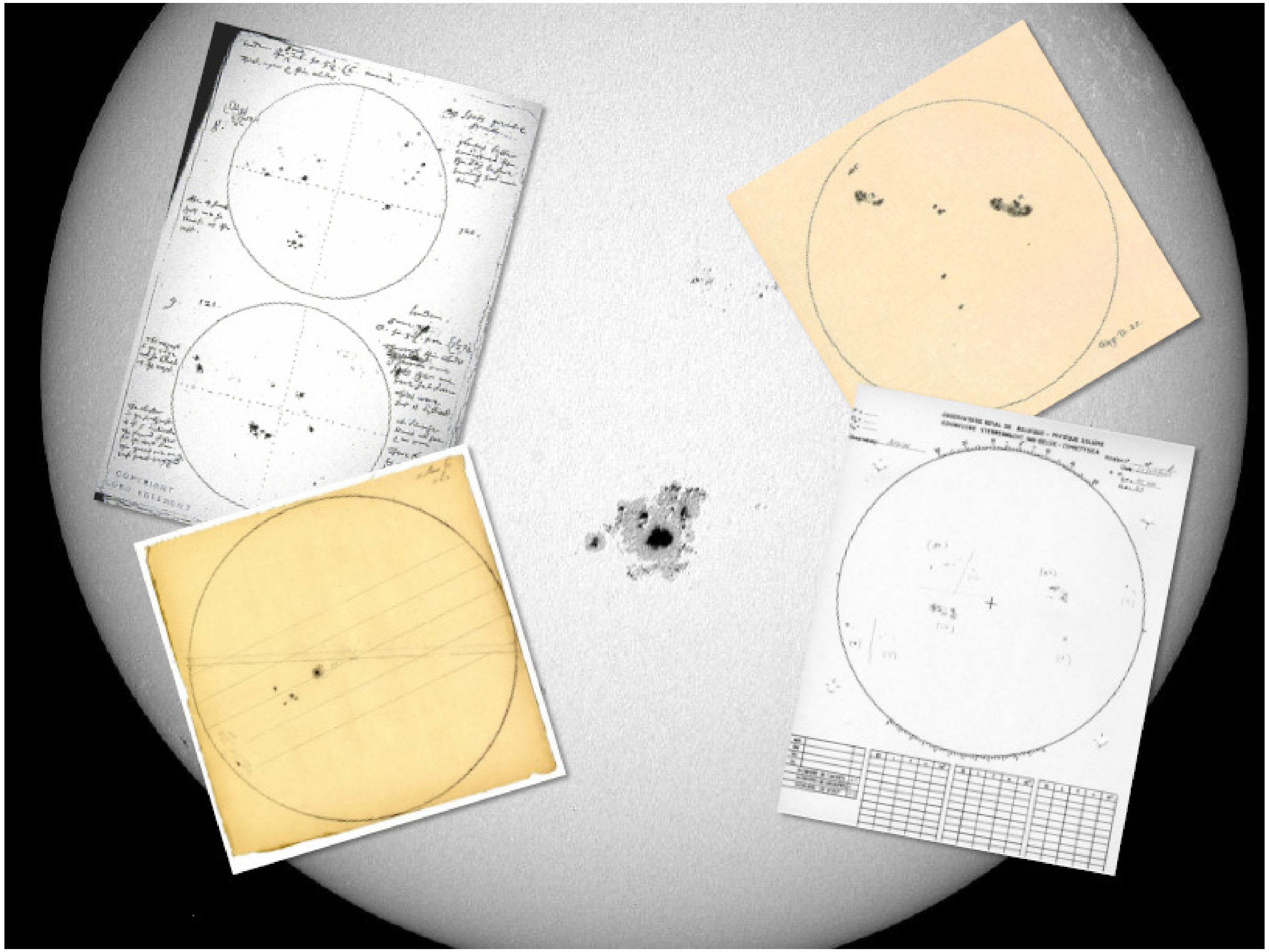
Recalibration of the sunspot indices: causes and consequences

Katya Georgieva

VarSITI co-chair

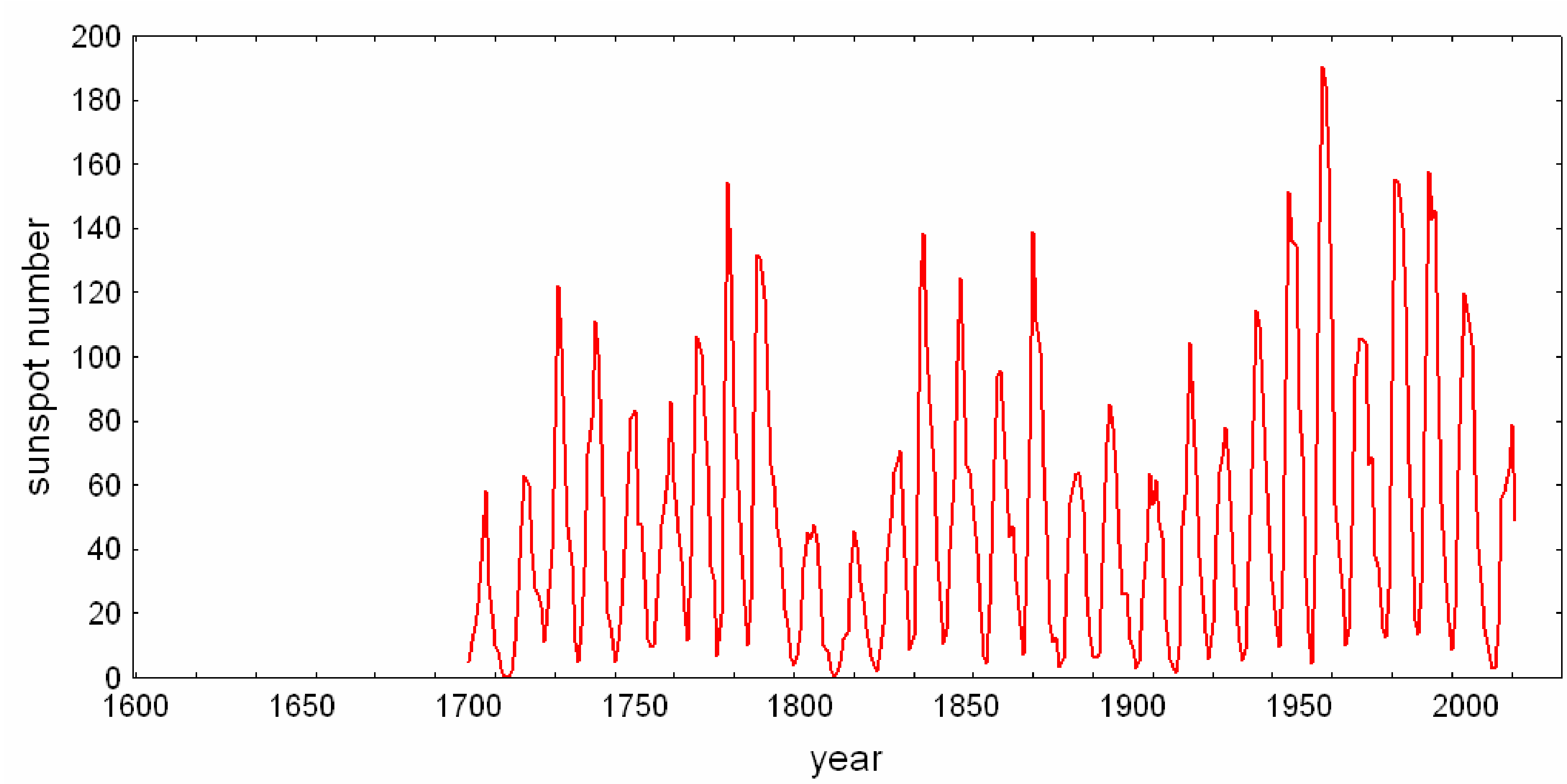
The sunspots are the most visible manifestation of solar activity



