Sunspot observations and the Sunspot Number

Dr. Renzo Ramelli, Istituto Ricerche Solari Locarno

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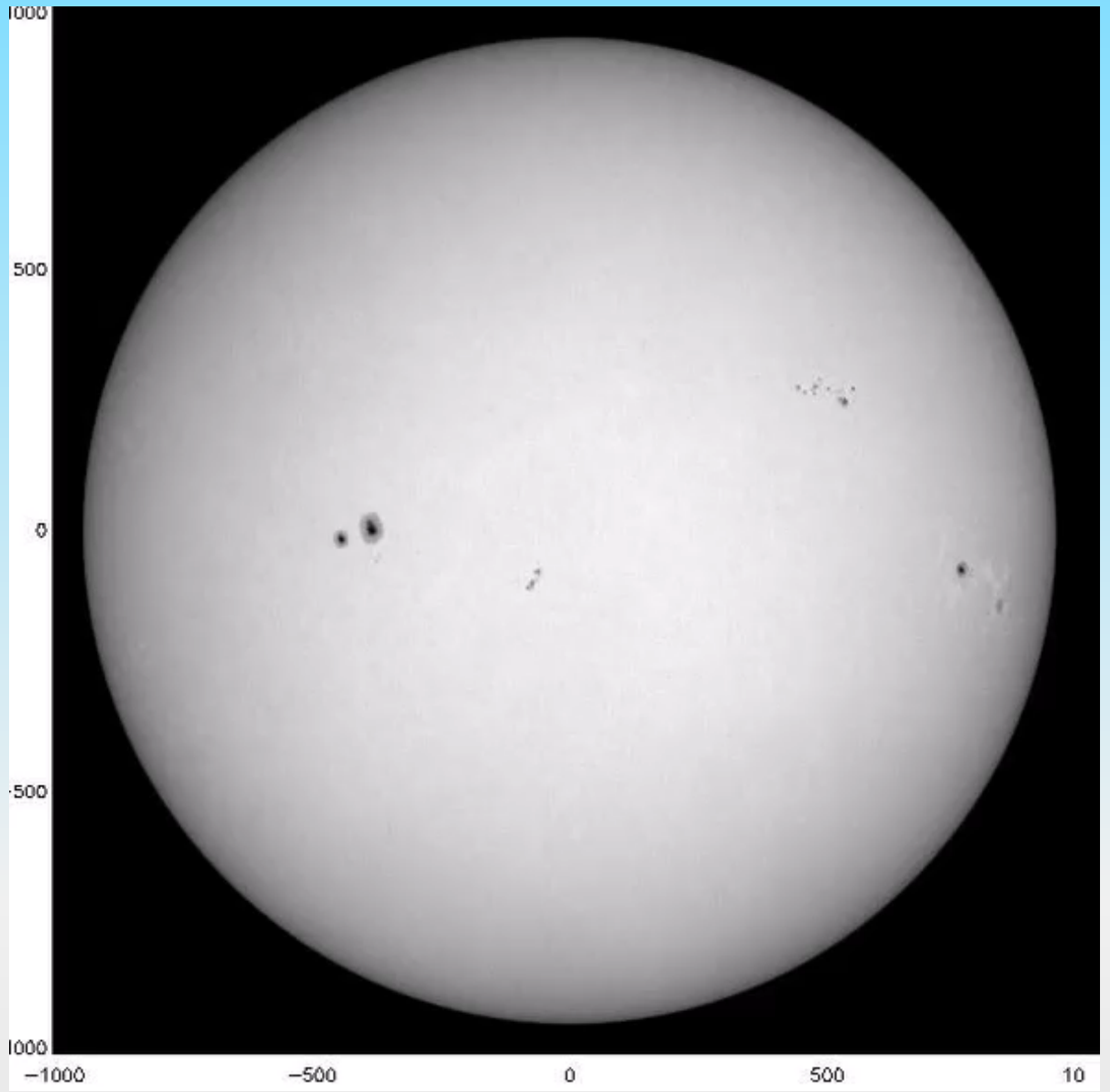
Outline

- **Introduction**: what are Sunspots?
- **Historical overview** of Sunspot observations and counting
- **Scientific relevance** of the Sunspot Number (SSN)
  - In general
  - For climate
- **Conclusion**
- **References** for further reading

What are Sunpots?

