Space Weather and the NSO Synoptic Program

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- *Deputy Director*

National Solar Observatory

- *and*
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- *NSO Synoptic Program Director*

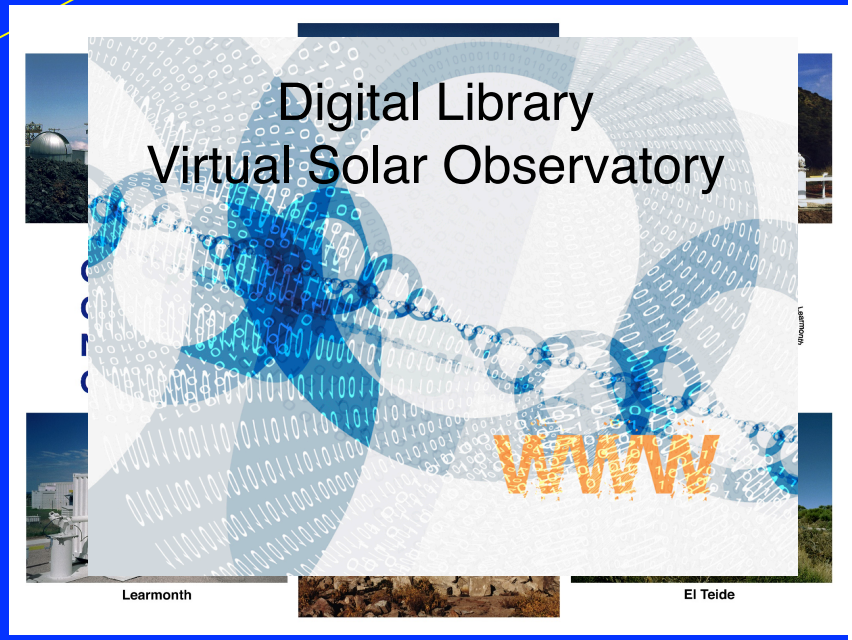
NATIONAL SOLAR OBSERVATORY

Kitt Peak, Arizona

Sunspot, New Mexico

Advanced Technology Solar Telescope ATST

Haleakala, Maui, HI



The NSO Synoptic Program

- Comprised of two major facilities
- **SOLIS** – **SO**lar **L**ong-term **I**nvestiagtions of the **S**un
- **GONG** – **G**lobal **O**scillation **N**etwork **G**roup

SOLIS

- A suite of instruments located at Kitt Peak
- **VSM** – **V**ector **S**pectro**M**agnetograph
  - Provides daily 2k x 2k full-disk vector and longitudinal magnetograms in the photosphere and chromosphere
- **ISS** – **I**ntegrated **S**unlight **S**pectrometer
  - Provides daily disk-integrated spectra in 12 wavelength regions
- **FDP** – **F**ull **D**isk **P**atrol
  - Provides 2k x 2k full-disk intensity images at 6 wavelengths every minute

GONG

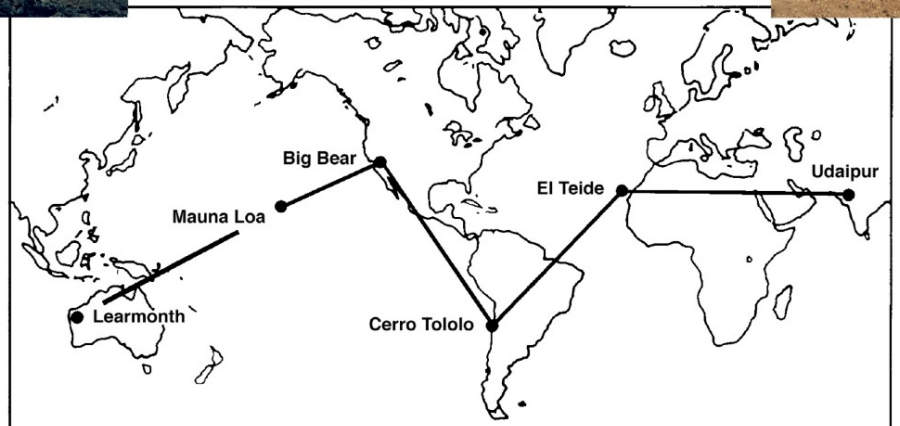
- A network of instruments located six sites geographically distributed around the world
- Observes the sun continuously with a duty cycle of ~87% since 1995
- Full-disk 1k x 1k Doppler images for helioseismology every minute
- Full-disk 1k x 1k longitudinal magnetogram every minute
- Full-disk 2k x 2k Hα image every 20 sec
- Data returned in near real-time to web

Mauna Loa

Big Bear

Udaipur

Global Oscillation Network Group



Learmonth

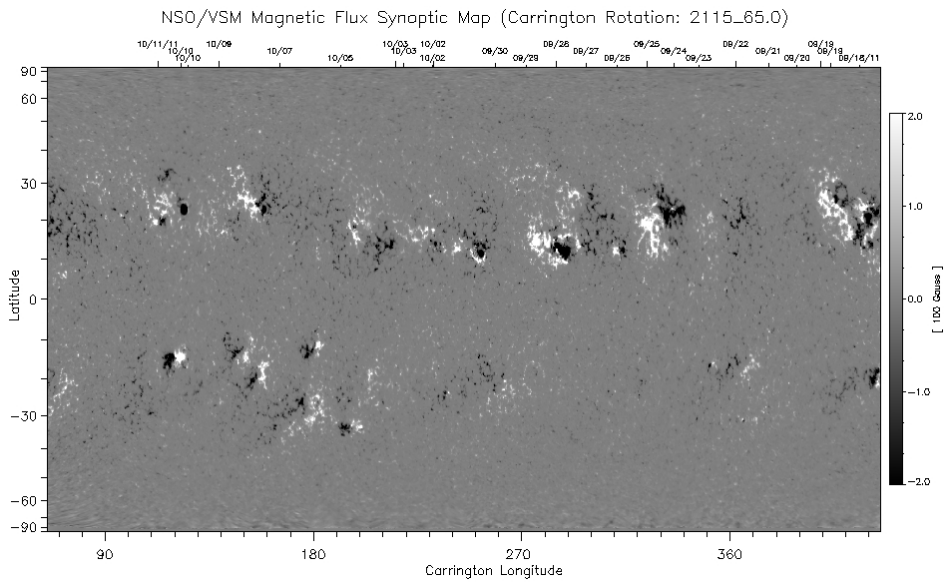
Cerro Tololo

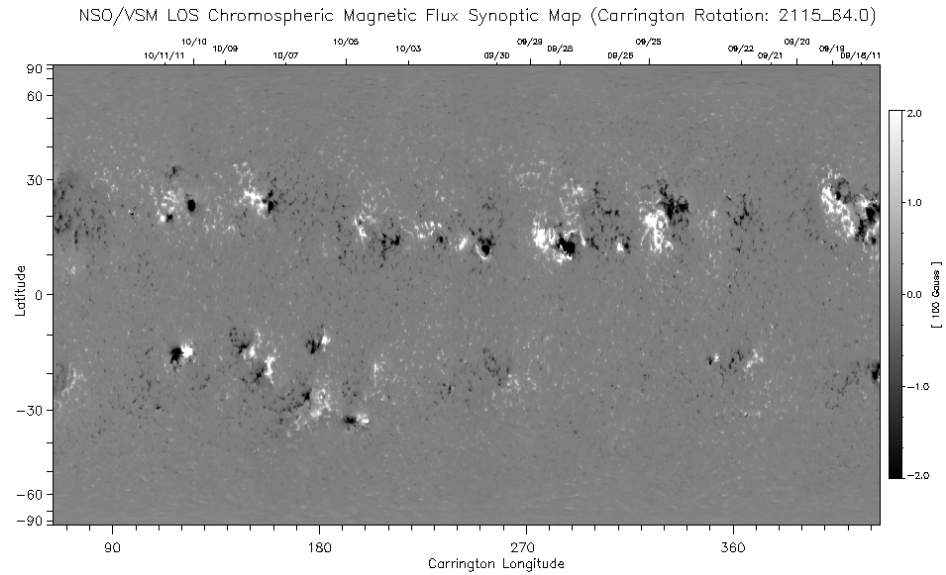
El Teide

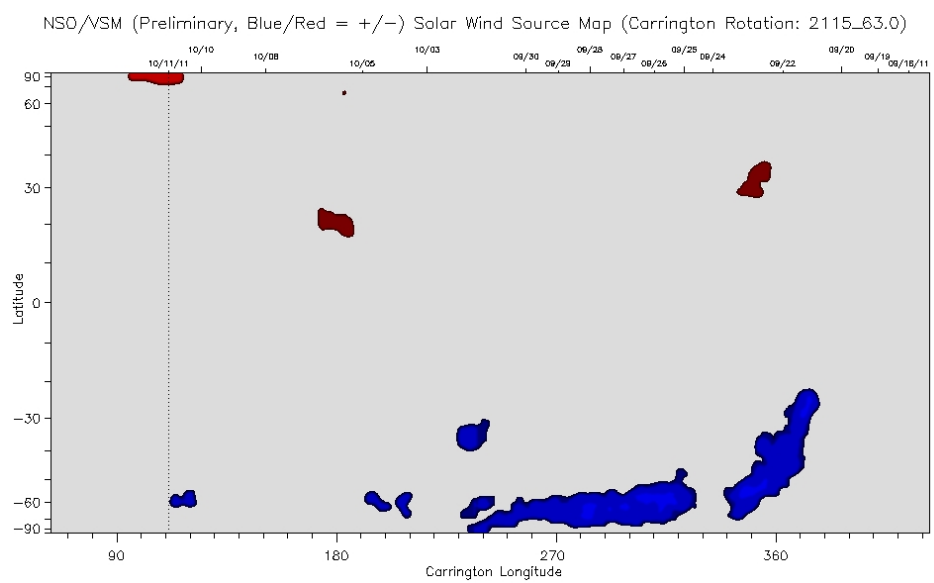
SOLIS Space Weather Data Products

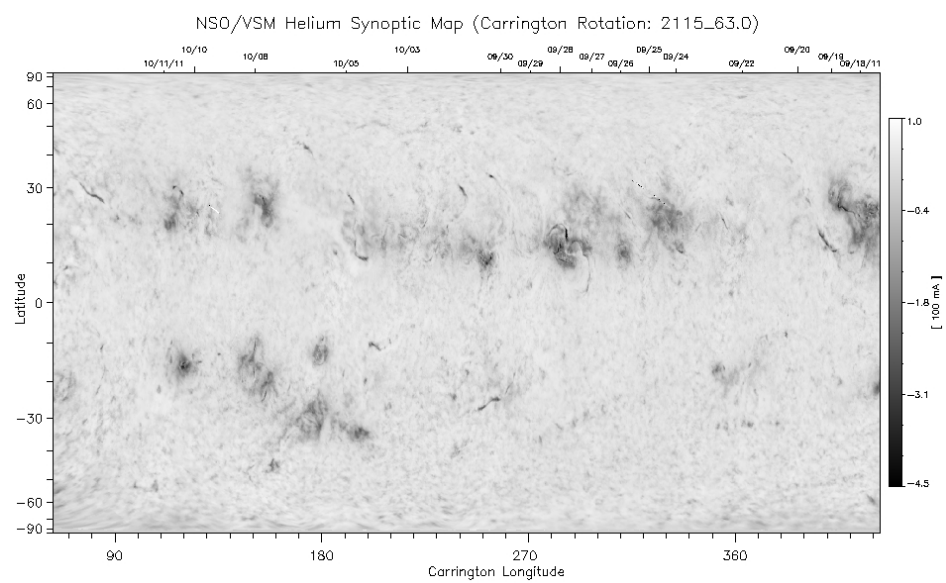
- Daily longitudinal magnetic field synoptic map in photosphere and chromosphere
- Vector magnetic field synoptic map in photosphere now in development
- Vector magnetic field measurements in chromosphere after replacement of polarization modulator optics
- Intensity images in Hα core and wings (soon)
- He 10830 images and derived coronal hole maps

