The International Sunspot Index R_i

A perspective on the last 50 years

Frédéric Clette

SIDC – WDS "Sunspot Index"

Royal Observatory of Belgium

The Sunspot Index: 4 eras

Epoch	Historical (1610-1848)	Wolf (1848 – 1882)	Zürich (1882 – 1980)	SIDC (1981 – now)
Observations	Sparse	Systematic	Systematic	Systematic
Obs. technique	Variable	Eyepiece	Eyepiece	Eyepiece or drawing (proj.)
Stations (daily)	Base: 1	Base: 1 Aux: a few	Base: 1 then 2 Aux: ~30	Base: 1 + full network (~45)
Geog. Distrib.	W-Europe	W-Europe	Europe + Asia	Worldwide
Processing	Manual	Manual	Manual	Computer
Reference	Successive obs. K=1	Wolf (Zürich) K=1	Zürich+Locarno K=0.6	Locarno K=0.6
Small spots	No	No	Yes	Yes
K coefficients	Estimates	Regular	Systematic (yearly)	Systematic (monthly)
Est. Yearly error (%)	10 - 45	10	< 5	< 1
Est. Accuracy (%)	20 - 50	20	5 - 10	~ 5
Drift control	Loose, indirect	Loose, indirect	Direct (RGO, $F_{10.7}$)	Direct (many)

The questions

- How did the transition Zürich – Brussels occur ? *(1957 – now)*
- What is the connection between R_z and R_i ?
- How is R_i currently produced ? *(The method)*
- What is the array of SIDC sunspot products ?
- How do R_z and R_i compare with other indices ?
- Subjectivity versus objectivity?

  The actual strengths and weaknesses of the visual index
- What can we do next?

  Perspectives for better understanding R_z & Ri

The Zürich era: 1957 - 1979

- Max Waldmeier [1912-2000] (Director: 1945-1979)
  - “Standard Curves” prediction method
  - Many eclipse expeditions
- 1951: renovation of the Zürich Observatory buildings (solar tower).
- 1957-1958 (IGY): Zürich is designated by the URSI as **World Data Center** for the sunspot number.
- 1957: Foundation of a new station in Locarno

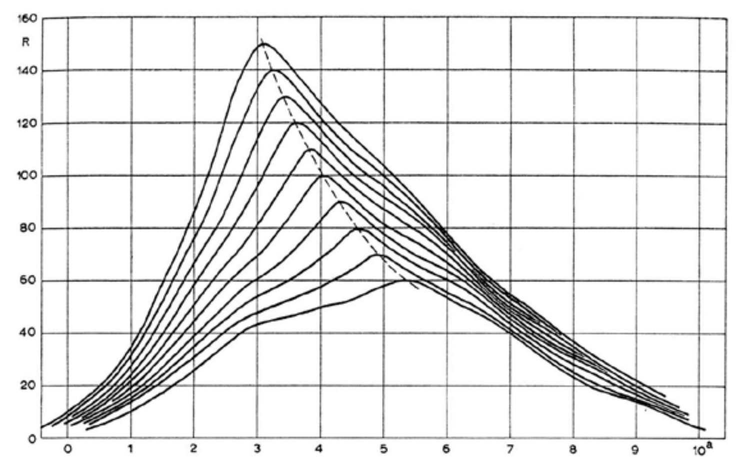


Abb. 3 Normalkurven für $R_M = 60$ bis 150. Abszisse: Abstand vom vorangehenden Minimum.

The other “Zürich“ station: Specola Solare in Locarno

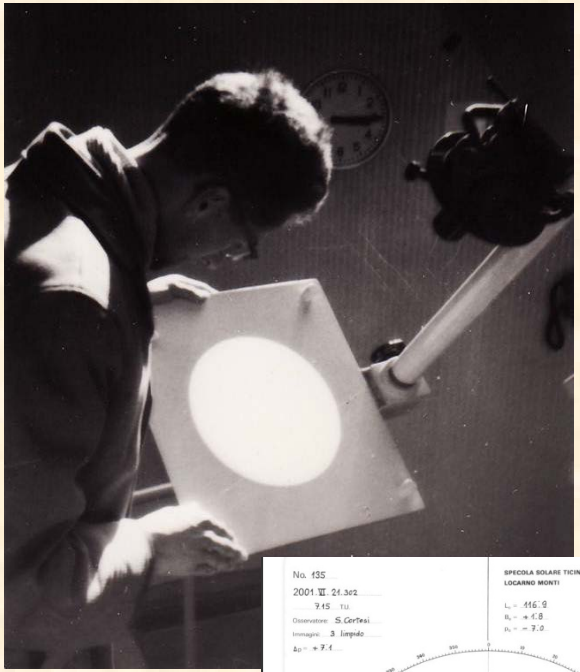
- Motivation:
  - Degradation of observing conditions at Zürich Observatory.
  - More observing days: anti-correlation of weather patterns North and South of the Alps.
- **“Specola Solare Ticinese”** station at Locarno Monti (alt: 370 m)
- Funding:
  - Canton Ticino: local education in astronomy (planetarium, lectures)
  - Private fundation (sponsors, national lottery, etc.)
  - Collaboration with IRSOL and ETH Zürich

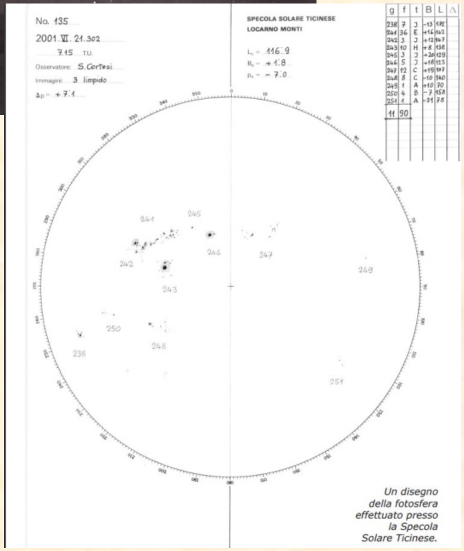
The other “Zürich“ station: Specola Solare in Locarno

- Instrument: Zeiss coudé refractor: D=15cm, F=2.25m
- Drawings: 25cm projected image.
- Sunspot counts: separate observation directly through eyepiece
- Main observer: S.Cortesi starts his uninterrupted observing series at Locarno (continue to these days !)
  - Young engineer
  - Amateur astronomer: accurate planetary drawings
- Since 2007, training of a successor: Marco Cagnotti (Director)

The other “Zürich“ station: Specola Solare in Locarno

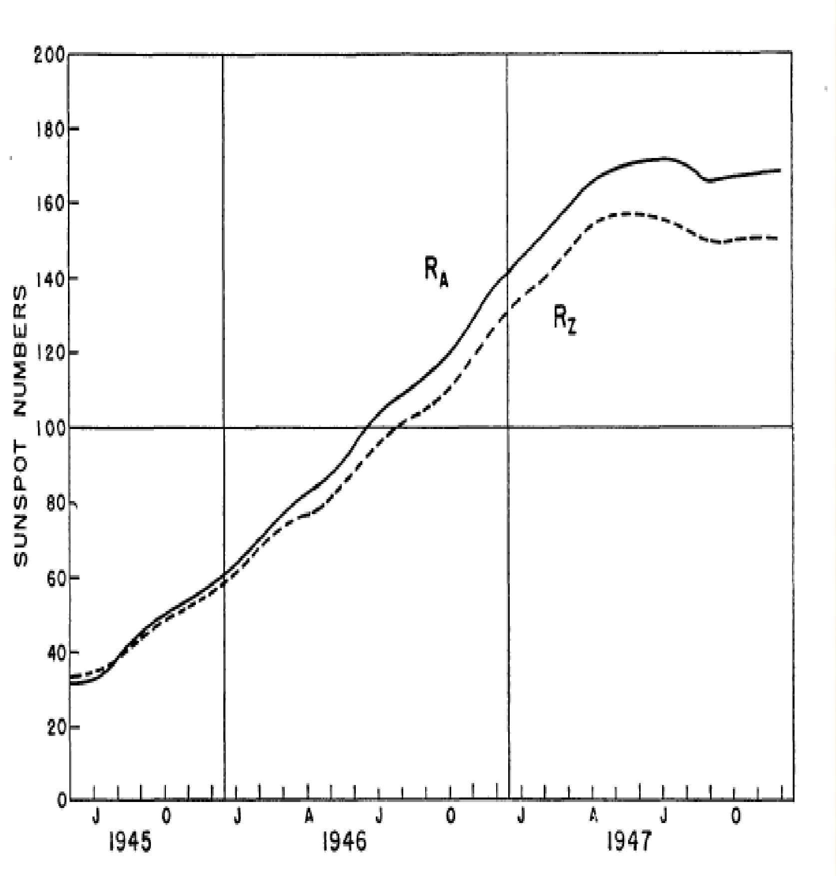
- After 1957, Locarno quickly becomes the main station for establishing R_z
- Training by M. Waldmeier:
  - Same observing method (aerial image, sunspot weighting)
  - Continuous cross-comparisons Zürich-Locarno (1957-1979)
- **In 1981, Locarno is chosen as the pilot station of the SIDC-Brussels to ensure a seamless Zürich-Brussels transition.**





The Zürich – Brussels transition (1979-1981)

- The context:
  - General mistrust versus the visual index in favor of new indices ($F_{10.7cm}$ radio flux)
  - Growing discrepancies between R_Z and the American sunspot number R_A (A. H. Shapley, AAVSO)
- In 1978-80, IAU Working Group involving A.H. Shapley & J.A.Eddy favoring the termination of the Zürich sunspot number

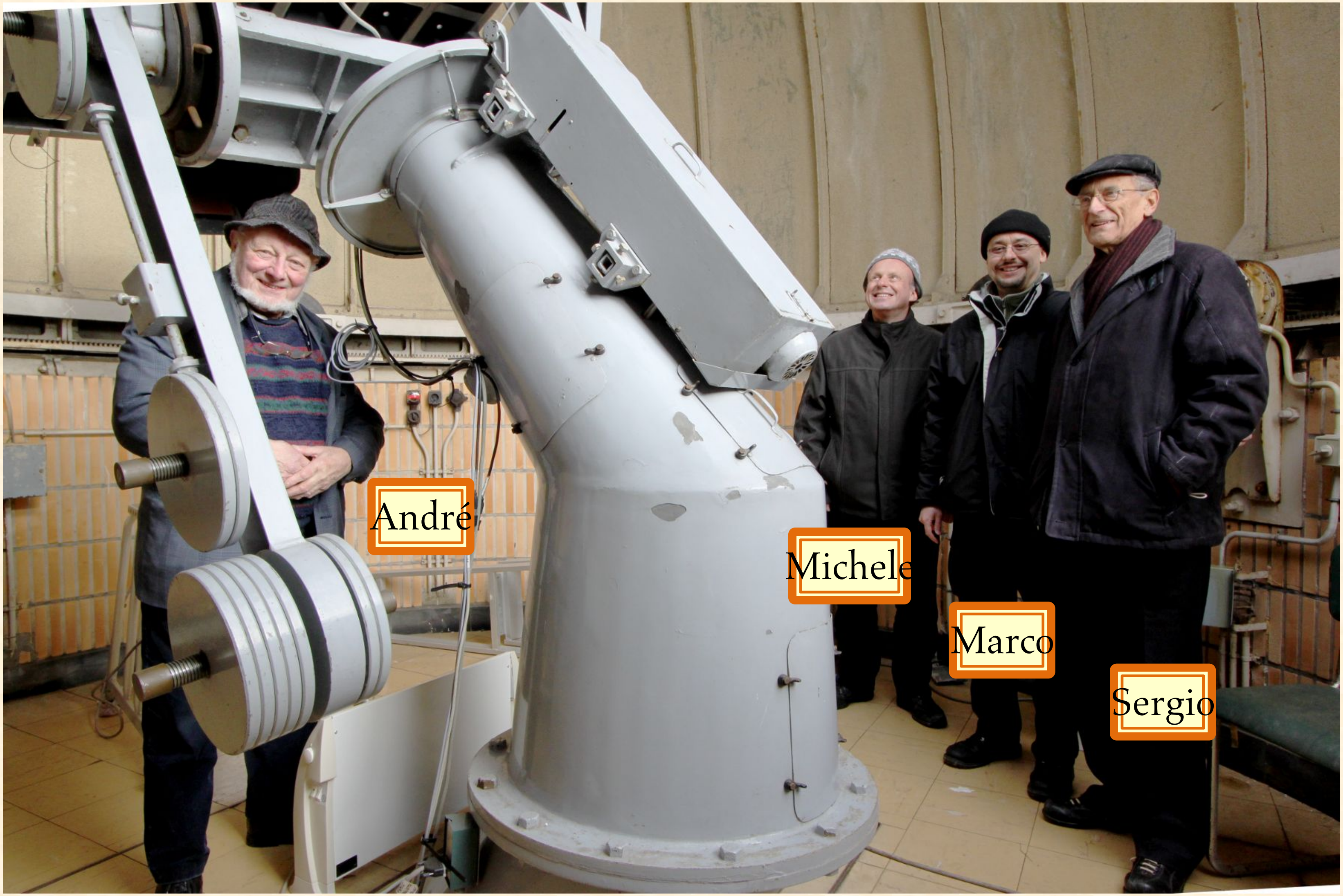


The Zürich – Brussels transition

- Internal reorganization at the Zürich Observatory:
  - In the 1970, integration in the Eidgenössische Technische Hochschule (ETH, Federal Institute of Technology).
  - New ETH Director J.O. Stenflo: new orientation in high resolution polarimetry
  - Global wish to close the Waldmeier era (felt as too authoritative)
- Strong support from international scientific community:
  - 1978: COSPAR resolution and URSI support requesting the continuation of the SSN
- Feb. 1980: call to the community issued by the Zürich Observatory
  - Contacts with A. Koeckelenbergh of the ROB (Uccle station)
- June 3-6, 1980, meeting at ETH Zürich (O.Stenflo, K.Dressler, M.Waldmeier, S. Cortesi, A. Koeckelenbergh):
  - Formal decision to transfer the WDC sunspot to Brussels

Meeting at the ROB: February 2011

Meeting at the ROB: February 2011



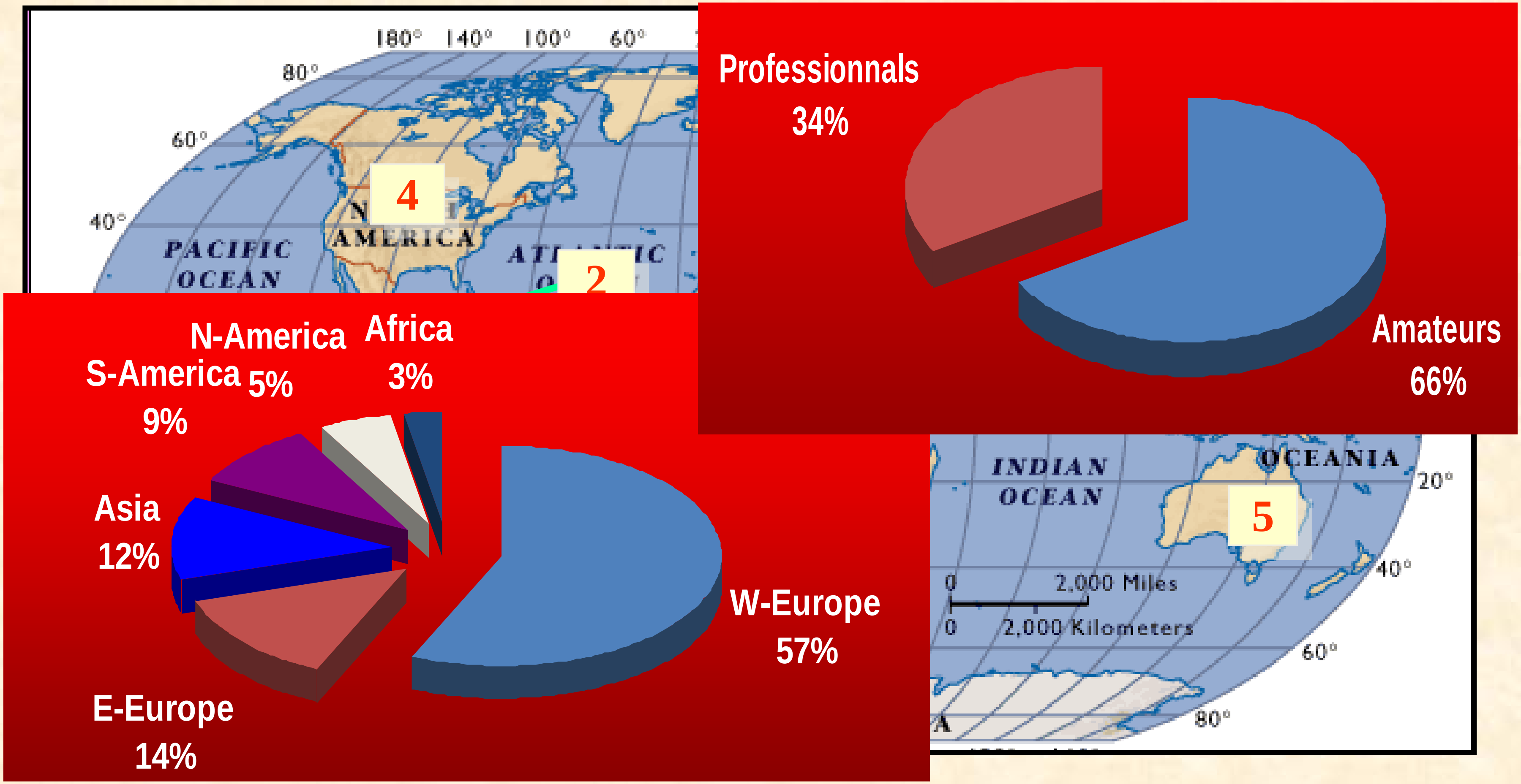
Creation of the Sunspot Index Data center

