High Altitude Observatory NCAR

Sunspot Contrast and Area Over Two Solar Cycles

Giuliana de Toma

Collaborators at SFO: G.Chapman, D. Preminger, A. Cookson

Thanks to : K. Tegnell, W. Denig, H. Coffey (NOAA), K. Balasubramaniam (AFRL)

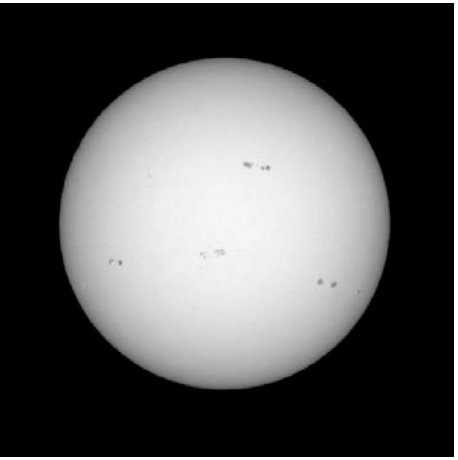
2nd Sunspot Number Workshop
Brussels, 21-25 May 2012

San Fernando Observatory (SFO)

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

Apr 20 2012

SFO Observations of Spots



CFDT1
1986-present

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

sunspots identified in contrast images

8.5% darker than quiet Sun

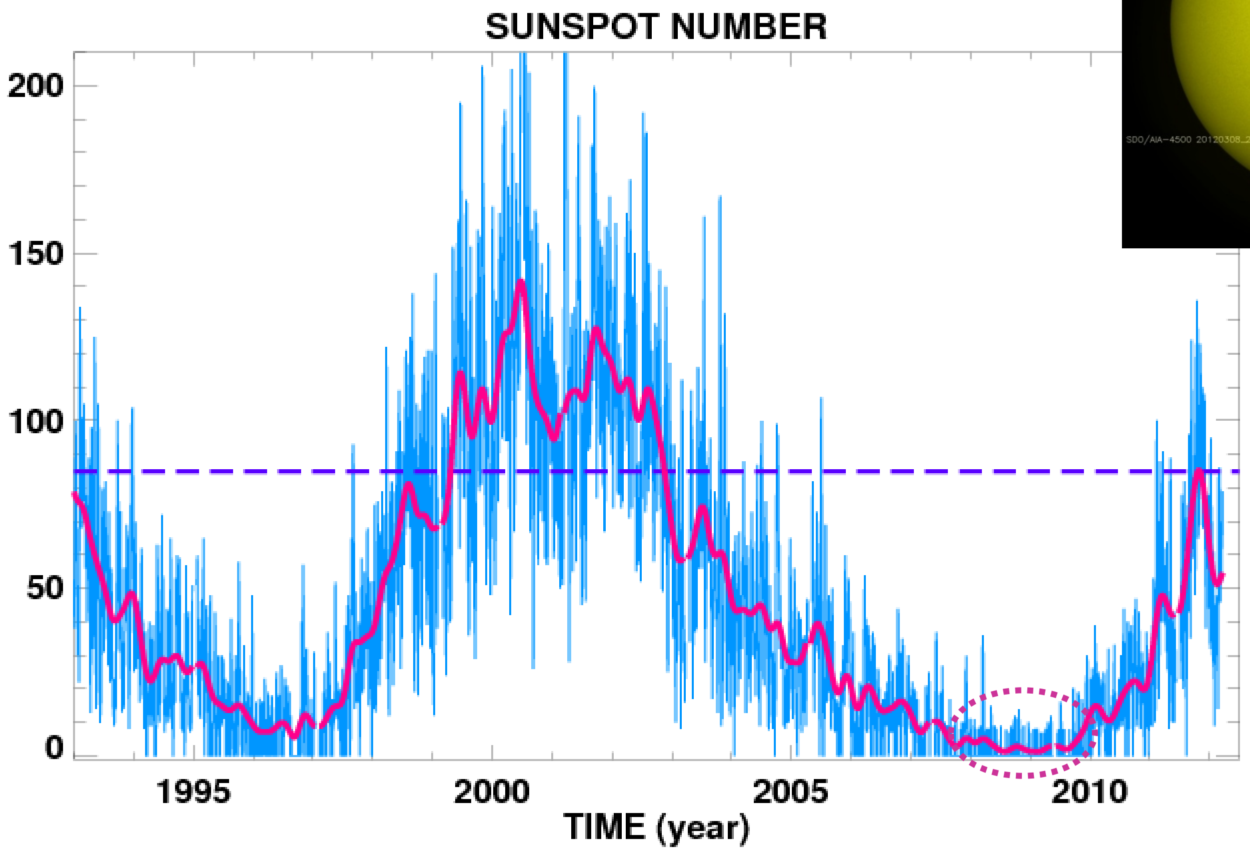
long, objective, consistent datasets

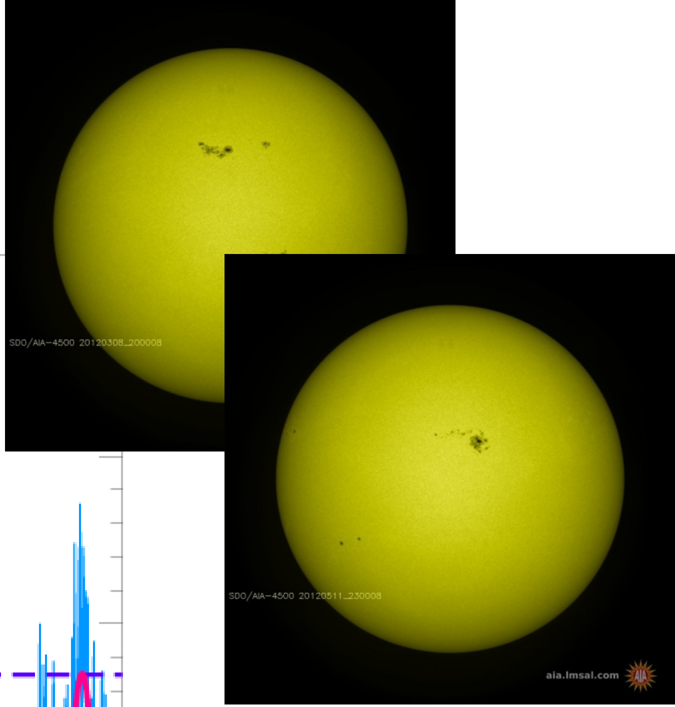
$$C_{spot} = \frac{I_{spot} - I_{quiet\ Sun}}{I_{quiet\ Sun}}$$

OUTLINE

- brief discussion of cycle 23
- contrast of spots in cycle 22 and 23 (SFO)
- area of spots in cycle 22 and 23 (SFO and USAF)

WAS CYCLE 23 UNUSUAL?





long minimum

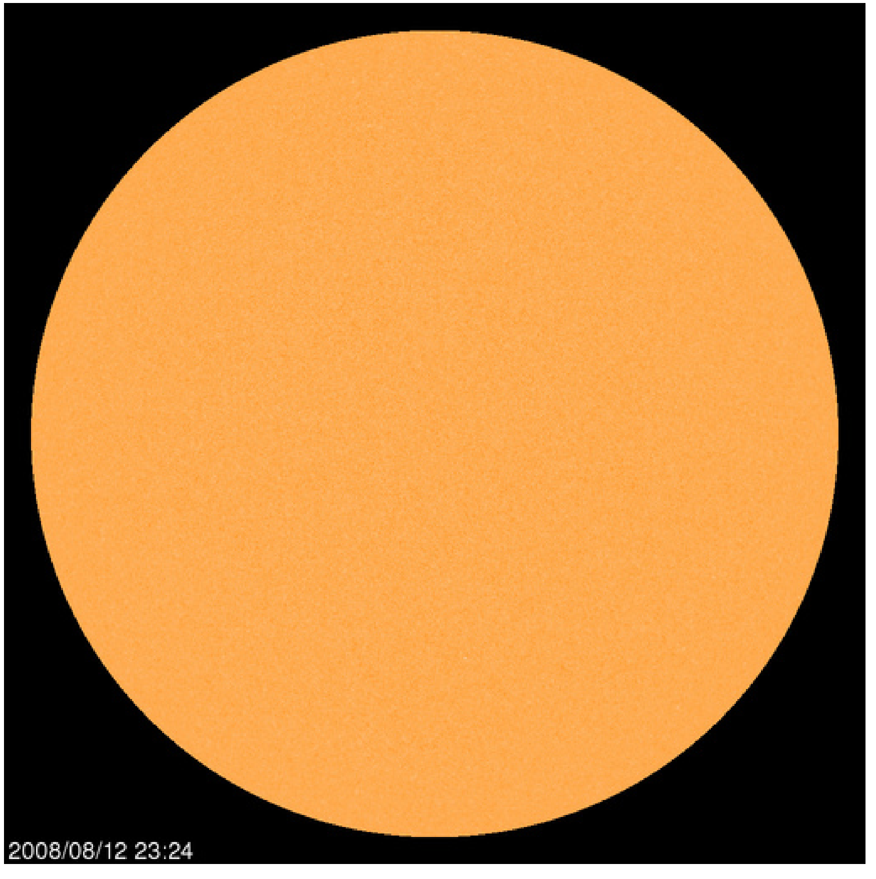
	1976	1986	1996	2006	2007	2008	2009	2010	2011
spot number	12.6	13.4	8.6	15.2	7.6	2.9	3.1	16.5	55.7

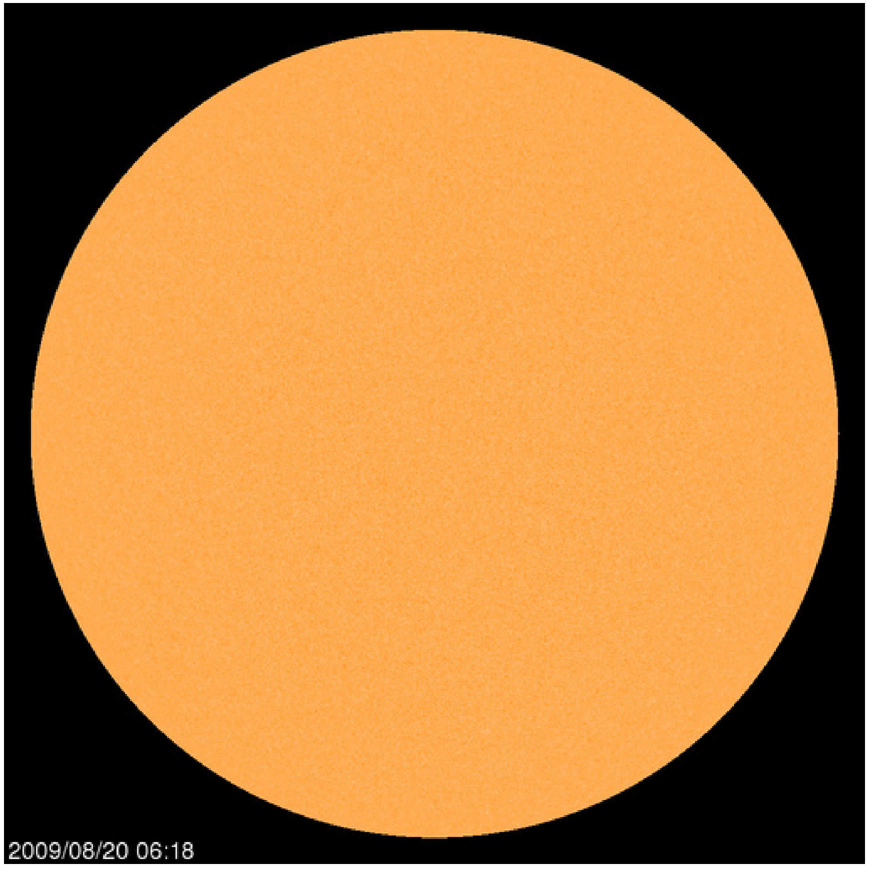
very quiet Sun in 2008-2009, longer than average cycle
only small spots at the start of cycle 24
North more active than the South

WHERE DID ALL THE SUNSPOTS GO?

total # spotless days in 2008-2009 > 500

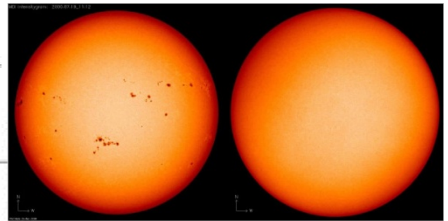
spots were present on the Sun less than 30% of the time





Aug 2008 and Aug 2009 longest periods with no spots

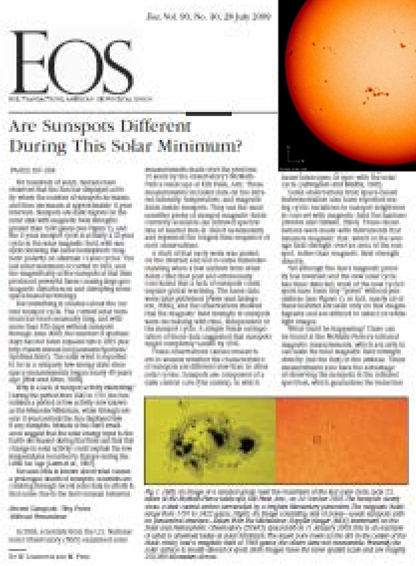
MUCH ADO ABOUT NOTHING……..



The Next Cycle

‘far too early to liken this delay to the Maunder Minimum’ ‘sunspots may be growing cooler and less magnetic and … may soon disappear’

Mar 2009



EOS

Are Sunspots Different During This Solar Minimum?

The New York Times

Sunspots Are Fewest Since 1954, but Significance Is Unclear

Oct 2 2008

Are Sunspots Disappearing?

Sep 2009

Is the Sun Missing Its Spots?

