Long-term Evolution of the Solar Corona using PROBA2 Data

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Introduction

Aim: to study the evolution of the solar corona between January 2010 and June 2019 (CR from 2093 to 2218), by using data from:

- PROBA2 (SWAP and LYRA): proba2.sidc.be/
- International Sunspot Number (ISN; version 2.0) dataset: sidc.oma.be/silso/
- The solar polar magnetic field strength: wso.stanford.edu/

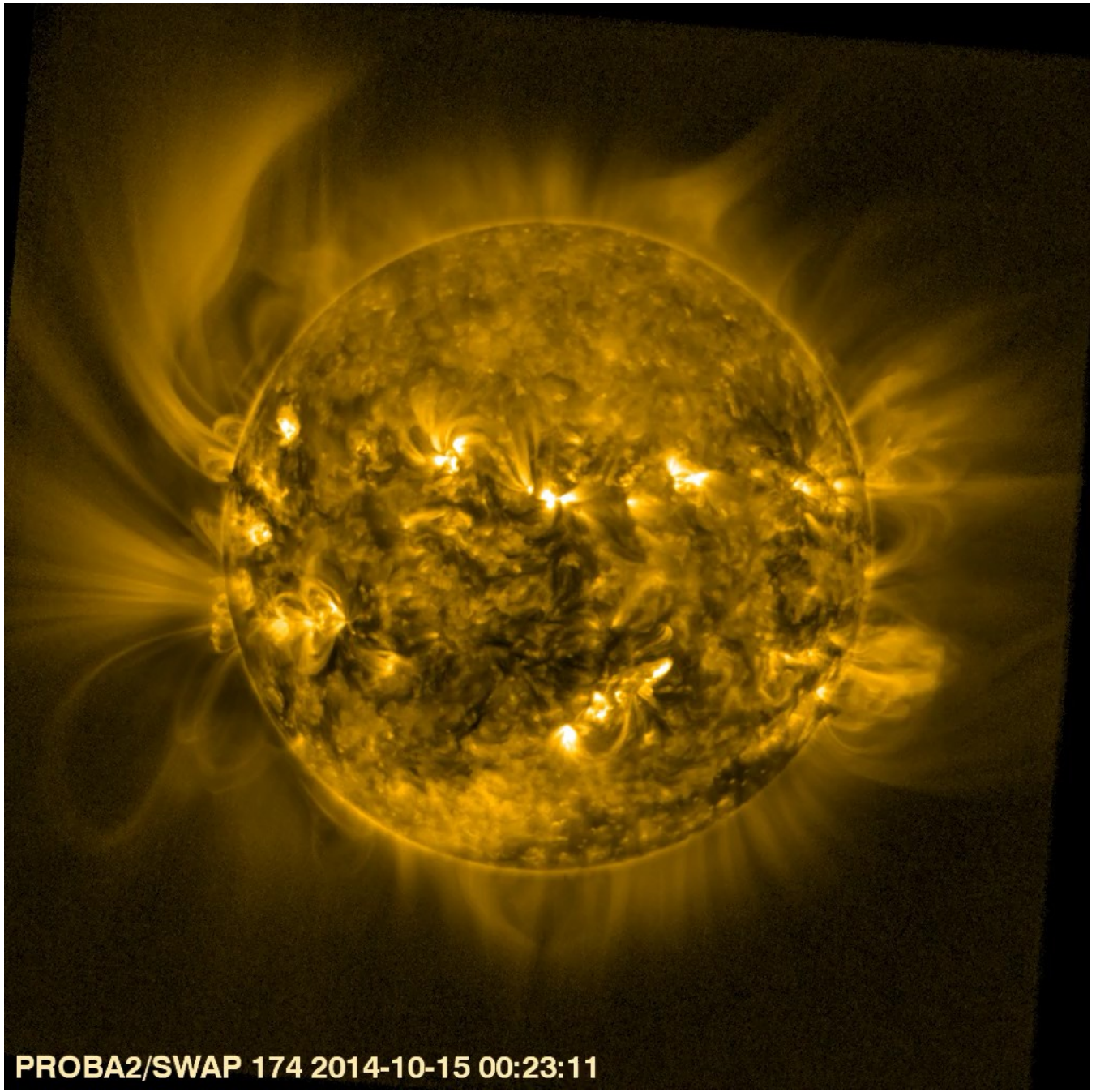
What:

- Solar-cycle evolution
- Dynamics of the solar features in terms of solar rotation
- Polar magnetic field reversal
- Evolution of large scale coronal features:
  - Loops
  - Streamers
  - Pseudostreamers
  - Coronal fans
  - Coronal holes

