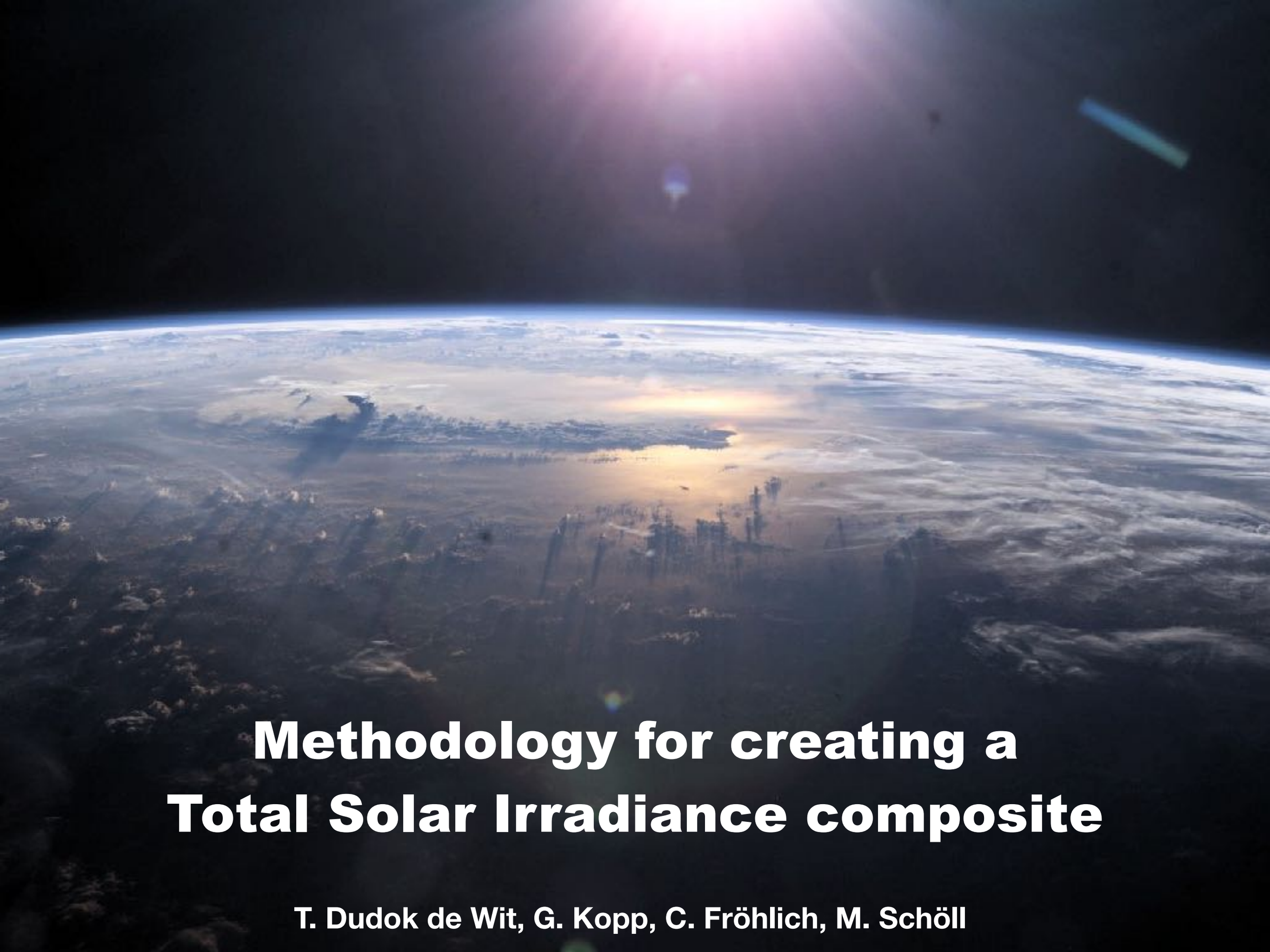
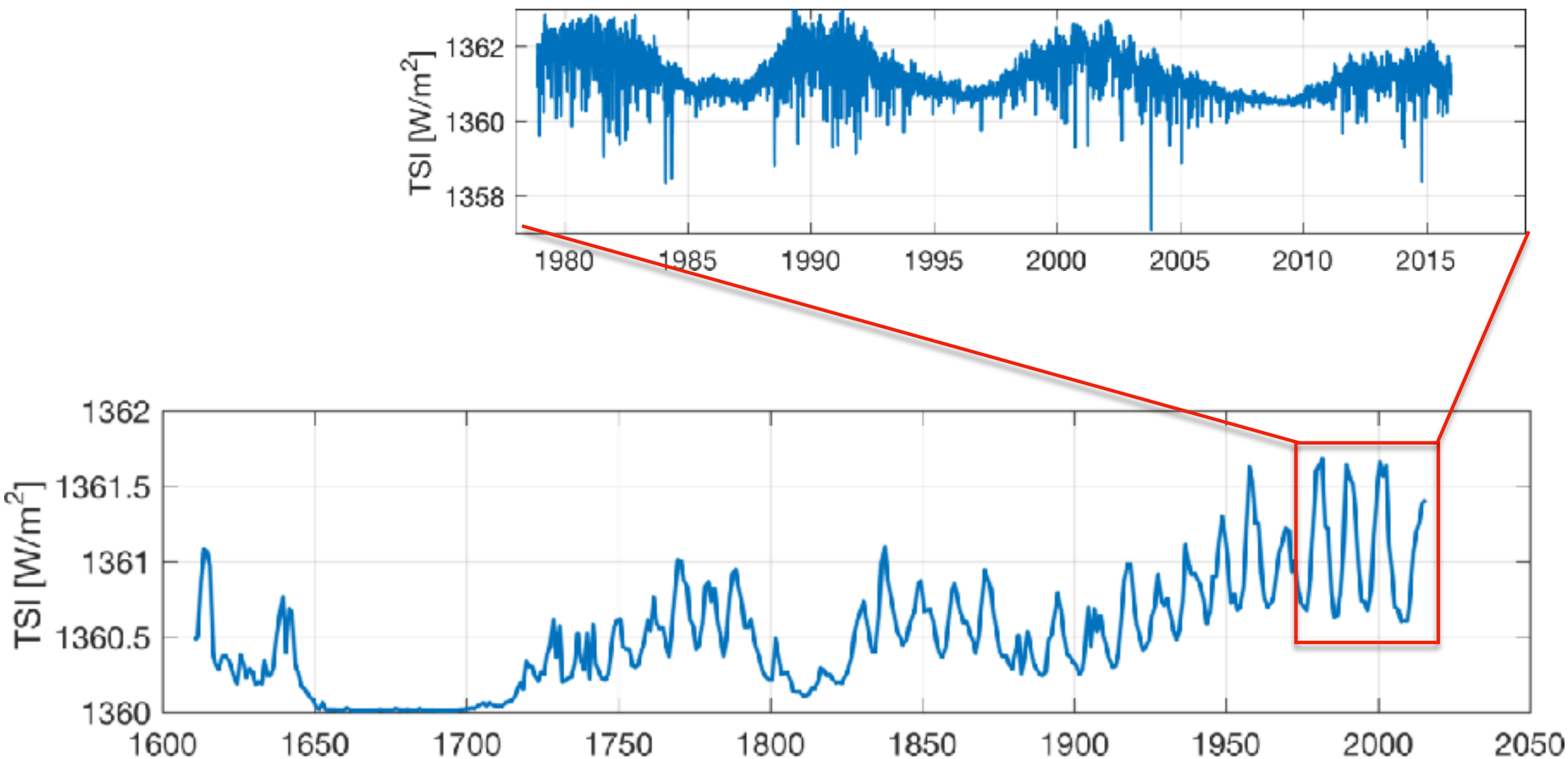


Methodology for creating a Total Solar Irradiance composite

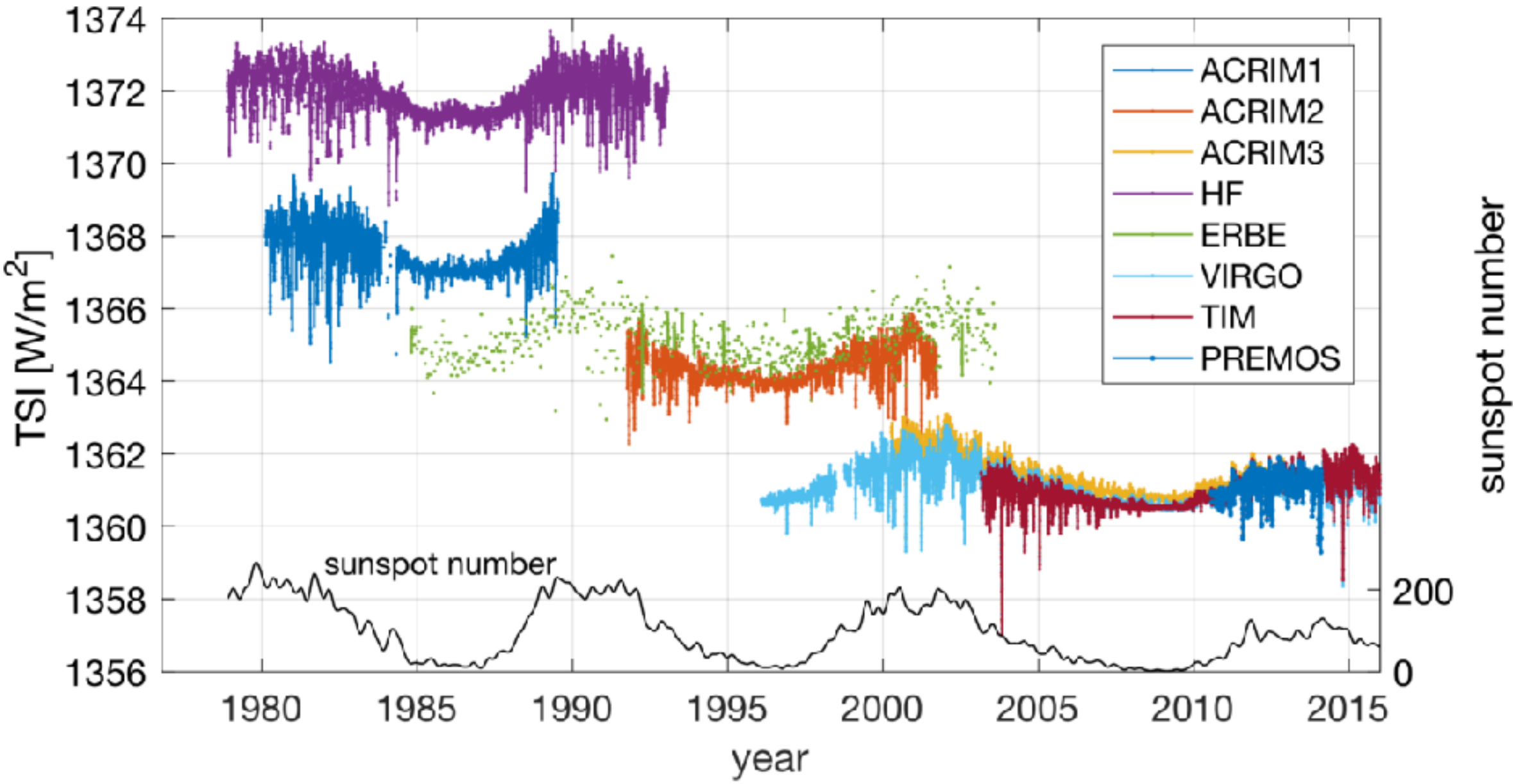
T. Dudok de Wit, G. Kopp, C. Fröhlich, M. Schöll