- **Cooler regions** of solar photosphere with strong **magnetic field**
- Typical **size**: ~ 10^4 km
- **Temperature:** ~ 4000 K (instead of 5800 K of the rest of the photostosphere)
- **Magnetic field:** few Kilogauss
- Sunspots are the most evident sign of the solar **magnetic activity**



Movie credit: HInode
http://solarb.msfc.nasa.gov

Historical overview

- 1610: **start** of the first systematic observations of Sunspots by **Galileo** and others
- 1844: discovery of the **11-years cycle** by Schwabe
- 1848: the Swiss astronomer **Rudolph Wolf** (prof. at ETH-Zurich) introduced a **Sunspot Number R_i (SSN)** (also called Wolf number) based on historical data and its own observations
  - The SSN represents a **long and homogenized time series** made available to the scientific community for systematic comparisons with several other scientific records (specially meteorological records)

Historical overview

- **Definition** of the international Sunspot Number R_i:

$$R_i = k(10 \times g + s)$$

  - g : number of Sunspot Groups
  - s : number of individual Sunspots
  - k : normalization factor depending on observer

Historical overview

- 1908: **Hale** observed the **magnetic field** in Sunspots (through the Zeeman effect)
- 1848 - 1980: the SSN is determined at ETH **Zurich** by Wolf and Wolf's successors (Wolfer, Brunner, Waldmeier)
- 1939 & 1957 (IGY): commissioning of the external ETH observing stations in **Arosa and Locarno** (Specola Solare)
- 1980:
  - The responsibility for the determination of the SSN is transferred to the Royal Observatory in Brussels (in agreement with the International Astronomical Union, IAU)
  - Specola Solare Ticinese in Locarno becomes the world reference station

Historical overview

- **July 2015: revision** of the SSN
  - Better calibration between different observers
  - Work of several years by many scientists expert on SSN (4 SSN-workshops)
  - Revision lead to a press release by the International Astronomical Union (IAU) Assembly in August 2015 in Honolulu

    (http://www.iau.org/news/pressreleases/detail/iau1508/)

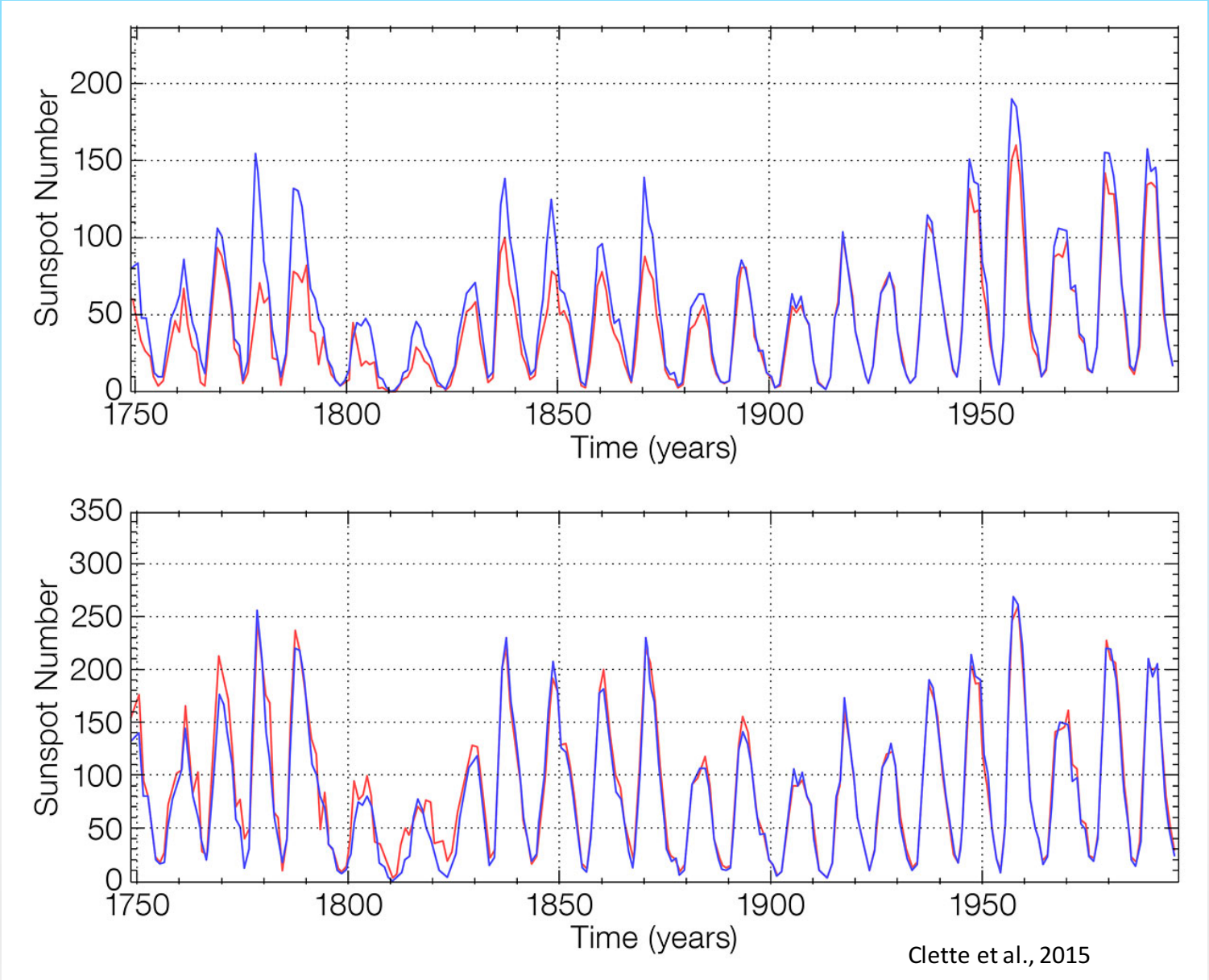
The SSN (1750 – now)

