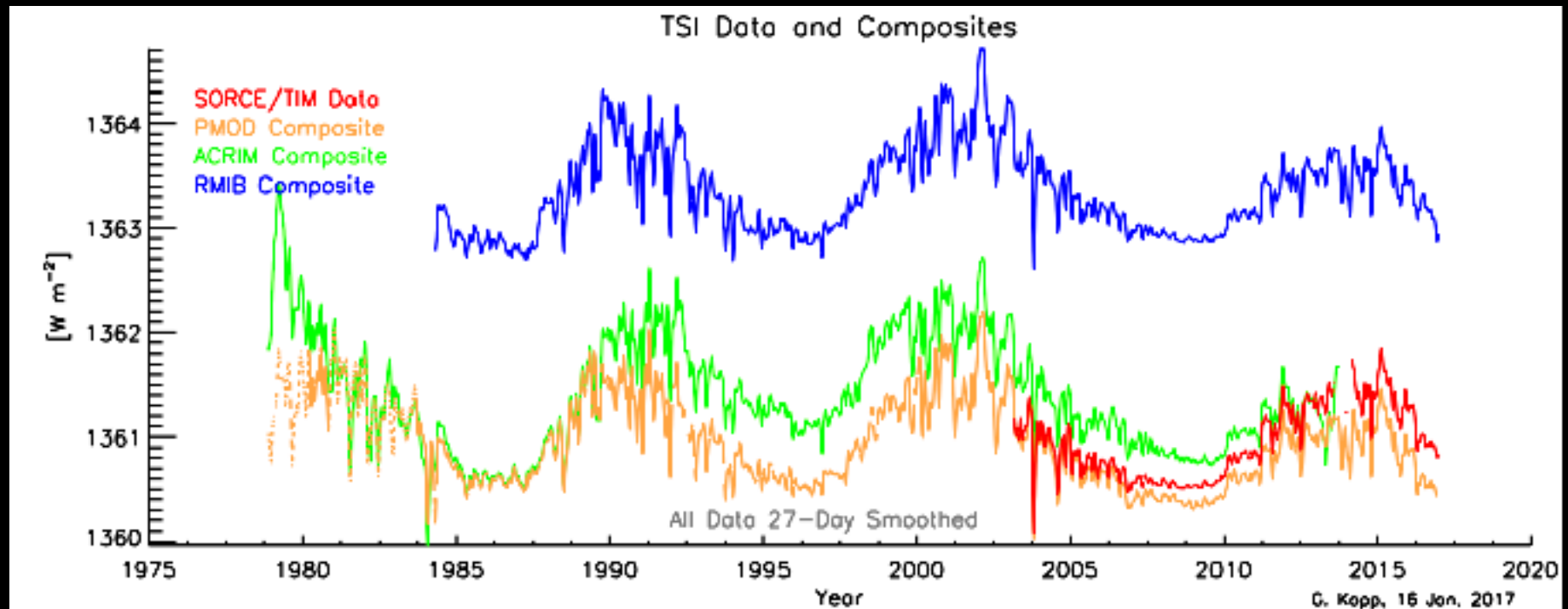
Issues with Existing Composites

- Binary (and biased) selection of instrument data used
 - Discontinuities at boundaries
- Uncertain corrections applied to data records
- Normalizations incorrect
- Lack uncertainties



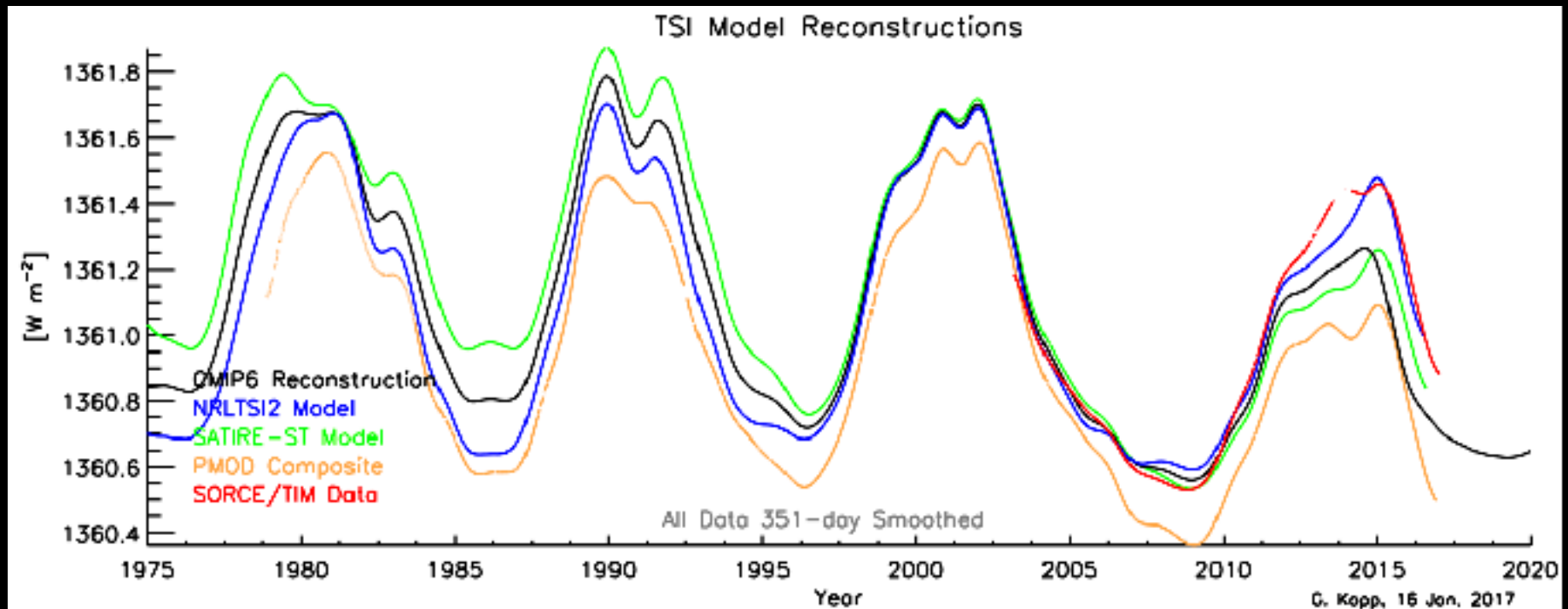
Comparisons of Models and Composites

- Long-term solar trends differ
 - Differences have significant effects for climate researchers and resulting sensitivities to solar vs. anthropogenic forcing
 - Solar-irradiance community needs to specify and validate stability-uncertainties in measurements and models



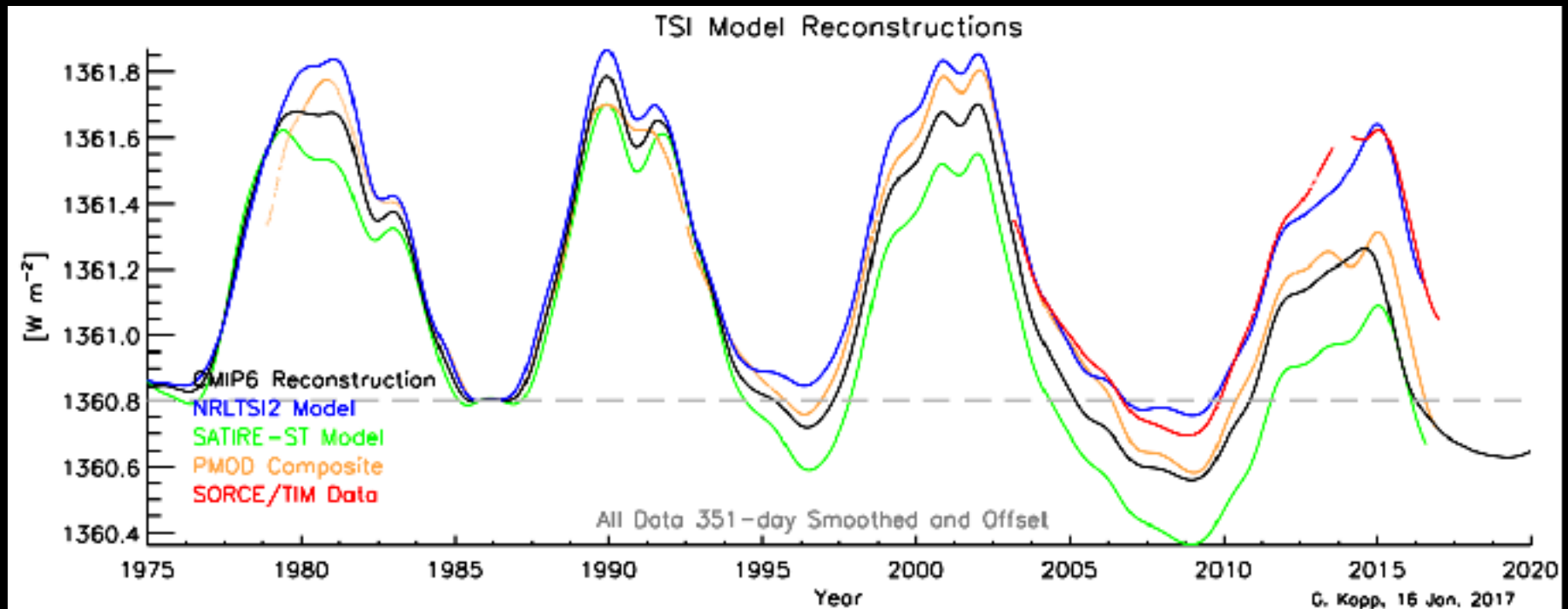
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Comparisons of Models and Composites

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New TSI Composite Being Created