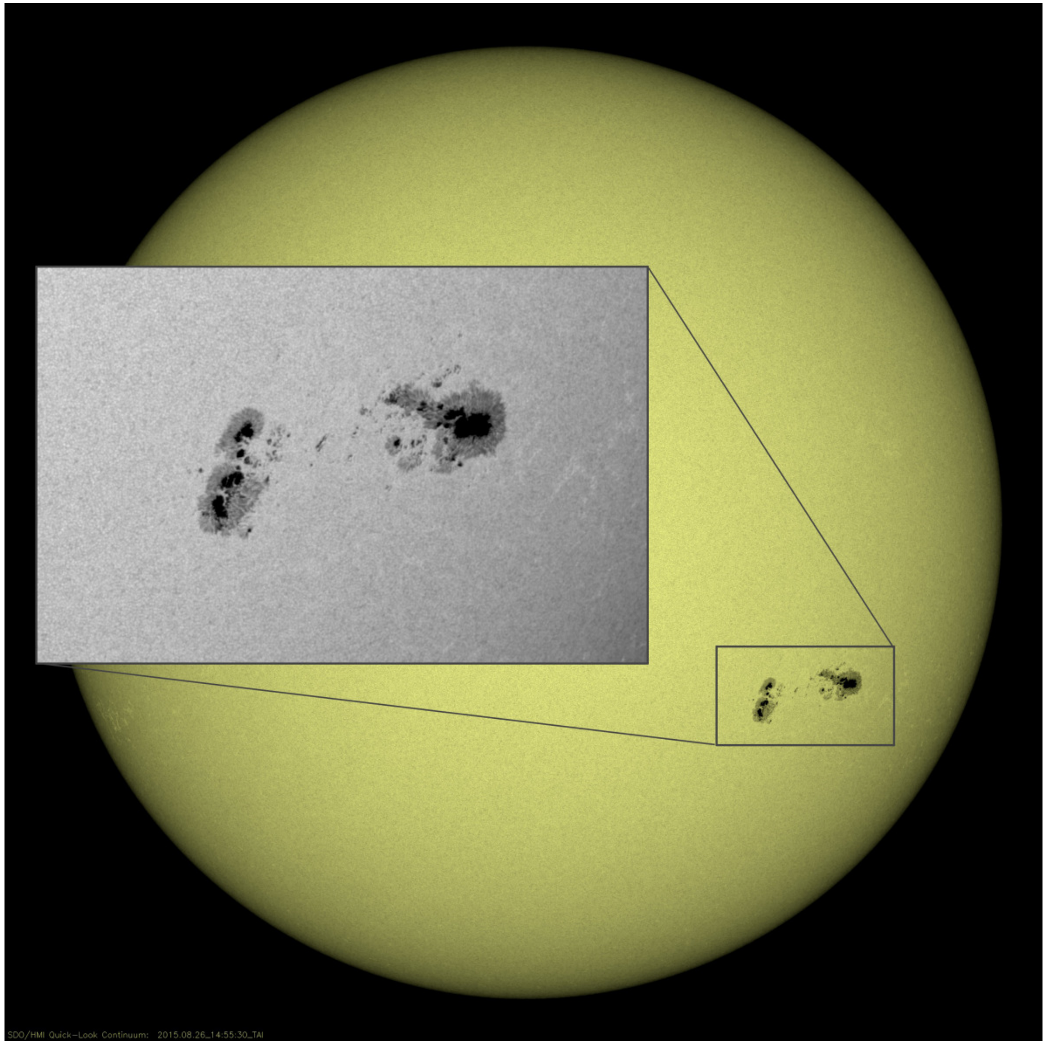
and with the longest record

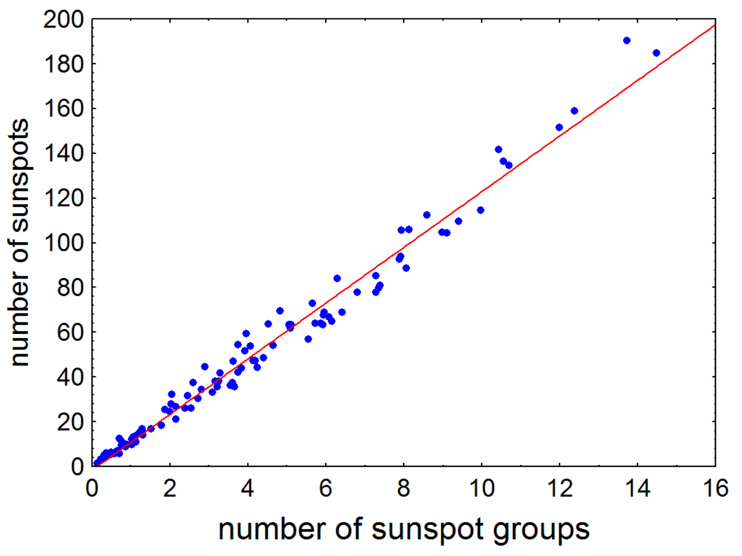
The original “relative sunspot number”, known also as “Wolf number” or “Zurich international sunspot number”, was defined by Wolf as

$$R_Z = k\,(10G + N)$$



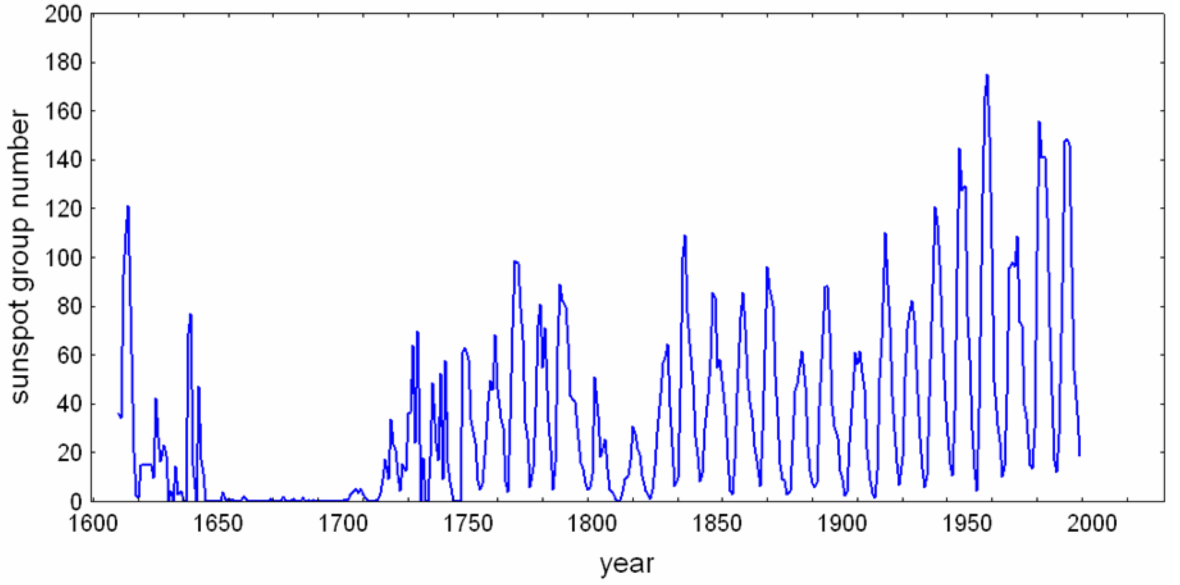
More reliable to count the number of sunspot groups





Linear relationship between the number of sunspot groups and the number of sunspots

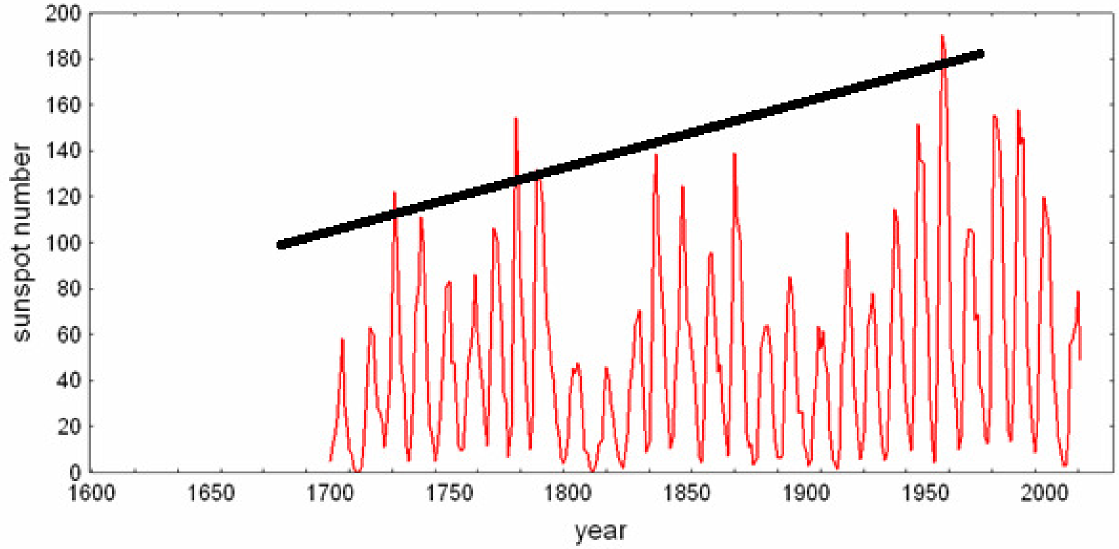
Group sunspot number (1611-1998)

