Sunspots during Cycle 23 Implication for TSI

Giuliana de Toma

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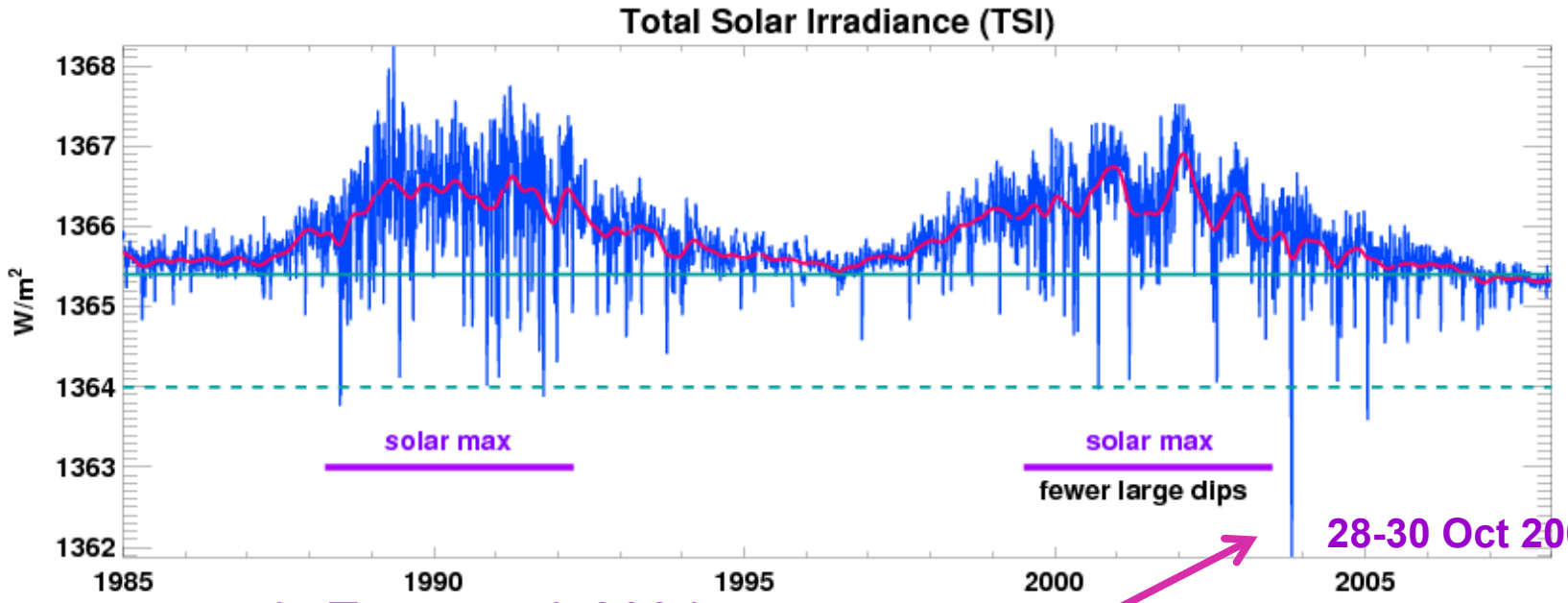
Thanks to : K. Tegnell, W. Denig, H. Coffey (NOAA), K. Balasubramaniam (AFRL) D. Hathaway (NASA), L. Gyori and T. Baranyi (Debrecen)

Sunspot Number Workshop
NSO, Tucson, January 2013

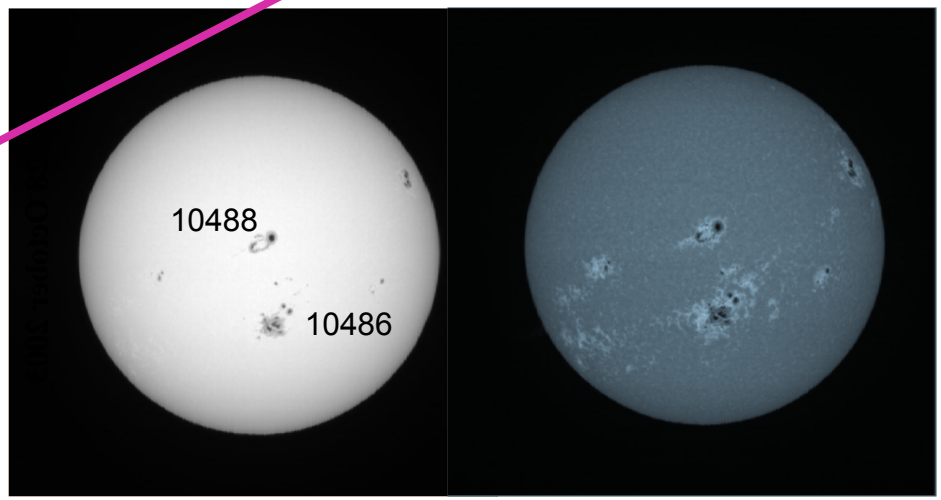
Lack of Large Spots Evident in the TSI record



de Toma et al. 2004

TSI dips > 1 W/m2
cycle 22: 102
cycle 23: 66

one noticeable exception:
AR 10484 (1750 μhem)
AR 10486 (2610 μhem)
AR 10488 (1750 μhem)
October-November 2003



SFO images October 2003

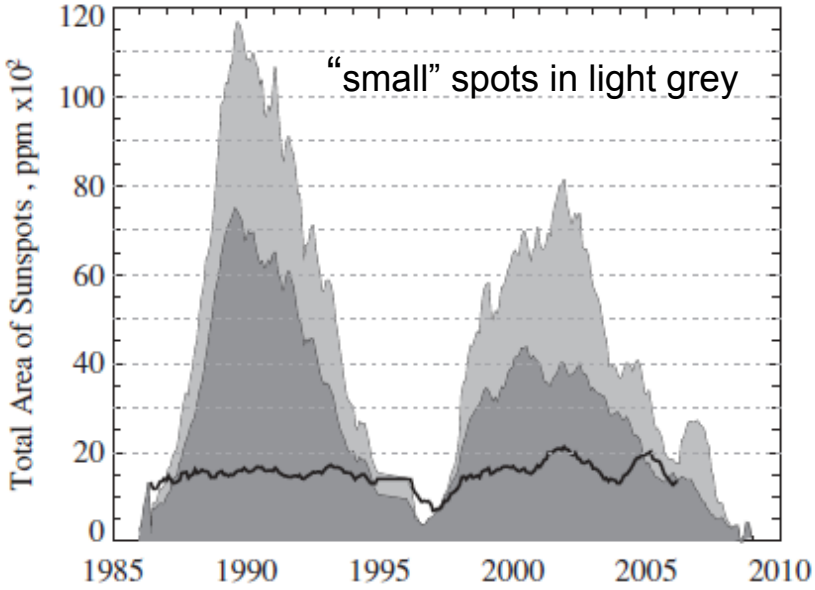
Kilcik et al. Spot Analysis

Kilcik et al. (2011) **claimed a** ***decrease in the number of "small" groups*** **from analysis of group class in the USAF/Learmonth data and an** ***increase in "large" groups*** **They called:**

small groups = groups in classes A, B, C, H

large groups = groups in classes D, E, F, G

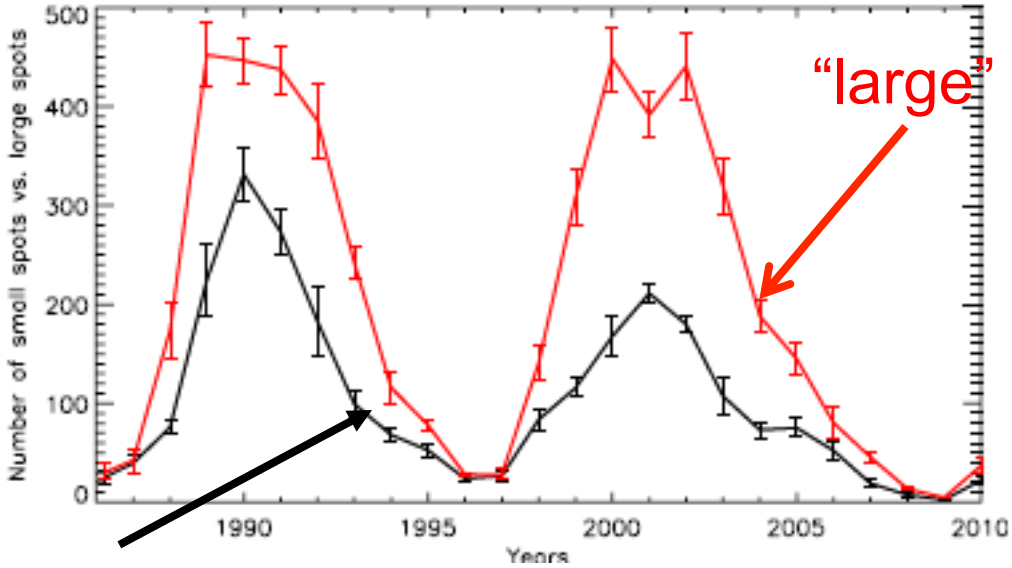
but morphological class is different from area



speculate that TSI did not change much in cycle 23 because of an ***increase in large and bright faculae associate with large groups*** **compensate increase in large groups**