- **Data service endorsed by 3 Unions: IAU, URSI, IUGG**
  - Official declaration: 1982, IAU General Assembly (Patras)
  - Supervision through ICSU, International Council of Scientific Unions (UNESCO; www.icsu.org)
  - Since 2011, integrated in the new **World Data Services (WDS)**
- New name: **"Sunspot index data Center": SIDC**
- New index: **International Sunspot Number R_i** (new method)
- **Funding**:
  - Mostly ROB: Integration among international services hosted by the ROB
  - Very limited resources: ROB computer infrastructure, running costs (mailings)
- **Staff** (all part time):
  - 1 lead scientist (Director) > F. Clette
  - 1 programmer/system manager > L. Wauters
  - 1 employee: O. Boulvin
- **Directors**:
  - 1981-1992: A. Koeckelenbergh SIDC founder, retired (prime information source!)
  - 1993-2002: P. Cugnon deceased 2002
  - 2003-2010: R. Van der Linden ROB Director since 2005
  - Since 2011: F. Clette involved since 1990

The R_i production method

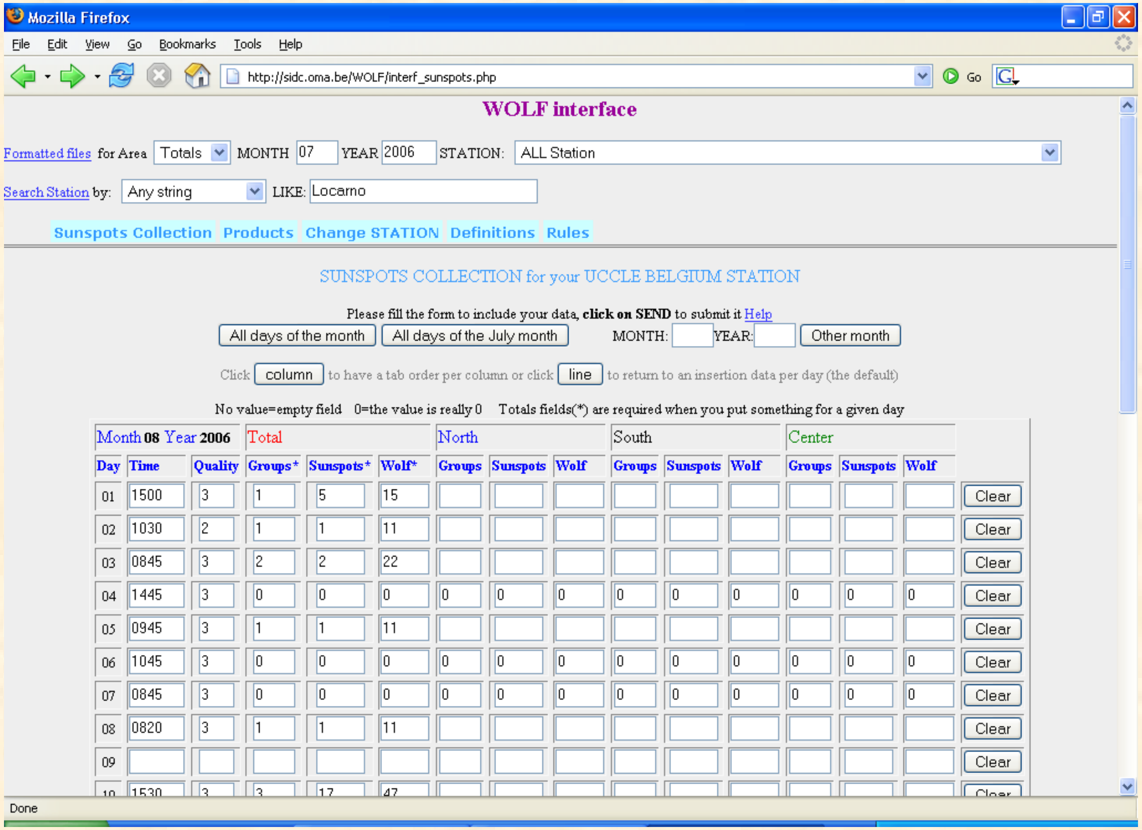
The SIDC worldwide network

- About 86 stations in 29 countries.
  - Still highly concentrated around Europe
  - Low participation in N-America (AAVSO)



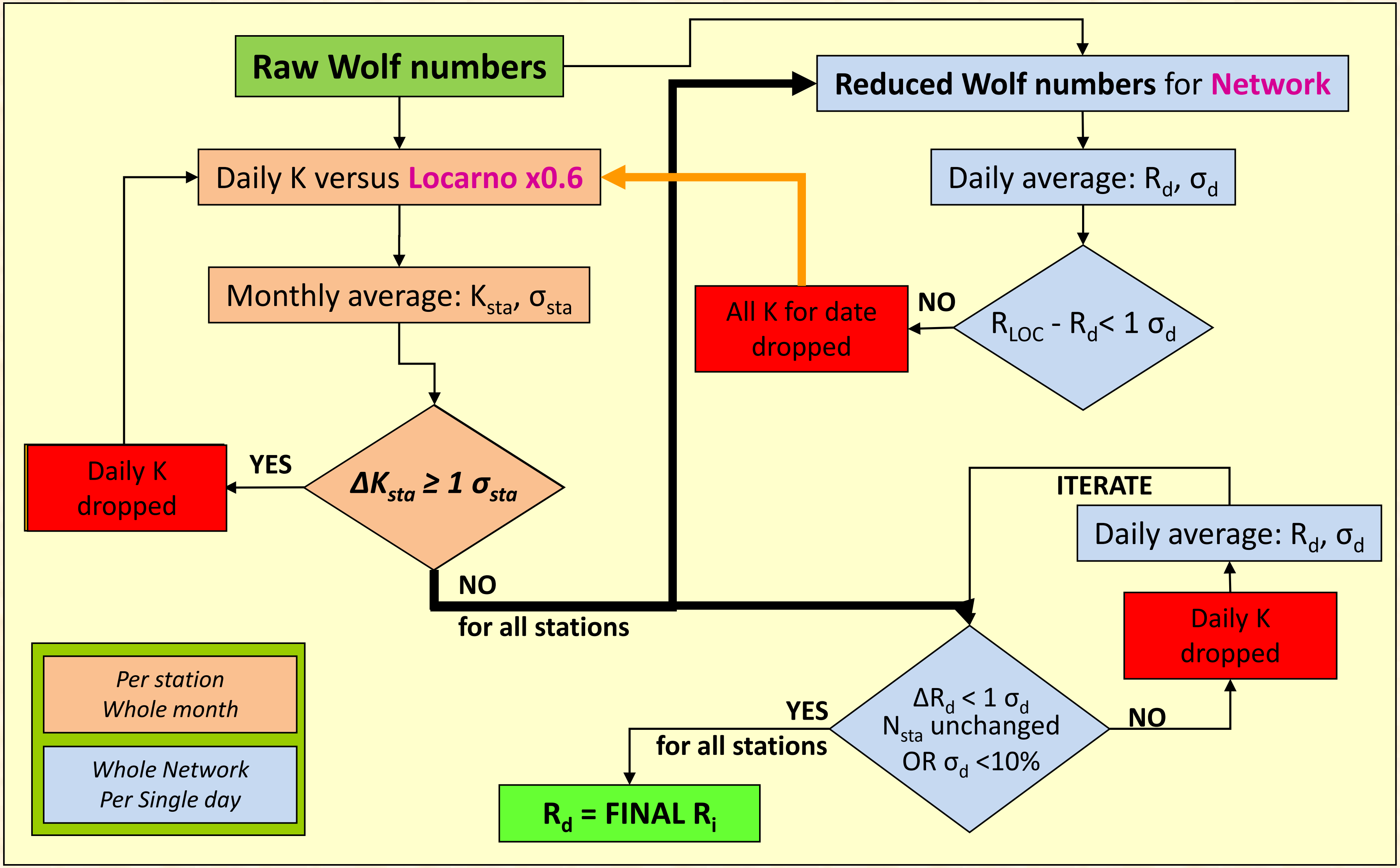
Data import

- Past: postal mail, faxes, e-mails
  > manual encoding, conversions
- **Since 2005, Web-based form**:
  - Private page for each observer
  - "Live" data consistency feedback (PHP)



- Data archival:
  - **All raw reports to SIDC since 1981 (spot & group counts)**
  - **Digitization of past reports to Zürich since 1950 (in progress)**
  - Tracking of stations used in the provisional and definitive calculations only since 1992

R_i processing flowchart



Special processing rules

- **Treatment of low R_i values (many stations reporting W=0):**
- Principle:
  - $R \neq 0$ at a significant number of stations = strong indication that there was a spot (part of the day?).
  - R=0 at a few stations: not sufficient to decide that there was no spot.
- Rule:
  - **If 20% < $N_{(R=0)}$ < 80% then only stations with $R \neq 0$ are taken into account.**
  - Based on the histogram of all observed R_i values
- **For consistency with R_Z** (single base station Zürich)**:**
  - **If $0 < R_i < 7$, R_i set to 7**

Definitive sunspot numbers

- Computed quarterly
- 3-month delay to leave time for late reports (snail mail)
- Typically 20 additional stations
- Same processing as the provisional SSN
- **Provisional values are not automatically replaced by the new values !** Most provisional values are left unchanged.
- Rule:
  - **Ri(Prov) is replaced by a new R_i(Def) value only if $|R_i(\text{Def})-R_i(\text{Prov})|> 5\%$**
- Manually supervised process:
  - Histograms of raw input data
- Once determined, definitive values cannot be changed !

R_i versus R_z

- Fixed computerized processing chain
- Continuous use of the entire network
- Scaling of each station to Locarno (monthly average K)
- Use of the K coefficient of the current month instead of the average of previous year
- Possible exclusion of anomalous daily Locarno values

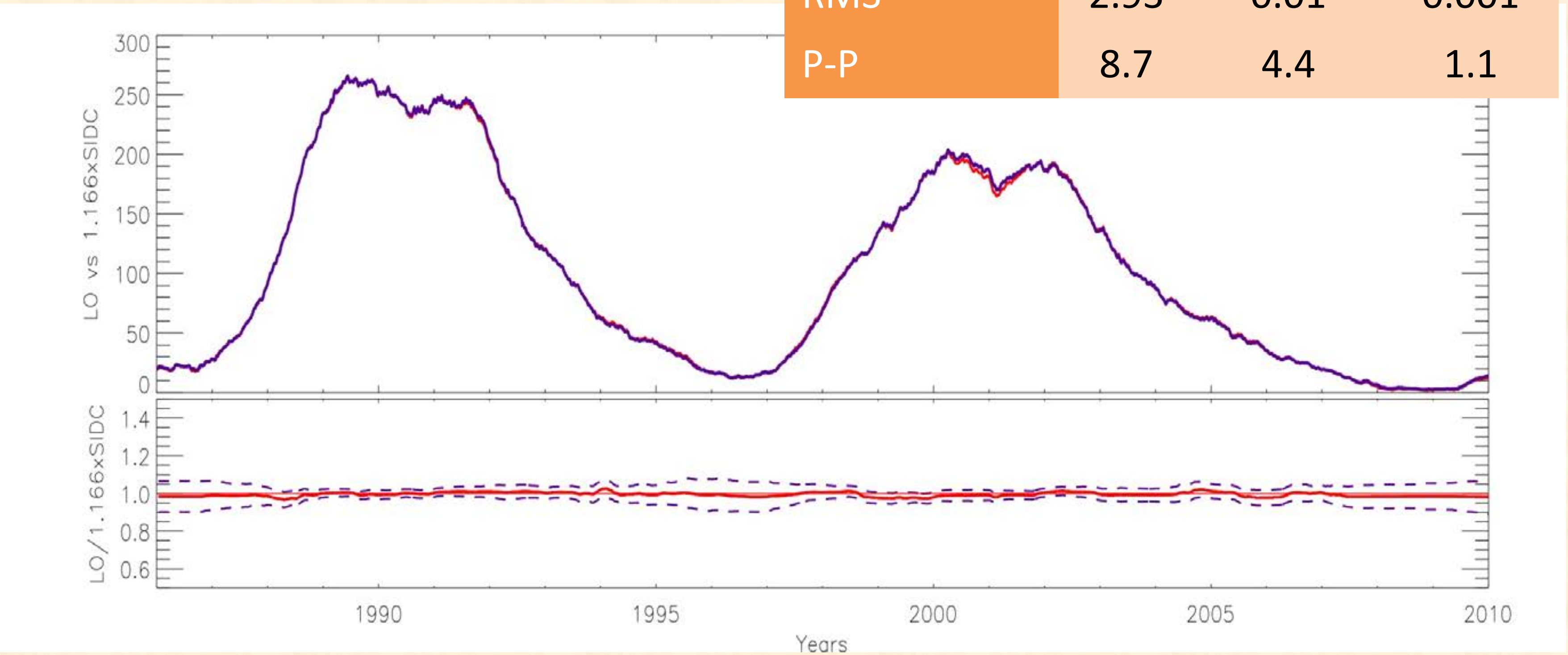
→ **Still a central role played by the Locarno station**

Stability of the Locarno station

The key role of the Locarno station

- R_i has accurately tracked the Locarno pilot station
- Trends fully removed for timescales > 1 month

Dispersion %	Daily	Monthly	Yearly
RMS	2.93	0.01	0.001
P-P	8.7	4.4	1.1



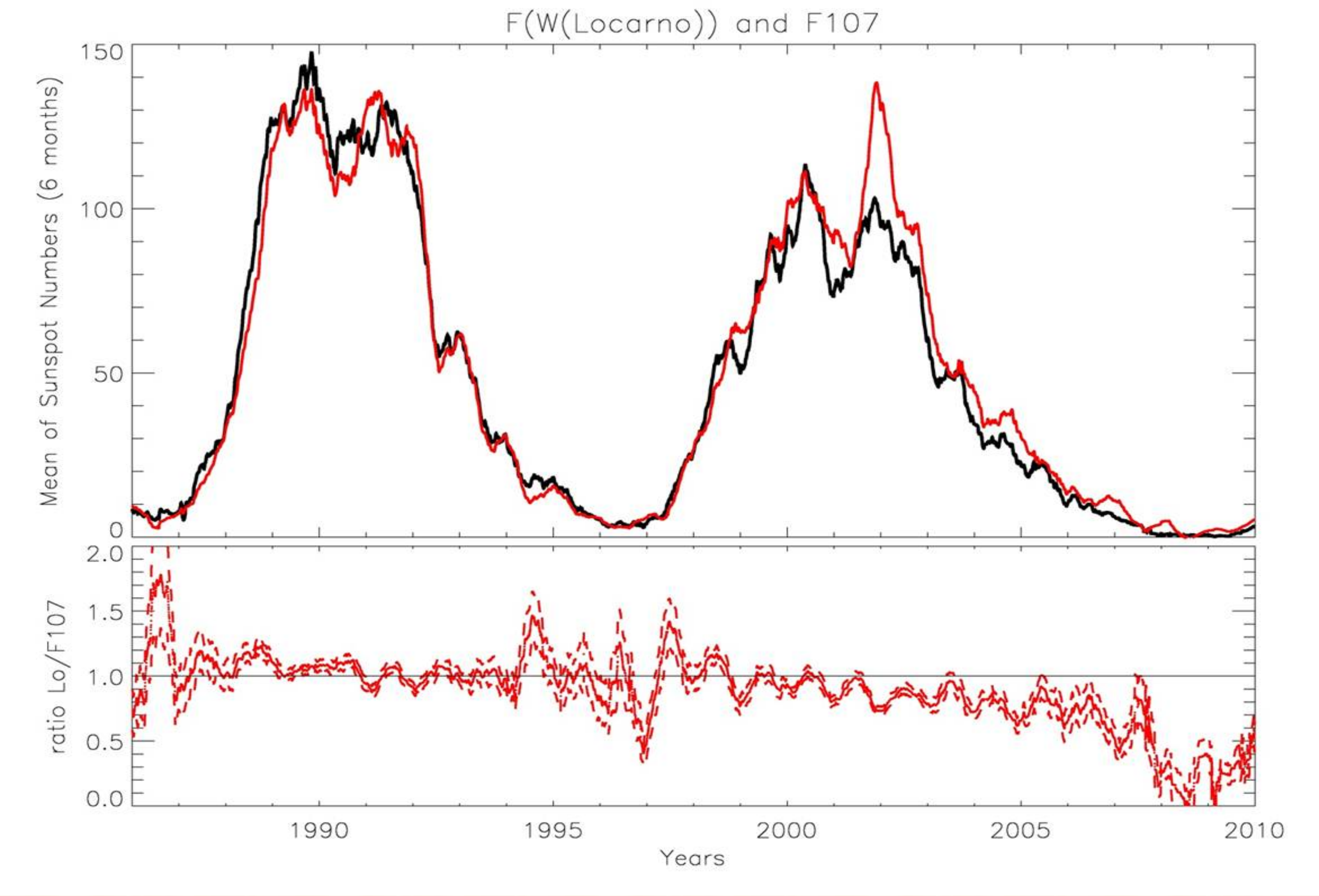
→ R_i and $W_{Locarno}$ are almost equivalent

