# Modelling TSI with a Monte Carlo simulation of Active Region Decay

**Cassandra Bolduc**
P. Charbonneau, A. Boucher
**Université de Montréal**

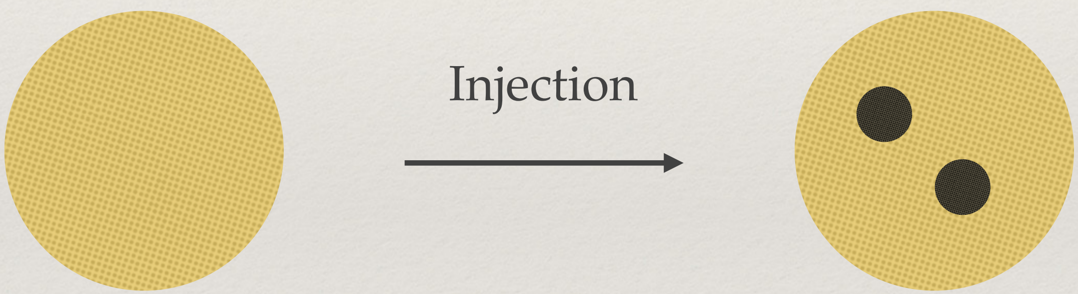
Solar Metrology, Paris
October 8, 2014

# Outline

- Our TSI model
- Modifications
- Optimization
- Reconstruction to the Maunder Minimum
- Conclusions and future work

# Our TSI model

- Crouch et al. (2008) ApJ, 677:723.
- Injection of observed spots

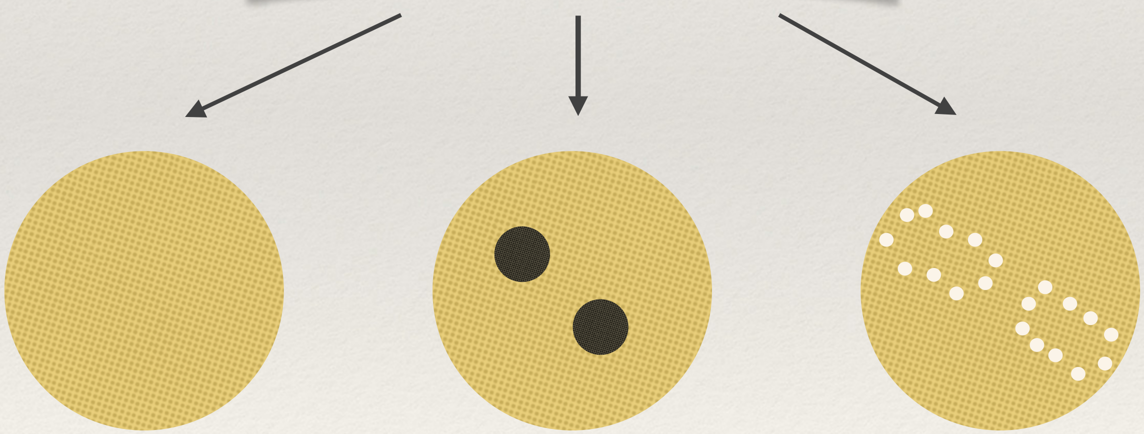



- Fragmentation —> Spots and Faculae

# Our TSI model

- Crouch et al. (2008) ApJ, 677:723.
- Calculation of irradiance

$$S = S_Q + \Sigma_i \Delta S_s + \Sigma_j \Delta S_{\rm fac},$$



# Our TSI model

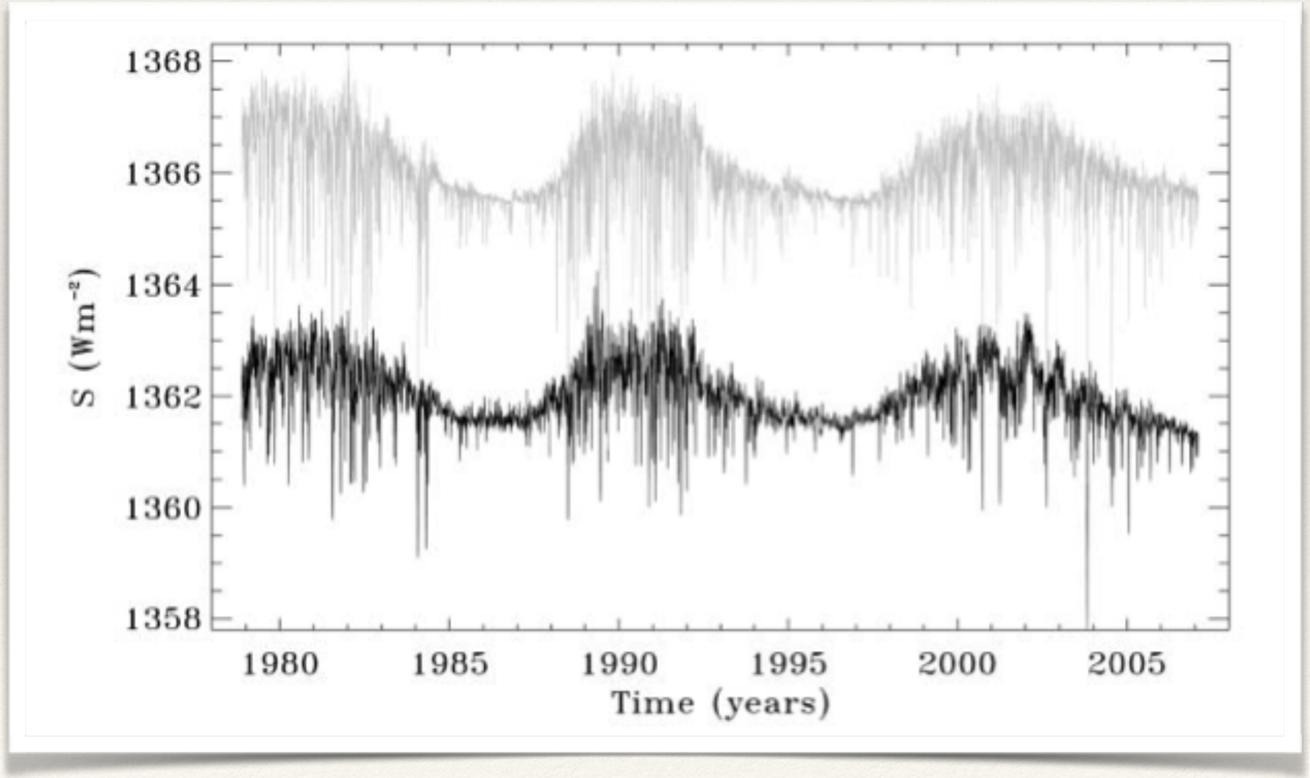
- Crouch et al. (2008) ApJ, 677:723.
- Calculation of irradiance