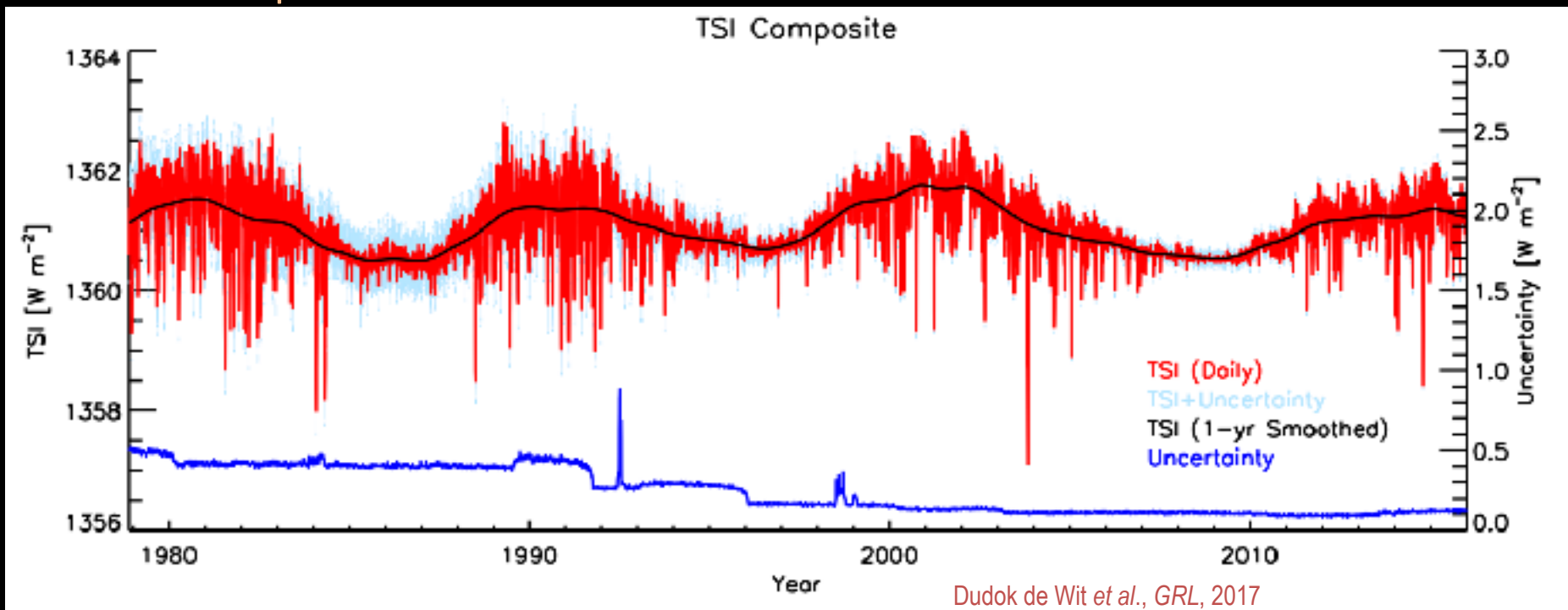
- Uses all available instrument data
 - Scale-wise weightings
- Uses an unbiased statistical approach
- Normalized to most accurate instruments
- Has time-dependent uncertainties

Confidential manuscript submitted to *Geophysical Research Letters*

Methodology to create a new Total Solar Irradiance record: Making a composite out of multiple data records

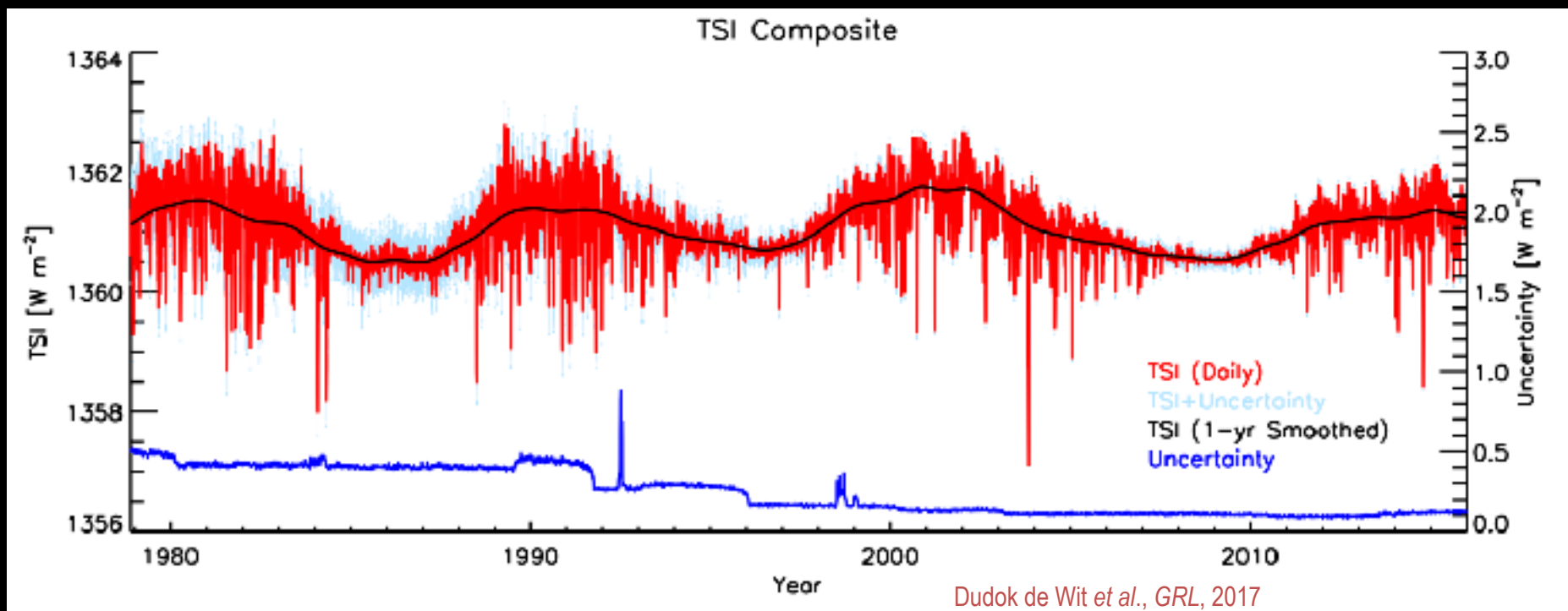
Thierry Dudok de Wit¹, Greg Kopp^{2,3}, Claus Fröhlich⁴, and Micha Schöll^{1,5}

¹IPCEP, CNRS and University of Orléans, France
²Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO, USA
³Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany
⁴Diplomwaldstrasse 30, Davos Wolfgang, Switzerland
⁵Physikalisch Meteorologisches Observatorium Davos and World Radiation Center, Davos Dorf, Switzerland



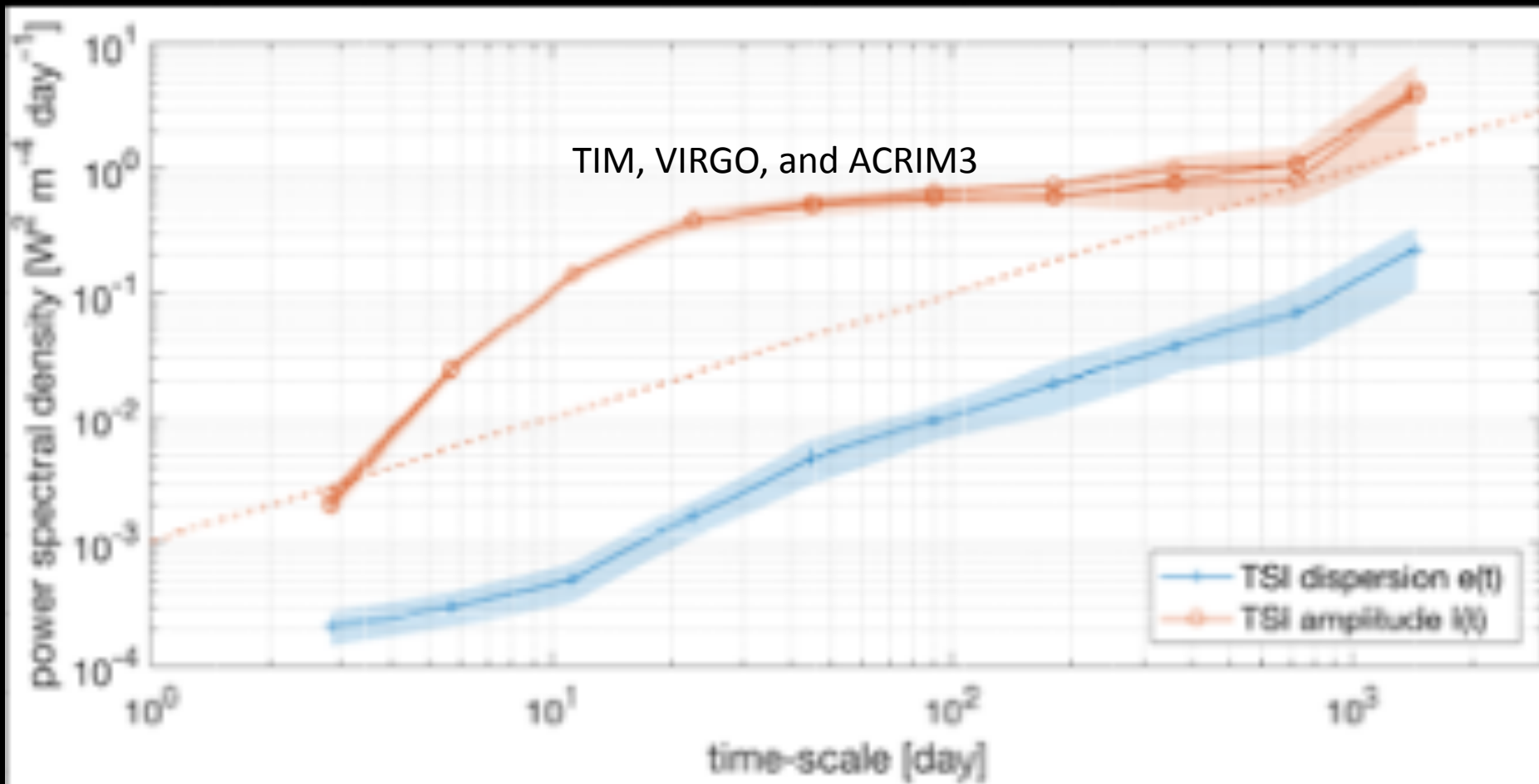
Needed TSI Composite Refinements

- Agree on amount of “early increase” correction (if any) to apply
- Estimate initial uncertainties
- Update regularly