old version

Plot with the new version of the Sunspot Number S_n :

SSN

Group number x 19



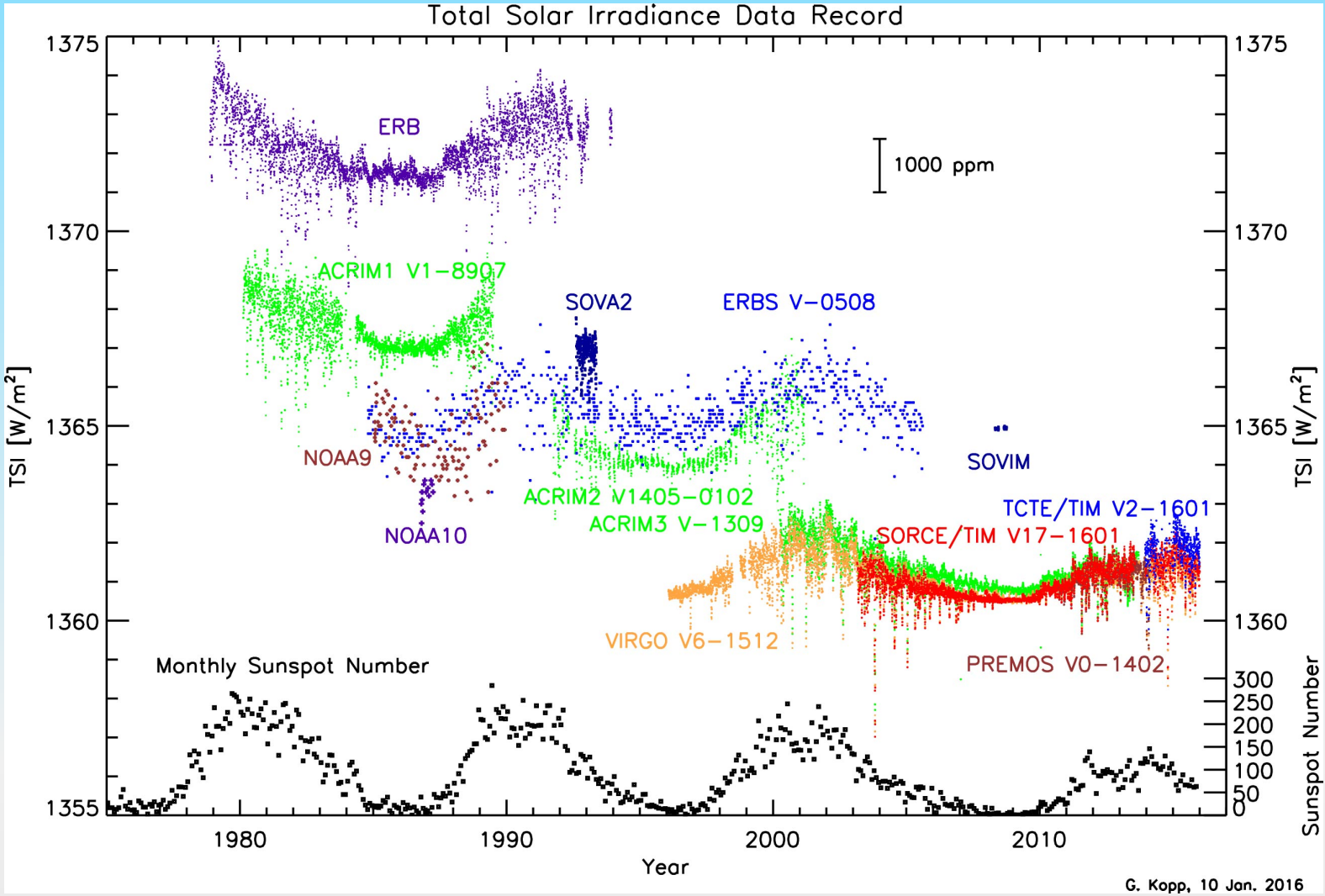
Clette et al., 2015

Scientific relevance of the SSN (in general)

- Only direct record of the evolution of the solar cycle over multiple centuries (400 years)
  - Longest scientific experiment still ongoing (B.Owens, Nature, March 2013)
- Multiple applications:
  - Long-term irradiance reconstructions **(TSI)** (Direct TSI measurements available since 1980!)
  - Calibration of the method based on cosmogenic radioisotope (^{14}C, ^{10}Be) production to study the evolution of the solar activity before 1610
  - **Earth climate change**
  - Radio communication **(e.g. HF radio forecast by Swiss Army based on SSN)**
  - Infrastructure maintenance (pipelines, electrical power grid)
  - Solar dynamo modelling
- Reference to SSN in > **100 scientific publications / year**

Scientific relevance of the SSN (climate)

- **Relation SSN ↔ TSI**
  - TSI varies of 0.1 % through the solar cycle
- **UV- part** of TSI more sensitive to solar cycle
- Significant correlation with climate records in the **upper atmospheric layers** has been reported (e.g. ionosphere, thermosphere)
- Expected change in average **Earth-surface temperature** due to solar cycle less than 0.1°