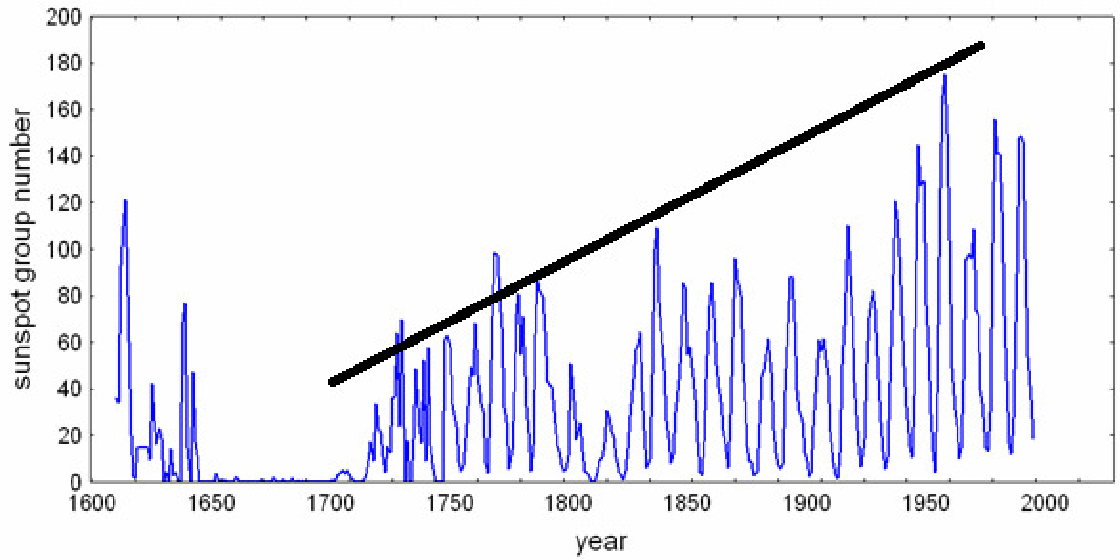


$R_G = 12.08\ G$

Hoyt and Schatten (1998)

However, R_Z and R_G are not identical
the main difference – the long-term trends



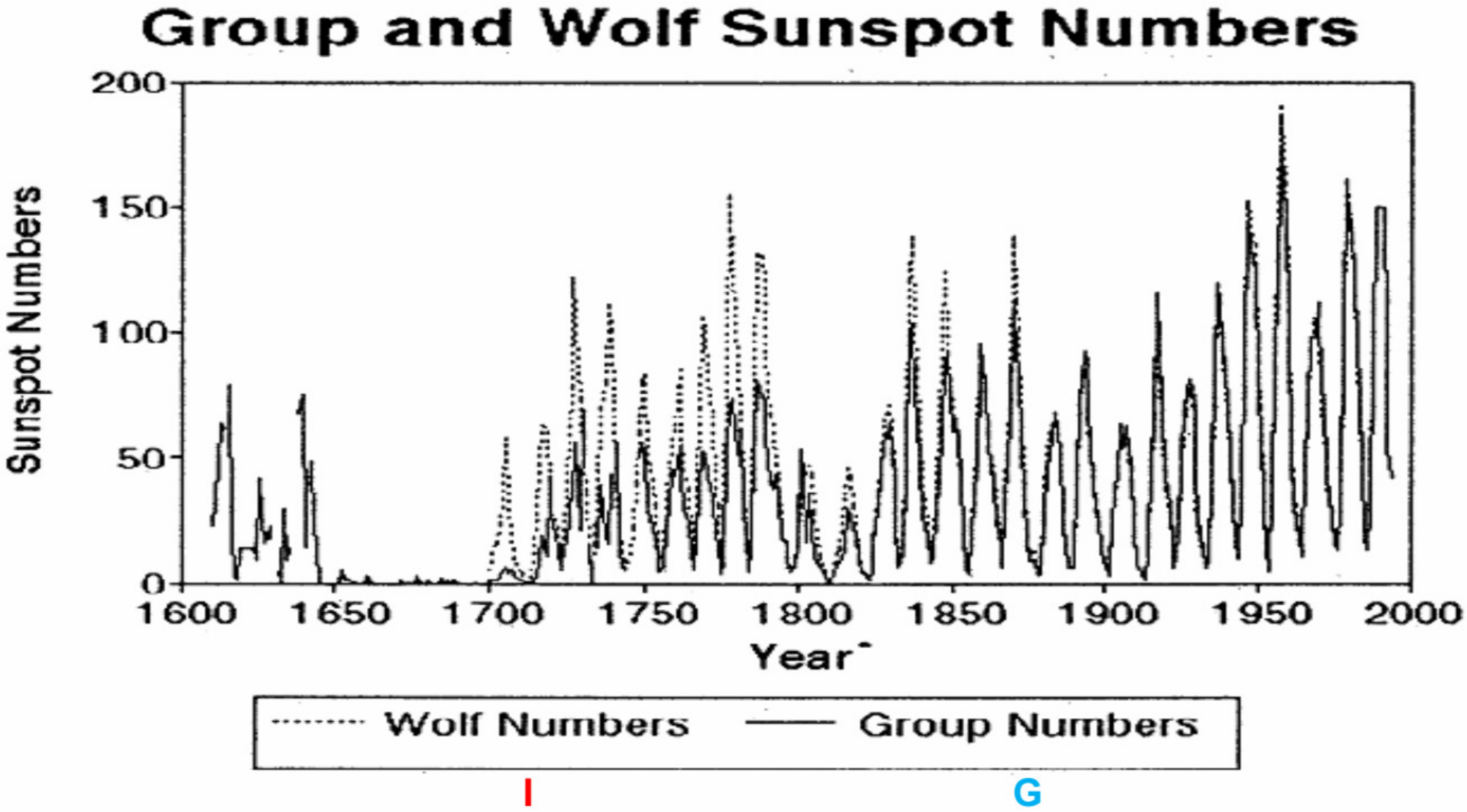


Why the Sunspot Number Needs Re-examination

E.W. Cliver
Space Vehicles Directorate
Sacramento Peak Observatory
Sunspot, NM 88349

Integrity ★ Service ★ Excellence

We have two sunspot numbers



Hoyt & Schatten, GRL *21*, 1994

With no consensus on which is more accurate

-Vieira et al. (2011) **G** (1610-1700); **I** (1700-present)

- Dikpati et al. (2006) **I** (1750-1880)

- Solanki et al. (2004) **G** (1610-present)

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RECALIBRATING THE SUNSPOT NUMBER (SSN): THE SSN WORKSHOPS

E. W. CLIVER[1], F. CLETTE[2] and L. SVALGAARD[3]

[1]*Space Vehicles Directorate, Air Force Research Laboratory, Sunspot, NM, 88349 USA*
[2]*Solar Influences Data Center, Royal Observatory of Belgium, 3 Rue Circulaire, 1180 Brussels, Belgium*
[3]*W.W. Hansen Experimental Physics Laboratory, Stanford University, Stanford, CA 94305 USA*

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The use of two SSNs might be acceptable if the differences between the two time series were insignificant. Figure 1 shows that that is not the case. The choice of which sunspot time series to use can have a substantial difference on the conclusions drawn. For example, the report that we have just experienced the most active period of solar activity in the last ∼8,000 years (Solanki *et al.*, 2004; cf., Usoskin *et al.*, 2006) is based on the use of the Group SSN.

To address the problem of the two discordant sunspot numbers, we have, with the sponsorship of the US National Solar Observatory (NSO), the Royal Observatory of Belgium (ROB), and the US Air Force, initiated a series of SSN Workshops.

