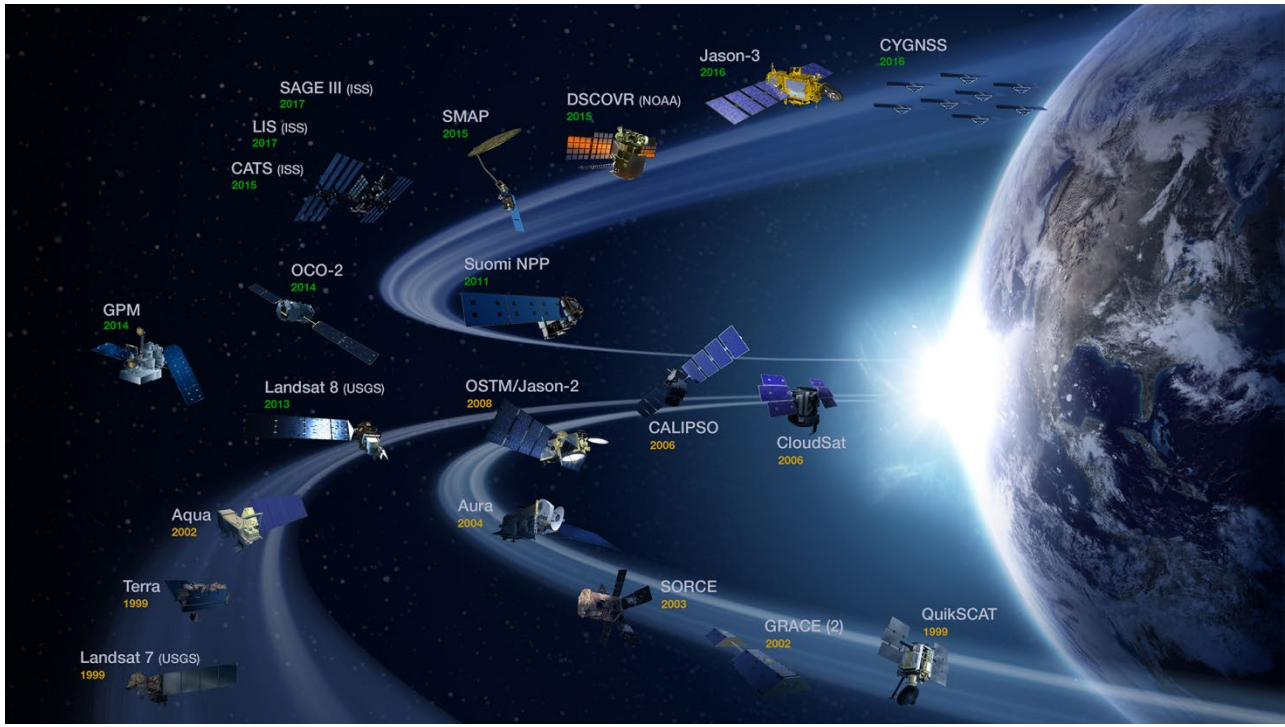


Satellite Overlap Requirements for Building Long-term Continuous Records – SORCE/TSIS Case Study

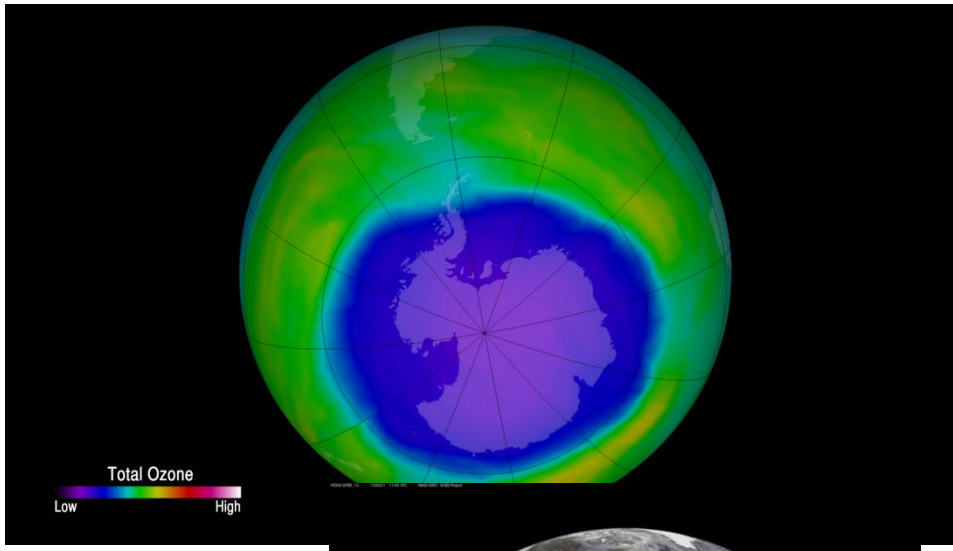
Betsy Weatherhead

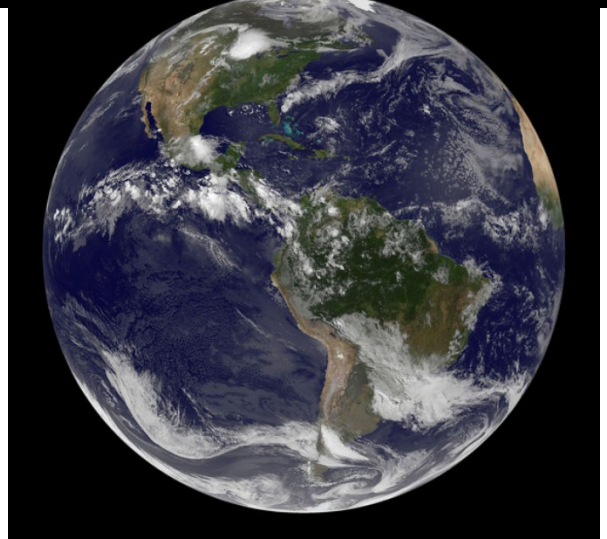
Jupiter

January 28, 2020

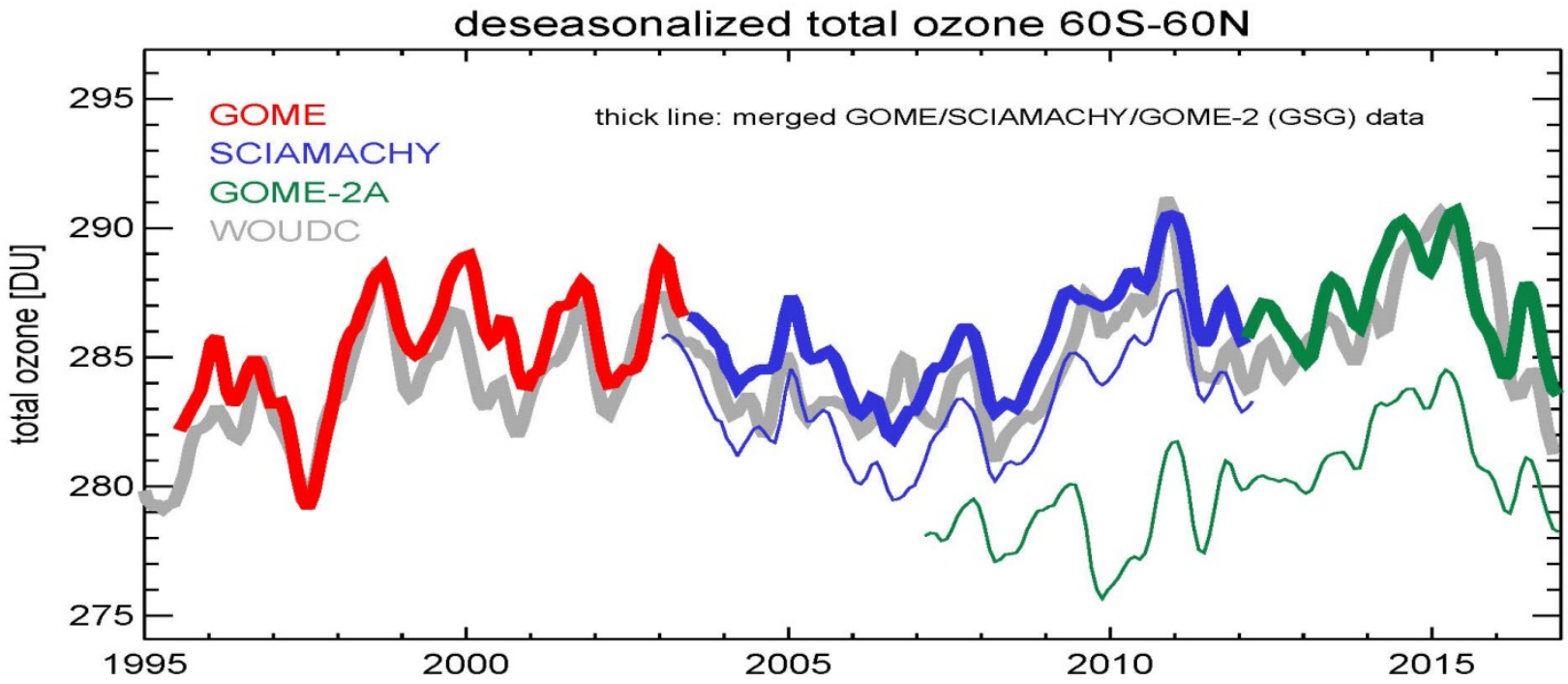
Motivation: Satellites have irreplaceable value in understanding the Earth system

- Global understanding of the depletion and recovery of stratospheric ozone.
- Unprecedented observations of sea level rise around the globe.
- Critical observations of solar spectra during multiple solar cycles.
- High resolution observations of land use.
- Valuable monitoring of Arctic Sea Ice during times of dynamic change.





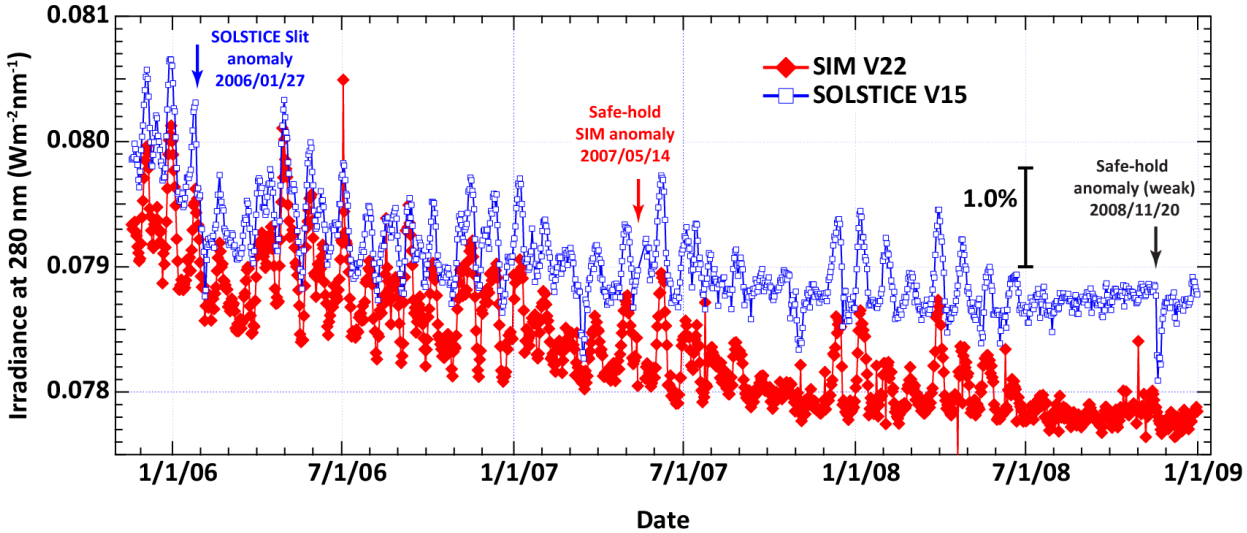
Challenge: Long-term changes are often longer than the lifetime of satellites.