Lefevre & Clette Spot Analysis

Lefevre & Clette (2011) **find a change only in the smallest spots (class A and B) in cycle 23 and** ***no significant change in large spots*** **but a** ***50% decrease in small spots (area < 17μhem) isolated or in groups***



"small"

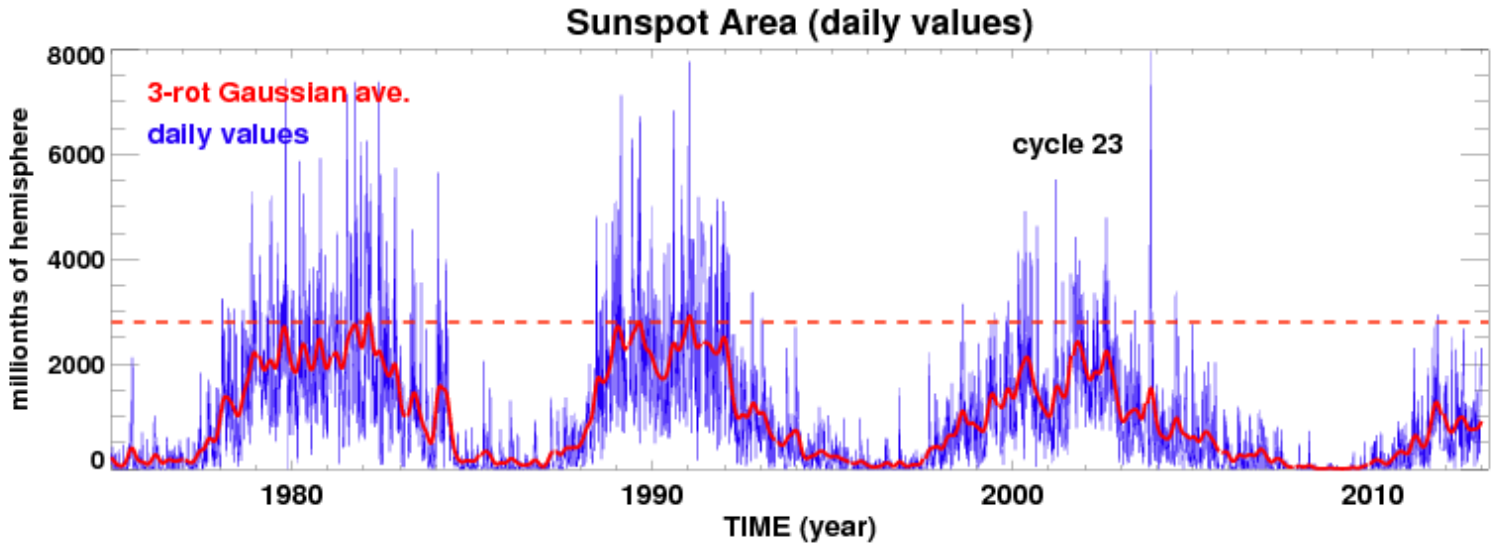
They concluded that all small spot are decreasing and this is possibly a consequence of the Livingston-Penn effect

"large" spots not large, include spots of all sizes
"small" spots are only a small subset of small spots

…….difficult to reconcile with other observations

Debrecen data indicate spots with area < 17μhem account for less than 10% of total sunspot area near solar max

total sunspot area was 27% lower during cycle 23 maximum



# of independent spot groups in USAF/NOAA with area ≥ 800μhem

cycle 21	cycle 22	cycle 23	cycle 24
109	98	65	7

updated Jan 15 2013

~40% decrease in very large groups
(counted only once at the time of maximum area)

Why do we care???

Because we try to understand how changes in the number spots affect other quantities like sunspot area and solar irradiance

This has also implications for solar models

Lefevre & Clette speculate 2 separate mechanisms for the formation of spots:
a near-surface dynamo that produces small spots (Shatten, 2009)
and
a deep-seated dynamo that produces large spots

This means that small and large spots in the same group are generated by two independent dynamos (very unlikely)

OUTLINE

analysis of sunspots and faculae (frequency, area, and contrast) from San Fernando Observatory

discuss the implications for TSI

compare results with NOAA/USAF and Debrecen sunspot areas

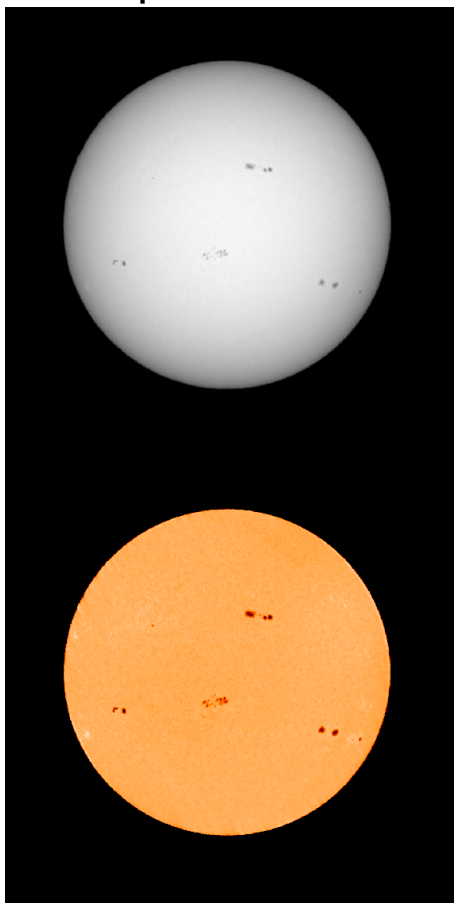
explain apparent disagreement among different sunspot studies

San Fernando Observatory (SFO)

research facility associated with the California State University at Northridge (CSUN)

SFO Observations of Spots

Apr 20 2012



Photometric Telescope Filters

Telescopes	Wavelength (nm)	Bandpass (nm)
CFDT1	672.3	10
(5″ pixels)	472.3	10
	393.4	1
CFDT2	672.3	10
(2.″5	472.3	10
pixels)	393.4	1
	393.4	0.3
	780	10
	997	10

spots & faculae identified in contrast images

8.5% darker than quiet Sun

4.8% brighter than quiet Sun

$$C_{spot} = \frac{I_{spot} - I_{quiet\ Sun}}{I_{quiet\ Sun}}$$

objective & consistent method

uses a physical property of spots and faculae

SFO Sunspot data

based on fully calibrated images, real continuum images

limb-darkening correction computed on the full-disk image

contrast images have about 1% accuracy
(each pixel can be treated in the same way)

contrast is a physical property of spots well correlated with magnetic flux

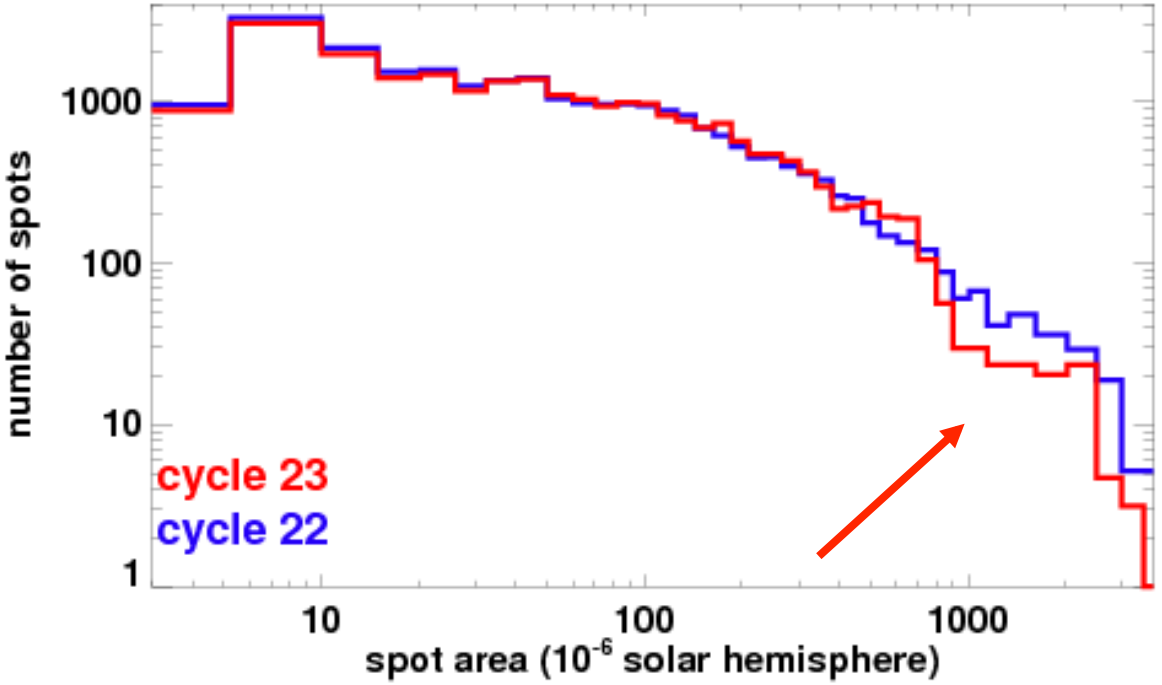
spots ⟷ −8.5% contrast
spot umbrae ⟷ −32% contrast

values based on analysis of large number of spots
simple, robust criteria, almost no false positive

low spatial resolution ~5”
pores/tiny spots with area ≤ 5μhem are detected only if they are within 30deg from disk center (~.5Rsun)

Are Small Spots Decreasing?