Why TSI observations matter

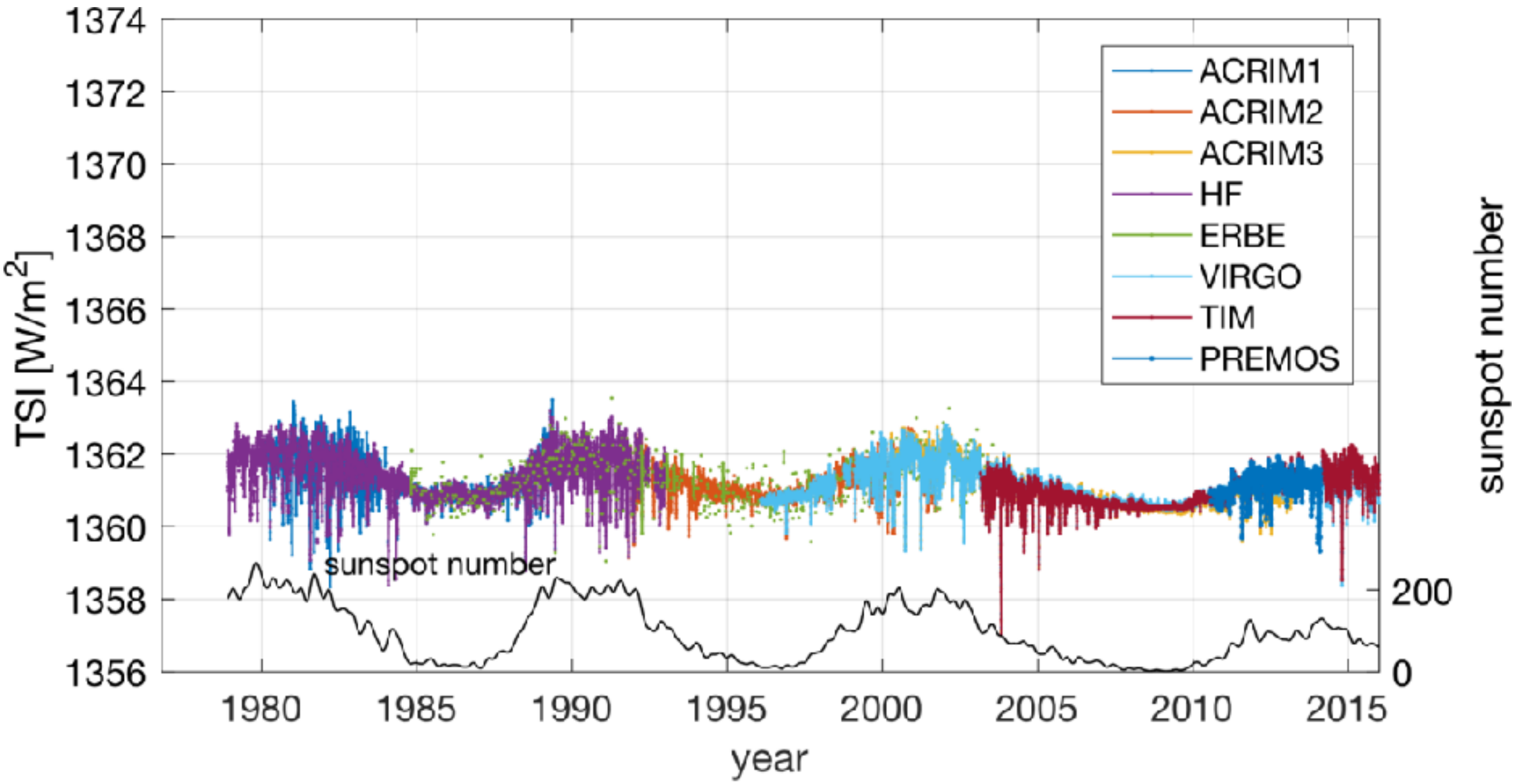
- Total Solar Irradiance observations are the key to understanding long-term solar variations



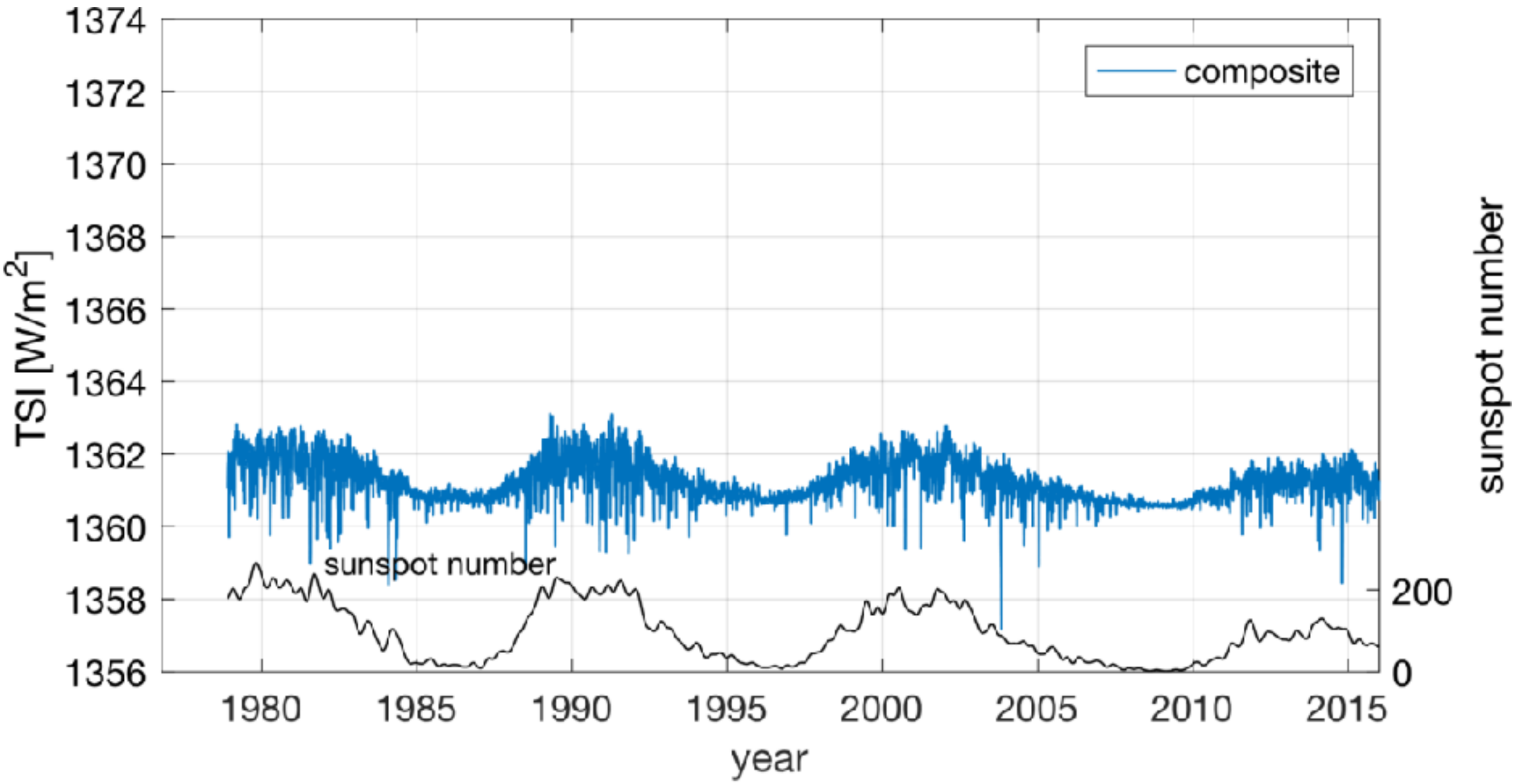
Observations we have



What we would like to have



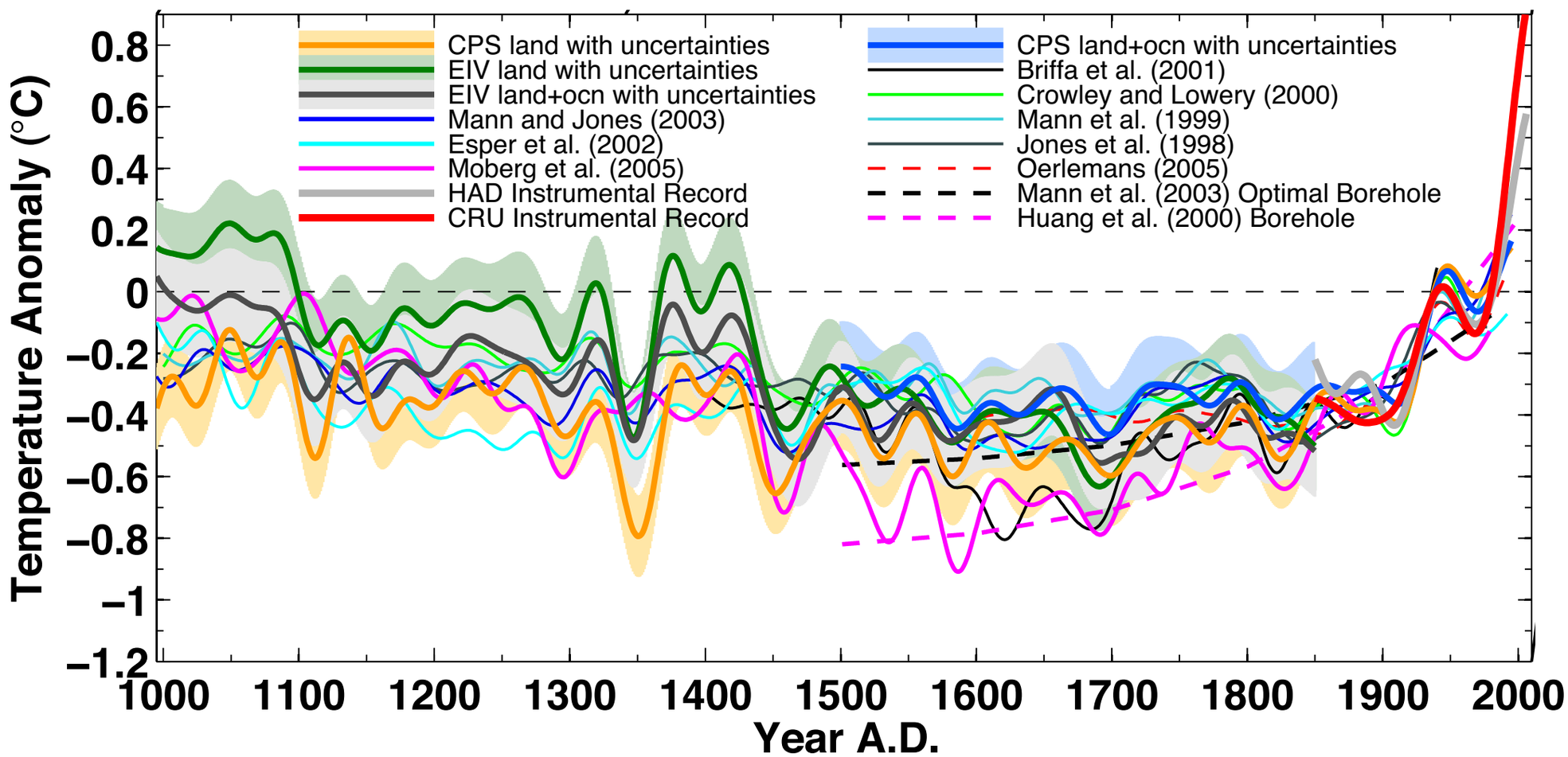
What we *really* would like to have



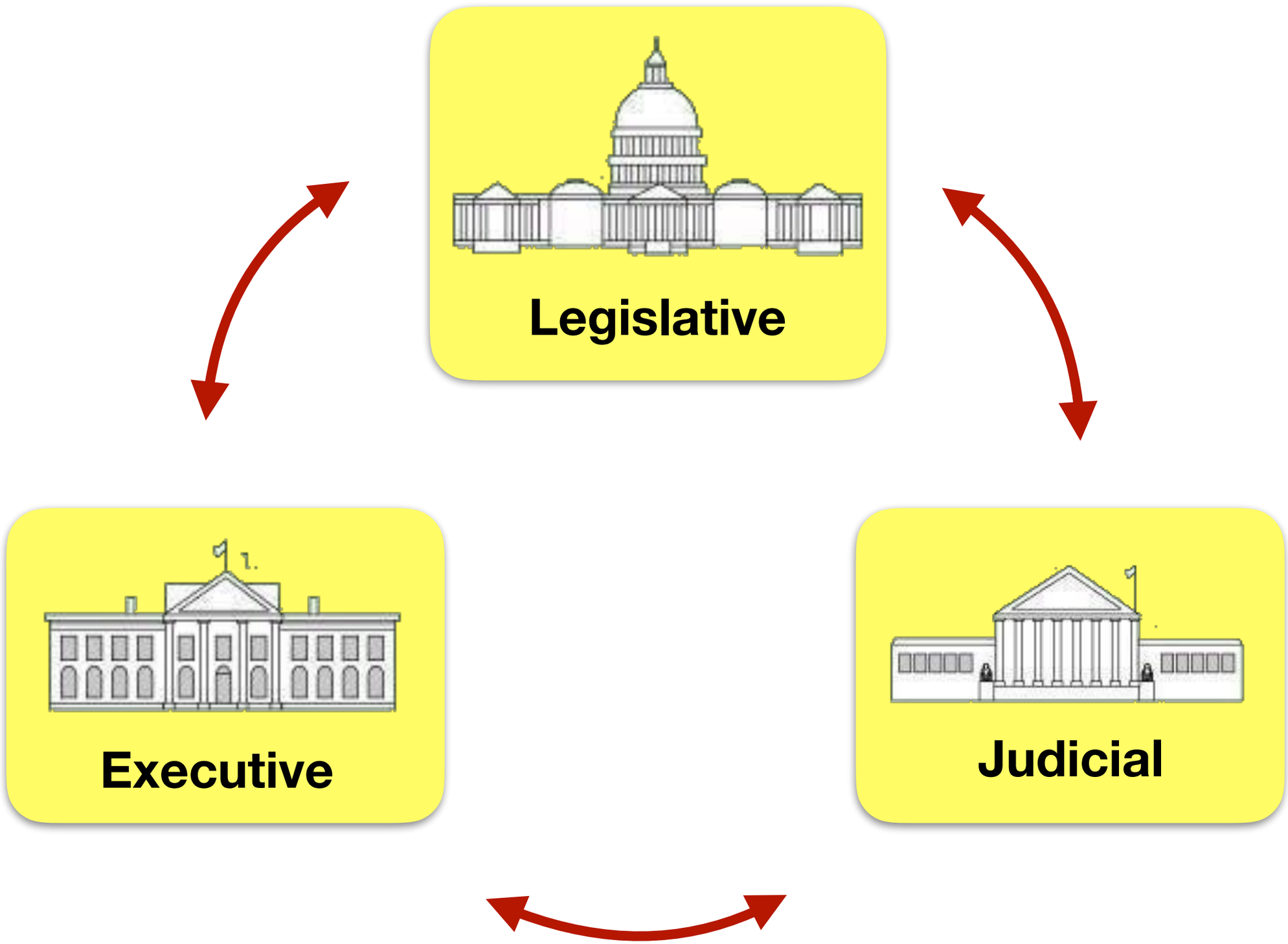
A common problem

- The problem of making composite arises other contexts

  e.g. Mann et al. (2008)



Separation of powers



Separation of powers

DATA

What prior information goes into the correction of the original data ?