$$S = S_Q + \Sigma_i \Delta S_s + \Sigma_j \Delta S_{\mathrm{fac}},$$

- Next time step: fragments+new emergences
- Faculae follow an exponential decay
- Backside emergences: stochastically

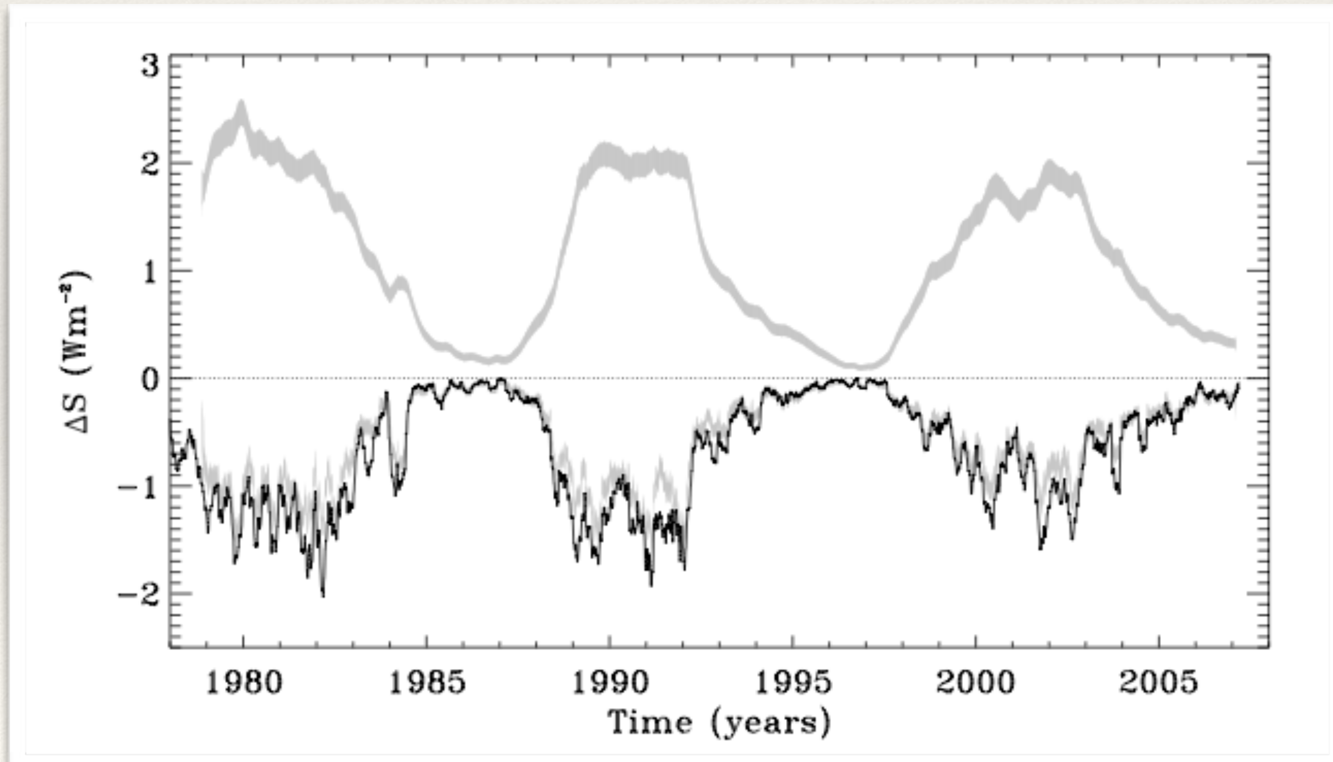
# Our TSI model

- Crouch et al. (2008) ApJ, 677:723.