Spots distribution as function of spot size for cycles 22 and 23



Cycle 22
1987- 1996

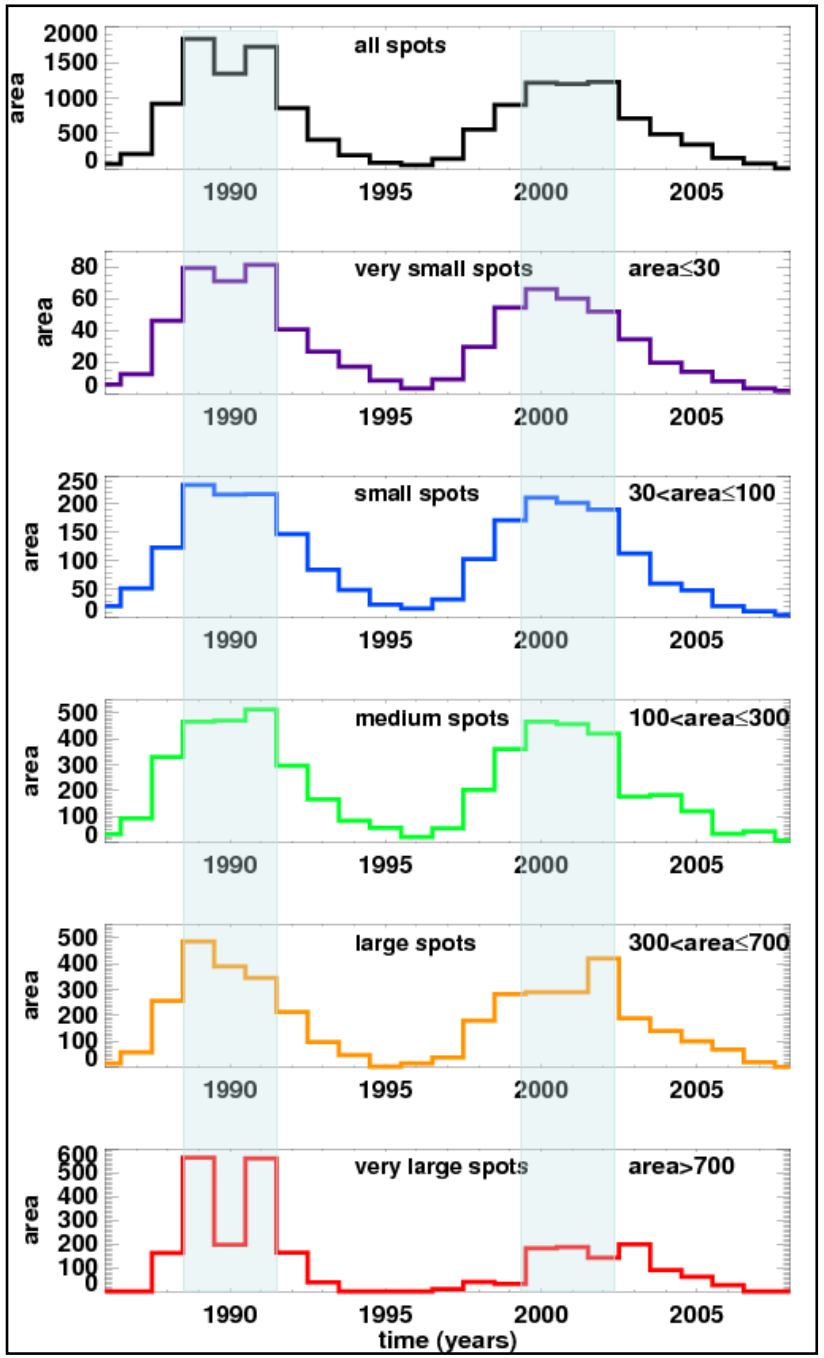
Cycle 23
1997- 2006

data corrected for duty cycle

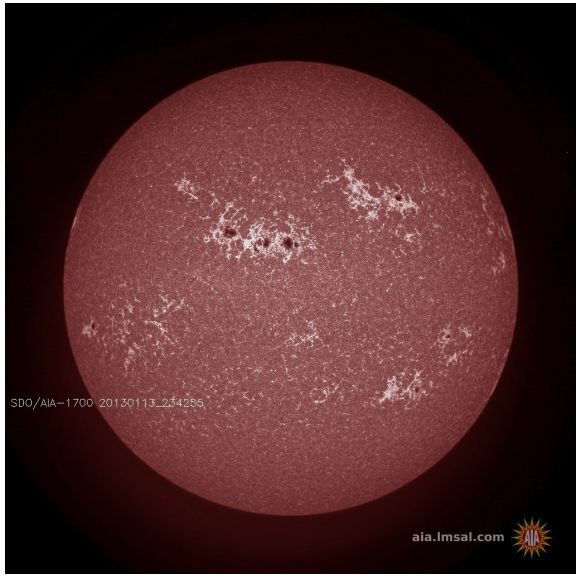
the major difference between the two cycles is in the tail of the distribution the number of very large spots (area > 700μhem) decreased by about 40% in cycle 23 the smallest spots (area < 30μhem) decreased by 8%

Variation in Sunspot Area

- 25% decrease in very small spots at maximum, does not contribute much to change in total sunspot area
- no large differences in the number of small and medium spots
- large difference in the large and especially the very large spots both in the frequency and timing, account for over 82% of the decrease in total sunspot area during the maximum of cycle 23
- number of spots with area > 700μhem less than half in cycle 23 maximum, account for 64% of the change in total sunspot area



Implications for TSI



If large spots decreased by over 50% why TSI did not change much during cycle 23 maximum?

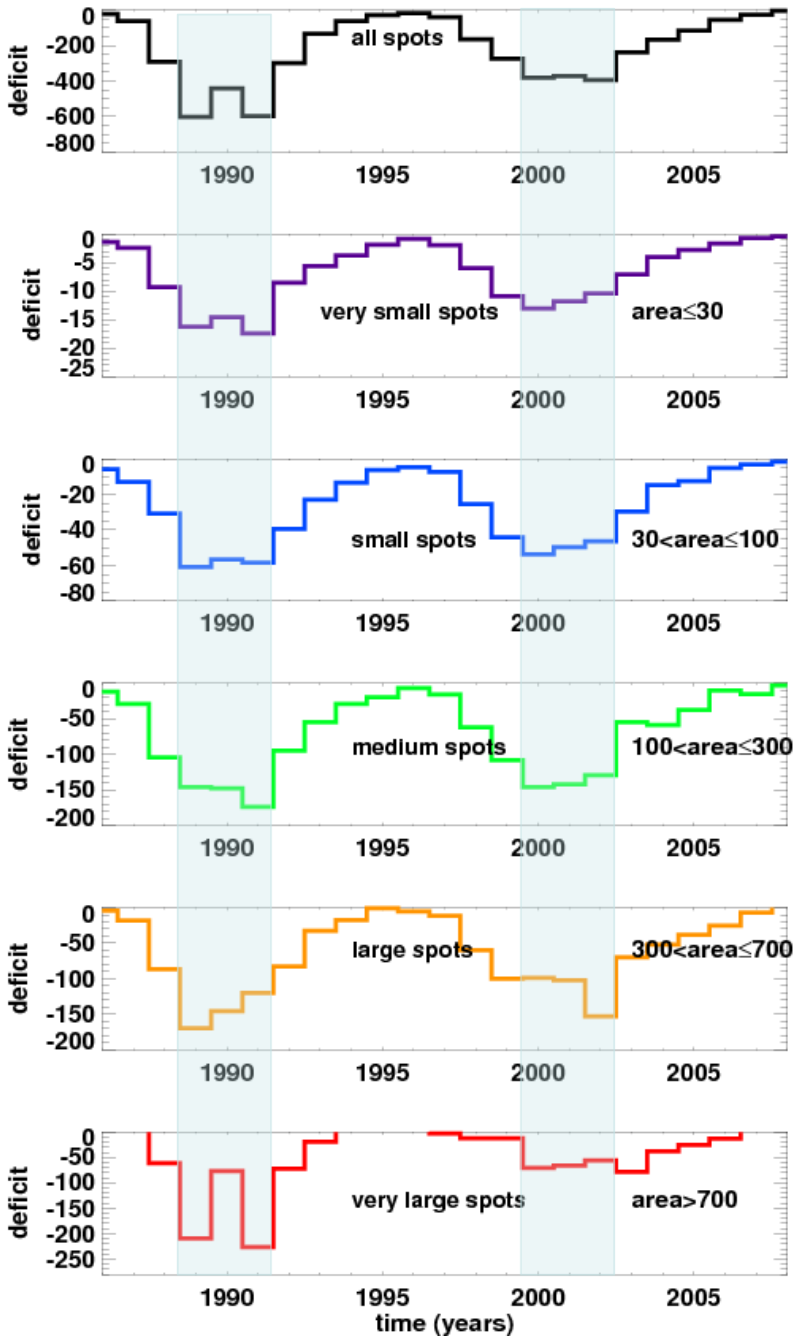
The TSI value depends on the balance between bright and dark features on the Sun

important quantities are: disk-integrated sunspot deficit and facular excess associated with faculae, plages, and network

$$\text{Deficit}_{spot} = \sum_{dark\ pixels} C_i \Phi(\mu_i)$$

$$\text{Excess}_{CaII\ K\ faculae} = \sum_{bright\ pixels} C_i \Phi(\mu_i)$$

facular index is based on Call K images at 393.4nm with 1nm bandpass (upper photosphere/lower chromosphere)