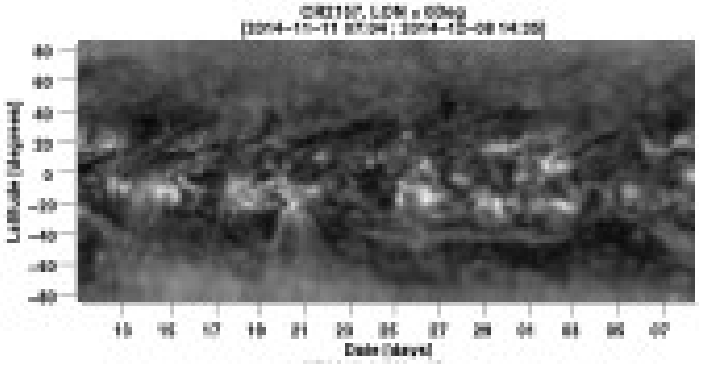
Processing SWAP images

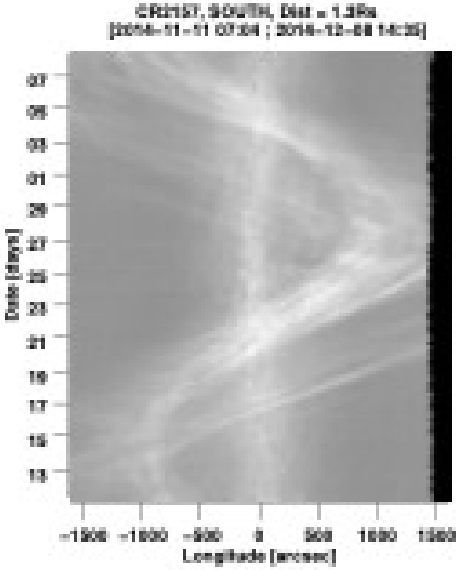
1. PROBA2/SWAP level 0 images are calibrated using the SolarSoft IDL routine p2sw_prep.pro
2. Dark current subtraction,
3. Flat-field correction,
4. Point-spread function (PSF) deconvolution,
5. The Sun is centered and rotated with its north pole up in the image frame.
6. Combine the calibrated images inside blocks of 100 minutes of observation and construct a new composite image by computing the median value of every pixel in these subset of images.
7. These images are then grouped in Carrington Rotation (CR) intervals.