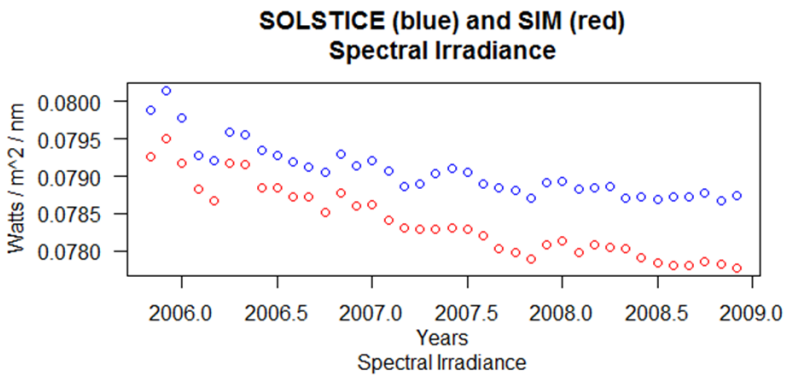
Previously presented

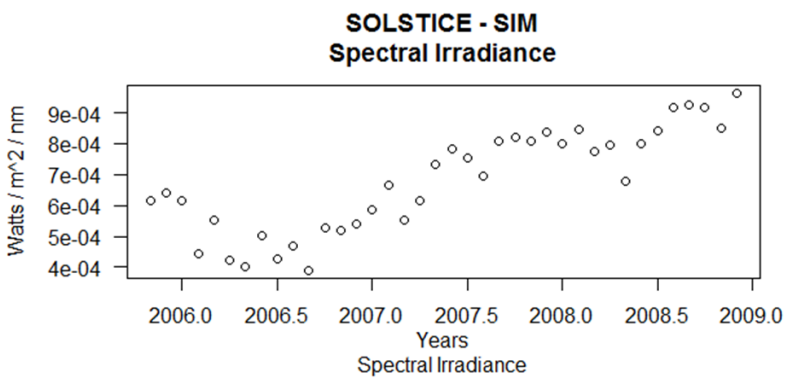
Looking at Offsets

- Overlapping satellites often show offsets.
- For the period of overlap, the differences can be calculated, often in an ideal region where footprints and time differences are minimized.
- Both the differences and the standard error on the differences can be estimated from the overlap data.
- Example:
  - SOLSTICE-SIM Overlap



Exploring overlap impacts using SOLSTICE and SIM data





Monthly averaged overlap data

- Mg portion of spectra
- Offset is clearly observable.
- Drift is also possible.

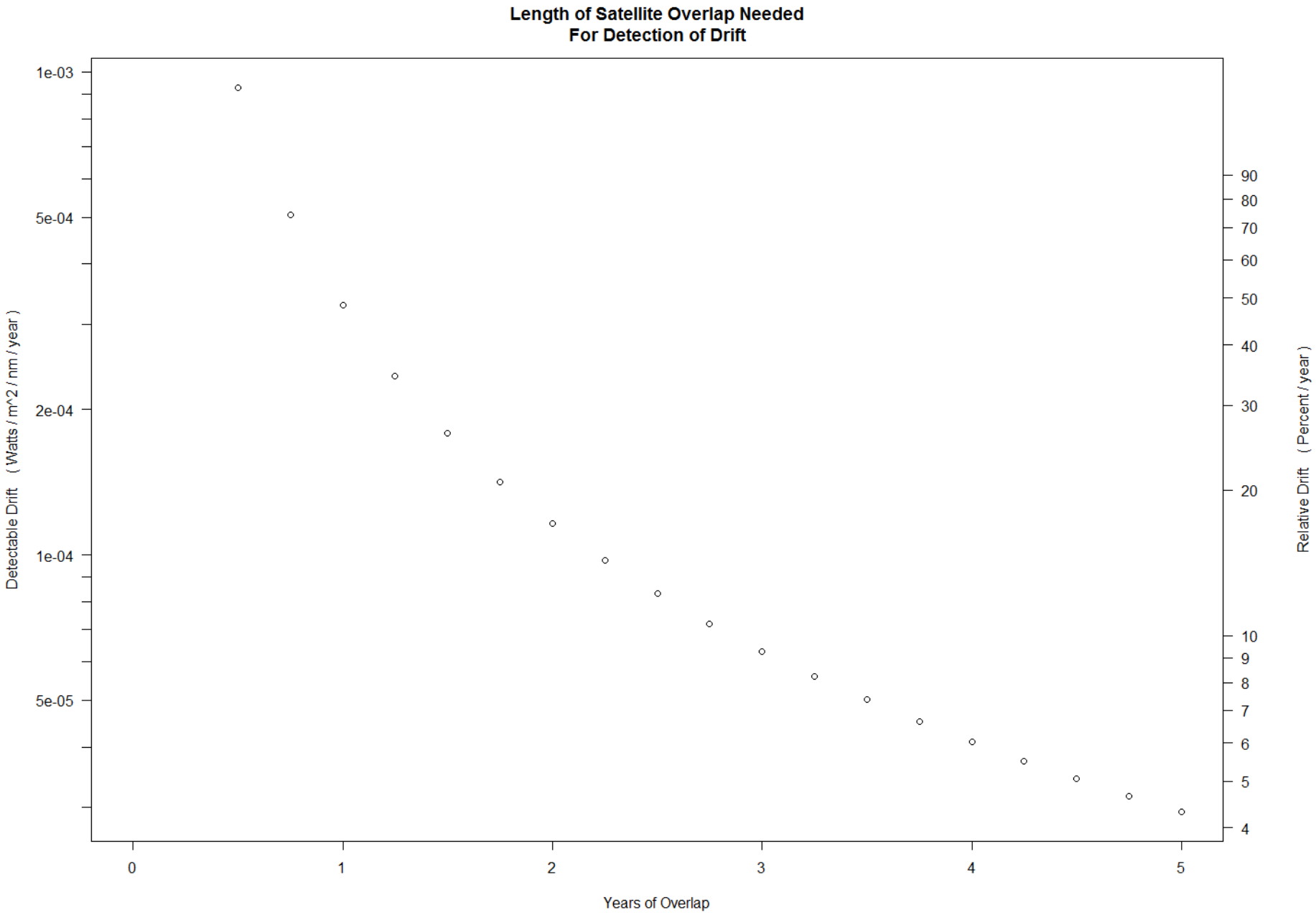
Adjusting for offsets

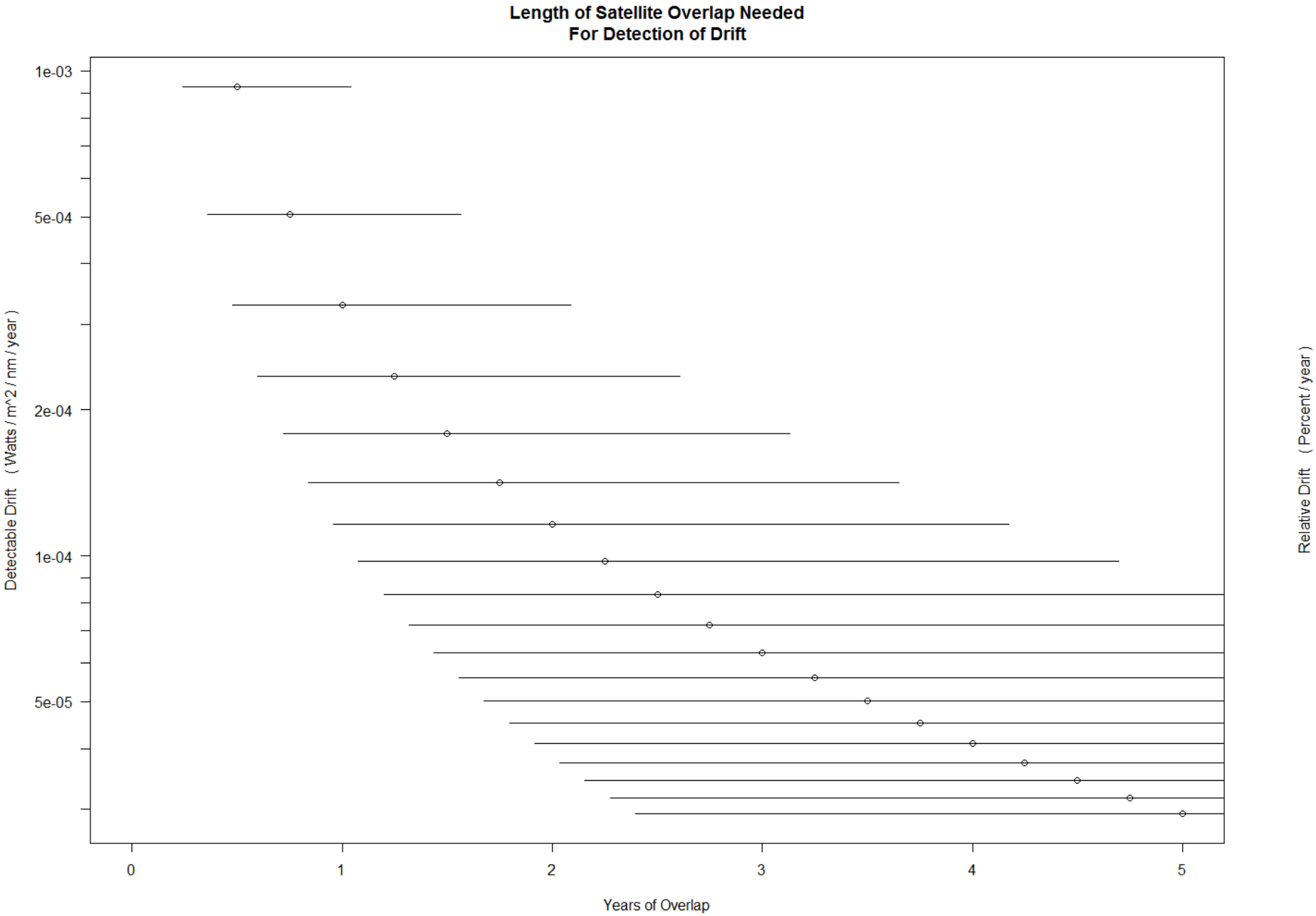
- Adjustments:
- $mean_{\boldsymbol{differences}} = \frac{<sat.1>}{<sat.2>}$
- $SE_{mean} \cong {}^{\sigma}/_{\sqrt{n}} \ \frac{\sqrt{1+\varphi}}{\sqrt{1-\varphi}}$
- Inverting:
- $Years\ to\ Estimate\ an\ Offset$
  $\cong 12 * \ 1.96^2 \ {}^{\sigma^2}/_{Offset\ Limit^2} \frac{1+\varphi}{1-\varphi}$
- Note that the time needed to understand an offset is independent of the size of the offset.

Adjusting for drifts

- Adjustments:
- $mean_{\boldsymbol{differences}} = \frac{<sat.1>}{<sat.2>}$
- $SE_{mean} \cong {}^{\sigma}/_{\sqrt{n}} \; \frac{\sqrt{1+\varphi}}{\sqrt{1-\varphi}}$
- Inverting:
- $Years\ to\ Estimate\ a\ Drift \cong$

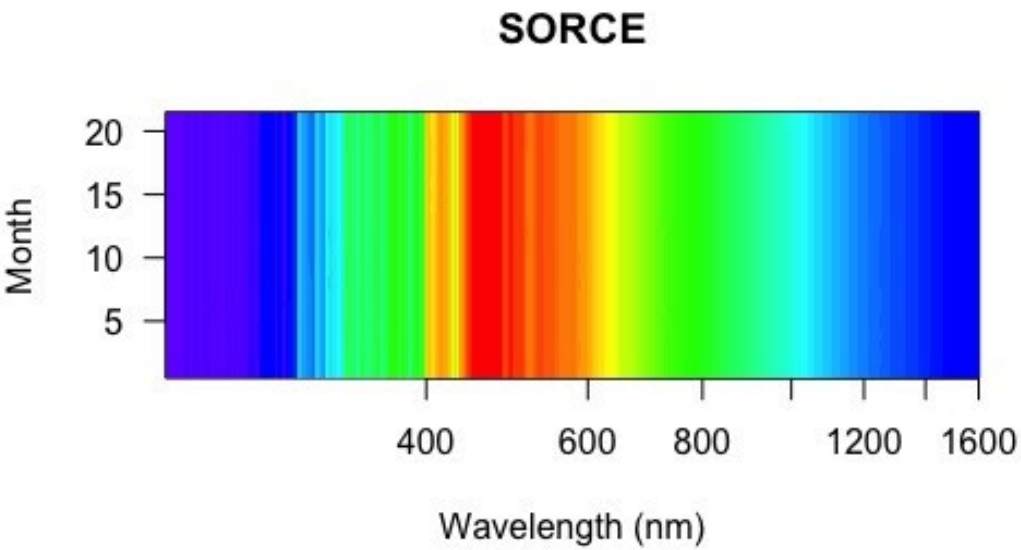
$$12 * \left[1.96 \frac{\sigma}{|drift|} * \sqrt{\frac{1+\varphi}{1-\varphi}}\right]^{2/3}$$