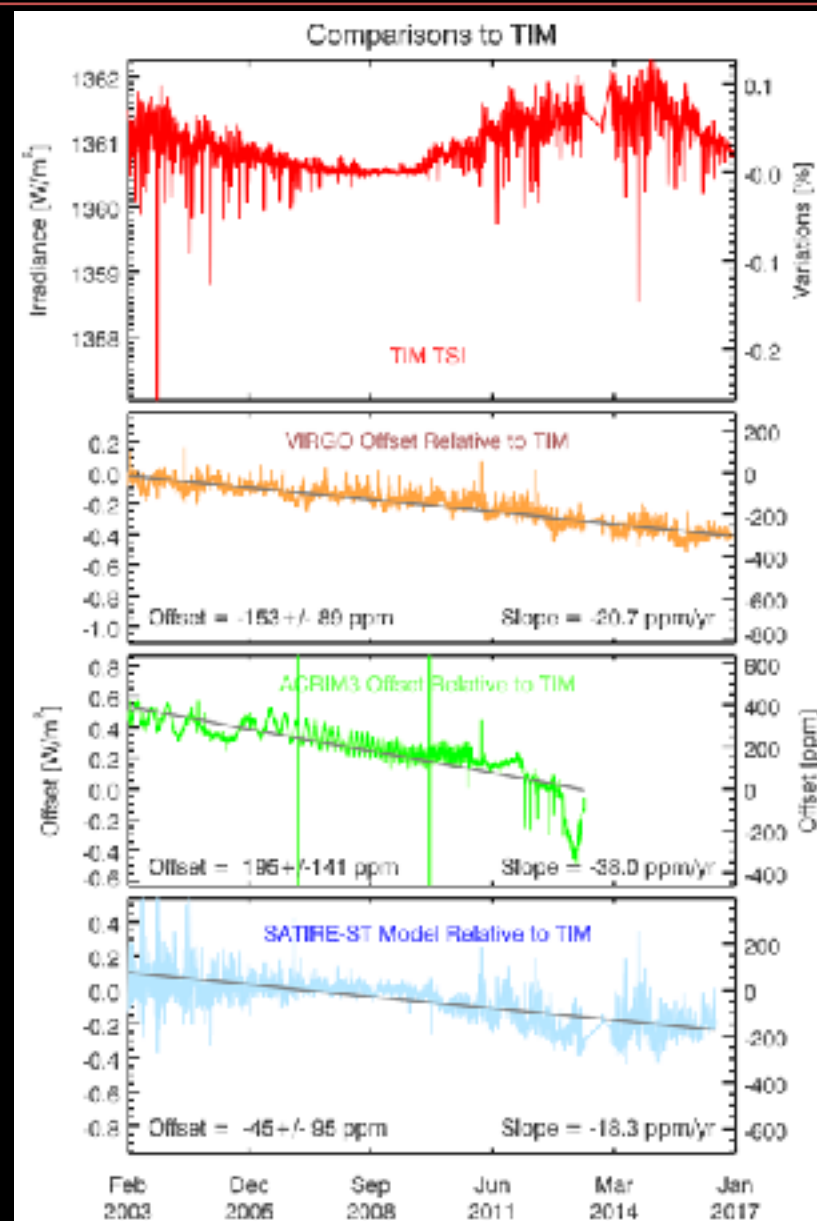
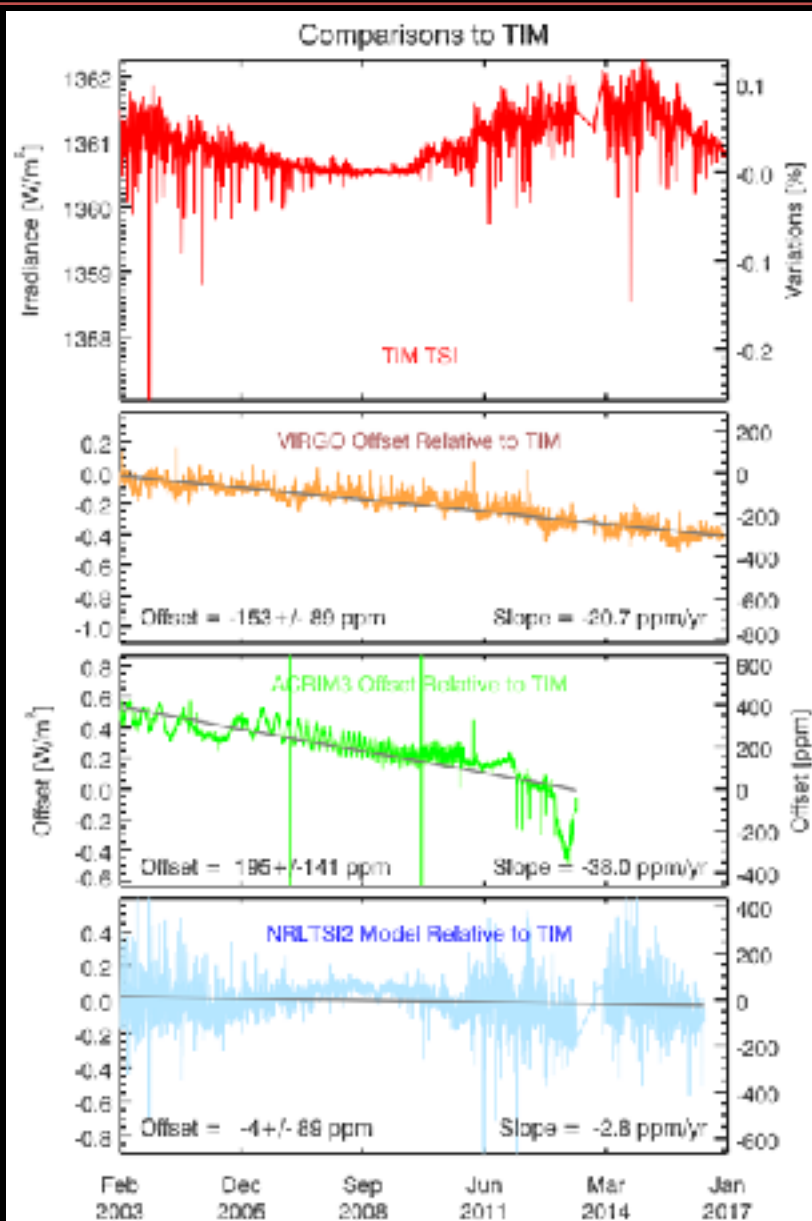
Measurement Differences Show $1/f$ Power Scaling