Example CR image

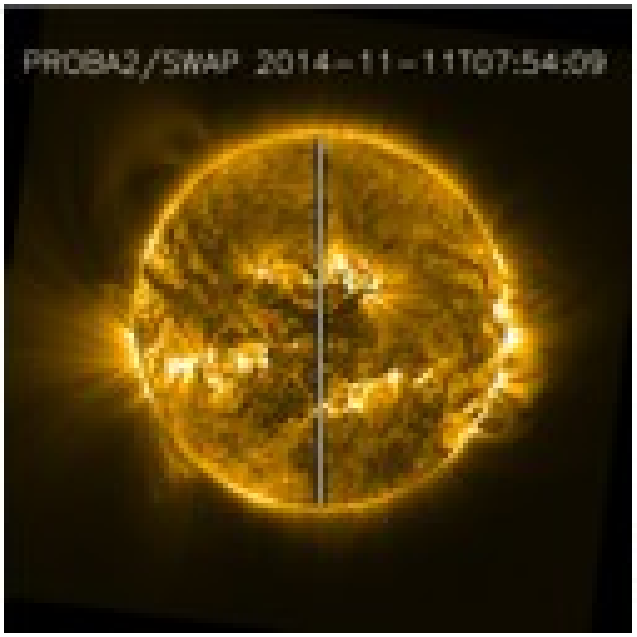


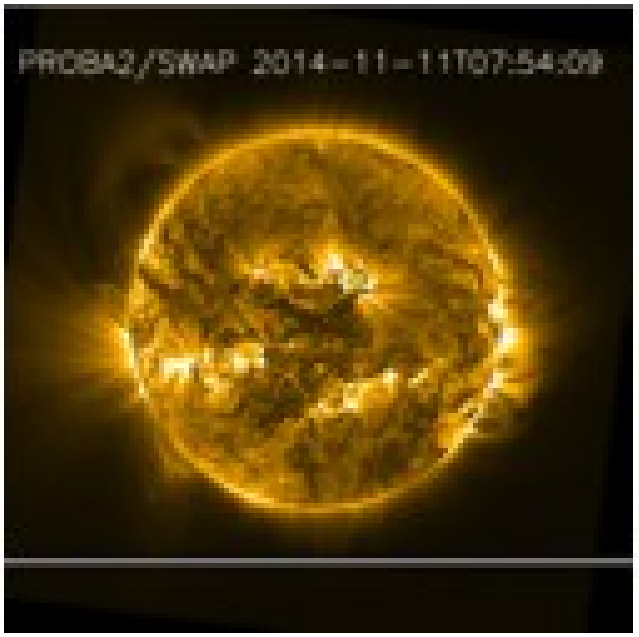
Building the maps and the average plots

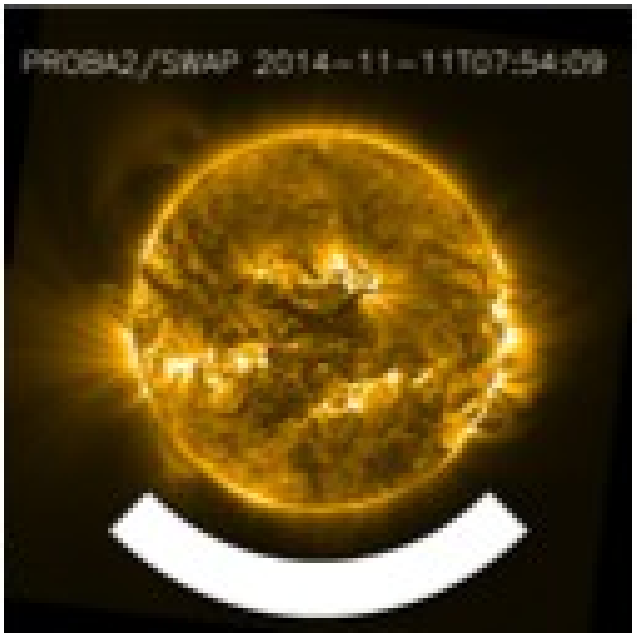




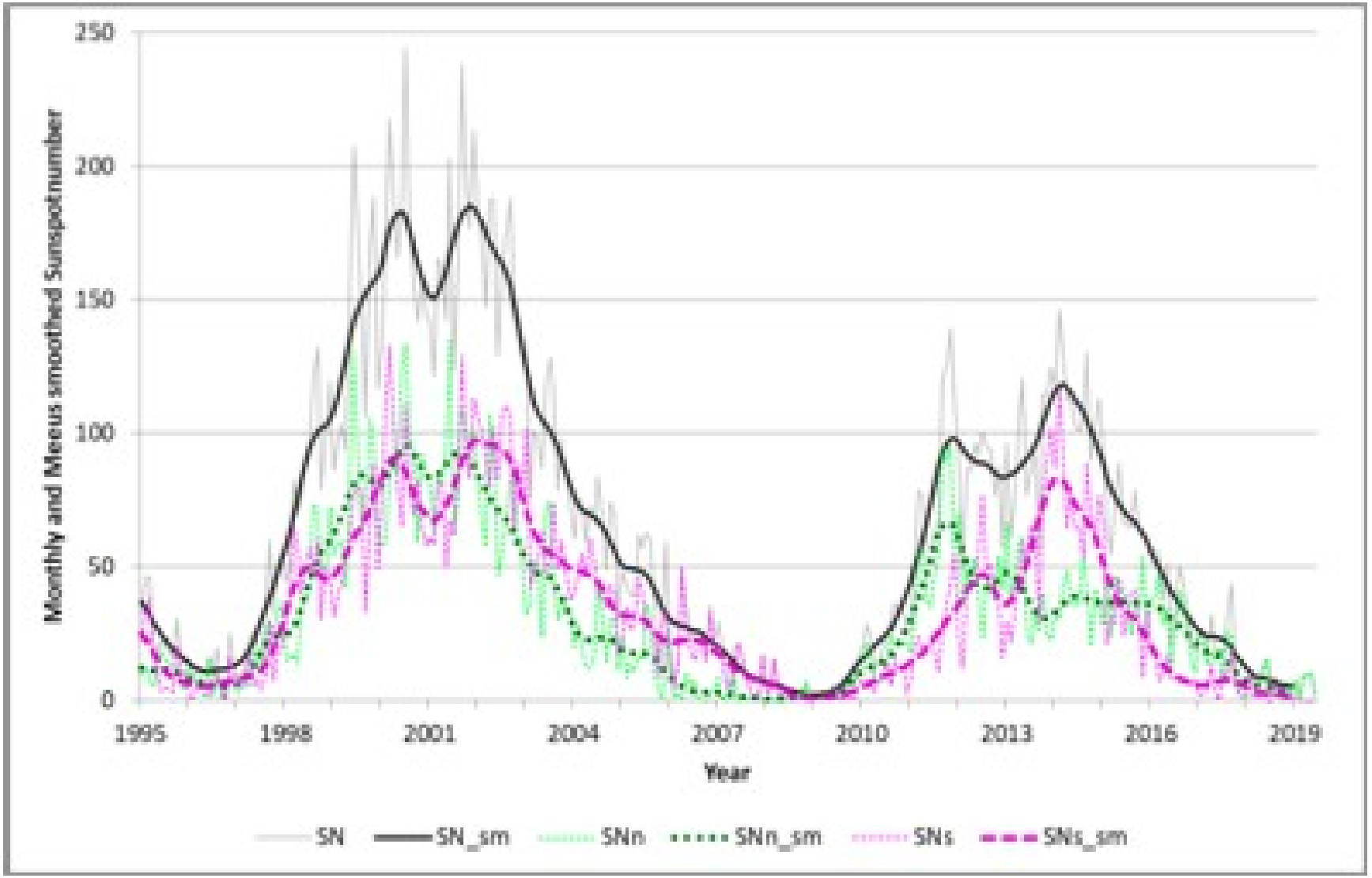
The mean brightness in each sector.