Jul 21 2009

Sun goes longer than normal without producing sunspots (MSU)

Jun 2008

Solar Cycle 24 is Late

Mar 2009

Longer term Solar Minimum

Aug 2009

Deep Minimum Continues

Jul 2009

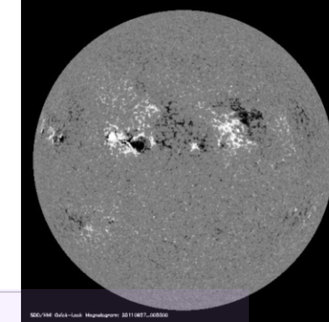
Quieter activity on Sun may push Britain into a modern-day Little Ice Age

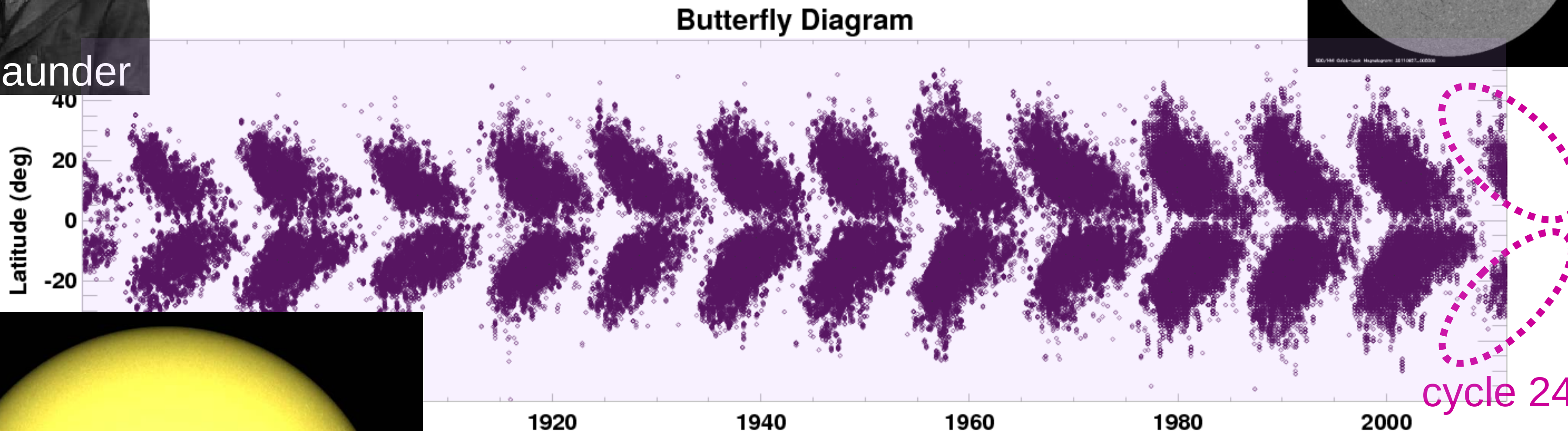
Scientists Link Quiet Sun & Cold Winters

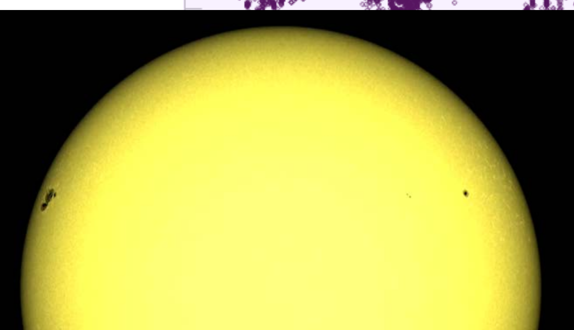
Sun blamed for Europe’s colder winters

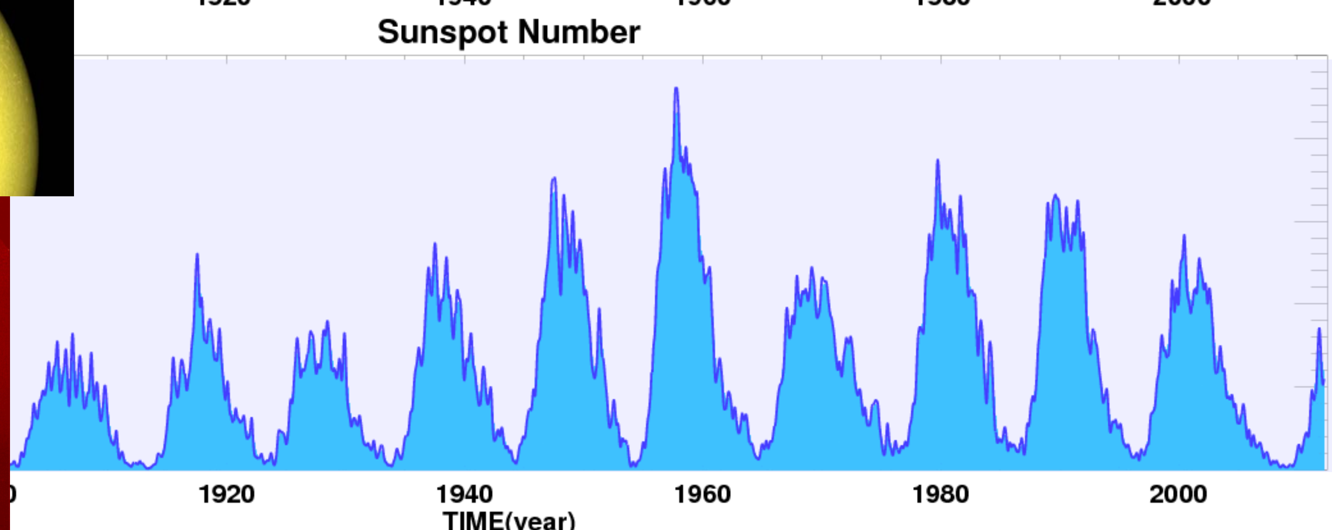
Physics World Apr 2010

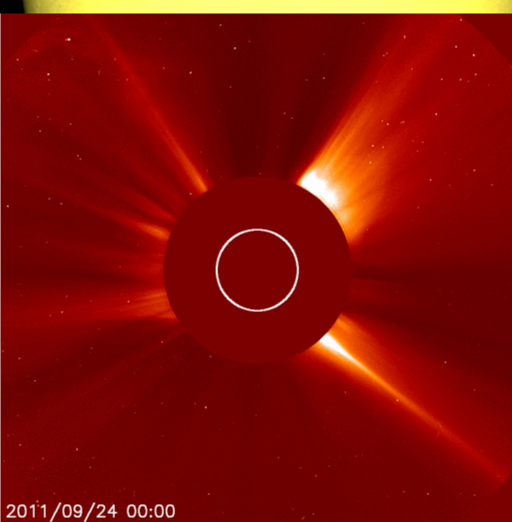
NO MAUNDER MINIMUM - SORRY









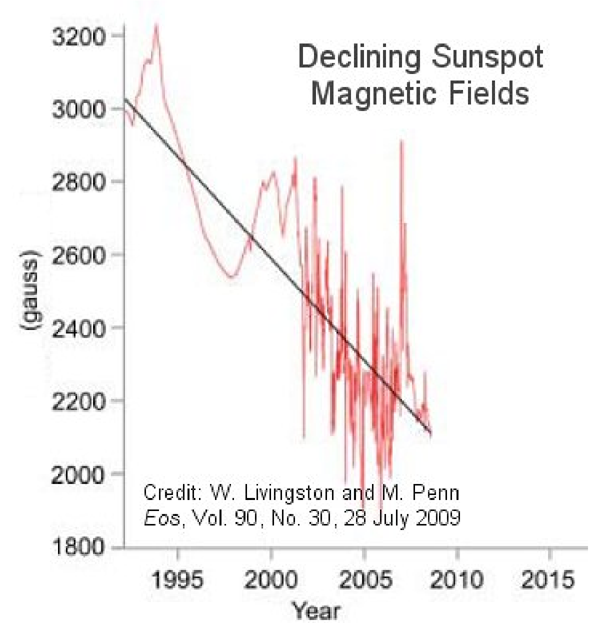


WHAT ABOUT CYCLE 25?


EOS
Are Sunspots Different During This Solar Minimum?

decrease in spot magnetic field
increase in brightness ~2% a year
linear trend
if trend continues
field falls below 1500Gauss
no more spots/pores after 2015!!!

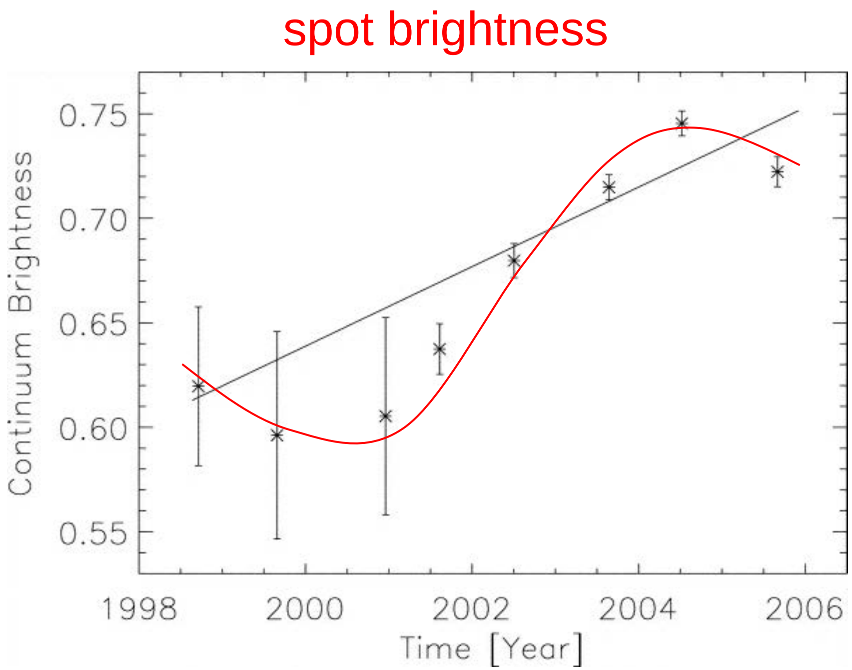
(Livingston & Penn 2009)

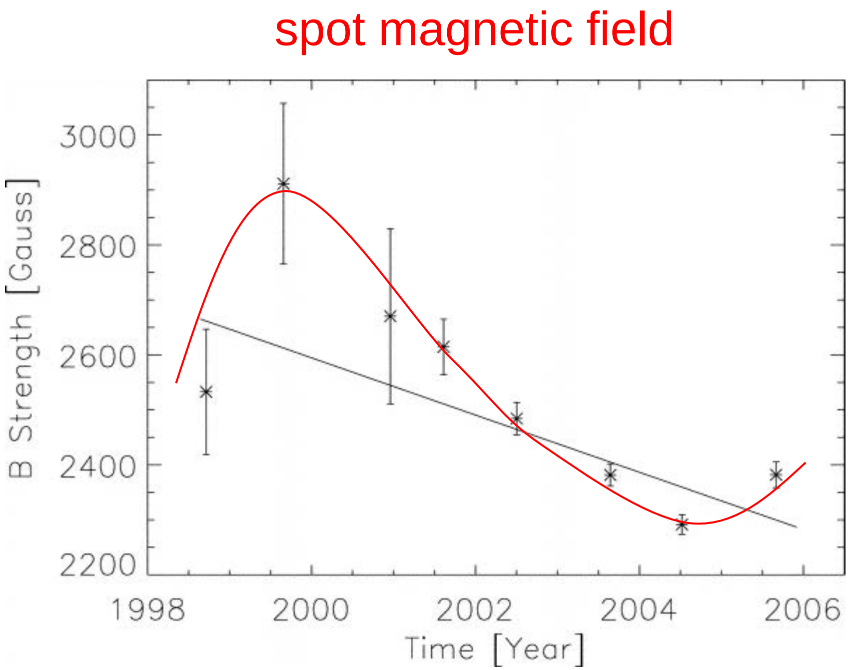


Zeeman splitting in the FeI 1564.8nm direct measure of mag. field strength

~900 sunspots from 1998 to 2005 relatively small # of points

ARE SUNSPOTS GETTING LESS DARK?





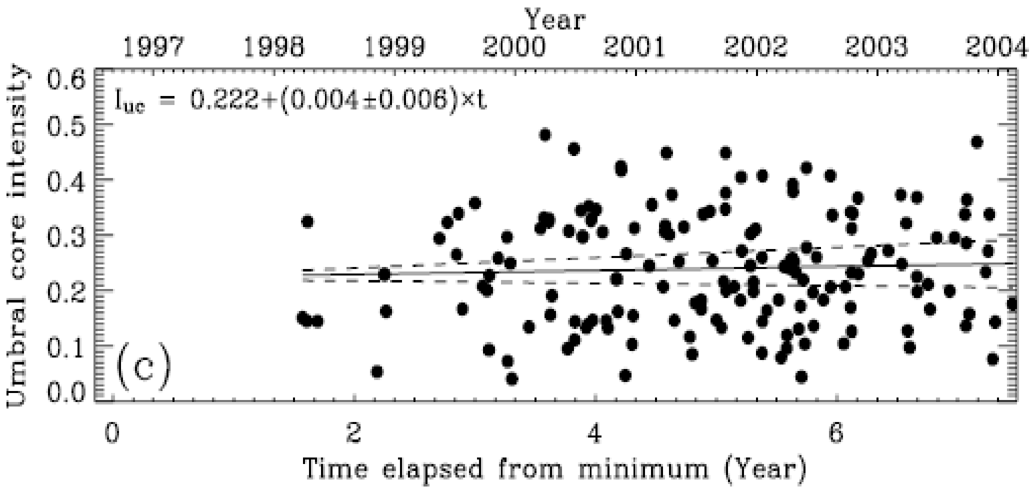
Penn & Livingston ApJ 2006

OR IS THIS A SOLAR CYCLE EFFECT?

sunspots are smaller, i.e. less dark, i.e. have weaker fields near solar minimum when activity is low

…..Several studies indicate they are not

either did not find a change
or
found a solar cycle signature



Norton and Gilman, ApJ 2004

Penn & MacDonald, ApJ 2007

Mathew et al., A&A 2007

Wesolowsi, Walton & Chapman, Sol Phys 2008

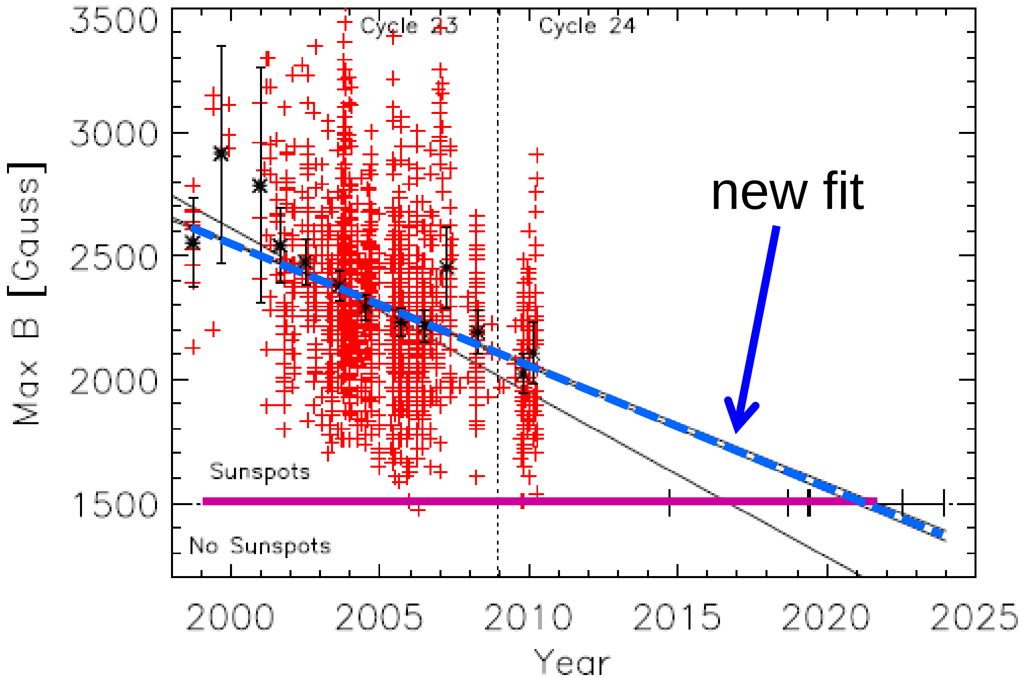
Watson & Fletcher, IAU Symp., 2010

Watson, Fletcher, & Marshall A&A 2011

Shad & Penn, Sol Phys 2010

Pevtsov et al., ApJ 2011

A New Maunder Minimum?