METHOD

What is the best way of making the composite ?

APPLICATION

What do I learn from applying these data ?

Separation of powers

DATA

What prior information goes into the correction of the original data ?

METHOD

What is the best way of making the composite ?

APPLICATION

What do I learn from applying these data ?

Open science : **transparency, replicability, traceability, community endorsement**

Making of the TSI composite

4-step procedure

1. Estimate the absolute TSI level
2. Estimate the uncertainty of each TSI record
3. Build composite by weighted averaging
4. Estimate the uncertainty of the composite

1. Absolute level

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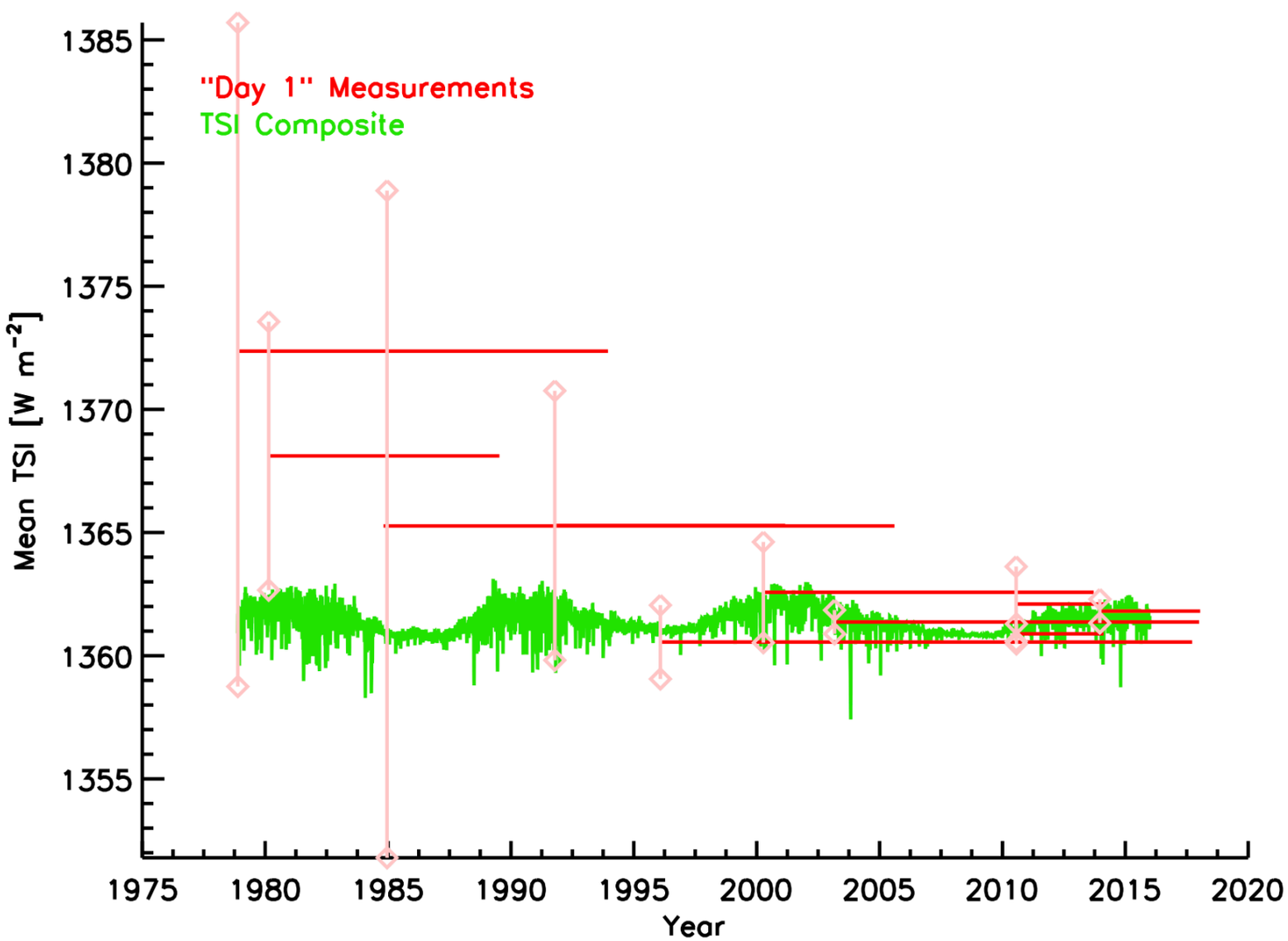
1. Estimate absolute TSI

- Absolute level :
  - average of “Day 1” absolute value of each instrument
  - weighted by uncertainty



2. Uncertainties

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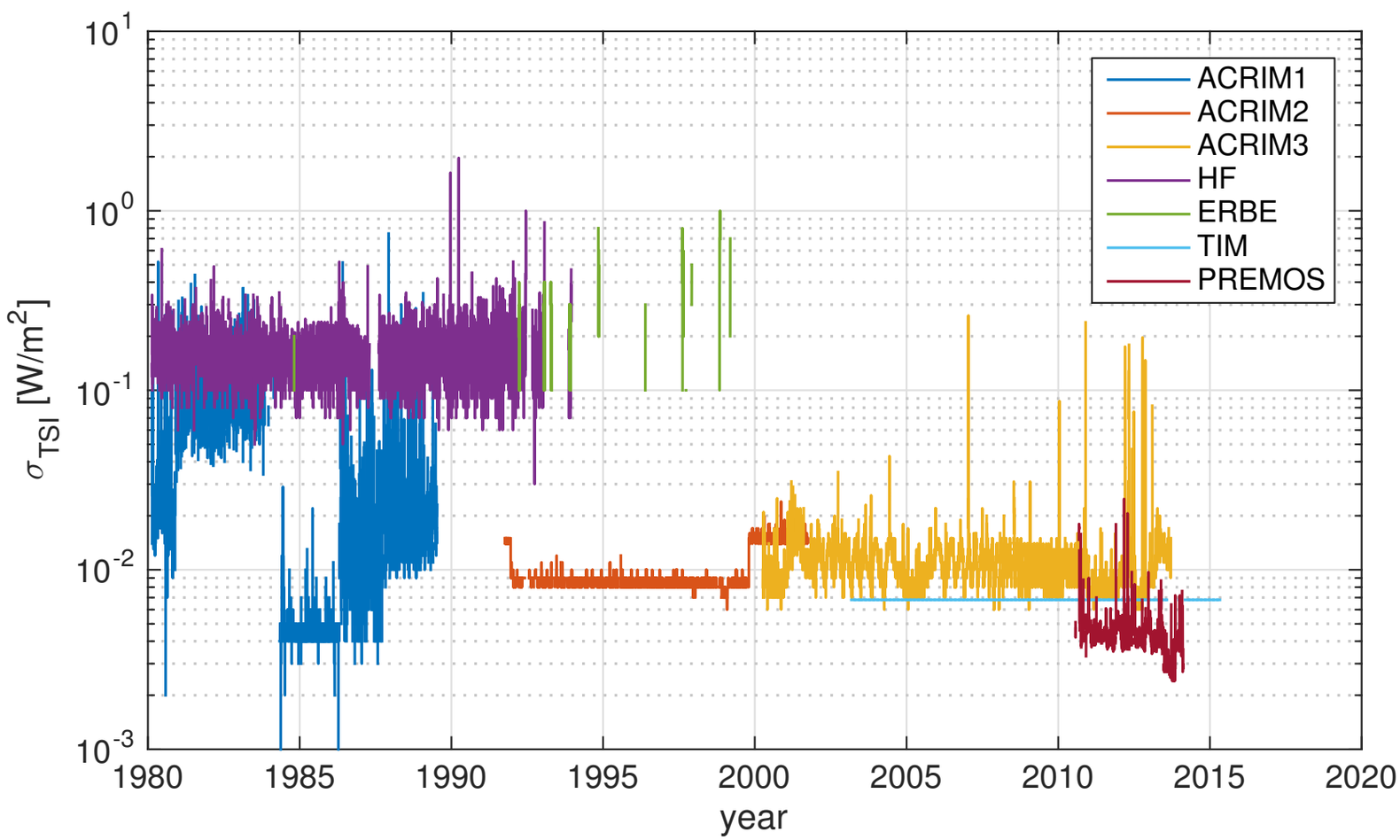
2. Uncertainties

- Uncertainties
  - essential to assign proper weights to each instrument
- But instrument teams provide very different (inconsistent) values



2. Uncertainties

- Uncertainties
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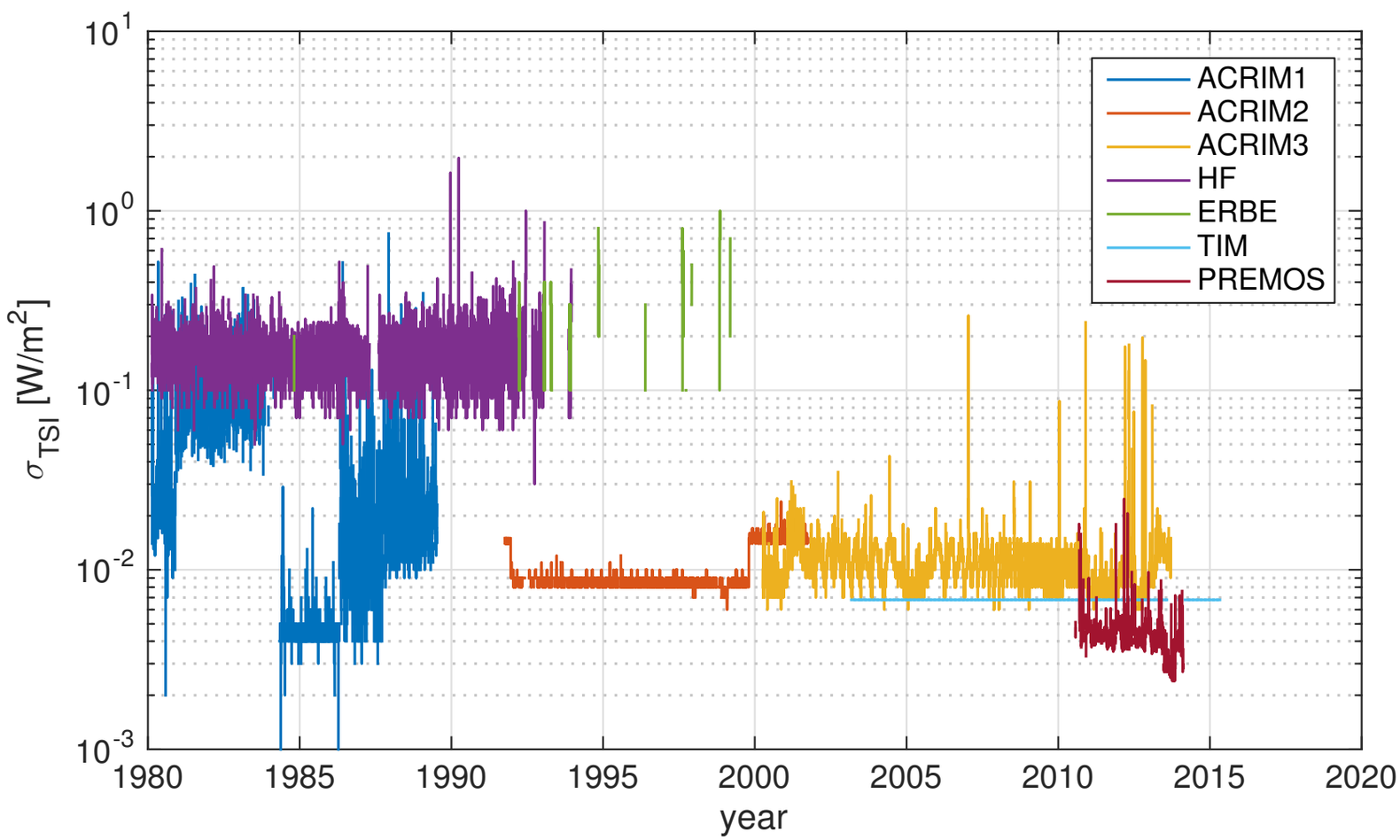
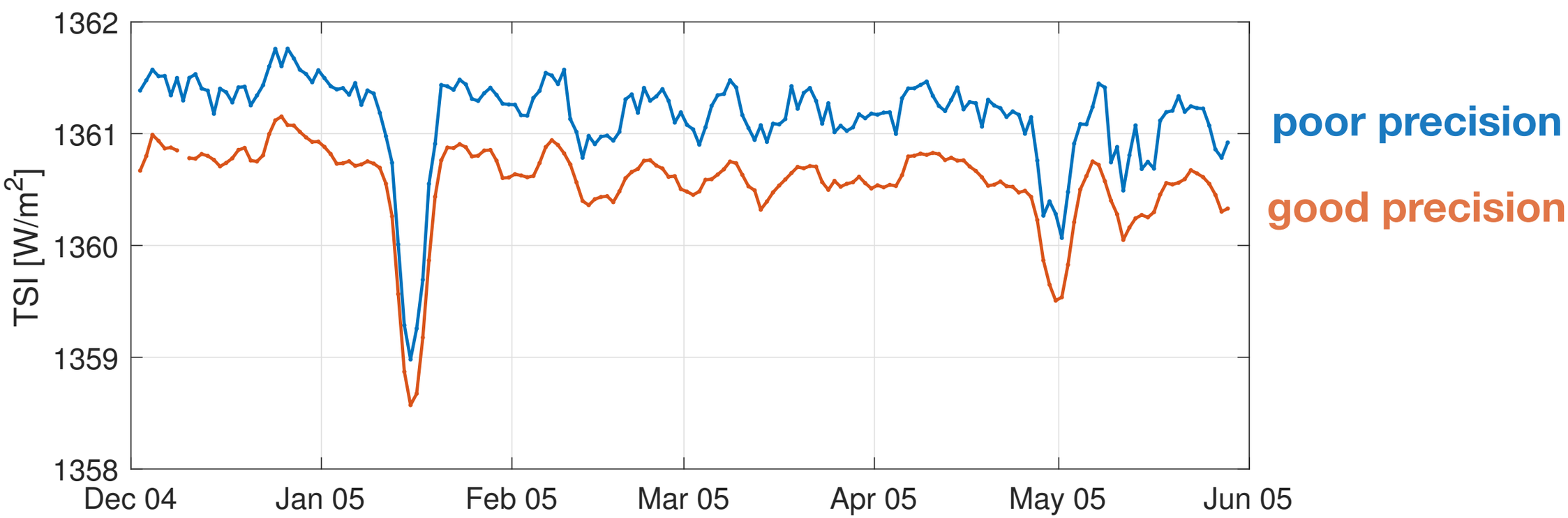