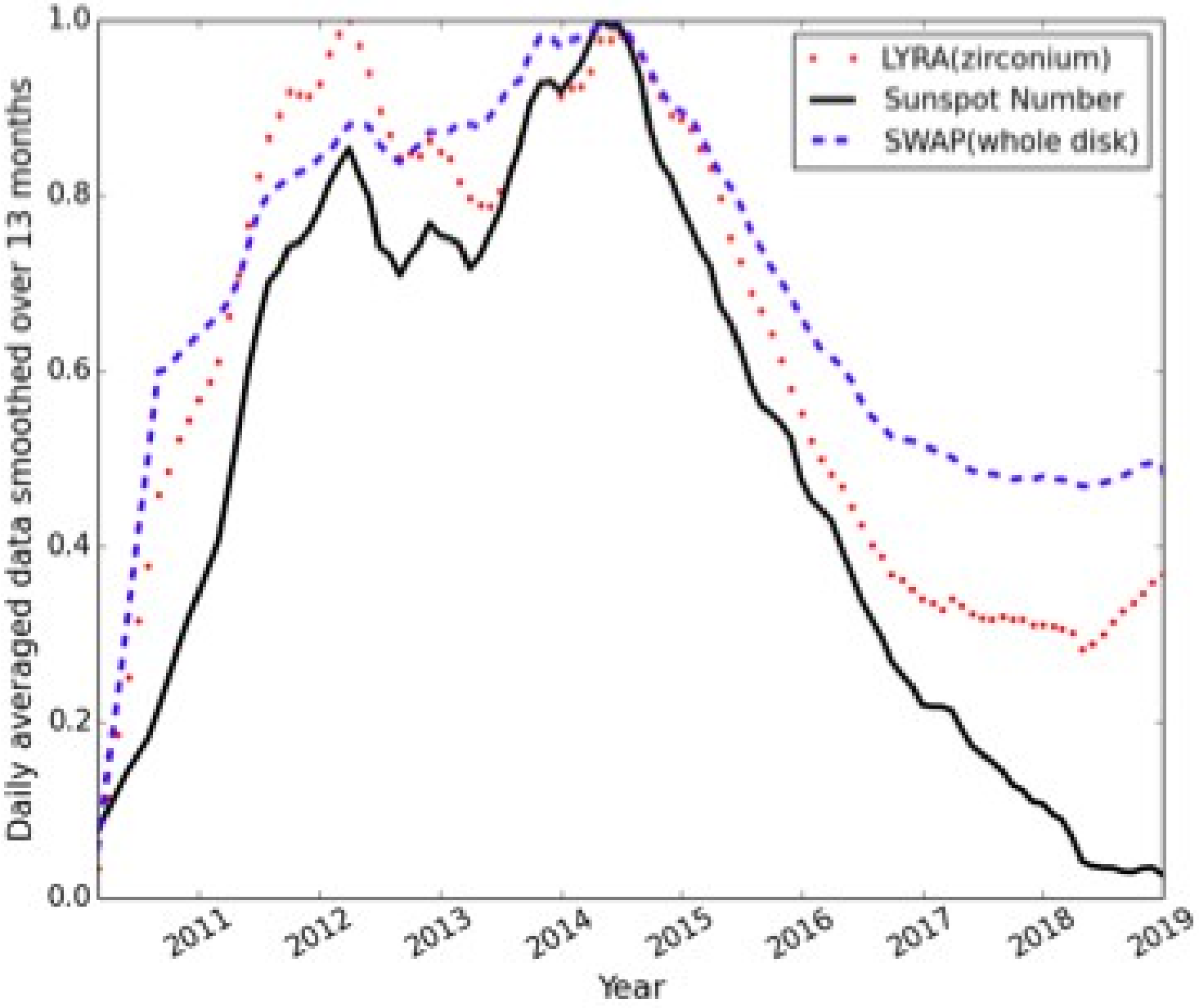




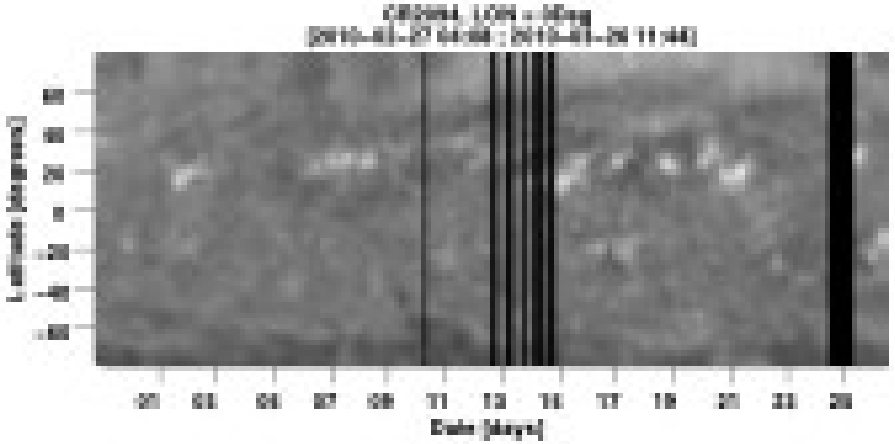
Solar-cycle evolution

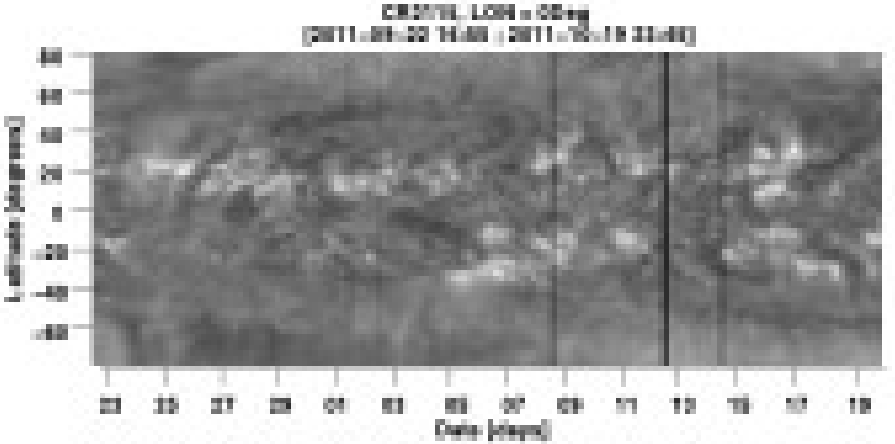


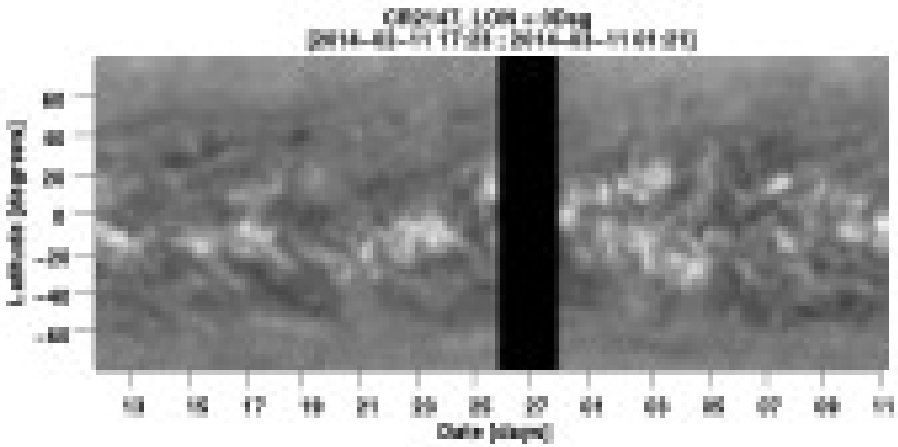
Solar-cycle evolution

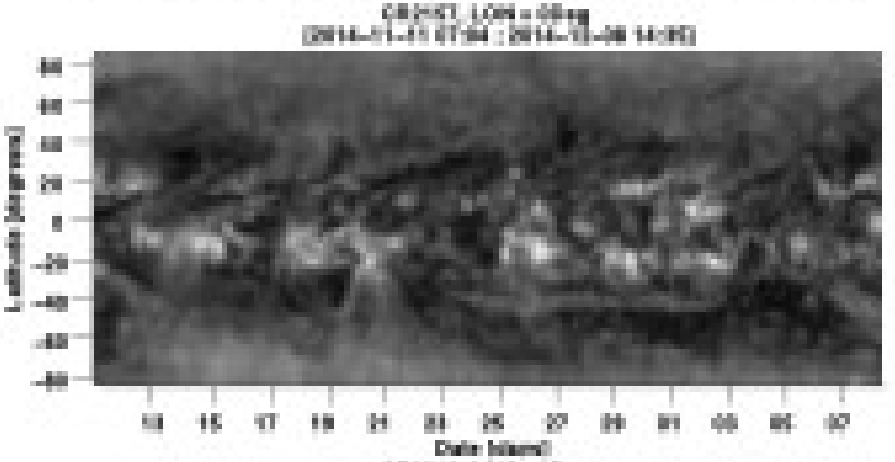


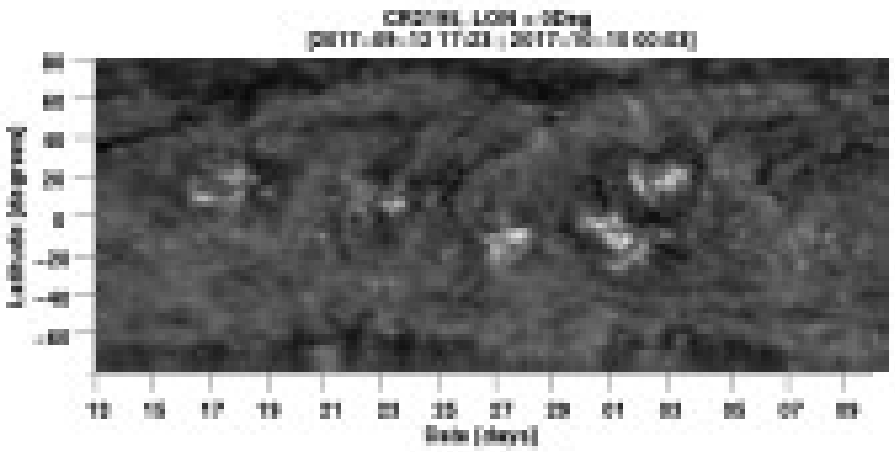
Solar-cycle evolution