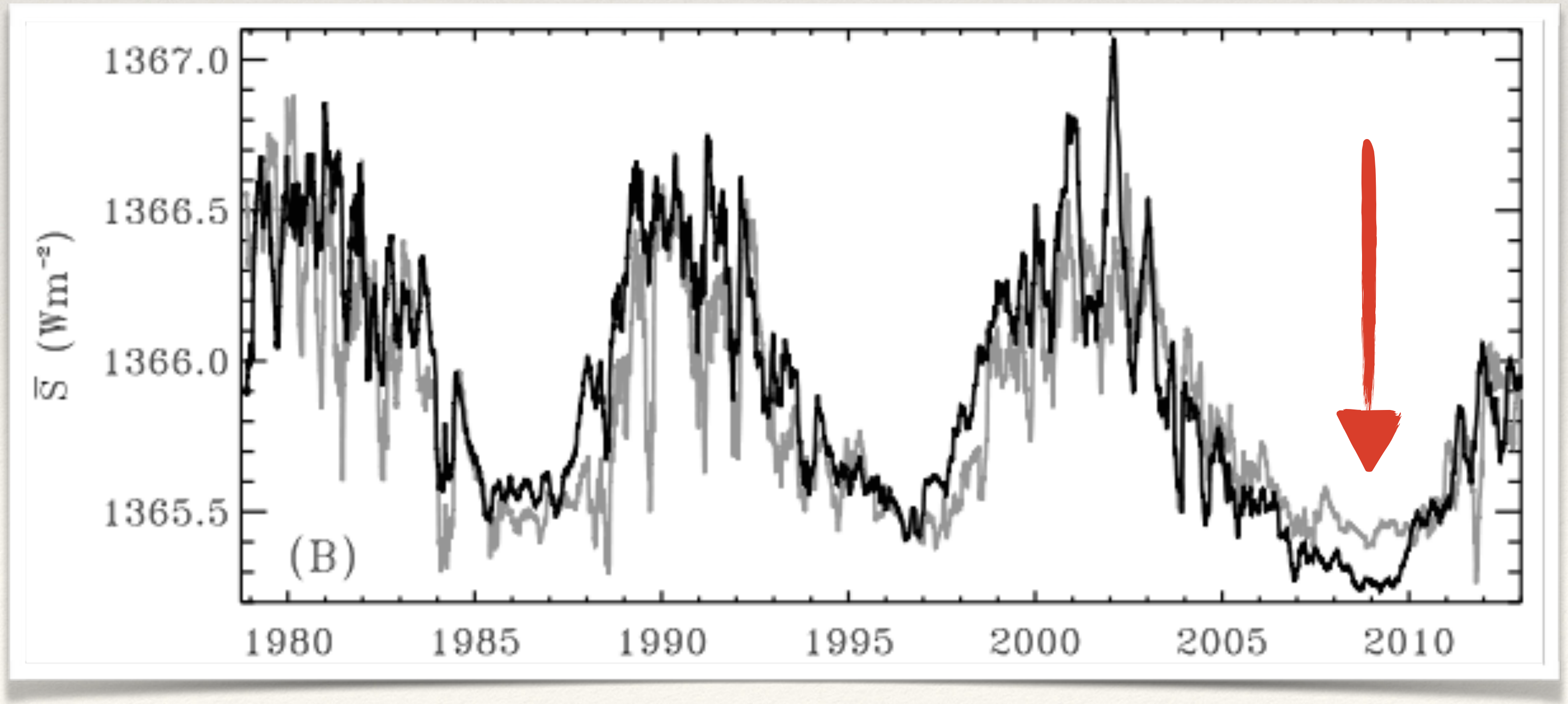
# Our TSI model

- Crouch et al. (2008) ApJ, 677:723.



# Modifications

- Problem 1: underestimate TSI during ascending phase
- Problem 2: minimum between Cycle 23 and 24
- No magnetic network in our model

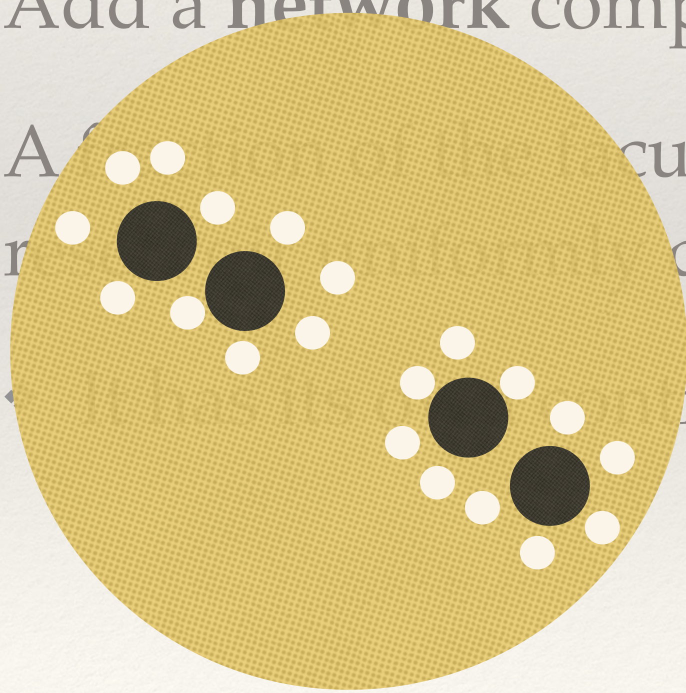


# Modifications

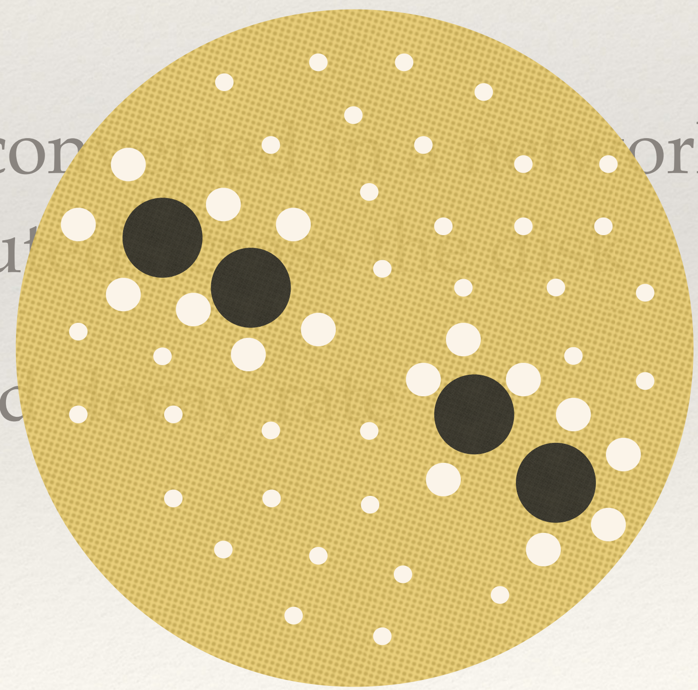
- Problem: minimum between Cycle 23 and 24
- No magnetic network in our model
  - Add a **network** component
  - A fraction of the faculae is converted in a network reservoir uniformly distributed across the disk
    - It has its own contrast and decay rate

# Modifications

- Problem: minimum between Cycle 23 and 24
- No magnetic network in our model
  - Add a **network** component
  - A f… culae is con… ork
    n… distribut…
    - … rast and …