SOLIS Space Weather Data Products

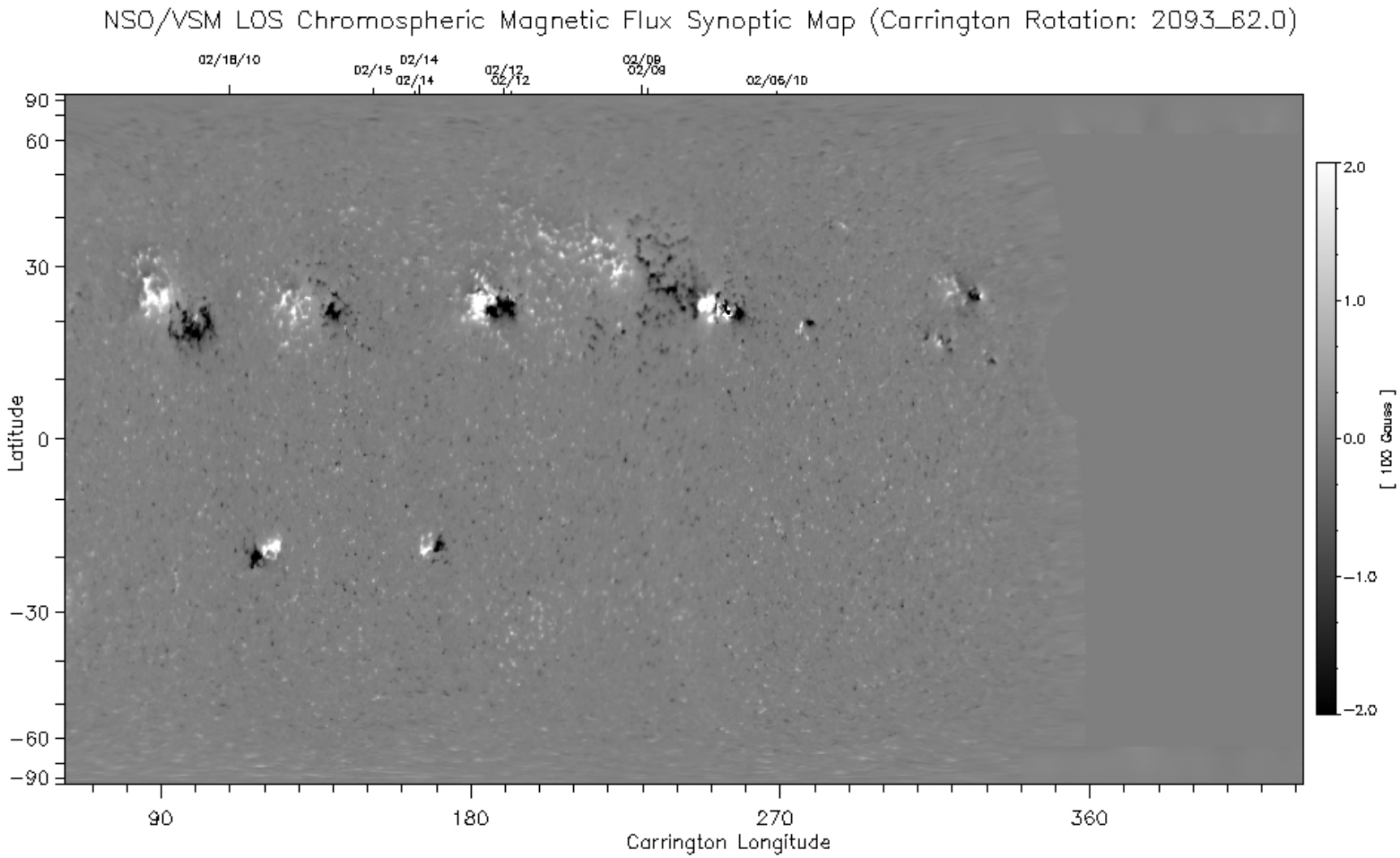








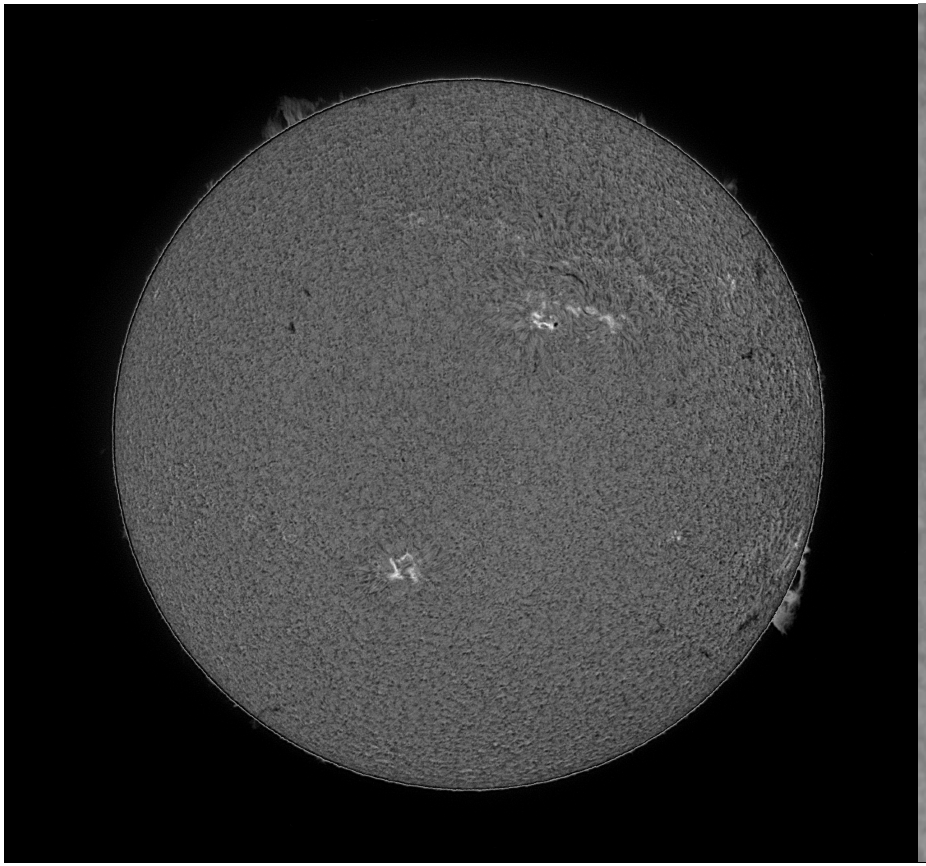
SOLIS Chromospheric Synoptic Maps



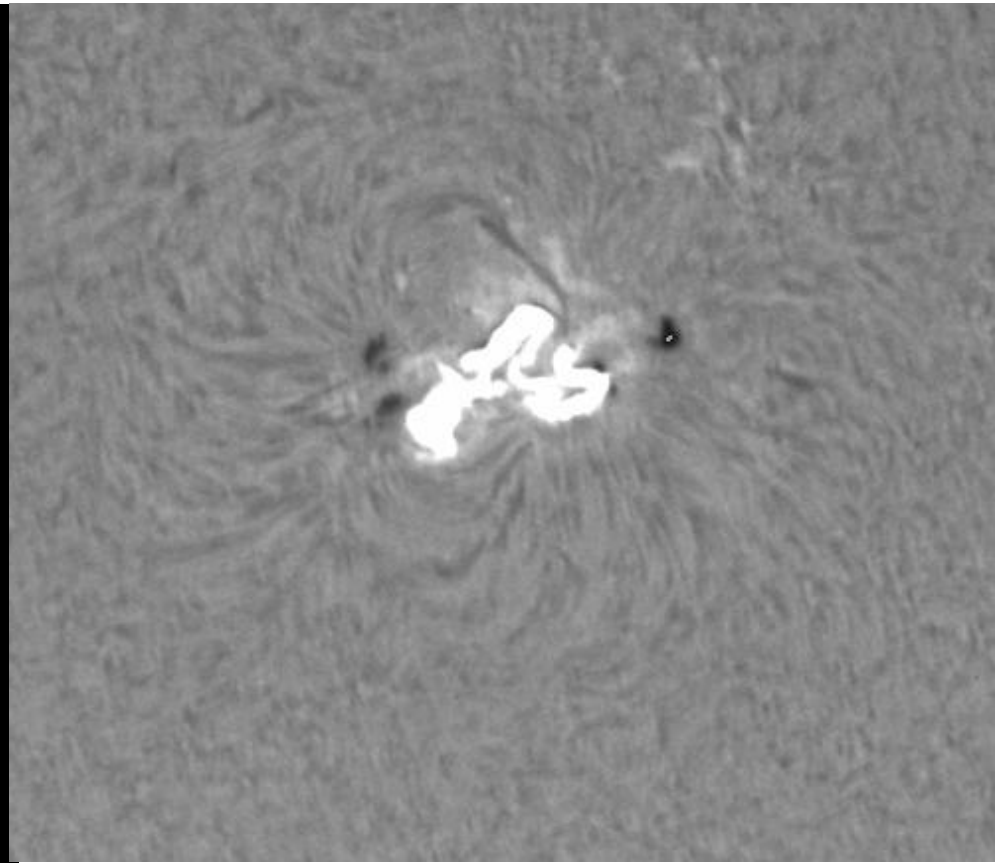
GONG Space Weather Data Products

- 10-min average full-disk magnetograms
- Hourly longitudinal photospheric magnetic field synoptic maps
- Hourly potential-field source-surface field extrapolations in several projections
- 2k x 2k Full-disk Hα line core image every 20 sec
- Twice-daily far-side magnetic field maps from helioseismology
- All products on the web in near real-time, 24/7

Sample GONG Hα Data

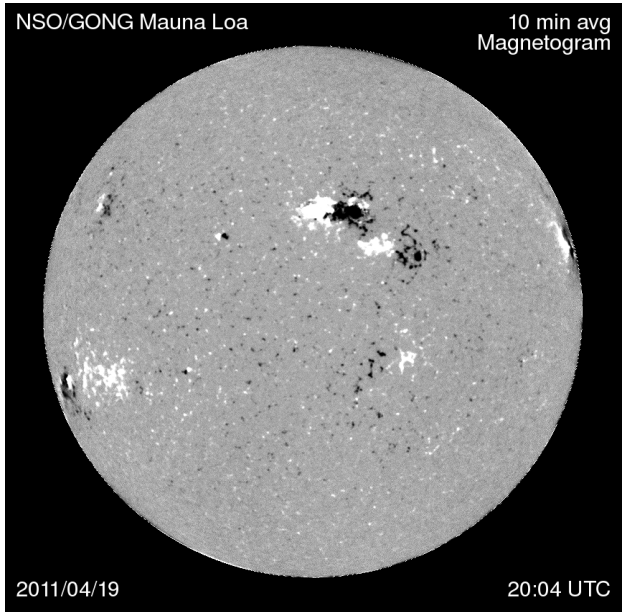


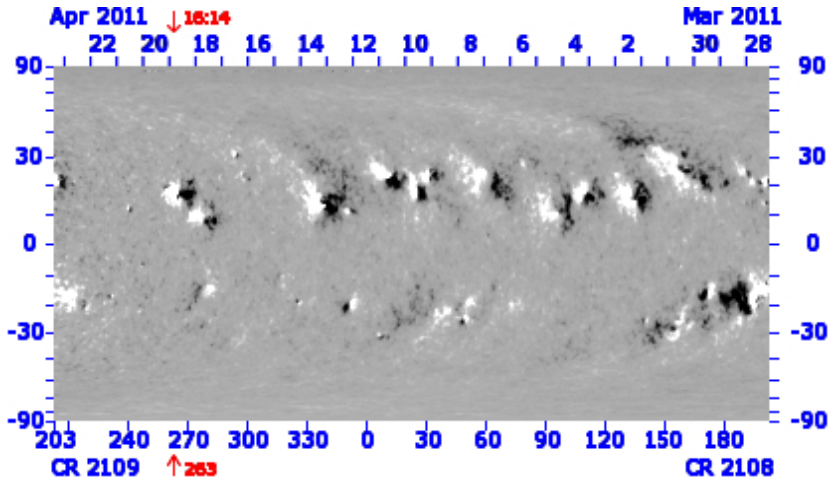
An image obtained at Learmonth, Australia, on 19 March 2011 at 0430 UT. This image has had limb darkening removed and contrast enhanced.

