SH11A-2220: The McIntosh Archive: A solar feature database spanning four solar cycles

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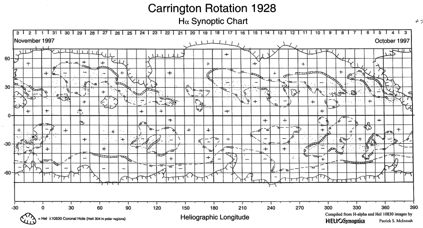
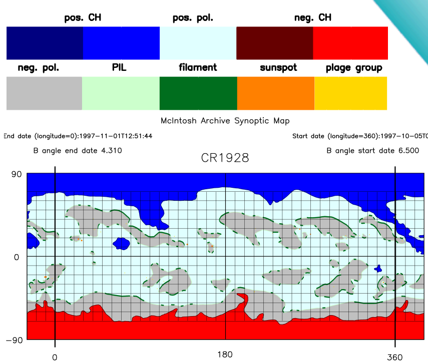


Fig. 1: The McIntosh Archive (McA) synoptic maps are a global representation of the evolving solar magnetic field. Over the four decades of their creation, McIntosh used Hα daily images to determine the polarity inversion line (PIL) (McIntosh, 1979). From 1981 onwards, the maps included coronal holes as a standard feature, primarily based upon ground-based He-I 10830 Angstrom images from NSO-Kitt Peak. Magnetograms were used, when available, to determine the overall dominant polarity of each region. **(Above)** Example of original, hand-drawn McA synoptic solar map. Magnetic polarity is indicated by +/-; polarity inversion lines (PILS) are dashed, with filaments shown as extensions of the PILs; coronal hole boundaries are indicated by hashed lines; plage by light dots, and sunspots by darker dots. **(Below)** Example of processed McA synoptic solar map for the same Carrington rotation. Magnetic features are identified by a distinct number that may be represented as a color, as described in the legend. Thus far SC 23 has been processed.



Introduction

In 1964 (Solar Cycle 20; SC 20), Patrick McIntosh began creating hand-drawn synoptic maps of solar magnetic features, based on Hα images. These synoptic maps were unique in that they traced magnetic polarity inversion lines, and connected widely separated filaments, fibril patterns, and plage corridors to reveal the large-scale organization of the solar magnetic field (**Fig. 1, top**). Coronal hole boundaries were later added to the maps, which were produced, more or less continuously, into 2009 (i.e., the start of SC 24). The result was a record of ~45 years, ~570 Carrington rotations (CROTs), or nearly four complete solar cycles of synoptic maps. We are currently scanning, digitizing and archiving these maps, with the final, searchable versions (**Fig. 1, bottom**) publicly available at NOAA's National Centers for Environmental Information. In this paper we present preliminary scientific studies using the archived maps from SC 23. We show the global evolution of closed magnetic structures (e.g., sunspots, plage, and filaments) in relation to open magnetic structures (e.g., coronal holes), and examine how both relate to the shifting patterns of large-scale positive and negative polarity regions.