2008



2014

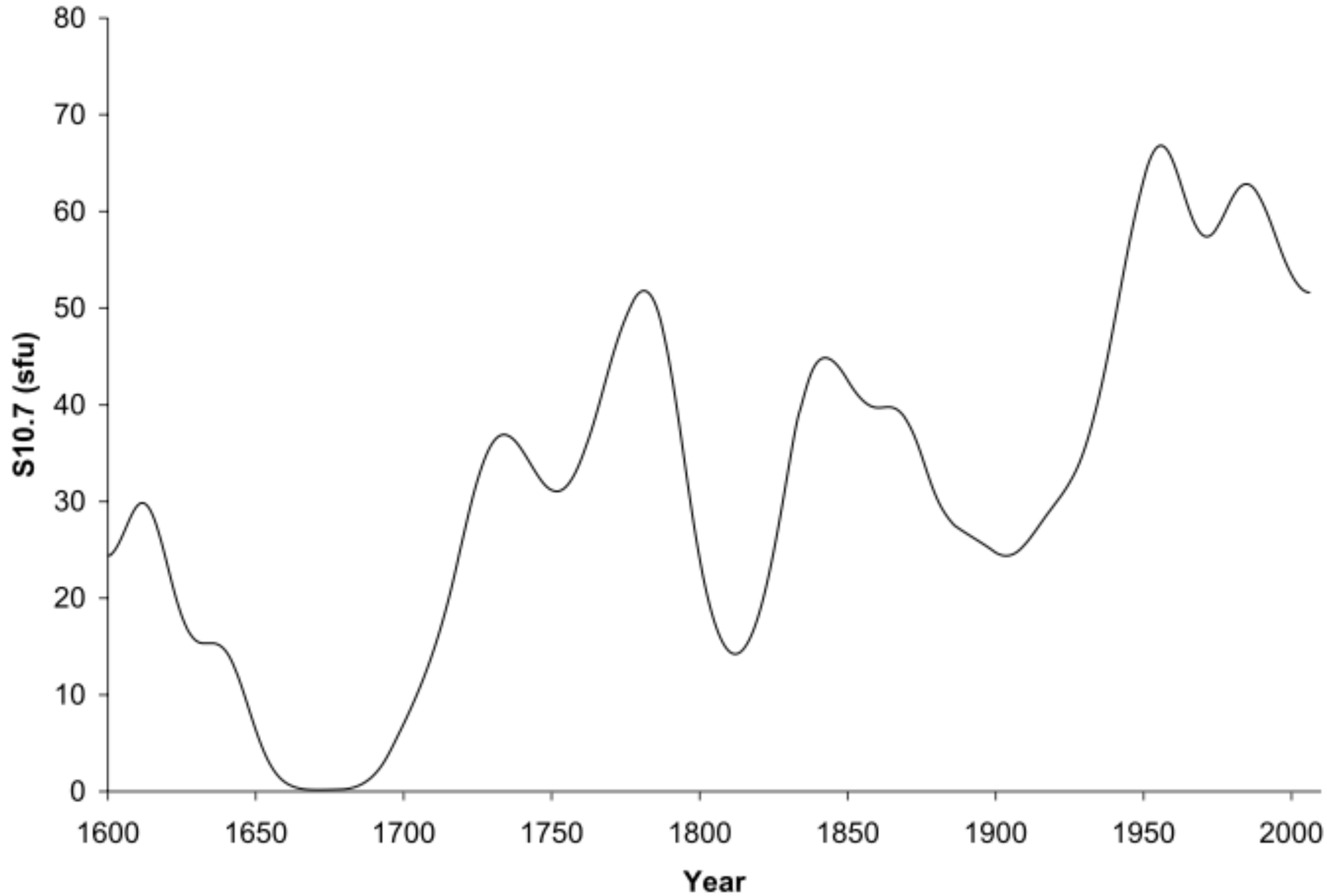
# Modifications

- Problem: minimum between Cycle 23 and 24
- No magnetic network in our model
  - Add a **variable Quiet Sun** component
  - Based on F10.7 reconstructions, smoothed (Tapping et al. 2007, Sol. Phys., 246:309)

# Modifications

❖

❖




et

**Figure 7** The variation in modelled $S_{10.7}$ since 1600 after filtering to remove the modulation by the solar activity cycle.

# Optimization

- 6 free parameters in the original model:

TABLE 1
MODEL PARAMETERS

| Description | Symbol | Free/Fixed | Value/Allowed Range |
|---|---|---|---|
| Fragmentation chances per day per element | (none) | Fixed | 2 |
| Fragmentation range | (none) | Fixed | 0.1–0.9 |
| Fragmentation probability | $p_{\rm frag}$ | Free | 0–1 |
| Threshold radius for large-scale elements | $r_f^*$ | Fixed | 250 km |
| Maximum radial thickness of the eroded annulus | $r_{\rm erode}^*$ | Free | 100 km – 2 Mm |
| Area conversion efficiency | $\eta$ | Free | 0–1 |
| Decay rate for small-scale elements | $\lambda$ | Free | 0–0.5 |
| Faculae intensity contrast | $\alpha_{\rm fac}$ | Free | 0.018–0.072 |
| Threshold radius for sunspots | $r_s^*$ | Fixed | 1 Mm |
| Quiet-Sun irradiance (and intercept of linear trend) | $S_Q$, $S_{Q,c}$ | Free | 1365–1366 W $m^{-2}$ |
| Gradient of Quiet-Sun irradiance linear trend | $S_{Q,m}$ | Free and fixed | [−1, 1] W $m^{-2}$ over 1978–2007 |
| Collective threshold radius for small-scale elements | $r_t^*$ | Fixed | 25 km |

# Optimization

- 6 free parameters in the original model
- We add 3 (4) more:
  - Fraction of faculae converted into "network" (BR)
  - "Network" decay rate ($\lambda_{disk}$)
  - "Network" contrast ($\alpha_{disk}$)
  - Variable quiet Sun factor ($C_{10.7}$)

# Optimization

- PIKAIA (get it here! http://www.hao.ucar.edu/modeling/pikaia/pikaia.php)
  - Population of 200 models with randomly chosen parameters
  - Run each model, compares to observations, calculates fitness
  - New generation!
    - Generate new parameters by "mixing" the previous generation population's parameters (encoded as strings, cut, then re-assembled)