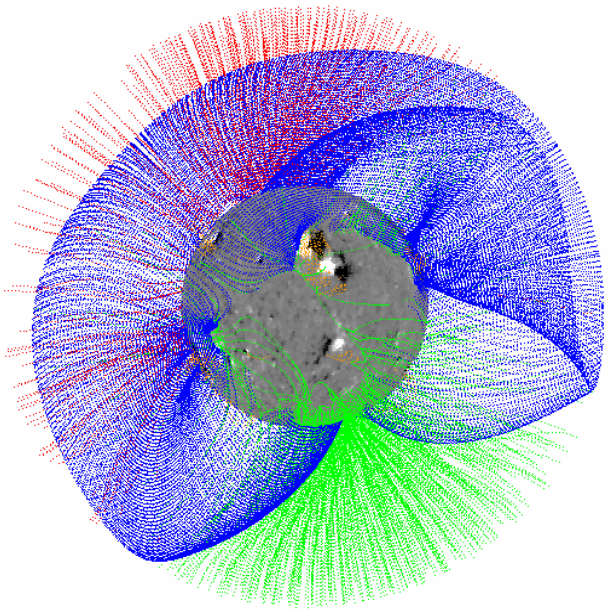


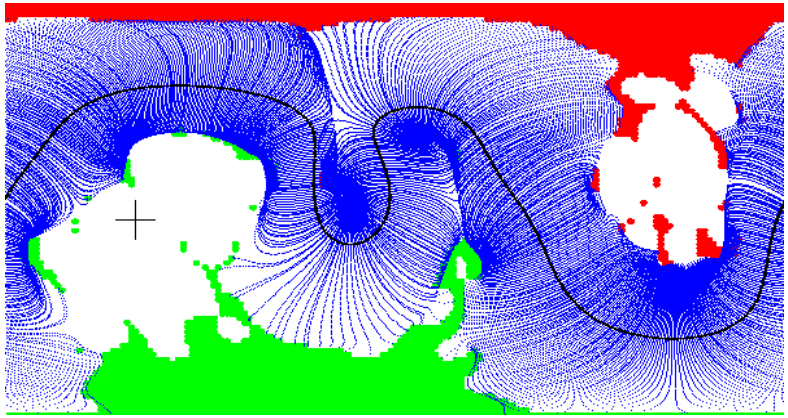
The X1.5 flare of March 9, 2011, observed at Big Bear, California, at 23:23 UT.

GONG magnetic field products for space weather

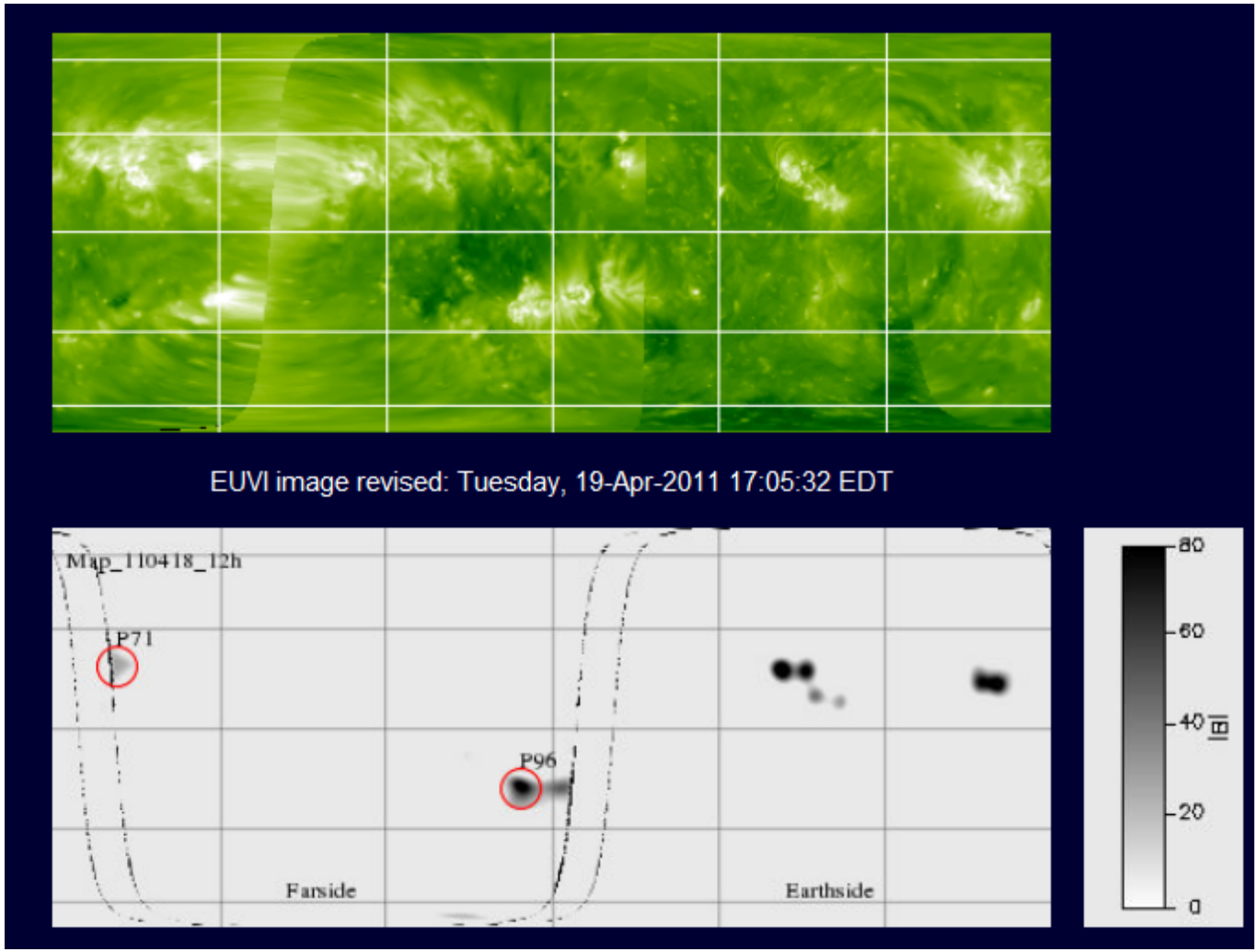








GONG maps of the far-side magnetic field from helioseismology



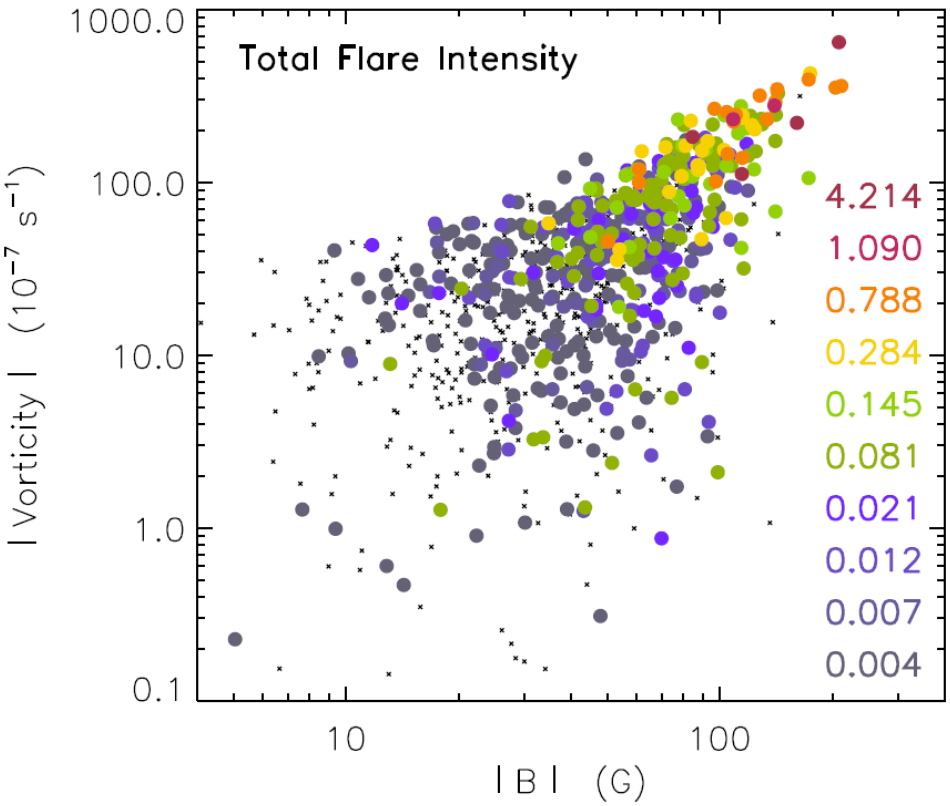
Lower panel: a calibrated far-side map, with potential far-side active regions circled and labeled with the probability that the detection is accurate. Upper panel: simultaneous STEREO EUVI synoptic map with direct observations of the EUV emission associated with active regions. There is good agreement between the images for the circled and more reliable far-side detections.

Current usage of NSO synoptic space weather data

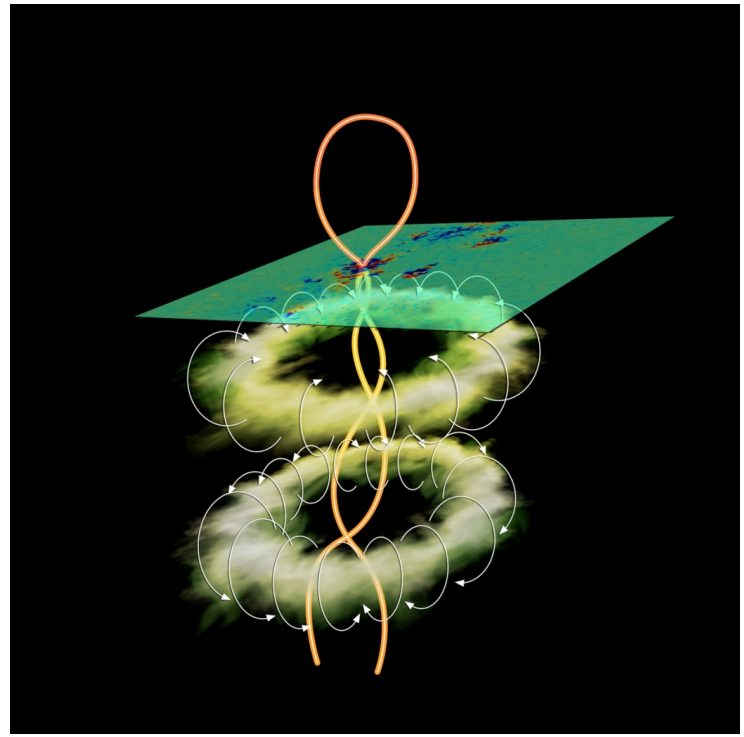
- SOLIS and GONG photospheric magnetic field synoptic maps are used by
  - NOAA/SWPC operational prediction of geomagnetic storms as input to the AFRL Wang-Sheeley-Arge (WSA) solar wind and Enlil propagation models to the Earth
  - AFRL ADAPT project to provide forecast of photospheric field via data assimilation
- GONG far-side maps are used by
  - NOAA/SWPC for long-range forecasts
  - AFRL ADAPT project
- GONG Hα images are used by the US Air Force Weather Agency (AFWA) for operational now-casting of space weather conditions

Predicting flares with helioseismology

- Can map flows below photosphere using frequency shifts of *p* modes in localized areas
- Find strong horizontal vorticity below all active regions (stacked “smoke rings”)
- Strength of vorticity and surface magnetic field are highly correlated with flare productivity
- Vorticity observed to rapidly change 1-3 days prior to a flare
- Currently developing technique to predict flare occurrence and strength



Location of ~1000 active regions as function of subsurface vorticity and surface magnetic field strength. Large dots are flaring active regions, color denotes total strength of flares. Extremely flare-productive regions have both strong vorticity and strong surface fields.