Given the importance of the reconstructed time series, the coexistence of two conflicting series is a highly unsatisfactory situation that should now be actively addressed. **Clette et al. (2015)**

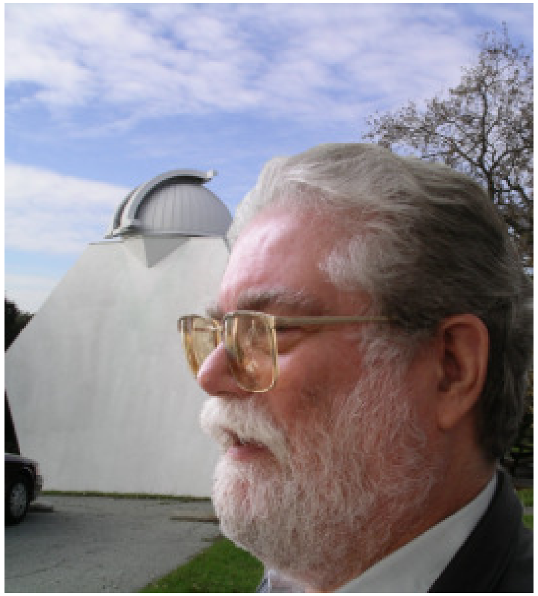
Goals of this workshop

Rectify discrepancy between G & I SSN series during 19^{th} century

Publish a vetted and agreed upon single SSN time series

Sunspot number workshop 19-22 September 2011

Sunspot (National Solar Observatory, Sacramento Peak , New Mexico)



Ed Cliver

National Solar Observatory

US Air Force Research Lab

Leif Svalgaard

Stanford University

Frederic Clette

Royal Observatory of Belgium

Sunspot number workshops

SSN1 – September 2011

SSN2 – May 2012

Mini SSN Workshop
September 2012

SSN3 – January 2013

SSN4 – January 2014

SIDC (Solar Influences Data analysis Center)

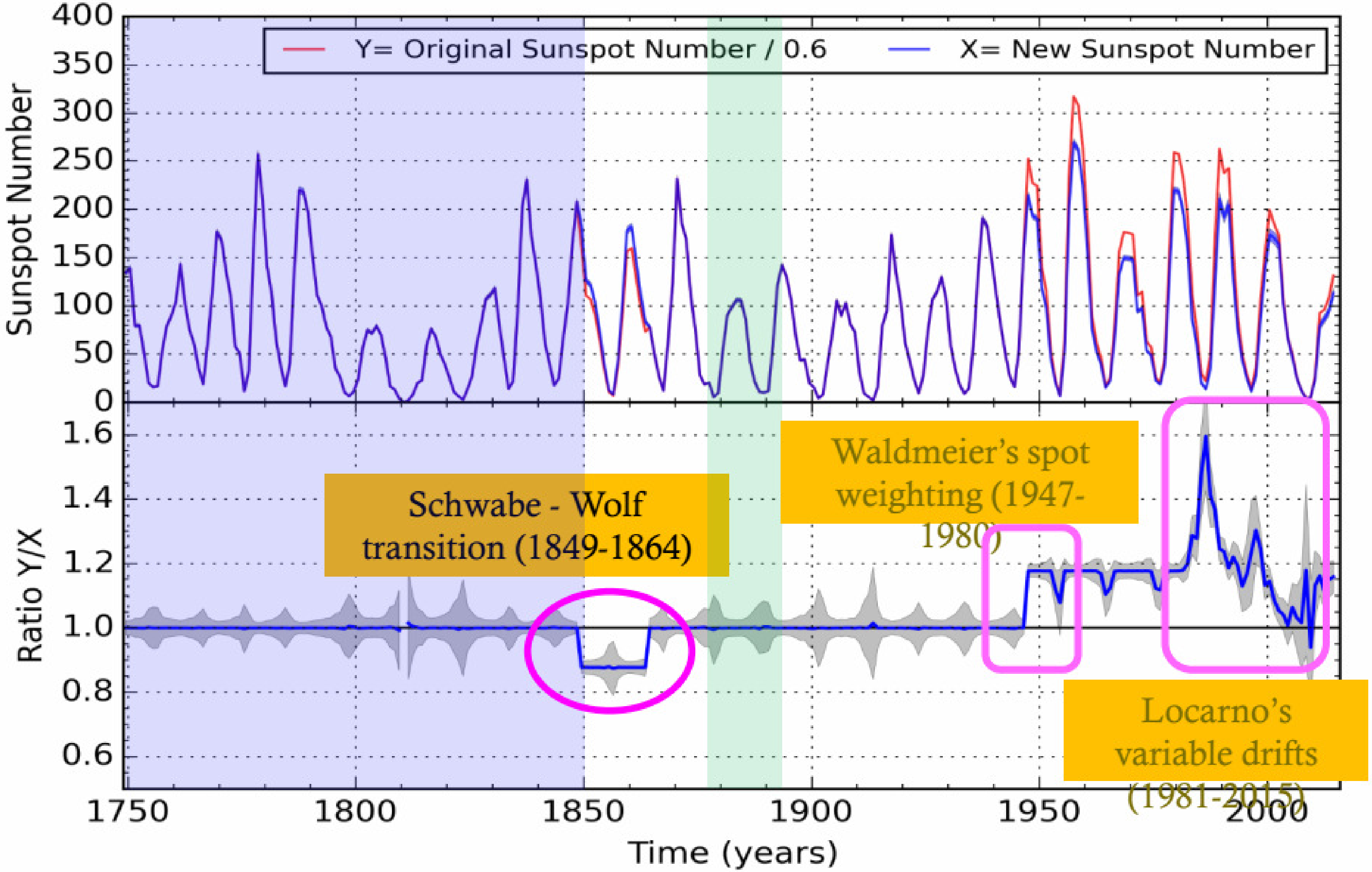
created in 1980 in the Royal Observatory of Belgium as a World Data Center with the task to continue the International relative sunspot number record after the decision of the new director of the Swiss Federal Institute of Technology J.O. Stenflo to terminate the 130-year-long Zürich sunspot number observational program initiated by R. Wolf

"Since July 1st 2015, the original Sunspot number data are replaced by a new entirely revised data series."

SILSO

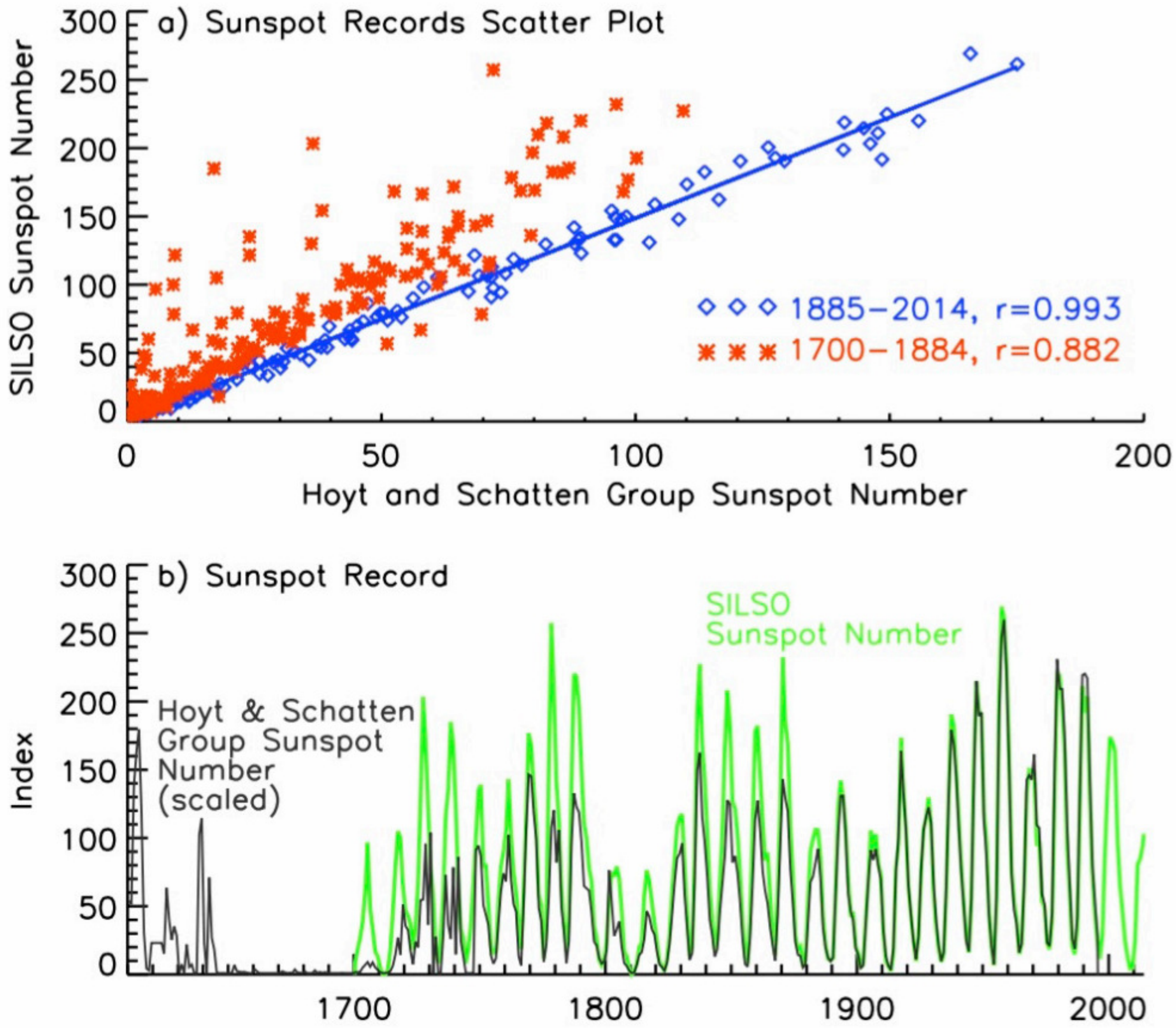
Sunspot Index and Long-term Solar Observations