Penn & Livingston 2011

if

- linear trend continues
- sample is representative of mean properties of spots

↓

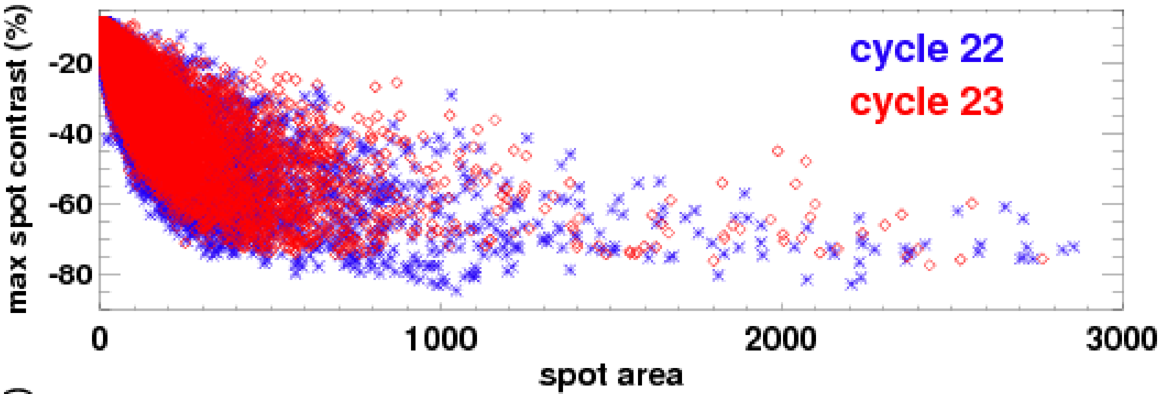
decrease of 65 Gauss per year

………….. sunspots will disappear by 2022

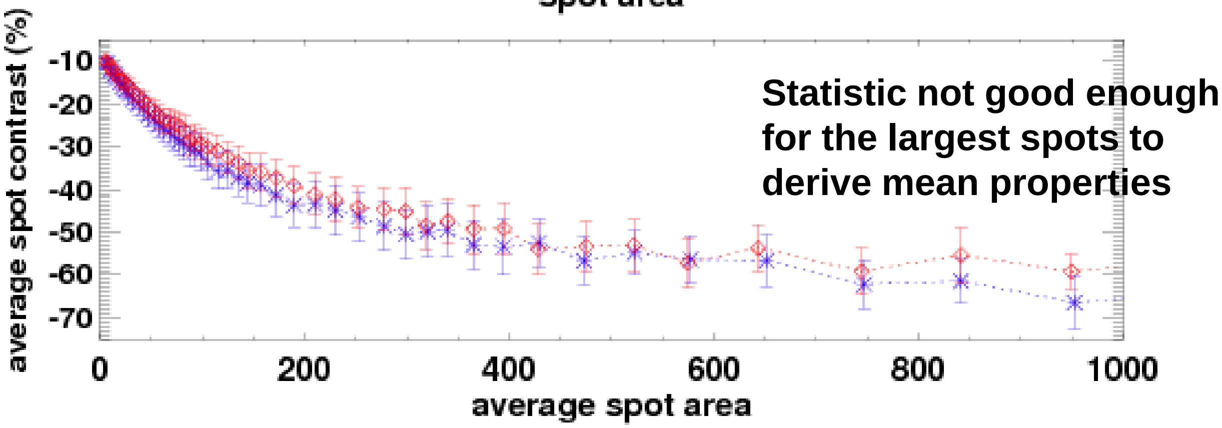
prediction: Cycle 24 peaks at ssn 65

Cycle 25 peaks at ssn 7 !!!

Spot Contrast vs. Spot Area



large variation in contrast for a given spot area

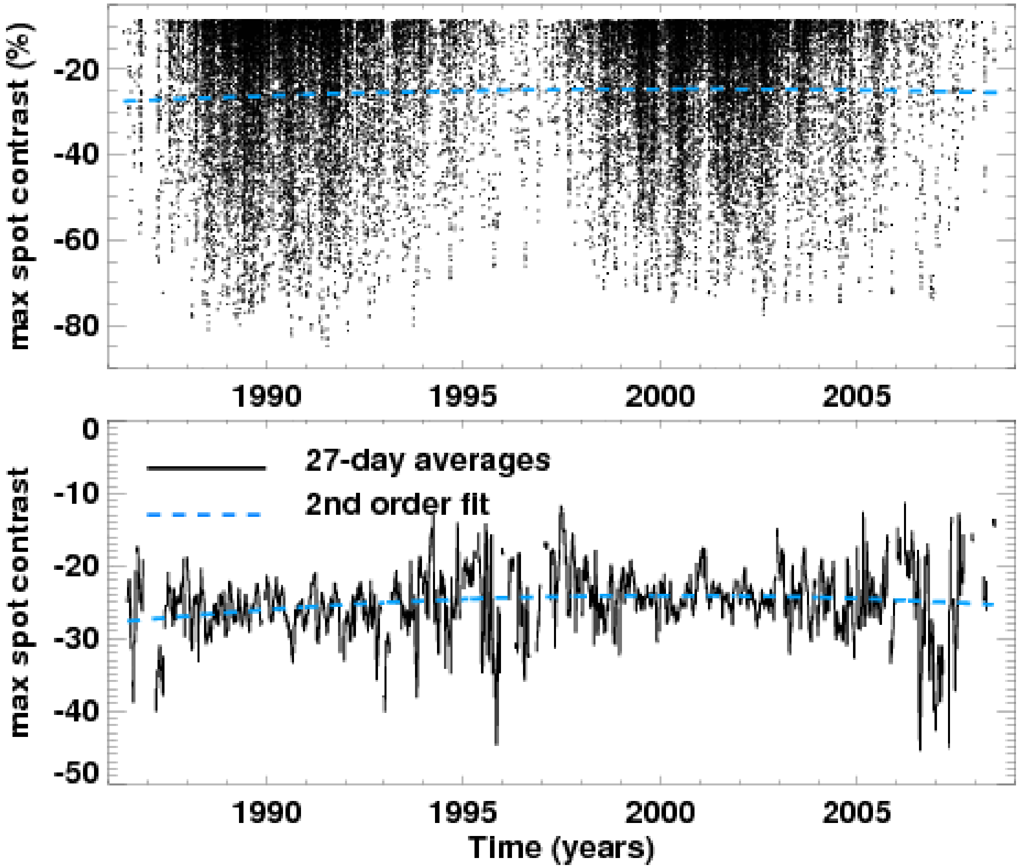


when data are averaged
nice correlation

Larger Spots are Darker than Smaller Spots

no significant differences between the two cycles

Sunspot Contrast as a Function of Time



all SFO spots
ca. 31000

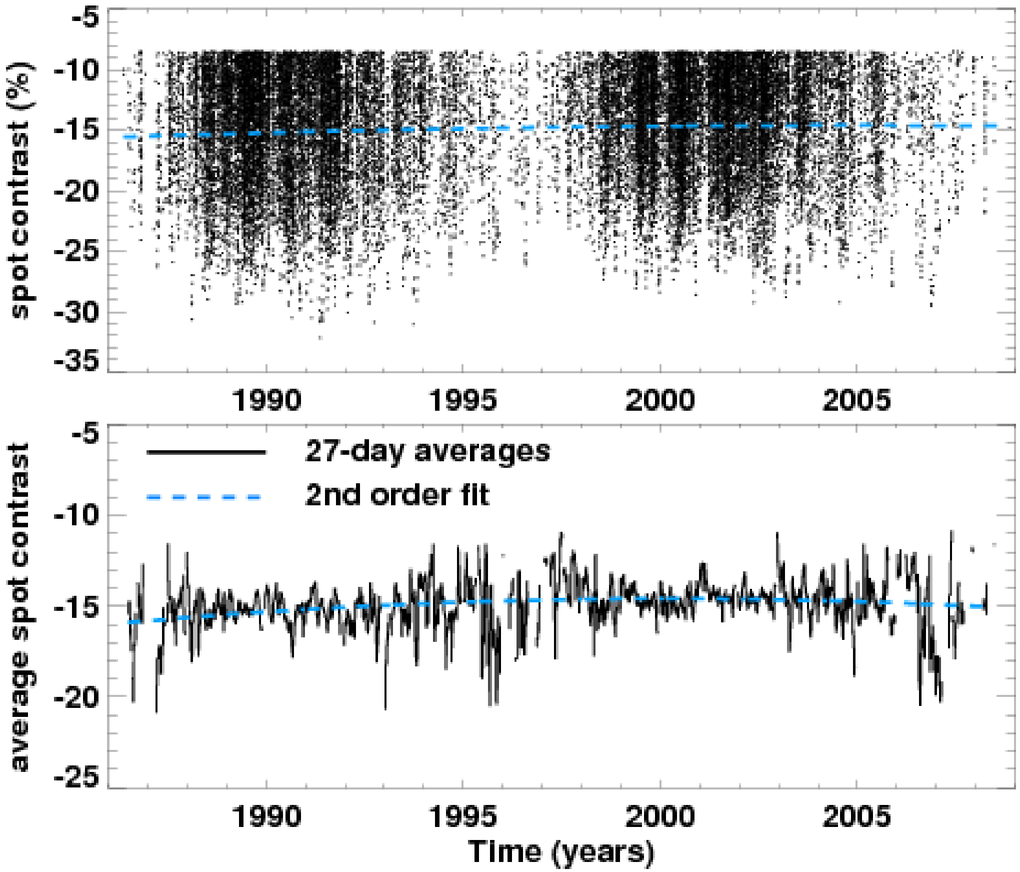
spots within 60º from disk center
27-day average
5 spots minimum
ca. 27000

Contrast in darkest pixel of each spot

No clear trend in spot contrast

No significant change in the mean spot contrast in cycle 23

Sunspot Contrast as a Function of Time



spots within 40°
from disk center
ca. 18500

27-day average
5 spots minimum

Average contrast of each spots

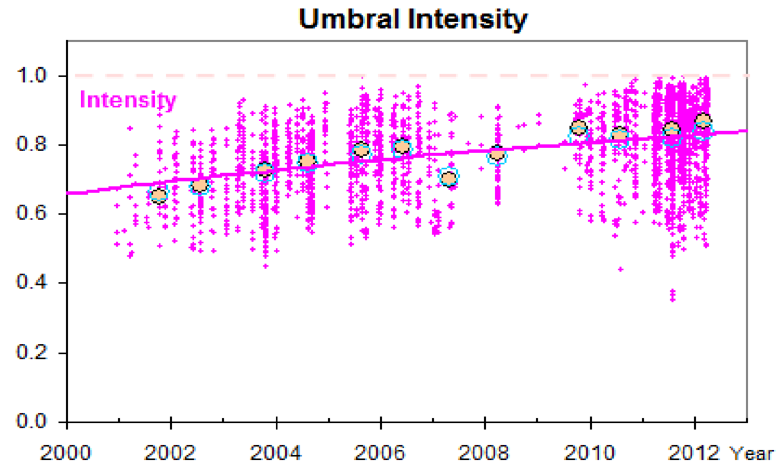
second-order fit gives a small increase in contrast of about 6% over 22 years, only about 2% over cycle 23

No significant change in the mean spot contrast in cycle 23

- **SFO results disagree with Livingston & Penn**

- **They reported a change of almost 2% a year in spot brightness for the period 1998-2006. We find less than 2% change over the entire cycle 23**

'Because of the nature of these observing program, the earlier measurements of this plot are probably skewed toward highest magnetic field values (larger spots), nonetheless the linear trend is clear even excluding all pre-1995 data.' (Livingston & Penn 2009)



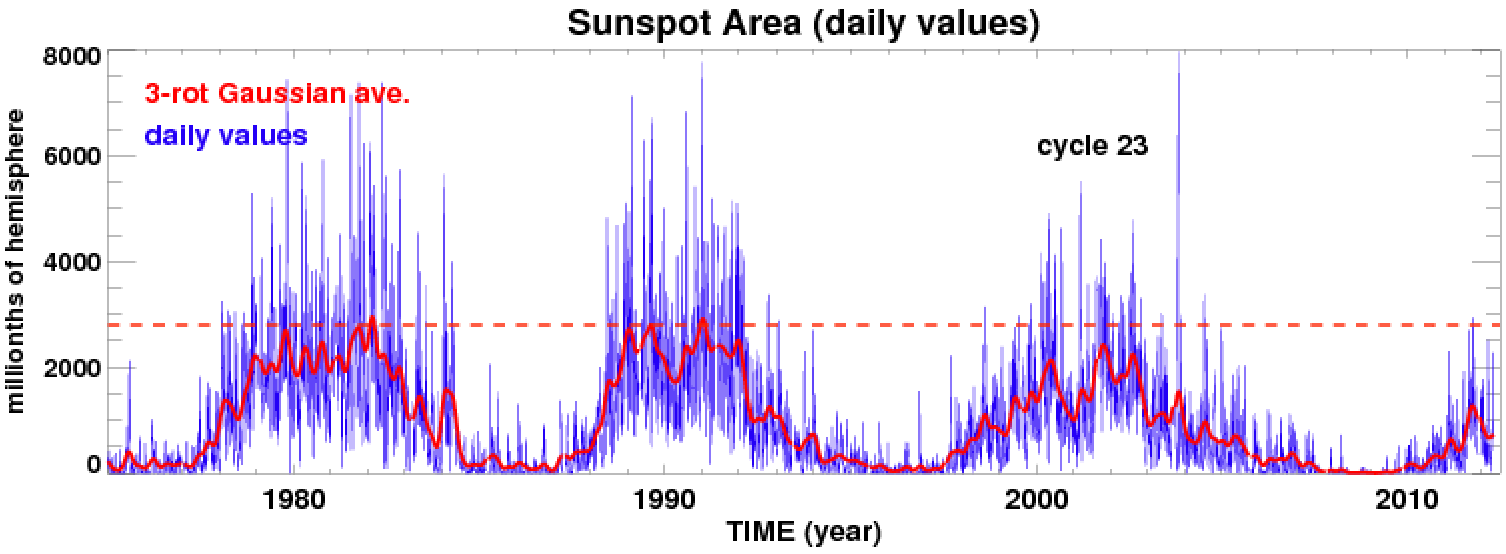
- **small-number statistics in Livingston & Penn dataset (~3000 data points vs. more than 30000 in SFO dataset) possible selection effects, i.e. if more small spots were included in recent times, this can explain the trend**

SUNSPOT AREA IN CYCLE 23

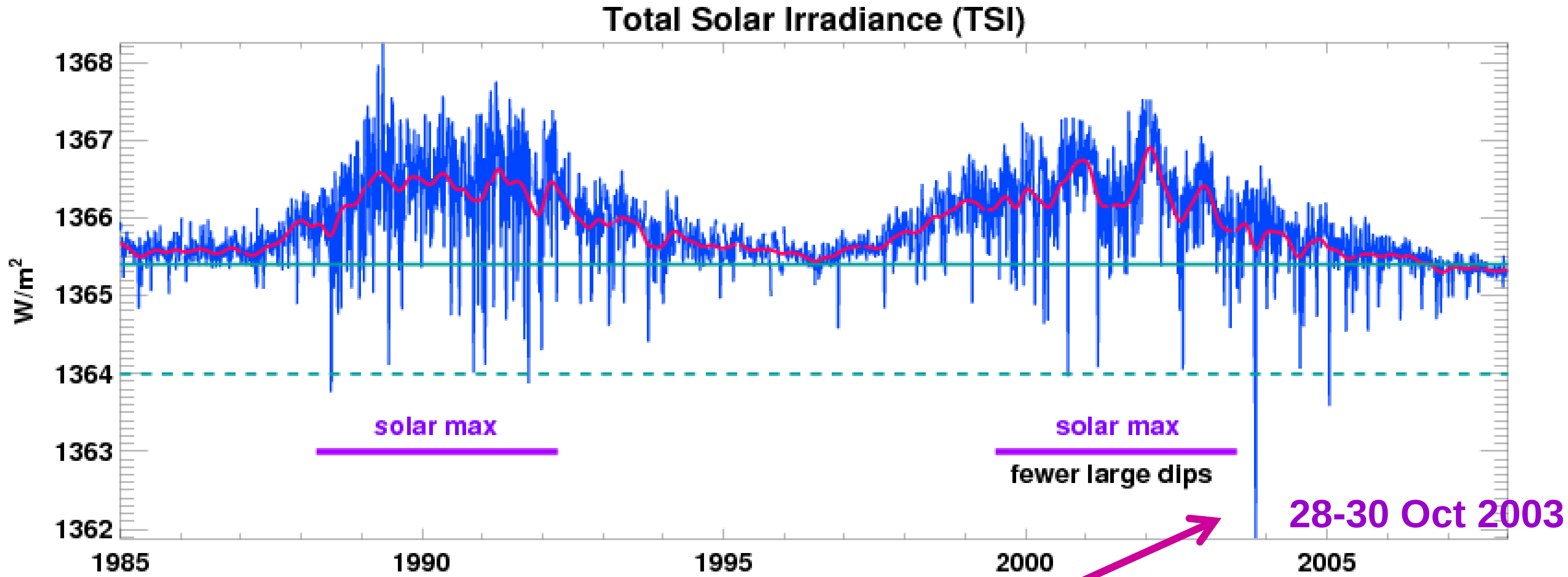
Kilcik et al. (2011) **claimed a *decrease in the number of small spots* from analysis of spot class and an *increase in large spots***