Conceptual image of the vorticity structure below active regions. Two “smoke rings” are stacked, with opposite senses of rotation around their small radius. This twists magnetic field until reconnection occurs.

The Sun in a Stellar Context
The HARPS Sample

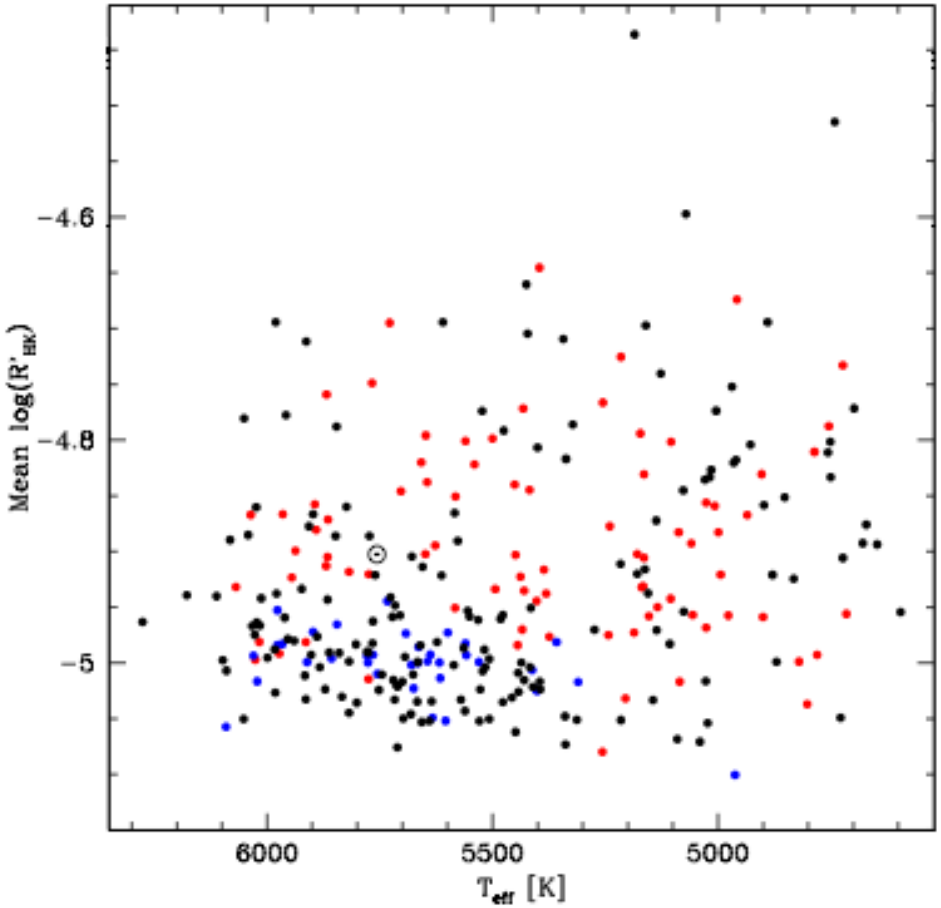
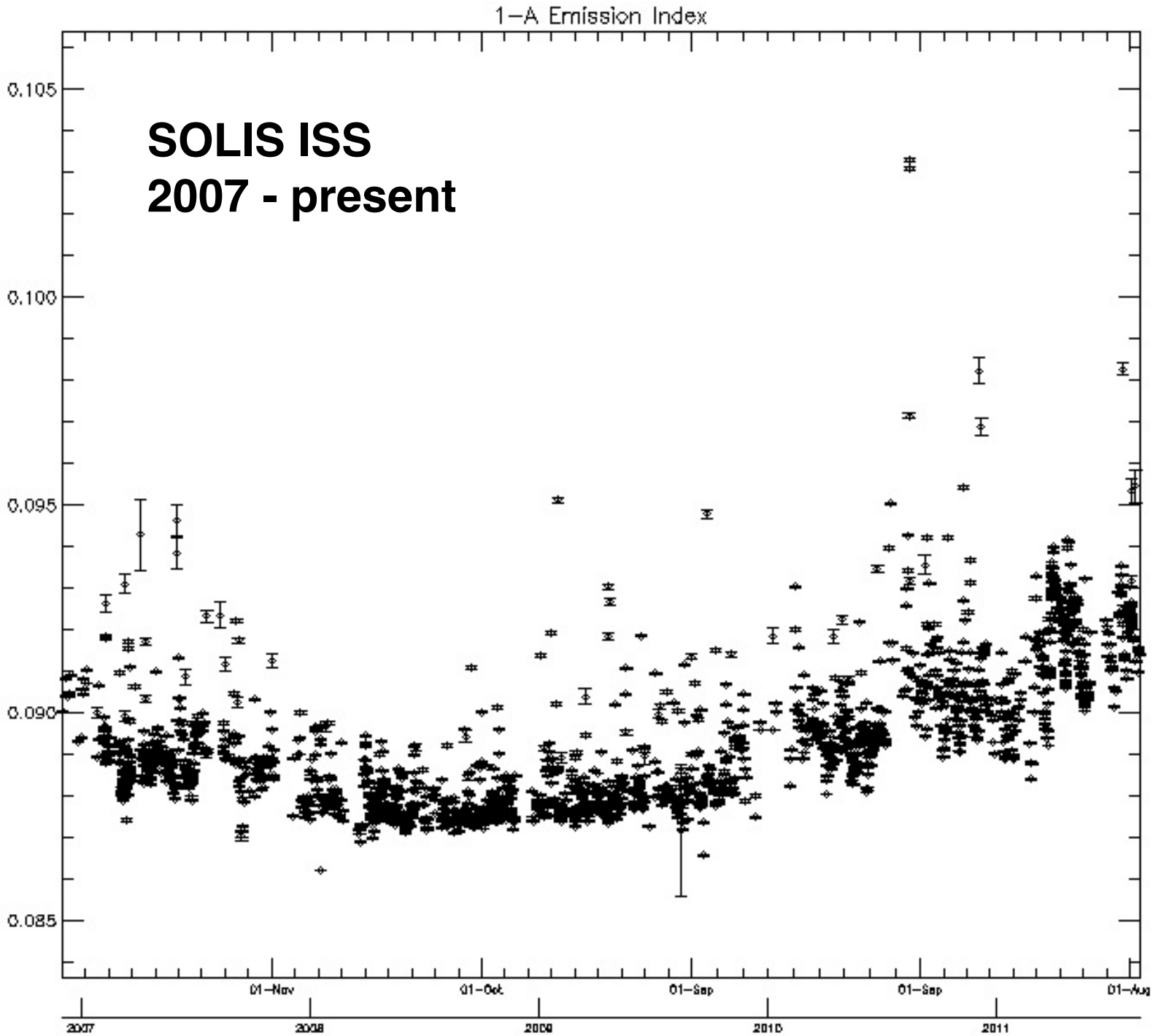
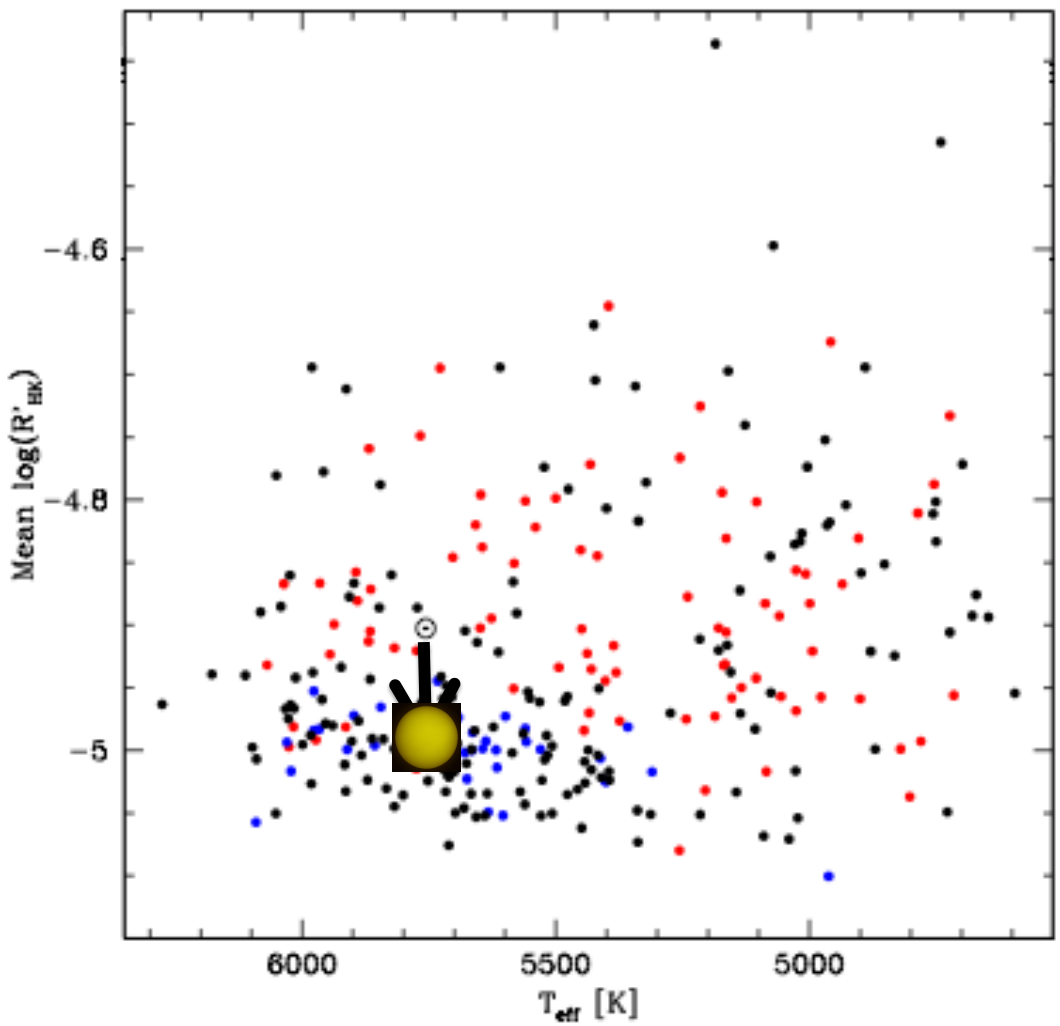


Fig. 14. $T_{\rm eff}$ vs. $\log R'_{\rm HK}$ plot showing stars with a large-amplitude magnetic cycle (red), stars with no large-amplitude cycle (blue), and stars of undetermined status (black). The position of the Sun is shown as a ⊙ symbol.