Long term stability of the Locarno station

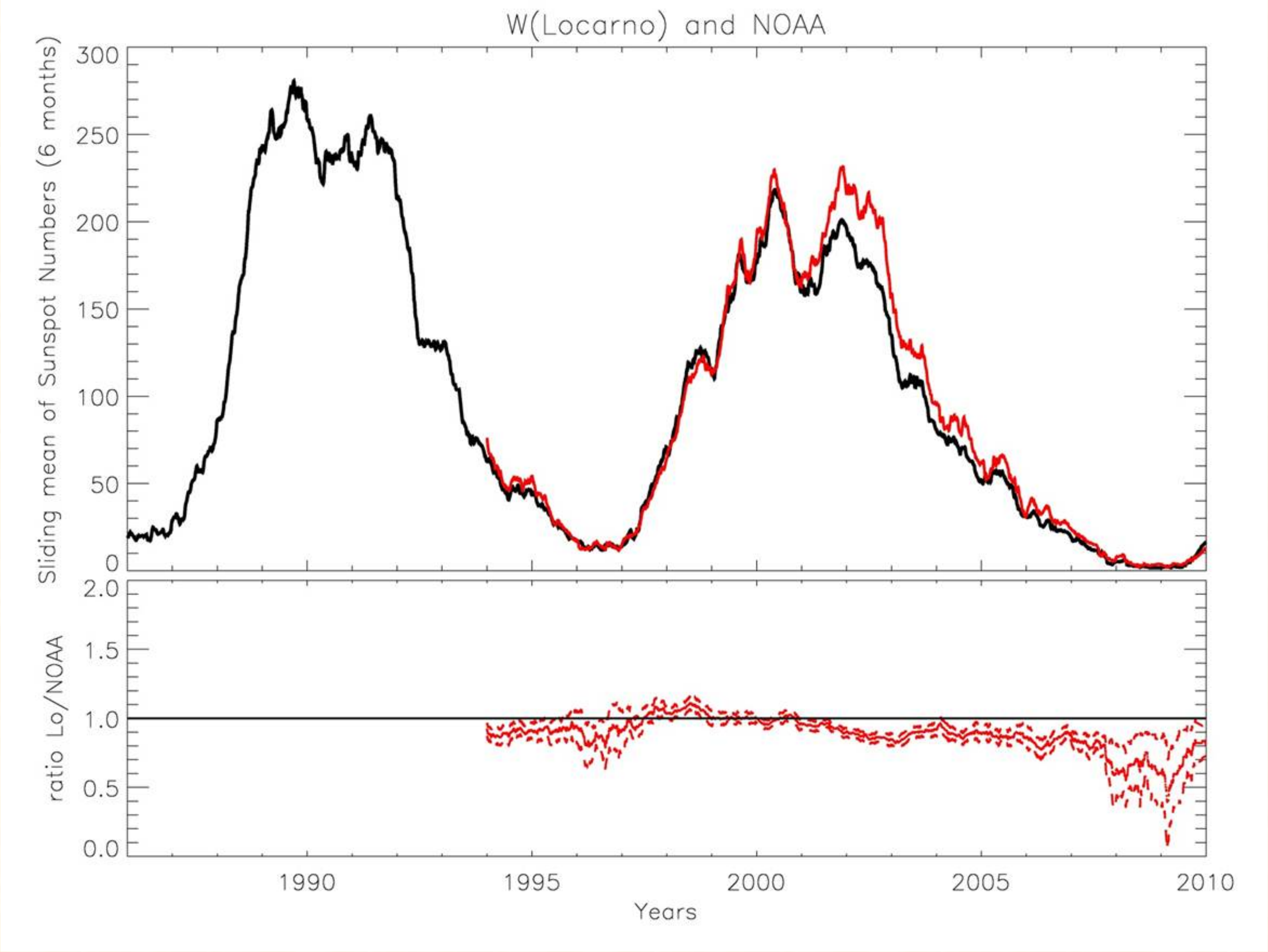
- Two kinds of validation: intrinsic and comparative
- **Cross-comparison with external data series**:
  - **Sunspot numbers from individual stations**:
  - **Sunspot numbers from independent networks**:
  - **Other solar indices (SS area, F10.7cm, CaII-K, MgII)**:

    But not fully comparable: different solar source (see later)