They called "small" spots: spots in classes A, B, C, H
"large" spots: spots in classes D, E, F, G
but morphological class # size
Lefevre & Clette (2011) **decrease in small spots only in classes A, B not C, *global deficit of small spots***

when spots are analyzed based on their size: the major difference between cycles 22 and 23 is in the frequency of very large spots



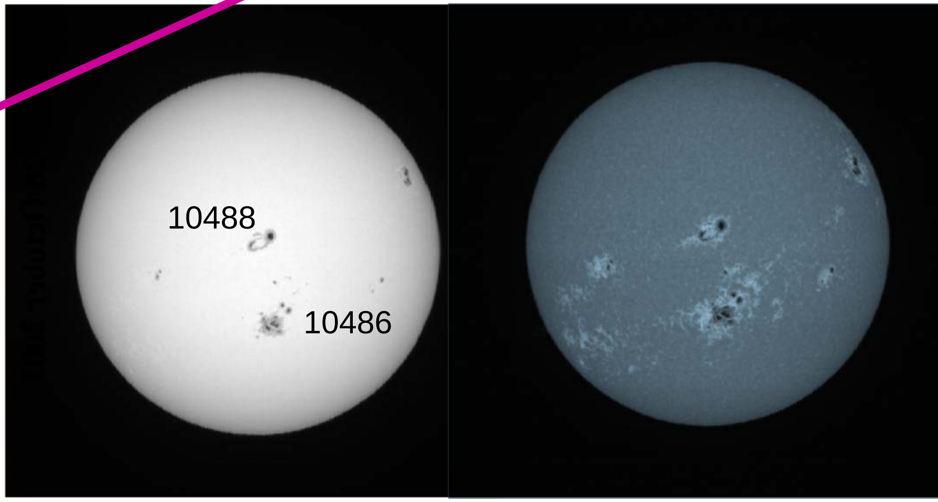
Lack of Large Spots Evident in the TSI record



de Toma et al. 2004

spot groups with area > 1400μhem
cycle 22: 30
cycle 23: 12

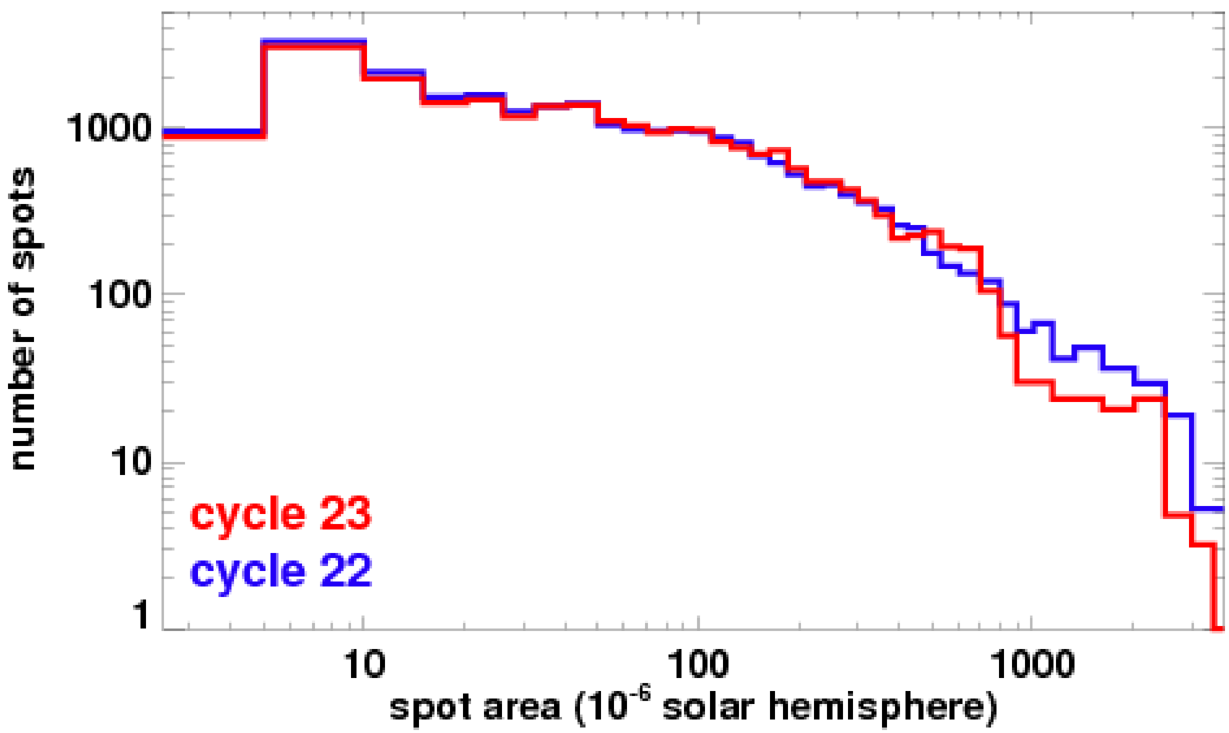
one noticeable exception:
AR 10484 (1750 μhem)
AR 10486 (2610 μhem)
AR 10488 (1750 μhem)
October-November 2003



SFO images October 2003

Are Small Spots Decreasing ???

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



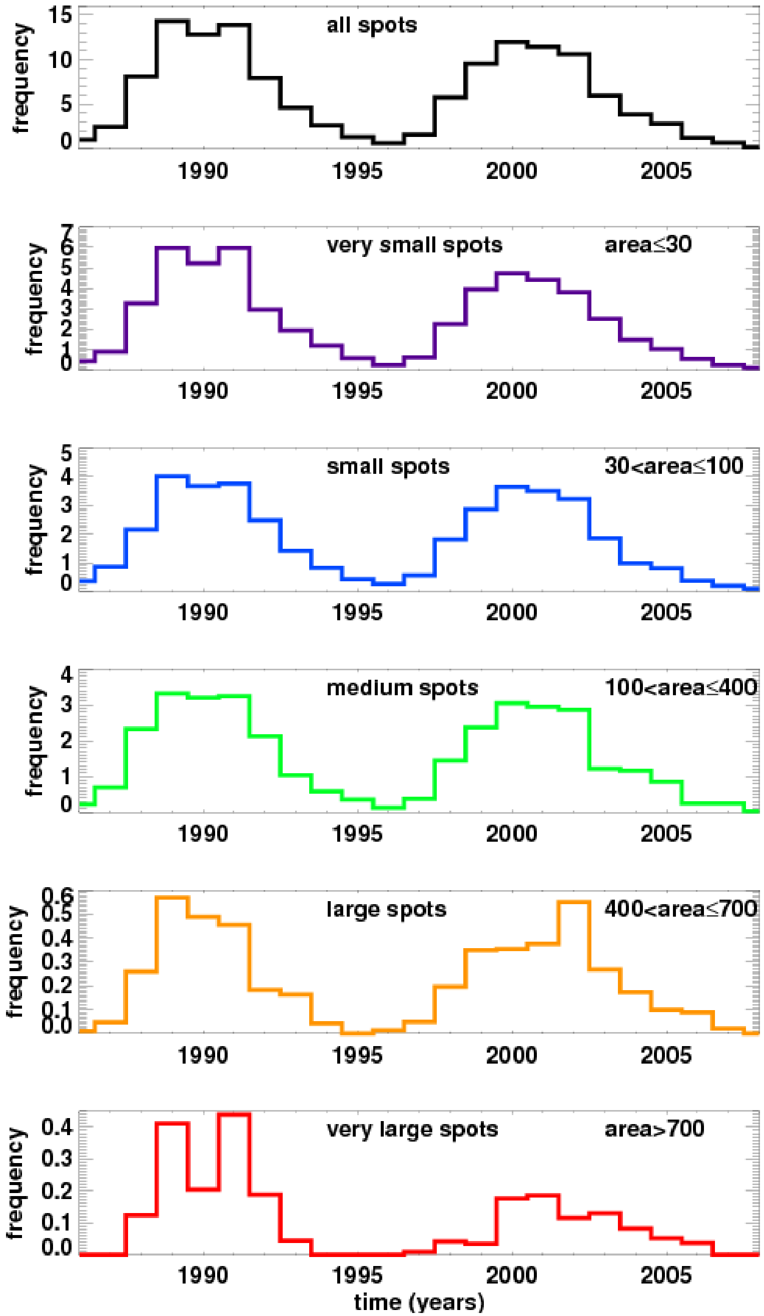
Cycle 22
Jul 1986-Dec 1996

Cycle 23
Jan 1997-Jun 2007

data corrected for duty cycle

the major difference between the two cycles is in the number of large and very large spots in the tail of the distribution
very large spots decreased by about 40% in cycle 23

Sunspot Frequency



- decrease of ~25% in the number of the very small spots with area < 30 μhem in 2000-2002 in agreement Lefevre & Clette (2011)

- no large differences between the two cycle maxima for the number of small spots and medium spots

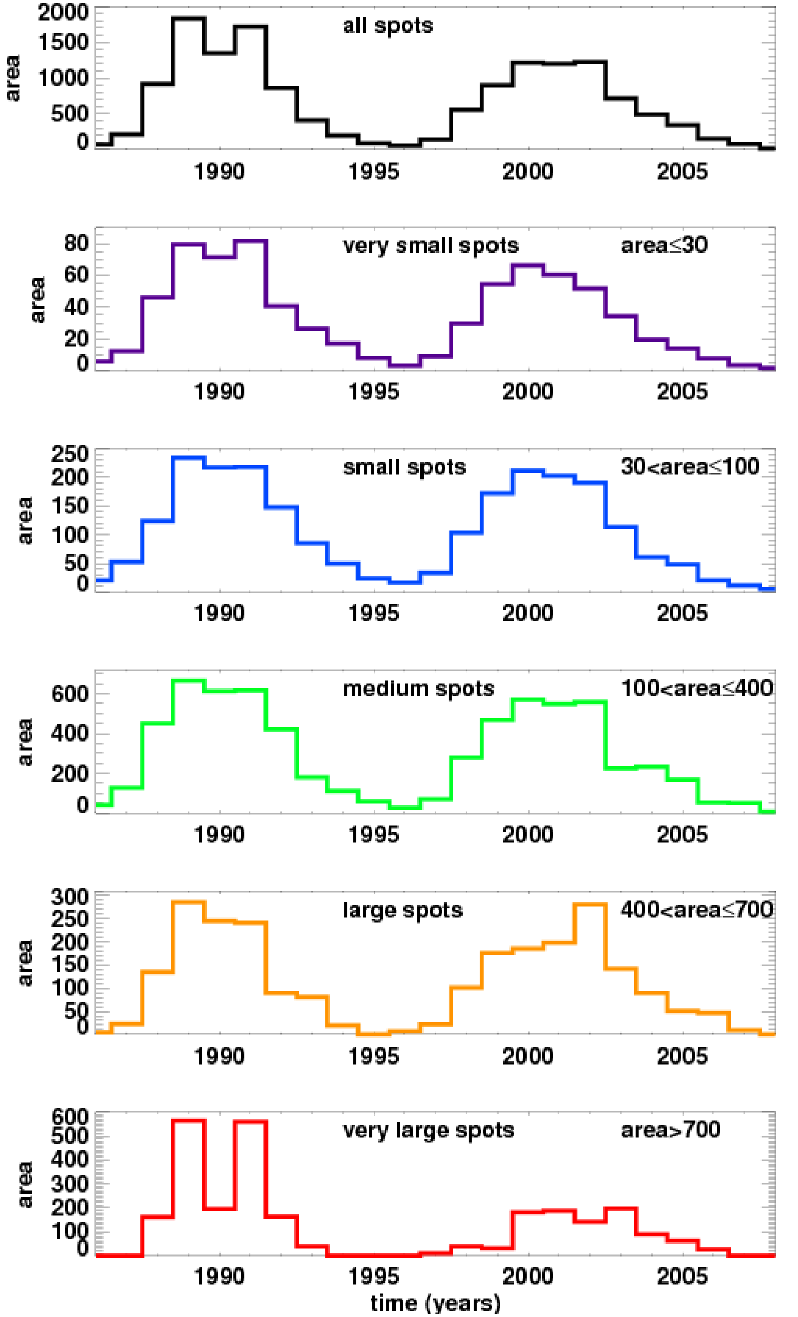
- large difference in the large and especially the very large spots both in the frequency and timing of appearance

- number of spots with area > 700 μhem less than half the number during cycle 22 maximum

Variation in Sunspot Area

decrease in total sunspot area cycle 23 maximum

- the decrease in the large and very large spots accounts for over 60% of the decrease in total sunspot area during the maximum of cycle 23, the very large spots alone for 46%
- medium spots accounts for about 25%
- decrease in small spots does not contribute much to change in total sunspot area, less than 4%, i.e. is an order of magnitude smaller than the effect of the very large spots



NOAA/USAF Spot groups

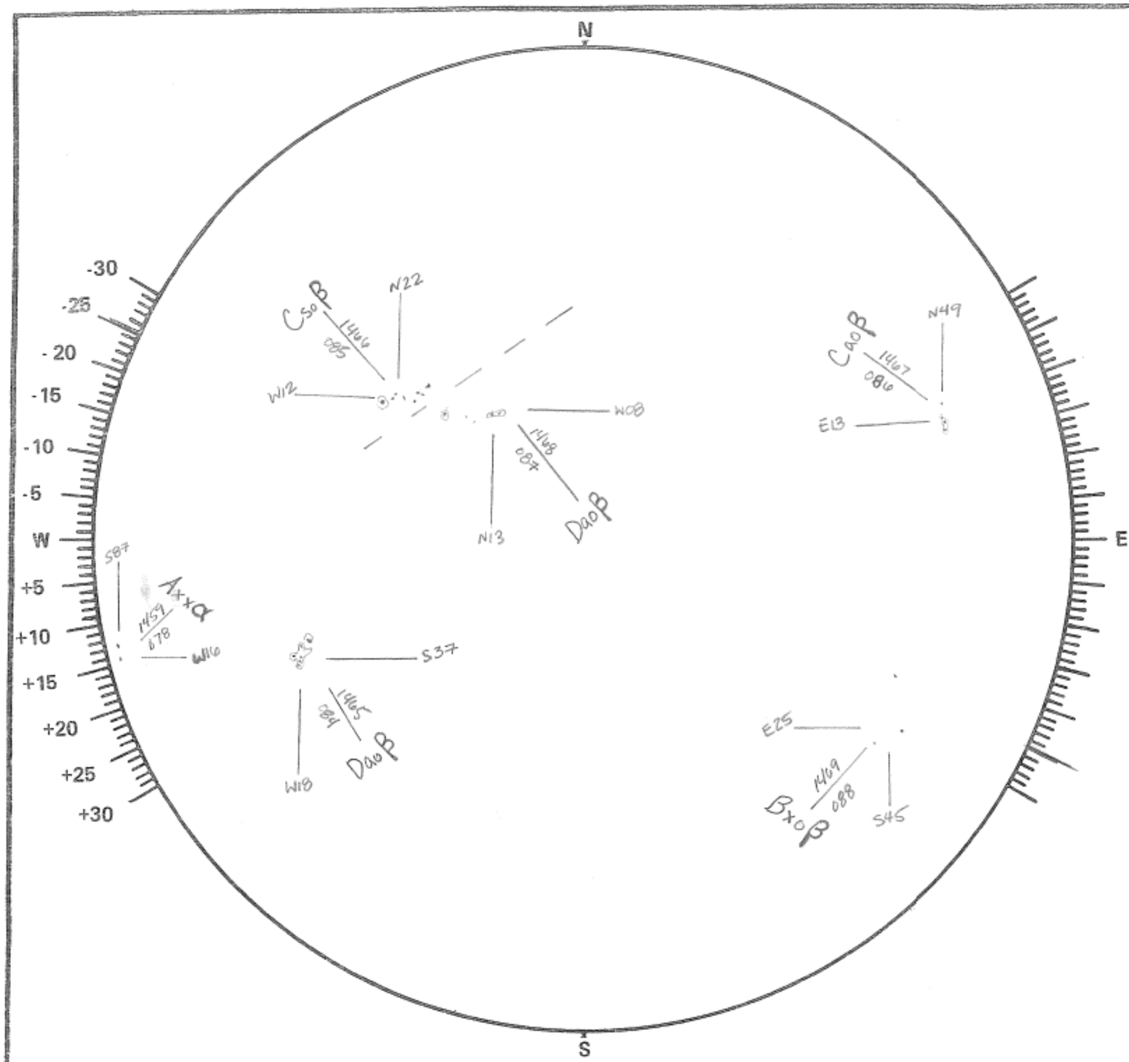
The USAF/SOON network consists of identical telescopes located within USAF bases has provided areas for sunspot groups since 1976