Lovis et al. (2011)

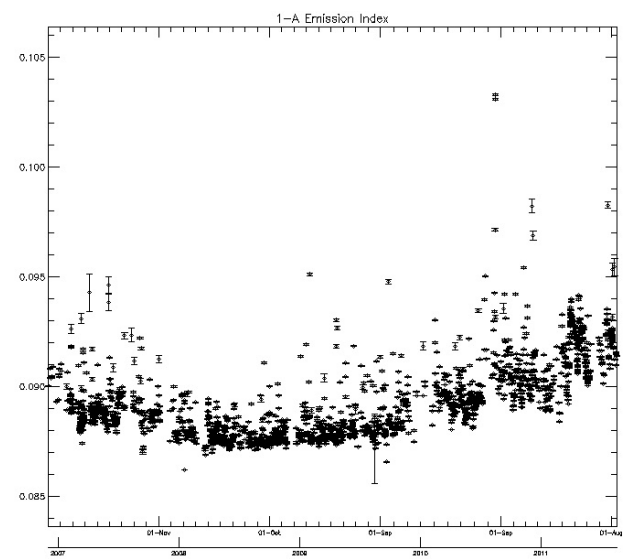

1−A Emission Index
SOLIS ISS
2007 - present
0.105
0.100
0.095
0.090
0.085
01−Nov
01−Oct
01−Sep
01−Sep
01−Aug
2007
2008
2009
2010
2011

The Sun in a Stellar Context
The HARPS Sample



2008 solar minimum in Ca II H&K

Log $R'_{HK} \approx -5.0$

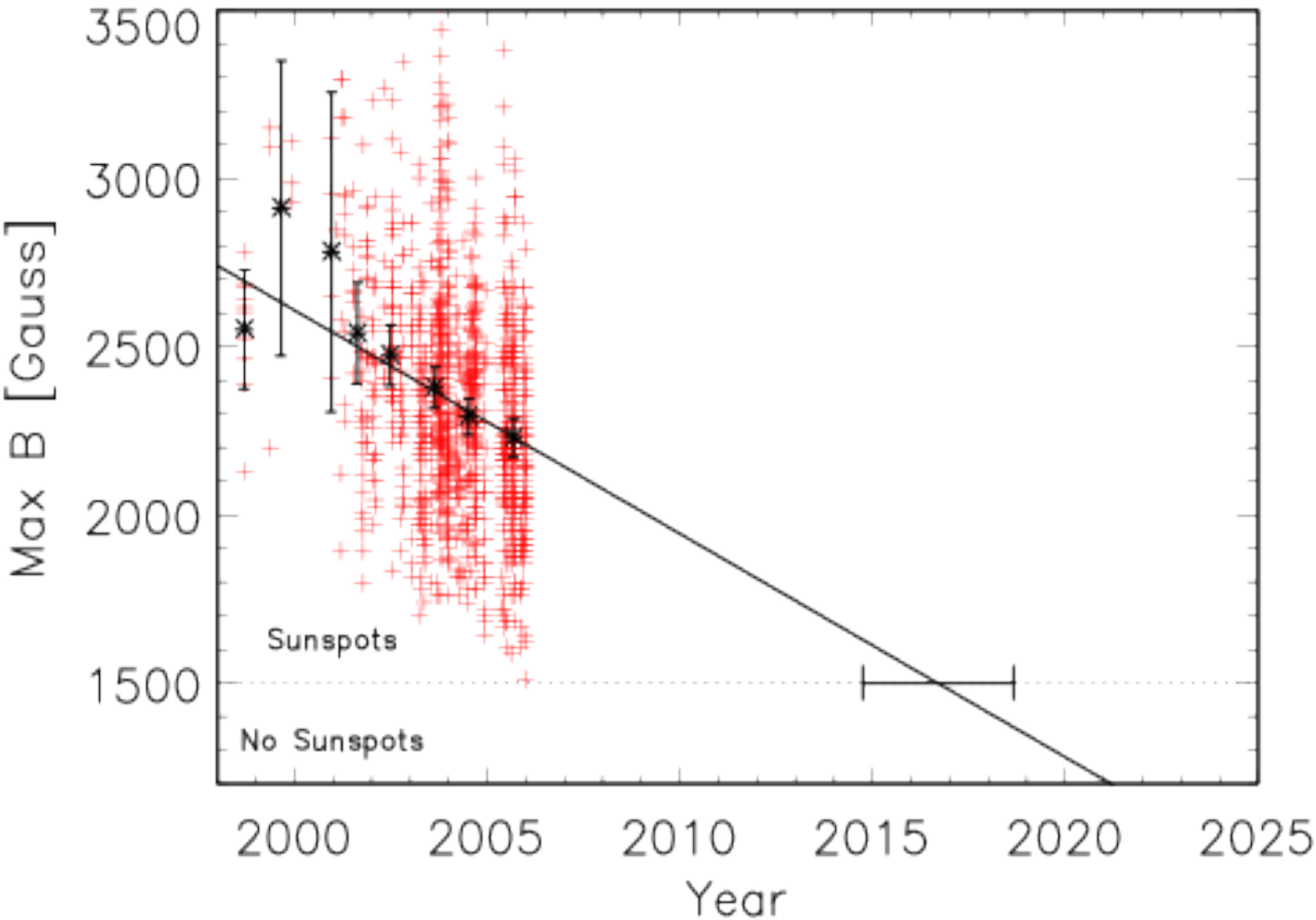


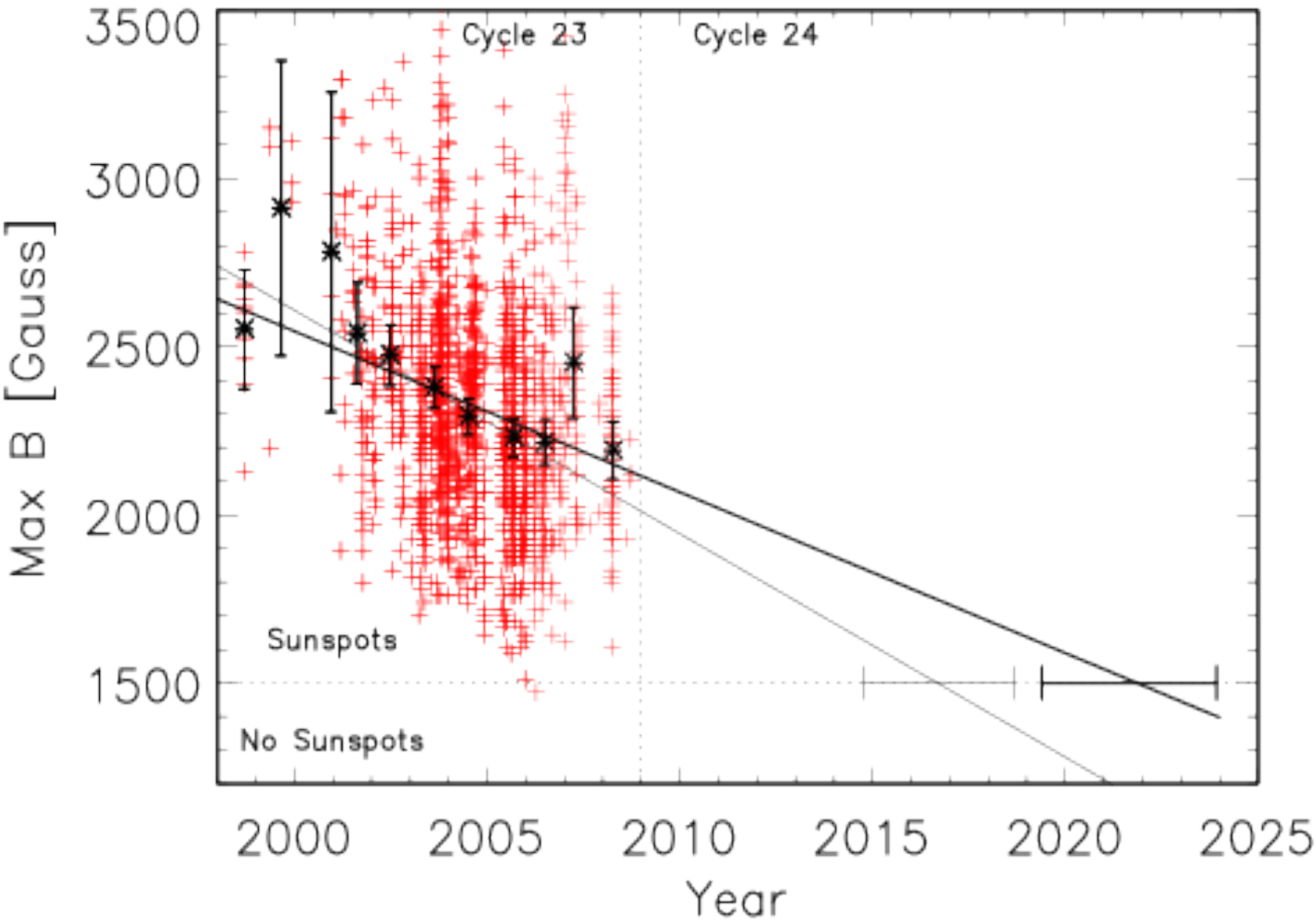
Operation costs and support

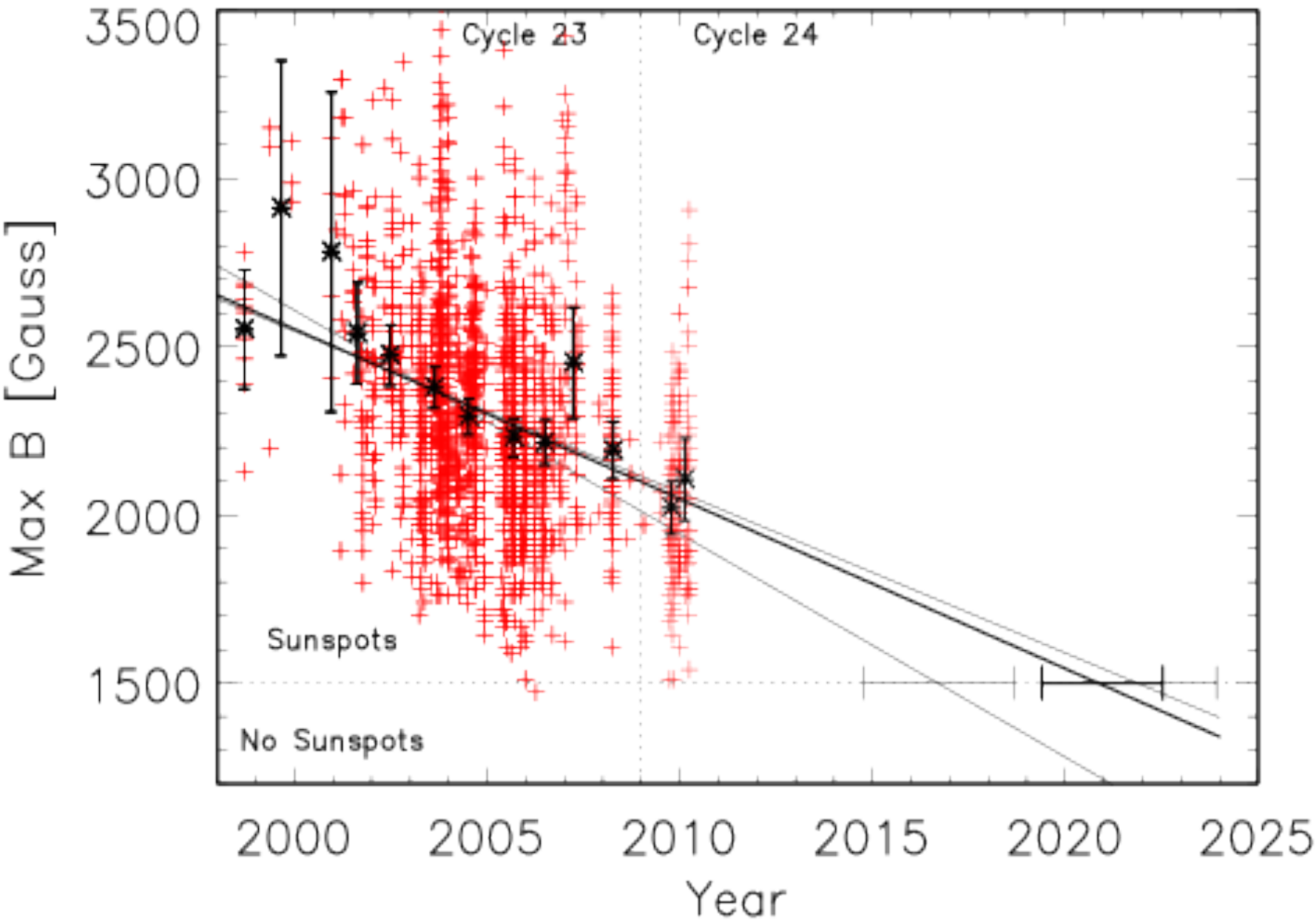
- Total annual budget of NSO synoptic program: $5.1M
- Includes operations, data reduction, and scientific staff
- GONG operational costs: $800k
- SOLIS operational costs: ~$500k
- Have operational support for GONG from AFWA ($800k per year)
- AFWA also funded the installation of the Hα capability in GONG (cost: $650k)

Vanishing sunspots?