SUNSPOT NUMBER CORRECTIONS



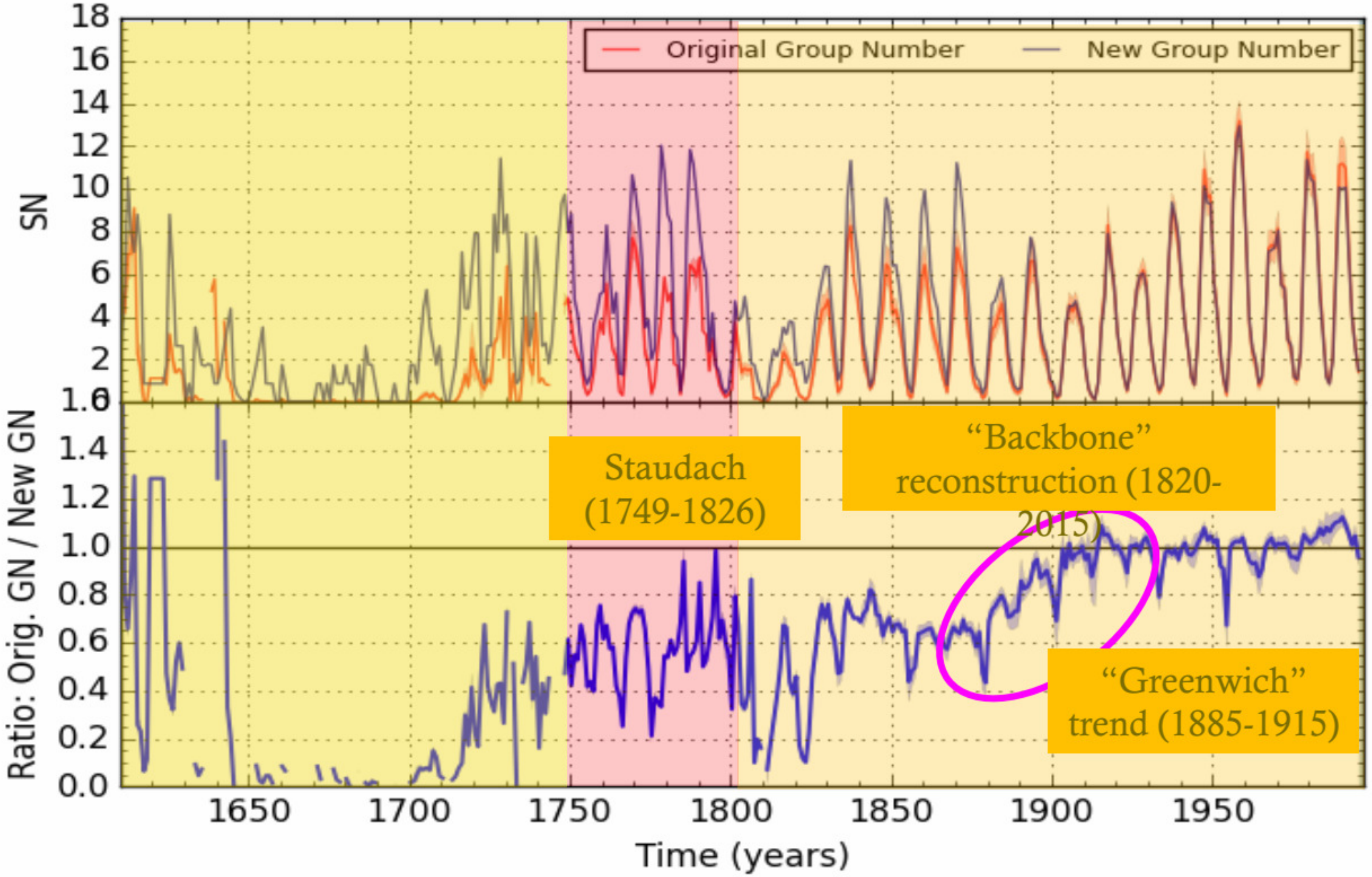
ICSU WORLD DATA SYSTEM

The difference is mainly before 1885



Kopp et al. (2016)