Sunspot Deficit

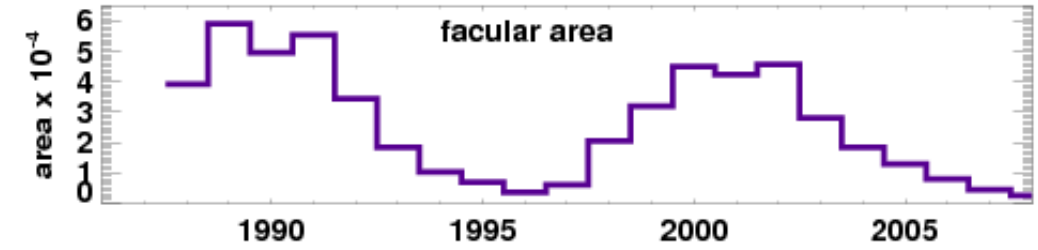
change by about 30% between maxima

- the main contributors to the total contrast are the medium, large, and very large spots because of their number and size

- small and very small spots have only a minor effect

- changes in TSI are mainly caused by the very large spots because they are the largest and darkest in spite of their small number

Facular Area and Facular/Network Excess



brightest faculae *decreased* by 45%

fainter faculae decreased by 24%

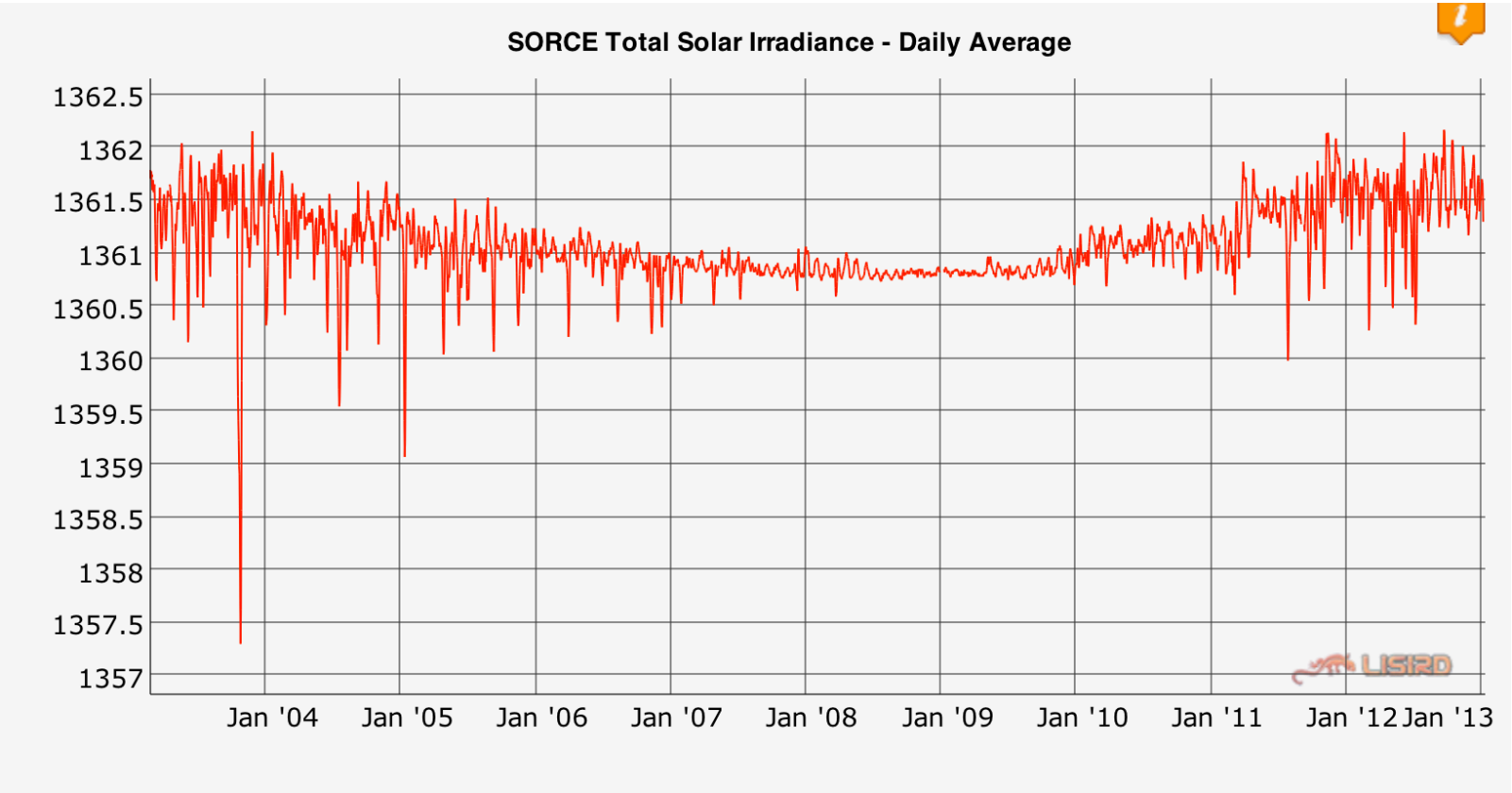
facular area decrease by 19%, i.e. less than sunspot area

both sunspot deficit and facular/network excess changed by approximately 30% compensating each other

↓

TSI remained at about the same level during the maximum of cycle 23

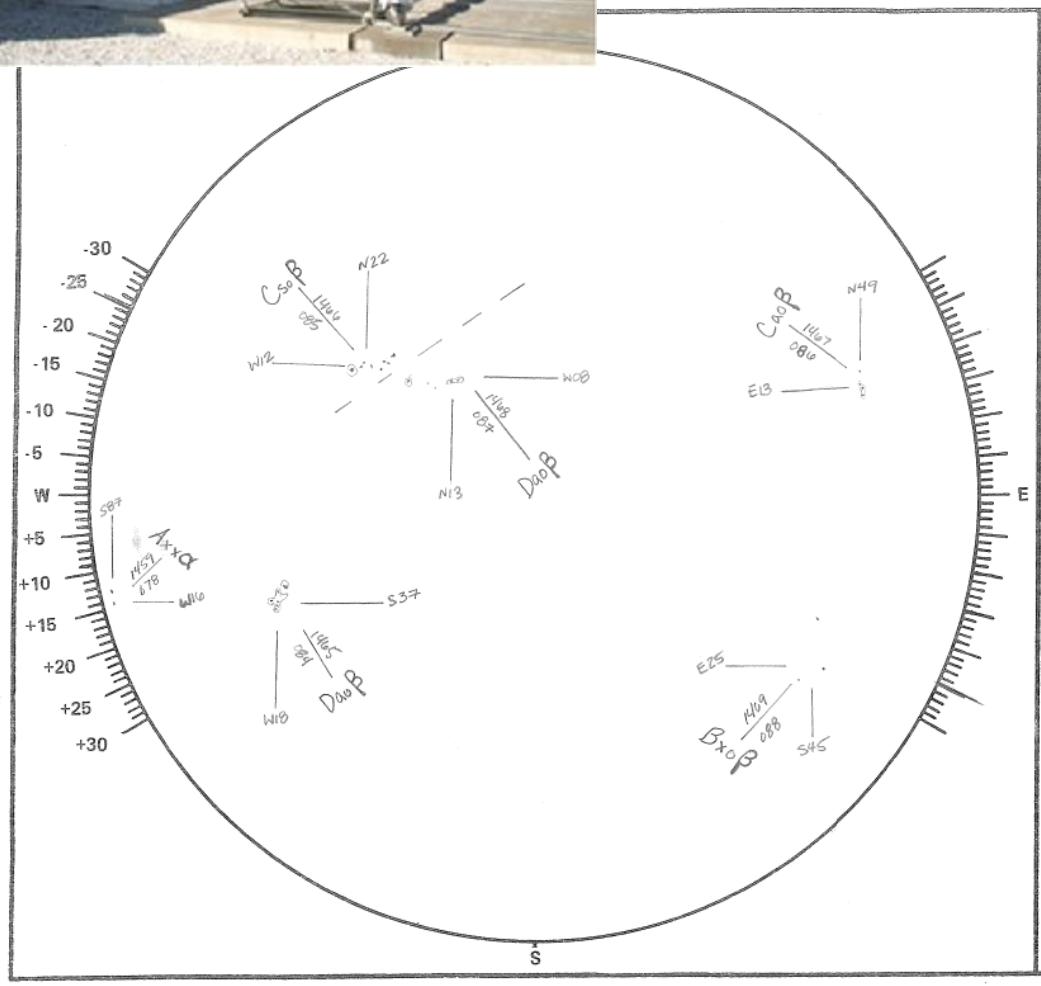
interesting to follow TSI in cycle 24 and how changes in sunspot and faculae will influence TSI value during this much weaker solar cycle