Matt Penn & Bill Livingston (2011)
National Solar Observatory

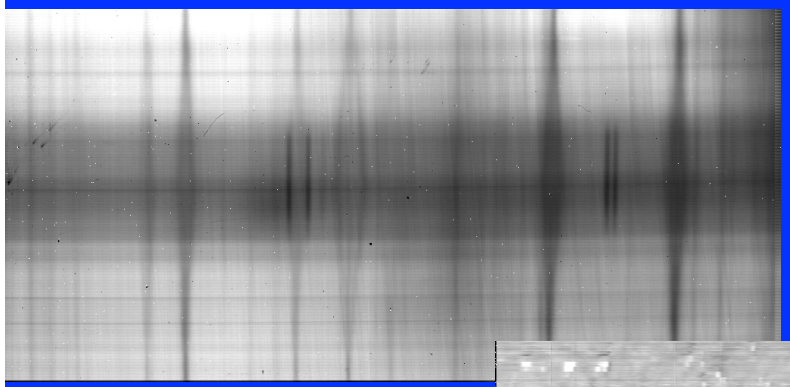

3500
3000
2500
2000
1500
Max B [Gauss]
Sunspots
No Sunspots
2000
2005
2010
2015
2020
2025
Year

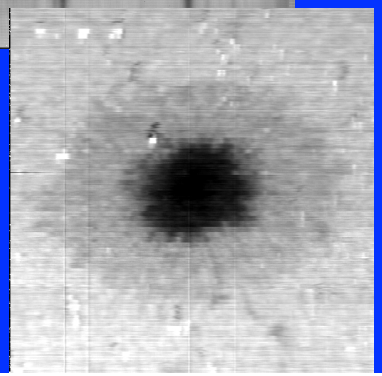

Cycle 23
Cycle 24
Sunspots
No Sunspots
Max B [Gauss]
3500
3000
2500
2000
1500
2000
2005
2010
2015
2020
2025
Year

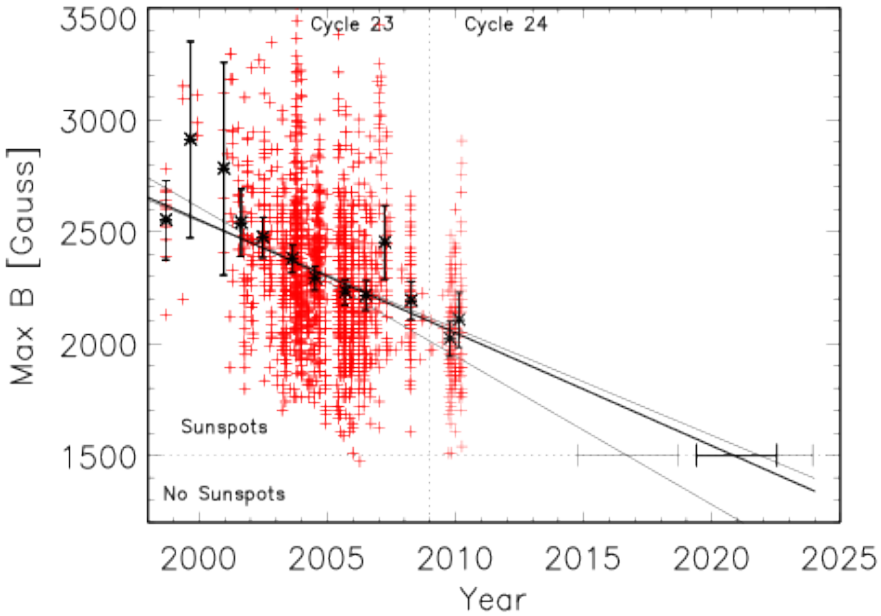

Cycle 23
Cycle 24
Sunspots
No Sunspots
Max B [Gauss]
3500
3000
2500
2000
1500
2000
2005
2010
2015
2020
2025
Year

McMP Science
Sunspot Magnetic Field Decay

1. Various press releases from NASA, Discovery, ScienceNOW, IAU273 paper: Livingston and Penn
   1. Cycle 24 sunspots show the same trend as seen in Cycle 23 so far
   2. Based on latitude of torsional oscillations, Cycle 24 sunspot number down by factor of 3 compared to Cycle 23
   3. New scanning measurements from NAC can continue the synoptic observations: need for IR Postdoc







…possible implication

- Making three assumptions:
  - Livingston's cycle 23 IR measurements represent the "true" sunspot magnetic field probability distribution function
  - There is a real physical cut-off so that no sunspots form with maximum magnetic fields less than 1500G
  - The decrease in the mean field continues

- …then Solar cycle 24 will peak with a spot number of 57, and cycle 25 will peak with a spot number of 3.

NSO Workshop #26

Solar Origins of Space Weather and Space Climate: Connecting the Interior to the Corona

April 30 - May 4, 2012 Sunspot, New Mexico

END NSO REPORT

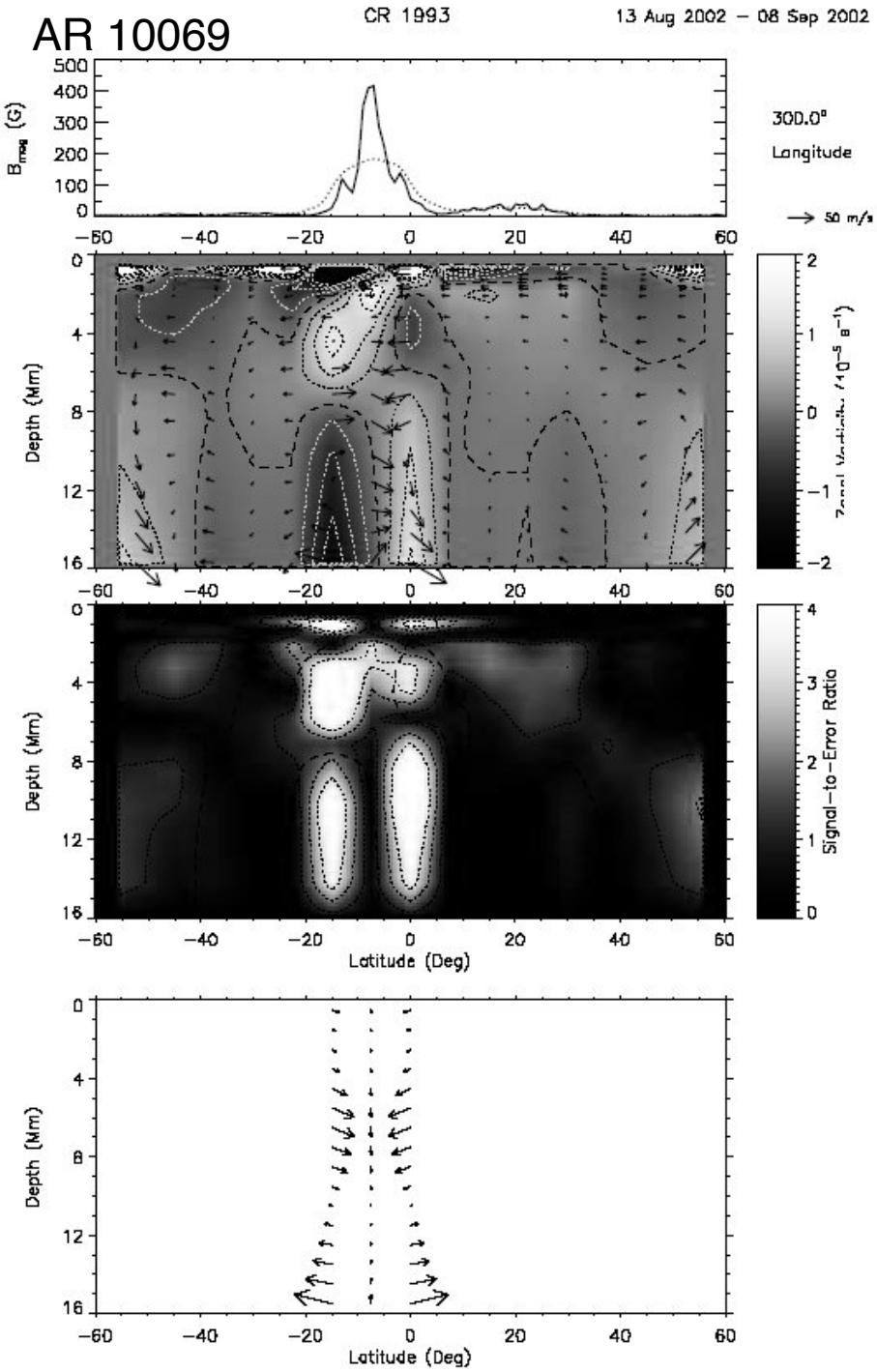
NSO Workshop #26

Solar Origins of Space Weather and Space Climate:
Connecting the Interior to the Corona

April 30 - May 4, 2012 Sunspot, New Mexico

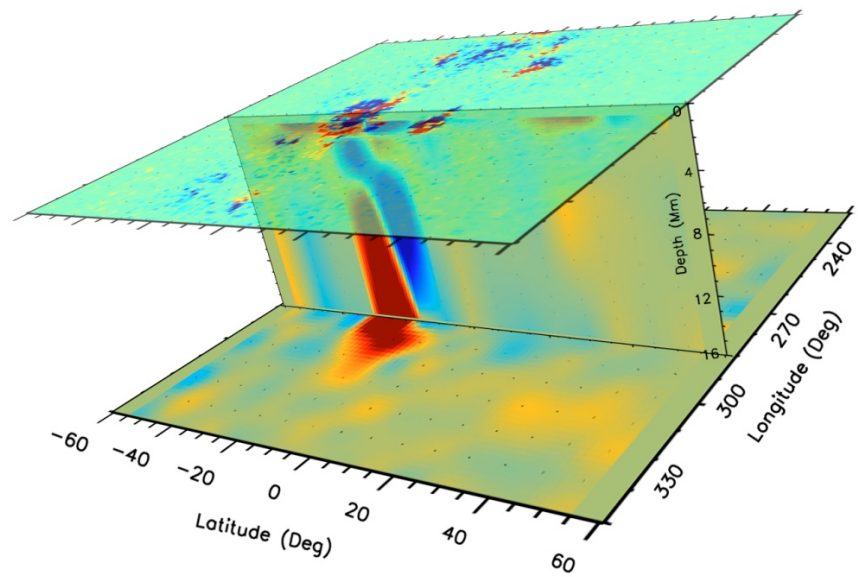
Extra slides follow

AR 10069



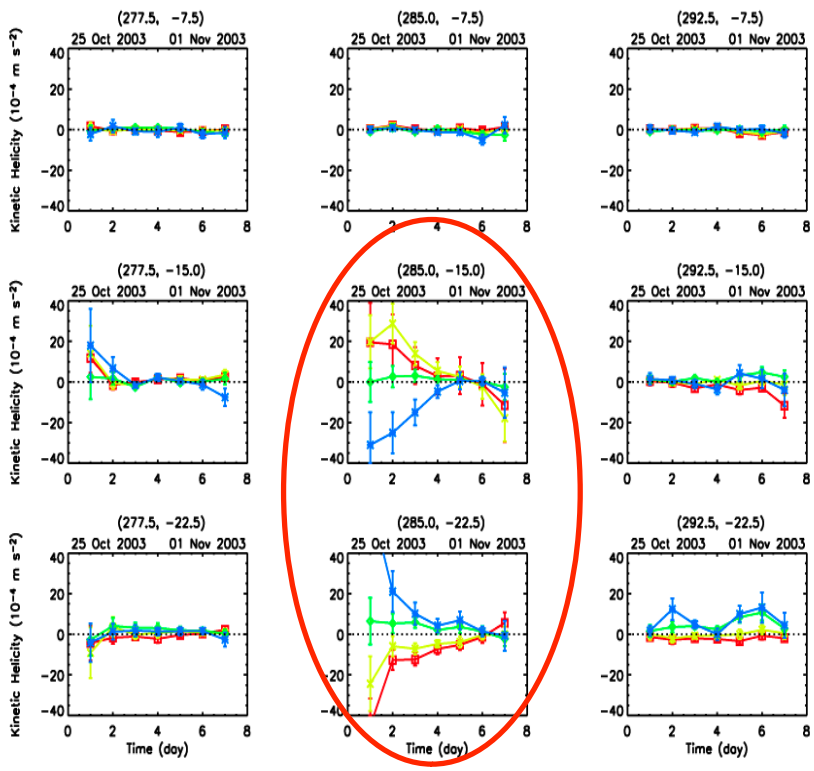
Vorticity below strong flare producers

Fig. 4.— Zonal vorticity, ω_x, at 300° longitude in CR 1993 as a function of latitude and depth. *Top:* gross magnetic flux (solid line) and binned over 15° (dotted line); *2nd:* the x-component of vorticity (ω_x); *3rd:* the signal-to-error ratio. The arrows represent the meridional and vertical velocity components with the vertical one increased by a factor of 10 for visibility. *Bottom:* idealized schematic for flows below a strong active region (with arbitrary amplitudes).