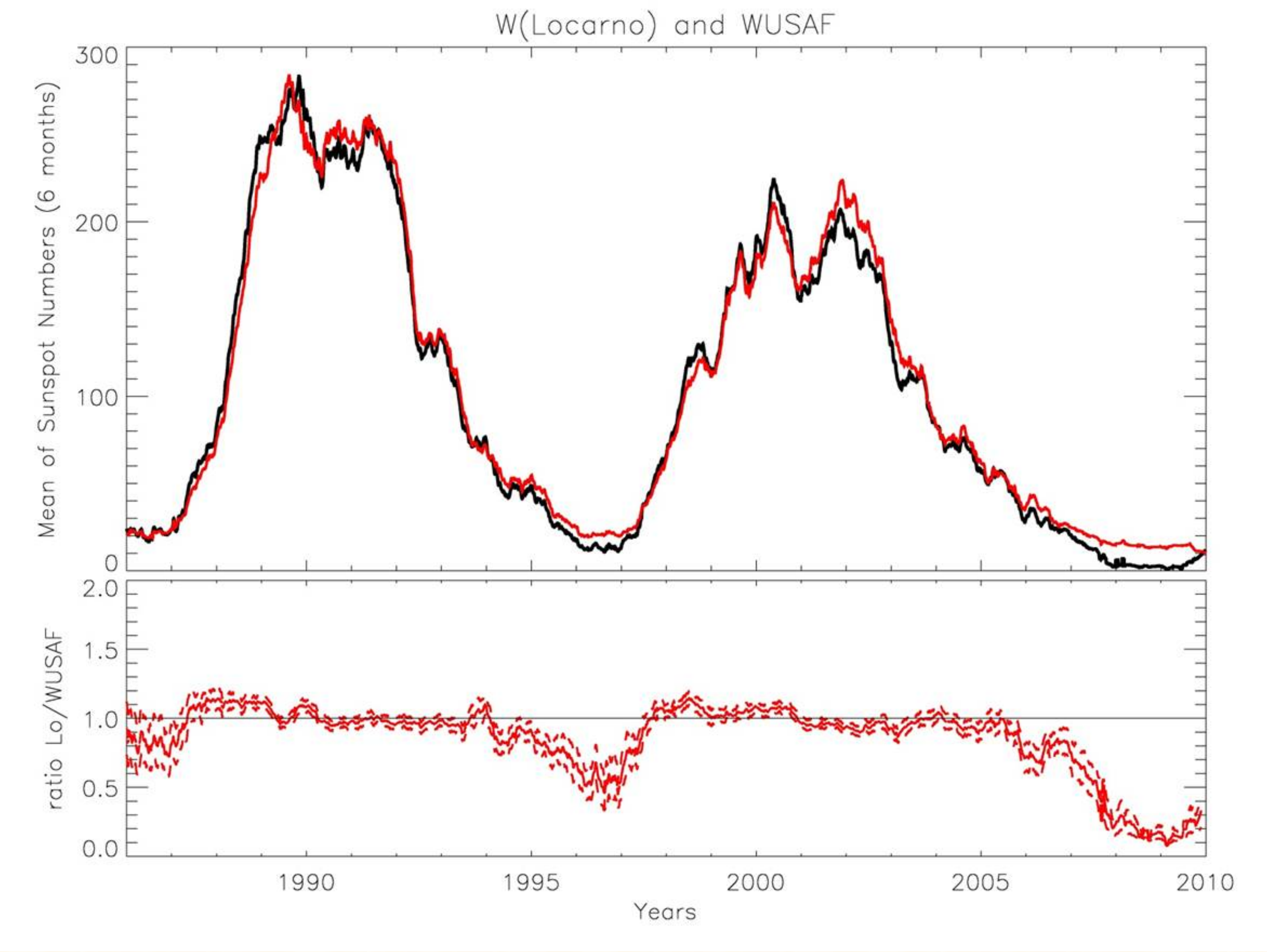
Locarno versus F10.7cm



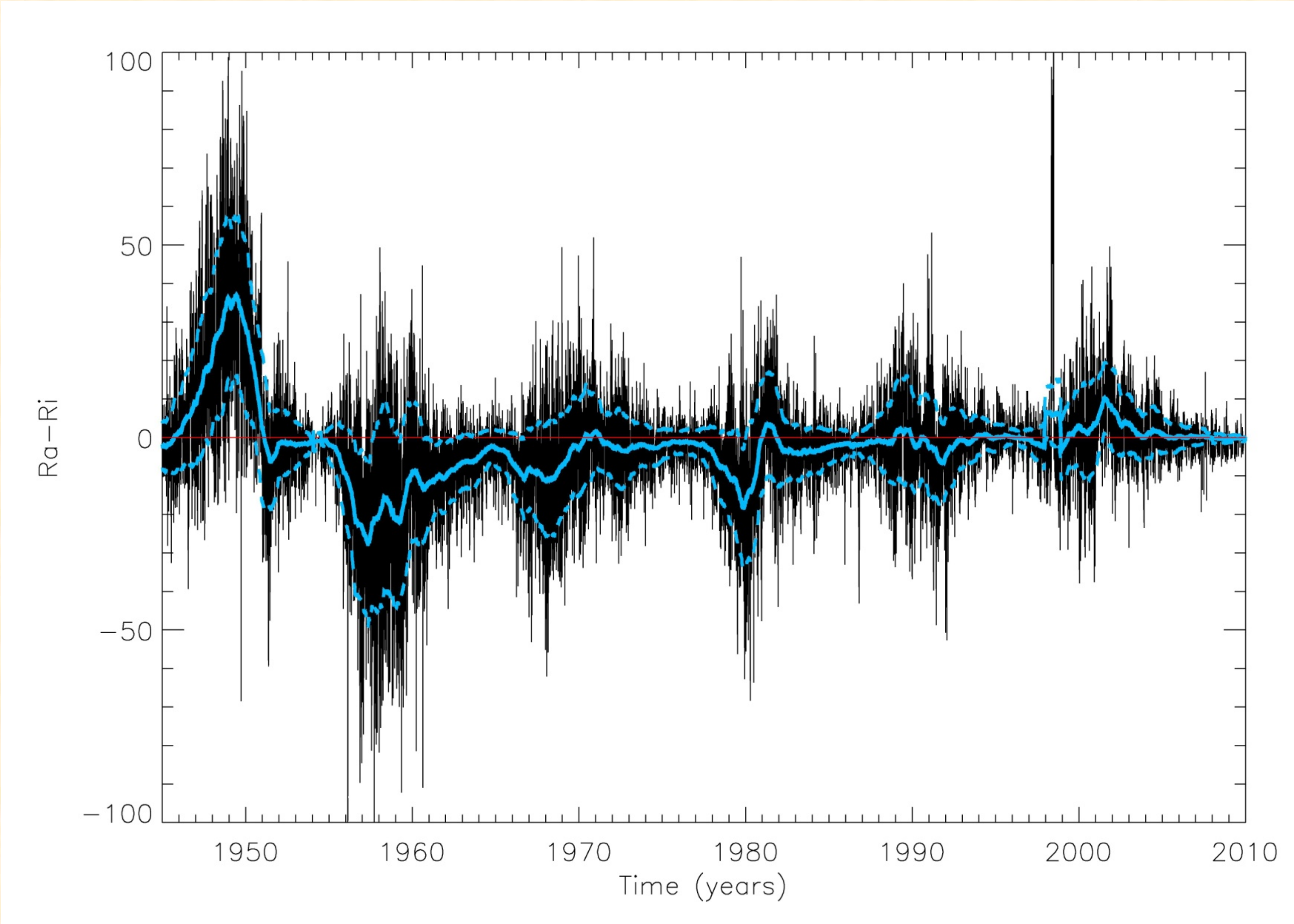
Locarno versus NOAA-Boulder SSN



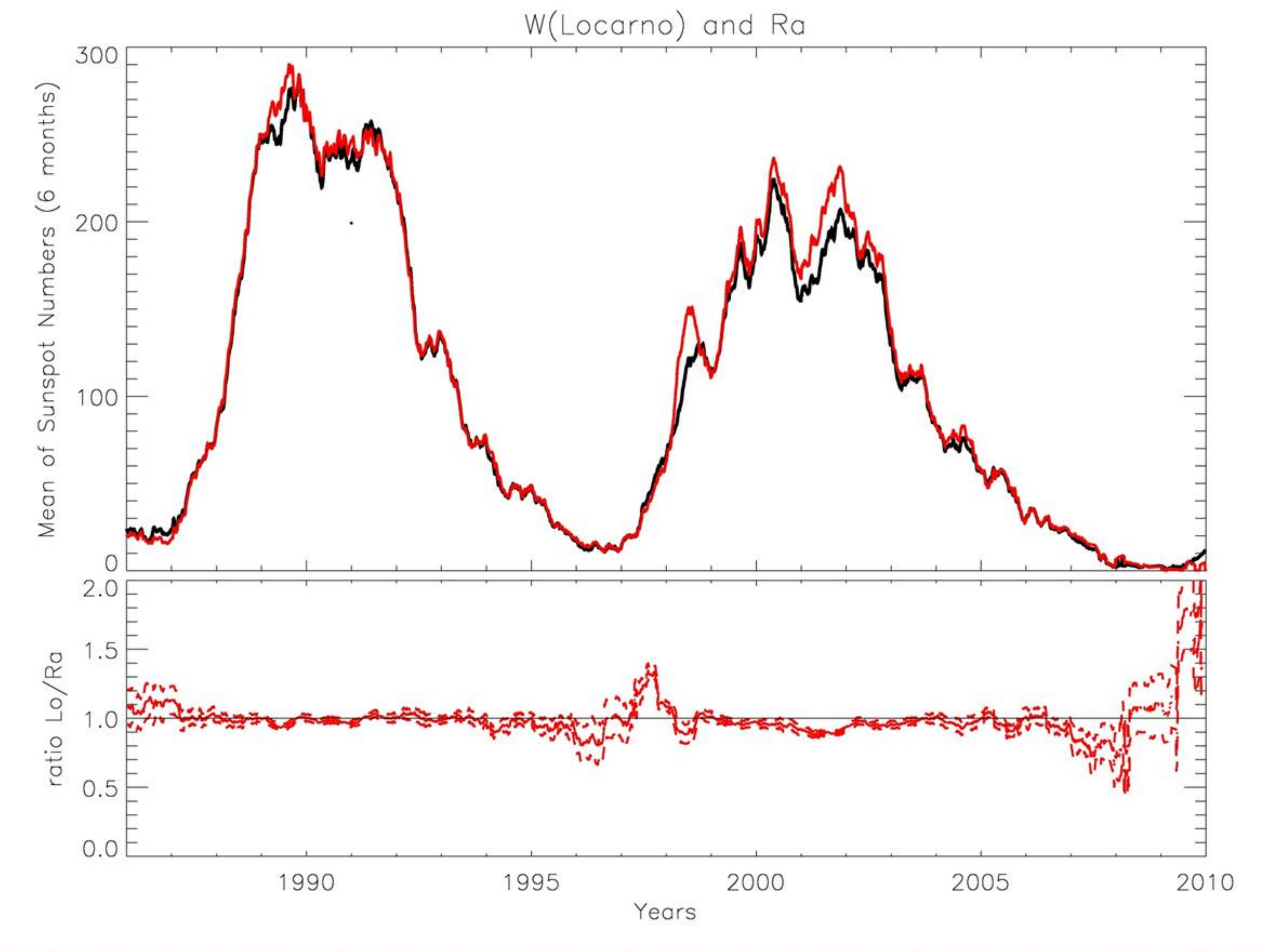
Locarno versus ISOON SSN



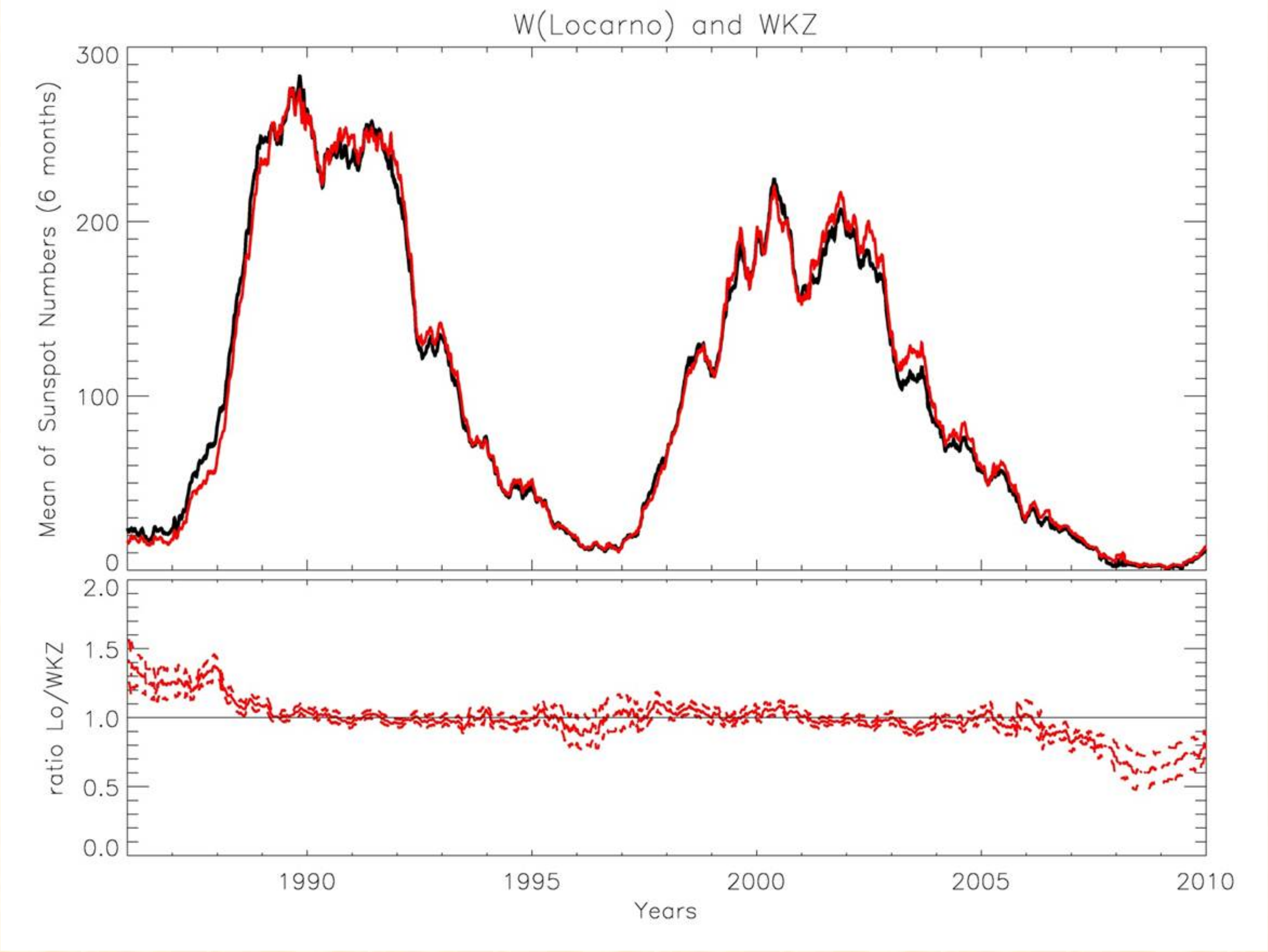
Locarno versus R_A SSN (AAVSO)



Locarno versus R_A SSN (AAVSO)



Locarno versus Kanzelhöhe



Internal Locarno diagnostics

- **R_i = absolute index (cf. TSI)**

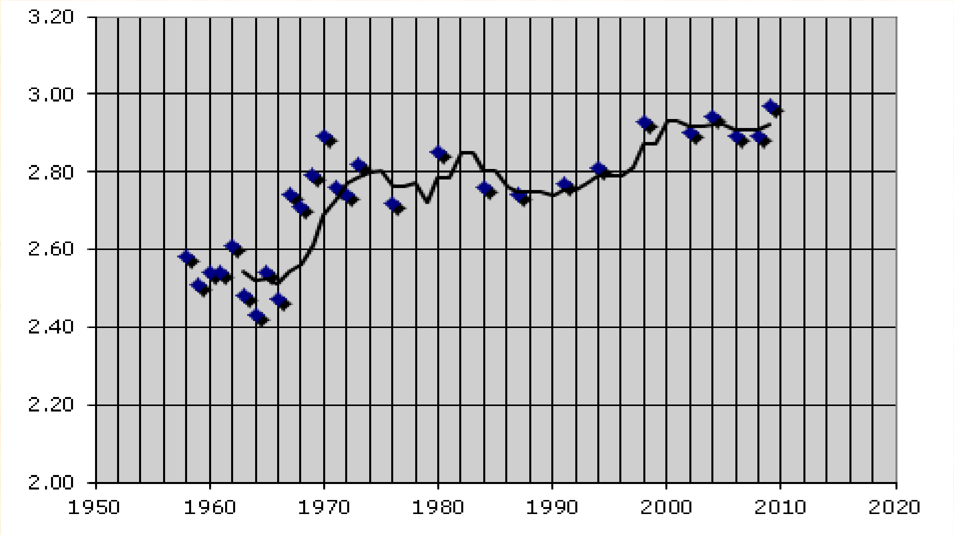
Validation rests primarily on the understanding and validation of the different elements involved in the measurements

- **Change in the instrument**:
  - No modifications
  - Ageing: verifications showed that the optics did not degrade (objective lens, staining of coudé mirror)

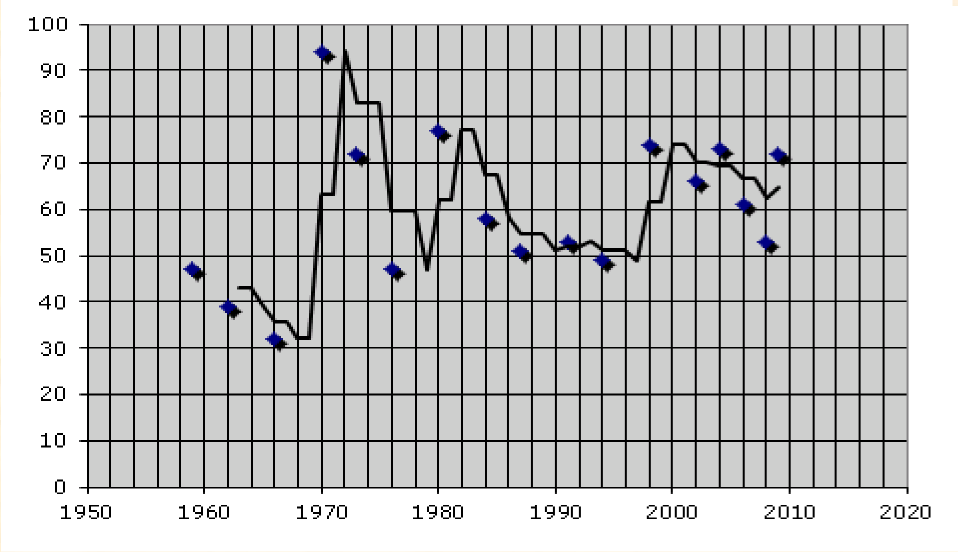
- **Change in the observing conditions (seeing):**
  - Small degradation around 1998 (reason non identified)
  - Minor change compared to larger degradation in 1967 (new villa built south of the observatory): no impact was identified on W_{LO} and R_Z.

Locarno seeing evolution

- Average yearly observing quality:
  - Step in 1967: 2.5 to 2.8
  - Trend after 1967: 2.8 to 2.9



- Number of bad days per year (Q>3):
  - [% of ~290 obs. Days/year]
  - Peak in 1967:
    40 [14%] to 90 [31%]
  - No definite trend after 1970
  - Jump 1997-2000:
    50 [17%] to 70 [24%]



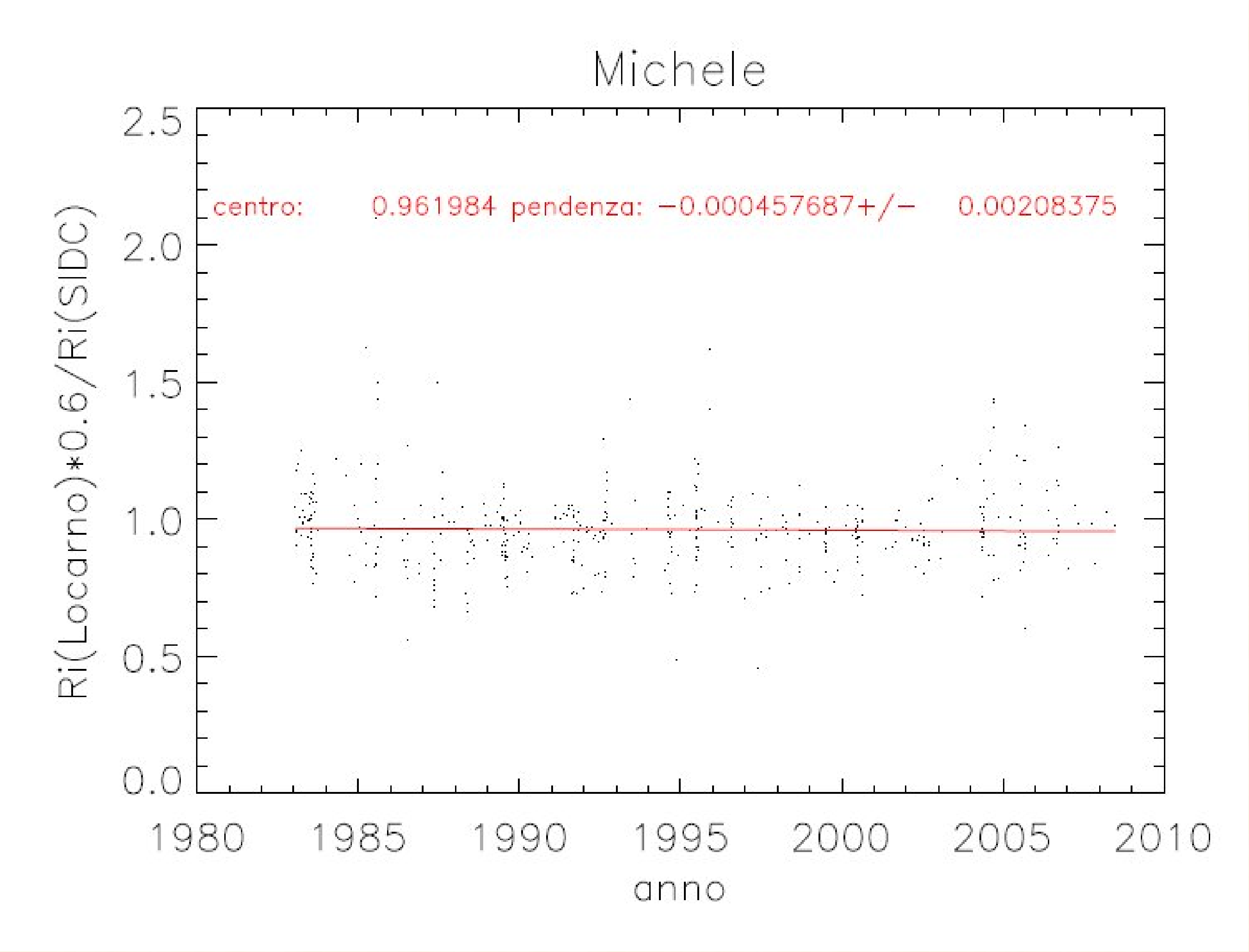
Internal Locarno diagnostics

- **Change of the observer:**
  - Only one main observer (>90% of observations): S. Cortesi
  - No health or eyesight problems
  - **Tracking of internal K coefficient of 4 alternate observers: no trend**

- **Change in the daily practices or counting method:**
  - Weighted Waldmeier counts since the origins: same person doing the counts
  - **Relative K coefficients of alternate observers close to 1:**
    0.961 to 1.037 (i.e. +/- 4 %)