# Optimization

For example

**Good fitting individual 1**

Some parameter's value:
$x_1$=0.54672
String:
54672

**Good fitting individual 2**

Some parameter's value:
$x_1$=0.98746
String:
98746

**New individual**

54**672**

**98**746

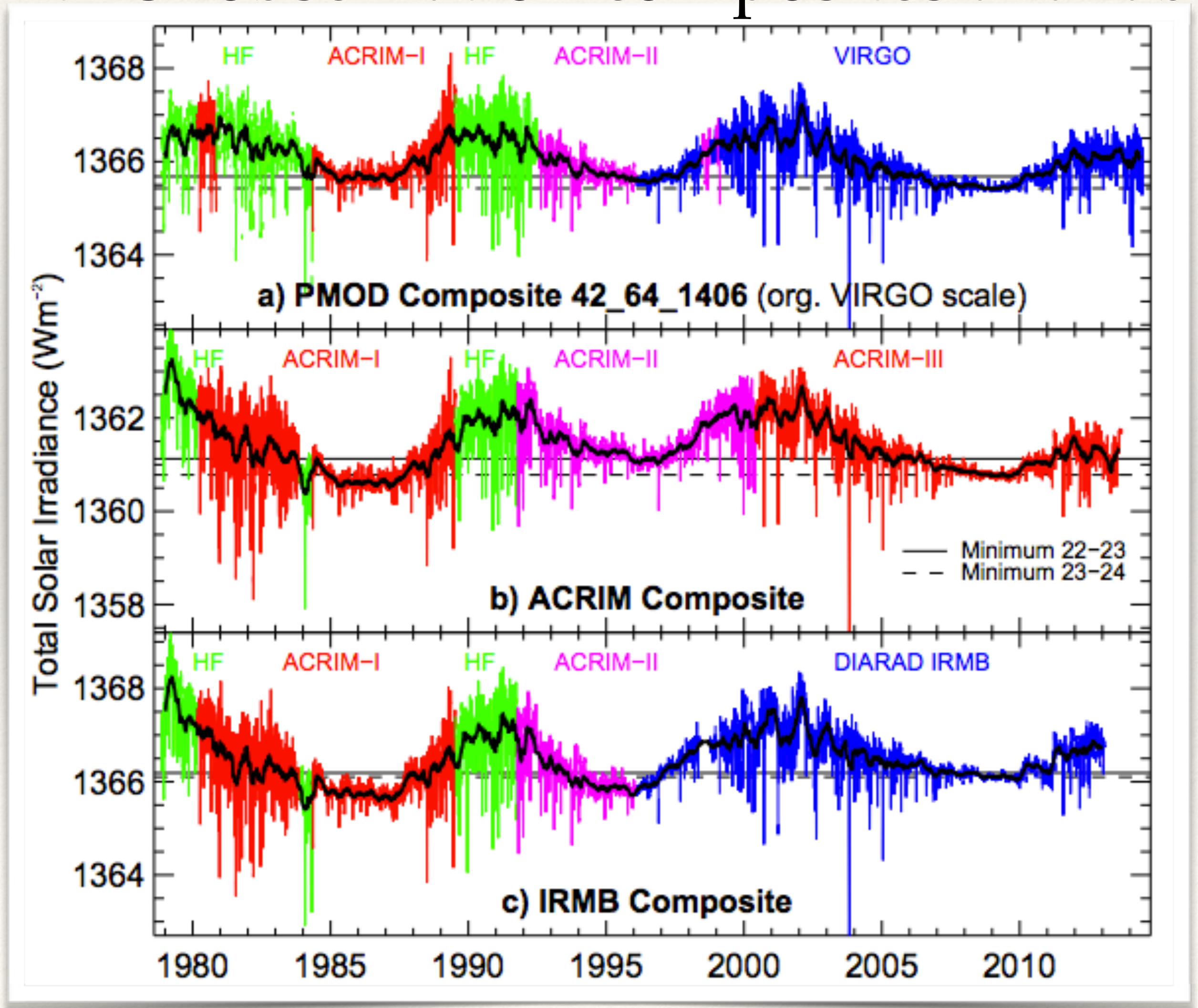
↓

**98672**
**$x_1$=0.98672**

- PIKA
  - Po … ameters
  - Ru … s
    fitr
  - Ne
    - … s
      … rings,

# Optimization

- 3 different TSI observation composites available



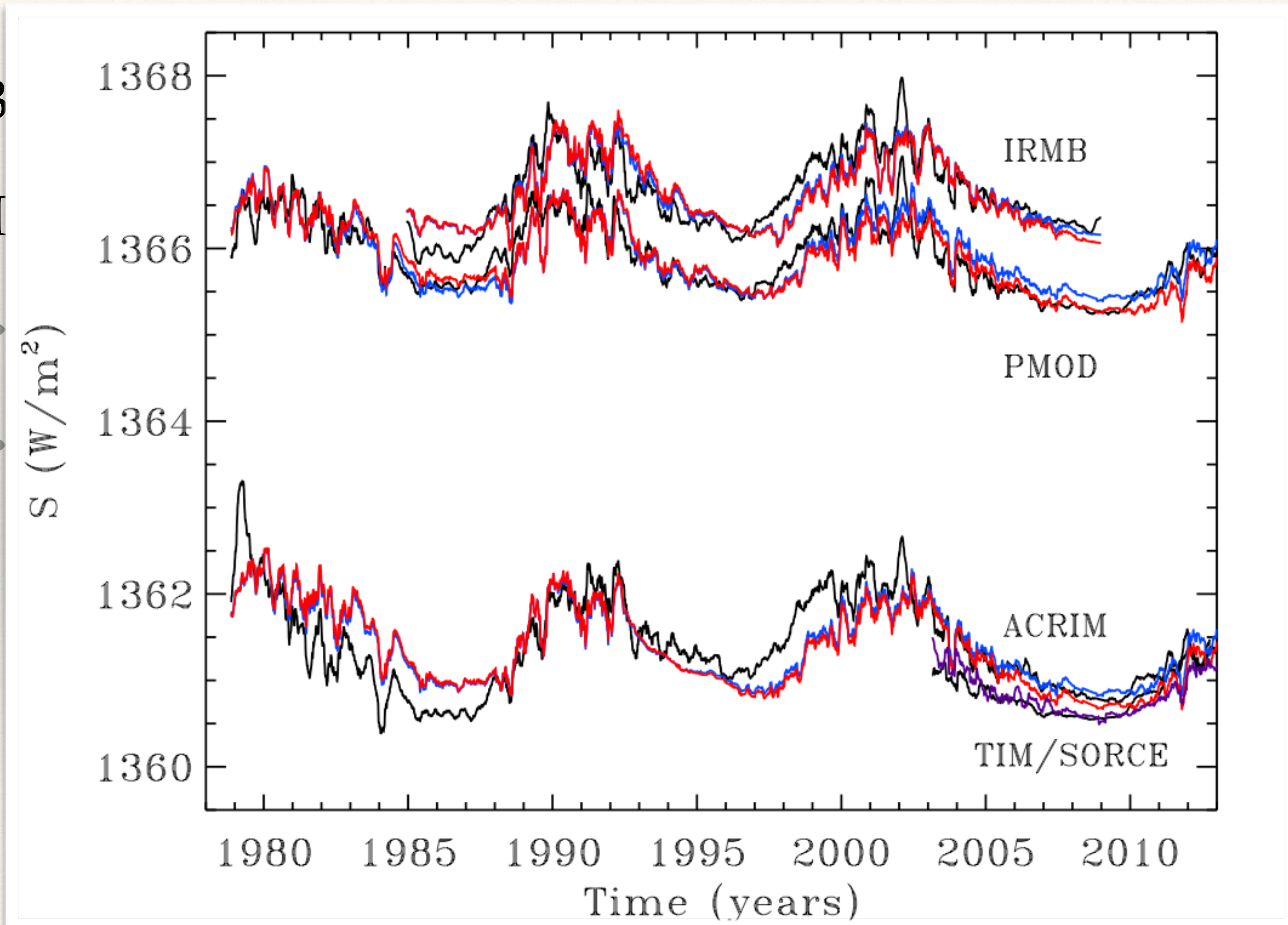

Credit: C. Fröhlich, http://www.pmodwrc.ch/pmod.php?topic=tsi/composite/SolarConstant

# Optimization

- 3 different TSI observation composites available
- TIM data
    - Optimization of parameters with each of them
    - Ten PIKAIA runs each time with different seeds for random number generator —> Errors bar on each value