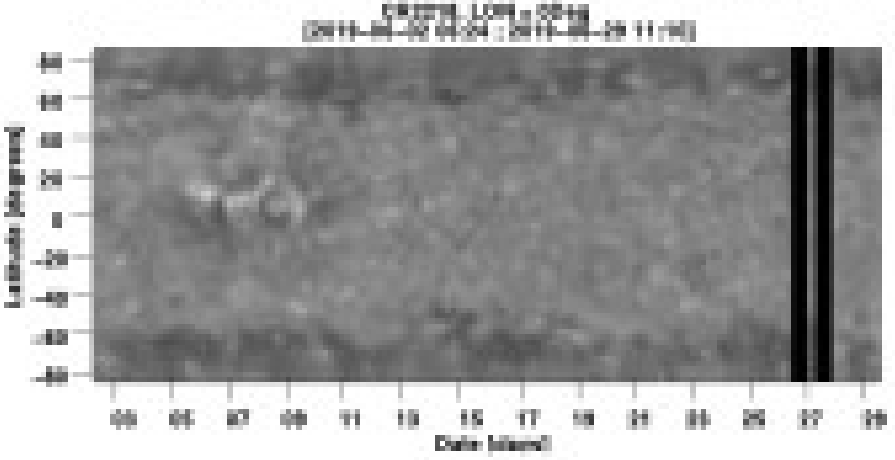








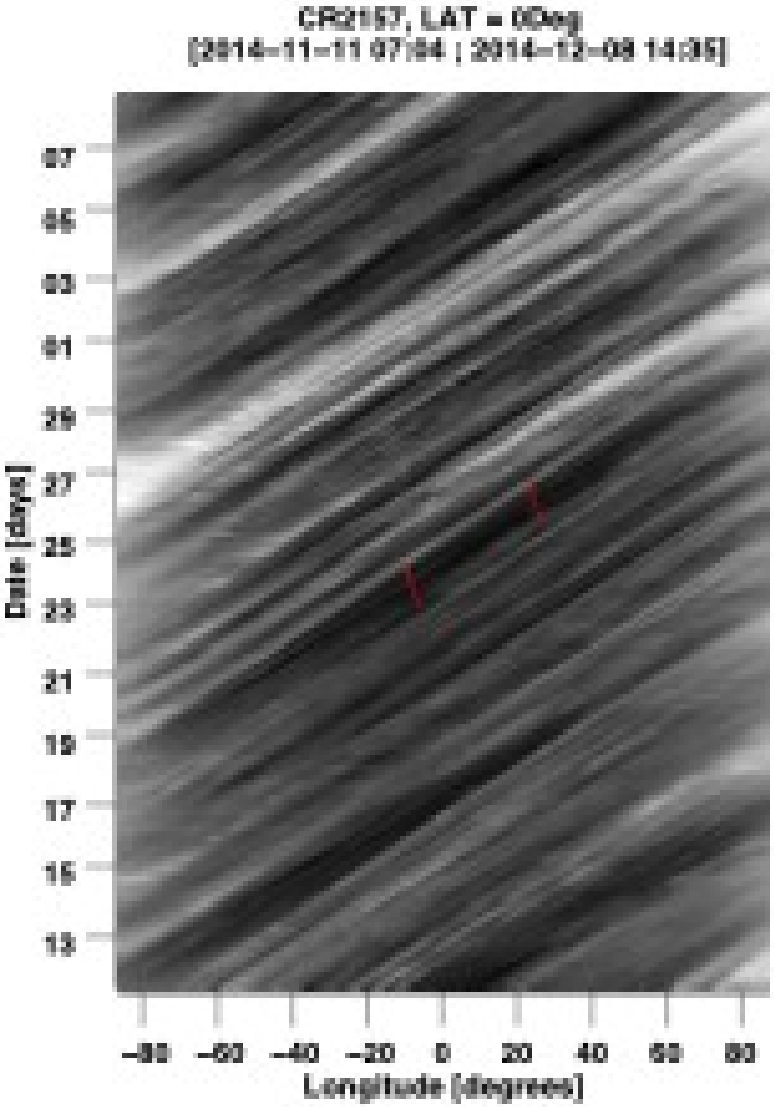




Dynamics of the Solar Features in Terms of the Solar Rotation

Any long-lasting features on the solar disk (e.g., bright ARs or dark filaments/CHs) can be seen as bright or dark stripes, respectively, in these synoptic maps.