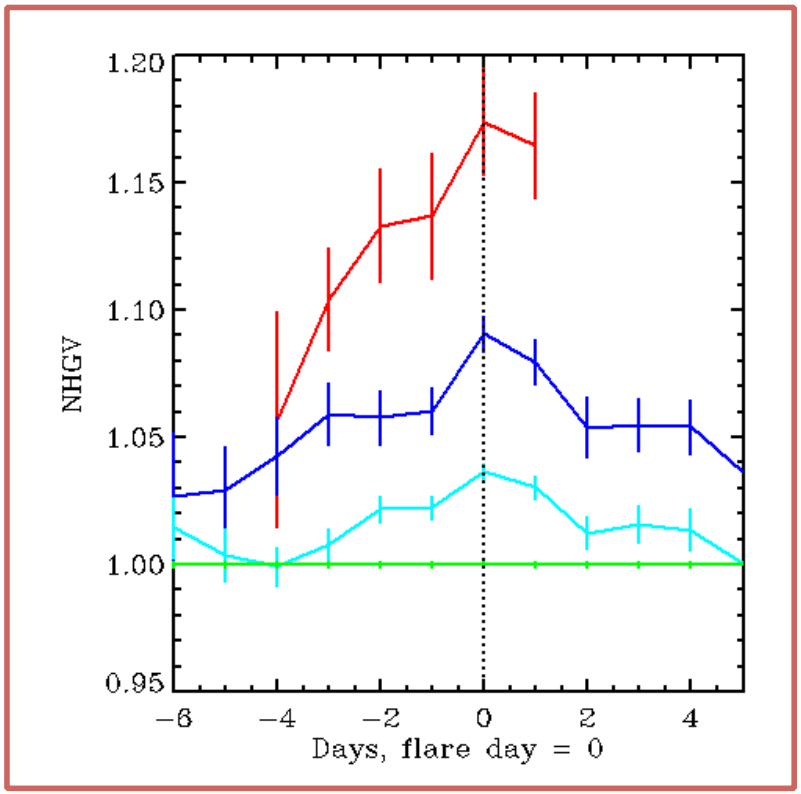


AR 10486

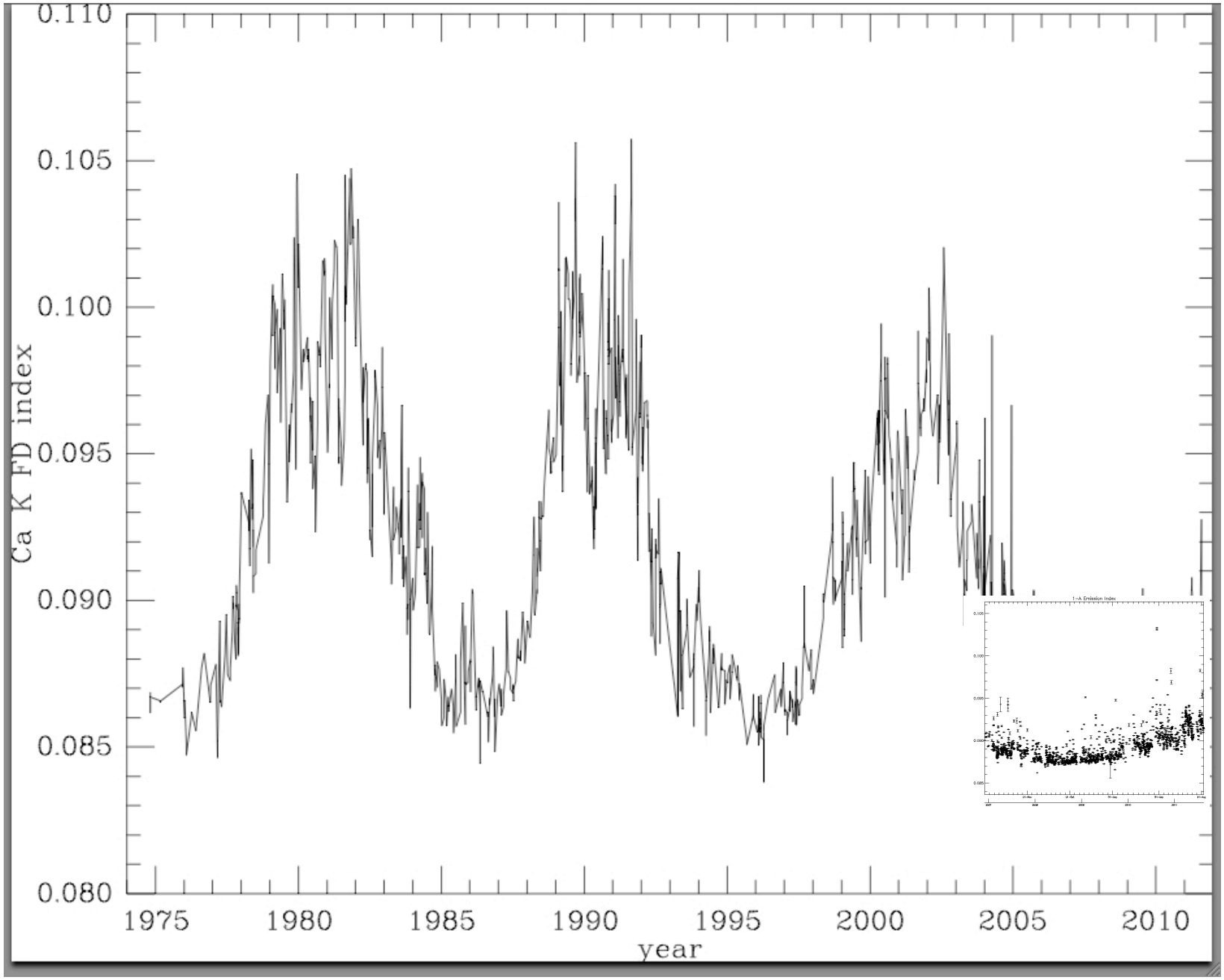
Changes in subsurface vorticity can predict flares



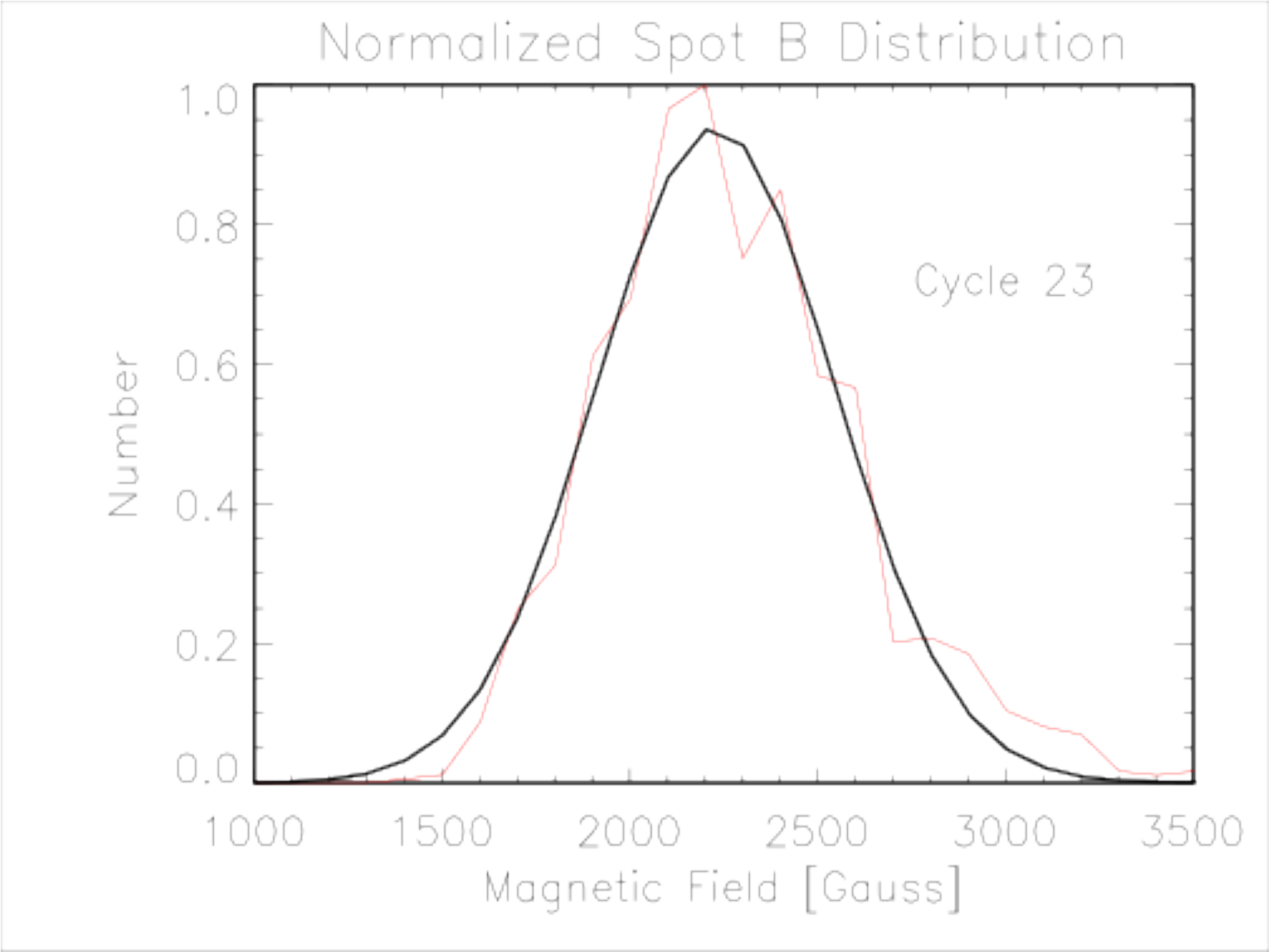
The temporal behavior of the subsurface vorticity/helicity at several depth below nine regions in the vicinity of one of the Halloween flares, which were located in the two regions with in the ellipse. The flare occurred on day five.