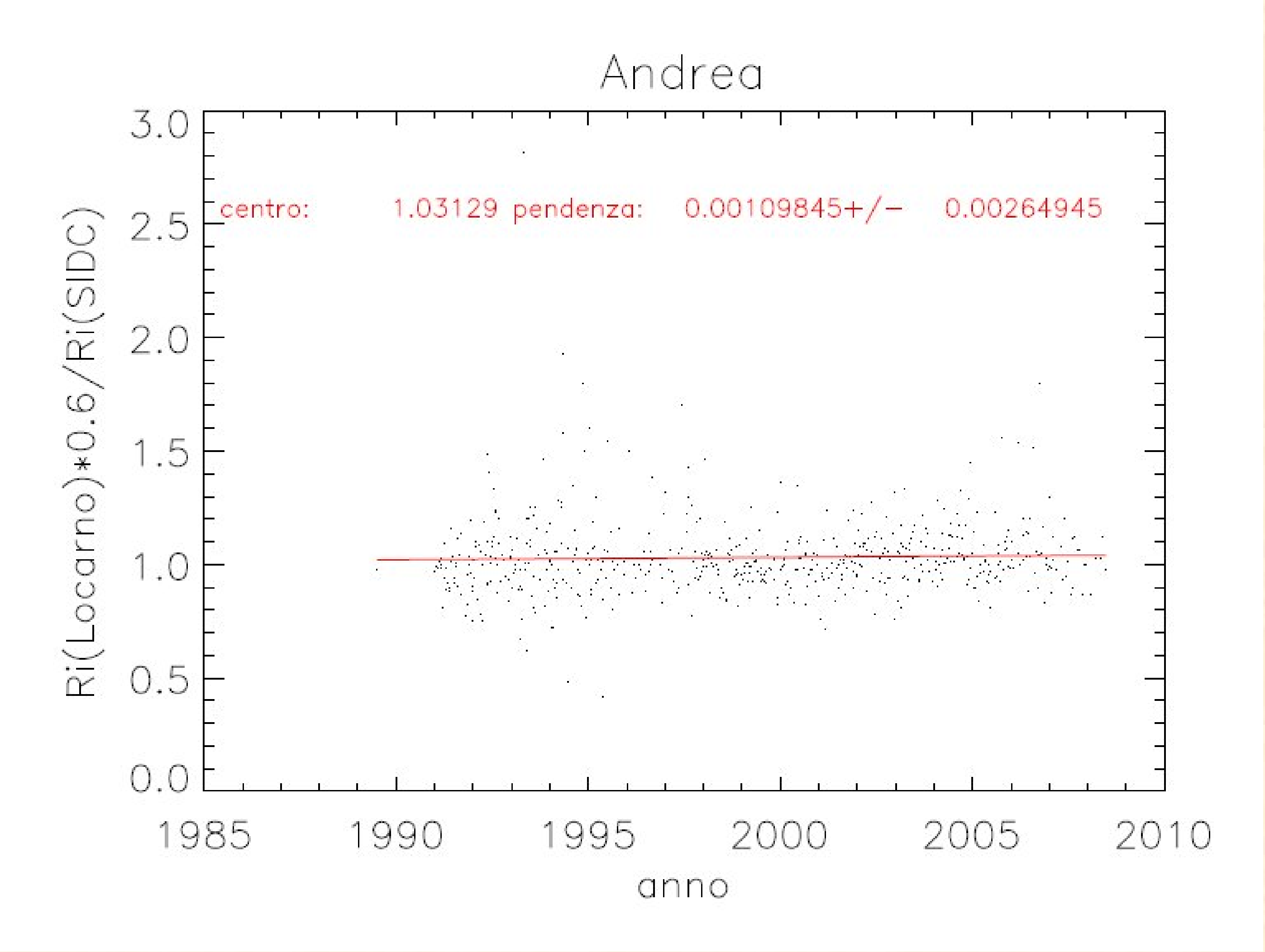
S.Cortesi versus other observers

- M. Bianda
- 25 years
- K= 0.961
- Trend= 0.0 +/- 0.002



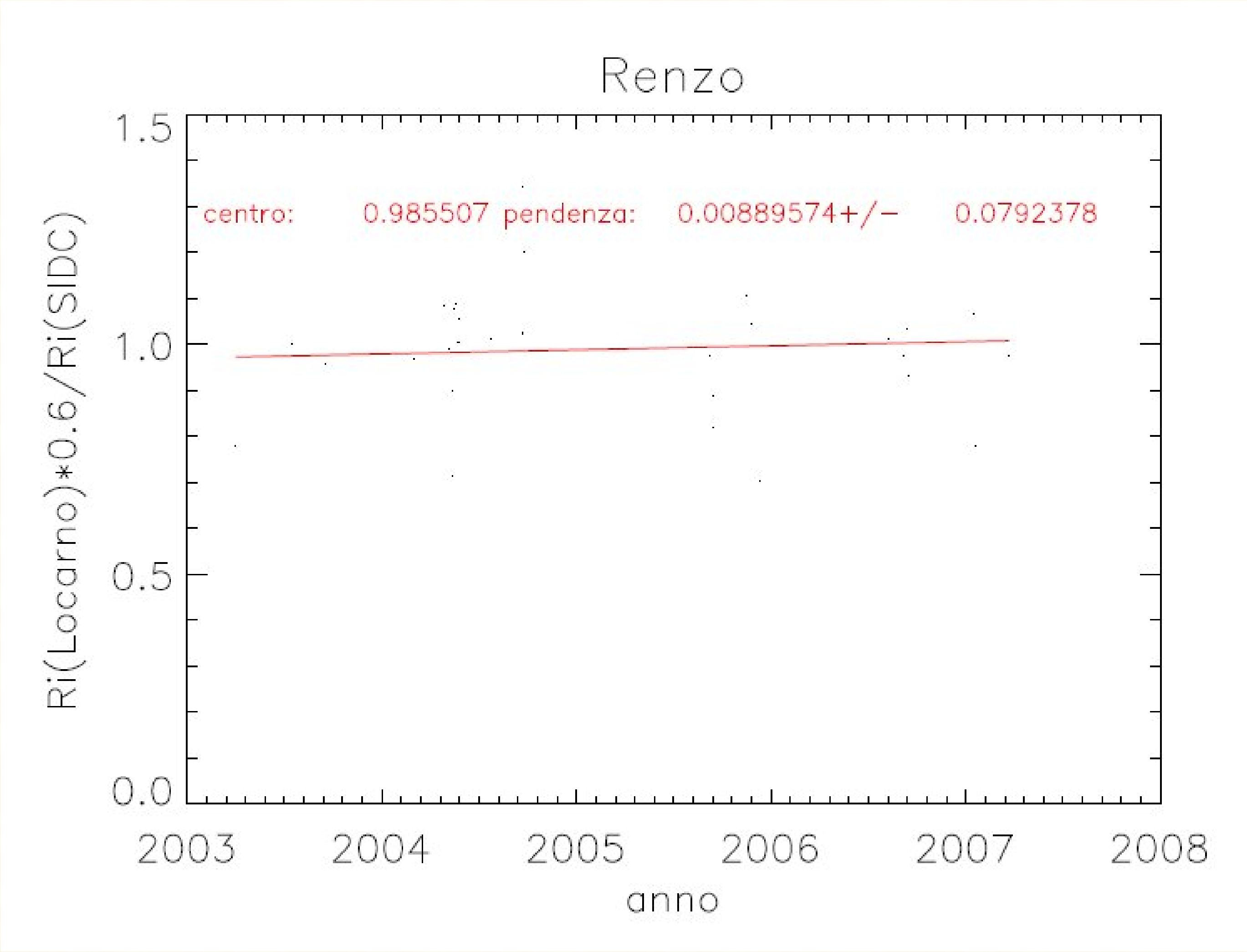
S.Cortesi versus other observers

- Andrea
- 18 years
- K= 1.031
- Trend= 0.0 +/- 0.002



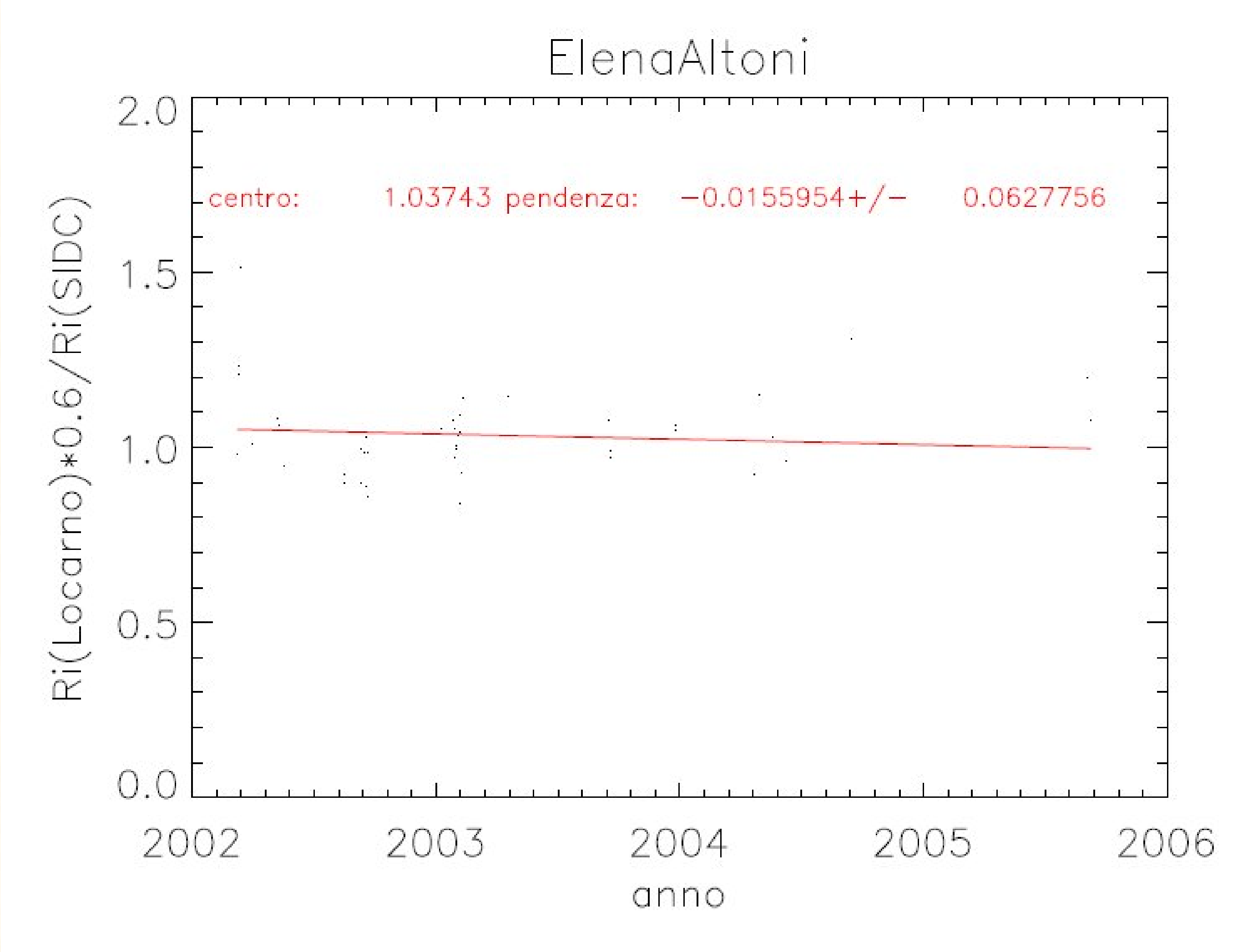
S.Cortesi versus other observers

- R. Ramelli
- 4 years
- K= 0.986
- Trend= 0.0 +/- 0.08



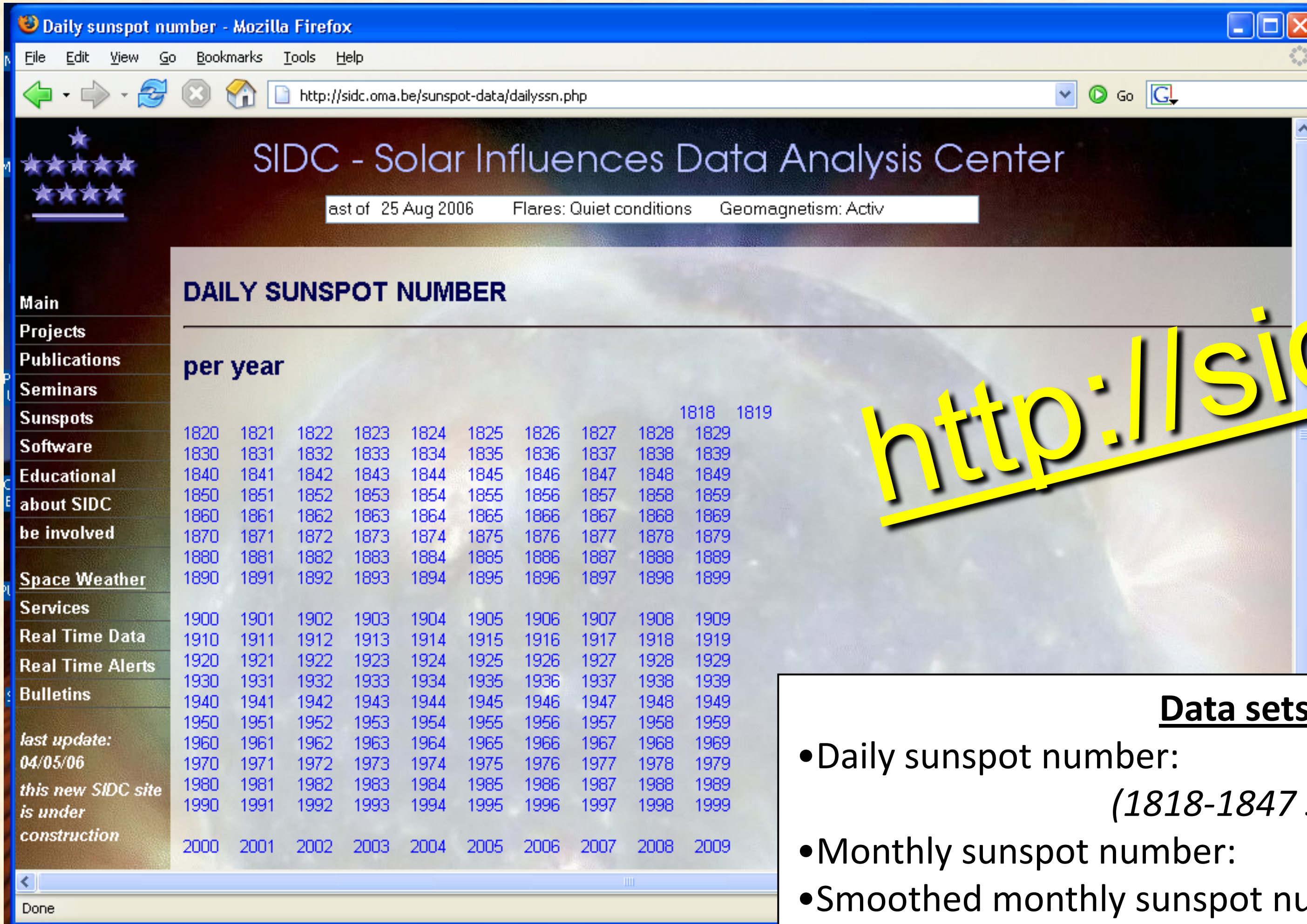
S.Cortesi versus other observers

- E. Altoni
- 4 years
- K= 1.037
- Trend:
  0.0 +/- 0.06



The SIDC data products

Web data access

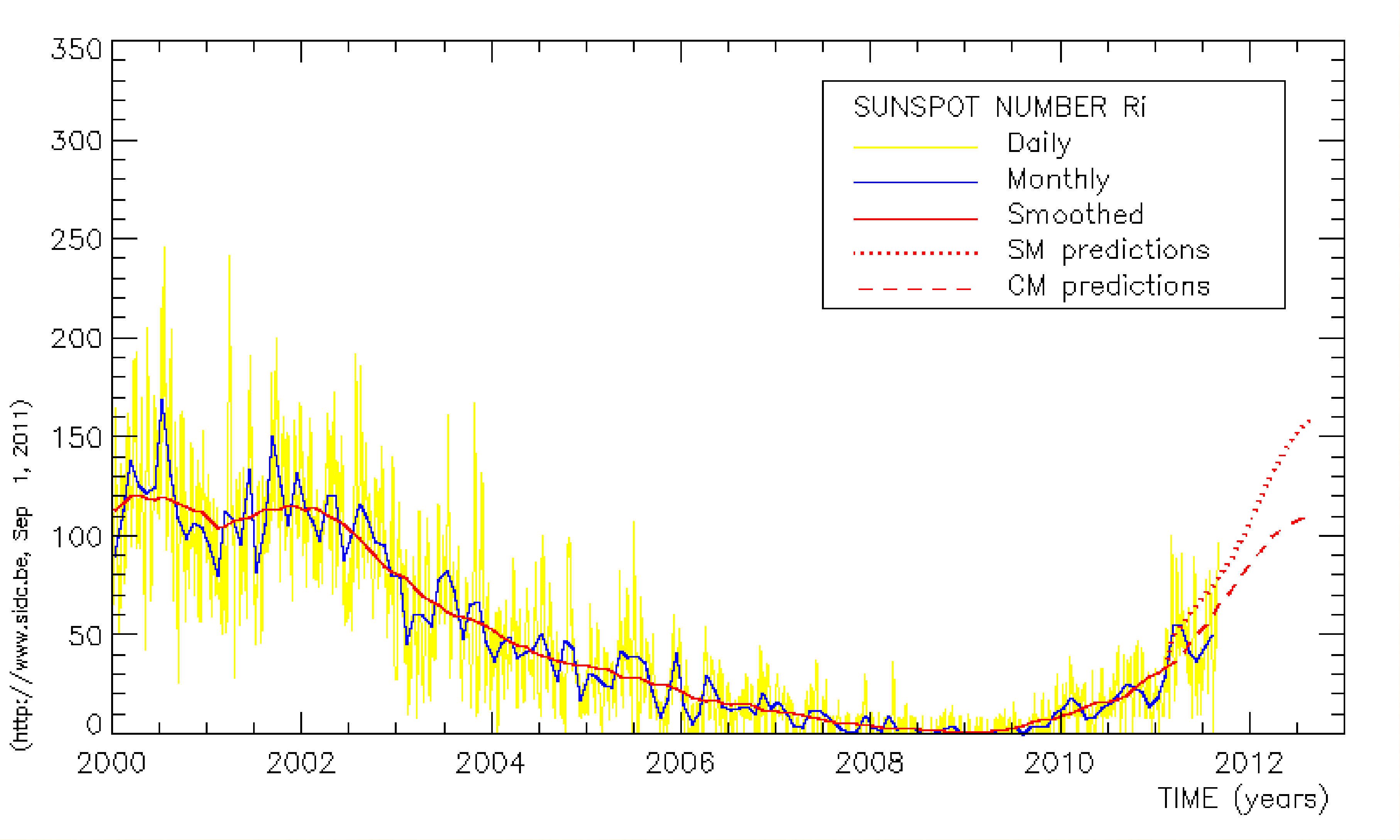


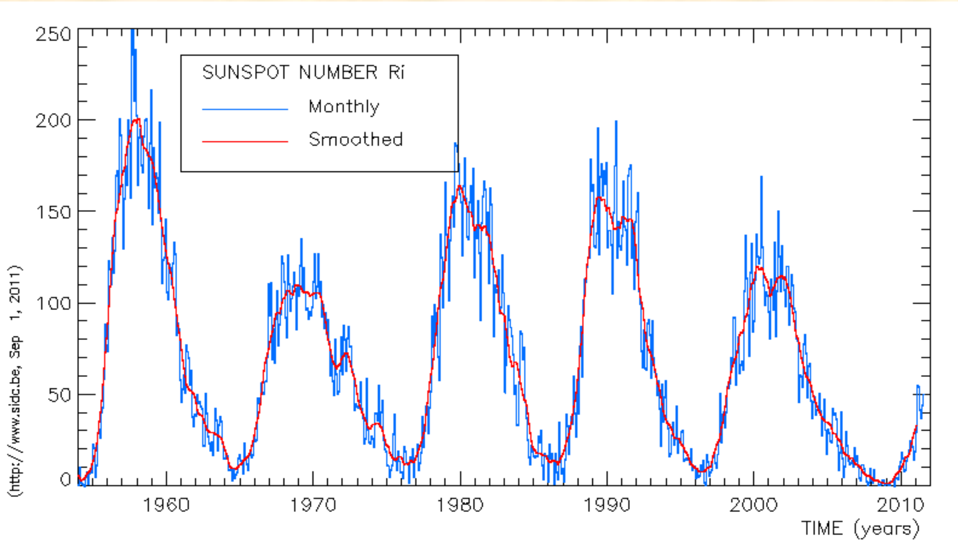
http://sidc.be

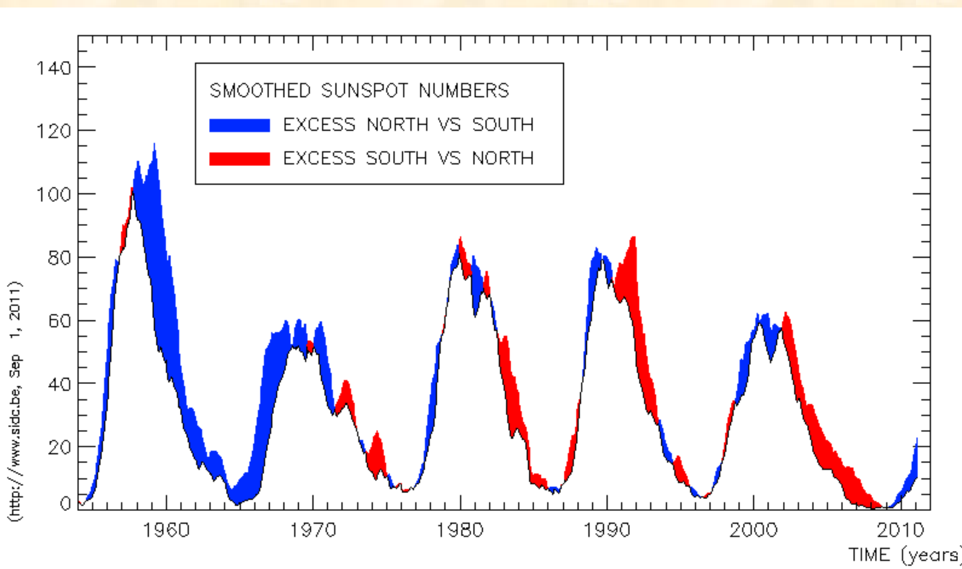
Data sets

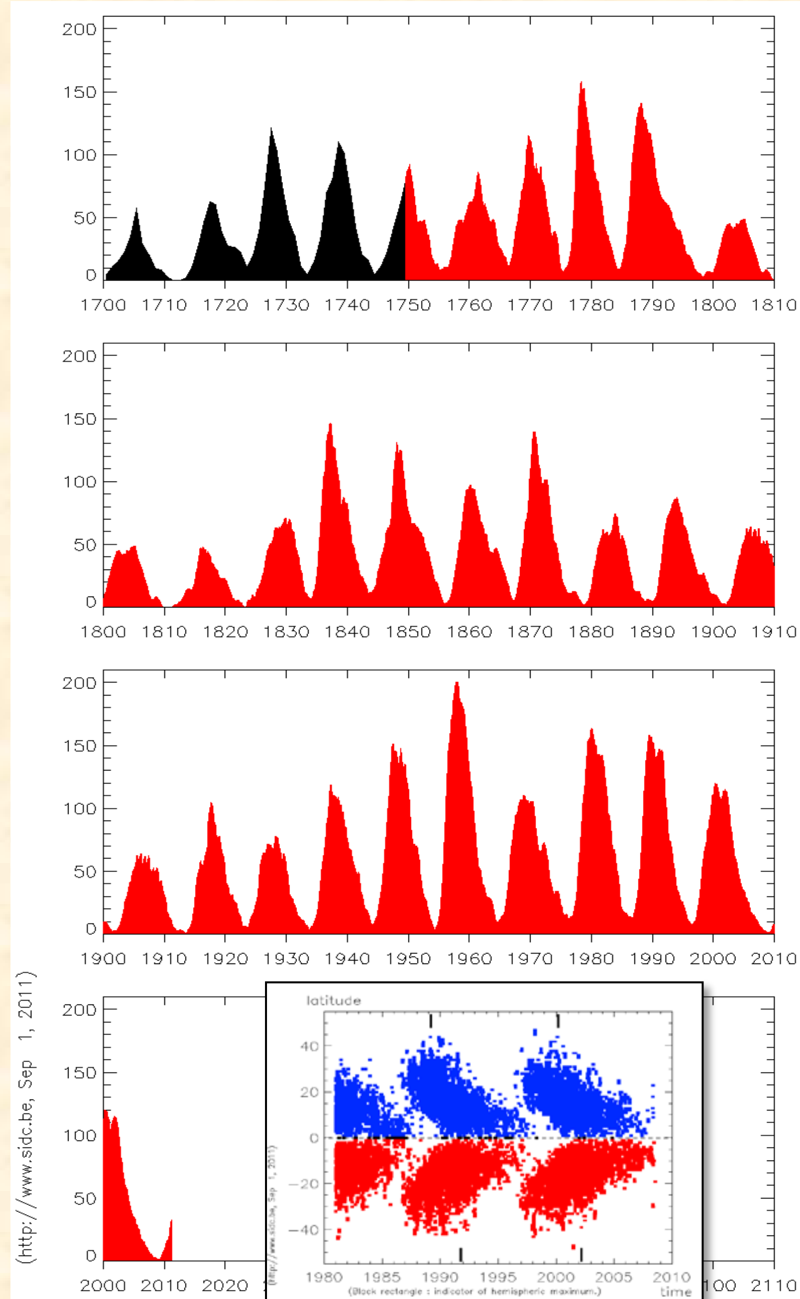
- Daily sunspot number: 1818 - now
  (1818-1847 sparse sampling)
- Monthly sunspot number: 1749 - now
- Smoothed monthly sunspot number: 1755 - now
- Yearly sunspot number: 1700 - now
- Hemispheric SSN: 1992 - now

Daily, monthly , monthly mean values and forecasts



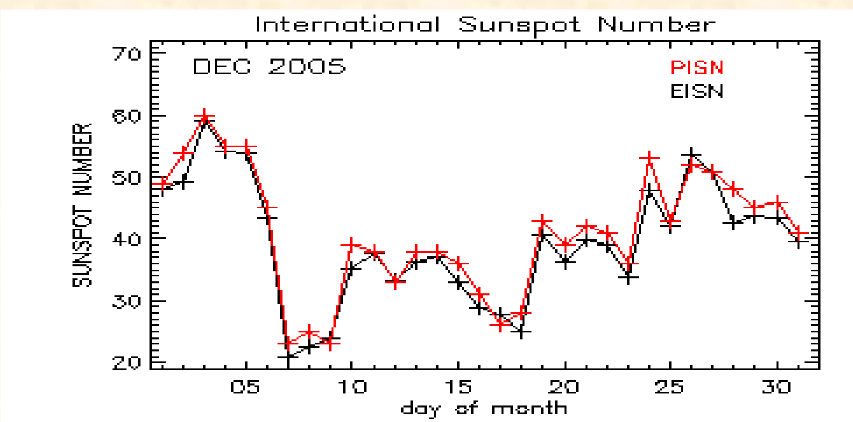

SUNSPOT NUMBER Ri
Monthly
Smoothed
TIME (years)
(http://www.sidc.be, Sep 1, 2011)
0
50
100
150
200
250
1960
1970
1980
1990
2000
2010


SMOOTHED SUNSPOT NUMBERS
EXCESS NORTH VS SOUTH
EXCESS SOUTH VS NORTH
TIME (years)
(http://www.sidc.be, Sep 1, 2011)
0
20
40
60
80
100
120
140
1960
1970
1980
1990
2000
2010


1700 1710 1720 1730 1740 1750 1760 1770 1780 1790 1800 1810
1800 1810 1820 1830 1840 1850 1860 1870 1880 1890 1900 1910
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
2000 2010 2020
100 2110
(http://www.sidc.be, Sep 1, 2011)
latitude
1980 1985 1990 1995 2000 2005 2010
time

Estimated International SSN (EISN)

- Increased demand for a daily sunspot index
- Derived from a subset of up to 15 stations providing data before 12:00UT.
- Simple average of raw counts
- Multiplied by the K personal reduction coefficients produced by the full monthly processing.
- Published in the daily SIDC URSIGRAM at 12h30UT:
  - Values for today and yesterday




```
SOLAR FLARES  : Eruptive (C-class flares expected, probability >= 50%)
GEOMAGNETISM  : Quiet (A<20 and K<4)
SOLAR PROTONS : Quiet
PREDICTIONS FOR 20 Dec 2005  10CM FLUX: 088 / AP: 019
PREDICTIONS FOR 21 Dec 2005  10CM FLUX: 088 / AP: 005
PREDICTIONS FOR 22 Dec 2005  10CM FLUX: 082 / AP: 001
COMMENT: The solar wind speed has been systematically rising in the
last 24 hours and is currently at 600km/s. We presume that this is due
to the influence of small coronal hole half way between active regions
NOAA837 and NOAA835. We expect that the influence on geomagnetic
conditions will in any case remain small. As of today, we start with a
new data product, the 'Estimated International Sunspot Number', which we
will distribute through these daily messages. Note also the link at the
bottom of this message where you can find more information.

ESTIMATED ISN       : 041, BASED ON 02 STATIONS.

SOLAR INDICES FOR 19 Dec 2005
SUNSPOT INDEX       : 069
10CM SOLAR FLUX     : 090
AK CHAMBON LA FORET : 018
AK WINGST           : 014
ESTIMATED AP        : 013
ESTIMATED ISN       : 044, BASED ON 04 STATIONS.

NOTICEABLE EVENTS SUMMARY
DAY BEGIN MAX  END  LOC    XRAY OP  10CM RADIO BURST TYPES     Catania NOAA NOTE