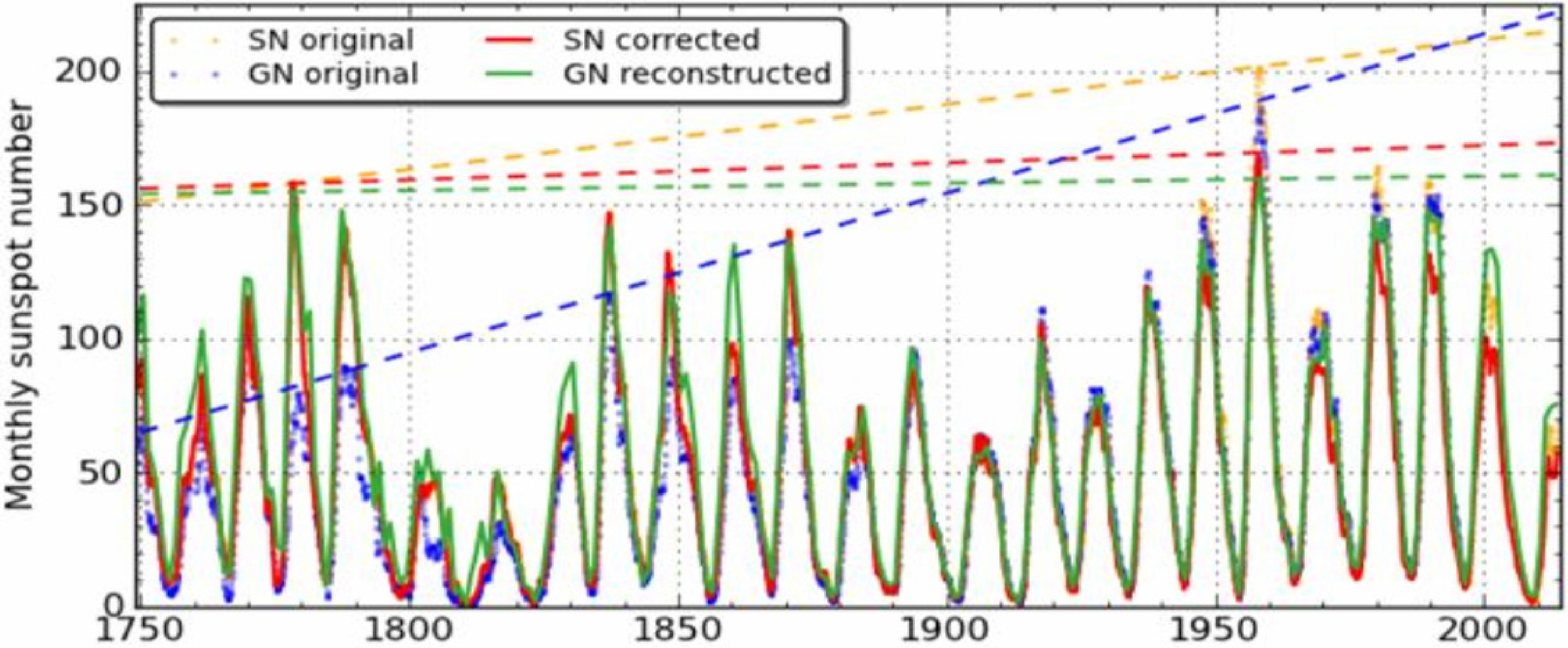
GROUP NUMBER CORRECTIONS



MAIN RESULTS OF RECONSTRUCTIONS

- Long term trends … gone

Difference between the two series … gone



Consequences of the recalibrations

A recent wave of new results: SN

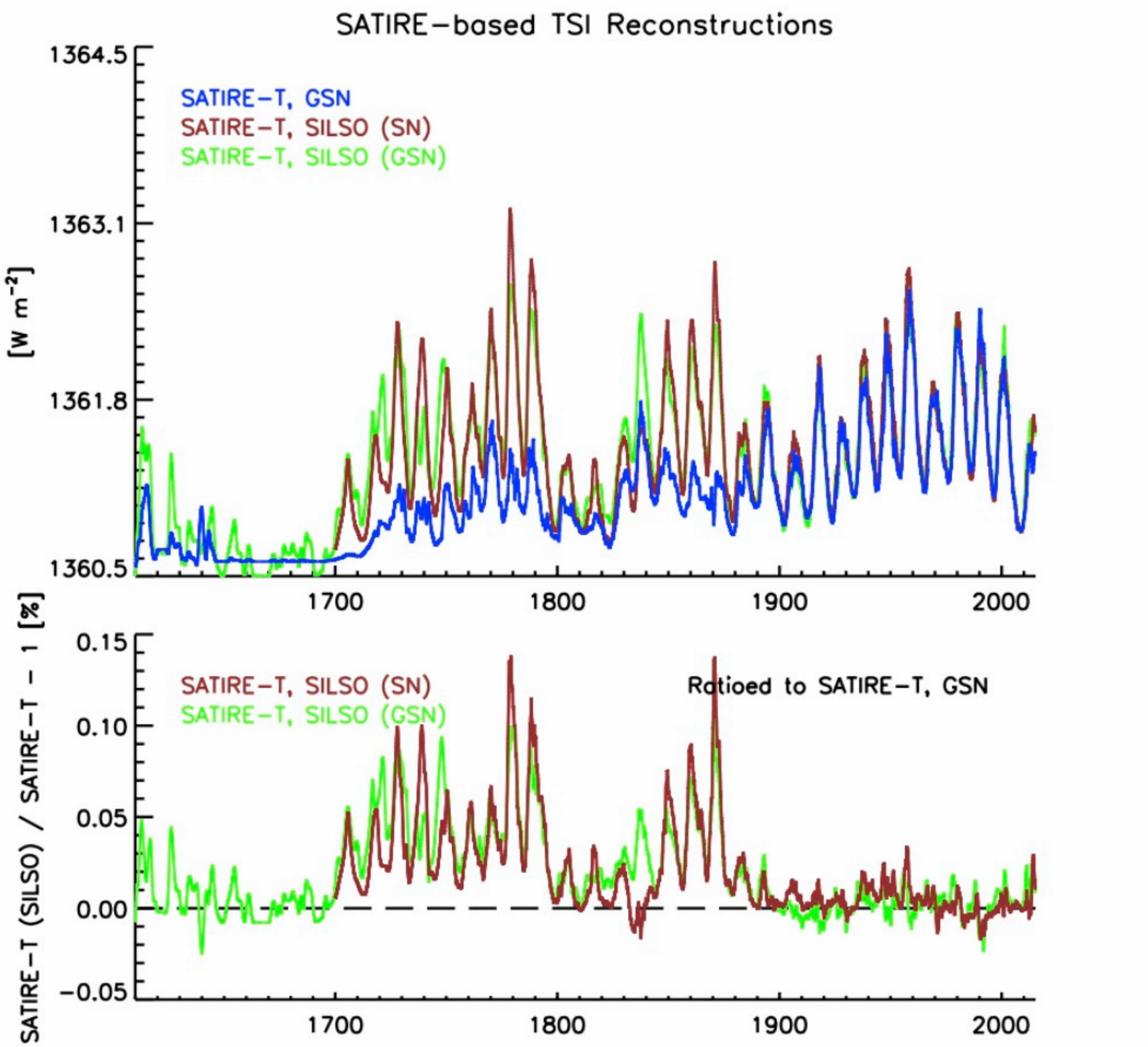
Reference	Topic	Pros	Cons
Leussu et al. 2013	1849 Schwabe Wolf transition	• Use of original Schwabe documents • True 20% jump in 1849	• Conclusions extrapolated outside the limited 1826-1868 data interval • Early Schwabe drift not taken into account
Lockwood et al. 2014	1947 Waldemeier jump	• Unbiased statistical estimator for jump factor • Use of multiple indices (RGO GN, spot area)	• Use of uncorrected original SN and GN • Influence of time windows ignored • Inclusion of the Leussu et al. 2013 20% correction
Lockwood et al. 2016	1947 Waldmeier jump	• Use of an external comparison (FoF2 ionospheric index)	• Only 15 years before 1947 transition • Homogeneity of early data is uncertain
Friedli 2016	Reconstruction of the Zurich SN series (1849-1981)	• Direct exploitation of original documents (Wolf)	• Only single standard Zurich observer • Assumed stability not verified

- Interesting ideas but new mistakes
- 2 new SN series proposed

A recent wave of new results: GN

Reference	Topic	Pros	Cons
Svalgaard & Schatten 2015	GN 1610 - 2015	• Daisy-chaining replaced by 5 primary "backbone" observers • Different group-splitting practices taken into account	• K factors by simple linear regressions • Yearly means • Staudacher k factor applied to 1610-1749 • 7% Zurich classification effect not proven
Lockwood et al. 2016	Biases in the determination of k factors	• Effects of non-proportionality and non-linearity on linear regression	• Simulation based on photographic data (RGO) • Only considers the acuity to detect small groups
Usoskin et al. 2016	GN 1749 - 1899 New active-days method	• Innovative approach • No need for k coefficients • Can bridge data gaps	• Calibration on simulated data (RGO catalogue) • Only considers the acuity to detect small groups • Wolf-Wolfer comparison: unexplained non-linearity
Cliver & Ling 2016	GN 1830 - 1995	• Reconstruction of original Hoyt & Schatten method • Diagnostic of 1884-1915 bias factor	• Same daisy-chaining as the original GN • K factors by linear regression

- 3 new GN series proposed



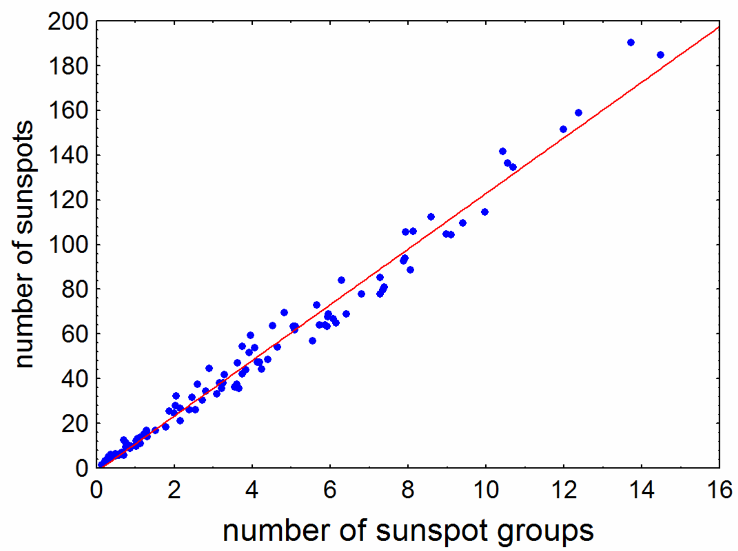
VarSITI Project “Long-term solar variability and sunspot indices”

Based on the knowledge of the mechanisms of solar activity and observations of its various solar and terrestrial manifestations, to answer two questions:

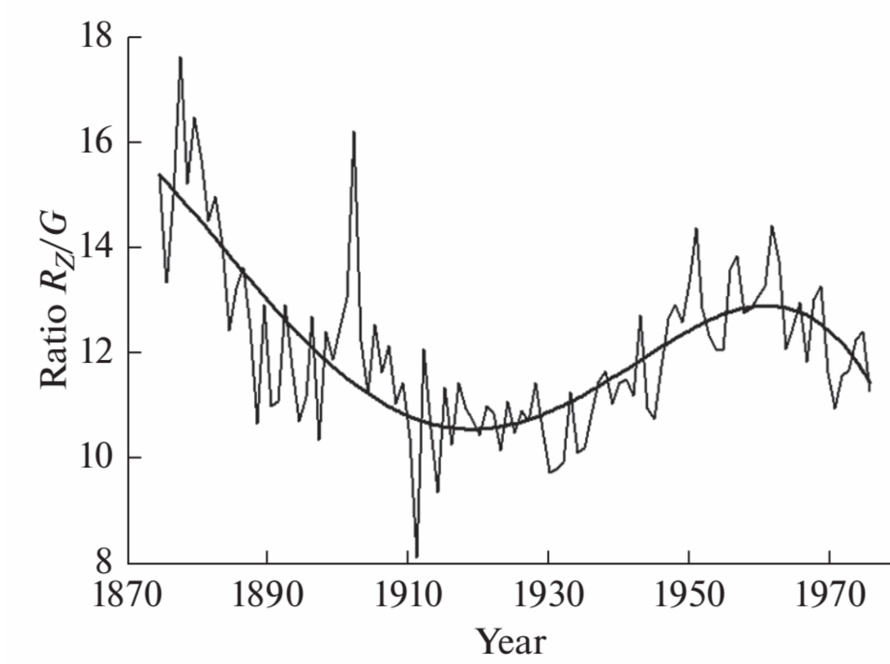
-whether there were century-to century variations of solar activity in the last 400 years

-whether the differences in the long-term variations of different sunspot indices (e.g. sunspot number and sunspot group number) are due to calculation or methodological errors and the indices need to be reconciled, or are due to physical reasons and the differences can give additional information about the way the Sun operates.