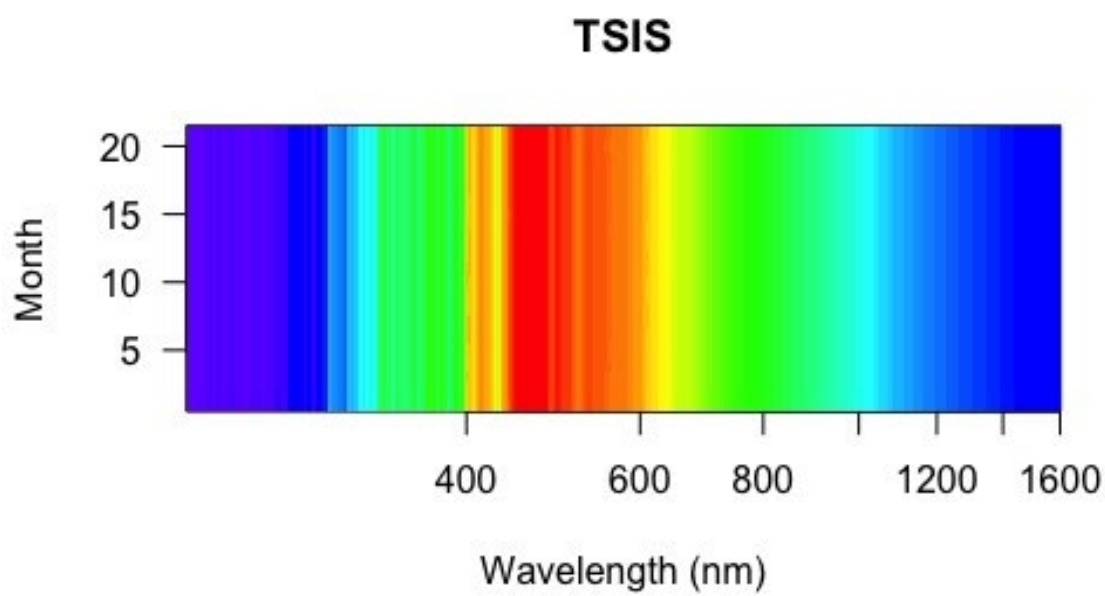

Length of Satellite Overlap Needed
For Detection of Drift
Detectable Drift (Watts / m^2 / nm / year)
1e-03
5e-04
2e-04
1e-04
5e-05
Relative Drift (Percent / year)
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
0
1
2
3
4
5
Years of Overlap


Length of Satellite Overlap Needed
For Detection of Drift
Detectable Drift (Watts / m^2 / nm / year)
Relative Drift (Percent / year)
Years of Overlap
1e-03
5e-04
2e-04
1e-04
5e-05
0
1
2
3
4
5

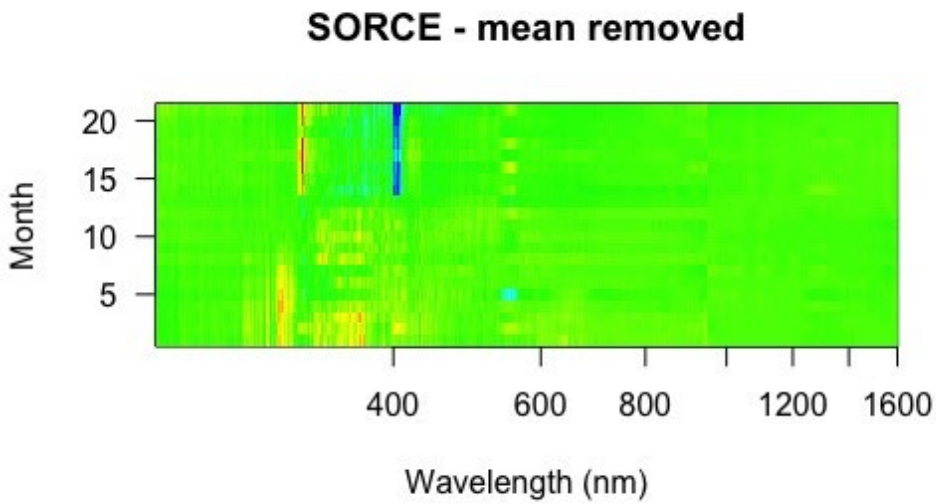
New information

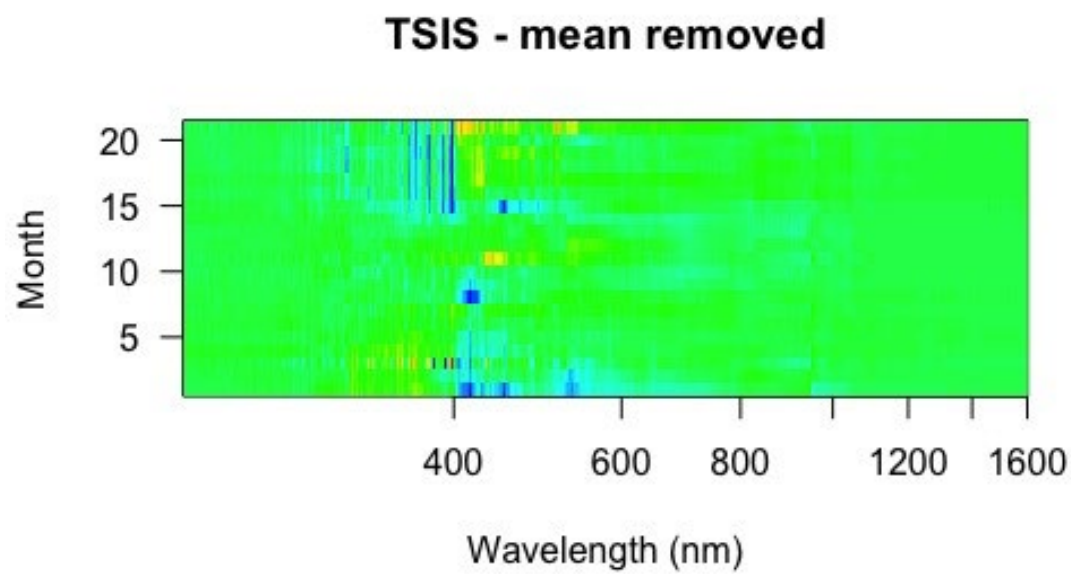
Monthly Data from SORCE and TSIS



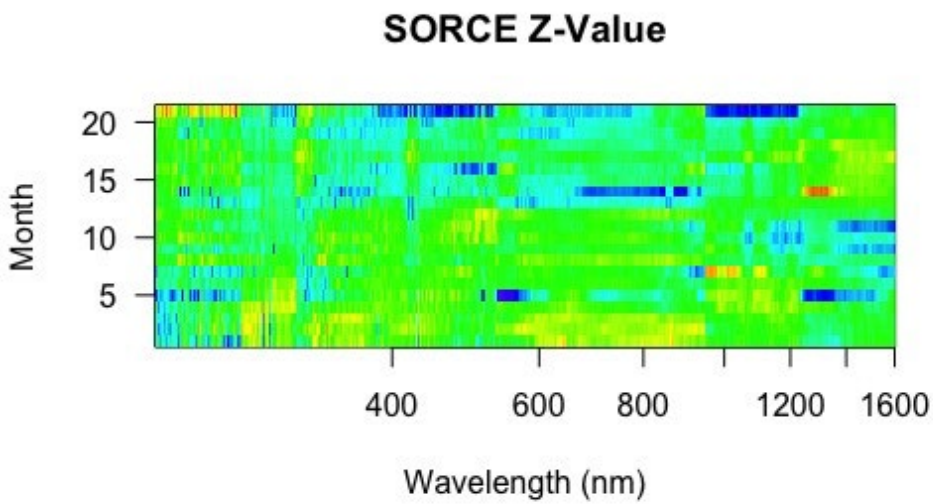


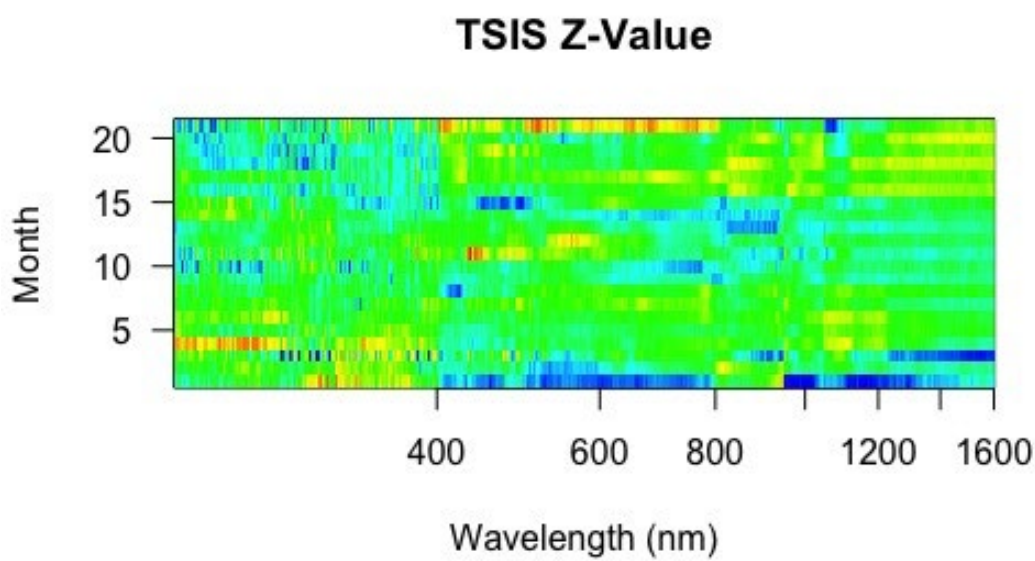
Monthly Data with Means Removed SORCE and TSIS



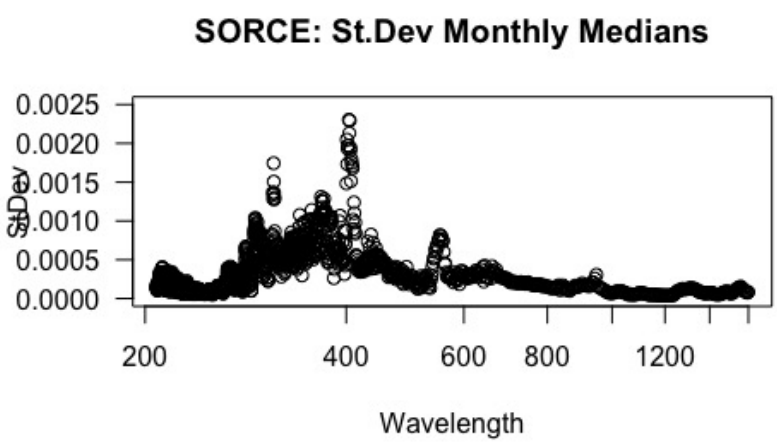


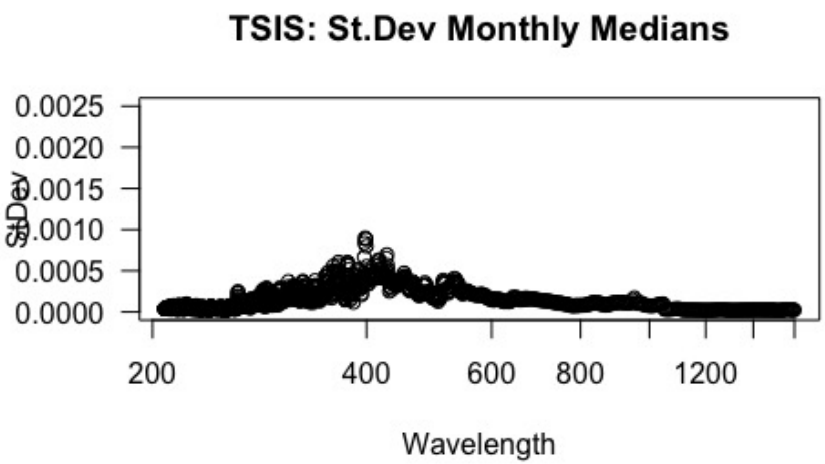
Monthly Data, Means Removed, Standardized: SORCE and TSIS