- Some bright stripes span the full longitude range, from -90° to 90°.
- Some appear and/or disappear at different longitudes, suggesting the birth and/or fading of the solar features at those locations.



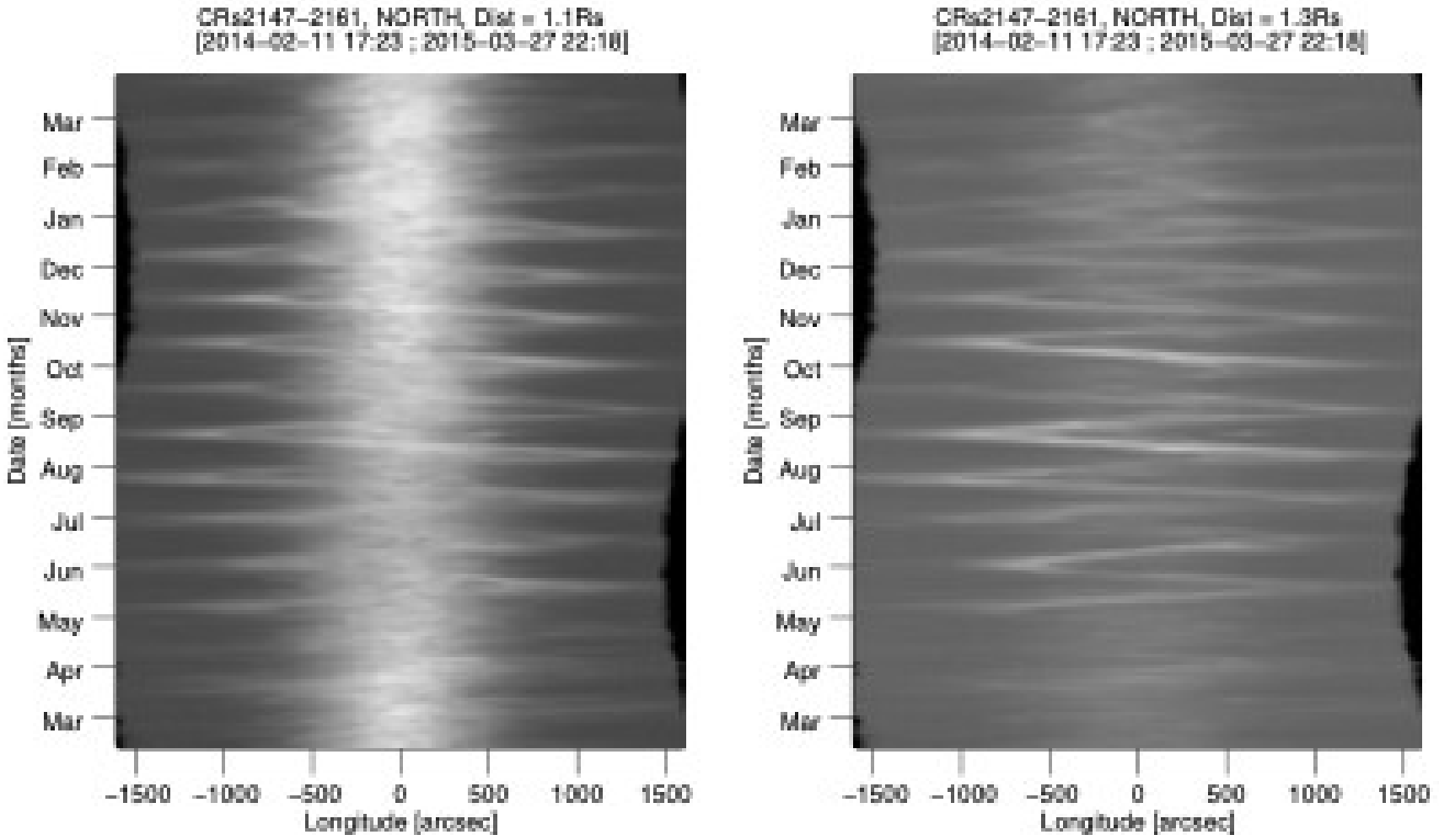
SWAP East–West (EW) synoptic map for CR 2157.