⇒ we need to build our own uncertainty estimates

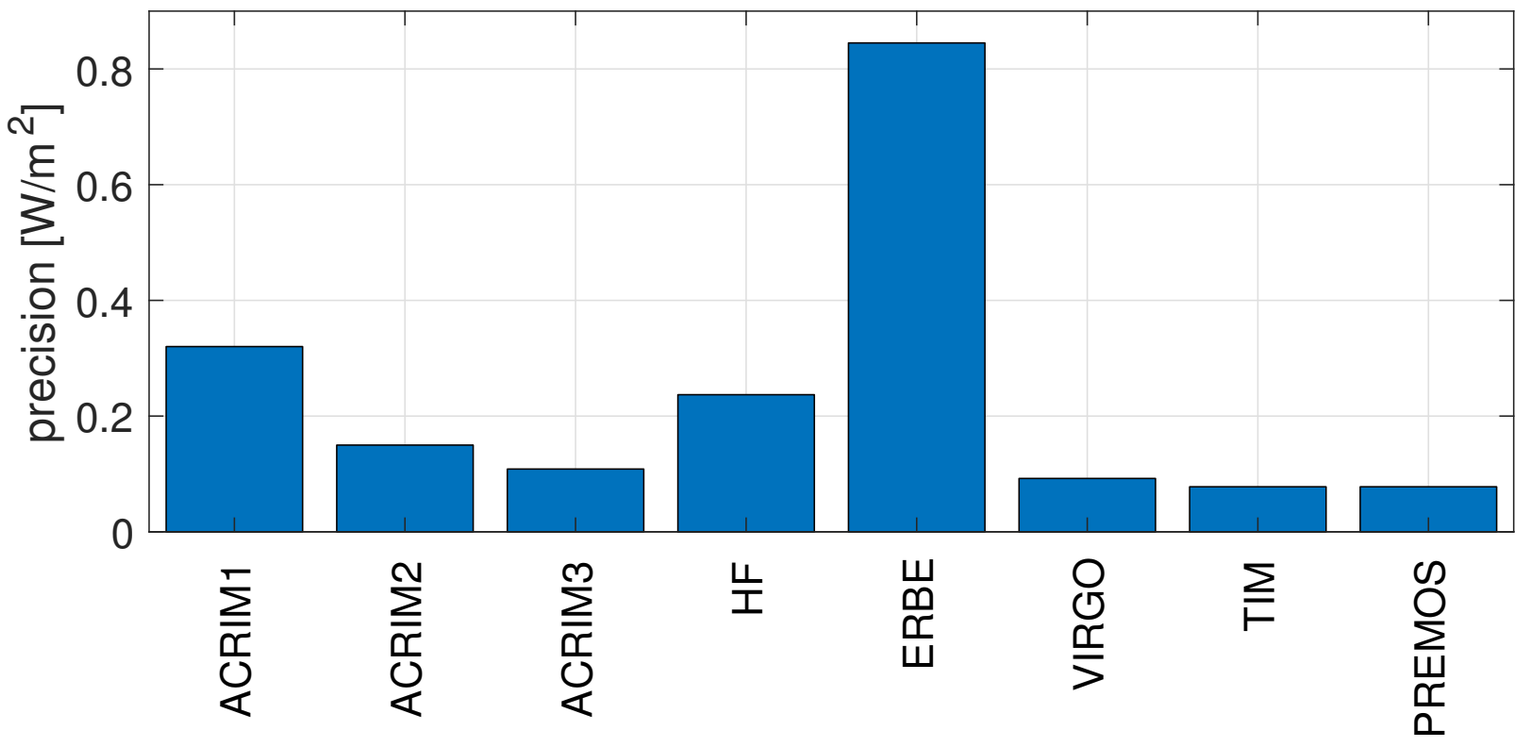
2. Uncertainties

- We tested 4 different estimators
- General idea : short-term uncertainty (precision) affects short-term predictability



2. Uncertainties

- Average precision of different records



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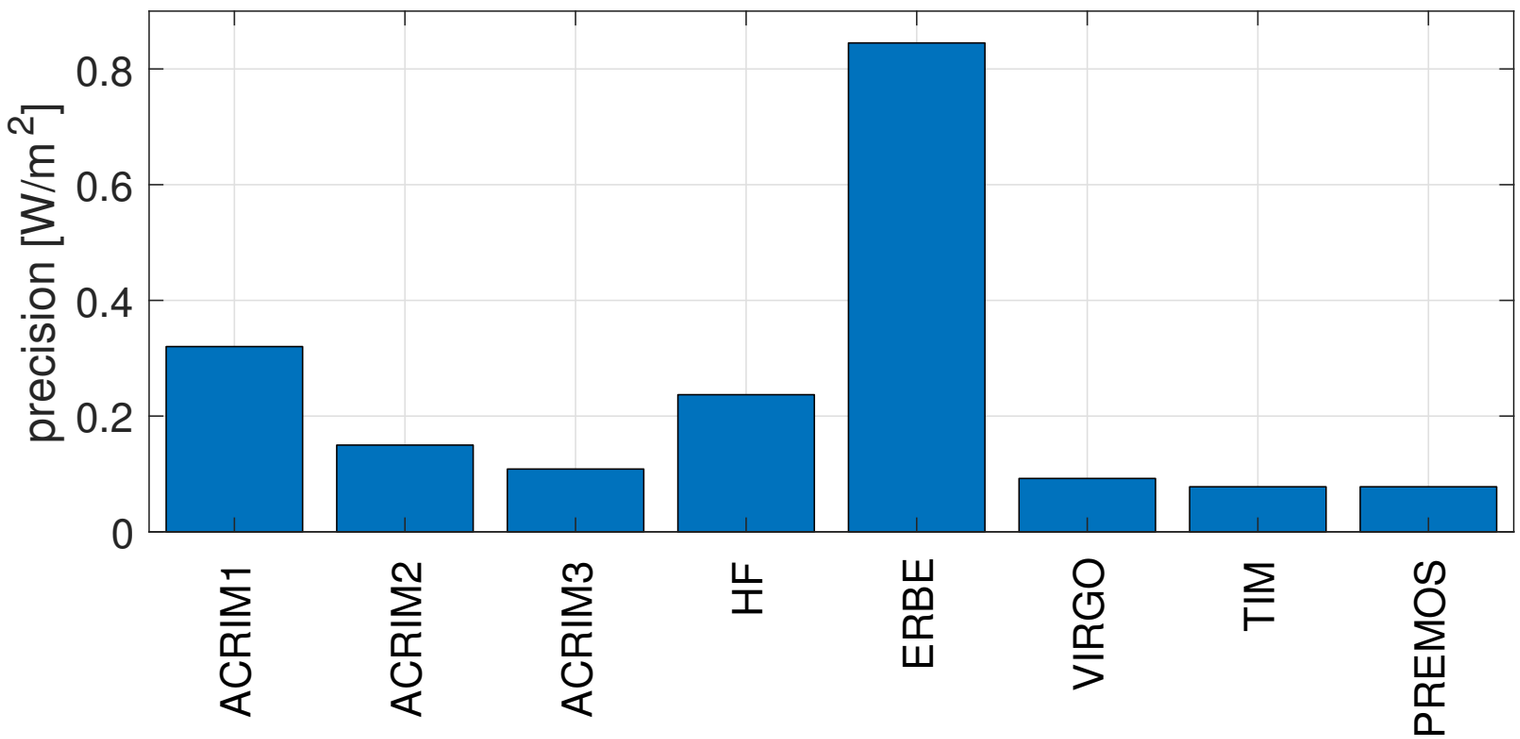
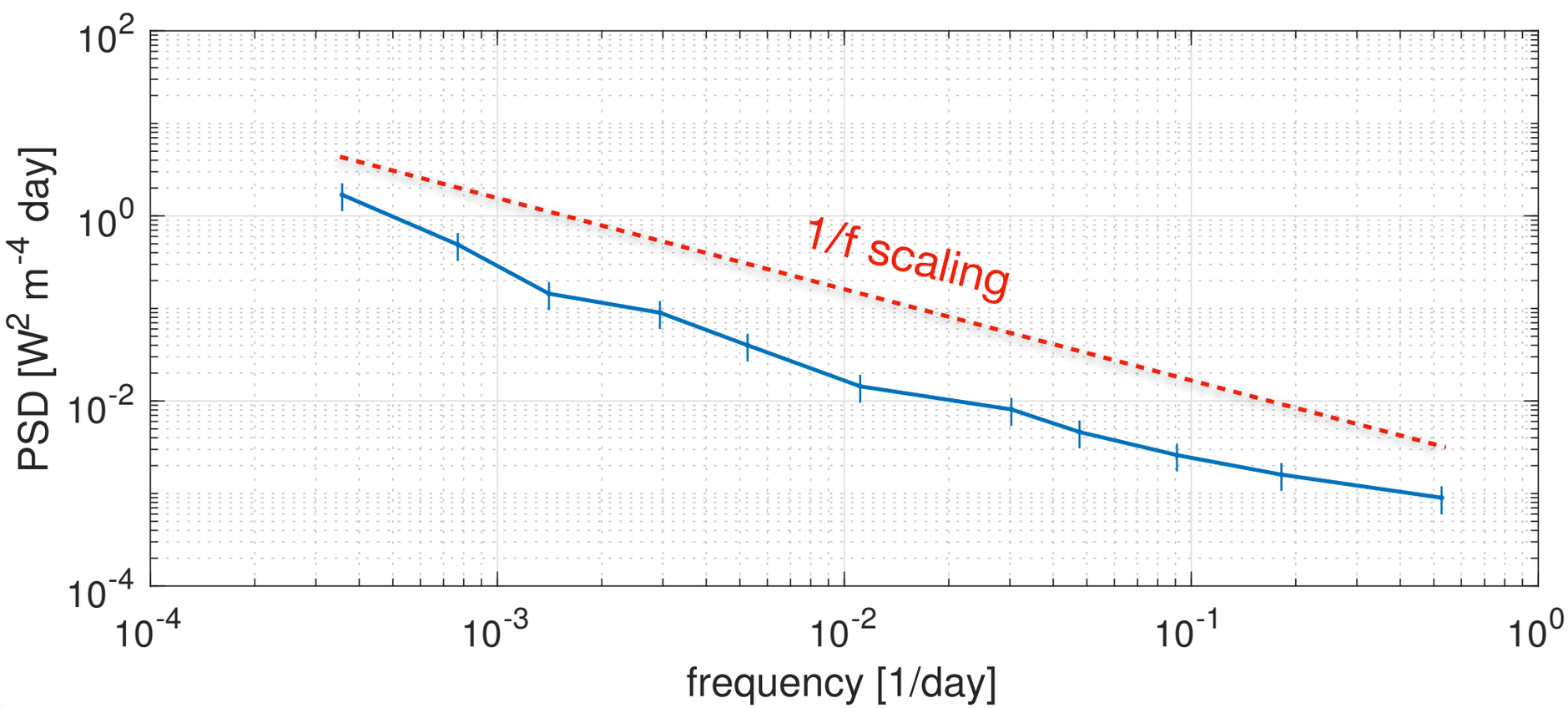


How do we estimate uncertainties at longer time-scales (i.e. stability) ?