# Optimization

- 3
- T

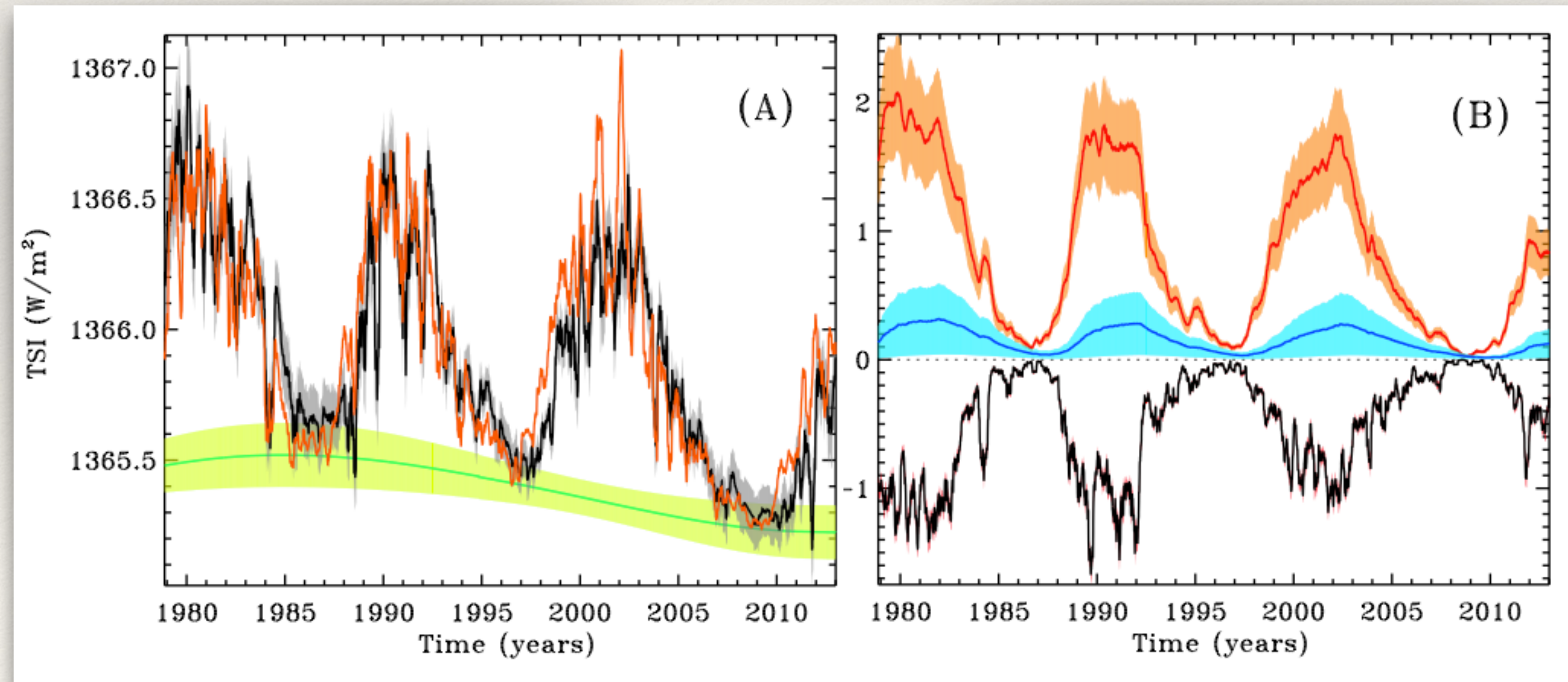



or

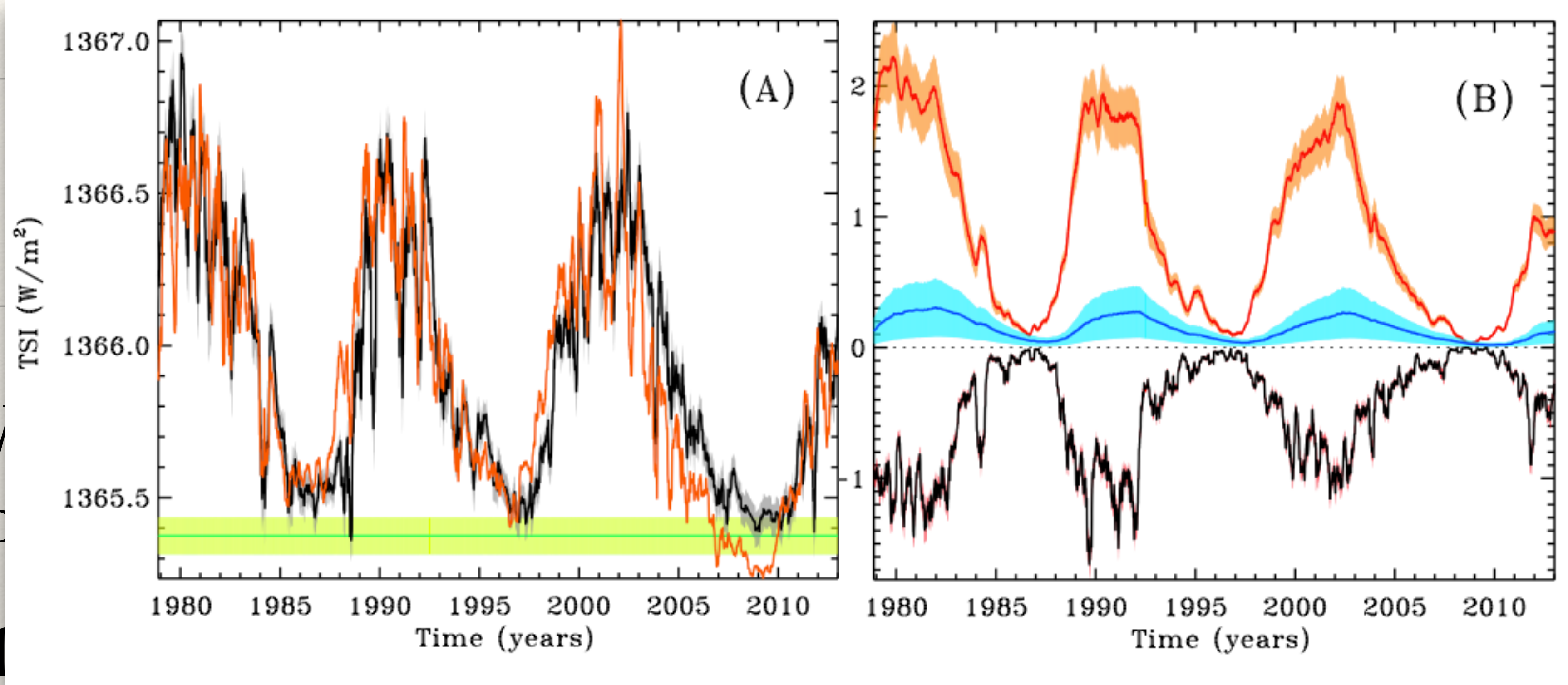
n

# Optimization