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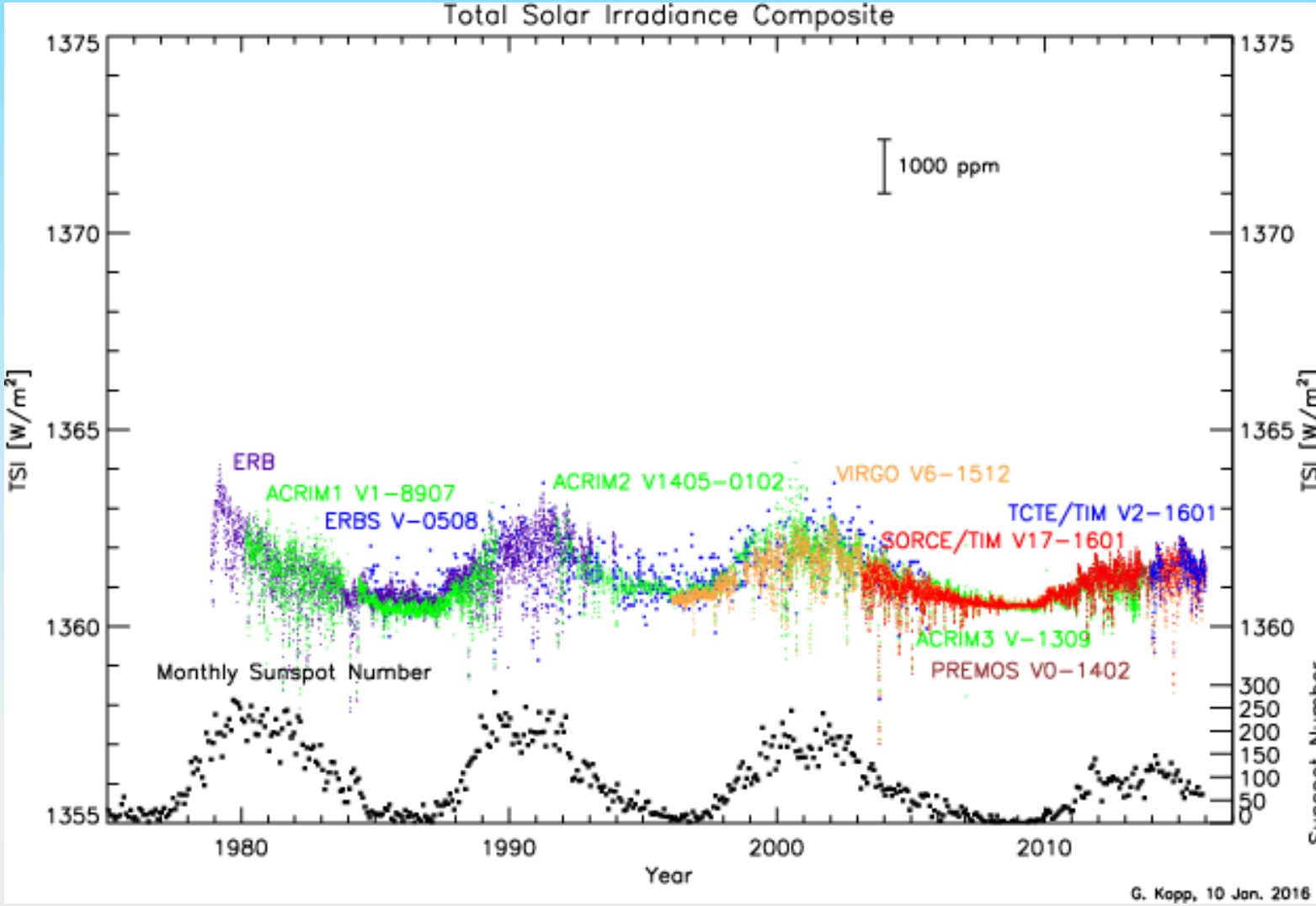