The number of stations decreased during the years. Data are currently taken at 3 locations: Holloman (USA), San Vito (Italy), and Learmonth (Australia)

Spot group hemispheric areas are derived from sunspot drawings made by rotating military personnel, using a visual fit to template ellipses of fixed size and correction for projection is based on a set grid whose steps are in increments of 10%. Errors in hemispheric areas are typically 10% or larger

Advantage of no data gaps

Example of USAF sunspot drawing



ANALYST: SSGT MULLINS / MR. PIETRZAK

DATE: 26 APR 12 | TIME: 1916 | QUALITY: GOOD

Bp: -4.55 | Po: -24.75 | Lo: 18.43 | NO GROUP: 06

NO SPOTS: 28 | R = 88

HQ AXXX63 KHMR 262105

SPOTS

72265 (IIIII) 20426 (YMMDD) 31916 (3HHMM) 43406 (4TQNN)

11111	22JJJ	QXXYY	LLAAA	//NNN	6ZPCM	9NNNN
11111	22 085	42212	07011	// 008	6 3272	9 1466
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
11111	22			//	6	9
11111	22			//	6	9
11111	22			//	6	9
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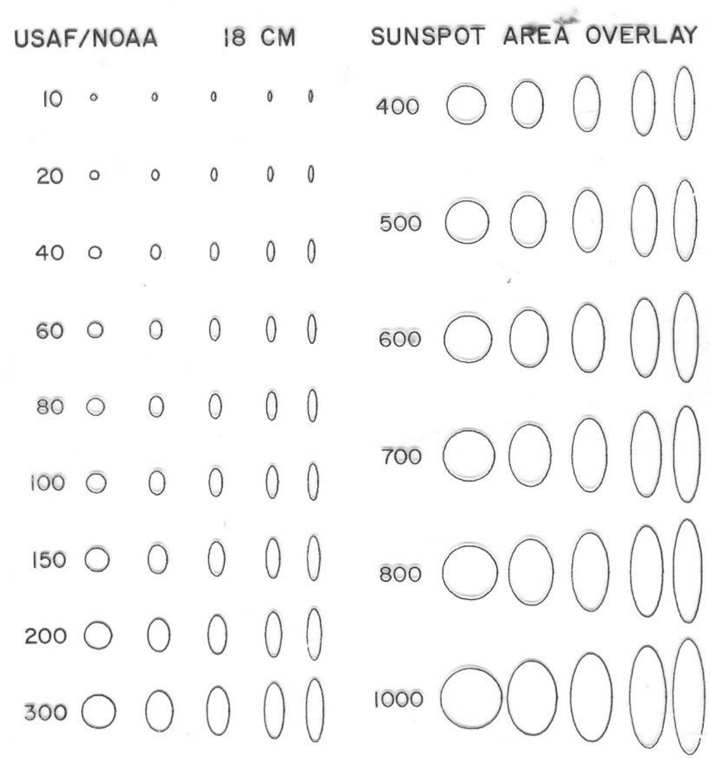
11111	22			//	6	9
11111	22			//	6	9
11111	22			//	6	9
11111	22			//	6	9

START 1913

AFWA Form 21, May 00

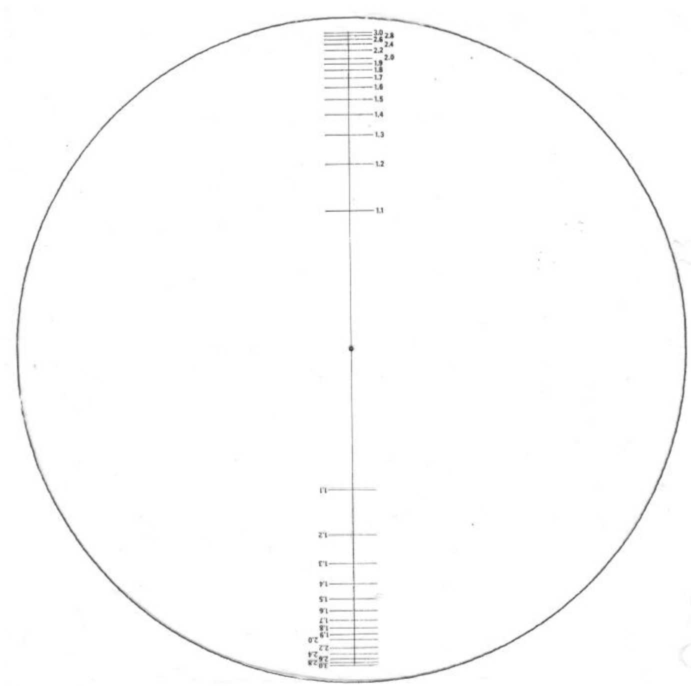
SUNSPOT ANALYSIS WORKSHEET

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



overlay for area estimate

overlay to correct for projection



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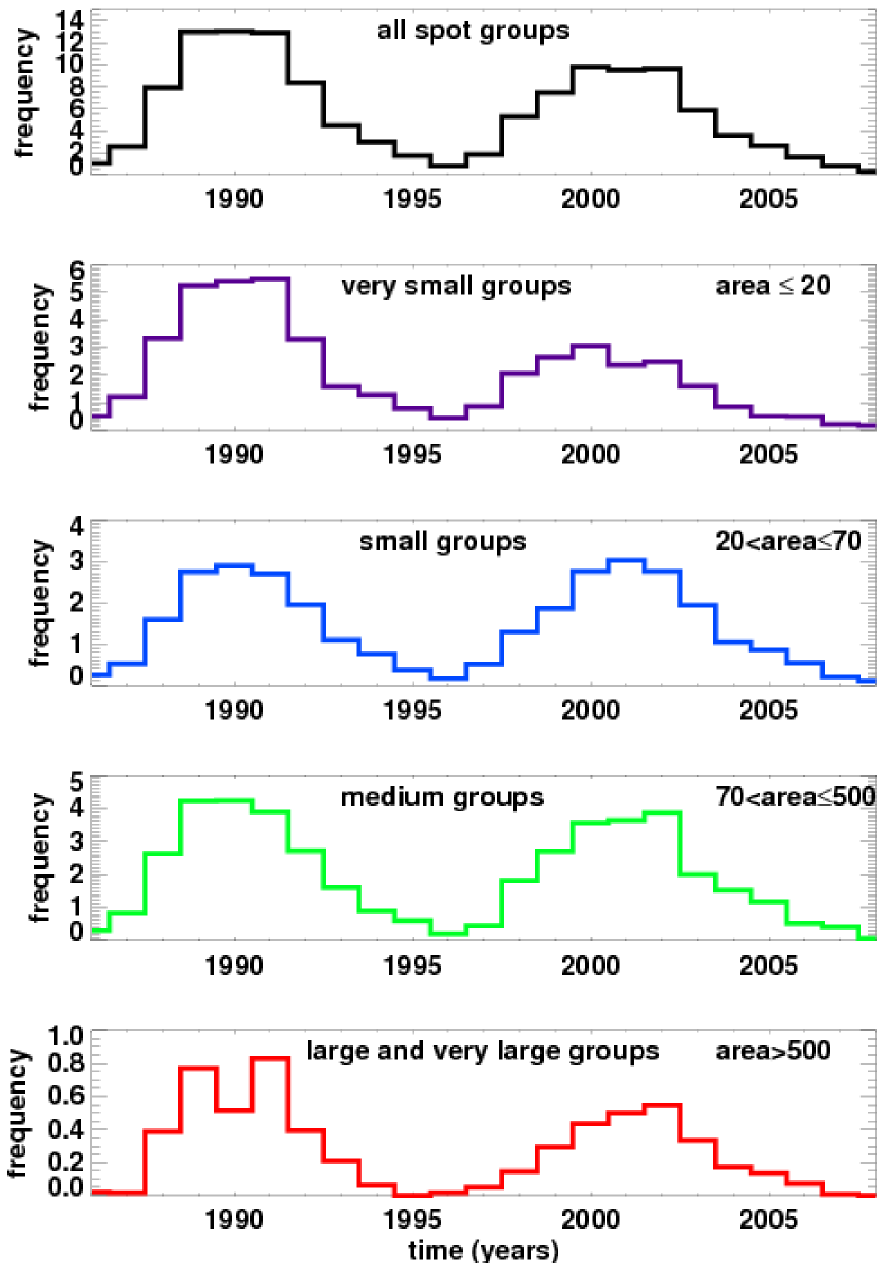
Advantage of no data gaps

NOAA/USAF dataset



weighted average from all available USAF stations

USAF spot group area are smaller than SFO group area by about 35% for small groups

- **decrease in very small spots of about 50%during cycle 23 maximum, larger than in SFO data**
- **decrease in the large and very large spots**

Contribution to total sunspot area variation

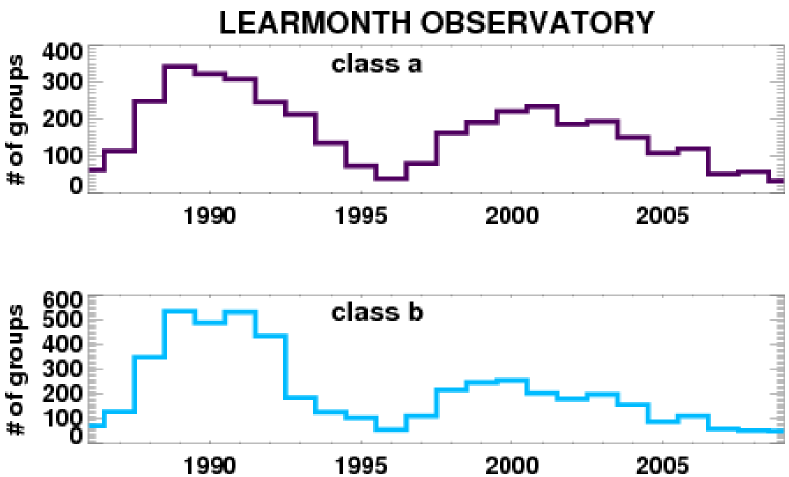
AREA	Cycle 22 max 1989-1991	Cycle 23 max 2000-2002	Difference Cycle 22 – 23
all	1850230	1343538	506692
very small	59340	34708	24632
small	142770	146790	-4020
medium	871360	739880	131480
large & very large	776760	422160	354600

- large and very large spots accounts for 70% of the deficit in total sunspot area during the maximum of cycle 23
- medium spots contribute about 26%
- very small spots for less than 5%

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

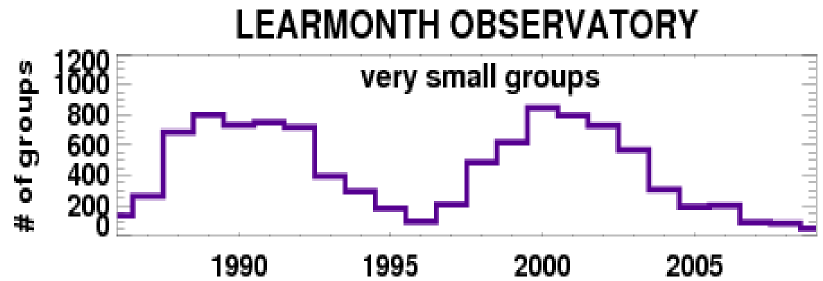
- **different number of observatories:**

Boulder stops in 1994
Paleuha stops in 1997
Ramey stops in 2003



(used in Kilcik et al 2011)

decrease in simple spots group also seen in Holloman & San Vito



Learmonth does not show a clear decrease in small spots Holloman and San Vito do

- **difference among observatories**

- **very small spots more subject to seeing conditions and reports of small spots/pores can vary from observer to observer**

SFO dataset more consistent for small spots than the NOAA/USAF

SUNSPOT AREA IN CYCLE 23

- remarkable decrease in the number of large and very large spots in cycle 23

- decrease in these larger spots accounts for more than 60% of the decreased observed at solar maximum in total spot area

- difference in the number of small spots in cycle 23 is unclear (conflicting results from different observatories)

- decrease in small spots during maximum of cycle 23 but not important for total sunspot area or total solar irradiance

EXTRA SLIDES

morphological class appears to be more subjective than area

11980403	0055	S31W56	A	8192	HS	1	1	20	980329.7	980329.6	064	3LEAR
11980403	0650	S33W59	B	8192	BXO	3	5	20	980329.7	980329.6	058	3SVTO
11980403	1716	S32W66	A	8192	AX	1		10	980329.6	980329.6	066	3HOLL
11980228	0019	S26W22	B	8167	CSO	5	8	20	980226.3	980226.3	///	4LEAR
11980228	0720	S25W27	B	8167	DRO	3	9	20	980226.2	980226.3	034	3SVTO
11980228	1453	S26W27	B	8167	BXO	3	3	10	980226.5	980226.3	042	3HOLL
11020623	0010	S11W01	B	10010	DRO	5	4	30	020622.9	020622.9	273	3LEAR
11020623	0550	S11W06	A	10010	HRX	2		0	020622.8	020622.9	246	3SVTO
11020623	1240	S11W10	B	10010	BXO	9	4	30	020622.8	020622.9	284	3RAMY
11020623	1327	S12W08	B	10010	CSO	4	4	30	020622.9	020622.9	287	2HOLL
11031023	0245	S06E33	B	10485	BXO	2	1	10	031025.6	031025.3	862	3LEAR
11031023	1332	S08E27	B	10485	CRO	2	2	10	031025.6	031025.3	235	2SVTO
11031023	1500	S08E26	A	10485	HSX	2	2	10	031025.6	031025.3	323	3HOLL
11060906	0427	S14E41	B	10907	BXO	2	9	10	0609 9.3	0609 9.3	081	3LEAR
11060906	0620	S13E38	A	10907	HRX	1	1	10	0609 9.1	0609 9.3	058	3SVTO
11060906	1730	S13E35	B	10907	CSI	10	7	40	0609 9.4	0609 9.3	082	4HOLL