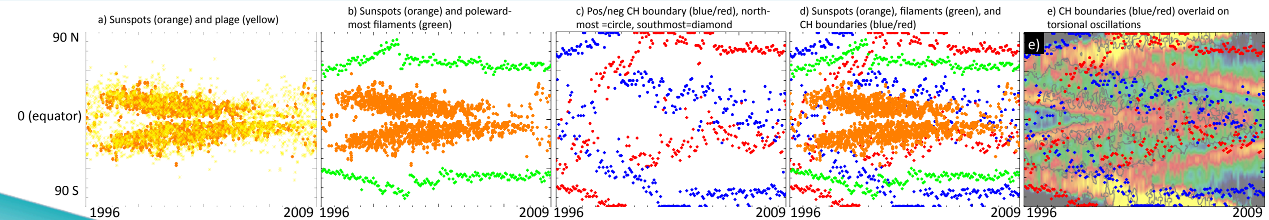


Fig. 4: Open vs. closed magnetic field evolution over SC 23. a) Classic butterfly diagram of sunspots (orange) and plage (yellow). **b)** Sunspots with location of most poleward filament per CROT (green), showing "rush to the poles" and reformation of polar crown filament (e.g., McIntosh, 1992). **c)** Coronal hole boundaries (red=negative, blue=positive; furthest north per CROT=circles, furthest south=diamonds). For most CROTs (other than at maximum): a polar and a low-latitude coronal hole boundary extent is shown, for both polarities, creating a double-helix pattern (S. McIntosh et al. (2014); see also Webb et al. (1984), Harvey & Recely (2002), Bilenko & Tavastsherna (2016), Fujiki et al. (2016)). **d)** Composite of **b)** and **c)**. **e)** Coronal hole plot overlaid on a plot of the zonal flows (torsional oscillations) of the near-surface (0.99R) magnetic field from GONG, MDI, and HMI data, covering the period from 1995 to the present (from Howe, 2016; prepared by R. Komm).

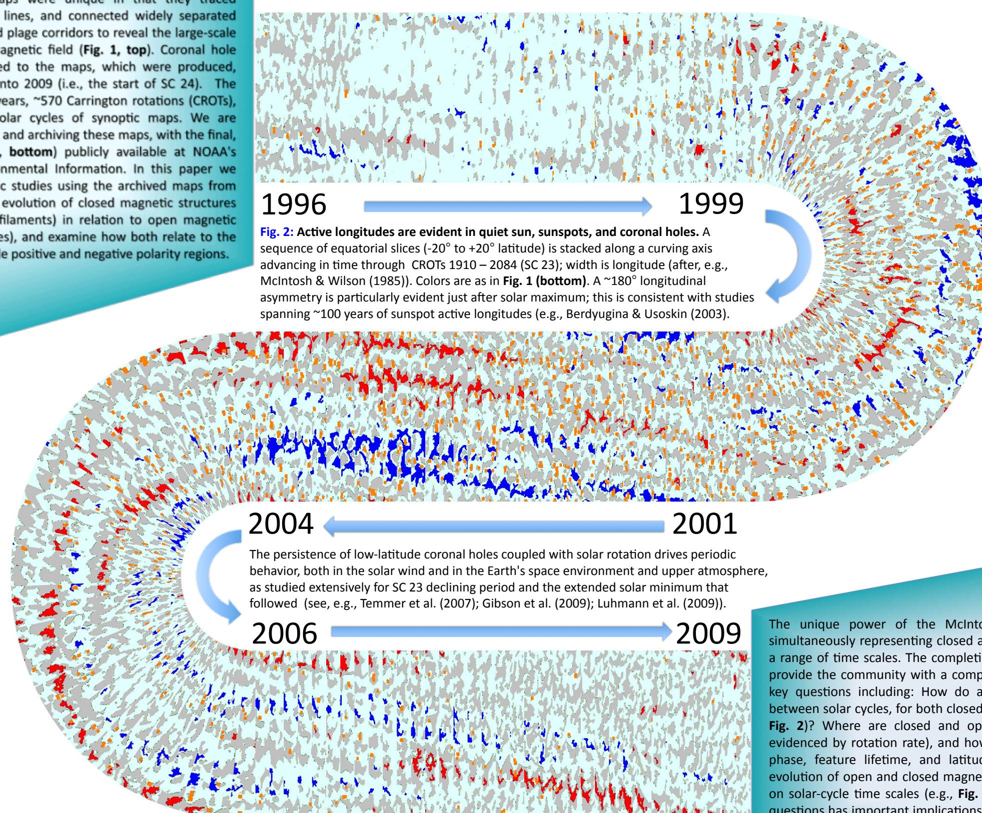


Fig. 2: Active longitudes are evident in quiet sun, sunspots, and coronal holes. A sequence of equatorial slices (-20° to +20° latitude) is stacked along a curving axis advancing in time through CROTs 1910 – 2084 (SC 23); width is longitude (after, e.g., McIntosh & Wilson (1985)). Colors are as in **Fig. 1 (bottom)**. A ~180° longitudinal asymmetry is particularly evident just after solar maximum; this is consistent with studies spanning ~100 years of sunspot active longitudes (e.g., Berdyugina & Usoskin (2003).