Dispersion is not indicative of linear trends or of white noise



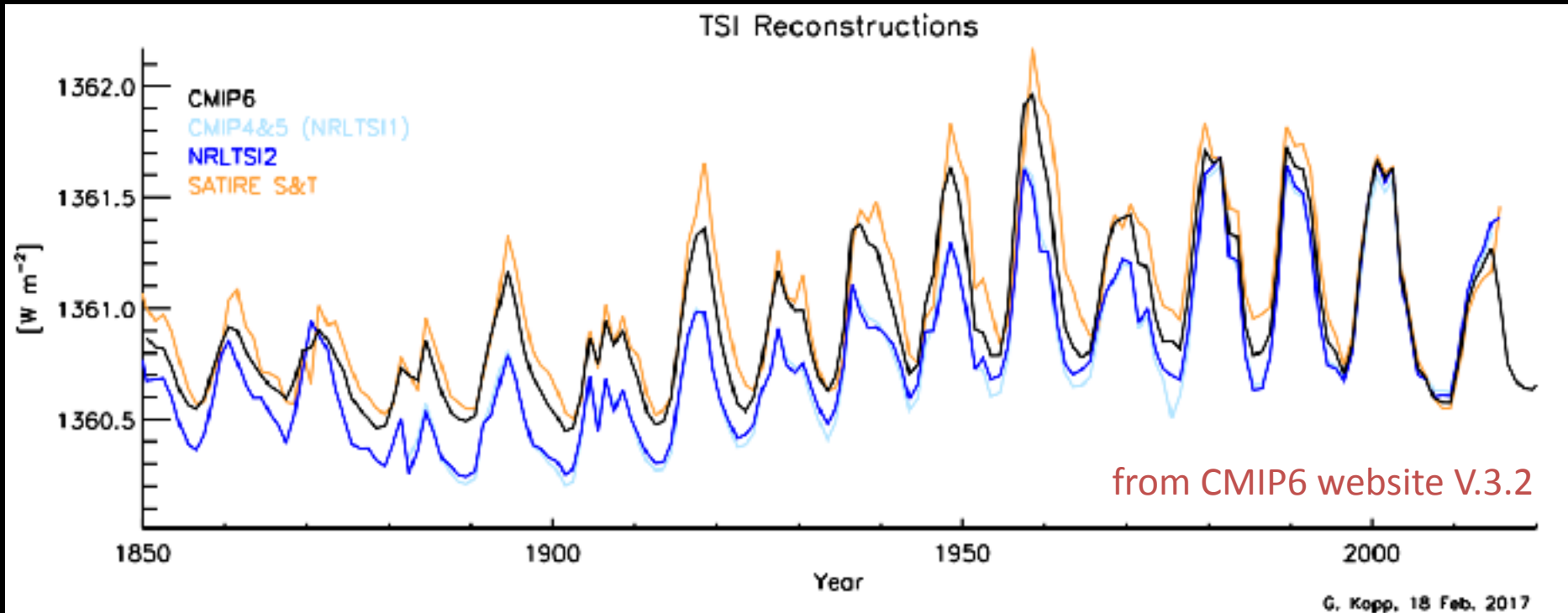
Dudok de Wit et al., GRL, 2017

TIM Comparisons



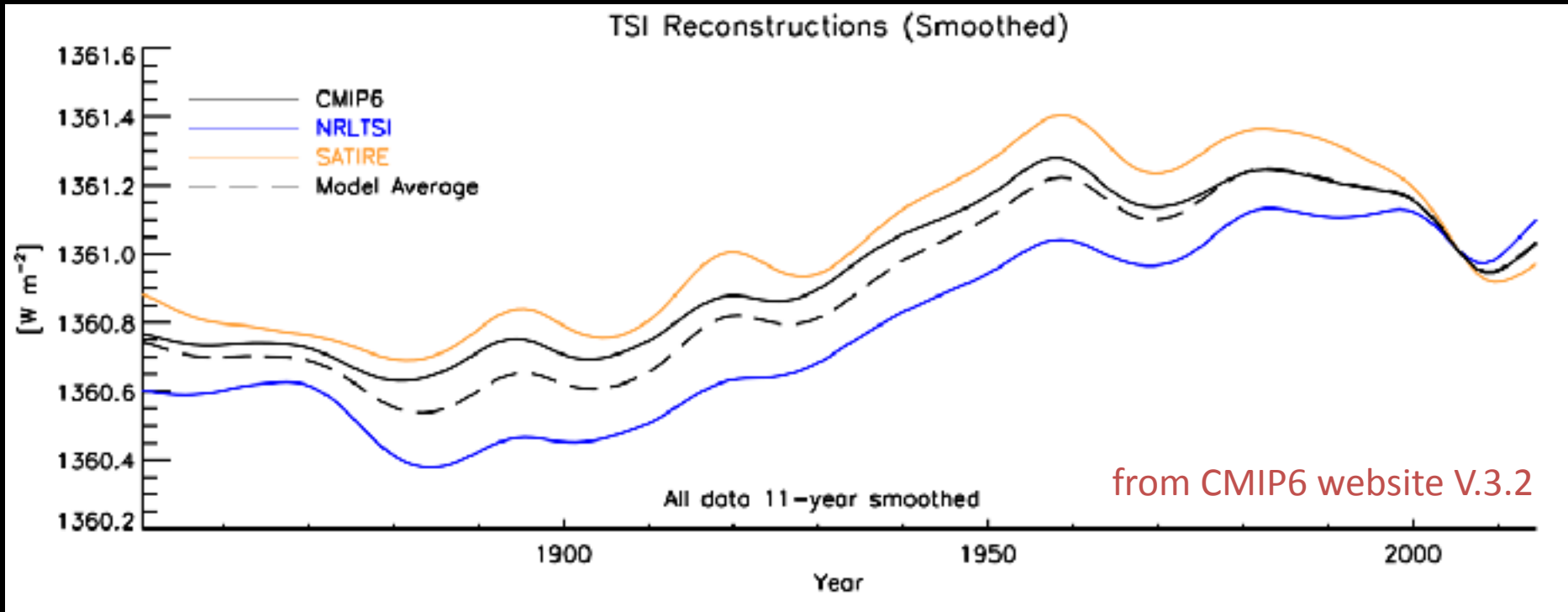
CMIP6

- Coupled Model Intercomparison Project (CMIP6) TSI inputs supposedly follow mean of NRLTSI2 and SATIRE TSI
- Shows a large modern-era downward trend compared to CMIP5
 - May affect global-climate-model sensitivity to solar forcing