- strong decrease in very large spots in cycle 23 but no large changes in small and medium spots
- decrease in large and very large groups in cycle 23 is mostly responsible for the decrease in total sunspot area
- sunspot area changed more than facular area but sunspot deficit and facular excess changed by about the same amount this is why TSI did not change much
- largest/darkest spots and largest/brightest faculae decreased by more than 40% in cycle 23 maximum
- smallest spots and faintest faculae decreased by about 24-25%

sunspot and facular contrast important for irradiance

USAF/SOON Dataset



ANALYST: SSGT MULLINS / MR. PIETRZAK

DATE	TIME	QUALITY
26 APR 12	1916	GOOD

B_P	P_O	L_O	NO GROUP
-4.55	-24.75	18 43	016

NO. SPOTS	R =
28	88

HQ AXXY63 KHMR 262105

SPOTS

7 2265 20426 31916 43406
IIIII YMMDD 3HHMM 4TQNN

11111	22JJJ	QXXYY	LLAAA	//NNN	6ZPCM	9NNNN
11111	22 085	42212	07011	// 008	6 3272	9 1406
11111	22 087	41308	08009	// 005	6 4372	9 1468
11111	22 078	38016	03006	// 002	6 10/1	9 1459
11111	22 084	33718	05021	// 006	6 4372	9 1465
11111	22 088	24525	09006	// 003	6 2072	9 1469
11111	22 086	14913	04010	// 004	6 3372	9 1467
11111	22			//	6	9
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START 1913 STOP 1918

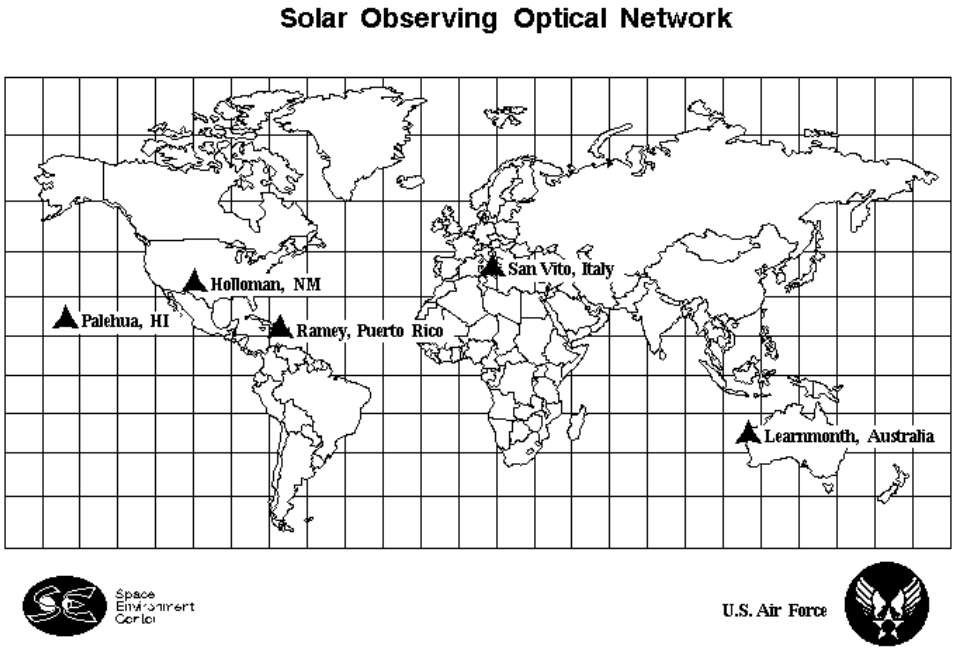
AFWA Form 21, May 00

SUNSPOT ANALYSIS WORKSHEET

USAF/SOON

USAF/SOON is a network of identical 25cm telescopes located within USAF bases operating since 1976

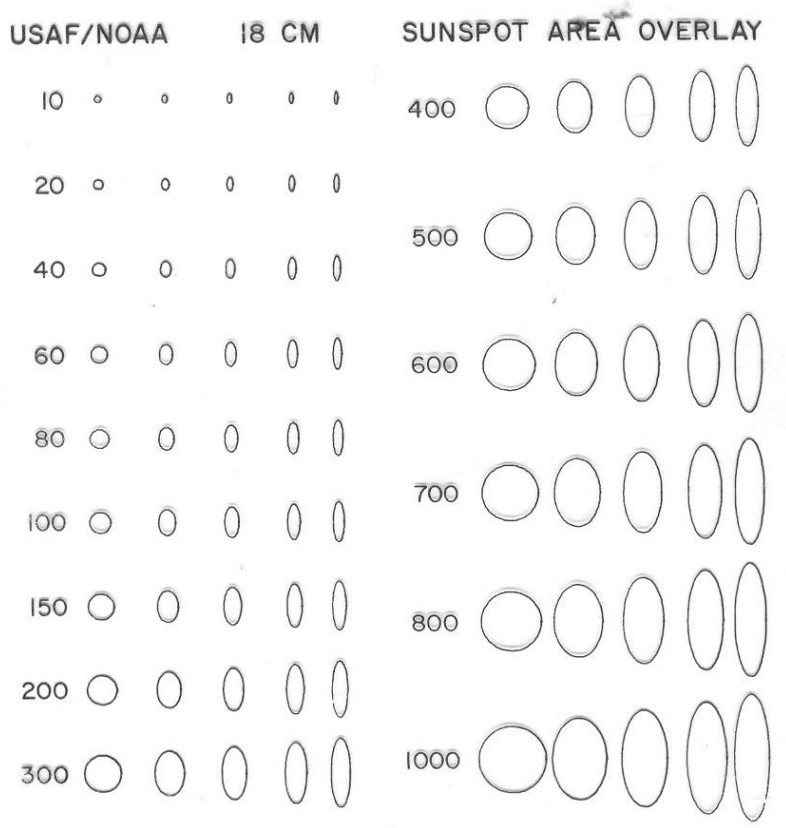
Holloman (USA)
San Vito (Italy)
Learmonth (Australia)
Palehua (USA/Hawaii)
ends in1997
Ramey (Puerto Rico)
ends in 2002



data are provided in real time, the main goal is space weather, never intended for scientific research but extensively used after the Greenwich Royal Observatory sunspot data ended

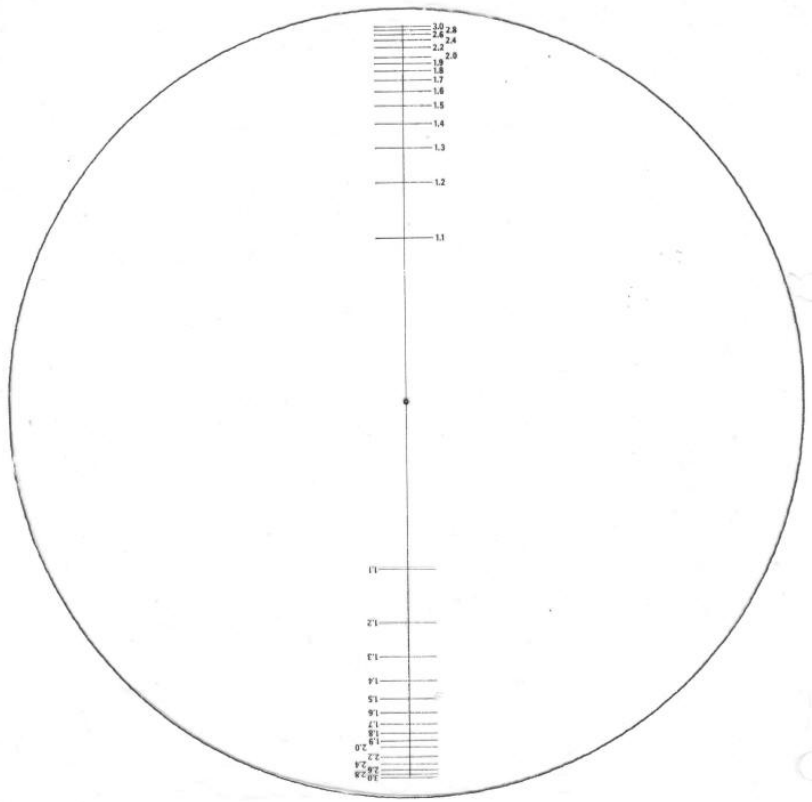
area measurements are given in steps of 10μhem: 0,10, 20,…