2. Uncertainties

- We observe a 1/f scaling in the uncertainty
- Use this scaling to estimate uncertainties at all scales
  - instrumental noise is **not white**
  - 1/f scaling means long-range correlations (non stationarity)

power spectral density of uncertainty



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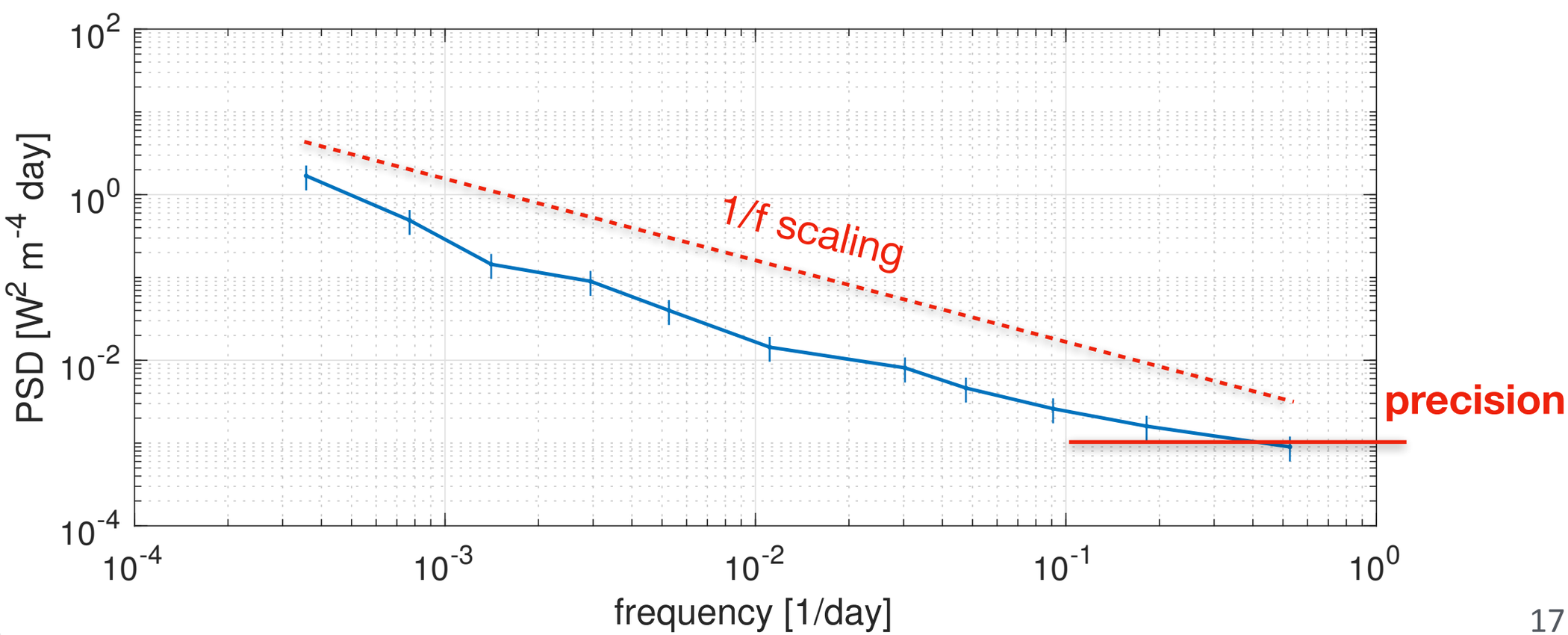

3. Making the composite

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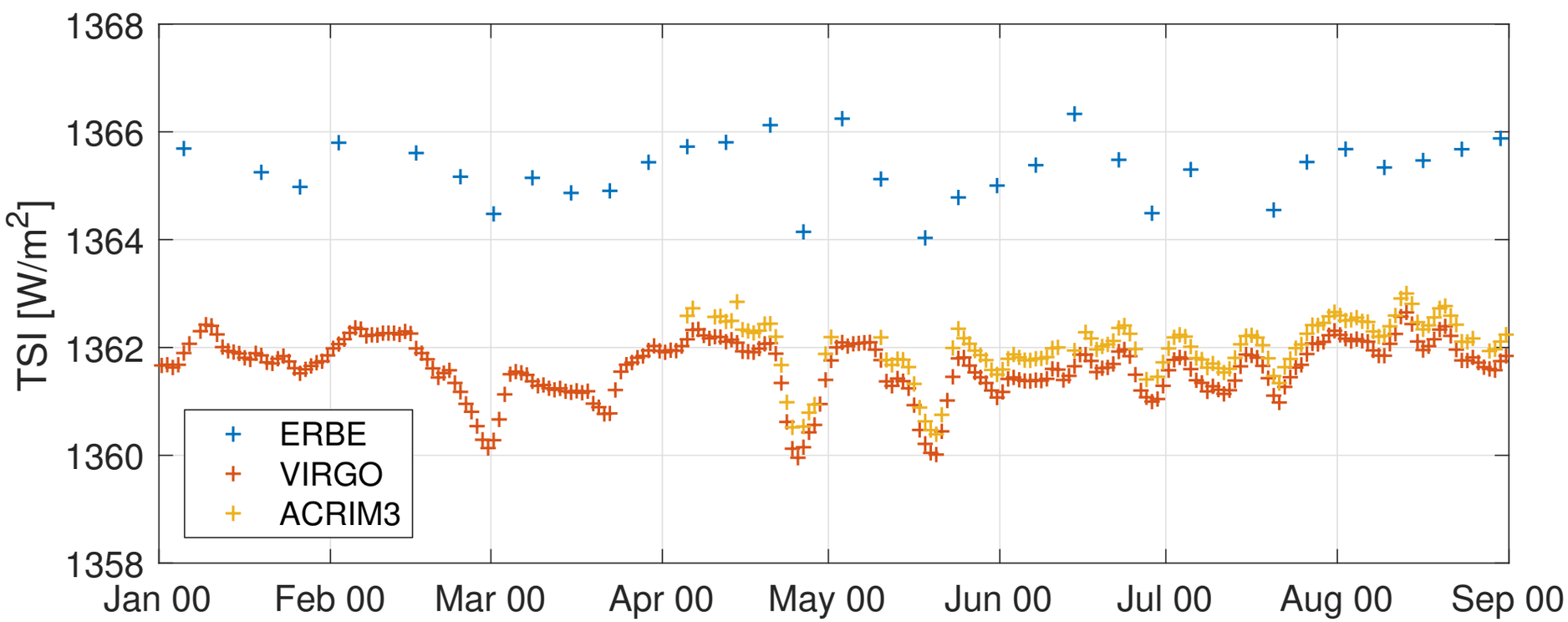
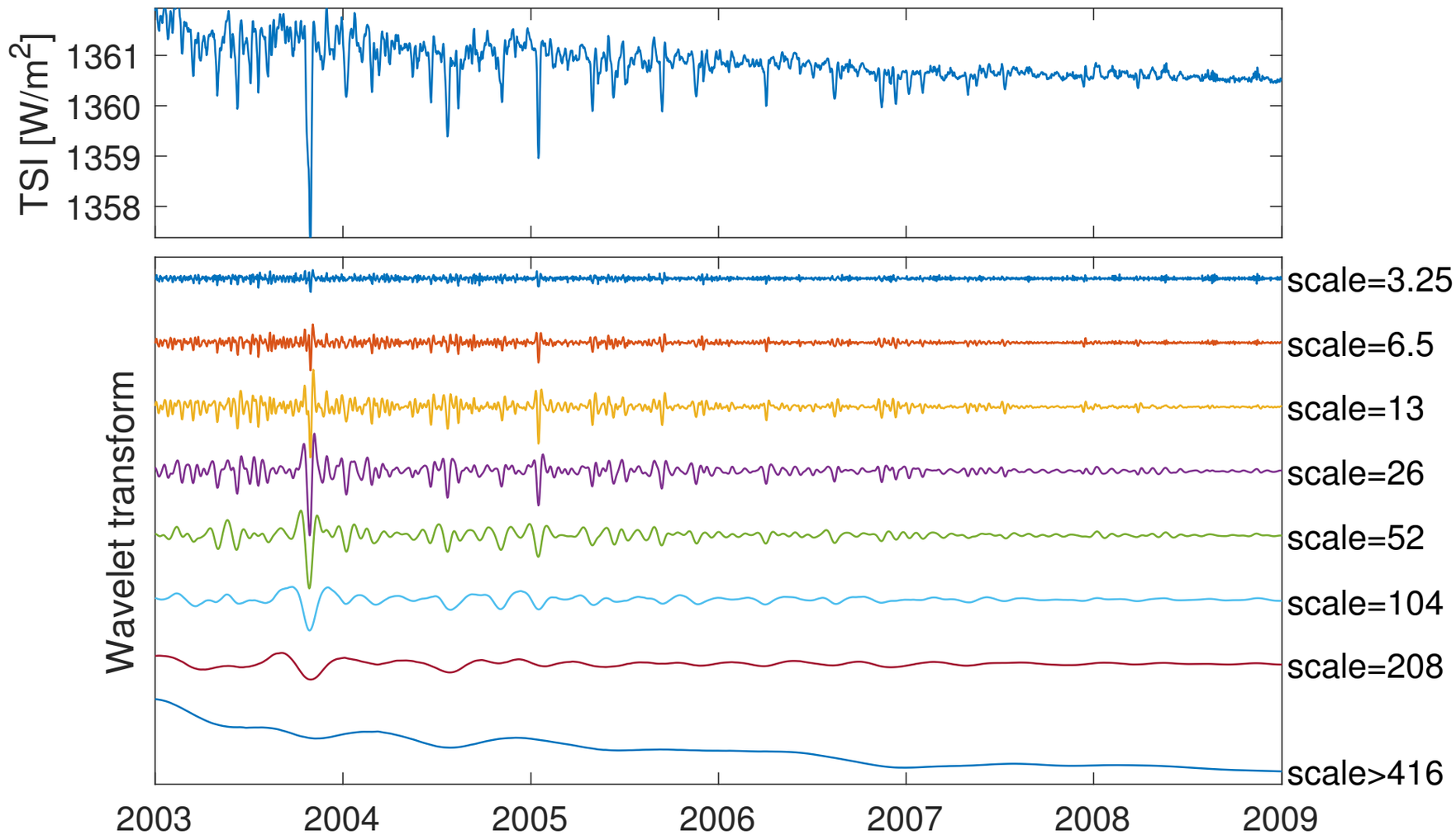
3. Making the composite

- Composite = average of all observations, weighted by their uncertainty
- How do we deal with discontinuous observations ?