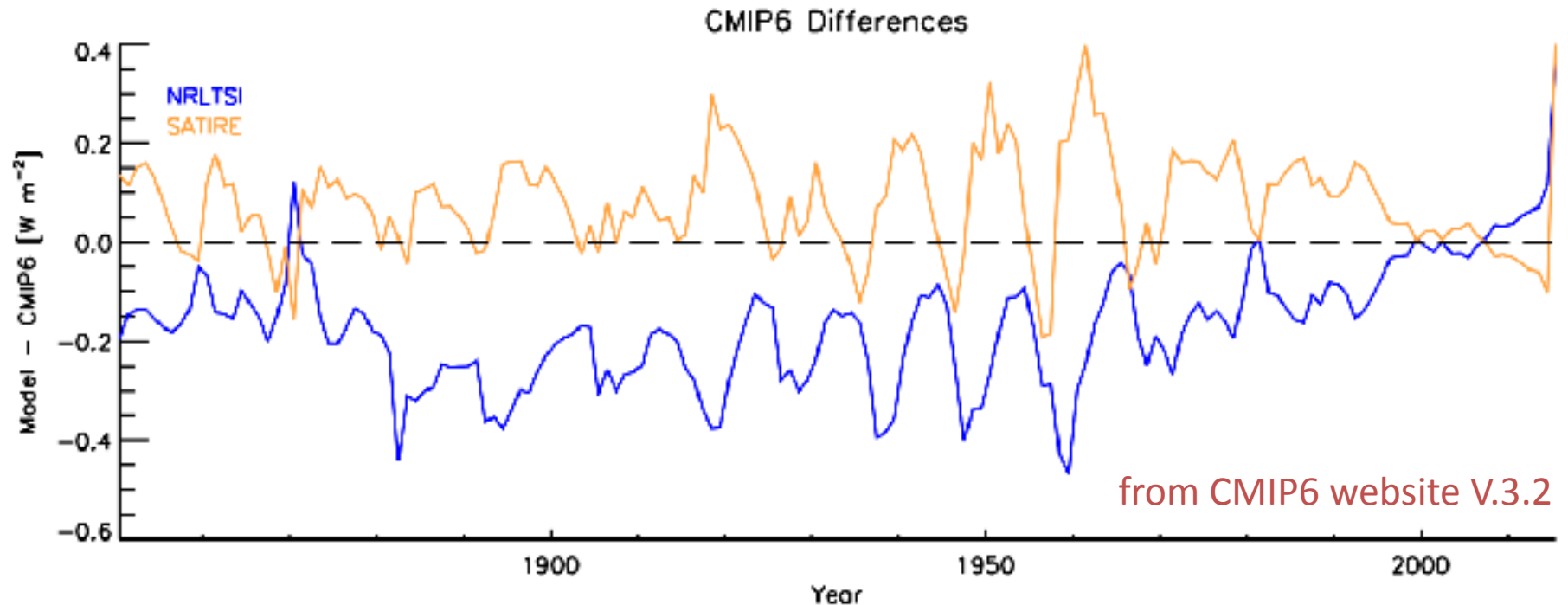
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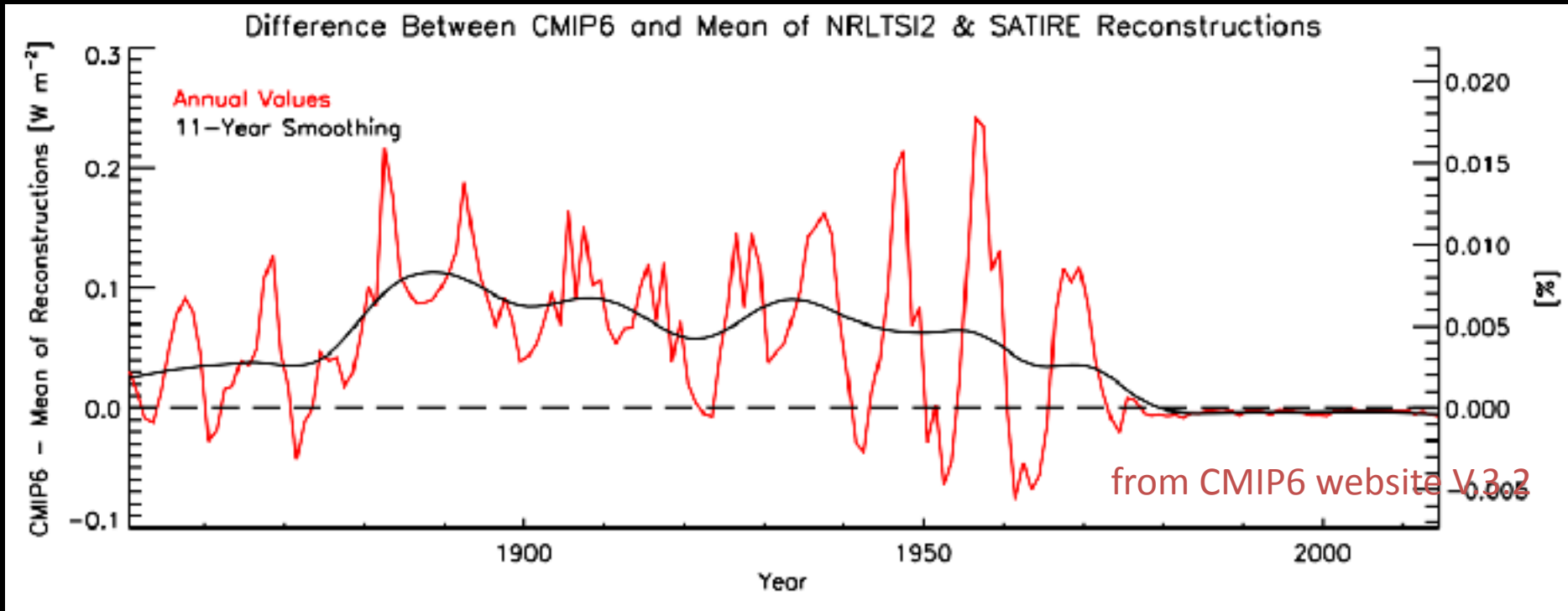
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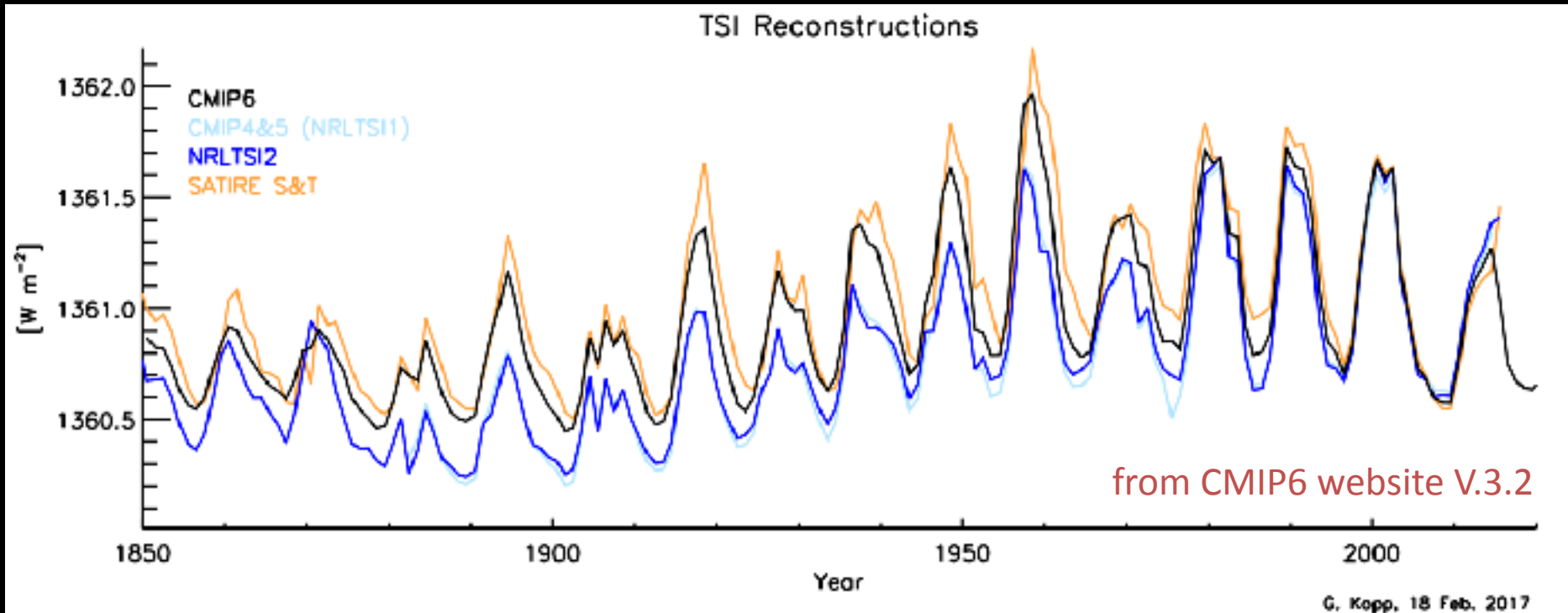
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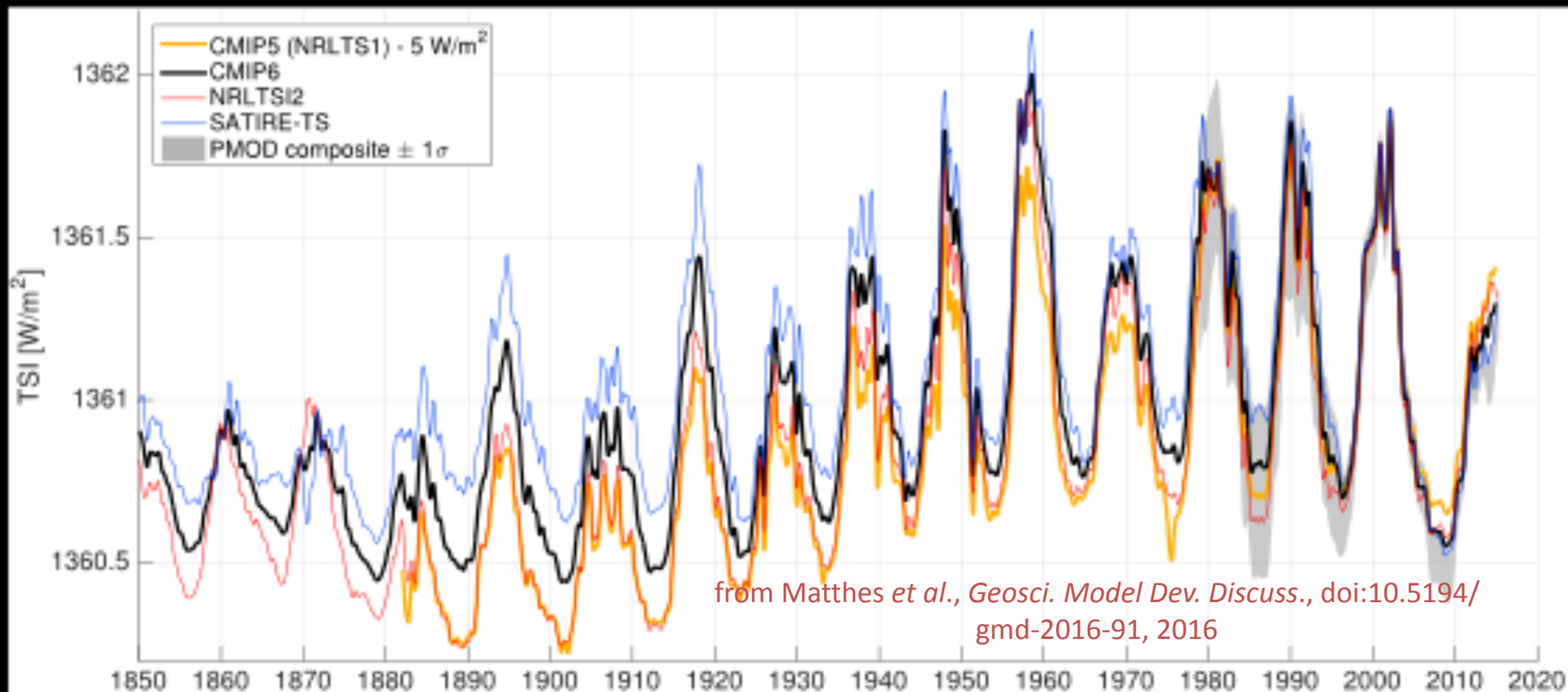
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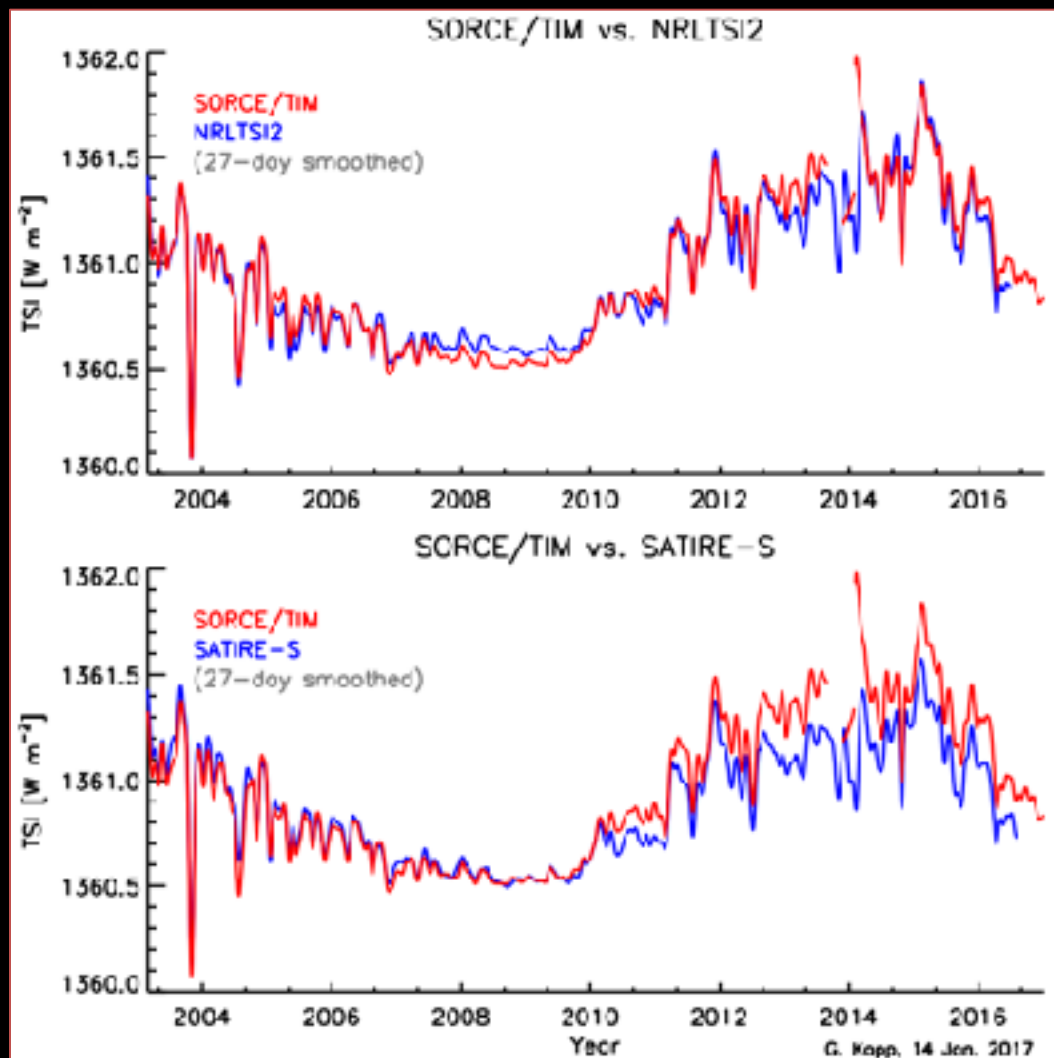
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Concerns with Models

- The last few decades...
 - ...when we should have been doing the best!