spots with area less than 10μhem not always reported



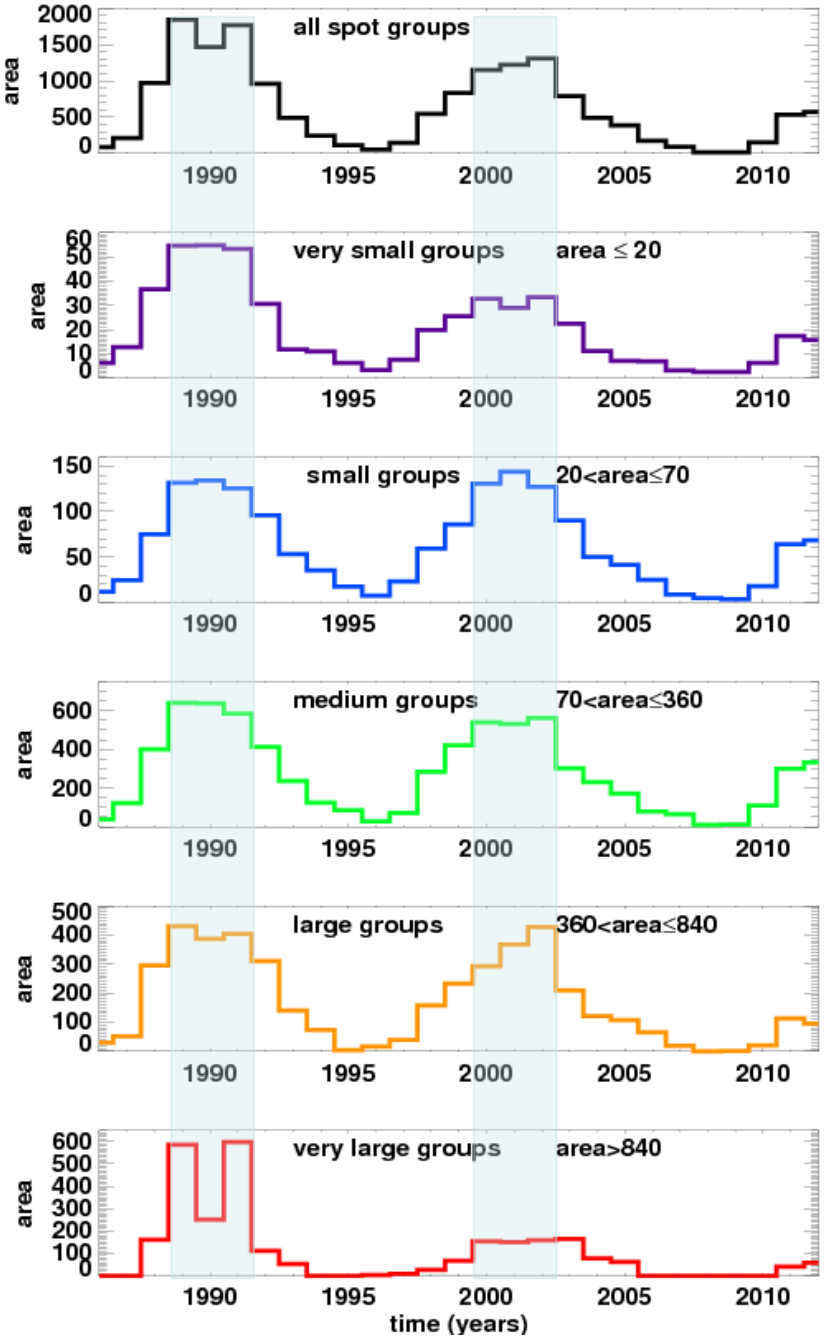
overlay for area estimate

overlay to correct for projection



NOAA/USAF dataset

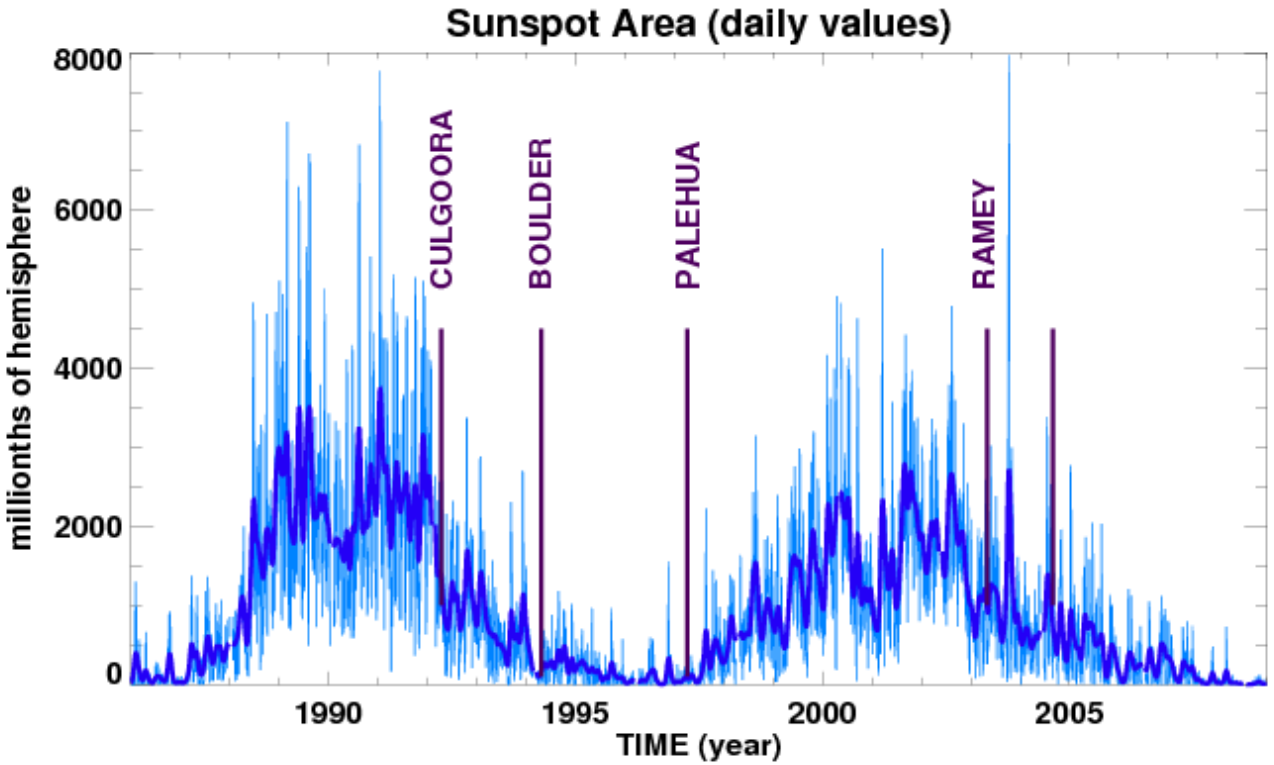
- decrease in very small groups of 48% during cycle 23 maximum, 40% over the cycle, contributes less than 5% to the change in total sunspot area
- no change in small groups
- small decrease in medium groups
- large and very large groups are only 8% and 2-3% of all groups in a cycle
- 60% decrease in the number of very large groups accounts for 70% of the decrease in total sunspot area during the maximum of cycle 23



How reliable are measures of small spots in the USAF/NOAA dataset?

USAF/NOAA shows a decrease in very small spots of 40% in cycle 23, the current USAF stations of less than 20%