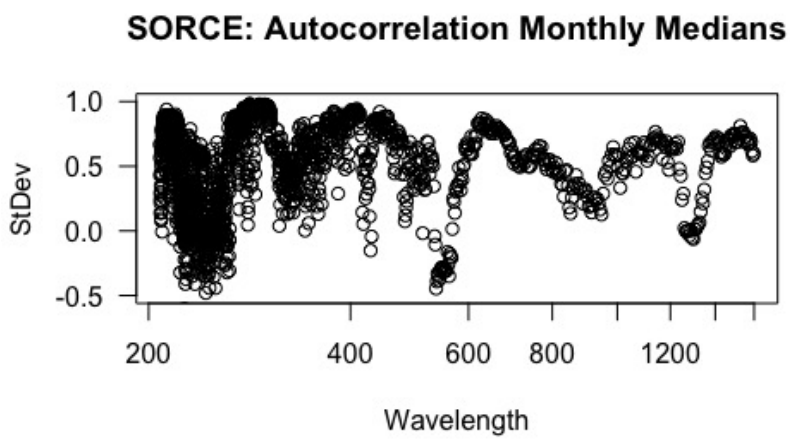


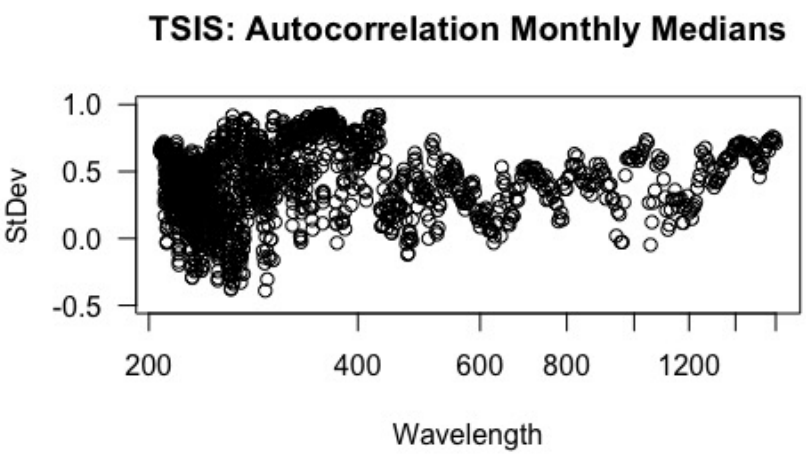


Fundamental Characteristics: monthly standard deviation and autocorrelation.