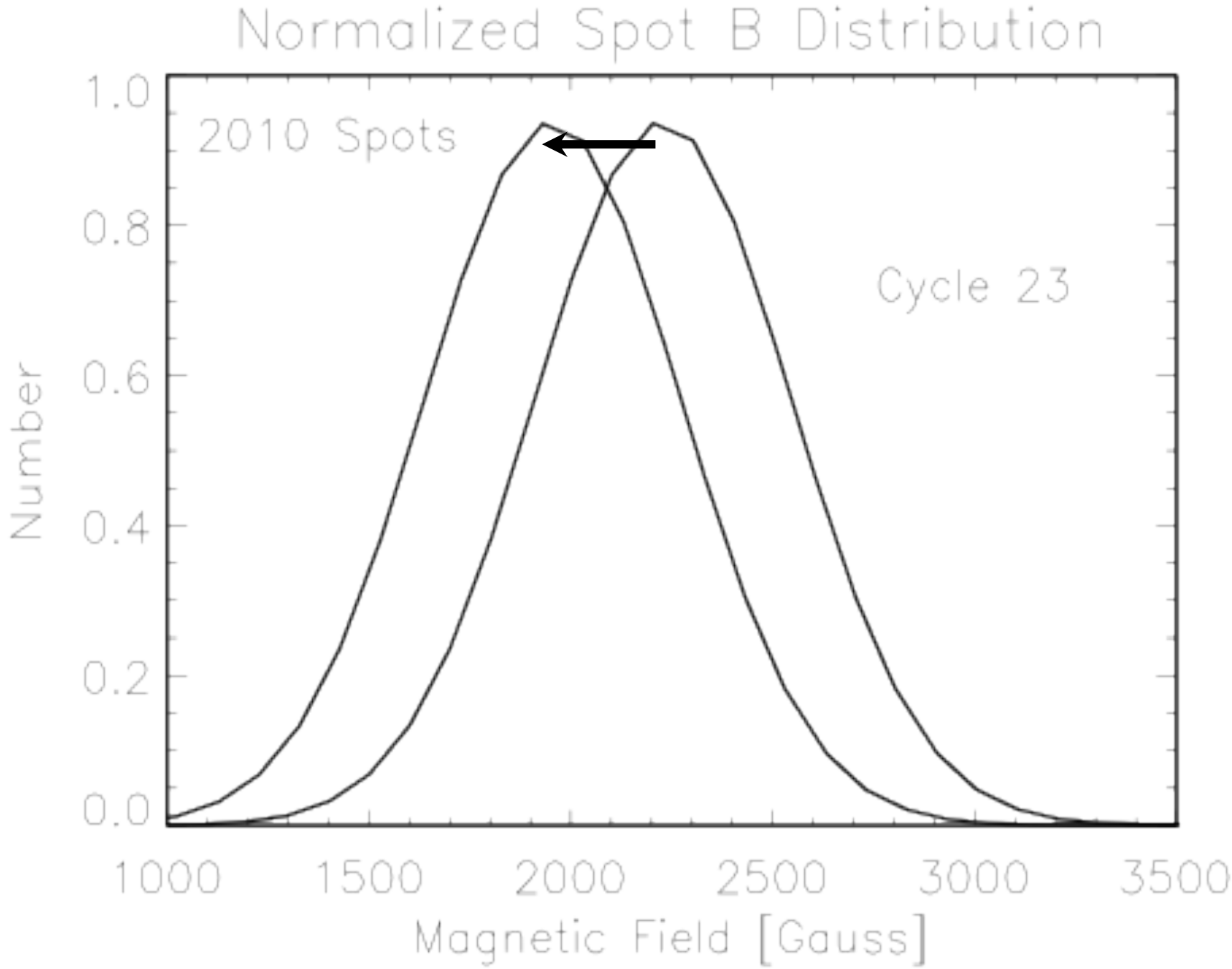


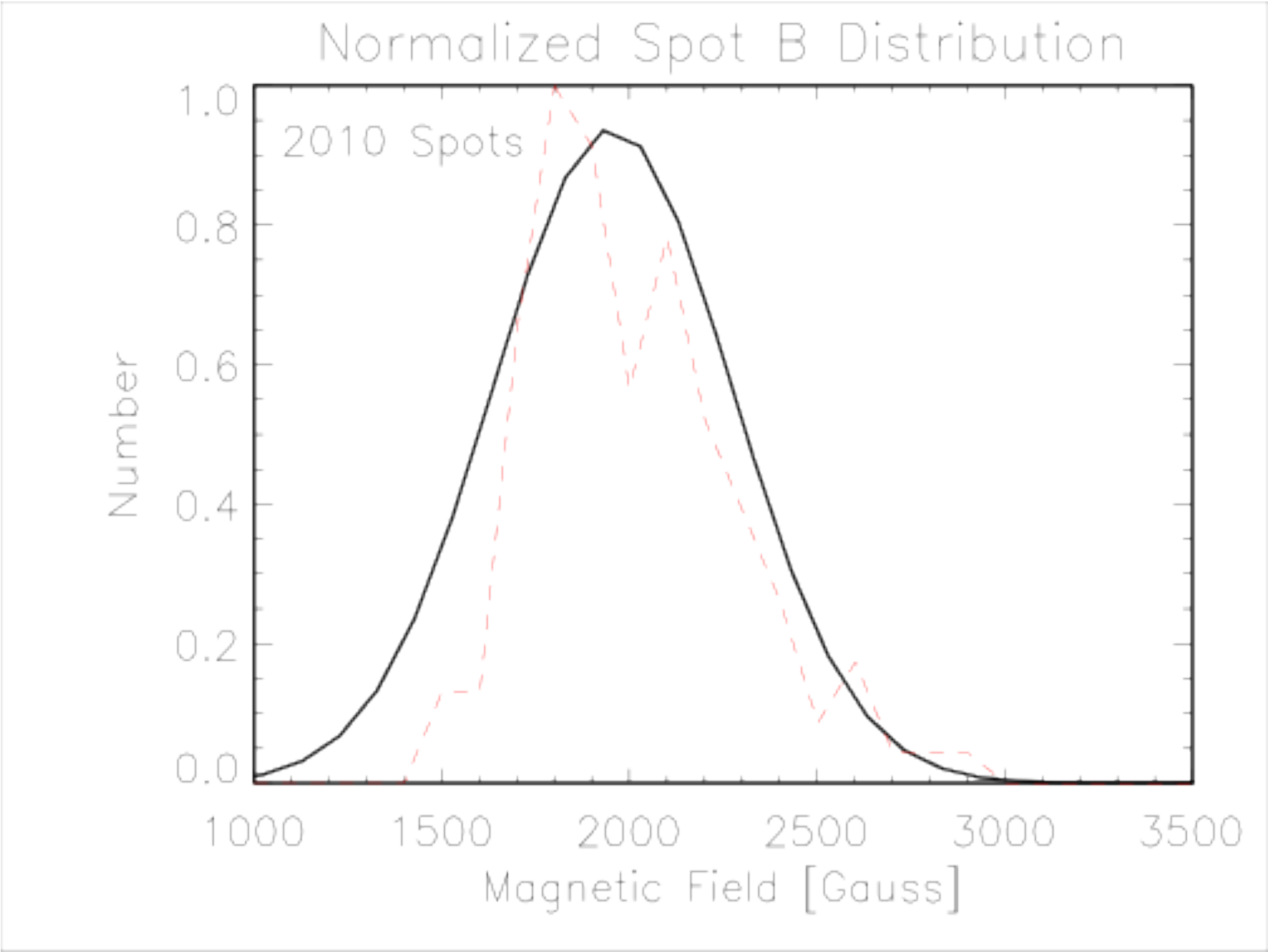
Superposed epoch analysis of changes in subsurface vorticity below ~1000 active regions. Time series were shifted so that a flare occurred on day 0. Red: X-class flares; blue: M-class; cyan: C-class; green: no flare normalization.

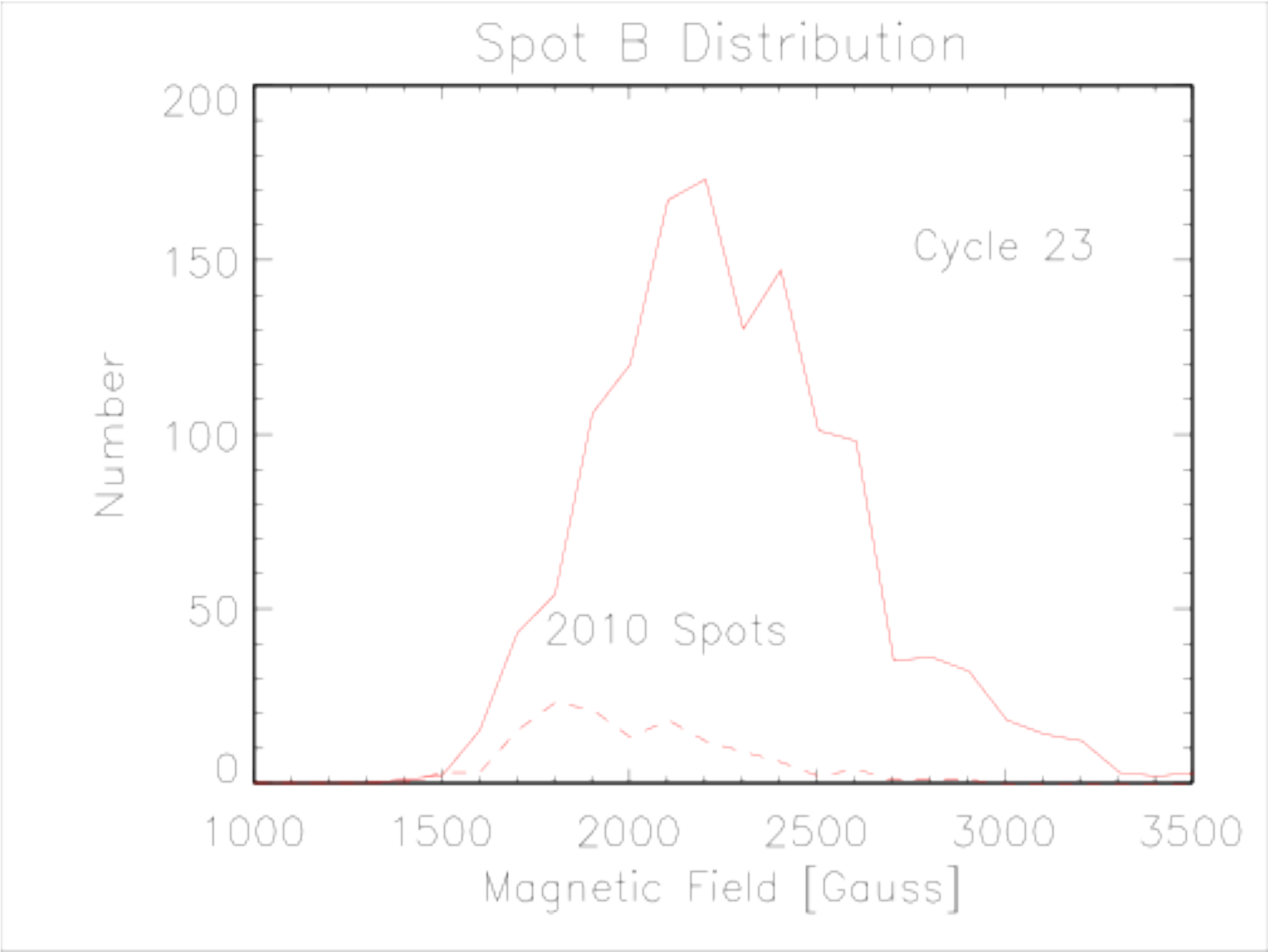


courtesy W. Livingston, NSO


Normalized Spot B Distribution
Cycle 23
Number
1.0
0.8
0.6
0.4
0.2
0.0
1000
1500
2000
2500
3000
3500
Magnetic Field [Gauss]


Normalized Spot B Distribution
2010 Spots
Cycle 23
Number
1.0
0.8
0.6
0.4
0.2
0.0
1000
1500
2000
2500
3000
3500
Magnetic Field [Gauss]


Normalized Spot B Distribution
2010 Spots
Number
1.0
0.8
0.6
0.4
0.2
0.0
1000
1500
2000
2500
3000
3500
Magnetic Field [Gauss]


Spot B Distribution
Cycle 23
2010 Spots
Number
200
150
100
50
0
1000
1500
2000
2500
3000
3500
Magnetic Field [Gauss]