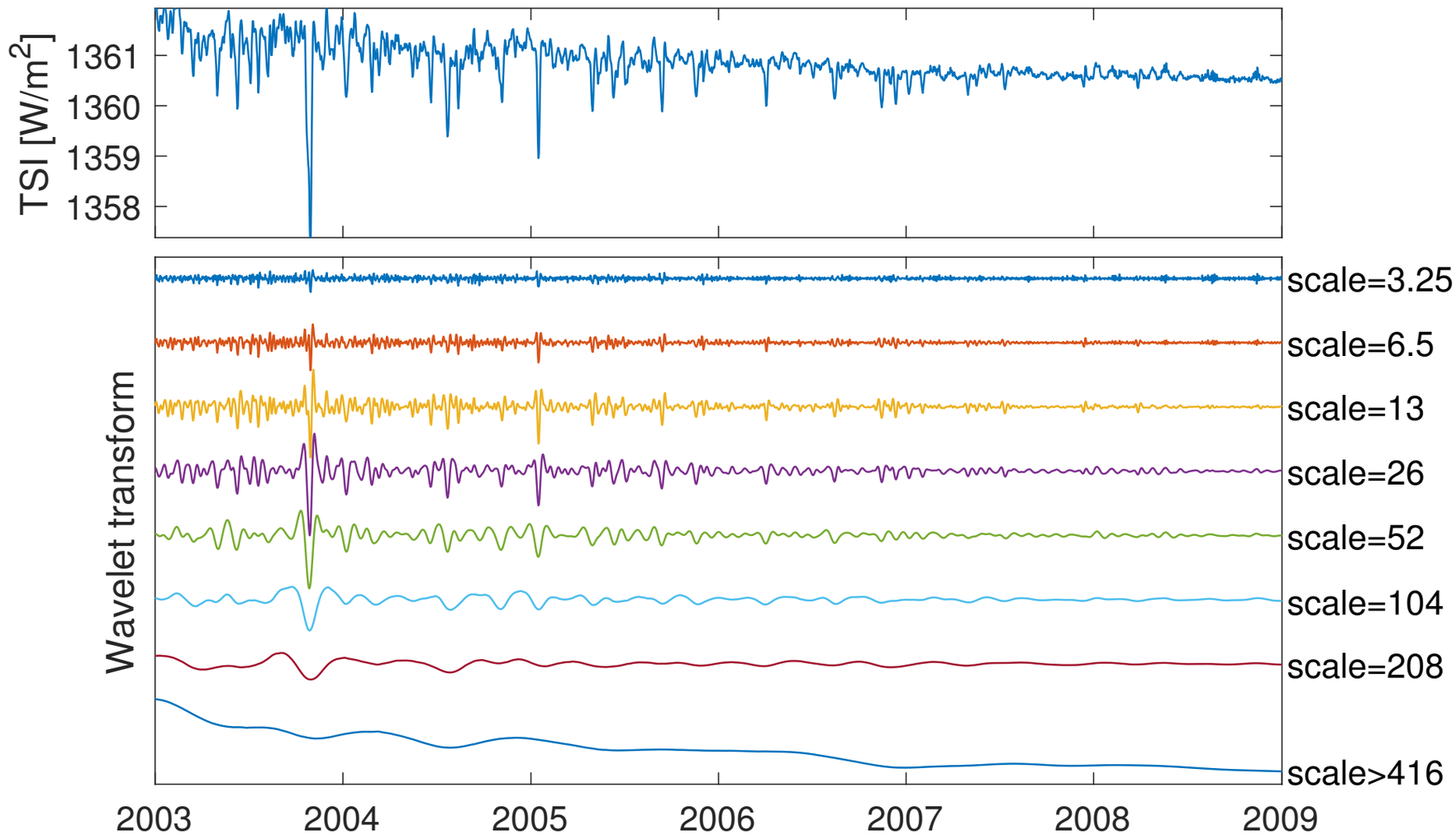
3. Making the composite

- Multiscale decomposition of the TSI : example



3. Making the composite

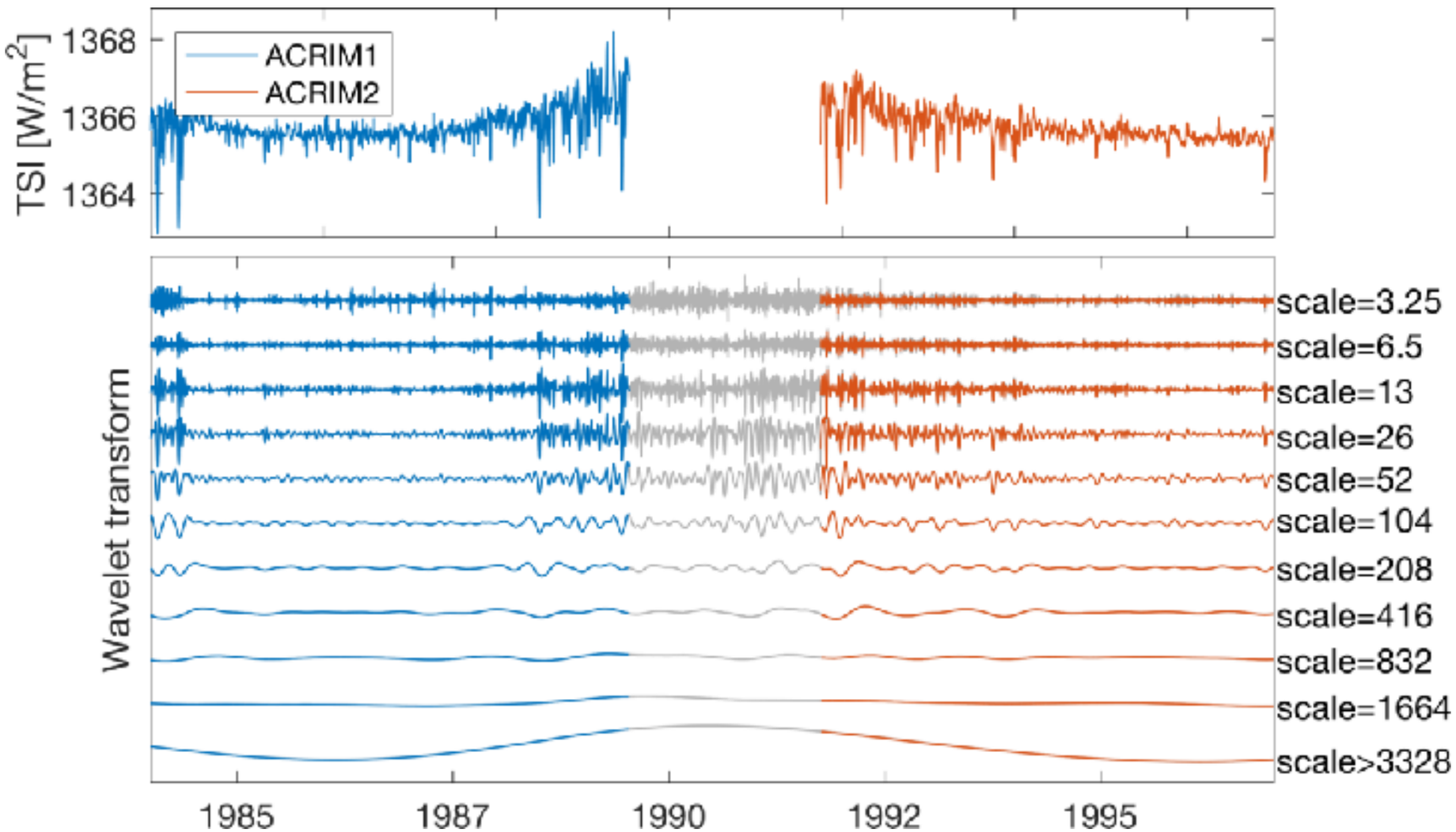
- Multiscale decomposition of the TSI : example



Solution: average the data scale-by-scale

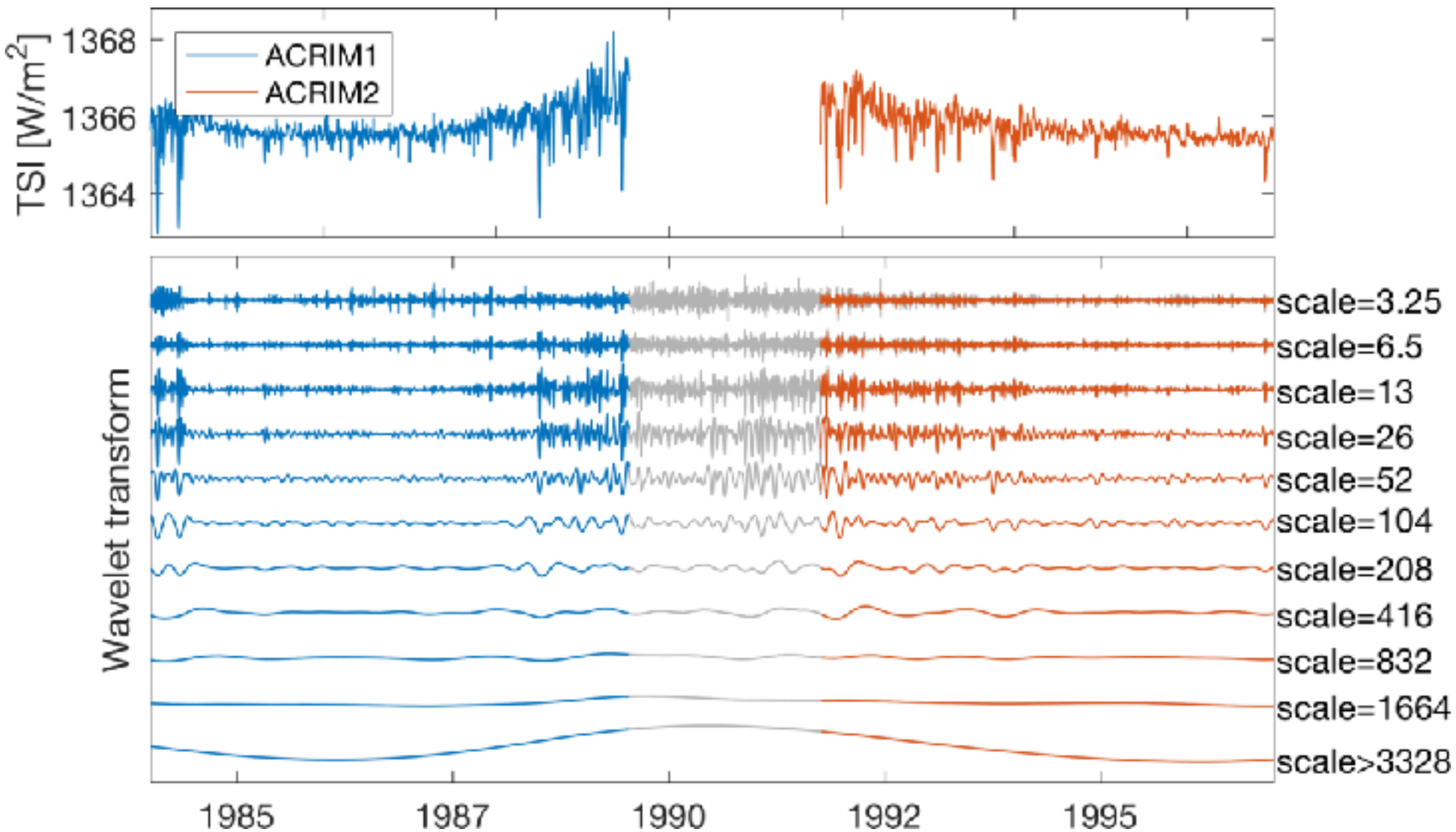
3. Making the composite

- Example : Bridging the ACRIM gap between 1989-1991



3. Making the composite

- Example : Bridging the ACRIM gap between 1989-1991



Stitching of partly-overlapping records is not essential for preserving long-term evolution