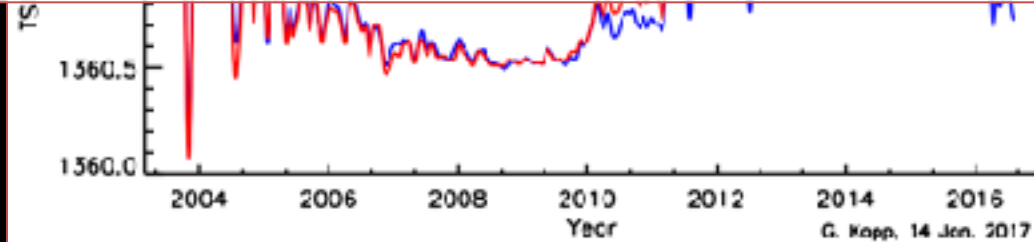
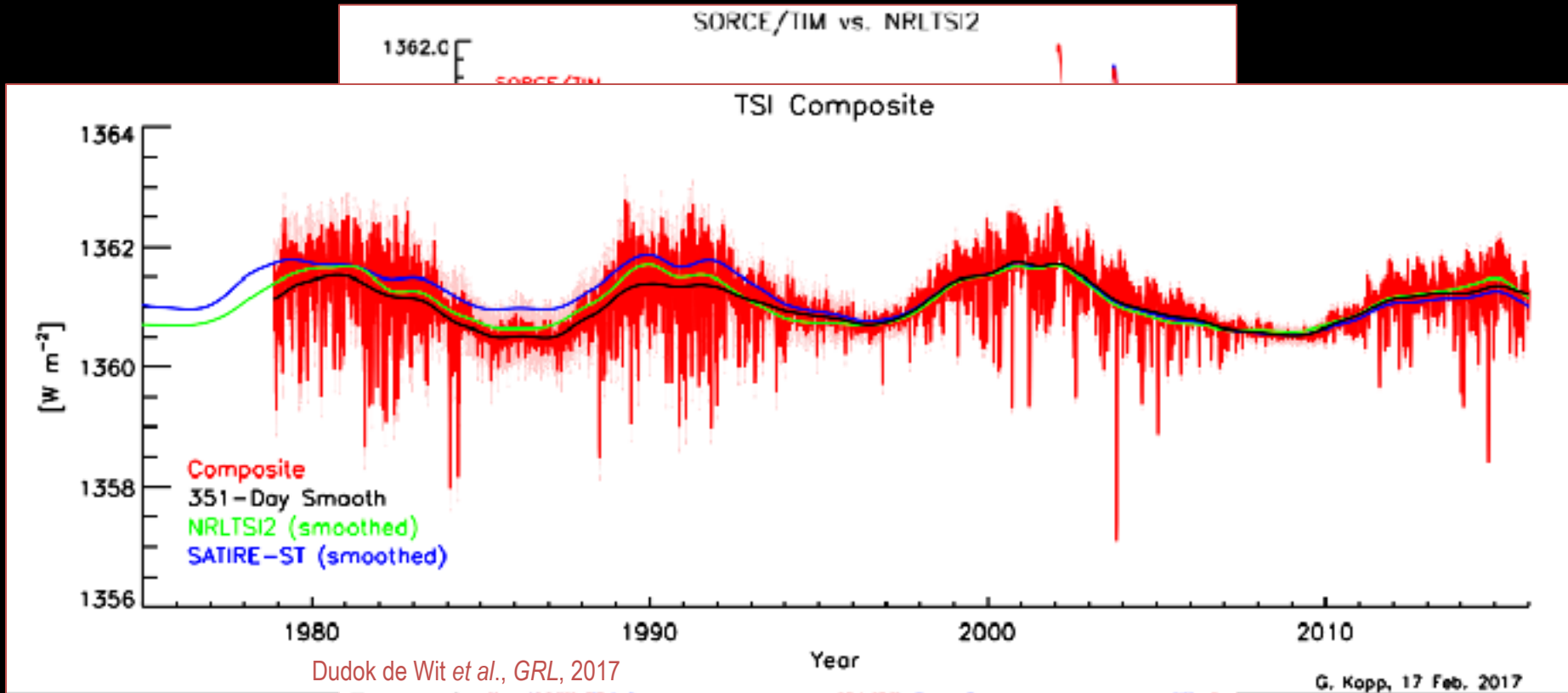


NRLTSI underestimates solar cycle (minor concern for climate)

SATIRE has large downward trend (more major concern)