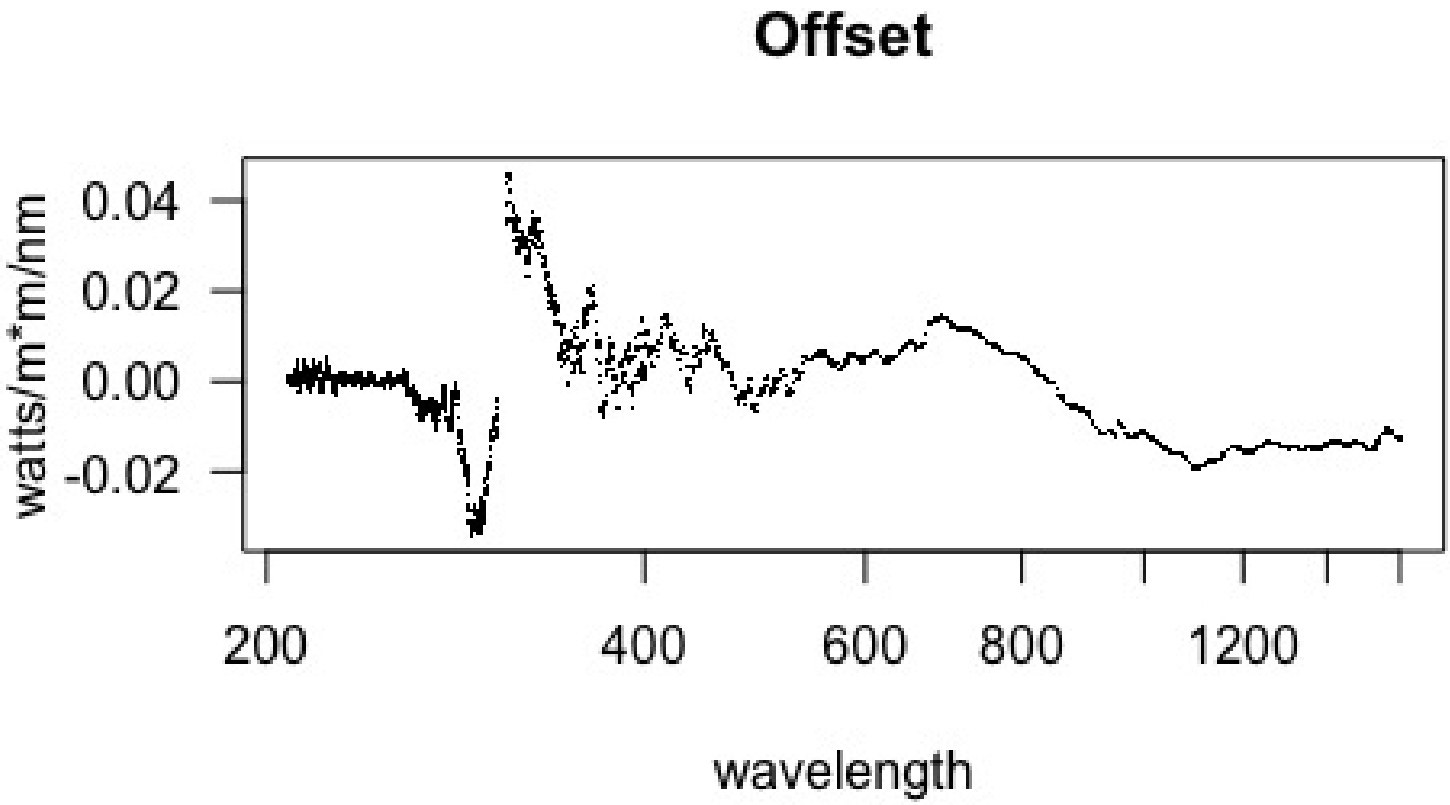




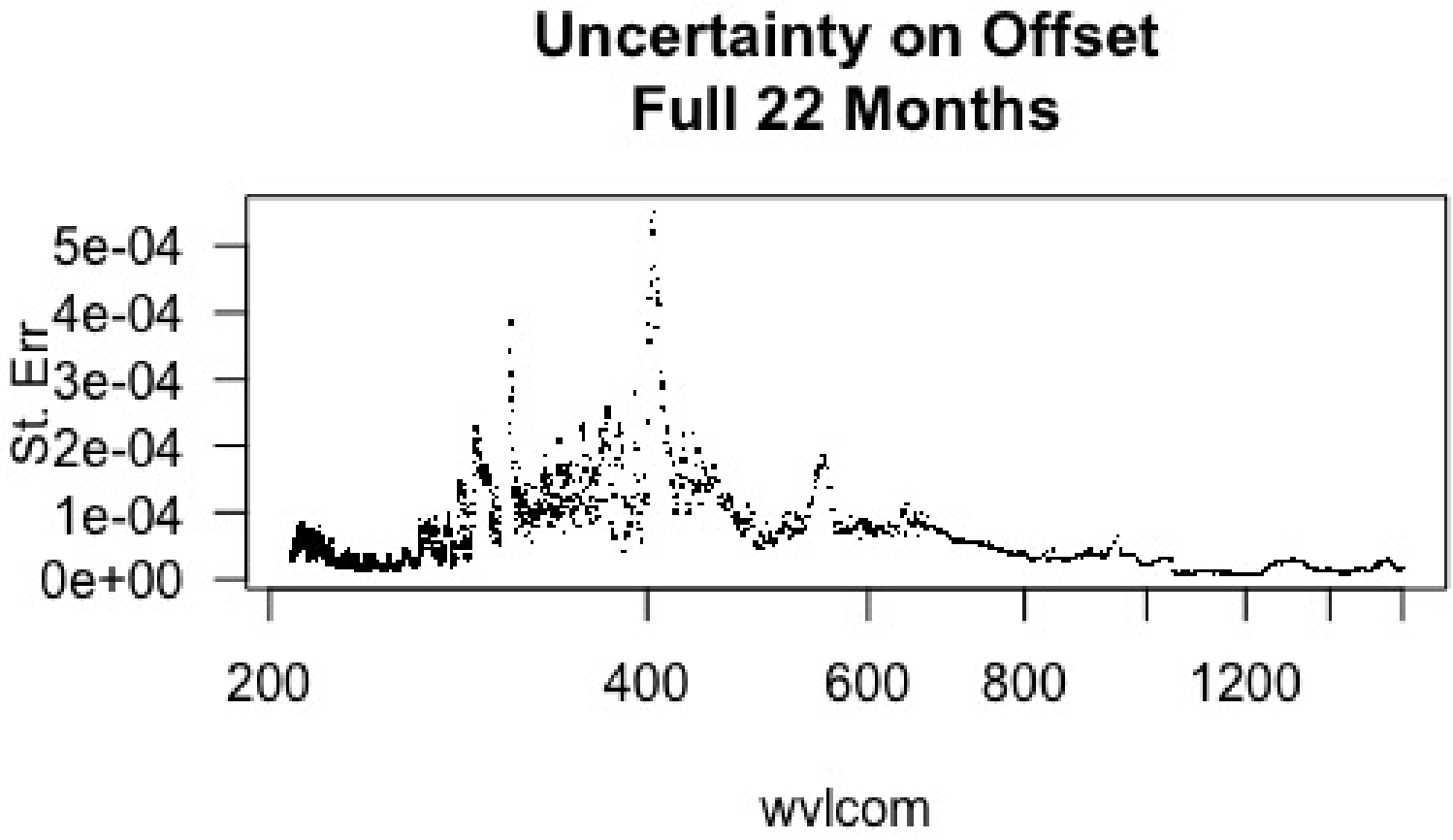




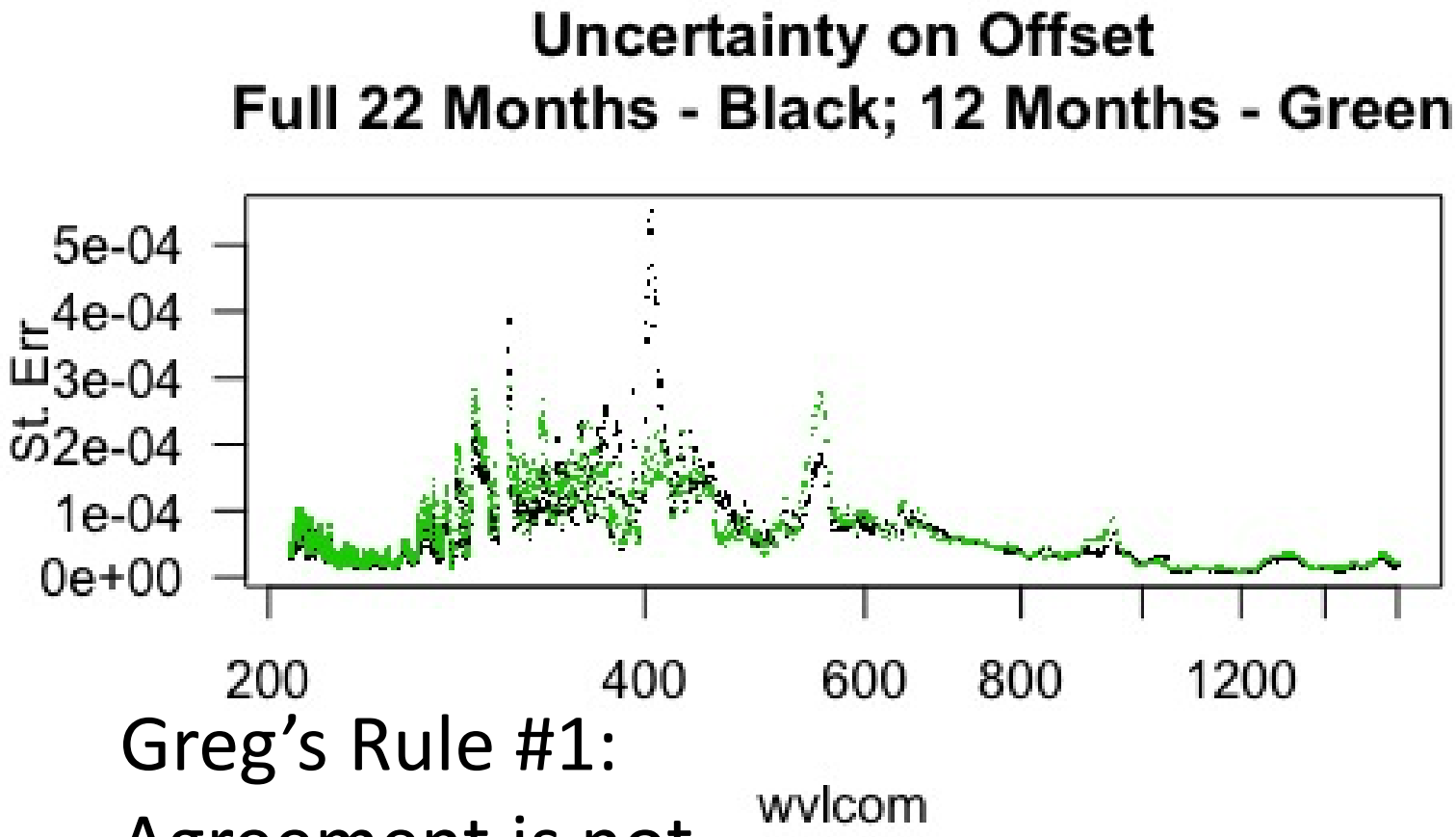
Derived Offsets



Uncertainty on magnitude of offsets

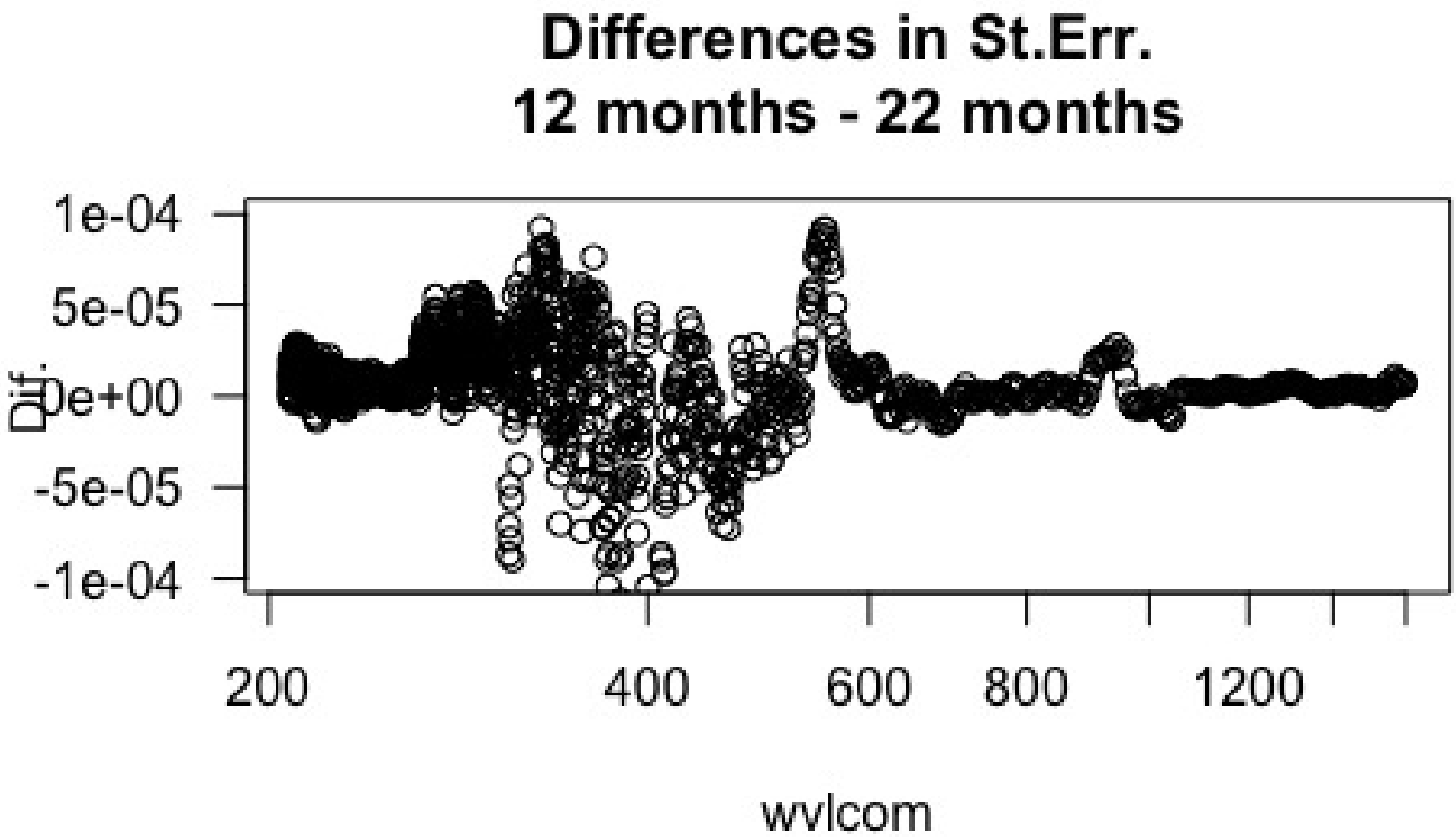


Uncertainty on magnitude of offsets

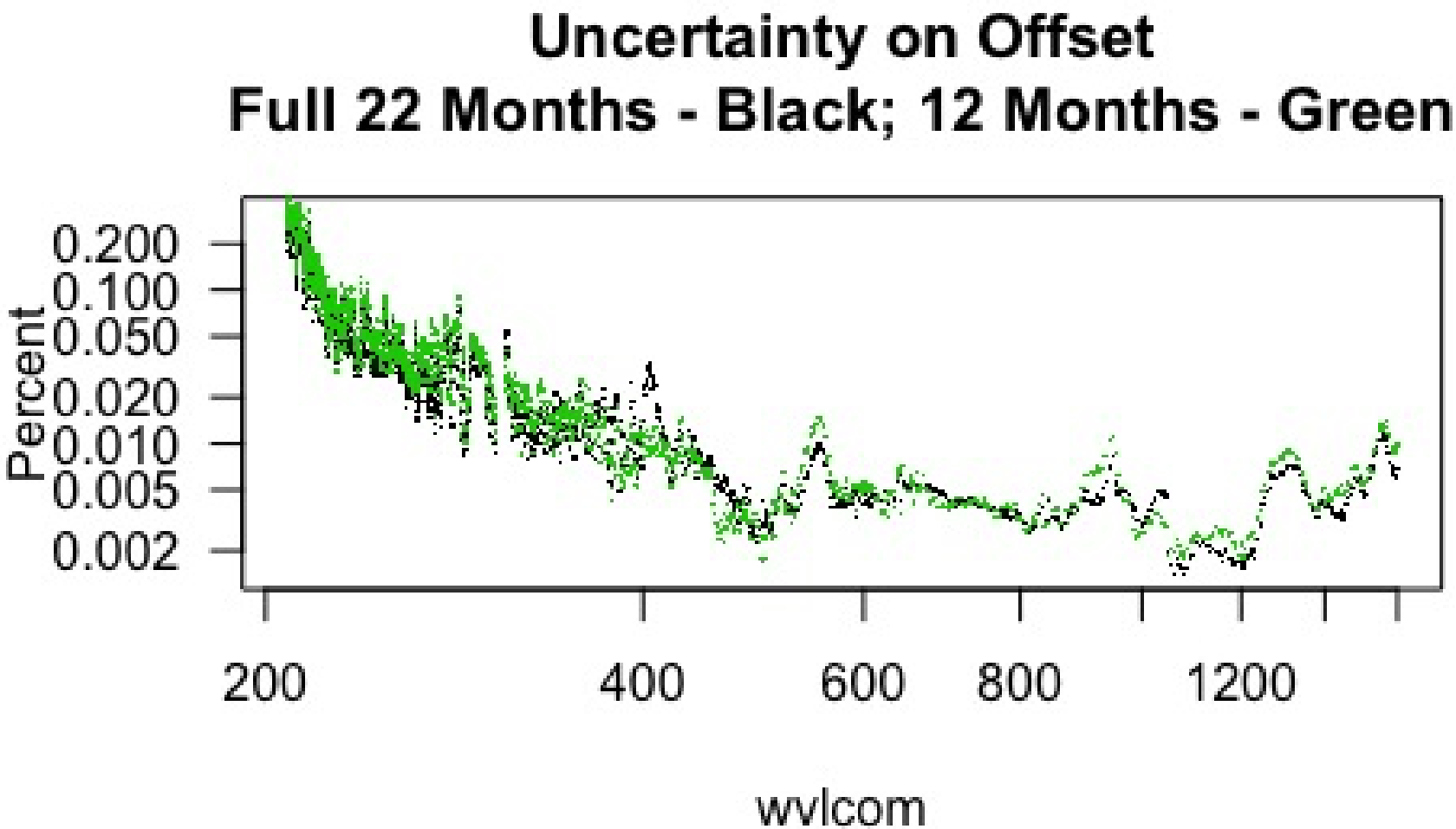


Greg's Rule #1: Agreement is not accuracy.

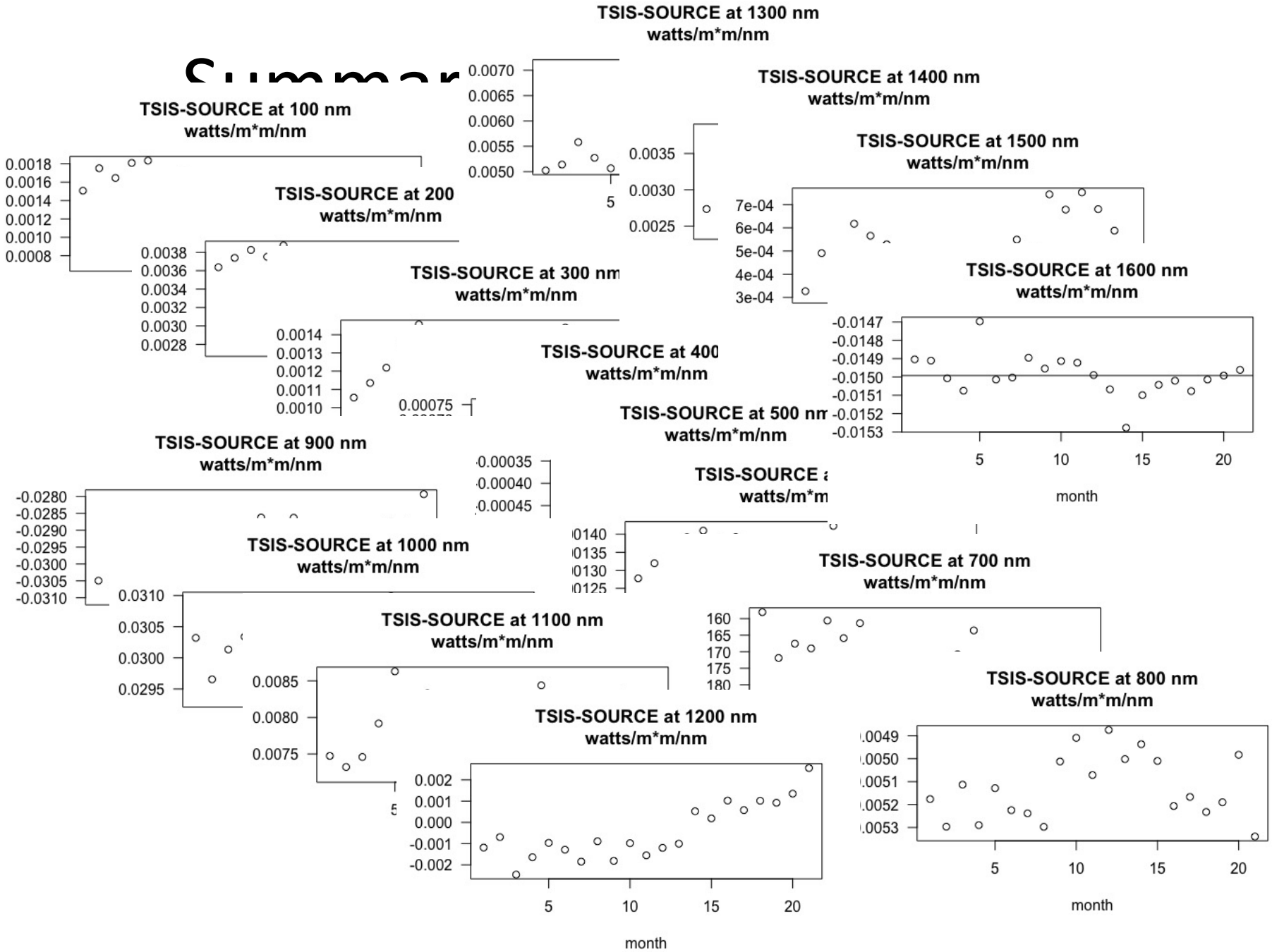
Added benefit of additional overlap time