- **Decrease in number of observing sites**

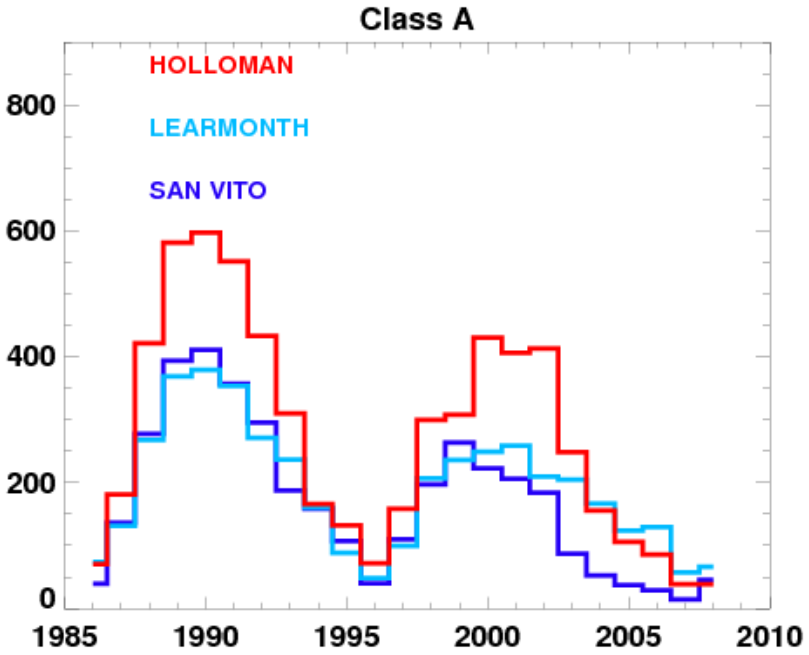


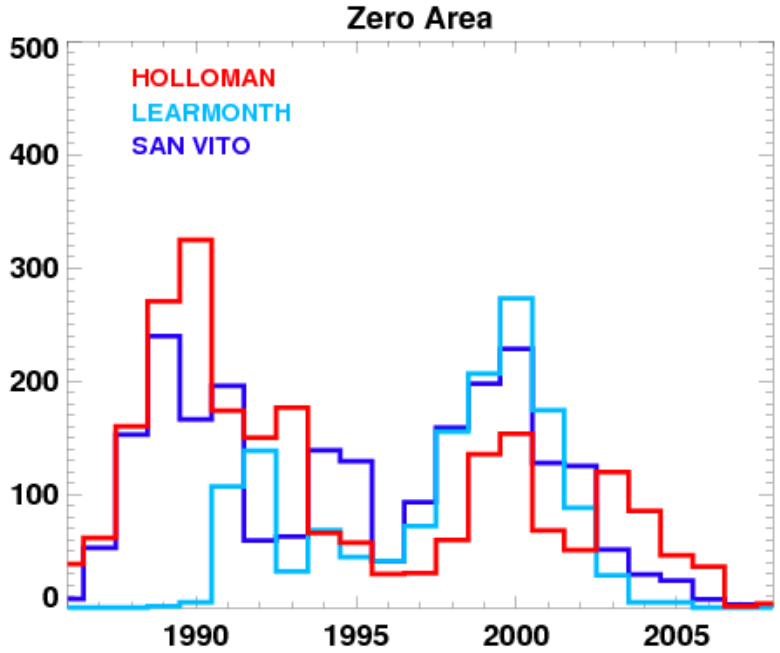
underestimate frequency of very small spots:

effect ~ 8-15%

not enough to explain differences

Very Small Groups



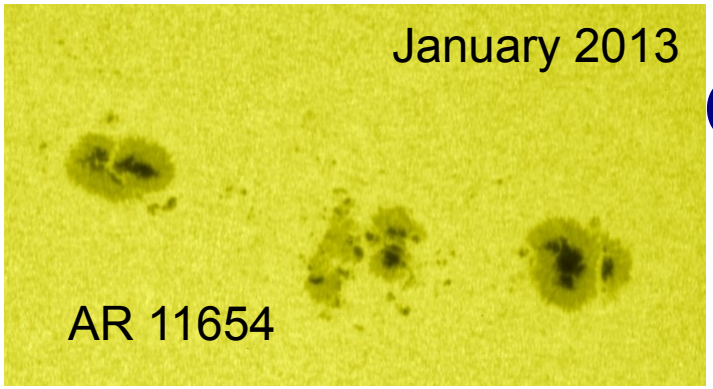


estimates for groups with zero area not reliable

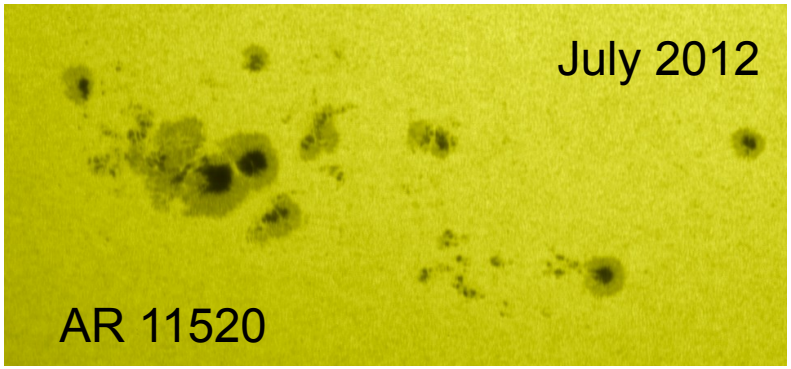
groups = 0−10μhem 30−35% **
groups = 20μhem < 4%

disagreement with SFO only for the smallest groups with area 0 and 10μhem

**** corrected for decreasing number of stations**



GROUP vs SPOT FREQUENCY



Fewer spots per group in cycle 23

the number of spots increases with group size

- **class A has 1 or 2 spots per group**
- **class B has typically 4-5 spots per group**
- **if only class A and B decrease the mean number of spots per group would go up**

so.....

- **there must be an unknown mechanism that reduces the number of small spots in large groups**

or

- **the number of large groups must decrease (observed)**

Holloman has good seeing and seems the most reliable of the USAF/SOON stations for small groups

mean number of spots for group

	cycle 22	cycle 23
large groups 360 < area ≤ 840μhem	27.7	27.1
very large groups area > 840μhem	42.5	41.5

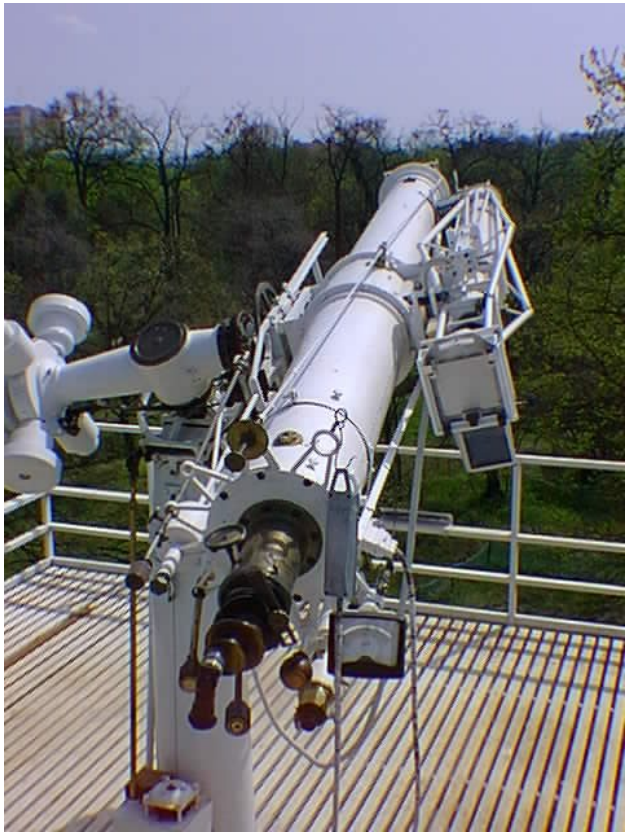
total number of groups

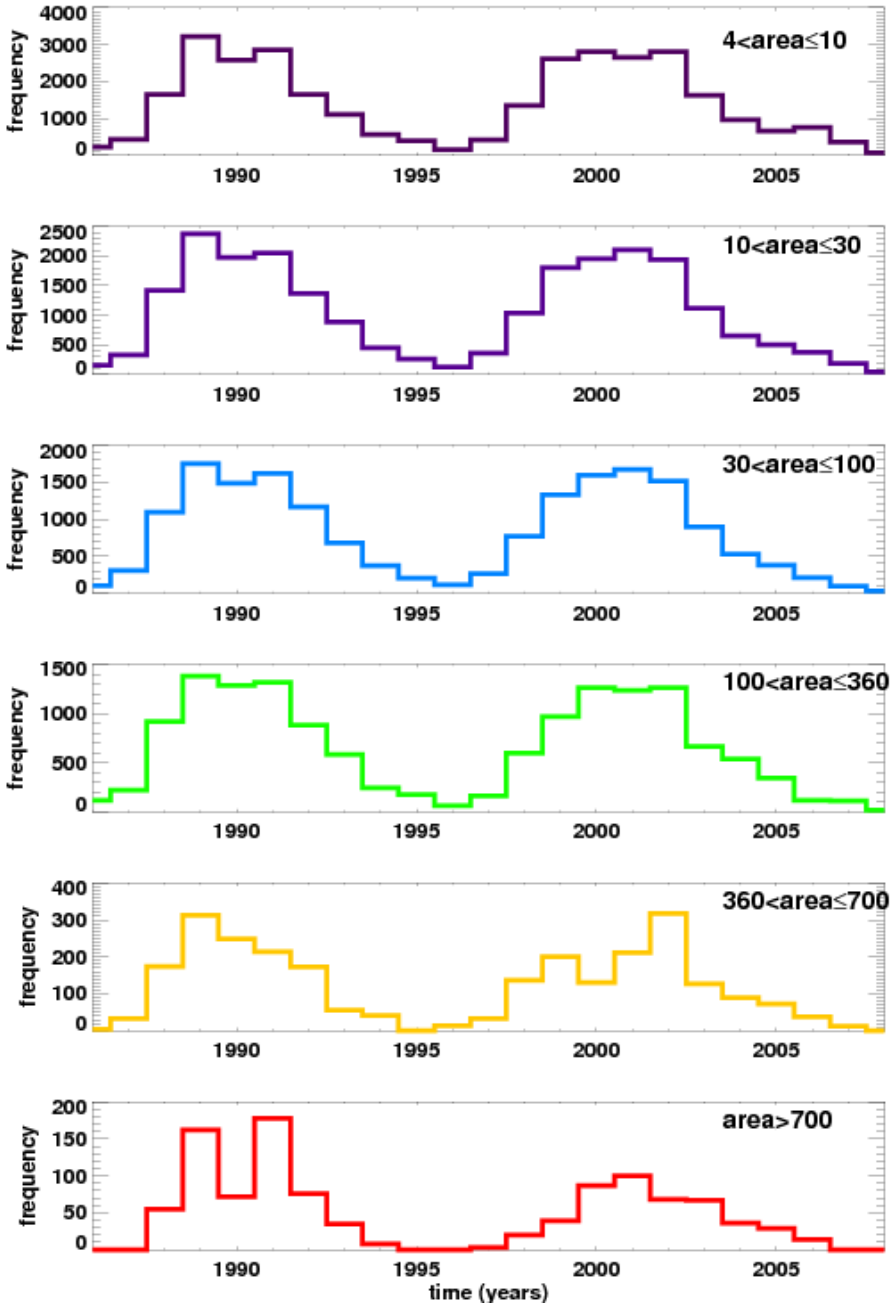
	cycle 23-22	Δ	
all groups	− 18889	− 10%	(100%)
area > 840μhem	− 9047		(48%)
area > 360μhem	− 14423		(76%)

the decrease of large and very large groups account for most of the decrease in (sm)all spots in cycle 23

Debrecen Photometric Catalog

The Debrecen catalog is a continuation of the Greenwich sunspot catalog. Photometric data from the Debrecen and Gyula Observatories used to derive the area and position of spots and spot groups.