Concerns with Models

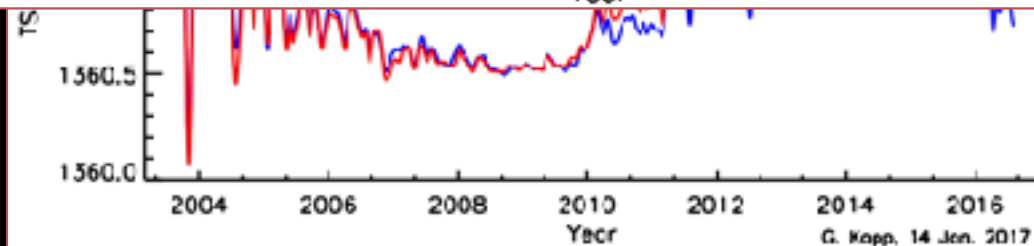
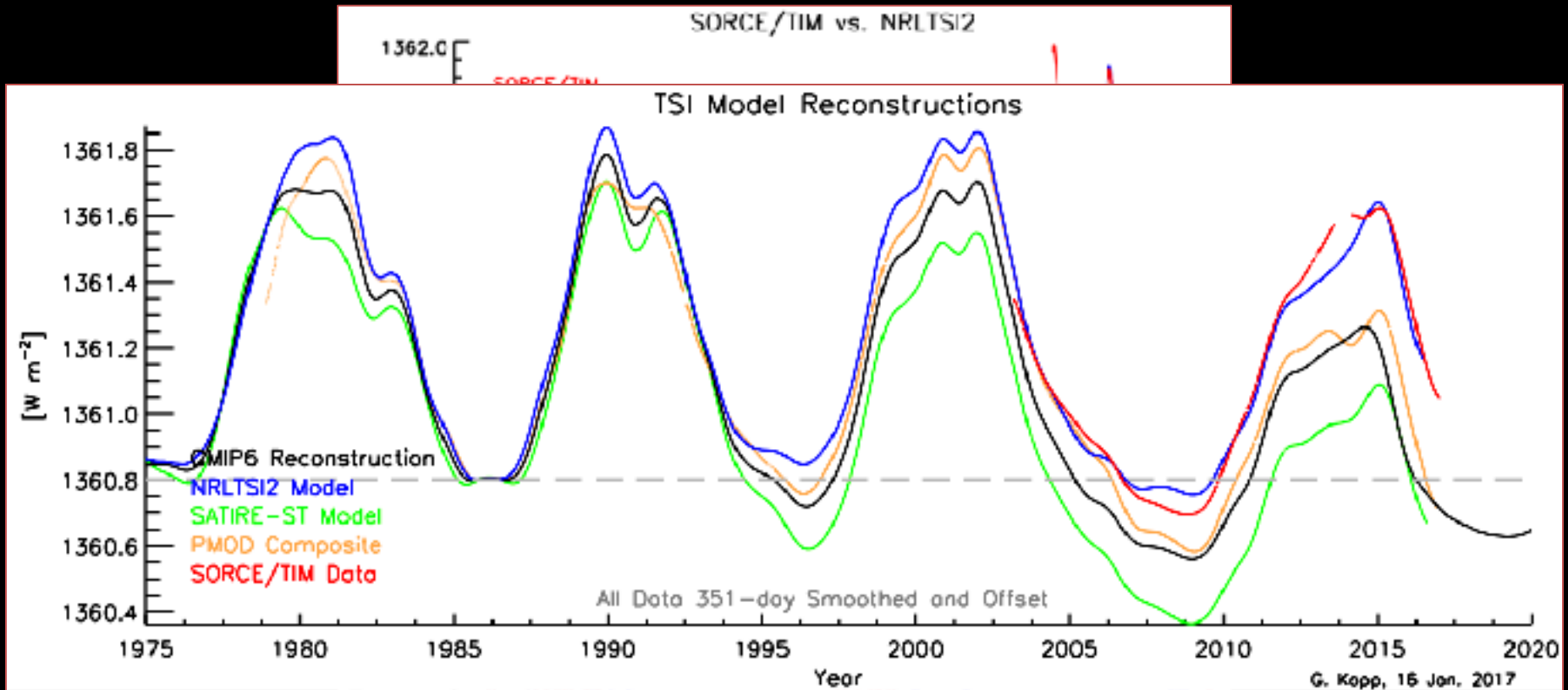
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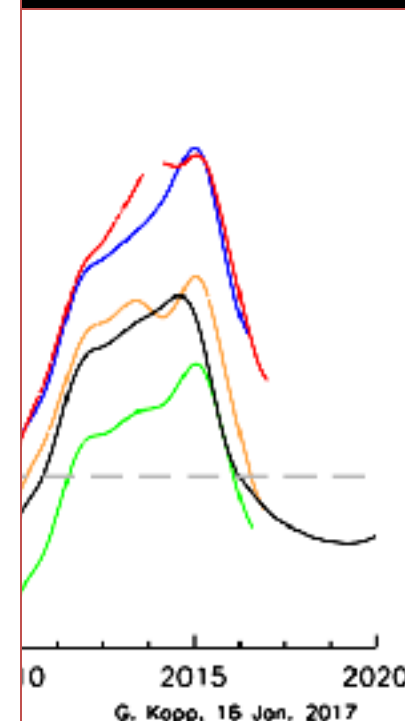
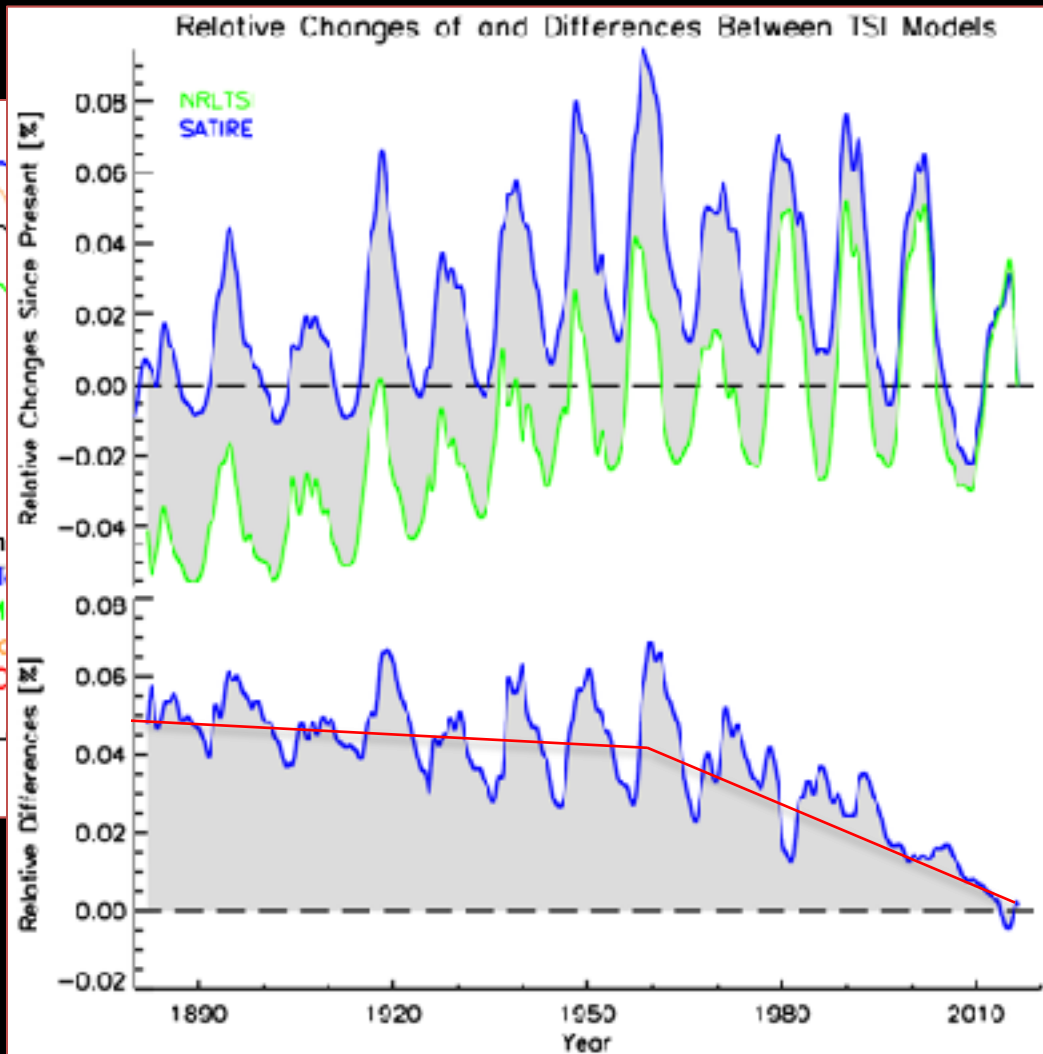
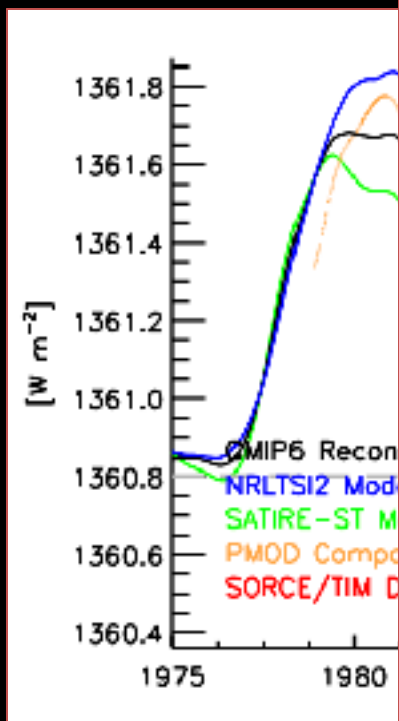
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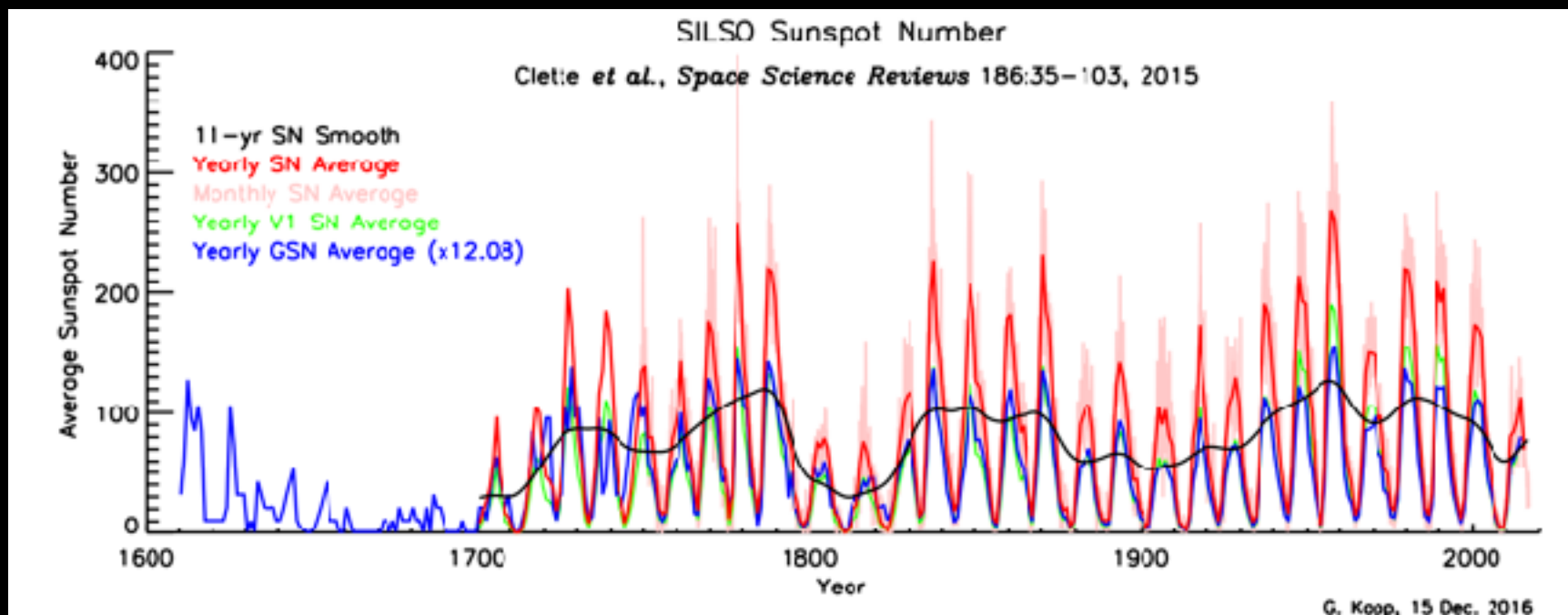
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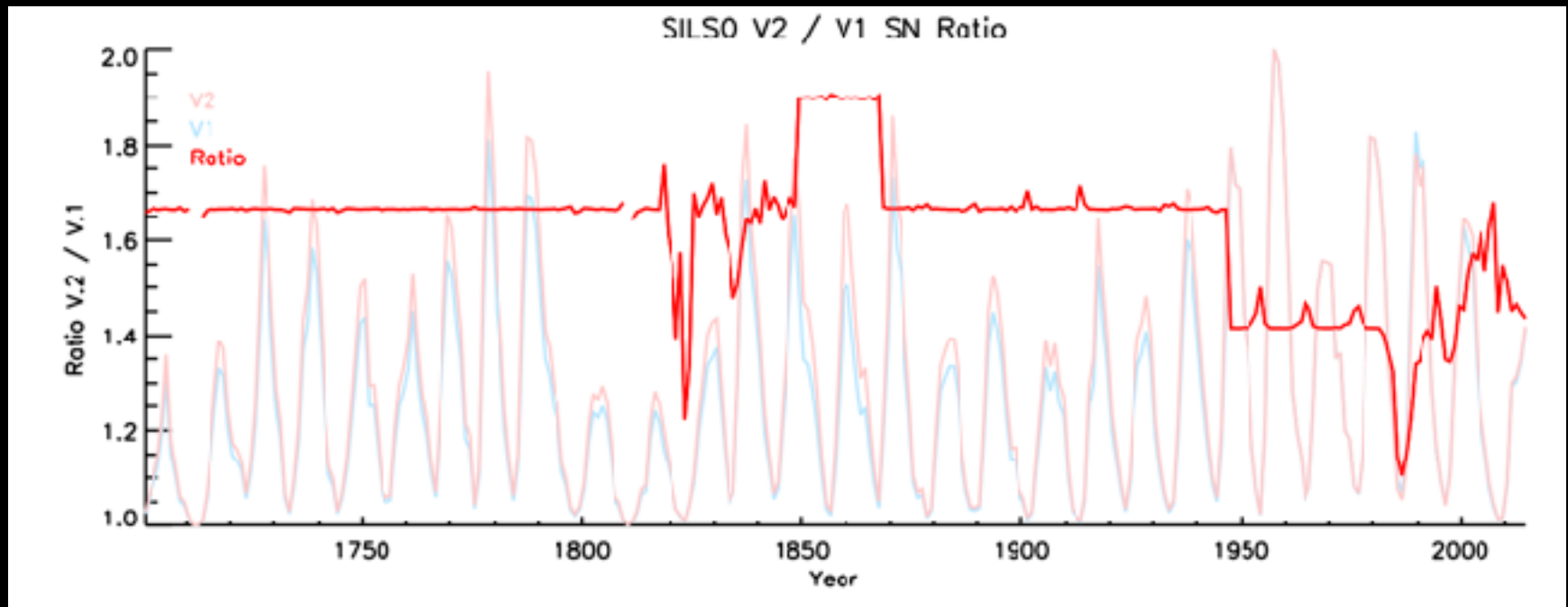
New Sunspot-Number Reconstruction(s)

- Community reanalysis of sunspot-number records lead to new series
 - Clette & Lefèvre, “The New Sunspot Number: Assembling All Corrections,” *Solar Physics*, **291**, 2016