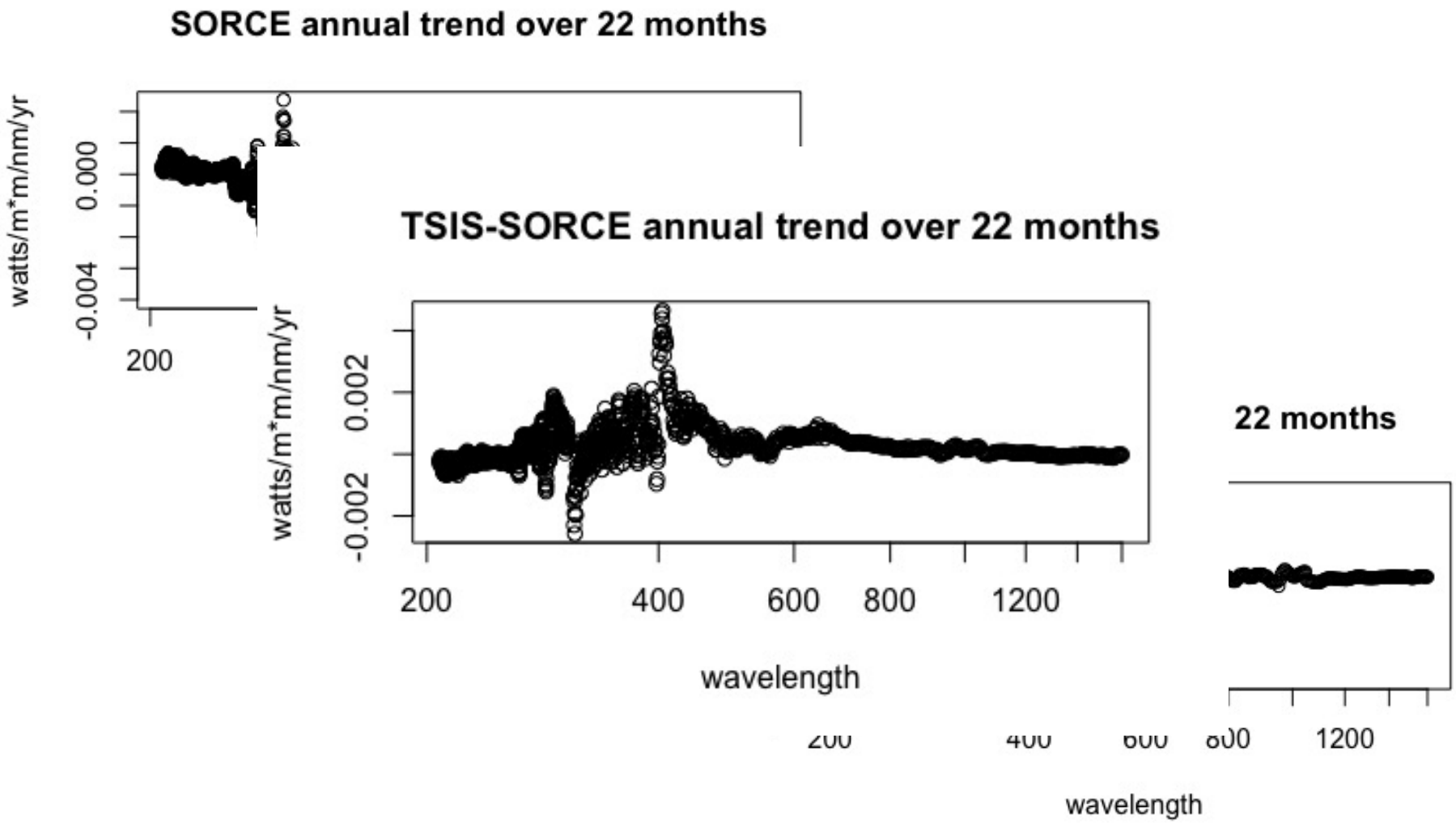
Improved Uncertainty
As a percentage



Summar


TSIS-SOURCE at 100 nm
watts/m*m/nm
TSIS-SOURCE at 200
watts/m*m/nm
TSIS-SOURCE at 300 nm
watts/m*m/nm
TSIS-SOURCE at 400
watts/m*m/nm
TSIS-SOURCE at 500 nm
watts/m*m/nm
TSIS-SOURCE at 700 nm
watts/m*m/nm
TSIS-SOURCE at 800 nm
watts/m*m/nm
TSIS-SOURCE at 900 nm
watts/m*m/nm
TSIS-SOURCE at 1000 nm
watts/m*m/nm
TSIS-SOURCE at 1100 nm
watts/m*m/nm
TSIS-SOURCE at 1200 nm
watts/m*m/nm
TSIS-SOURCE at 1300 nm
watts/m*m/nm
TSIS-SOURCE at 1400 nm
watts/m*m/nm
TSIS-SOURCE at 1500 nm
watts/m*m/nm
TSIS-SOURCE at 1600 nm
watts/m*m/nm
month
month

Changes over time



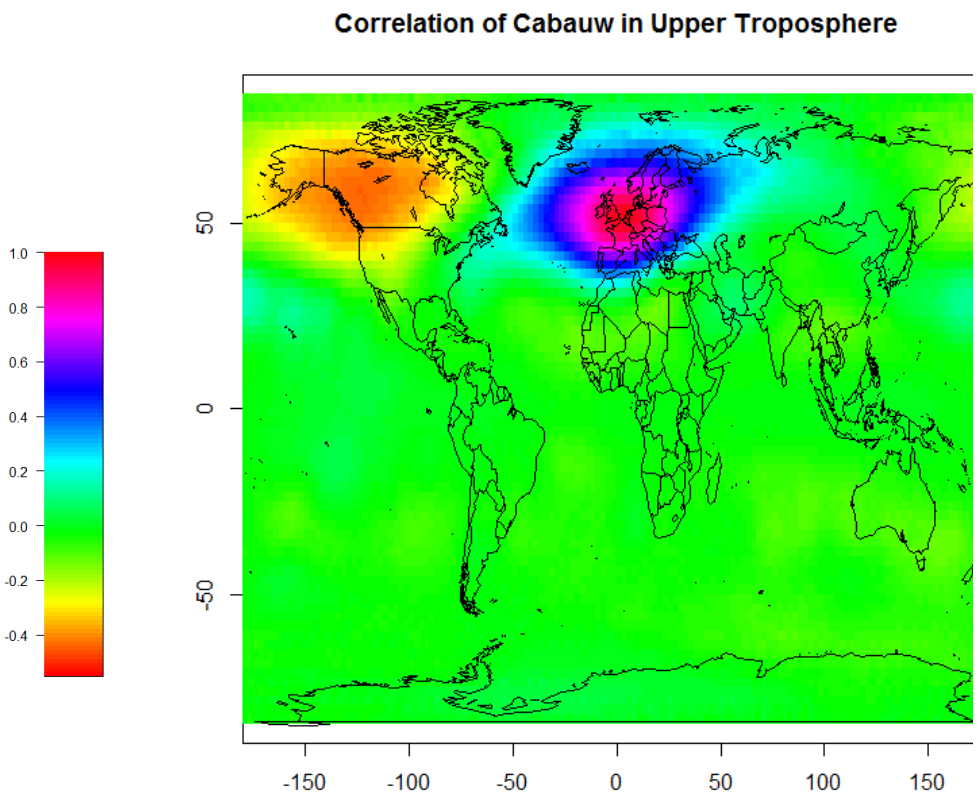
Conclusions

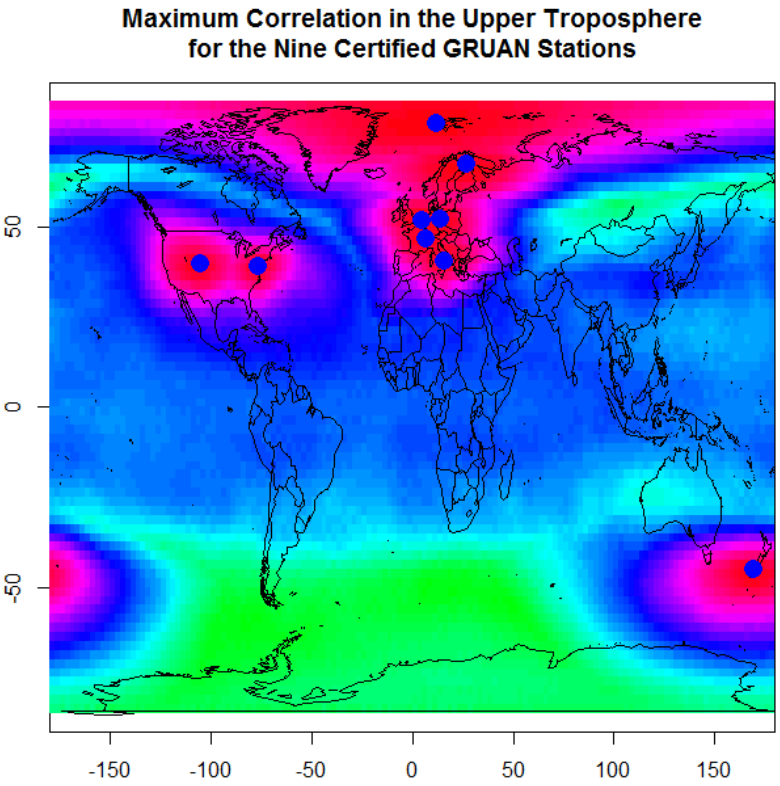
- Understanding overlap implications for long-term records:
  - Quality of data
  - Offsets
  - Drifts
- Satellites at both the beginning and end of life are challenging.
- Added overlap with SORCE and TSIS show increased accuracy for long-term dataset, wavelength dependent.
- Estimates of impact of additional months of overlap are roughly in line with expectations—but show surprises as well.

JUPITER™

Challenge

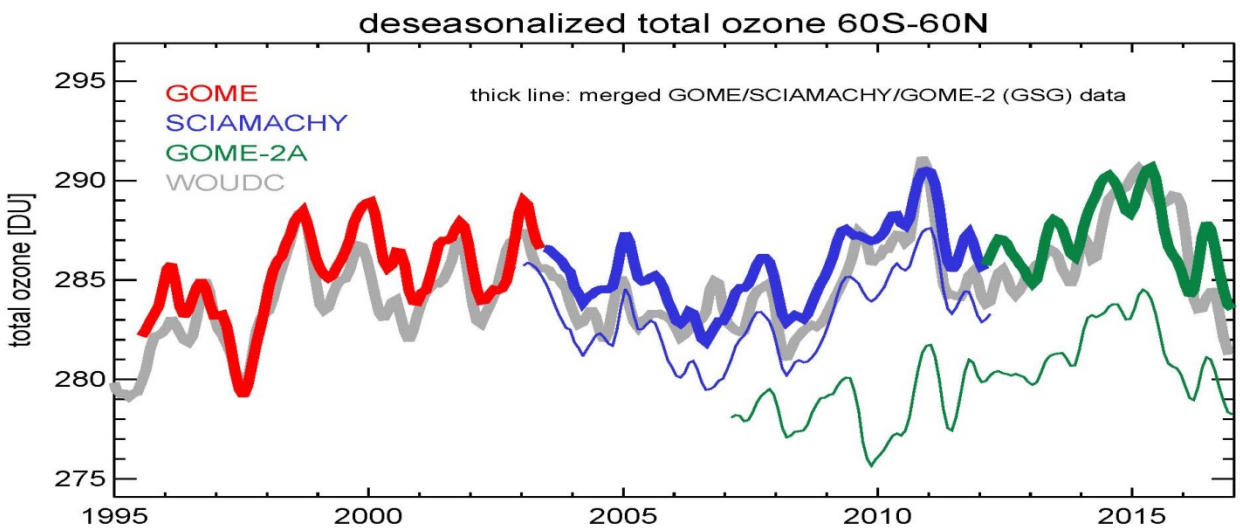
- Many satellite records do not last long enough to monitor long-term changes.