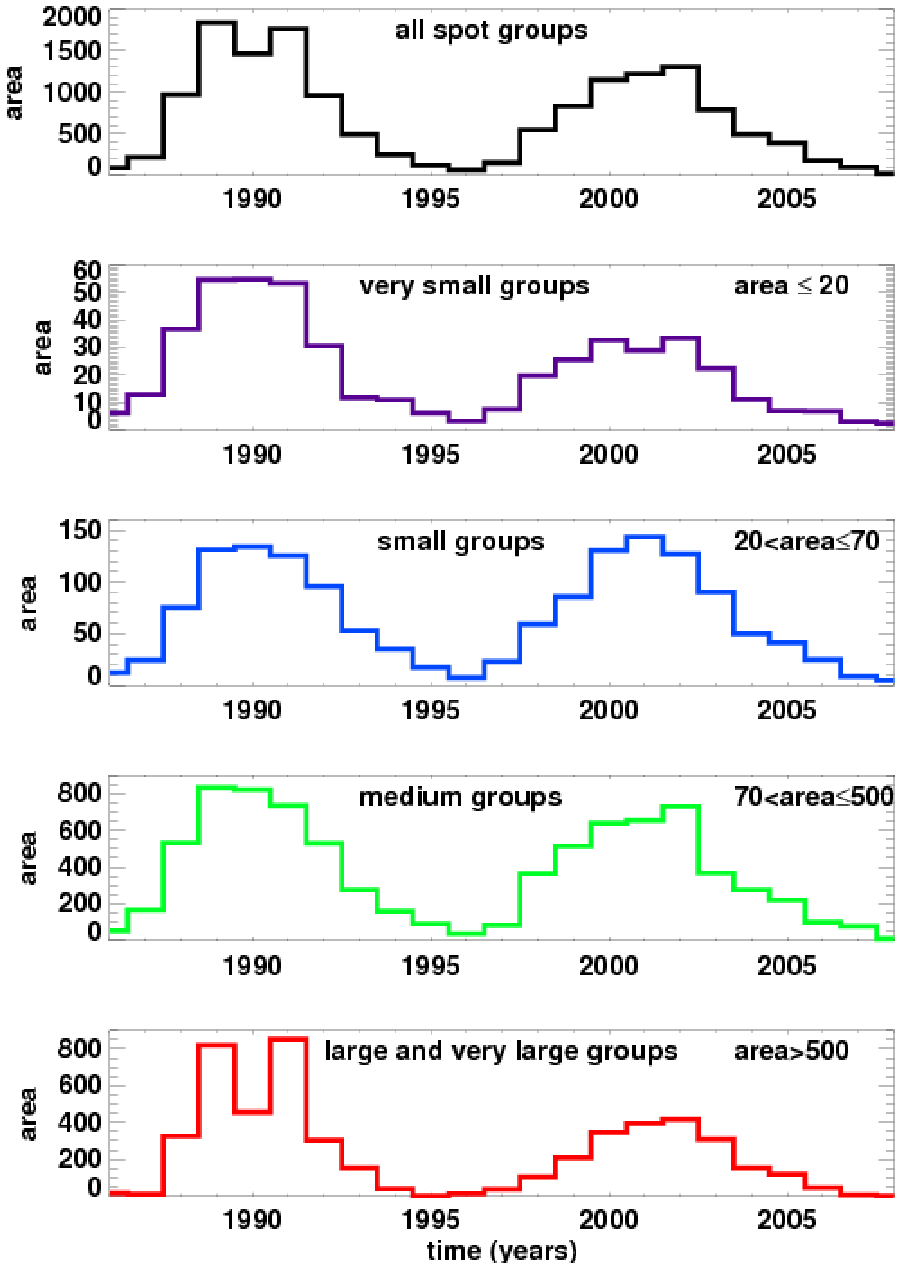
NOAA/USAF dataset

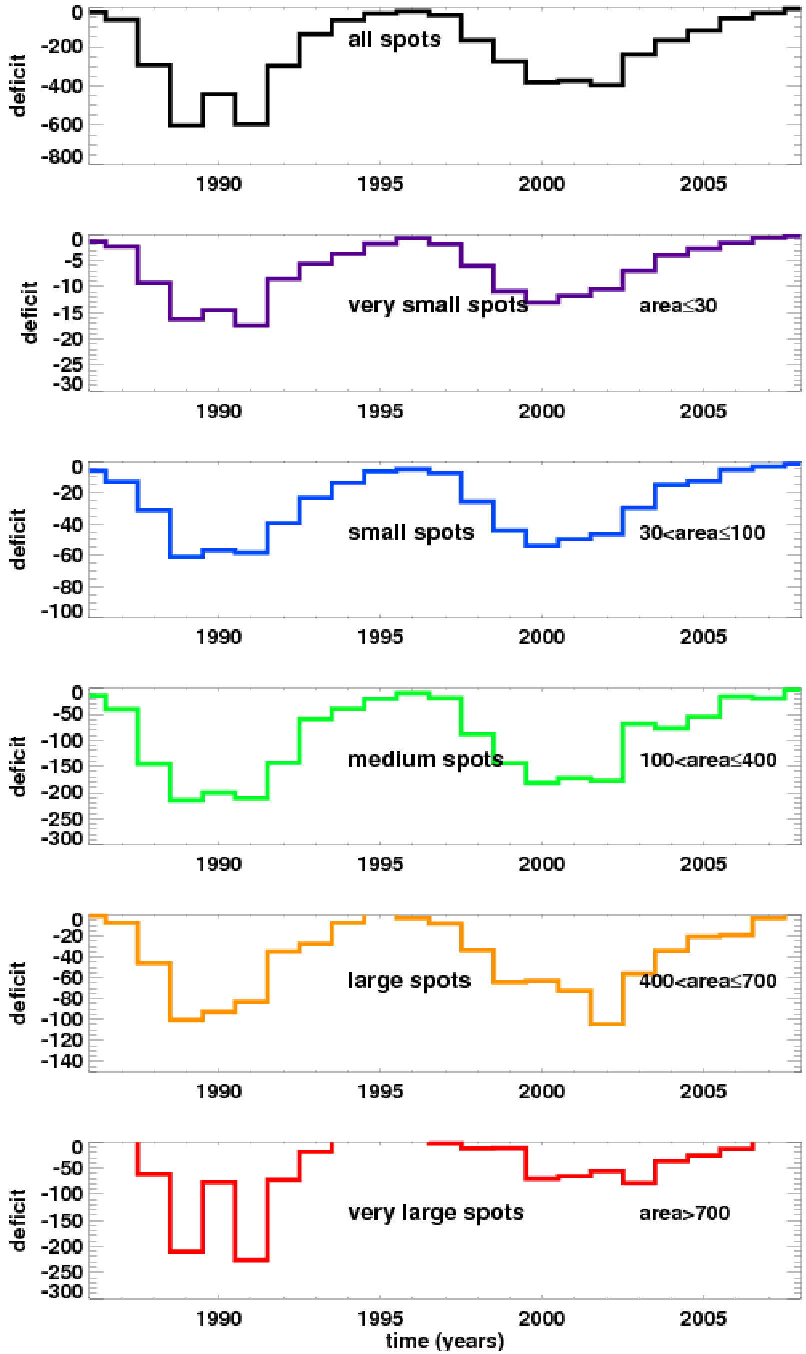
decrease in total sunspot area of about 35%

- **the decrease in the large and very large spots accounts for about 70% of the decrease in total sunspot area during the maximum of cycle 23**

- **medium spots accounts for about 26%**

- **decrease in very small spots contributes less than 5% to the change in total sunspot area**

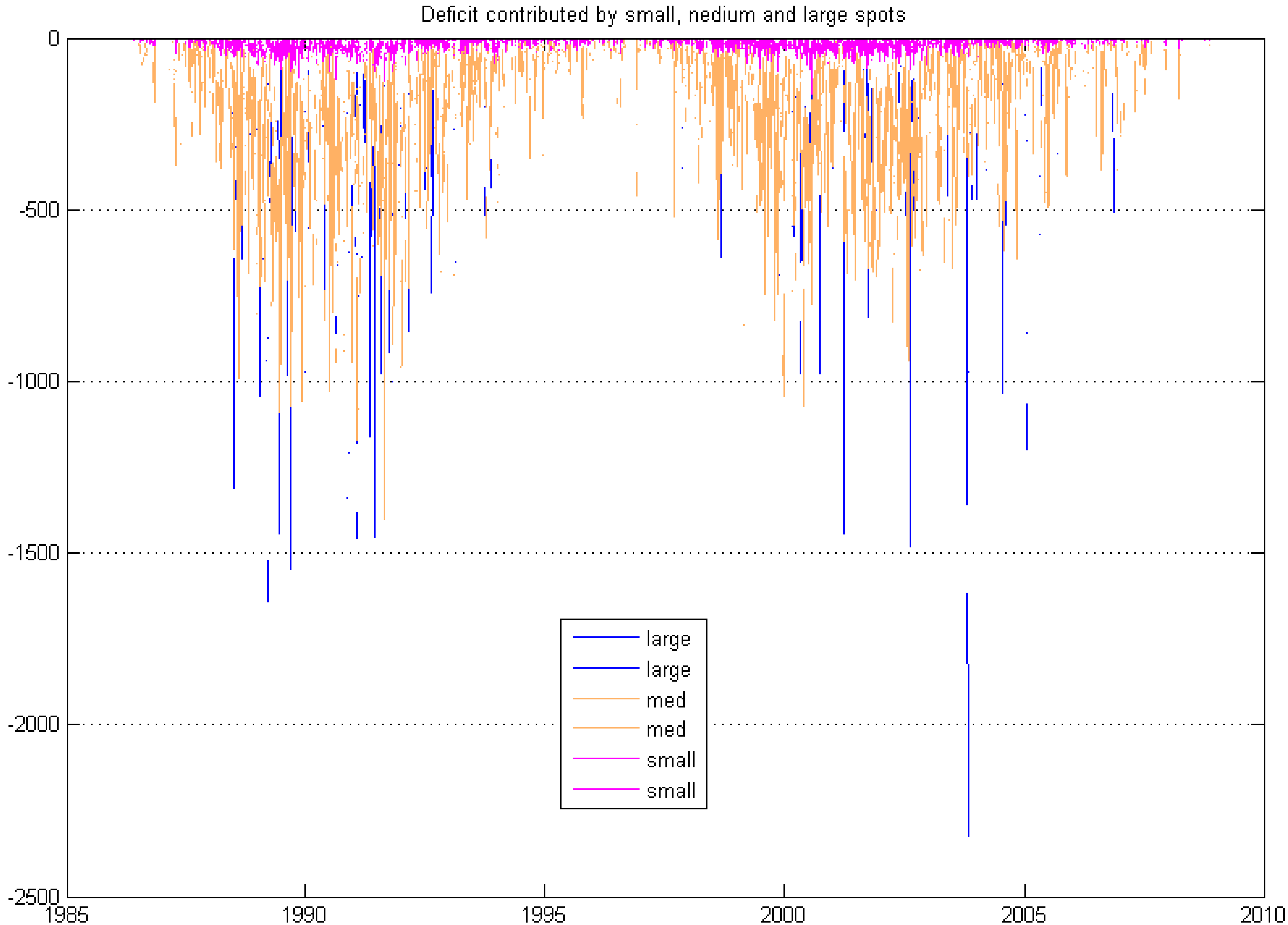




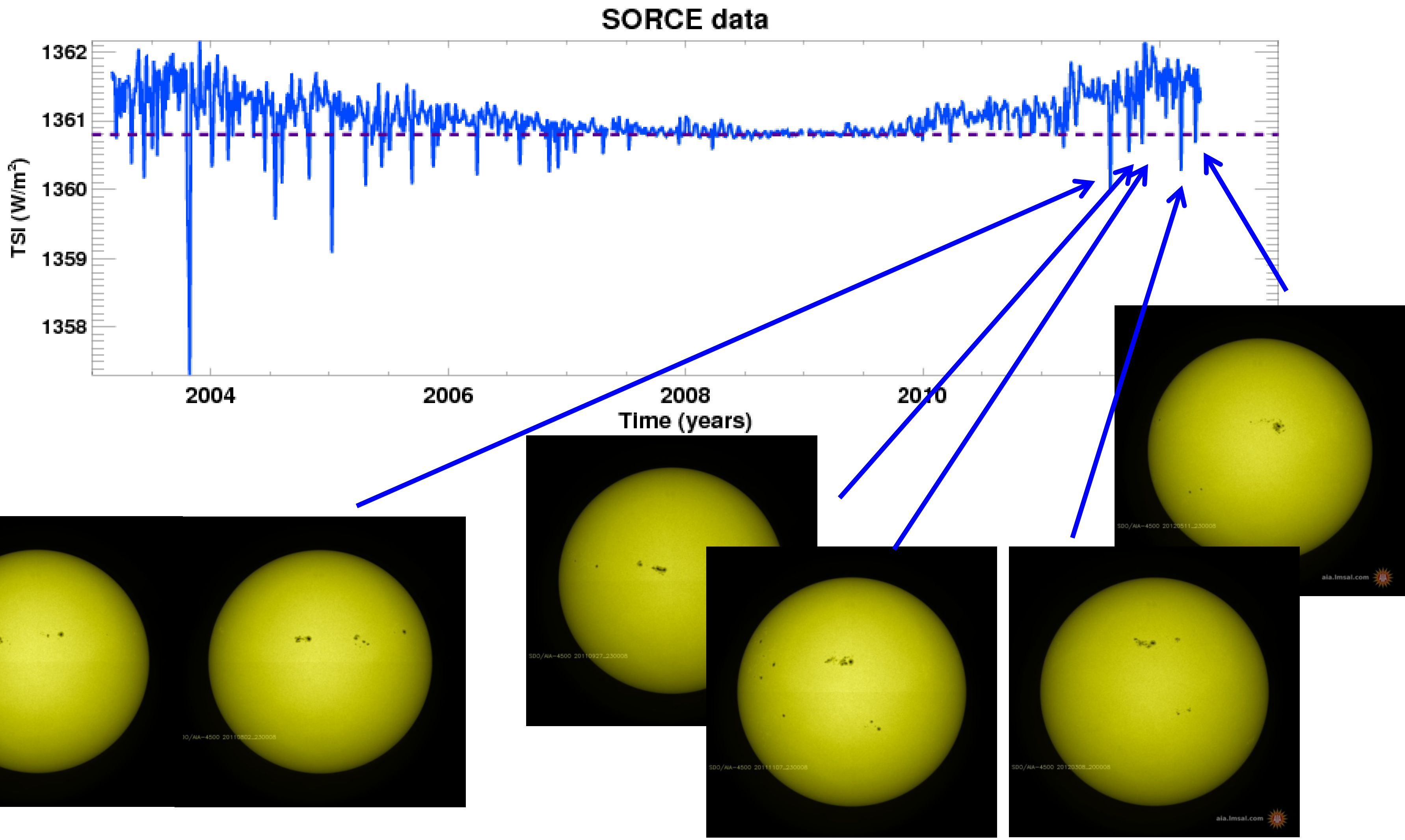
Sunspot Deficit

The changes in TSI are dominated by the very large spots, because of their size/contrast

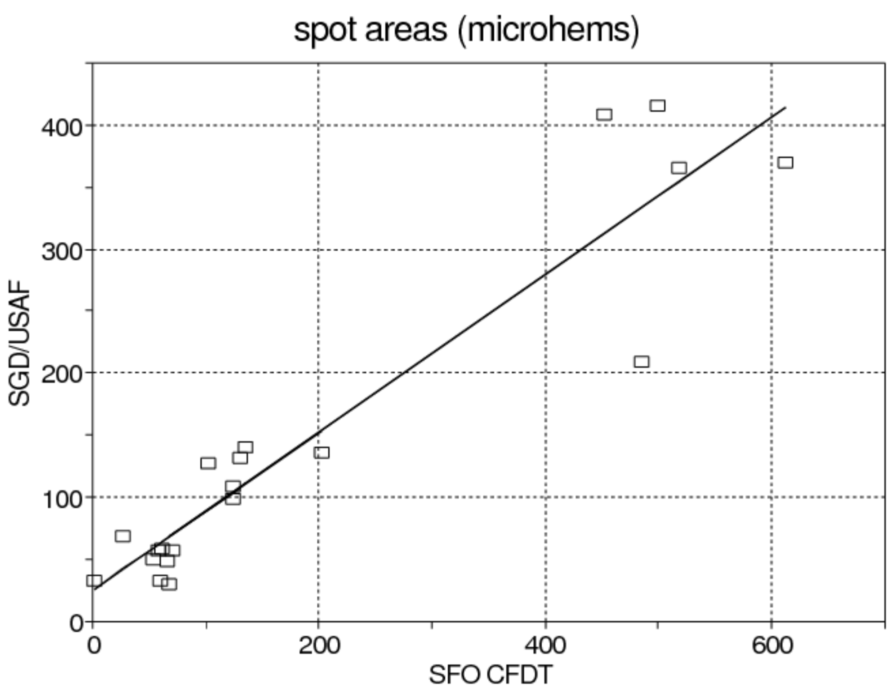
The second larger contributor are medium spots because of their number/size