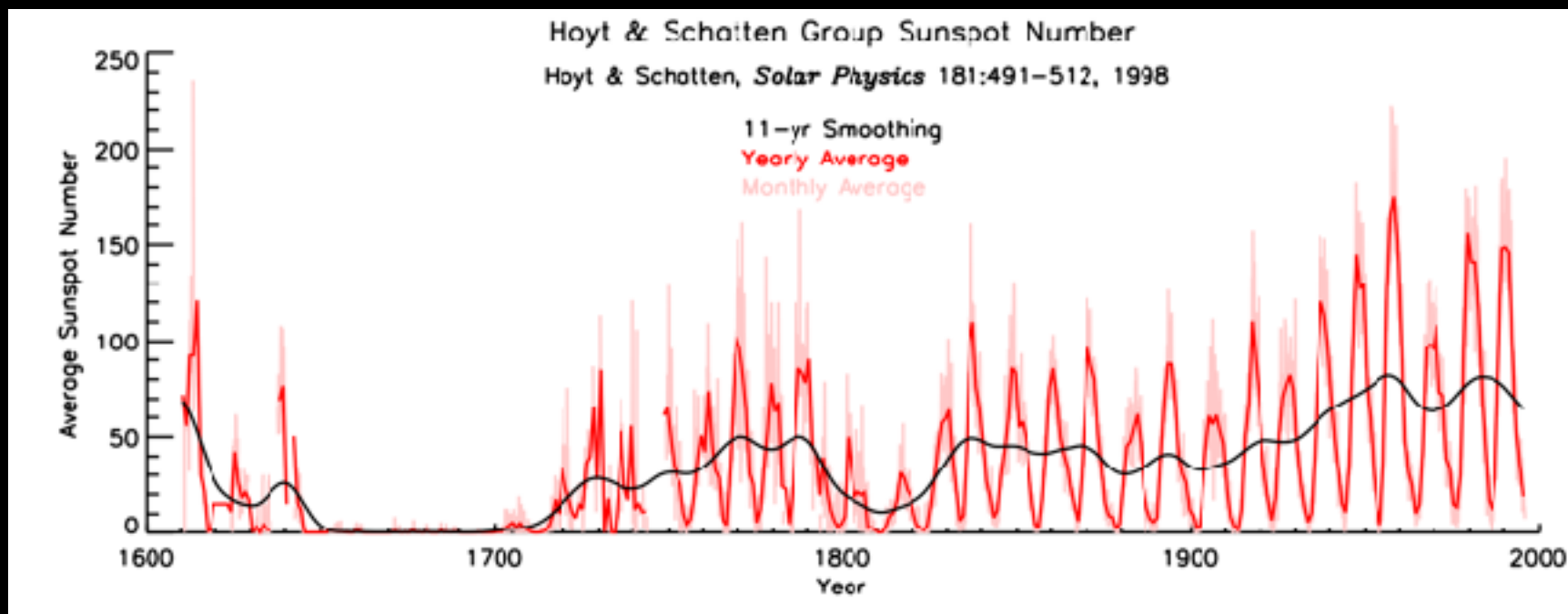
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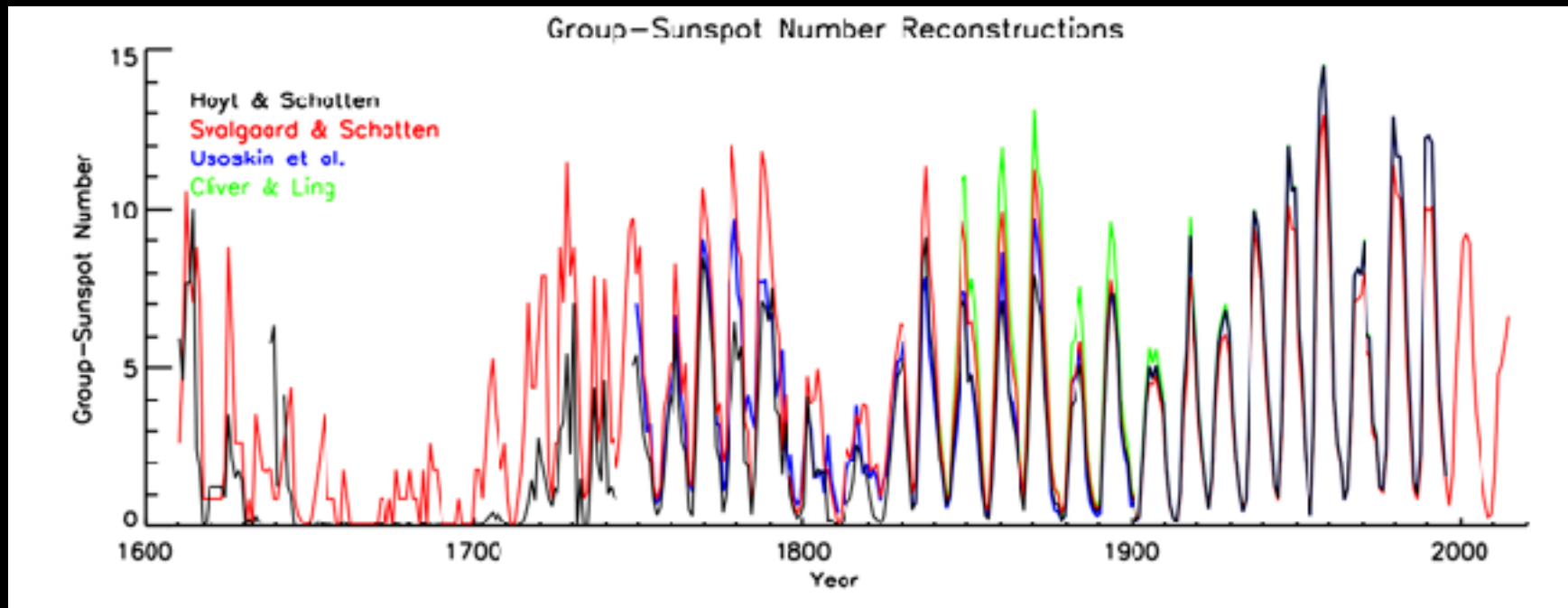
New Sunspot-Group-Number Reconstruction(s)

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 - Svalgaard & Schatten, “Reconstruction of the Sunspot Group Number: The Backbone Method,” *Solar Physics*, **291**, 2016



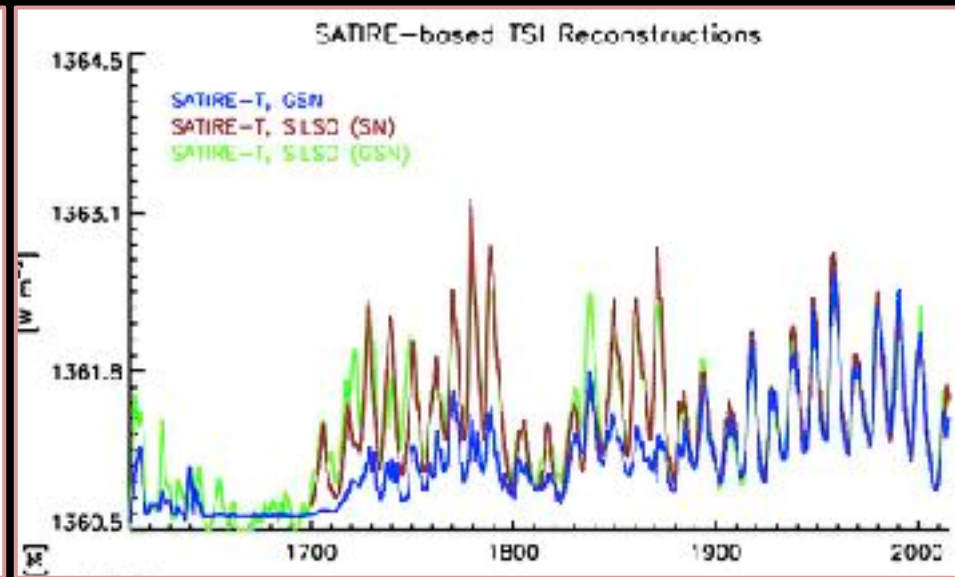
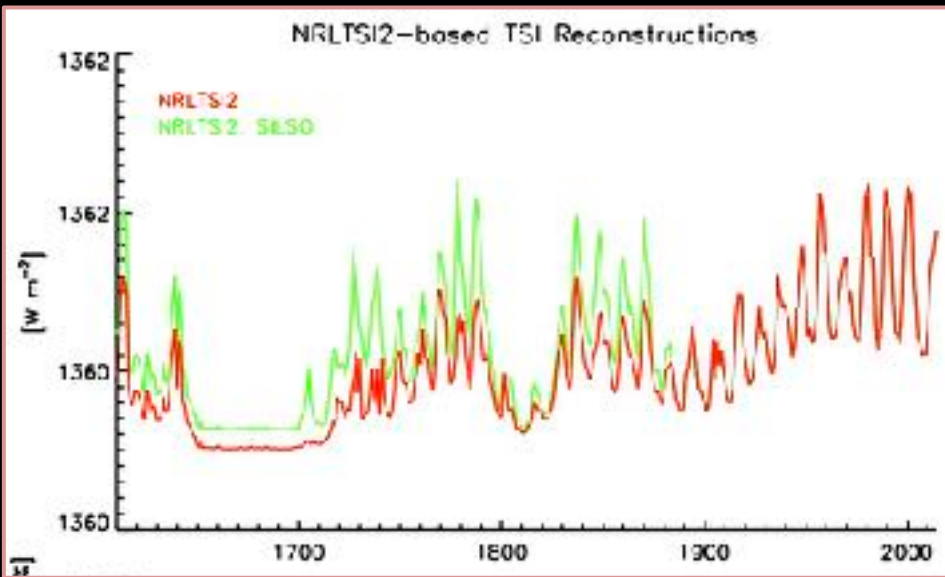
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Sensitivity of TSI Models to Sunspot Record(s)

- Kopp, G., Krivova, N., Lean, J., and Wu, C.J., “The Impact of the Revised Sunspot Record on Solar Irradiance Reconstructions,” *Solar Physics*, 2016, doi: 10.1007/s11207-016-0853-x



Improvements. And What Needs Improving

- Have improved TSI-record accuracy and understanding of artifacts
 - Older TSI instrument-data are not as good as assumed by users; newer better
- TSI composite improved with reduced biases and better instrument-transition overlaps
 - Methodology demonstrated, but final composite needs refining
- Models are getting more sophisticated
 - But large downward trend of SATIRE relative to measurements and NRLTSI in recent decades is concerning
- CMIP6 clarity on models used and arithmetic mean
- The sunspot-number reconstruction may make this all irrelevant...