Is it justified to aim at "rectifying" the discrepancy between the Wolf and group numbers?



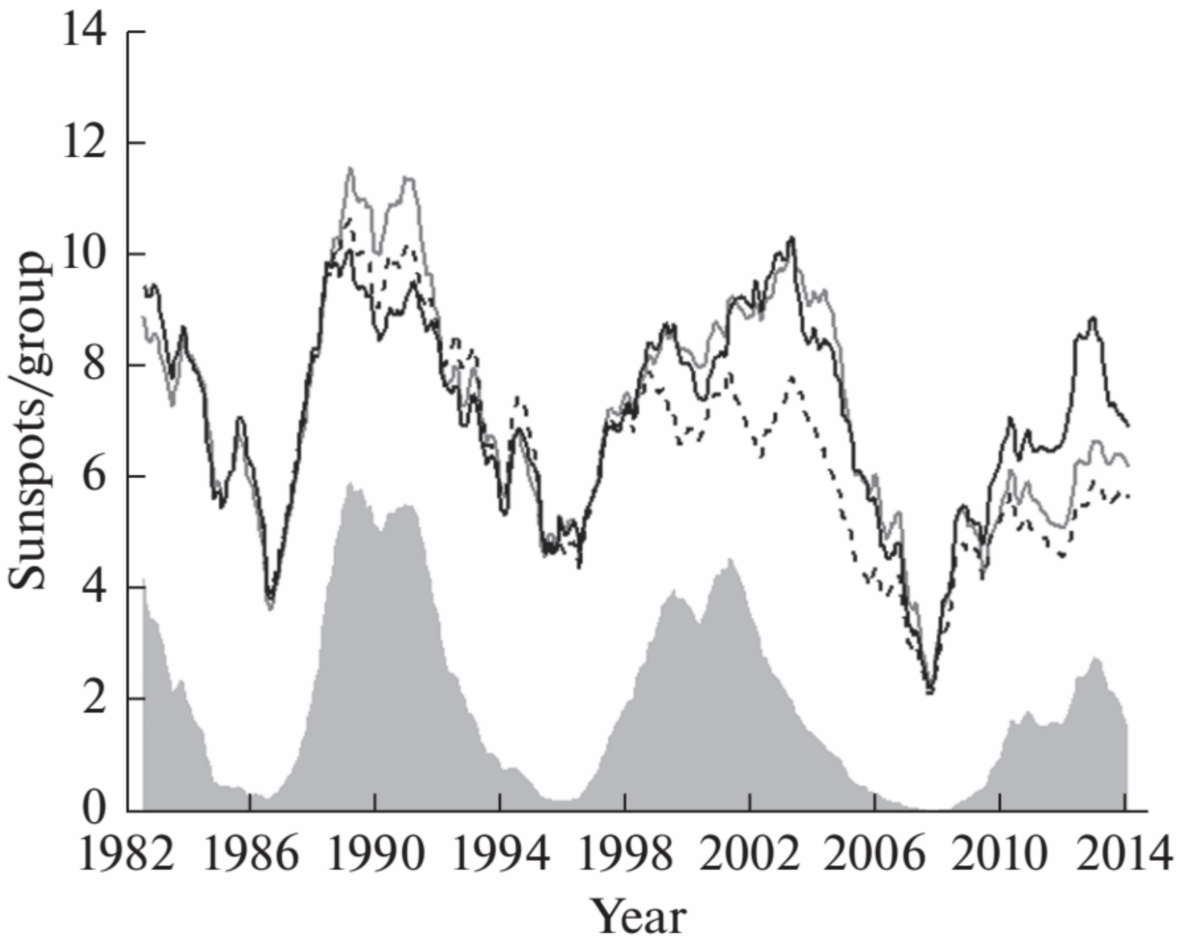
$R_G = 12.08\ G$



Geomagnetism and Aeronomy, 2017, Vol. 57, No. 7, pp. 1

Their ratio varies in quite a systematic way

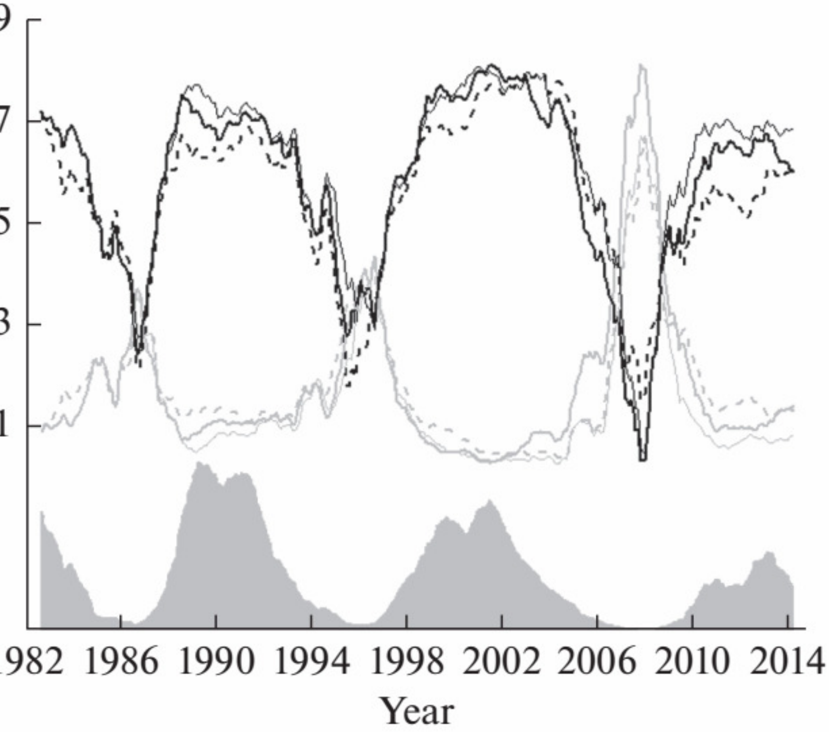
Number of sunspots per sunspot group



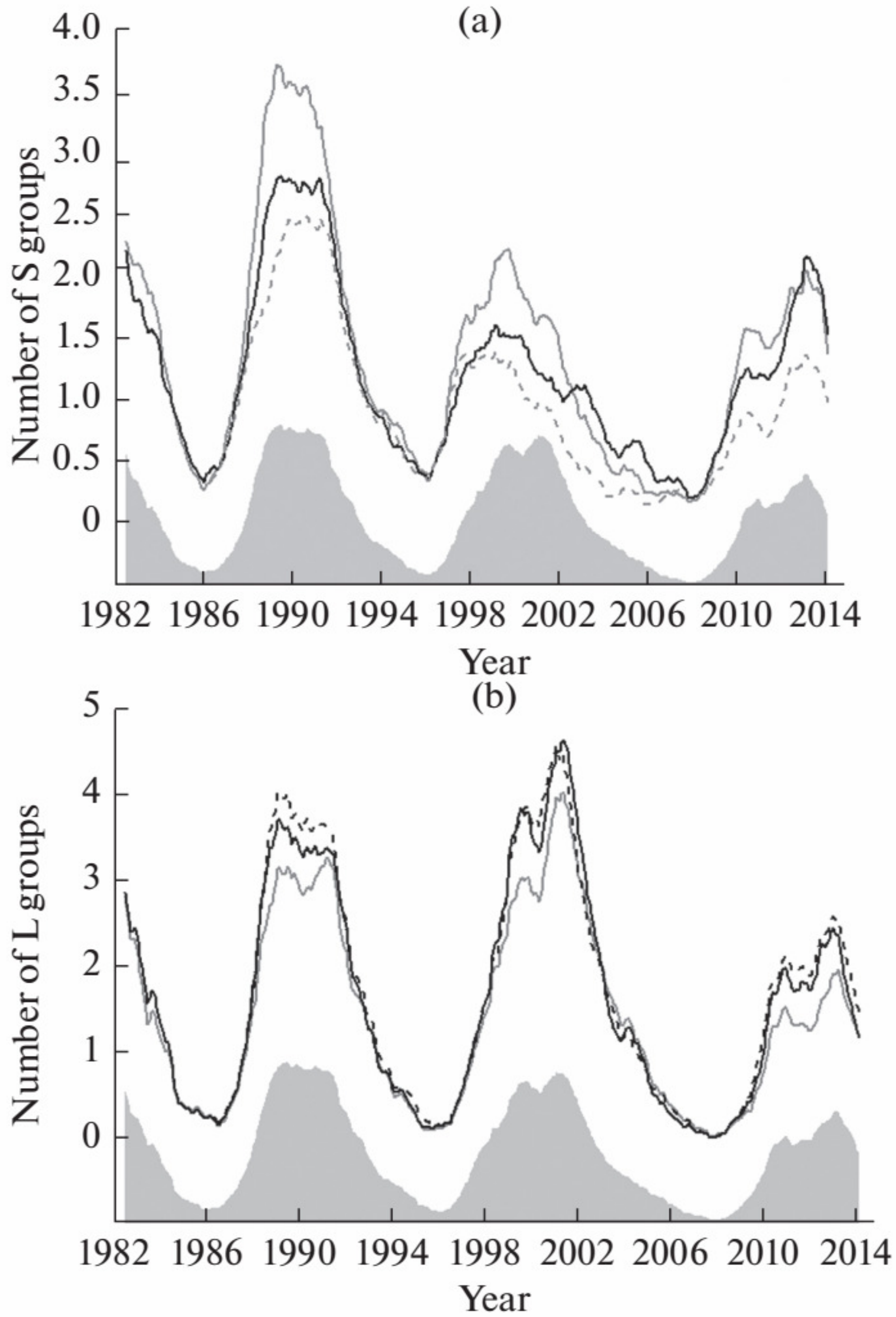
The number of sunspots pe
sunspot group has solar cyc
and cycle-to-cycle variation

Fig. 3. Total number of sunspots per sunspot group
sured by LEAR (black solid line), HOLL (grey solid
and SVTO (black dotted line), 12-point smoothed m
values, compared to the total number of sunspots av
over the three observatories (grey shading), 12-
smoothed monthly values.

The number of different groups varies differently

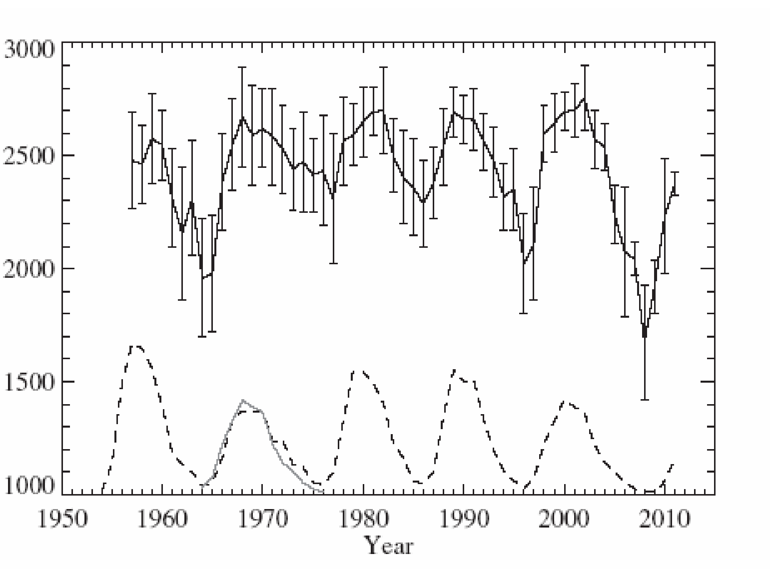