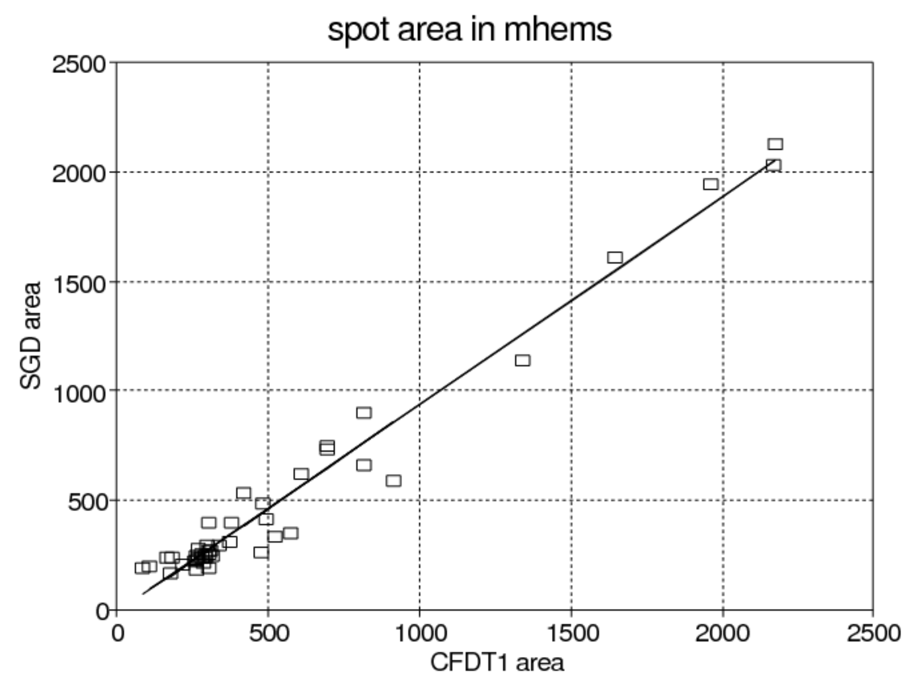

Deficit contributed by small, nedium and large spots
0
-500
-1000
-1500
-2000
-2500
1985
1990
1995
2000
2005
2010
large
large
med
med
small
small

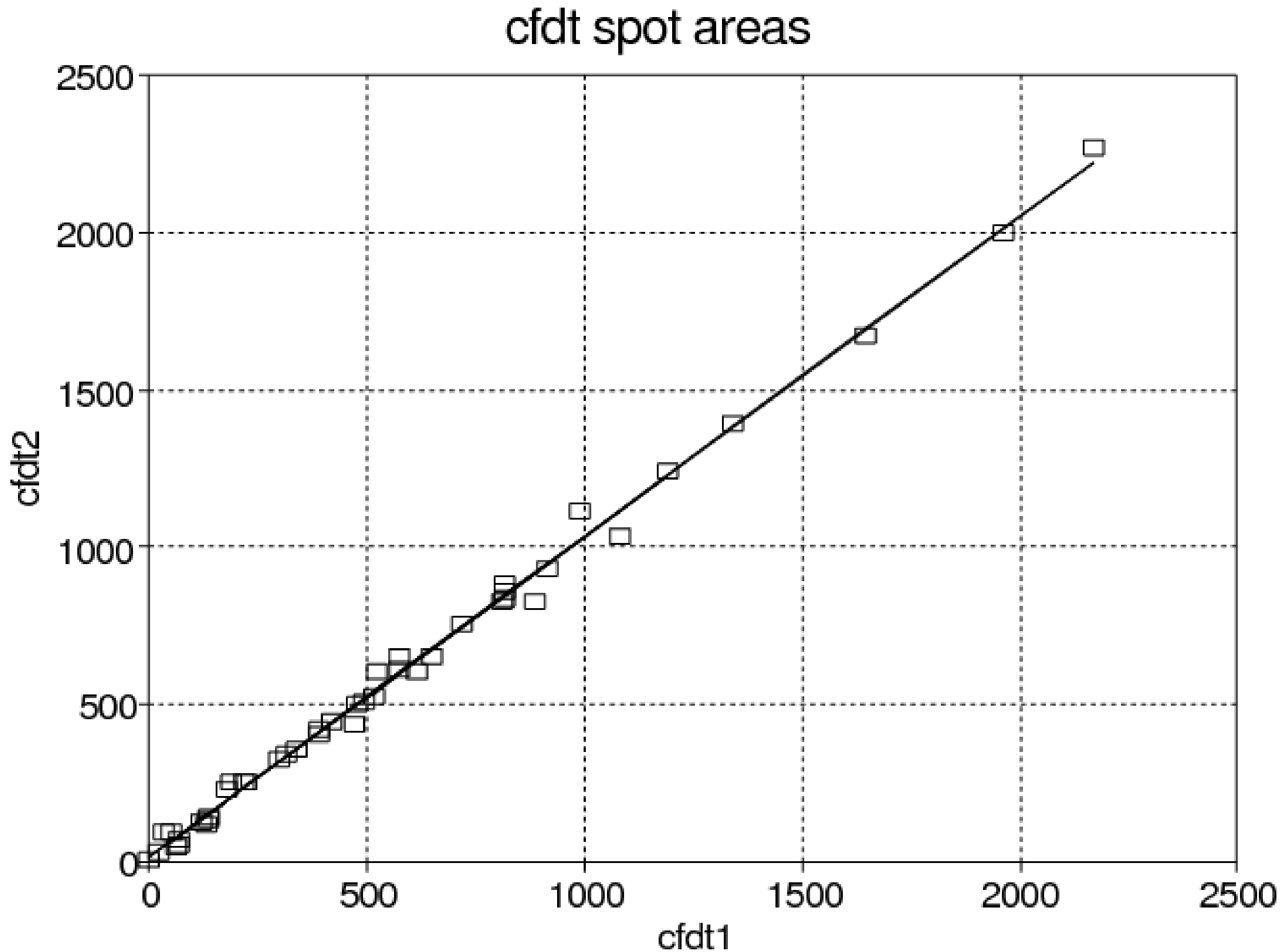
Recent TSI record - Cycle 24



Only 7 spot groups larger than 700 μhem in cycle 24

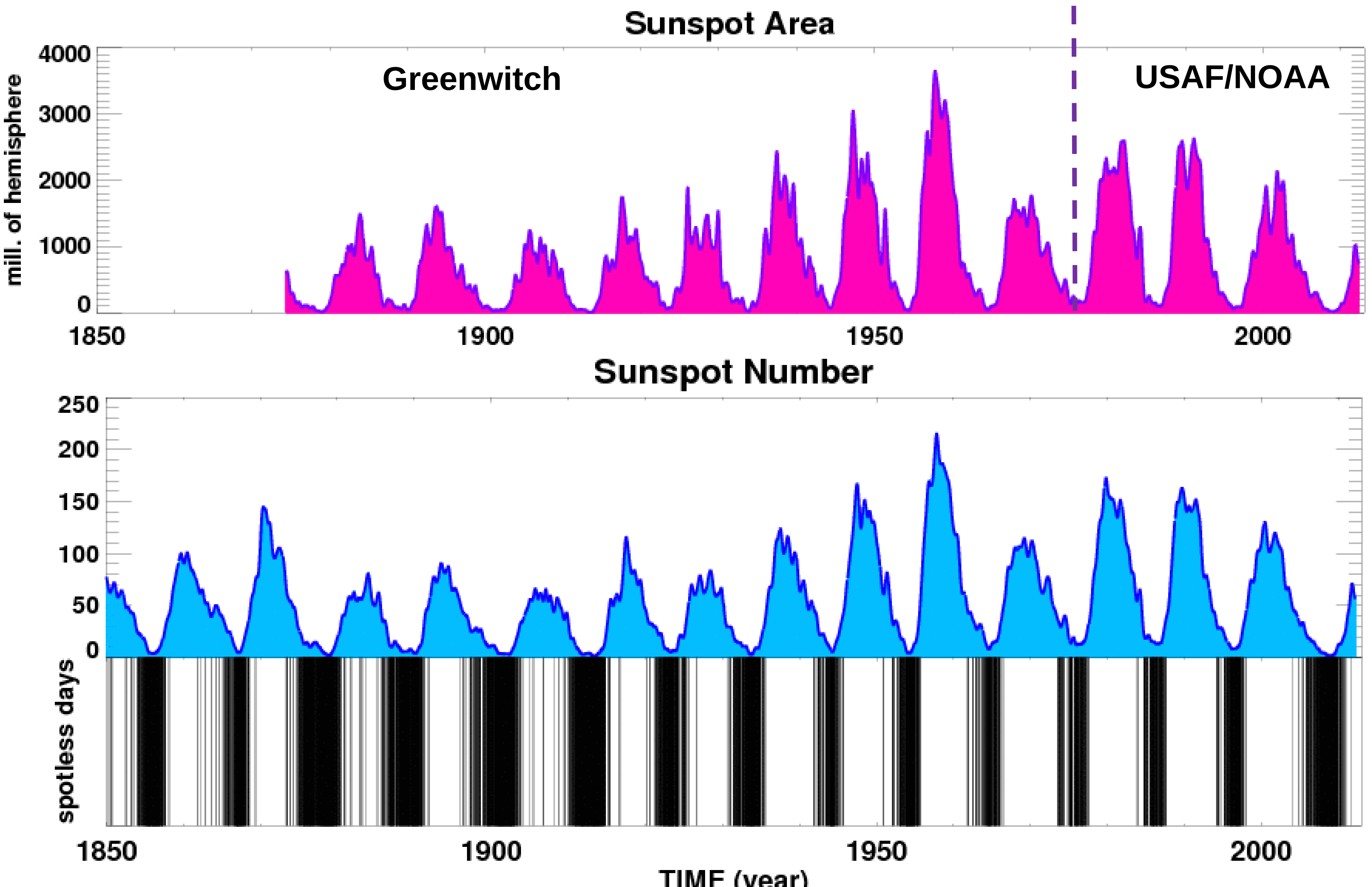

spot areas (microhems)
SGD/USAF
SFO CFDT
0
100
200
300
400
0
200
400
600


spot area in mhems
SGD area
CFDT1 area
0
500
1000
1500
2000
2500
0
500
1000
1500
2000
2500


cfdt spot areas
2500
2000
1500
1000
500
0
cfdt2
0
500
1000
1500
2000
2500
cfdt1

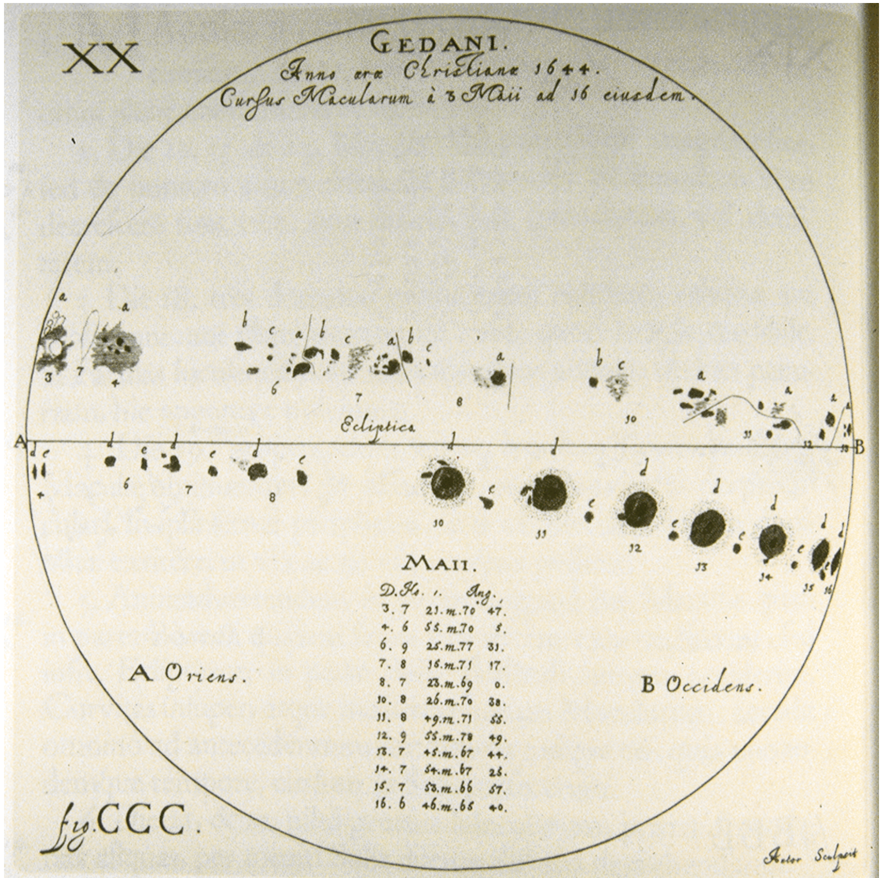
r = 0.997

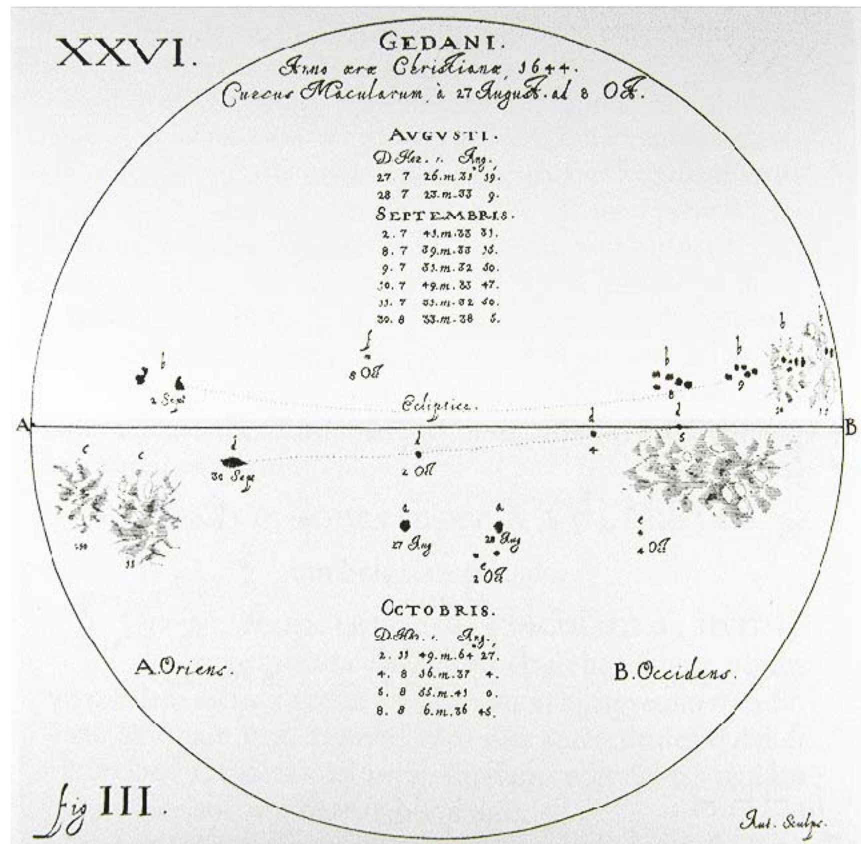
WAS CYCLE 23 UNUSUAL?