NONE
END
```

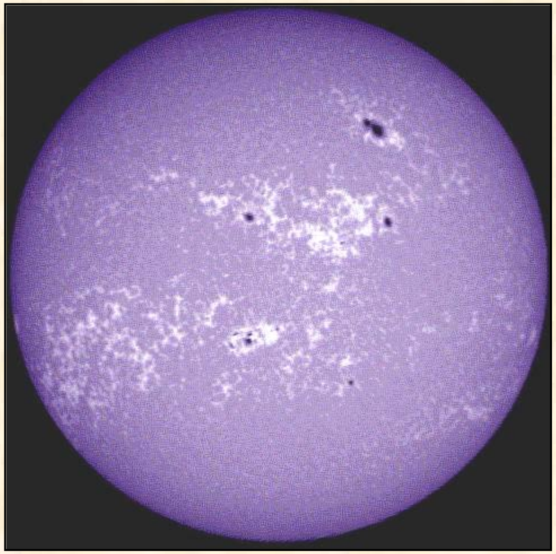
The SSN and the other global solar indices

R_i compared to other solar indices

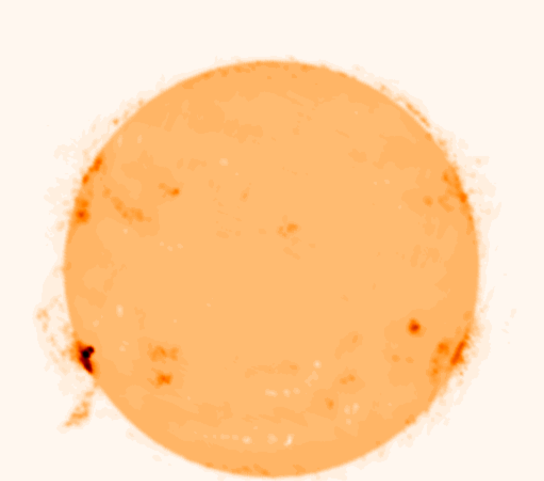
- Most indices are chromospheric or coronal ($F_{10.7cm}$, CaII-K, MgII c/w) or contain a wide mix (TSI):
  - Different physical relation to the underlying magnetic flux emergence:
    - Non-linear relation
    - Time lags
  - **R_i closely related to magnetic flux emergence**:
    - High threshold on magnetic field (> 1000 Gauss)
    - Spots disappear early in the magnetic decay of an active region
  - **Chromospheric and coronal indices contain a strong contribution from weak decaying fields** (flux dispersion): plages, faculae, ephemeral regions, quiet Sun/ coronal hole relative area.

Discrepancies do not mean disagreements and flaws !

- ***Index differences = solar information***



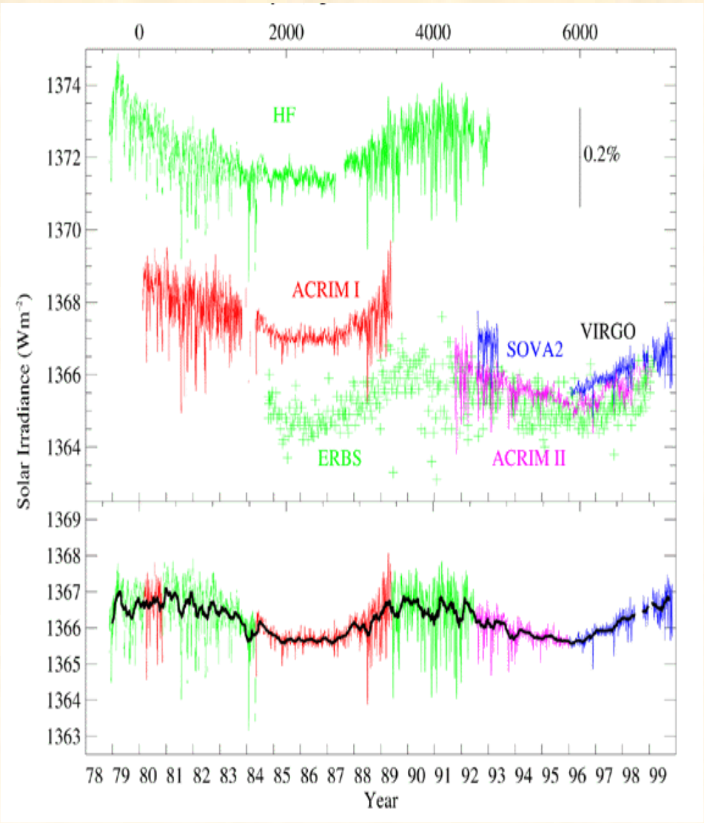
CaII K, Kitt Peak Obs.



Nobeyama, radio, 17GHz

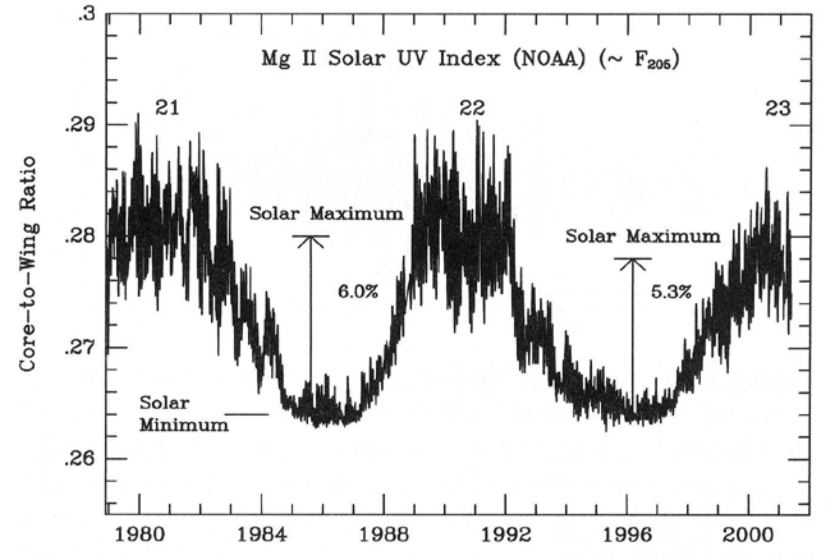
Assumptions in all solar indices

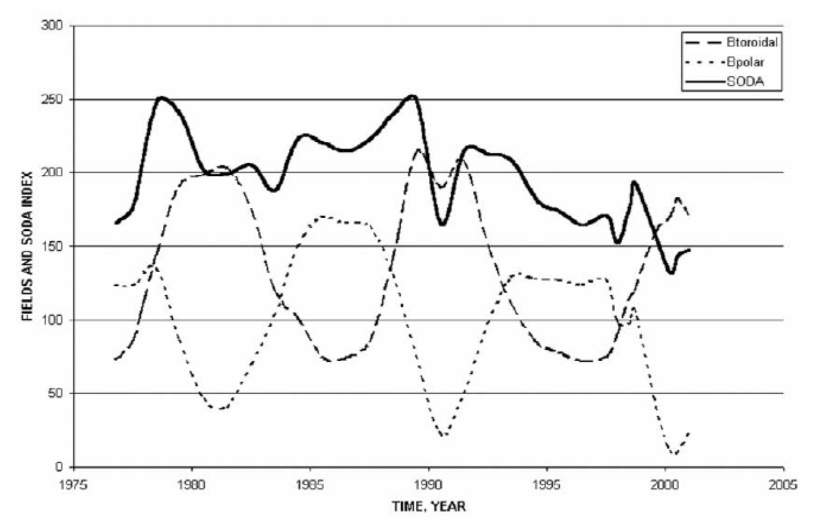
- **Group sunspot number**: $R_g = \frac{1}{N}\sum_{i=1}^{N} k_i 12.08\, g_i$
  - All groups contain the same average number of spots at all epochs
- **Total Sunspot area**:
  - Choice in the definition of sunspot boundary: error up to 100% *(Pettauer,T. & Brandt, P.N. 1997)*
  - Different methods (RGO, ISOON) > 1.4 scaling factor *(Wilson & Hathaway, 2006)*
- **F10.7 radio flux**:
  - Undersampling and empirical filtering rules *(Tapping, K.F.& Charrois, D.P. 1994)*
- **Total solar Irradiance**:
  - Assumptions in instrument models: 0.6% disagreements = 4x amplitude of solar cycle in TSI.



Assumptions in all solar indices

- **CaII-K plage index** *(e.g. Foukal,P. 1996, 1998)*:
  - Different photographic plates
  - Assumptions in definitions of plage areas and brightness
- **MgII c/w ratio** *(e.g. White et al. 1996; Svalgaard 2007):*
  - Assumption: core to wing ratio cancels out instrumental effects
  - Not true! Disagreement > 5% between UARS and earlier spacecraft calibrations
- **Polar magnetic field** *(Schatten, K.H. & Pesnell,W.D. 1993; Schatten,K.H. 2002)* :
  - Grazing LOS: projection effect
  - Incomplete view of polar regions
  - Assumptions (radial field lines, etc.)





R_i and other solar indices

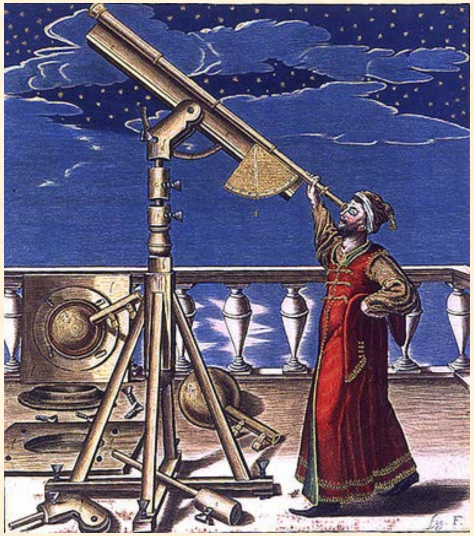
- High correlation of R_i with recent indices:
  - > 97% with photospheric indices
  - R_i is a quantitative index
- **Advantages of other indices:**
  - Based on a quantitative “impersonal” measurement (flux, area)
  - Precision equal or higher than R_i
- **Limitations of other indices:**
  - Short duration (only recent solar cycles)
  - **Difficulty of long-term absolute calibration**
    - Single or few stations (no cross-validation or trend diagnostics)
    - Short-lived instruments replaced by new different ones (space)
    - Few non-overlapping or discontinuous data sets
  - **Subjectivity “layer” at the processing stage:**
    - Index definition (assumptions: choice of thresholds, boundaries)
    - Instrument modeling (assumptions: ageing, response, stray light, etc.)
    - Elimination of artifacts: empirical filters and criteria

The R_i human factor: subjective or objective ?