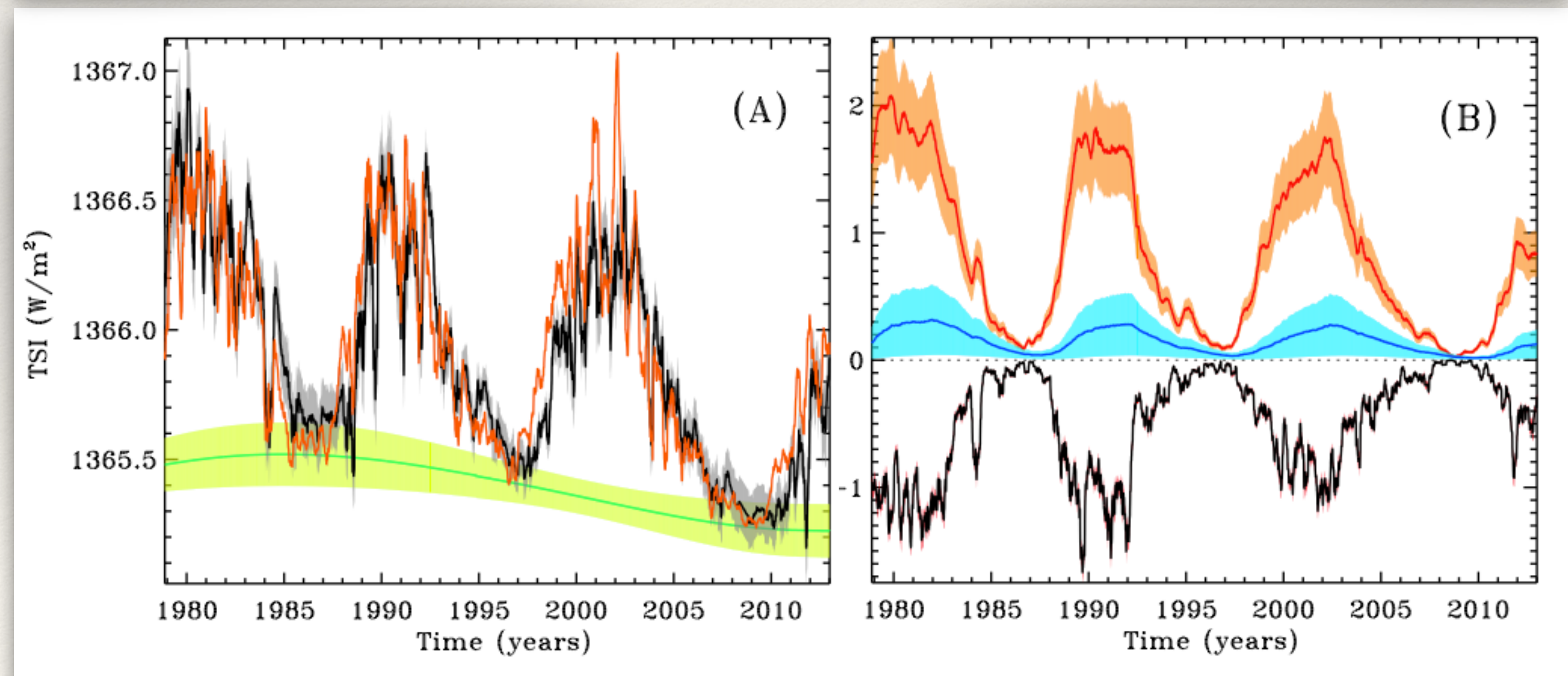
- We use set of parameters determined with the PMOD composite
- Plot each component's contribution to the TSI