Debrecen dataset

results are very similar to the USAF/NOOA and SFO:

- **Decrease of 36% for very large spots at the maximum of cycle 23**
- **no large changes in the number of small and medium spots**
- **no large changes in the very *small spots* at maximum *increase over solar cycle 23***

+10% for spots with area 5-17μhem

+7% for spots with area of 10-30μhem

Summary of small spot changes in cycle 23

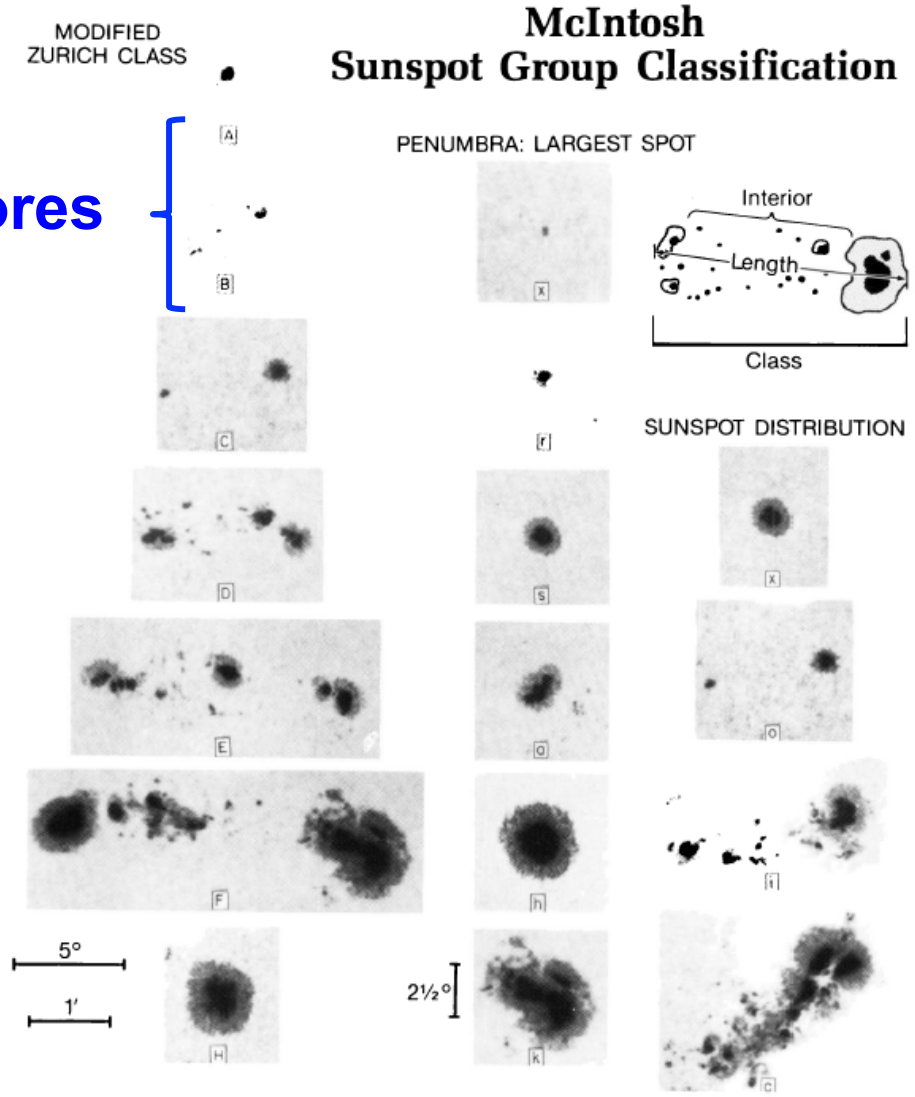
SFO all < 30μhem	− 8%
NOAA/USAF 0-10μhem	− 30−35% **
NOAA/USAF 20μhem	− 2−4%
Holloman 10μhem	− 18%
Holloman 20μhem	+ 8%
Debrecen 5−17μhem	+ 10%
Debrecen 10−30μhem	+ 7%

small spots did not change much in cycle 23

Still an open question:

Why Kilcik et al. (2011) and Lefevre & Clette (2011) came to different results?

Zurich-Modified classification of Spots



pores

Logic sequence for determining McIntosh sunspot types

Unipolar or bipolar?
Penumbra or no penumbra?
Penumbra on one end or both ends?
Length of group?
Rudimentary or mature penumbra?
Symmetric or asymmetric largest spot?
N–S diameter of largest spot?
Spots between leader and follower?
Mature penumbra in interior?

uses polarity (magnetograms?)

umbra/penumbra separation

group length (not area)

subject to seeing conditions, limb effects, etc….

group area and class are not equivalent

24% and 22% of groups in class C, H have area > 100μhem
41% and 9% of groups in class D, E have area < 100μhem

classes C, H, D, and E overlap significantly in area

Learmonth data shows a large decrease in groups in class A and B but no change in very small spots

D, E, and F groups (all defined as large groups) in cycle 23 have:

- **the same number or fewer spots per group**
- **much smaller area**

Lefevre & Clette Area Analysis

small spots defined as:

number of spots with area ≤ 17μhem
(umbra+penumbra) ≤ 7*umbra and umbra > 0

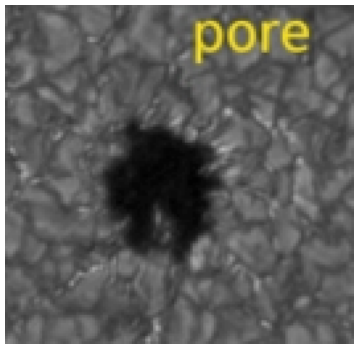
remove all "penumbral spots"

"small" spots are small spots with a large umbra
subset too small only 11% of all spots with area < 17μhem
large decrease only seen in spots with area < 5μhem that are the most uncertain in the Debrecen dataset

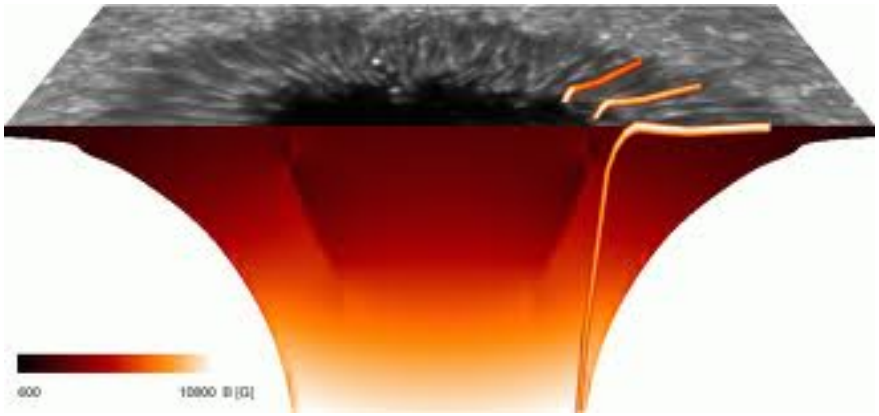
"large" spots have areas that range from 8 to 4000μhem
14% of their "large" spots have area < 20μhem and
64% have area < 100μhem
90% have area < 300μhem
subset too large not really large spots!!

umbra and penumbra are defined on intensity not |B|

most pores/small spots are not dark enough to be classified as umbrae, so they are classified as penumbral spots



penumbral spots should not be removed
60% of spots in class A and B groups are listed as "penumbral" spots in the Debrecen catalog



"penumbral" spots do not mean that |B| is mostly horizontal

intensity in non calibrated images should be used with care

- decrease in very large groups in cycle 23 seen in all datasets: SFO, USAF/NOAA (Learmonth, Holloman, and San Vito), and Debrecen strong evidence for a decrease of very large spots/groups
- change in the smallest spots < 30μhem is not consistent among different datasets no strong evidence for a large decrease in small spots in cycle 23
- measures of very small spots are more difficult and less reliable than for larger spots but have only a marginal effect on total sunspot area
- number of spots per group increases with spatial resolution, spot group area does not change much

sunspot area is a more reliable and more objective measure of solar activity than sunspot number