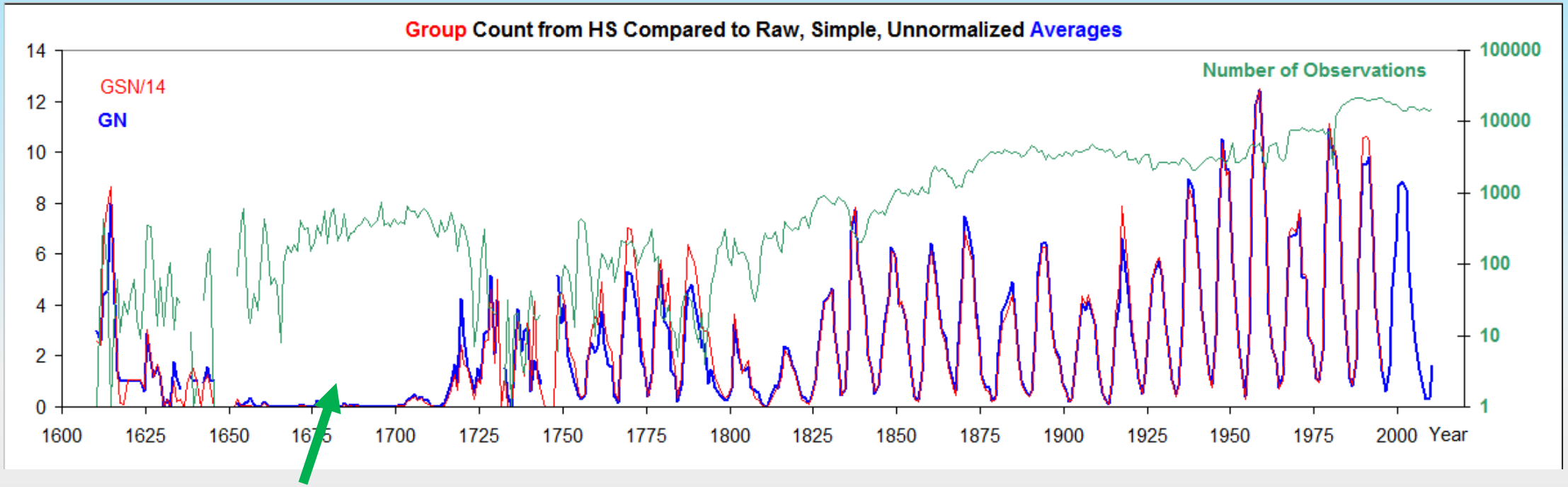


Scientific relevance of the SSN (climate)

- Little Ice Age related to Maunder minimum?