- W
co
- Pl

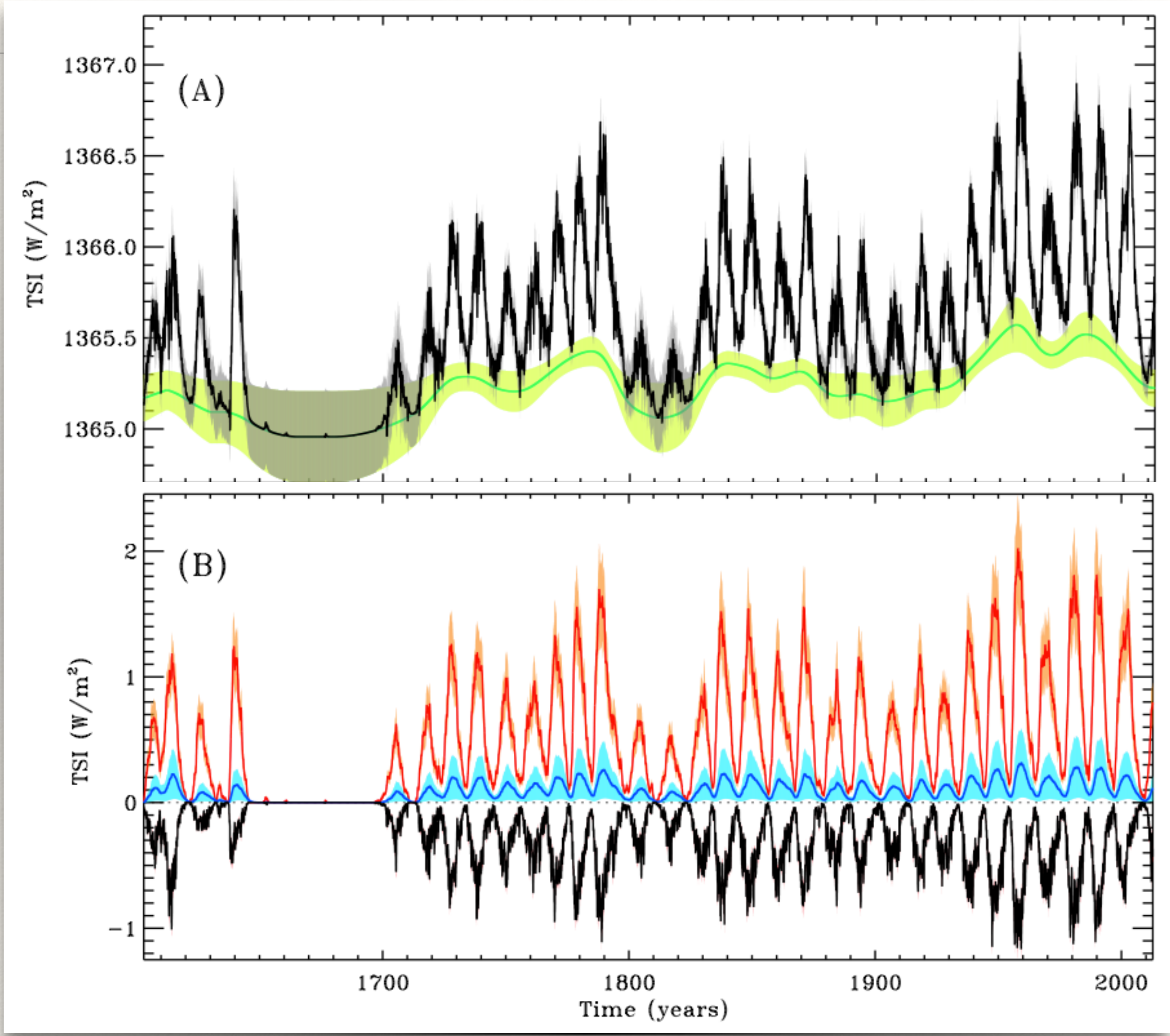


(A)
(B)
TSI (W/m²)
1367.0
1366.5
1366.0
1365.5
2
1
0
-1
1980 1985 1990 1995 2000 2005 2010
Time (years)

(A)
(B)
TSI (W/m²)
1367.0
1366.5
1366.0
1365.5
2
1
0
-1
1980 1985 1990 1995 2000 2005 2010
Time (years)

# Reconstruction to the Maunder Minimum



# Conclusion and future work

- Our model succeeds best in reproducing the PMOD composite
- The network contribution does not help reproducing the 2009 minimum
    - The variable quiet Sun does!
- Future: include this network representation in MOCASSIM

# Thank you

Special thanks to

**Paul Charbonneau**

**Anne Boucher**

# More equations for TSI

$$\frac{\Delta S_s}{S_Q} = \frac{1}{2}\mu A_s(3\mu + 2)\alpha_s,$$

$$\alpha_s = -\left[0.2231 + 0.0244\log\left(A_s \times 10^6\right)\right],$$

$$\frac{\Delta S_{\text{fac}}}{S_Q} = \frac{1}{2}\mu A_{\text{fac}}(3\mu + 2)(1/\mu - 1)\alpha_{\text{fac}},$$