Dynamics of the Solar Features in Terms of the Solar Rotation

CRs	CR starting date	S15	0	N15	Mean
2098	2010.06	13.65	15.51*	14.15	14.43
2111	2011.06	14.39	14.70*	14.89	14.66
2124	2012.06	14.74	15.80	14.35	14.96
2138	2013.06	14.22	14.42	13.97	14.20
2151	2014.06	14.22	14.33	14.28	14.27
2164	2015.06	14.98	15.72	14.60	15.10
2178	2016.06	14.34	16.16*	13.80*	14.76
2191	2017.06	15.07*	16.15*	15.16	15.46
2205	2018.06	15.36*	14.81	14.94	15.03
2218	2019.06	13.77*	15.12	14.70	14.53
Mean	-	14.47	15.27	14.48	**14.74**

Rotation rates [degree/day] of bright features at three different latitudes: S15, 0, N15 for CRs in June, for each year from 2010 to 2019. The values with stars indicate a very small stripe from which the rotation speed was calculated. The CR starting date is in the format yyyy.mm

Evolution of Large Scale Coronal Structures

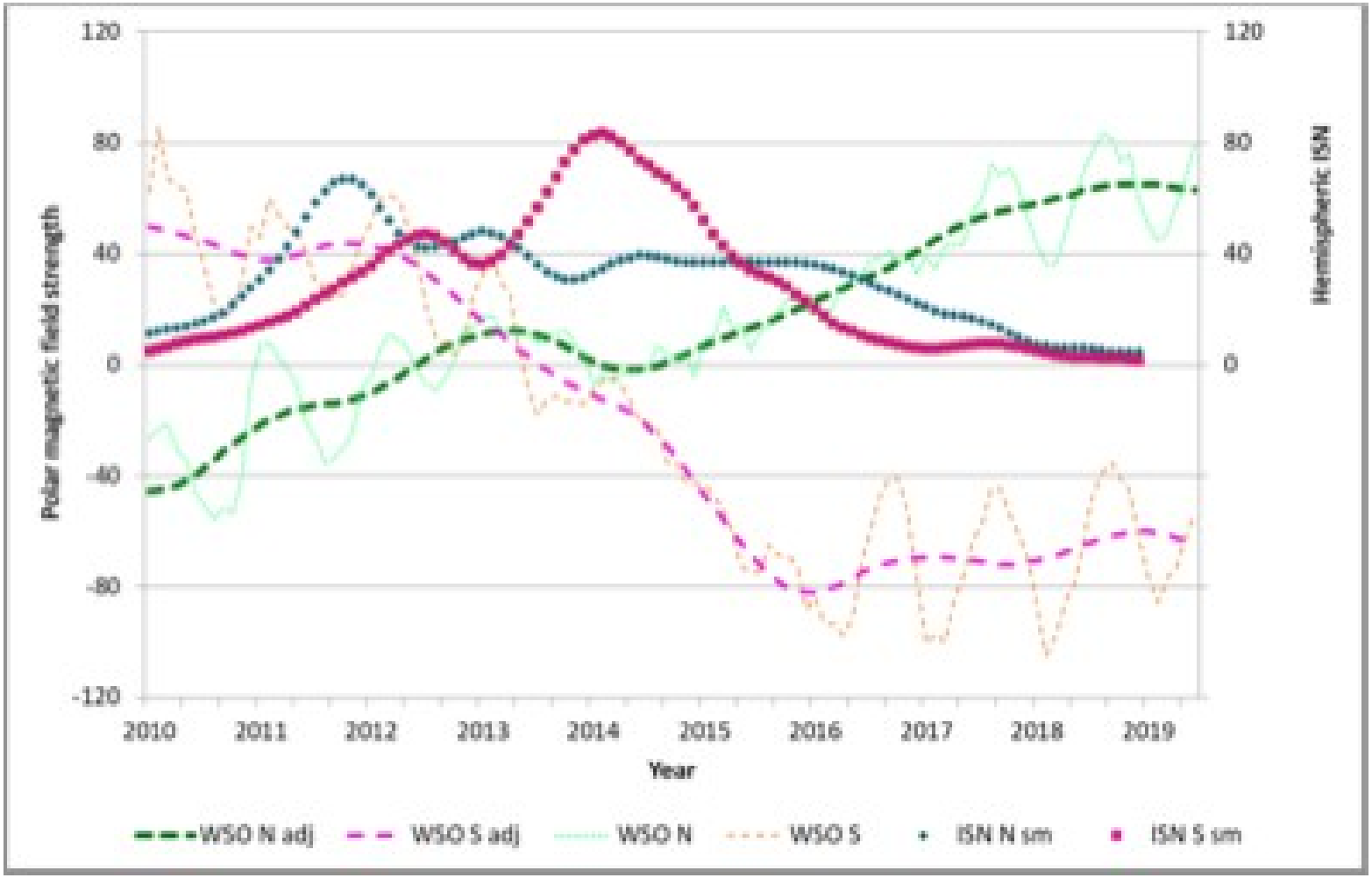


SWAP EW off-limb synoptic map (or off-limb time-longitude maps) for CRs 2147 to 2161 at North Pole for the central distance of 1.1 and 1.3 Rs from the Sun center.