Ozone Satellite Data

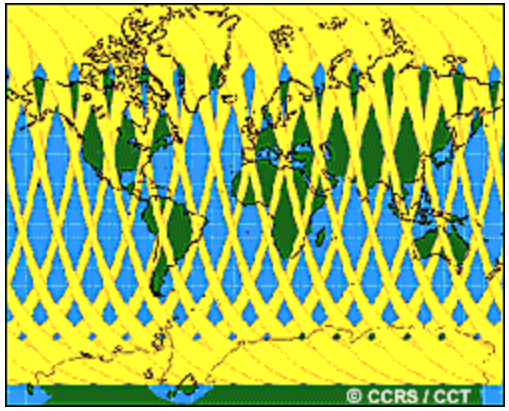
- Stratospheric ozone should be recovery, however the signal is small and the observational uncertainty is large.
- Ozone satellite data show notable differences which change over time.
  - Large compared to signal of long-term increases



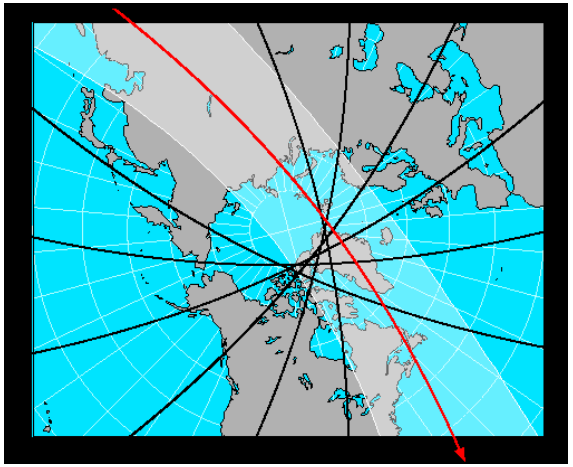
Key Issues

- Looking at level of agreement:
  - Spikes
  - Offsets
  - Drifts
- Uncertainty inherent in merging two datasets.
  - Quantifying
  - Minimizing
  - Communicating
- Impact of longer overlap time
  - TSIS-2 is in the plans for 2023 (6 month overlap f TSIS-1 and -2)

Challenges with Satellite Overlap



- Not always possible
- Changes in technology
- Changes in footprints
- Temporal matching, including diurnal biases
- Not true calibration
- Marginally expensive for lengthy overlap

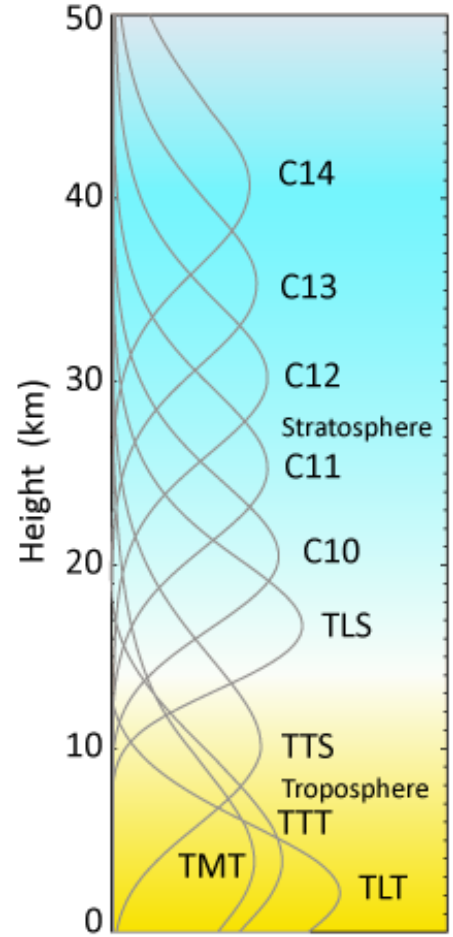


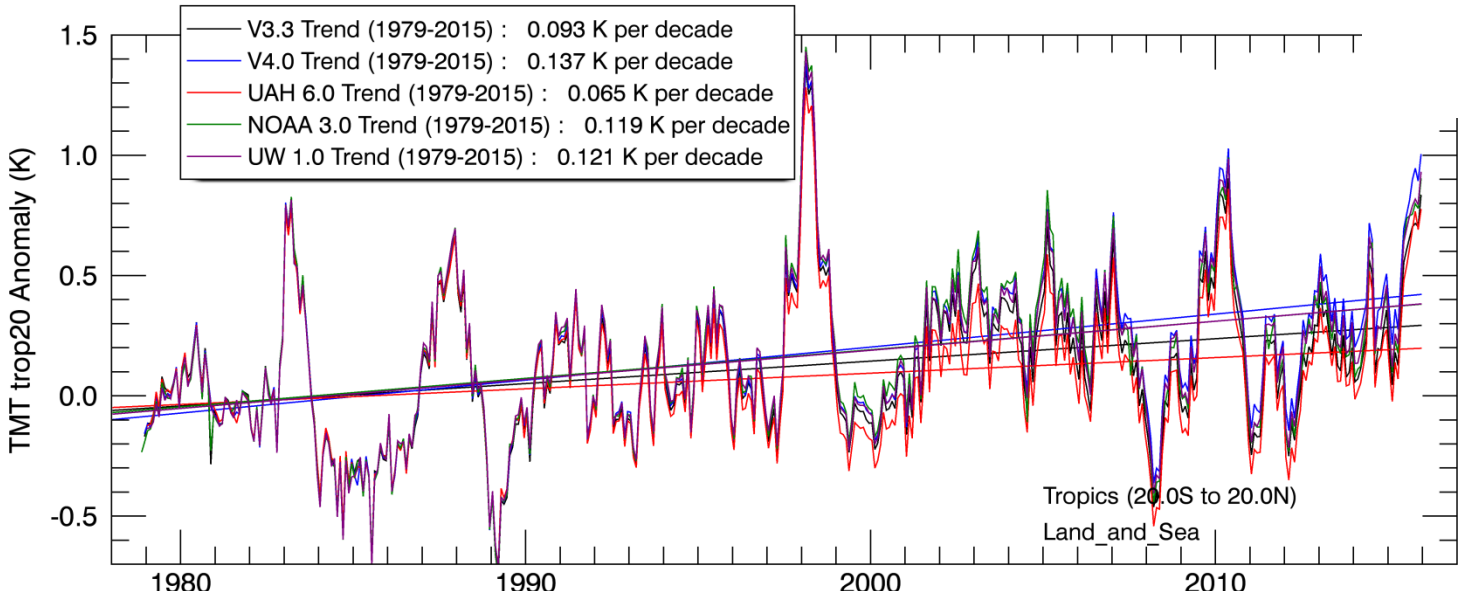
Some common wisdom on satellite overlap

- Overlap for a full year so that the range of values can be observed.
  - This ignores the burn-in time that many satellites require before they stabilize.
  - Not all phenomena display their full range of values in one year.
- More overlap is better
  - This ignores the expense in overlapping which could deny other efforts to quality assure observations such as on-board calibrations, campaigns to verify observations, analysis of the data.
- Don’t worry about the overlap because analysis can handle the discontinuities
  - Wishful thinking, but the claim needs to be verified.
  - Multiple examples show that analysis can not always solve quality issues in observations (Free et al.)
- Fundamentally, these issues to do not compare the purpose of the observations to the value of information from the overlap.

Temperature Satellite Data

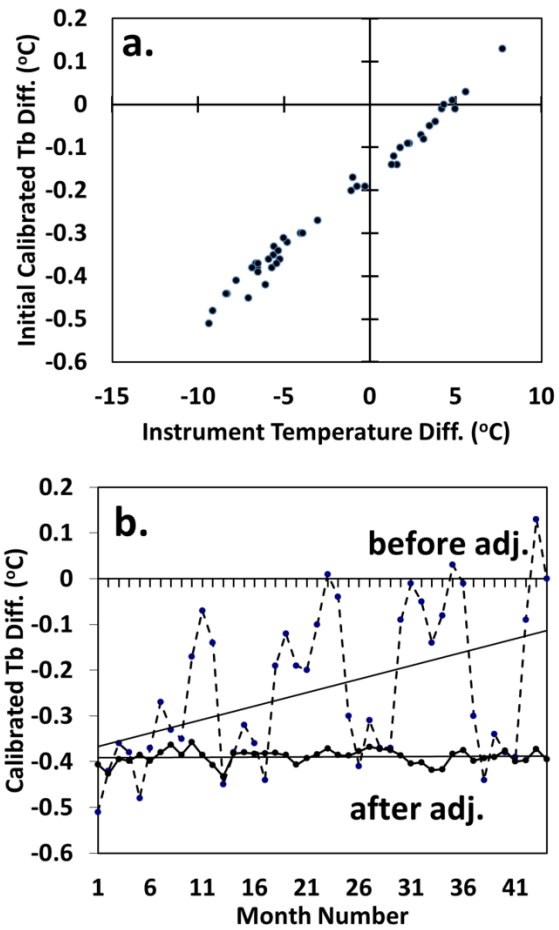
- Perhaps the most studied satellite dataset on record.
- Notably challenging and difficult
  - With in situ observations and multiple satellites.



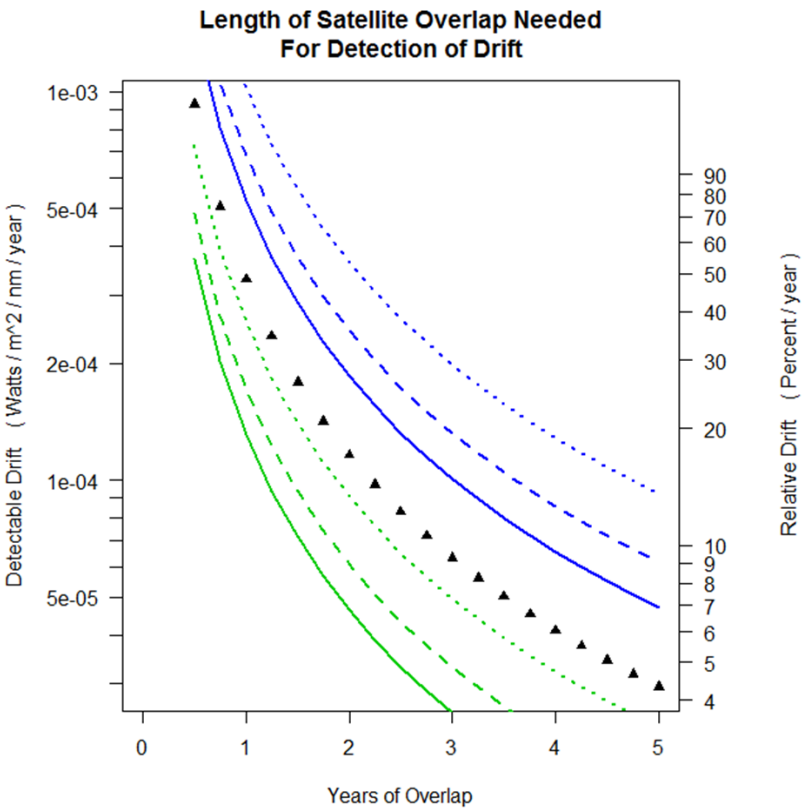


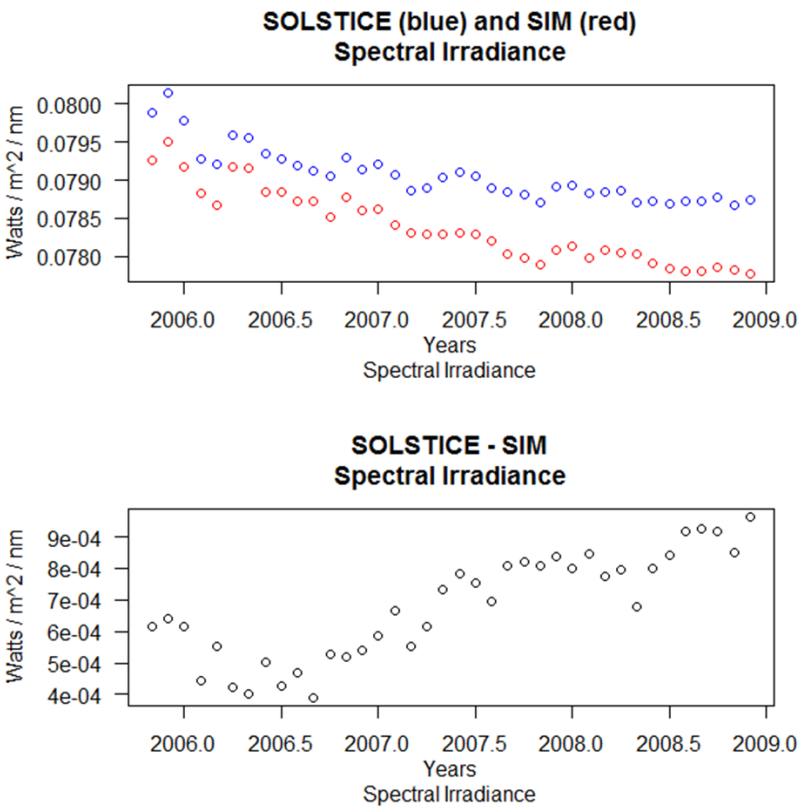
How much information can we get from overlapping satellites?