3. Uncertainty of the composite

ʌnˈsəːt(ə)nti of ðiː ˈkɒmpəzɪt

4. Uncertainties of the composite

- We propagate uncertainties by using a Monte-Carlo approach

- Errors are not white

  $\Rightarrow$ uncertainty on $TSI(t_1)-TSI(t_2)$ depends on $|t_1-t_2|$

4. Uncertainties of the composite

- We propagate uncertainties by using a Monte-Carlo approach

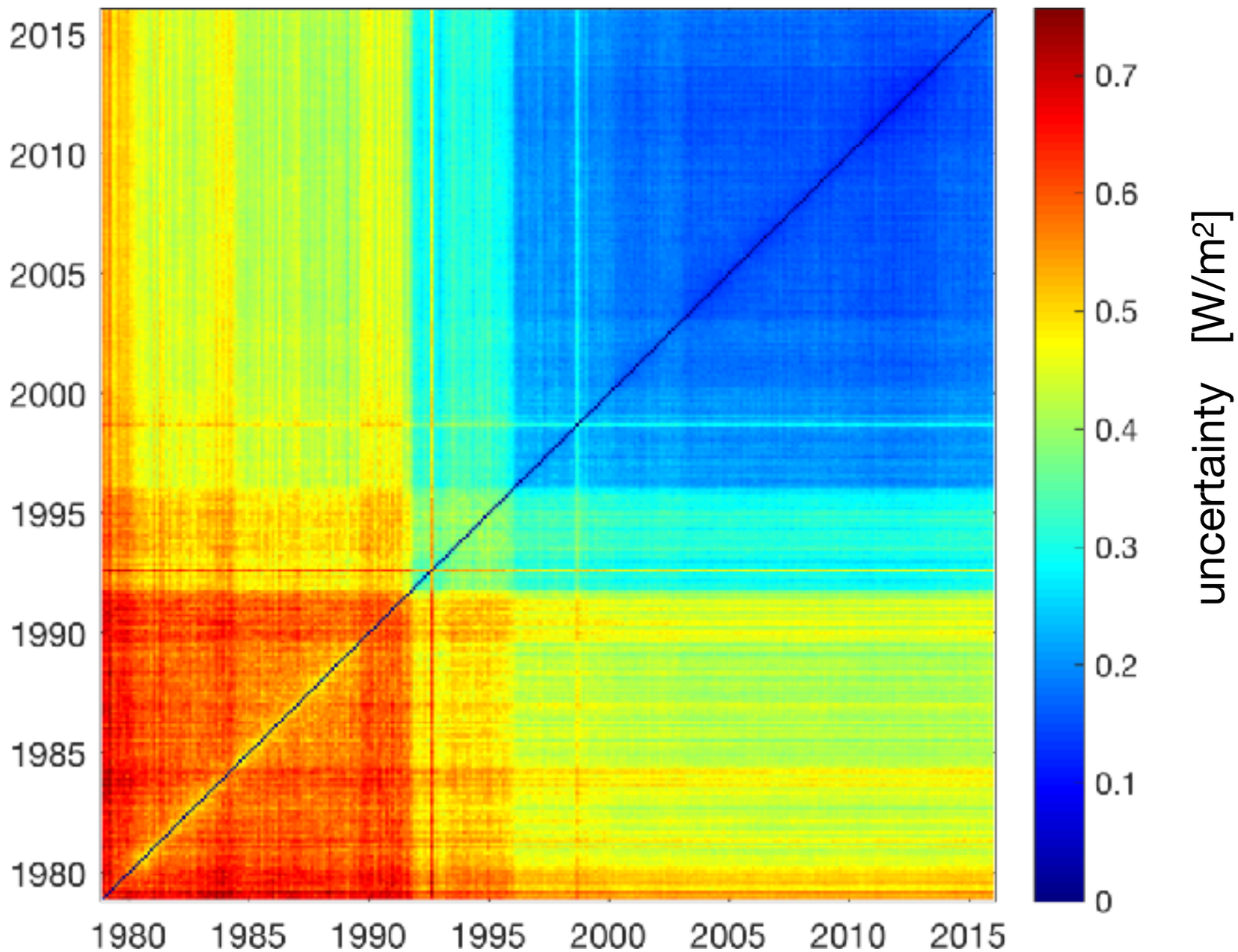
- Errors are not white

  $\Rightarrow$ uncertainty on $TSI(t_1)-TSI(t_2)$ depends on $|t_1-t_2|$

Expressing stability in % per decade is not correct

4. Uncertainties of the composite

- Uncertainties are best expressed in 2D



Finally, the composite

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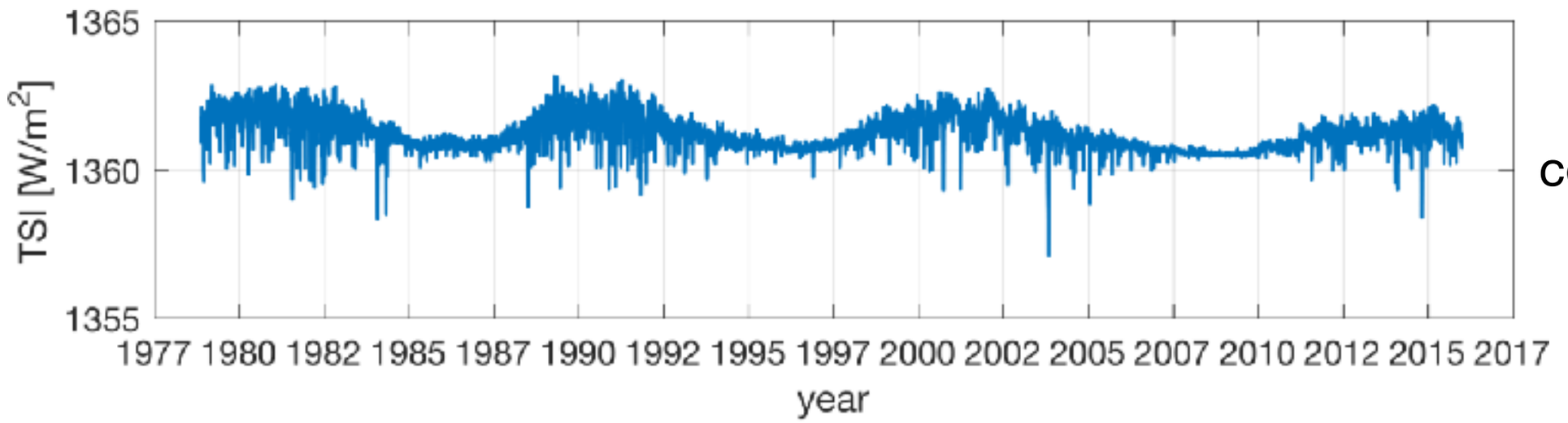
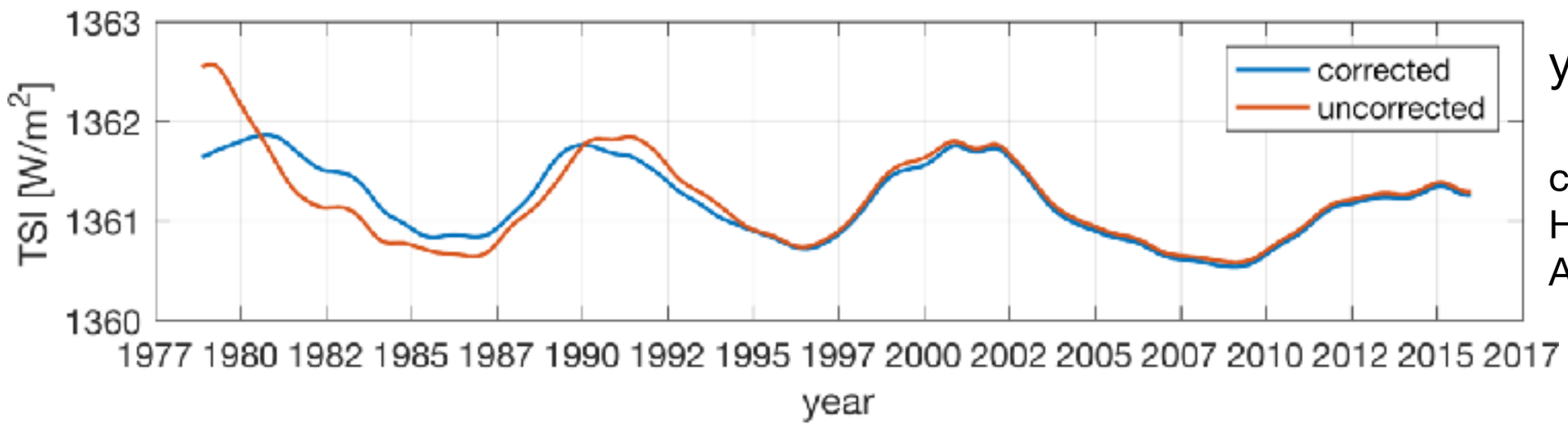
The composite

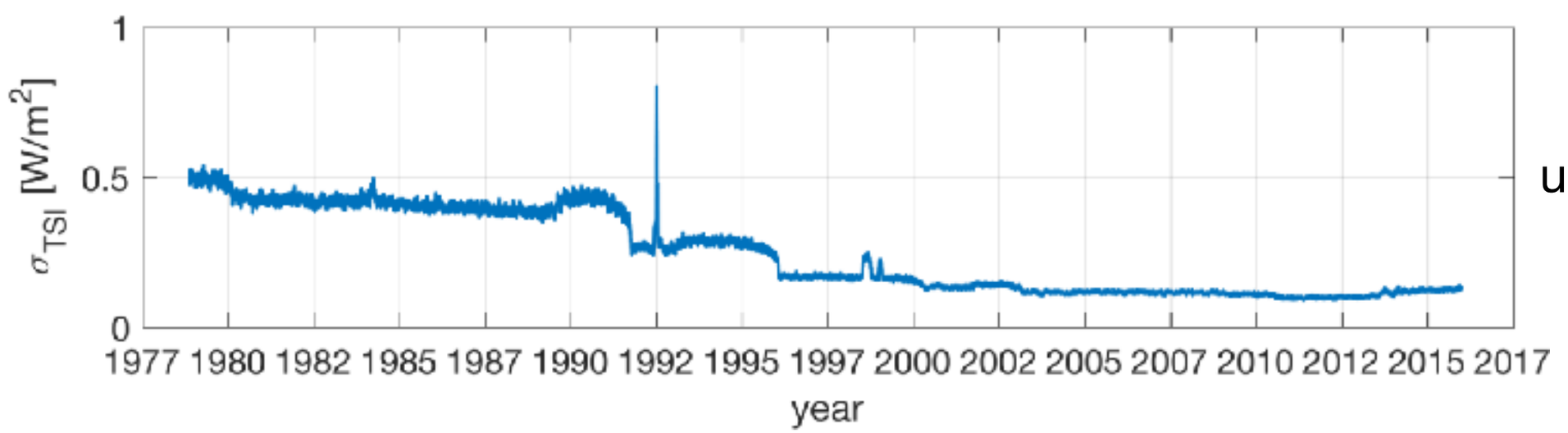


composite



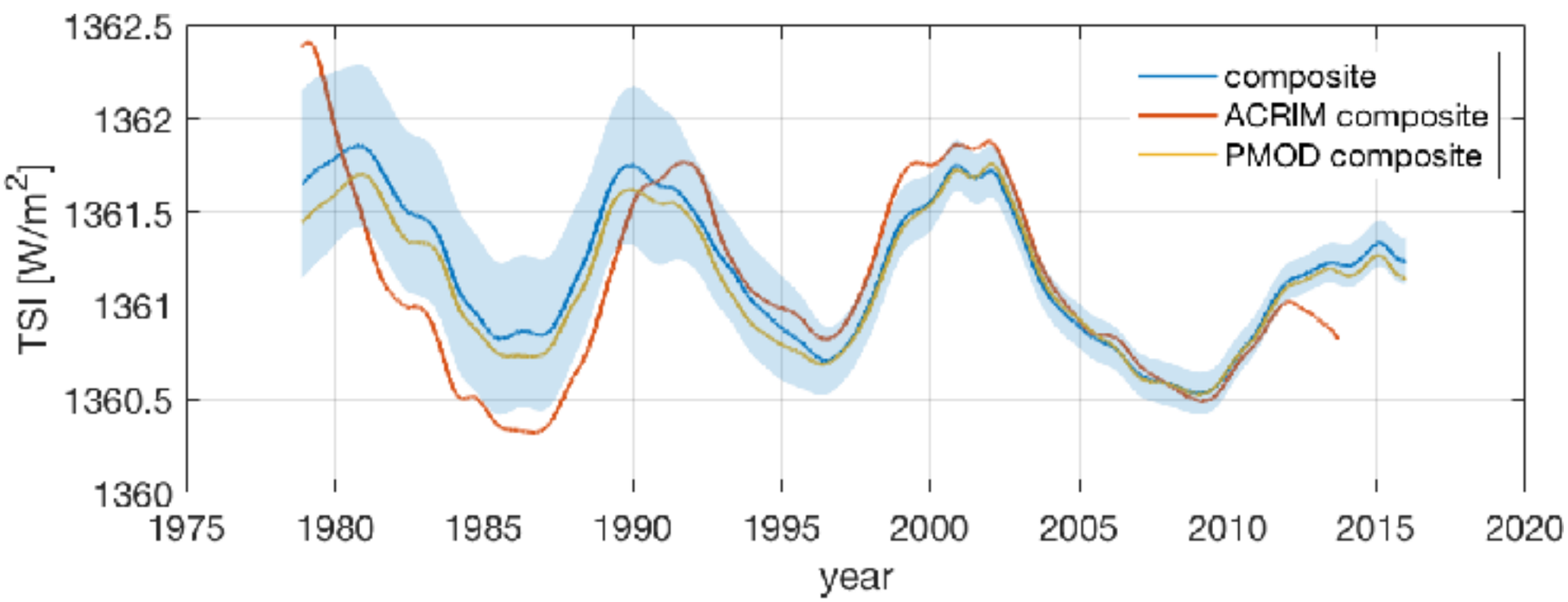
yearly average

corrected records: HF, ACRIM1, ACRIM2, ERBE

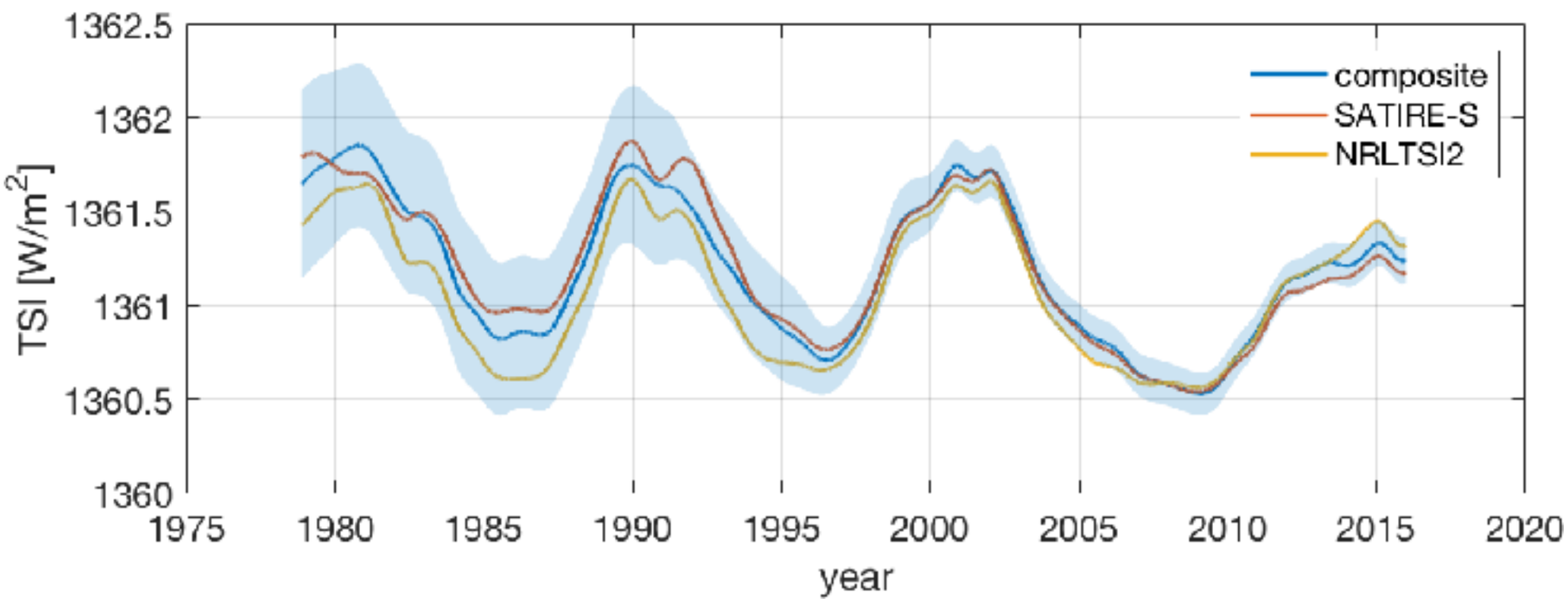


uncertainty

The composite



comparison with other observational composites



comparison with TSI models

Conclusion

- a new methodology for creating composites
- advantages :
  - performance : uses all available information + data-driven
  - transparency : all assumptions are made explicit
  - traceability : you know what your inputs are

- Open issues & future
  - validation : ongoing (issue with boundary conditions for wavelet transform)
  - include information from instrument teams (e.g. time-dependent errors)
  - provide guidance for observation strategy
  - application to spectral irradiance data & sunspot record data

OFFICIAL ANNOUNCEMENT

- Two initiatives to pursue this work, both led by Greg Kopp
  - ISSI team (2013-2014)
  - Solar Irradiance Science Team (SIST) proposal on “TSI Composite and Historical Extensions via Updated Sunspot Record” (2018)