Minimum before the Maunder Minimum had several cases of large spots

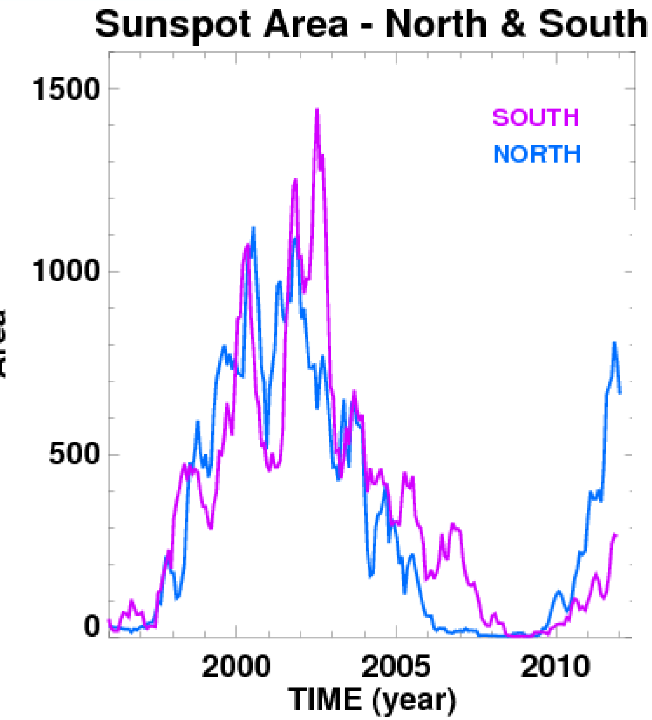
very different from the recent minimum



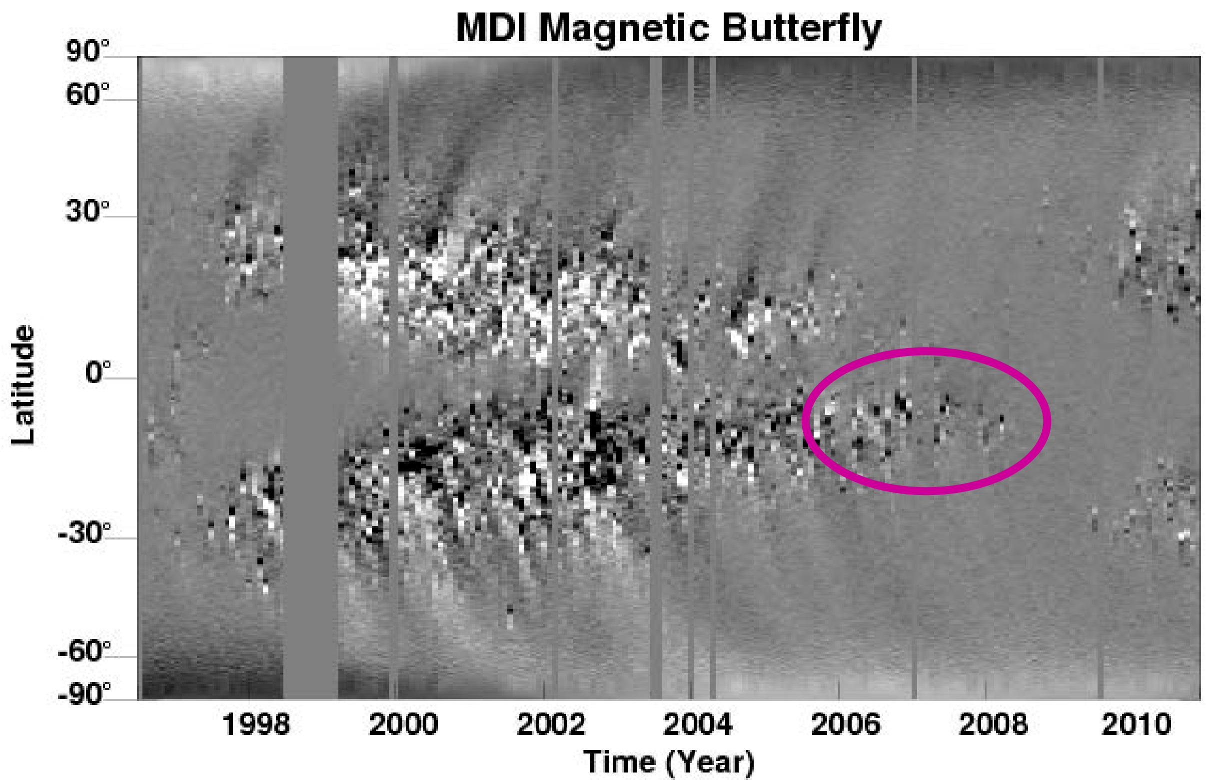


Hevelius drawings in 1644

HEMISPHERIC ASYMMETRY



	N	S
2005	136	251
2006	14	162
2007	9	86
2008	4	13
2009	13	6
2010	108	45
2011	402	134

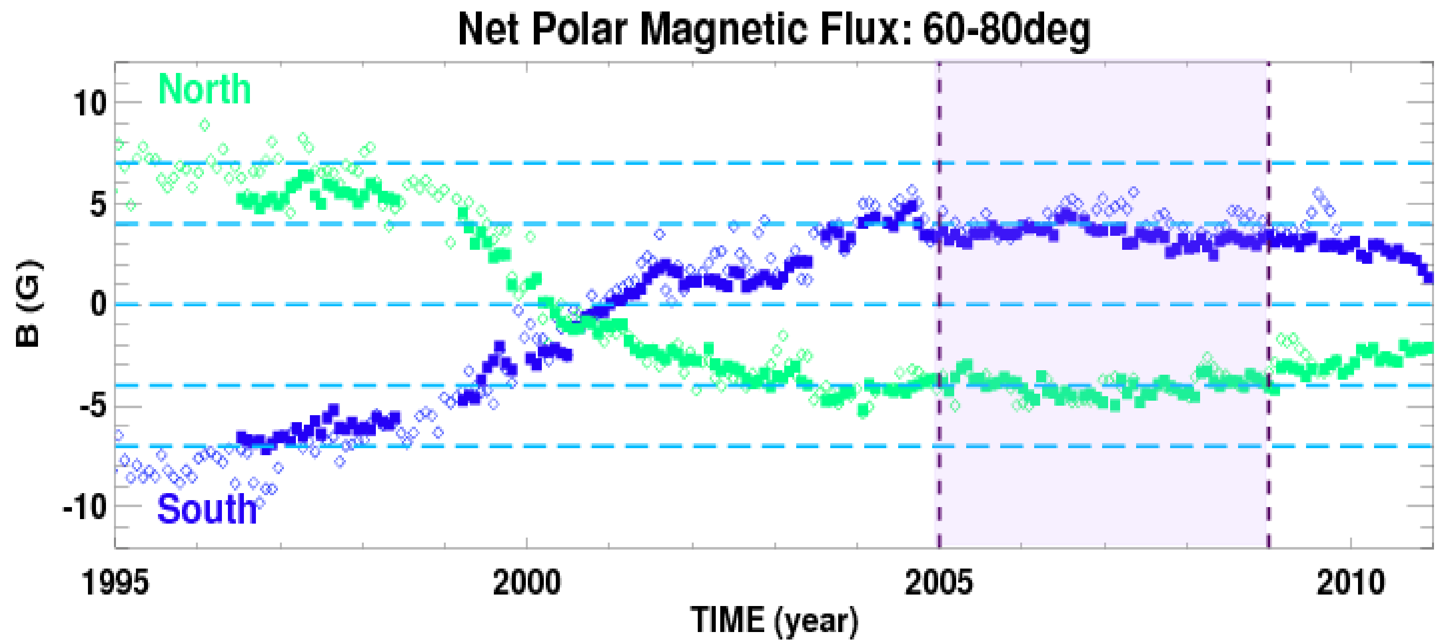


large asymmetry between North and South

North reached minimum conditions already in 2006

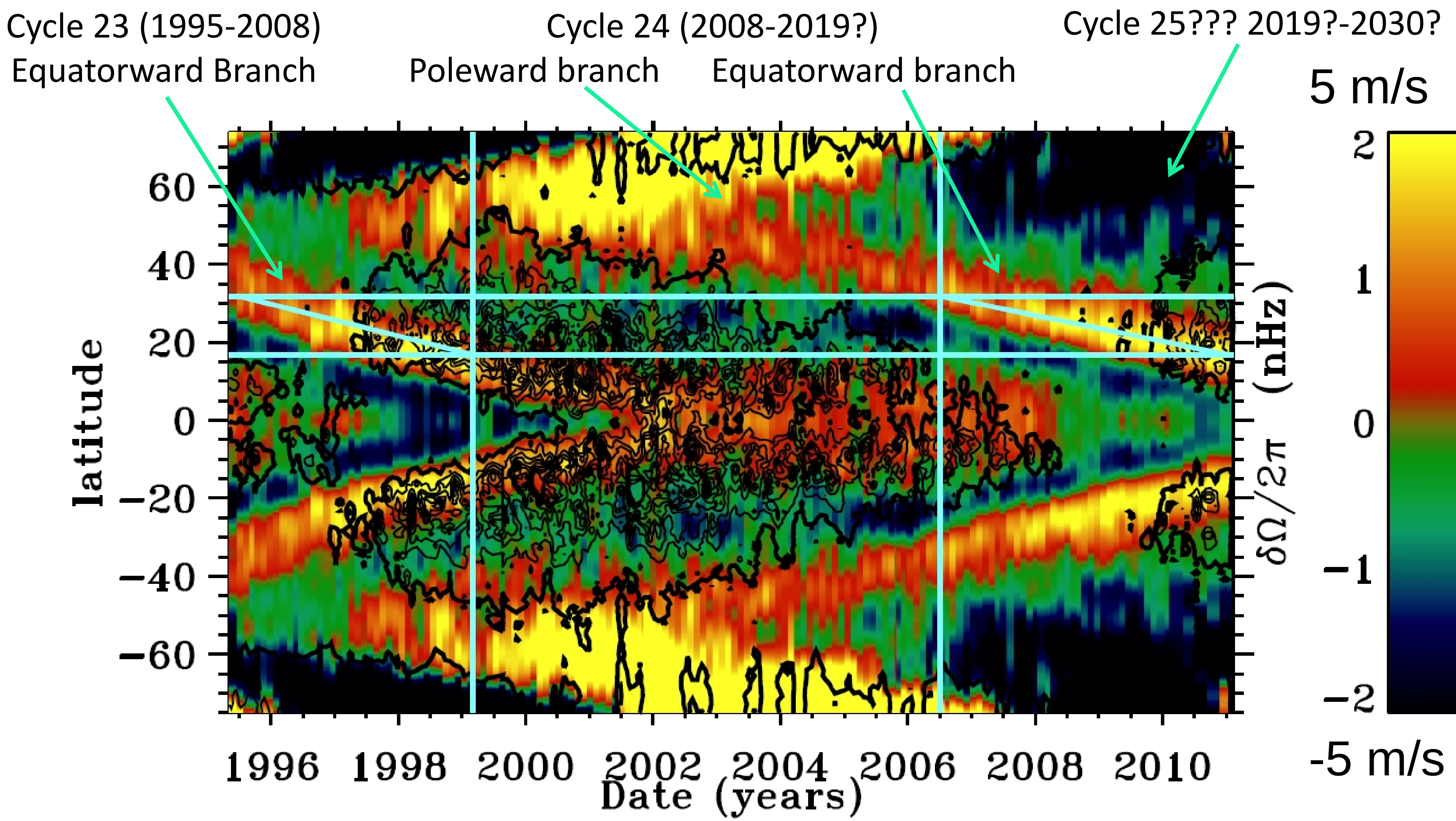
Polar Magnetic Fields

weak polar magnetic fields ca. 40% lower than in 1996
consistent with the observed decrease in open flux in the heliosphere
non-dipolar solar corona in 2007-2008



What caused a decrease in the polar fields?
meridional flow *(Schrijver & Liu 2008,Wang et. al 2009, Nandy et al. 2011)*
α-effect *(Dikpati 2011)*
tilt of active regions *(Petrie 2012)*

Torsional oscillation at a depth of 7 Mm



No sign yet of poleward branch flow for Cycle 25.

Does irt mean that Cycle 25 will not start until at least 2023 ?

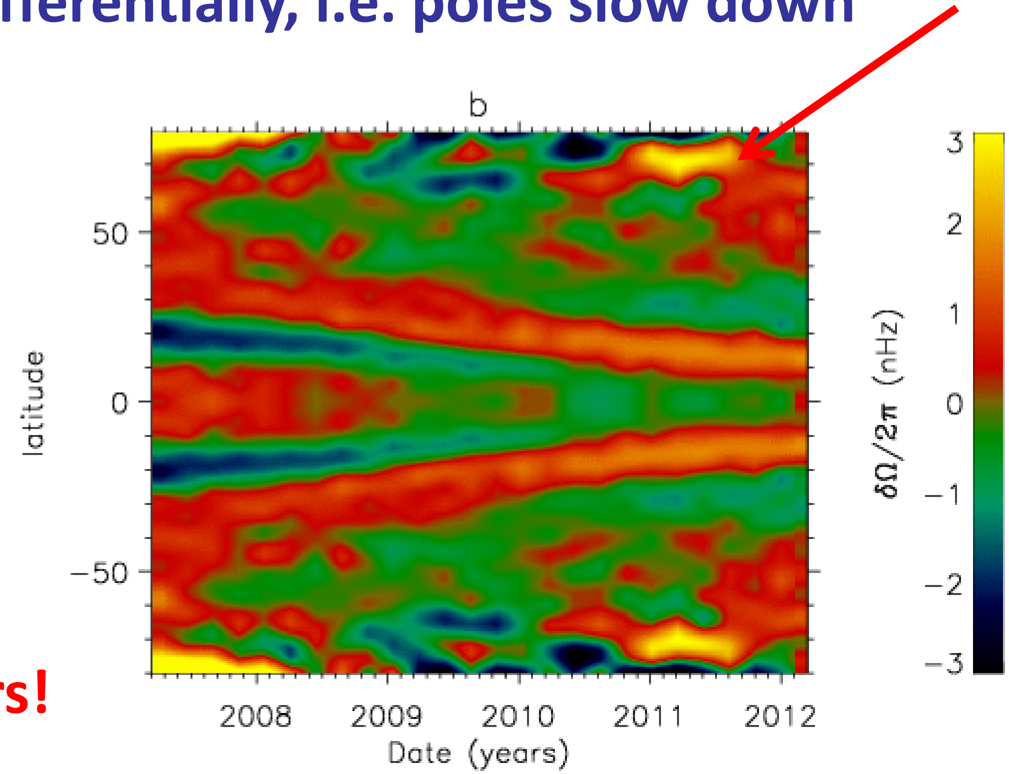
M. Rempel (2012)suggested that the non-appearance of the high-latitude branch may be due to a change in the differential rotation profile that arises from a reduction of the α effect

Strong cycles have more rigid differential rotation
(magnetic tension tends to reduce rotation shear)

Weak cycles rotate more differentially, i.e. poles slow down

If a mean differential rotation is subtracted this would hide polarward branch

MDI with 5-year rotational mean subtracted
polarward branch reappears!



The slowing ‘rush to the poles’

cycle 24 started “late”, but cycle 23 was 12 years long, 2 years longer than the previous two cycles. Iron emission seems to appear right as expected, 12 years after the last one

no physical reason to connect high- and low-latitude branch

correspond to different coronal structures

temperature effect

Robbrecht et al. 2010