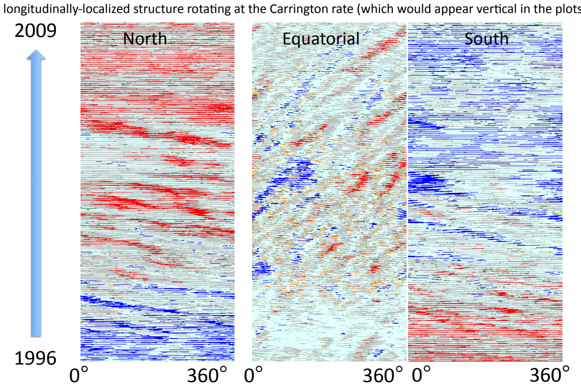
The persistence of low-latitude coronal holes coupled with solar rotation drives periodic behavior, both in the solar wind and in the Earth's space environment and upper atmosphere, as studied extensively for SC 23 declining period and the extended solar minimum that followed (see, e.g., Temmer et al. (2007); Gibson et al. (2009); Luhmann et al. (2009)).

We dedicate this project to Pat McIntosh, who died this year. We are grateful to his daughter Beth Schmidt for granting us permission to use Pat's original data. We thank Don Kolinski for assistance with the "snake". This work is supported by NSF RAPID grant #1540544, and by NCAR, which is funded by the NSF.

The McIntosh Archive is available via

https://data.noaa.gov/dataset/solar-imagery-composites-synoptic-maps-mcintosh/

Fig. 3: (below) Magnetic feature rotation rates vary with latitude, solar-cycle phase. SC 23 stack plots for **(left)** North polar zone: 30° to 70° latitude, **(middle)** Equatorial zone: -20° to +20°, and **(right)** South polar zone: -30° to -70° degrees, for all of SC23. Horizontal axes = longitude. The Carrington rate (27.2753 days as viewed from the Earth) corresponds to a mid-latitude surface rotation rate, so equatorial zone features generally rotate faster, and polar features slower than a longitudinally-localized structure rotating at the Carrington rate (which would appear vertical in the plots below).



Conclusions

The unique power of the McIntosh archive is its capability for simultaneously representing closed and open magnetic structures over a range of time scales. The completion of the full McA digitization will provide the community with a comprehensive resource for addressing key questions including: How do active longitudes vary within and between solar cycles, for both closed and open magnetic features (e.g., **Fig. 2**)? Where are closed and open magnetic features rooted (as evidenced by rotation rate), and how does this depend on solar cycle phase, feature lifetime, and latitude (e.g., **Fig. 3**)? How does the evolution of open and closed magnetic features relate to surface flows on solar-cycle time scales (e.g., **Fig. 4**)? Answering any or all of these questions has important implications for our understanding of the solar dynamo, and for our interpretation of periodic variations of Earth's space environment and upper atmosphere.

Berdyugina, S. V. & Usoskin, I. G. 2003, A&A, 405, 1121
Bilenko, I. A., Tavastsherna, K. S. 2016, SP, 291, 2329
Fujiki, K. et al., 2016, APJL, 827, L41
Gibson, S. E. et al., B. J., 2009, JGR, 114, A09105
Harvey, K. L. & Recely, F. 2002, SP, 211, 31
Howe, R., 2016, *Asian Journal of Physics*, **25**, 311
Luhmann, J. G. et al., 2009, SP, 256, 285
McIntosh, P. S. 1975, UAG-40 (NOAA/SEL, Boulder, CO)
McIntosh, P. S. 1992, in *The Solar Cycle* (ASP: San Francisco), 27, 14
McIntosh, P. S. & Wilson, P. R. 1985, SP, 97, 59
McIntosh, S. W. et al., 2014, APJ, 792, 12
Temmer, M., Vrsnak, B., & Veronig, A. M. 2007, SP, 241, 371
Webb, D. F., Davis, J. M., & McIntosh, P. S. 1984 SP, 92, 109