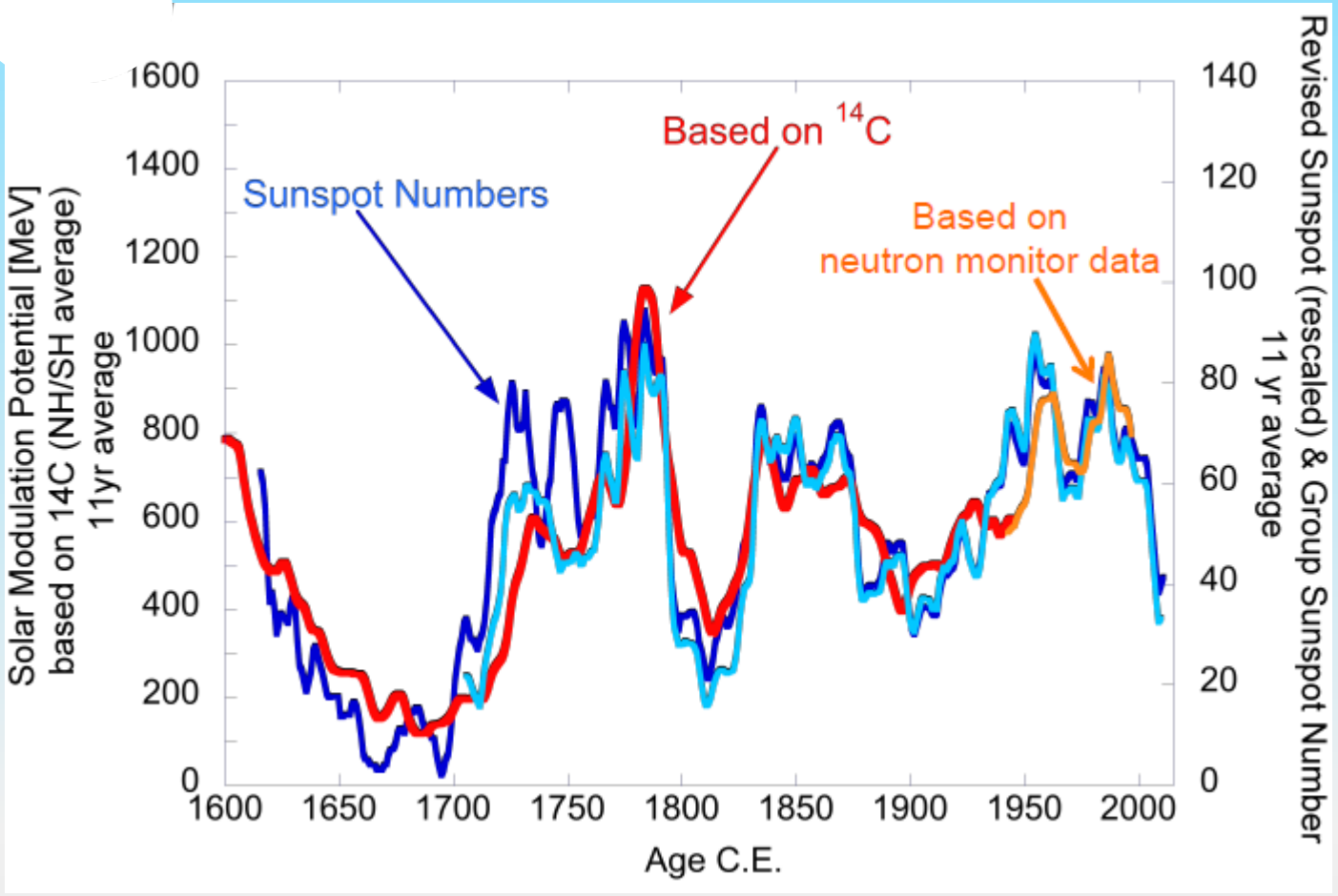


Maunder minimum

Credit: Svalgard & Schatten, Solar Physics, 2015

Cosmogenic nuclei and SSN

- Correlation between ^{14}C atmospheric concentration and revised SSN
- Cosmogenic nuclei ^{14}C and ^{10}Be allow to study the relation between solar activity and climate before 1610.



Credit: Muscheler et al., AGU fall meeting, December 2015

Scientific relevance of the SSN (climate)

- Other topics studied:
  - Impact of modulation of cosmic rays through the solar cycle on cloud formation
  - Impact of solar variability on the atmospheric global electric circuit.
  - …

Conclusion

- Due to the relevance of the **Sunspot Number (SSN)** time series for the climate studies over multiple centuries and in particular for the TSI reconstruction, we recommend the inclusion of the SSN as a relevant parameter for the TSI long term studies **in the new GCOS implementation plan**.
- This recommendation has been proposed in a **statement signed by 33 leading scientists** in solar physics.

References for further reading

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- Solar Physics (journal), Topical issue about Sunspot Number (2016 in press)
- http://www.iau.org/news/pressreleases/detail/iau1508/