- Four steps where the human factor can play a role:
  - **Observation**:
    - Visual factors (human vision)
    - Optical factors (instrument, seeing)
    - Observer bias (state of mind, personal habits)
  - Choice of **processing method**

The R_i human factor: human vision

- No biological change in the detector at century scales (eye + visual cortex)
- **Capacity to "integrate" seeing distortions** (not a simple averaging !):
  - Visual cortex plays an essential role
  - Until recently (SDO, HMI), capacity to detect the smallest spots was superior to photography and CCD
- **Imaging data not directly comparable or substitutable**:
  - Effects of sensor/optical resolution, seeing will have a different influence on the resulting counts for images and human eye



The R_i human factor: optical factors

- ***No specific aperture required for SIDC contributing observers***
- *How is the detection of the smallest spots influenced by the resolution?*
- Two factors:
- **Theoretical optical resolution** (unobstructed aperture):
  - Rayleigh criterion: $\theta = 138 / D(mm)$
  - Dawes criterion: $\theta = 116 / D(mm)$
- **Seeing:**
  - variable with time, daytime range similar for all low-altitude sites:
    1.5 to 3, typ. 2 arcsec (equiv. D= 45 – 90 mm, typ. 70 mm)
  - Large apertures more affected (size of turbulent eddies ~8 -12 cm):

→ **Reduces the difference of effective resolution between small and large apertures (> 10 cm)**

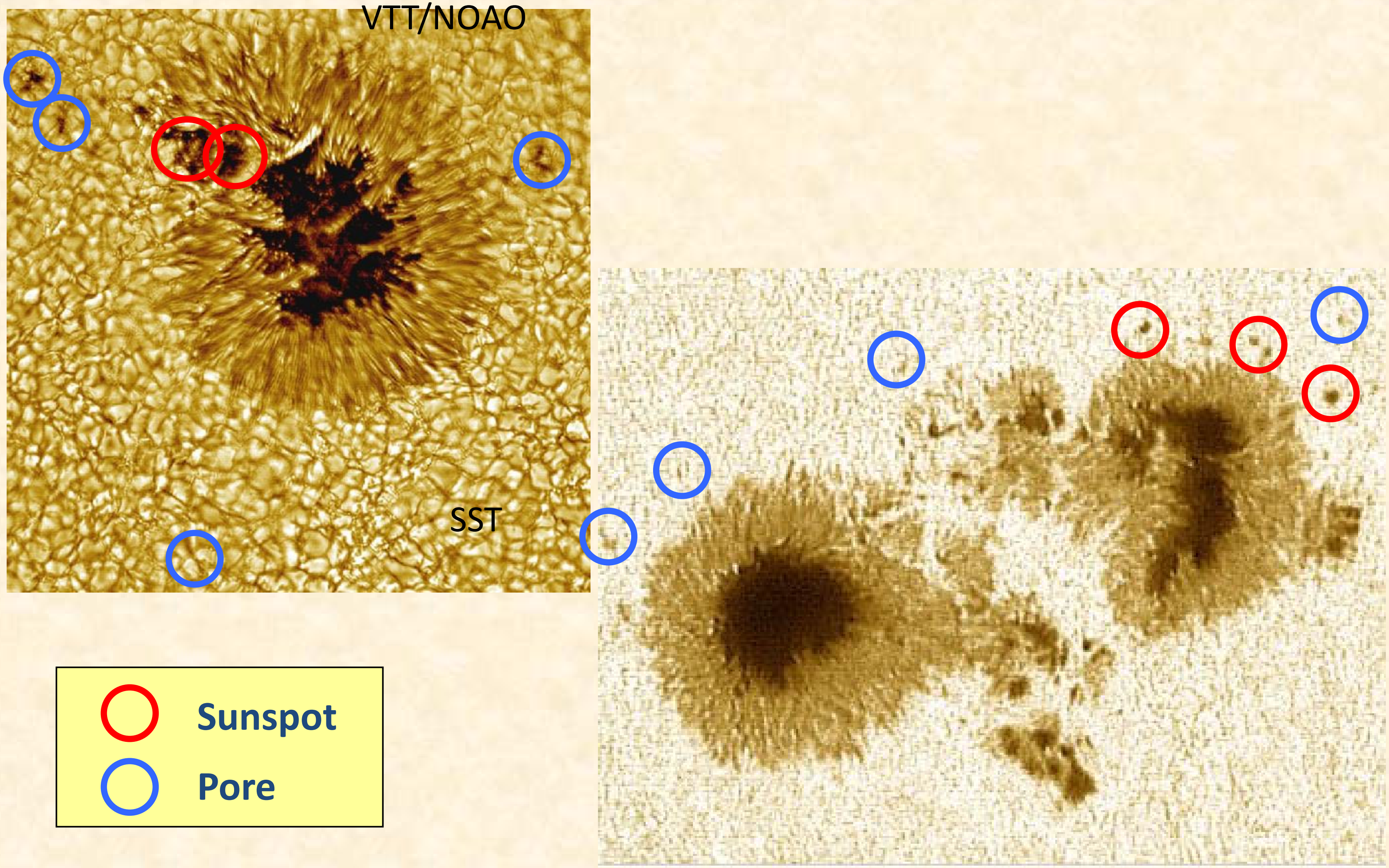
What is the smallest possible sunspot ?

- Various definitions:
  - Semantic problem “pore” vs “sunspot”:
    - Pore = small spot without penumbra
    - Pore = random intergranular blemishes that are not real sunspots

Source	Spot diameter	Spot lifetime	Pore diameter	Pore lifetime
Bray & Laughhead 1964	With penumbra		Without penumbra	
Waldmeier *(Husar 1967)*	**>3” (2000km) = 1 granule**	**> 30 min**	< 3”	< 30min
Bruzec & Durrant 1977	>10” (6000km)	> 1 day	< 5”	< 1 day
McIntosh 1981	**> 4” (2500km) = 1 granule**		< 4”	

- Overall agreement: lowest spot size near 2000 km (3 arcsec)
  - Dictated by granulation dynamics rather than spots (cancellation of convective motion): lifetime: avg. 10 min (up to 30 min)

Sunspots and “pores”



What is the smallest possible sunspot ?

- Best “observational” definition:

	Diameter	**Lifetime**	**Outline**	**Contrast**	Penumbra
Granulation (pore)	< 3” < 2500km	**< 30 min**	**Fuzzy** **Irregular**	**low**	none
Sunspot	> 3” > 2500 km	**> 30 min**	**Sharp** **~ round**	**High** **Dark core**	none

- Simple criteria naturally adopted by all observers
  - No major discrepancies due to personal subjective interpretation

Match of the smallest real-spot angular size with usual seeing (3 arcsec) and telescope aperture D= 50 mm:

  - Limited gain in small spot counts at apertures > 50 - 80 mm

    (cf. Svalgaard, private communication)

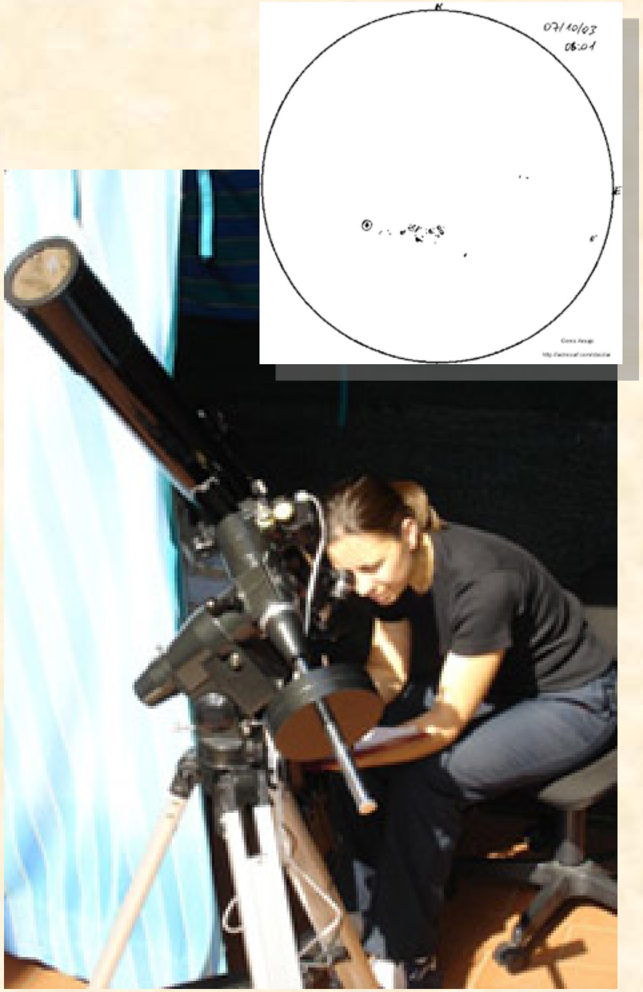
  - **Small-aperture bias only expected for early historical observations before the 19th century (D << 70mm)**

The R_i human factor: SIDC "freewheel" philosophy

- **No detailed counting rules imposed to SIDC observers.**
  - Observers reluctant to obey rules
  - Danger of imposed rules: slow insidious return to natural practices
  - Relying on the **observer experience**:
    - Same observer & instrument over years or decades

Long term self-consistency is more important than equivalence to a model (network average, pilot station)

Importance of dedicated amateurs vs "volatile" professionals.



The R_i human factor: random variations

- **Causes of random variations**:
  - Daily mood, mistakes
  - Daily changes of the observer (group splitting, umbral splitting)
  - Seeing variations
  - Random daily subset of network contributors (local weather) ~50/85
- **Sampling = One-day binning (UT)** >> "aliasing":
  - Fast small-scale changes in active regions (small short-lived spots)
  - Limb transits of large active regions
  - Strong effect mainly when a single spot/group on the solar disk!

→ Equivalent to **detector noise**

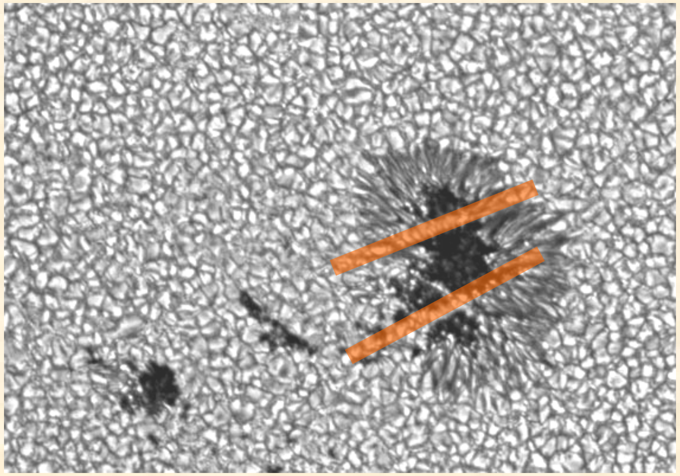
- **Filtered out by the daily tracking of K coefficients:**
  - Elimination of outliers based on standard deviation of daily K values.

Main biases: Group and umbral splitting

- **Group splitting:**
  - Topological criteria without external information (magnetograms)
  - No general scientific rule
  - Impact on W number limited:
    - Involves only a minority of groups
    - Can raise or lower W
- **Umbral splitting**:
  - Each umbra in common penumbra is counted as a separate spot (Wolfer rule)
  - Two umbrae considered as split only if separated by a complete light bridge
  - Prone to interpretation
  - Can lead to a net bias

Various group splitting rules *(Kunzel 1976)*:

- Non-bipolar groups: all spots within 5°x5° (60,000 x 60,000 km)
- Bipolar groups: up to 20° extension
- Rules for marginal cases:
  - Two spots up to 15° apart form a single group if they are the remainder of a large extended group
  - A bipolar collection of spots forms one group if Lat(West) ≤ Lat(East)
  - Typical tilt angles: 1-2° at 10° latitude, 4° at 30° latitude



The R_i human factor: observer bias

- **Causes of biases**:
  - **Splitting of large complex groups**
  - **Splitting of multiple umbrae in common penumbra**
  - Frantic quest for the largest count (including tiny ephemeral blemishes)
  - Prior consultation of other observations (WEB CCD images) leading to expectations:
    - Bias emerging in recent years?
- **Sources of trends** (slow variations in the personal biases):
  - Observer ageing (visual acuity; age > 50)
  - Trend in sky quality (urbanization)
  - Slow evolution of network members
  - Instrument ageing
- **Tracked by K-coefficient system**:
  - **Uncorrelated biases (network)**: independent worldwide observations
  - **One special case: the Zürich-Locarno reference station**

An essential step: processing method

- **Change in the data processing method**
  = primary cause of possible biases

Problem common to all indices

- **Zürich-Locarno Sunspot Index**:
  – Choice to drop smallest spots (Wolf)
  – Magnetic needle corrections (Wolf)
  – Weighting of sunspot counts (Wolfer – Waldmeier ?)
  – Change of primary station (Zürich – Locarno)
  – Change in the composition of network (observer mix, geographical distribution): e.g. Zürich-SIDC transition
    - Smaller impact for large networks (SIDC strategy)
  – Manual method: sparsely documented (occasional indications scattered over many different issues of the Mitteilungen)

An essential step: processing method

- **The case of the American number R_A (AAVSO):**
  - Lack of reference station
  - Manual processing
  - Additional observer rating factor
  - Flaws in the processing method: found after 50 years
  - Original data lost before 1992 → No correction possible

<u>The Golden rules</u>

1.Archival of all raw input data

2.Detailed documentation of the processing method and definitions and of the observing technique

3.Tracking of processing changes

4.Change only when it is essential (e.g. discovery of a flaw)

5.Long overlap periods:

old and new indices computed in parallel (min. one solar cycle)

Future prospects

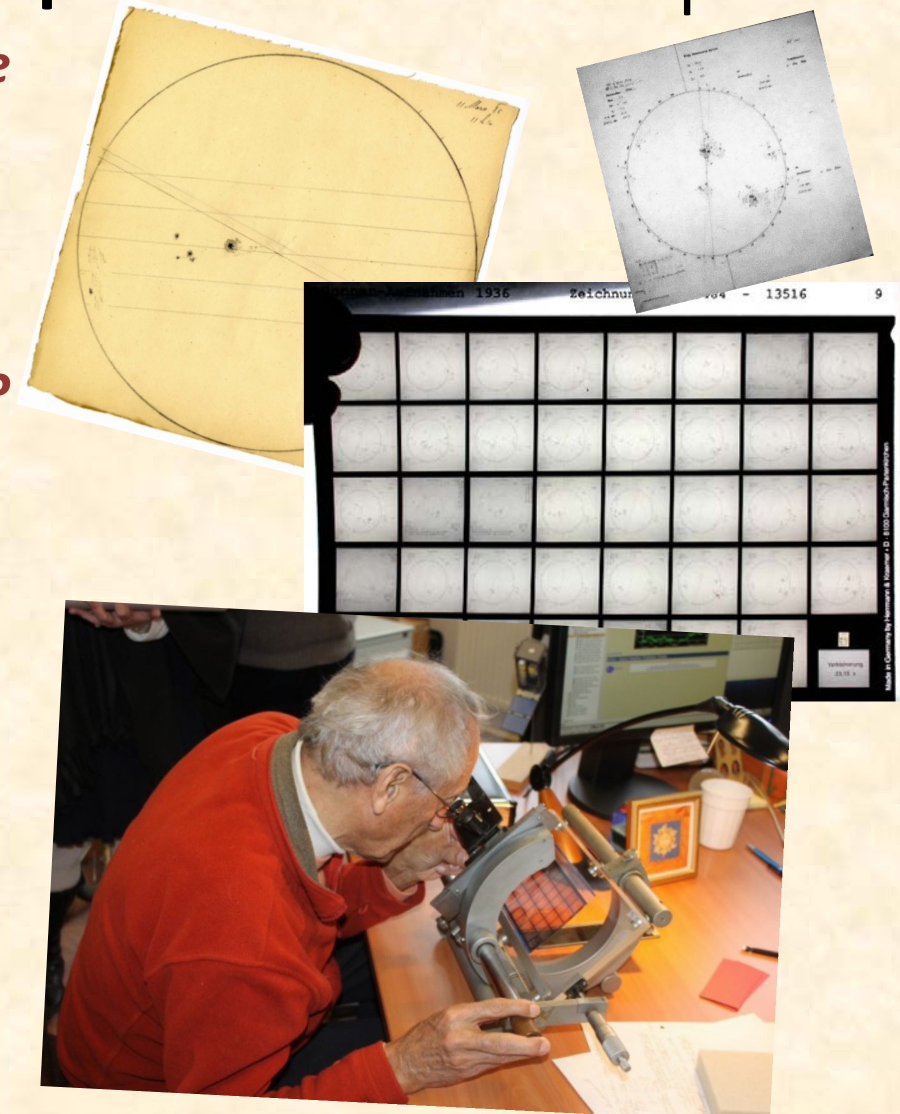
Future prospects for R_i: Exploring and understanding R_Z to improve the current R_i