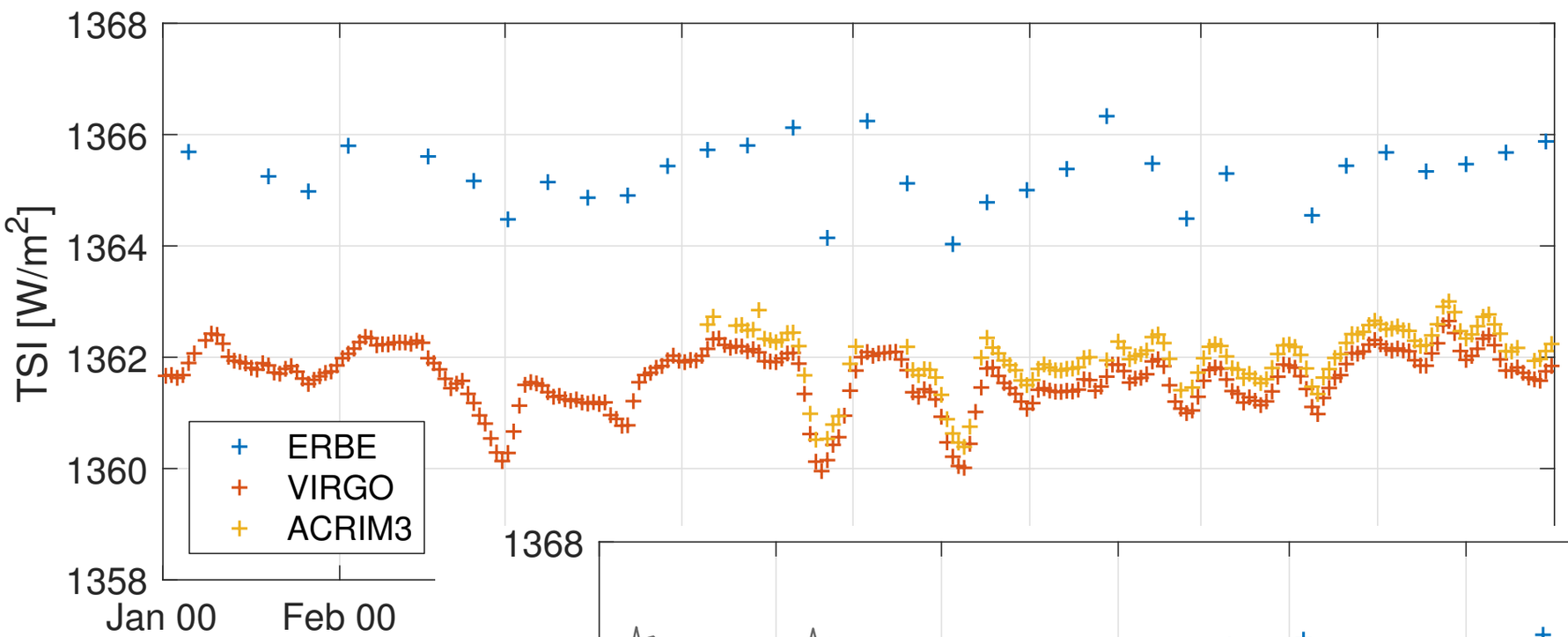
- The team will soon propose this new TSI composite to the community

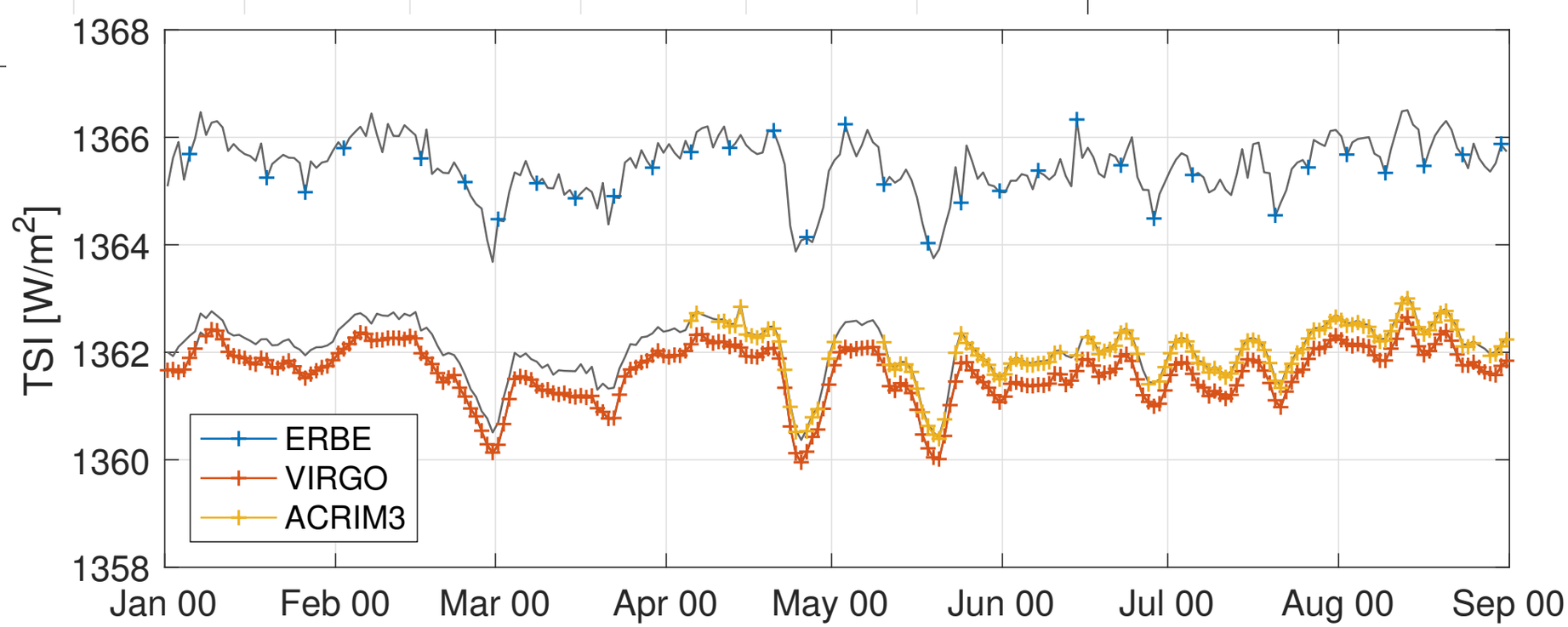
- Pending issues
  - tweaks and adjustments in the method
  - decision on what corrections should be made to the original data

Stay tuned !

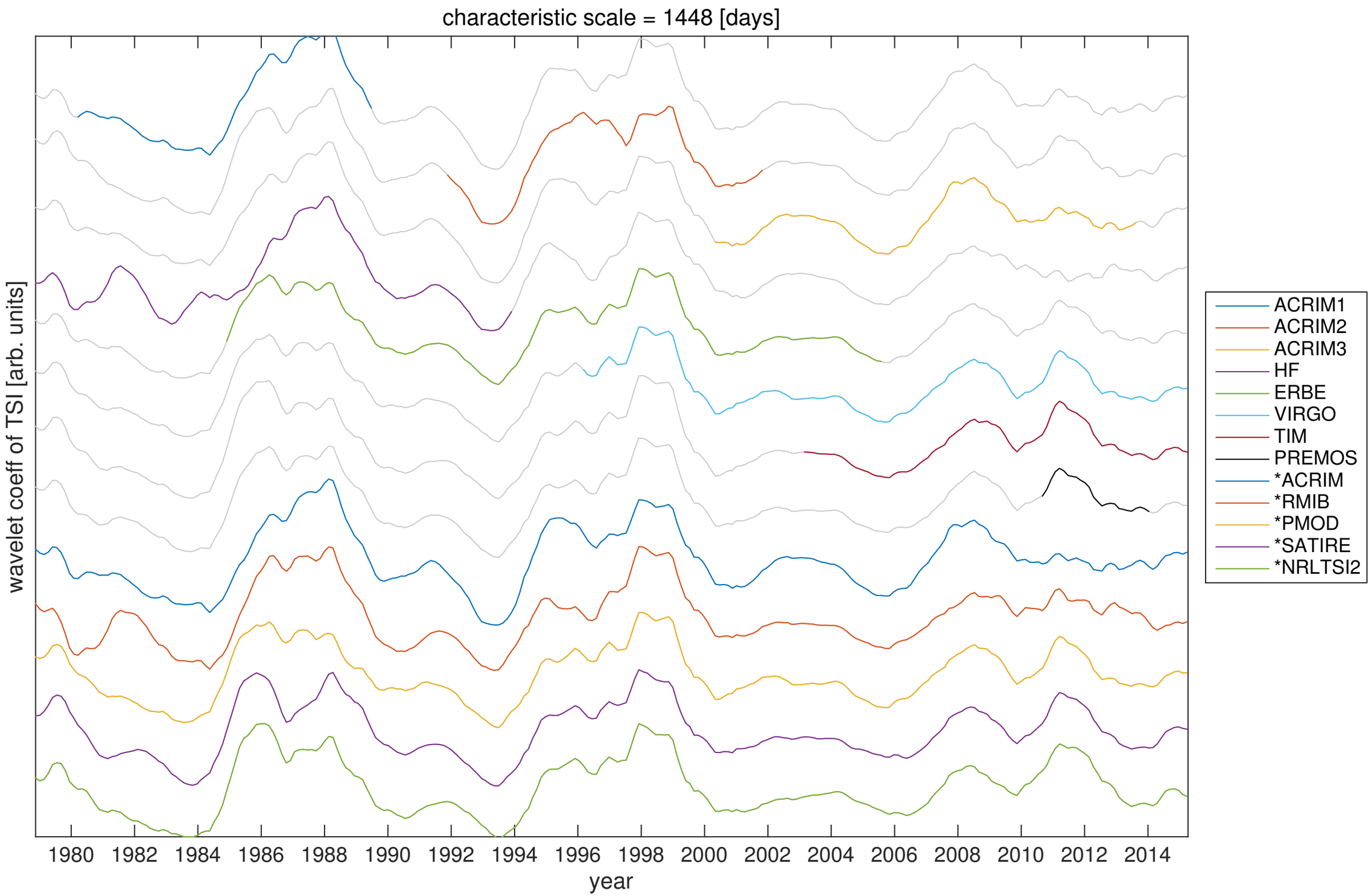
Interpolation

- Missing data are interpolated by expectation-maximization

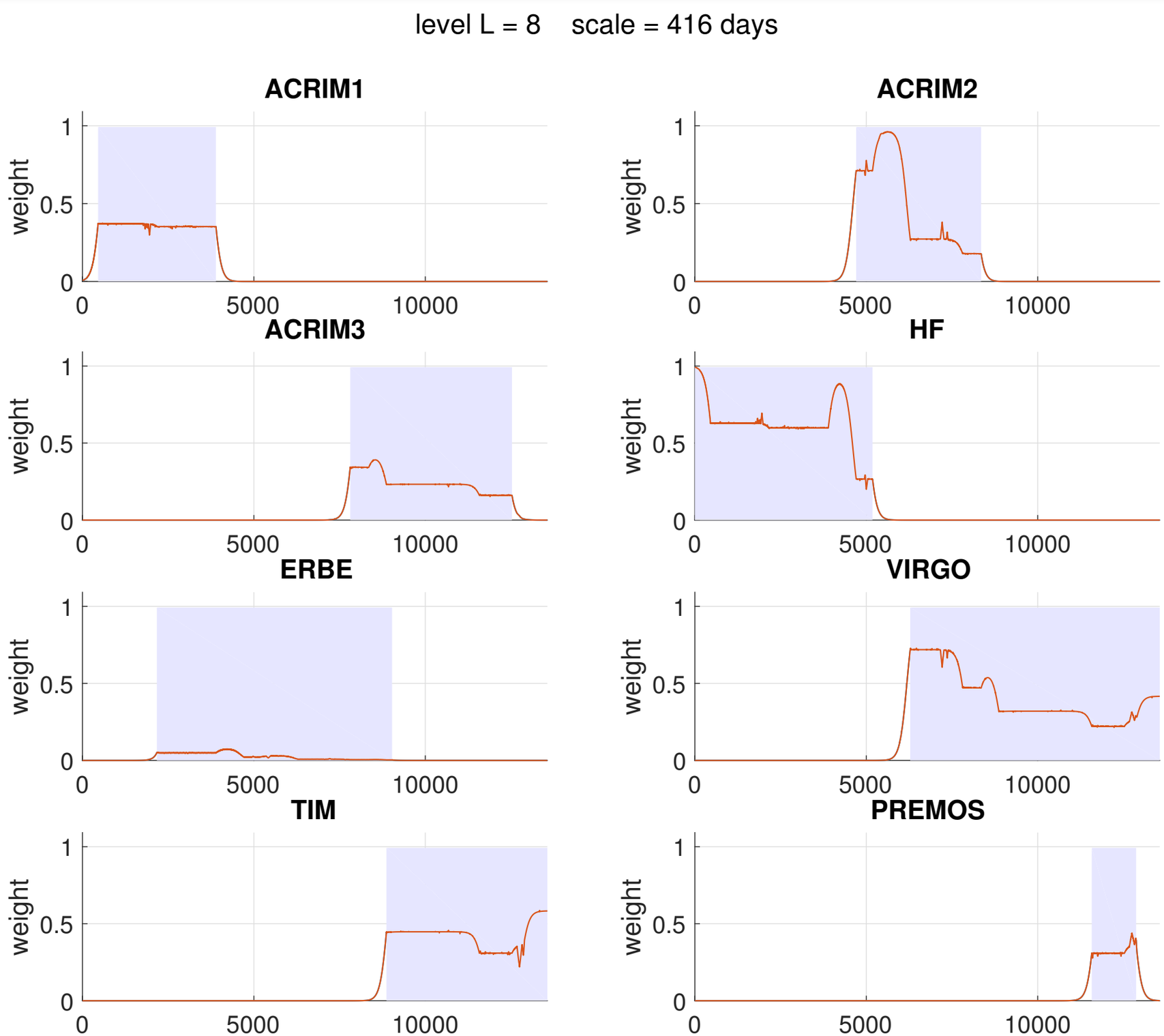




Wavelet transform



Weights


level L = 8 scale = 416 days
ACRIM1
ACRIM2
ACRIM3
HF
ERBE
VIRGO
TIM
PREMOS
weight
0
0.5
1
0
5000
10000