6. Variations of the fraction of sunspots contained in S ups (grey) and in L groups (black) in LEAR (thick solid), HOLL (thick dotted line), and SVTO (thin solid), with the total number of registered sunspots, aver- l over the three observatories (grey shading), 12-month othed monthly averages.

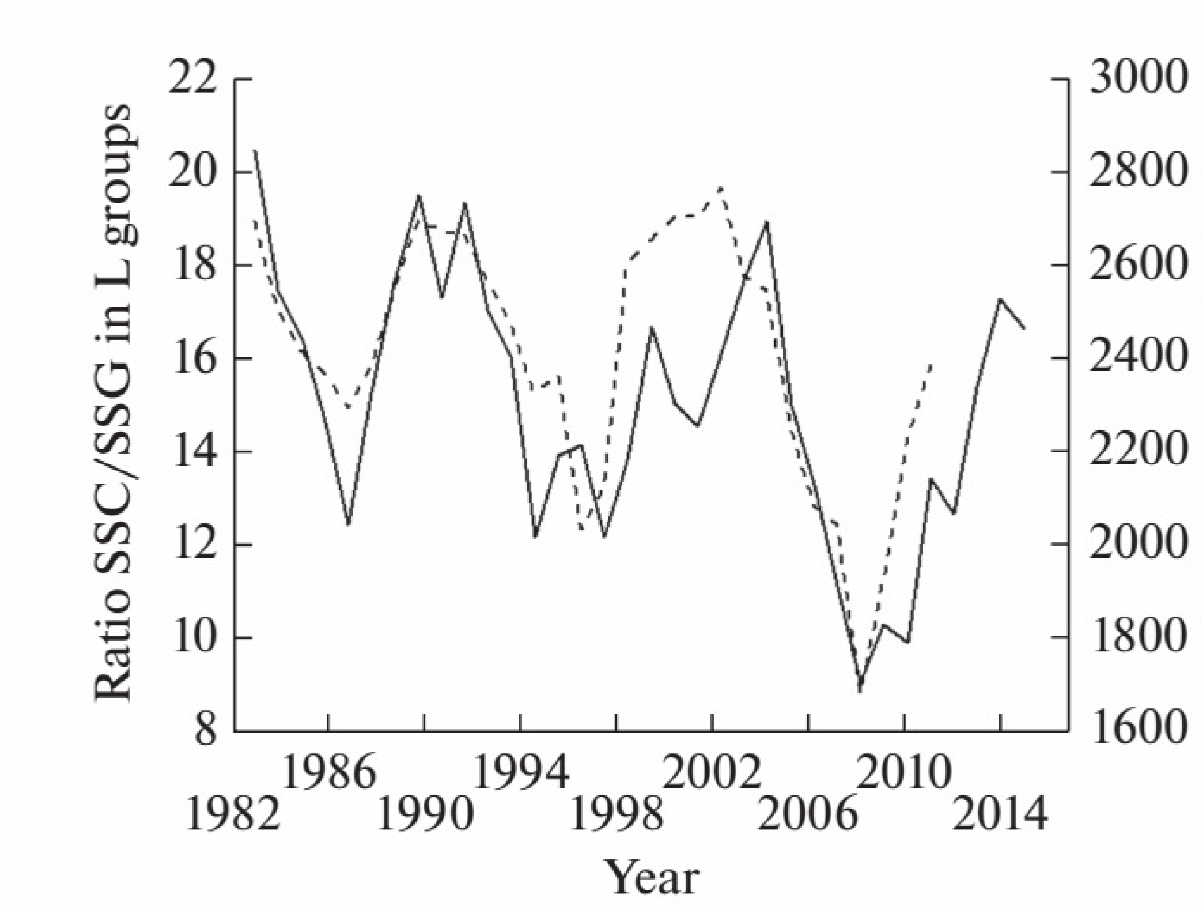


S – simple gr
(Zurich class
and B)
M – medium
(class C)
L – large gro
(classes D, E
F – final grou
(class H) = de
remnants of
L groups

e complexity of a sunspot
oup (and the number of
nspots in it) increases with its
agnetic field.
heeley, 1966)



sunspot magnetic field varies in the sunspot
e (Pevtsov et al., 2012)



The discrepancy between the sunspot number and the group sunspot number is a real feature reflecting variations in the operation of solar dynamo.