- At a minimum, we'd like to address offsets.
- Confounding this is that problems in the overlap data can drift over time.
- And, sudden changes, "jumps" can occur.



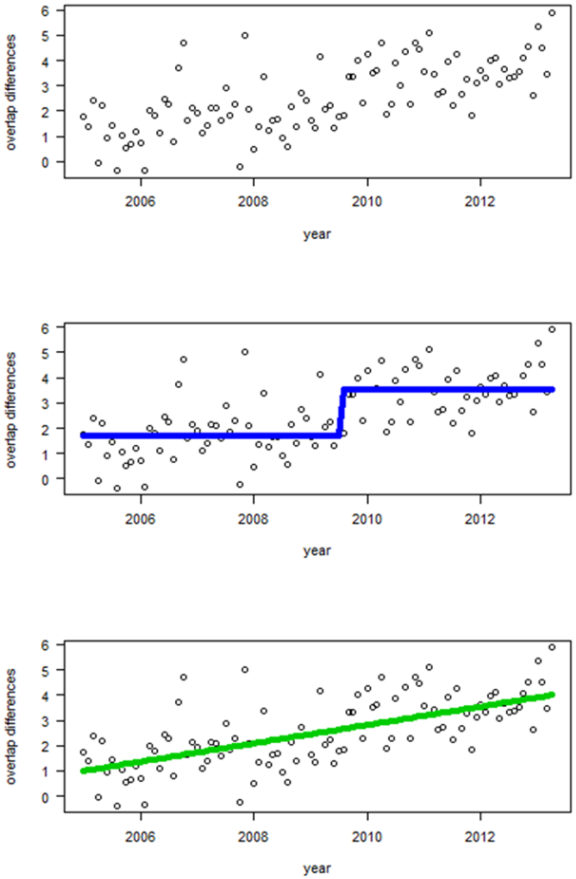
Results are dependent on the character of the overlap data.





Unfortunately, not all instrument behavior can be assumed to be offsets and drifts.

- Sudden jumps in data can obscure the long-term offsets and drifts.
- Large offsets can be identified, but corrections still introduce uncertainty.



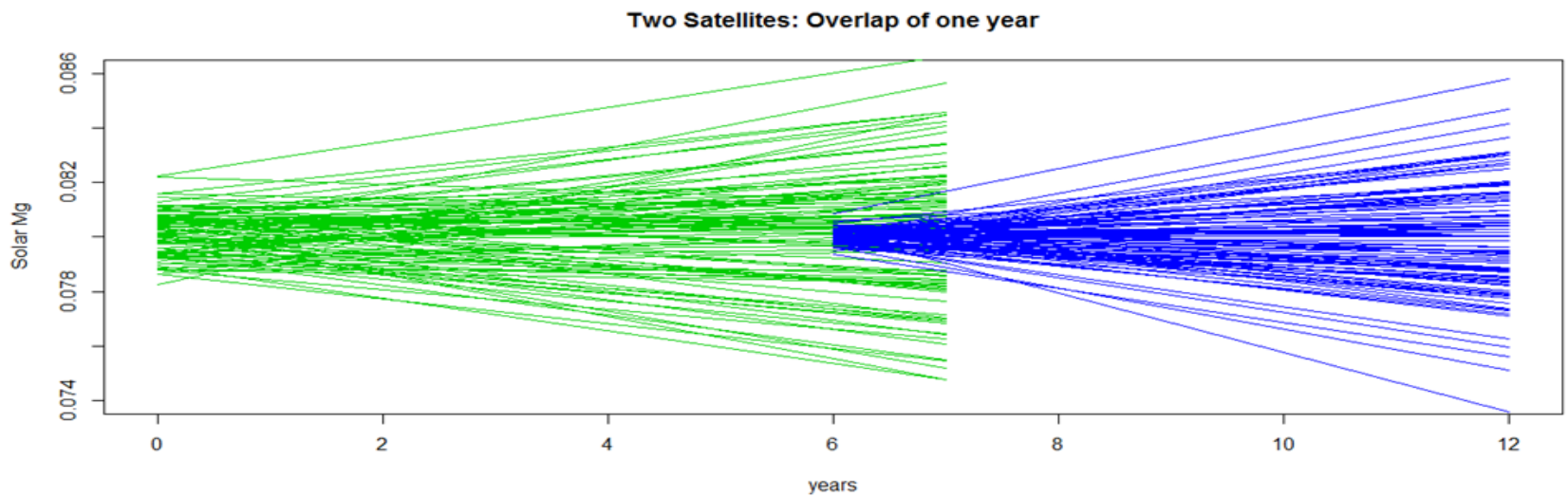
Adjusting for jumps

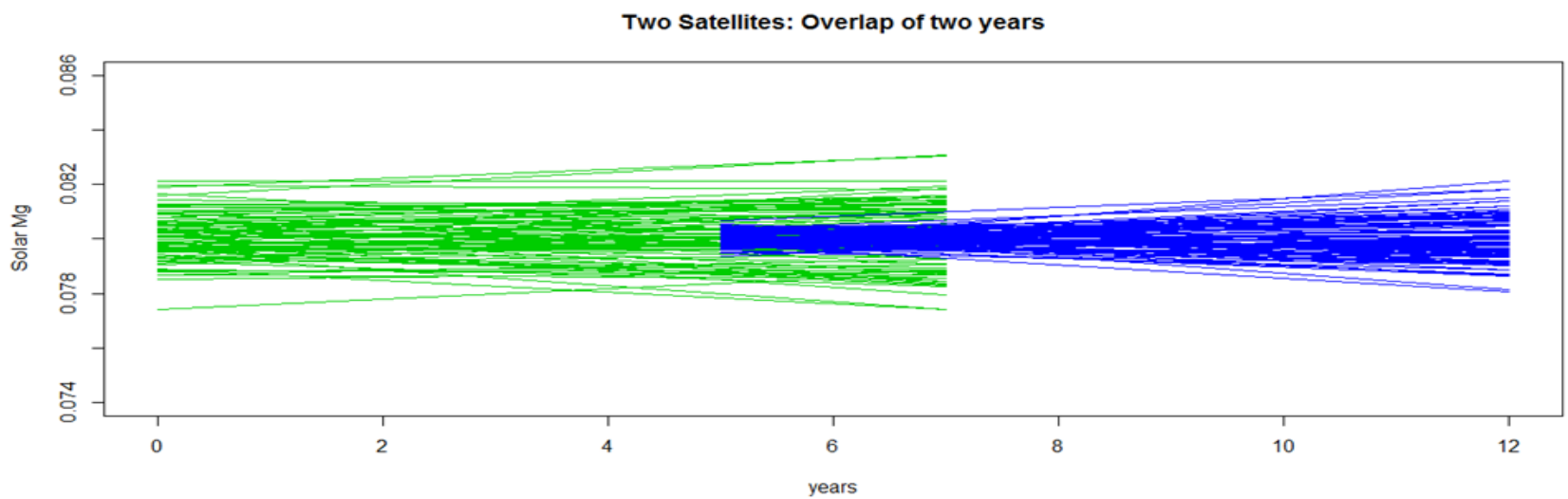
- Adjustments:
- $Environmental\ Data = Mean + Linear\ Drift + Offset_{\tau} + Noise(0,1)$ $\ SE_{mean} \cong {}^{\sigma}/_{\sqrt{n}}\ \frac{\sqrt{1+\varphi}}{\sqrt{1-\varphi}}$
- Inverting:
- $Years\ to\ Estimate\ a\ Drift\ \cong\ 12 * \left[1.96\ \frac{\sigma}{|drift|} *\right.$

Why does this matter?

- We likely can not “analyze this” to remove offsets, drifts and jumps.
- This is assuming we have already incorporated everything we know about the instruments.
- We can not add “weighted uncertainty” to the data when we perform trend regression.
- Weighted regression assumes no systematic changes in the data.

Is this a large or small effect?

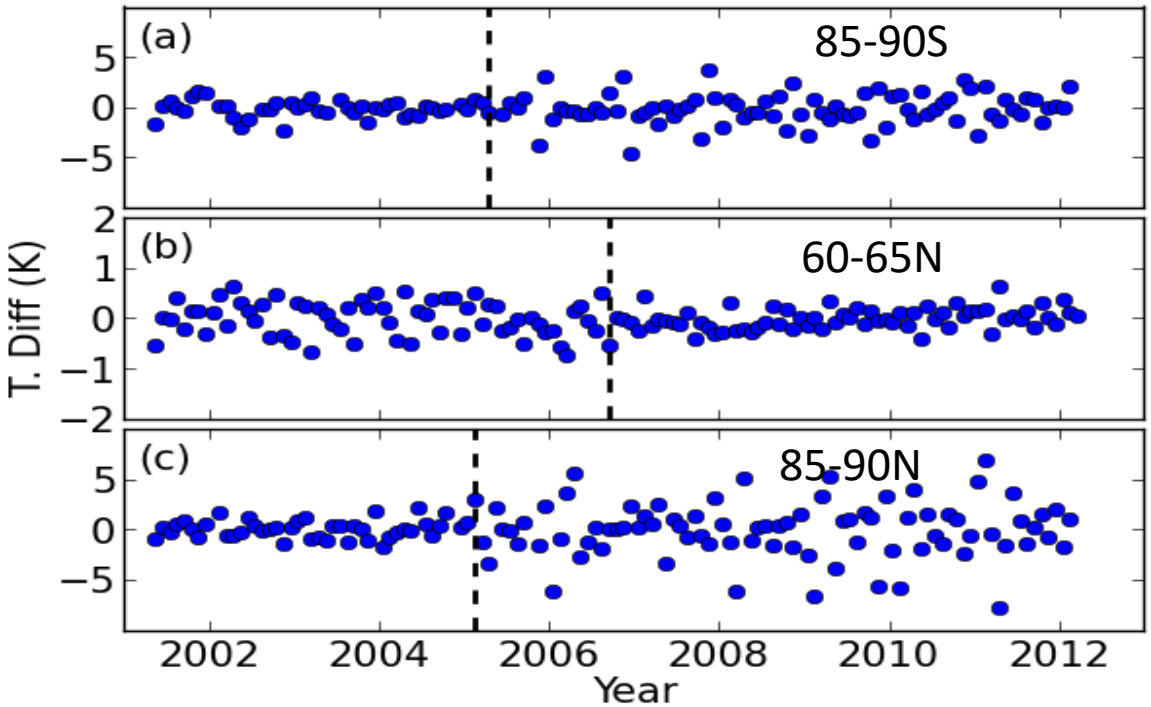




Complications with Earth observations

- Temperature overlap
- http://www.atmos-meas-tech-discuss.net/amt-2014-372/

- Footprint match-up
- Temporal match-up
- Location dependent results.



Conclusion

- Satellites provide some of the most important data for understanding the Earth System: continuous records are valuable to science and to policy.
- Proper overlap of satellites is critical for constructing the long-term records and understanding our confidence in those records.
- Merging satellite records is extremely difficult; uncertainty is inherent in the final product.
- We can estimate the amount of time needed to achieve a particular level of uncertainty in the long-term records.
- Much more work to be done in this area.

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