Evolution of the Average Solar Corona at Poles

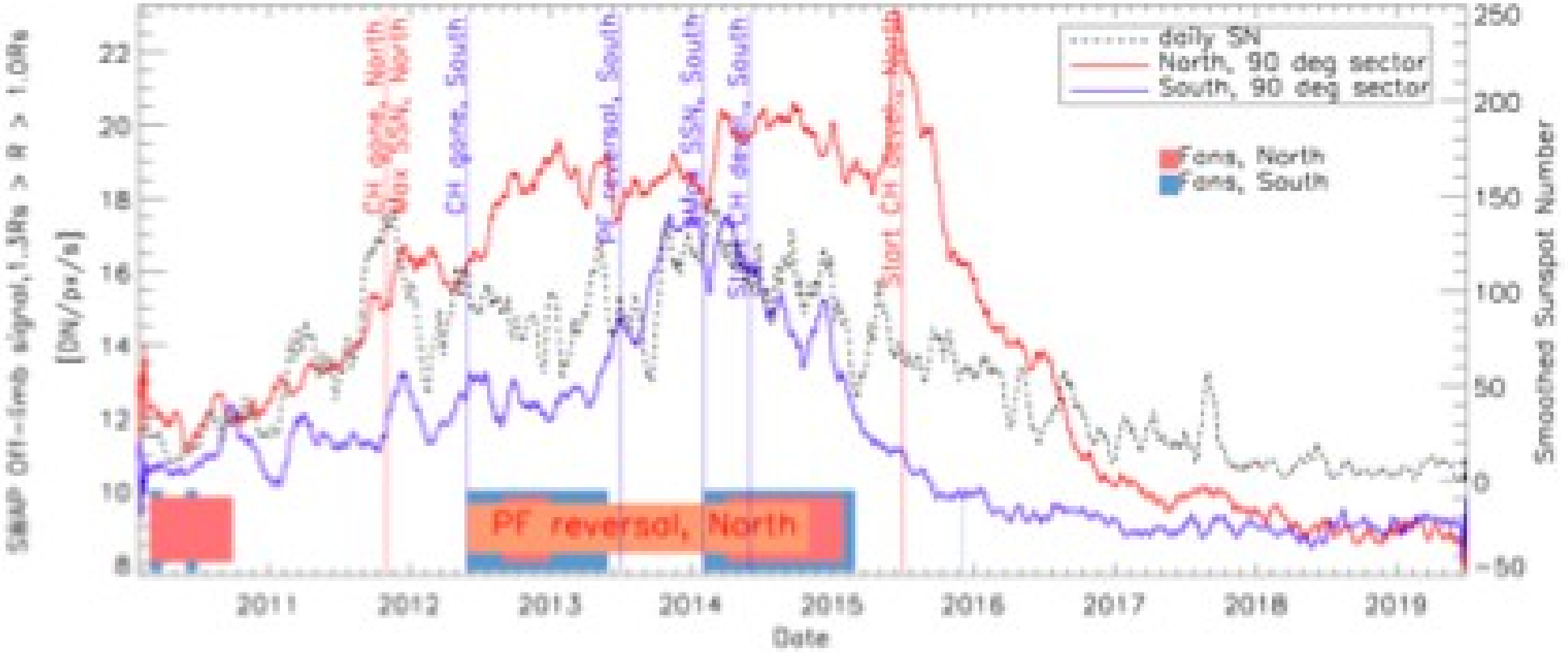
The average solar corona at poles [DN/s] (sector of 90 degree centered on the pole), from 1 Rs to 1.3 Rs. Black curve represents north pole and red south pole.

Magnetic Field Reversal



Polar magnetic field strength (WSO) and sunspot numbers (SILSO) per solar hemisphere. The magnetic field strength is expressed in 0.01 Gauss.

Time-line of the events



Summary of polar phenomena in SC24.

Time line of the events

Table 4. Summary of polar phenomena in SC24. Time is expressed in year.month. CH = Coronal Hole and PF = Polar Field.

Time	North	South
2010.03–2010.04		Coronal fan (Talpeanu, 2016)
2010.03–2010.10	3 Coronal fans (Talpeanu, 2016)	
2010.06–2010.07		Coronal fan (Talpeanu, 2016)
2011.11	Polar CH gone	
2011.11	Max. sunspot number	
2012.06		Polar CH gone
2012.06	Starts PF reversal	
2012.06–2013.06		Pseudostreamer (Seaton *et al.*, 2013a)
2012.07–2012.10		2 Coronal fans (Talpeanu, 2016)
2012.09–2013.01	Coronal fan (Talpeanu, 2016)	
2013.01		Coronal fan (Talpeanu, 2016)
2013.05		Pseudostreamer (Rachmeler *et al.*, 2014)
2013.07		PF reversal
2014.02		Max sunspot number
2014.02–2015.03		Pseudostreamer (Guennou *et al.*, 2016)
2014.04–2015.02	3 Coronal fans (Talpeanu, 2016)	
2014.06		Start polar CH development
2014.11	End PF reversal	
2014.11		Pseudostreamer
2014.12		Peak (spike) SWAP
2015.06	Peak (spike) SWAP	
2015.07	Start polar CH development	
2015.12		Pseudostreamer
2017.06–2017.10	Max. magnetic field	

Summary

- The three time series (SWAP on-disk average brightness, sunspot number and LYRA irradiance) are very well correlated, with correlation coefficients around 0.9.

- More ARs started to appear (starting in the northern hemisphere) in February 2011 and they became less frequent beginning in December 2016, reaching a very low number from September 2017 onward, indicating the passage from solar minimum to maximum and back again.

- The average rotation rate of bright features at latitudes of +15°, 0°, and -15° was around 15 deg/day throughout the period studied.

Summary

- Large-scale off-limb structures were visible from around March 2010 to around March 2016, meaning that they were absent at the minimum phase of solar activity.

- A fan at the North pole persisted for more than 11 Carrington rotations (February 2014 to March 2015), and it could be seen up to altitudes of 1.6Rs.

- A secondary peak in EUV averaged intensity at the Poles was observed on the descending phase of SC24. These peaks (at North and South poles respectively) seem to be associated with the start of the development of the (polar) coronal holes.

Mierla et al. 2020, SolPhys, PROBA2 topical collection

Future work – use SOLO/FSI data