- ***Scaling of the Wolf values before 1882? Size of the corrections? Weren't raw values better?***
- ***What is the actual date of the introduction of large spot weighting still in use at Locarno?***

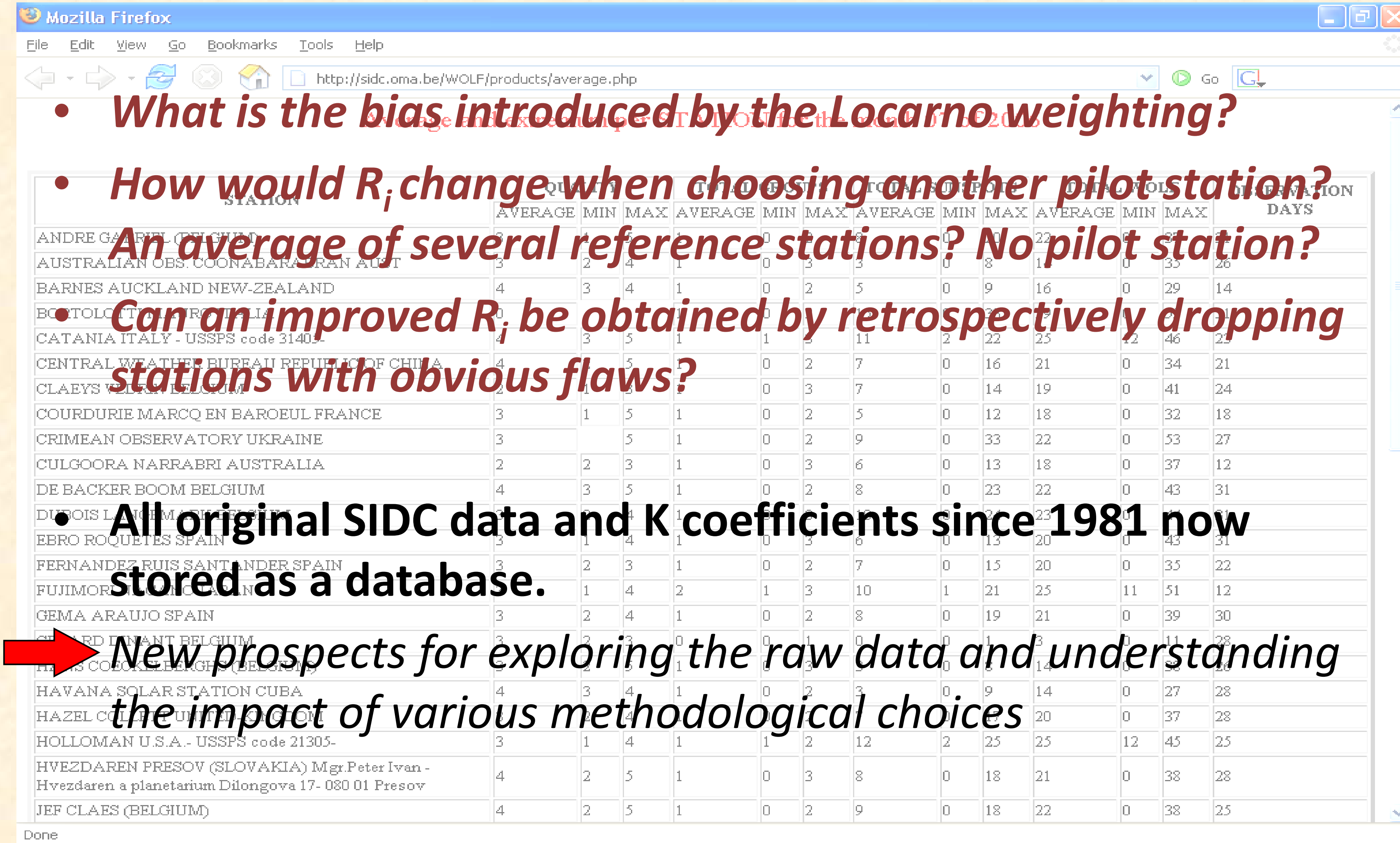
➡ Need to recover information about individual sunspot groups: historical sunspot drawings (*cf. next session)*

  – in particular collections from observers who contributed to R_Z

- **Zürich & Locarno original sunspot drawings awaiting processing ! (since 1911 on microfilm)**



Future prospects for R_i:
Exploring R_i to better understand the past index R_Z



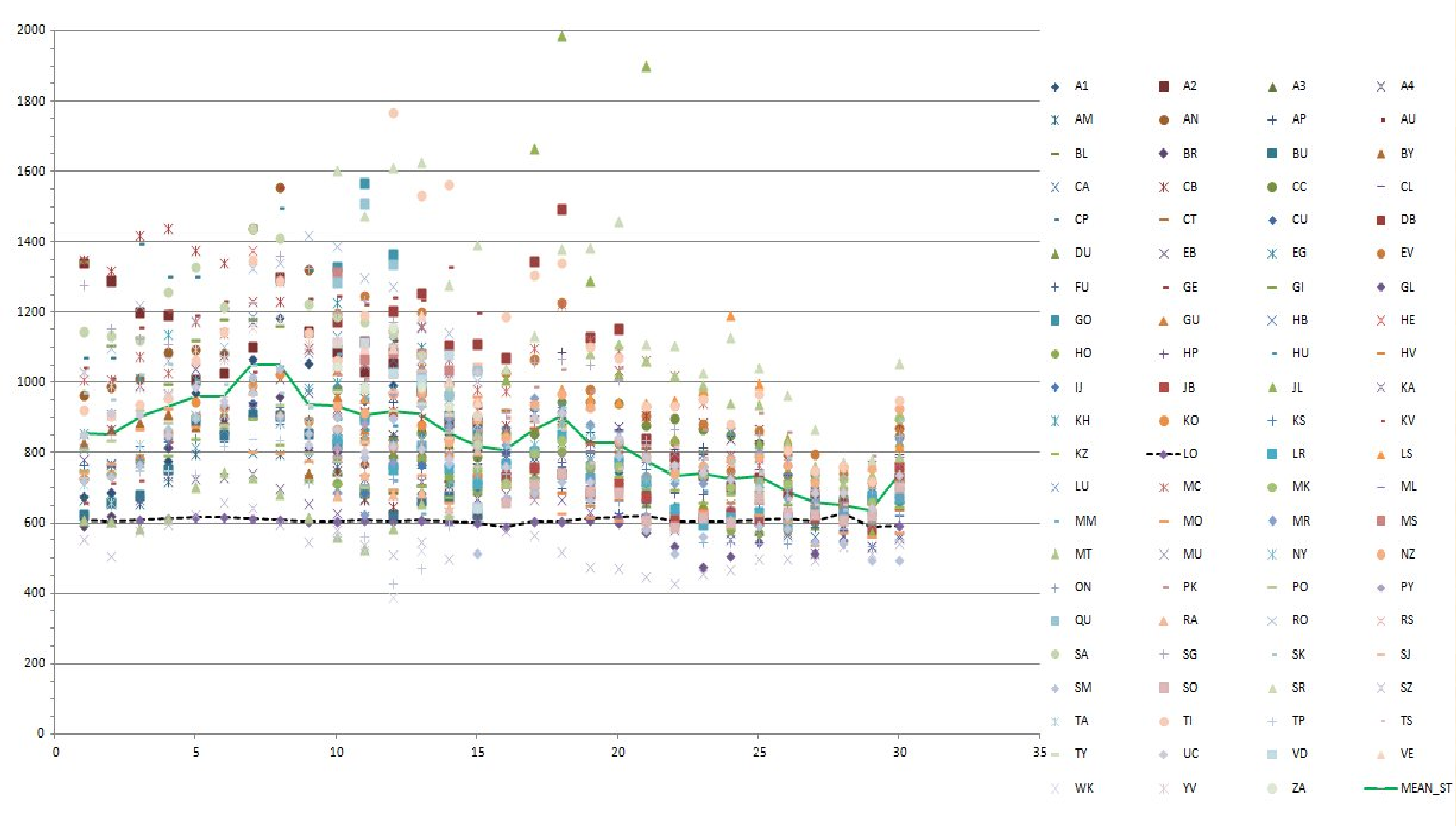
- *What is the bias introduced by the Locarno weighting?*
- *How would R_i change when choosing another pilot station? An average of several reference stations? No pilot station?*
- *Can an improved R_i be obtained by retrospectively dropping stations with obvious flaws?*

- **All original SIDC data and K coefficients since 1981 now stored as a database.**

New prospects for exploring the raw data and understanding the impact of various methodological choices

SIDC stations: 30-year panorama of K coefficients

- All stations



Future prospects for R_i: Investigation of image-based indices (photo, CCD)

- ***Can a proxy of R_i be created in the future, based on images data?***

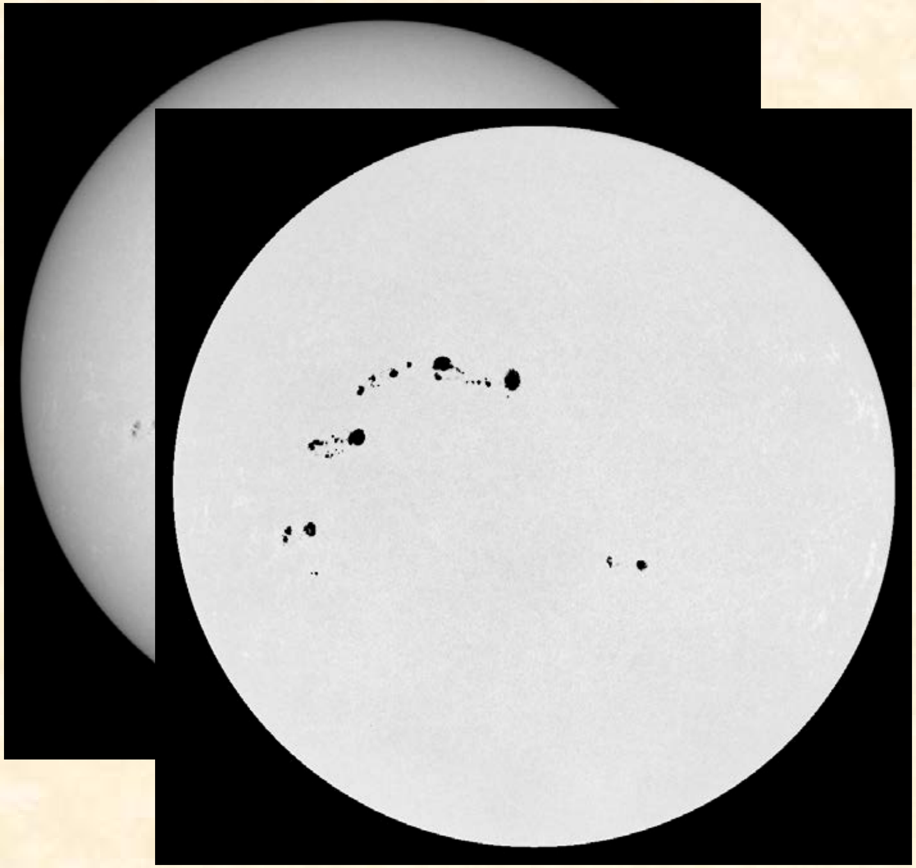
➡ require long cross-calibration (whole range of activity

➡ more than one cycle)

– complex visibility of smallest spots vs seeing, contrast.

➡ No replacement soon.

– New indices can be created but are distinct from R_i and derived in parallel.



(Zharkova et al. EGSO, 2003)

$$R_W = \sum_g \left(10 + \sum_{f \in g} 1 \right) \Rightarrow R_C = \sum_g \left(W_g + \sum_{f \in g} A_f \right)$$

Conclusions

- **The R_i index = a decisive modernization vs the manual R_Z**
  - Large base of observers in a worldwide network
  - Constant & documented processing scheme over 30 years
- **R_i is still scaled according to a single pilot station: Locarno**
- Multiple validations confirm the **good stability of the pilot station over at least the last 25 years**.
- **R_i is a quantitative measurement** highly correlated to equivalent modern "flux" indices.
- **The subjectivity in the SSN is limited by intrinsic factors.**
- **It can now be largely tracked and corrected by statistics over many stations.**

Conclusions

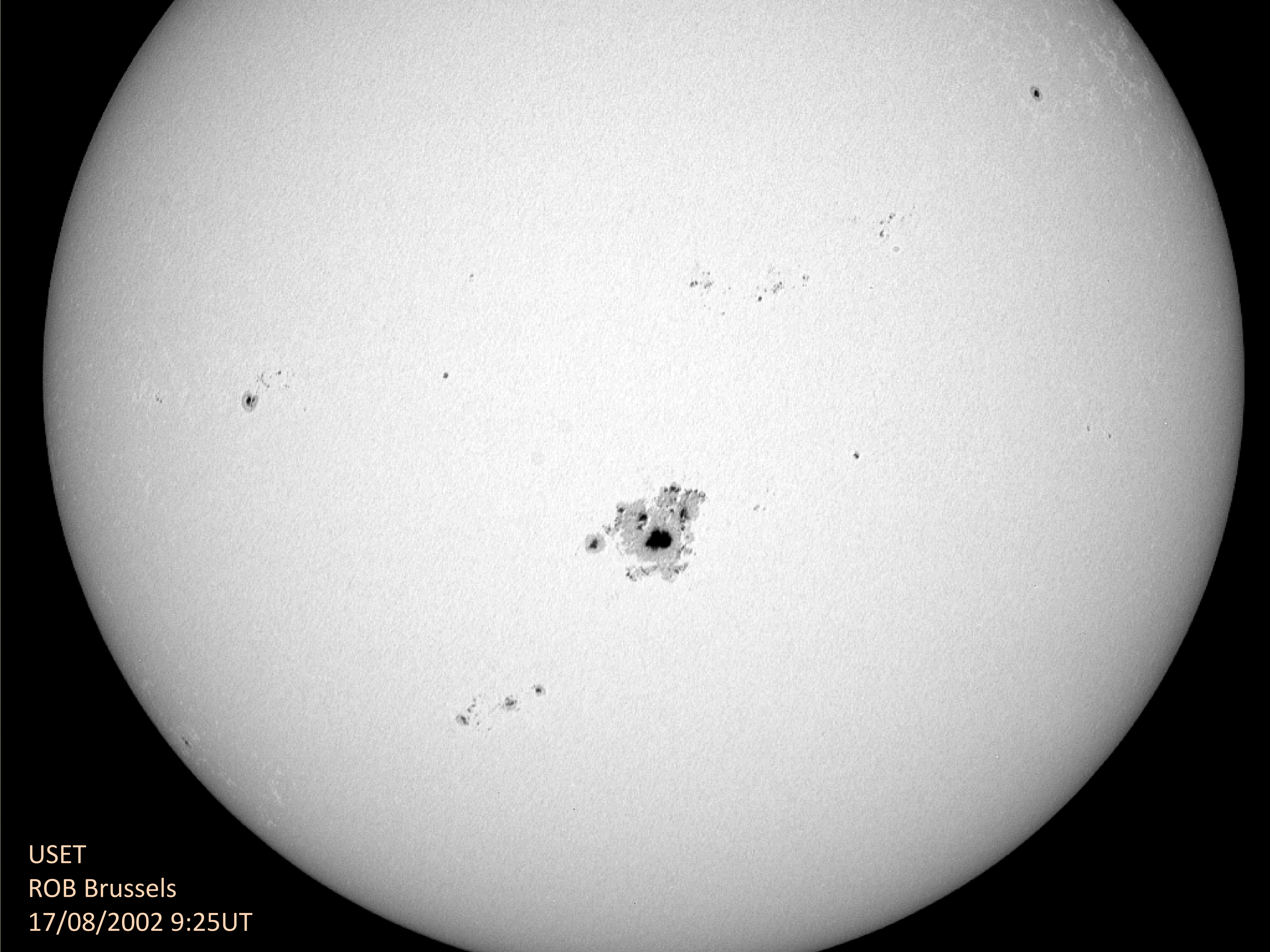
- **Interpretations of differences and drifts of SSN vs other indices must be done with caution**:
  - *Most indices include human assumptions (empirical, instrument model, etc.)*
  - *Different non-linear relations to magnetic flux emergence.*
    - **Cf. other talks !**

- **New prospects are opening up for better understanding R_Z and R_i:**
  - **Exploitation of historical drawing collections: Zürich-Locarno**
  - **Full SIDC database of raw observations and K coefficients.**

Conclusions

- **Unparalleled long-term robustness** of a visual index compared to other indices now and in the future:
  - Cheap and simple measurements ➡ permanent reservoir of observers
  - Many data sources (no interruptions, cross-validation)
  - High resilience to changes in the social & political context (wars, budget cuts!)

- **Large educational and social impact**:
  - Easy to understand and part of public culture (songs, movies):
    ➡ Excellent support for communicating about solar physics and space weather
  - Anyone can take part and contribute:
    ➡ Entry point for many amateur astronomers and scientific vocations.


USET
ROB Brussels
17/08/2002 9:25UT