As of 11 Jul 2016 (Dave Webb, Boston College)

Preserving a Unique Archive for Long-Term Solar Variability Studies

1. Background

In October of 1964 Patrick McIntosh began creating hand-drawn synoptic maps of solar activity based on hydrogen-alpha line (Hα) measurements. Hα is the primary line of hydrogen and is formed in the chromosphere. By carefully tracing Hα observations of filaments, fibril patterns and plage corridors (dark lanes within active regions), the global structure of the polarity inversion line (PIL) could be determined. At the time, magnetographs were expensive and the resultant magnetograms were not routinely available. Another advantage of Hα measurements vs. magnetographs was that PILs could be more precisely determined in weak field regions and near the poles of the Sun (Fox et al. 1998, McIntosh 2003).

It has been shown that the large-scale Hα patterns on the surface match well the large-scale magnetic fields measured with magnetographs (e.g., McIntosh 1979). Filaments observed in Hα mark the boundary between areas of opposite magnetic polarity – the so-called neutral line or PIL. McIntosh (1972) described the five basic structures seen on Hα photographs: filaments, filament channels, fibrils, arch-filament systems and plage corridors. These features align with the PIL and can be linked to provide a global view of the large-scale solar magnetic field, particularly when viewed for a full Carrington rotation (CR - McIntosh 1972). Individual maps were made of each CR by compiling carefully hand-drawn daily images. In these synoptic maps, features such as coronal holes (CHs) and active regions were shown at their maximum extent and the large-scale evolution of features such as filaments was indicated.

For synoptic maps in solar cycles 20-21, Hα photographs from Big Bear, National Solar Observatory (NSO), and Arecibo Observatories were used. Improved images in Hα from ground-based observatories in 1998 and again in 2005 provided the ability to include changes in the development and evolution of filaments (especially in the polar crowns) and active regions on the maps. CHs were added to the maps starting in 1978 and consistently since 1981, primarily using ground-based He I 10830Å images. Magnetograms were used, when available, to determine the overall dominant polarity and to show where the polarities changed. Some of the original hand-drawn McIntosh maps were published as Upper Atmosphere Geophysics (UAG) reports in McIntosh (1975), McIntosh and Nolte (1975), and McIntosh (1979). Versions of the maps were also routinely published in the Solar-Geophysical Data (SGD) Bulletins (the "Yellow books") in the Prompt monthly reports. The UAG and SGD reports are all archived at the NOAA National Centers for Environmental Information (NCEI, formerly the National Geophysical Data Center).

McIntosh and his assistants created these synoptic maps for each CR during the interval 1964-2009, with the exception of a 2-year period from CR 1617-1642 (July 1974-June 1976). Thus, the synoptic maps cover more than 40 years, or nearly four complete solar cycles. Although scientists at the Meudon Observatory (France) and in Russia and China attempted to create similar maps in the 1970s and 1980s, those efforts were short-lived, making the McIntosh collection of maps a unique and consistent set of global solar magnetic field data.

Unfortunately, Pat McIntosh is now disabled from Alzheimer's disease and cannot continue the mapping. However, Ian Hewins and Robert McFadden were trained in the mapping by Pat and worked on this effort with him from 2000-2009. They have preserved all the mapping paperwork and some of the digital files. However, many of the original maps exist only on paper in boxes and are either in pencil or reproduced black-and-white images. Under an NSF grant, all of the existing mapping paperwork and digital files have been brought to HAO/NCAR, and our group is working to preserve this unique data set in digitized formats that will become a unique and powerful resource for the scientific community.

These maps provide a significant measurement of the evolution of large-scale solar features over

the course of four solar cycles. Once digitized, these maps can be used to measure the proportions of the solar surface exhibiting specific phenomena, and the locations of these features as a function of latitude and longitude (as defined by pixel location). The digitized data can be used to graph the proportions and their changes over time. This information will be useful in predicting the Sun's activity as a whole over a single cycle or over numerous cycles. It will also be useful for studying certain features such as filaments, CHs or plage regions, and their variations over time in terms of quantity, location or movement.

2. Previous Studies Using the Synoptic Maps

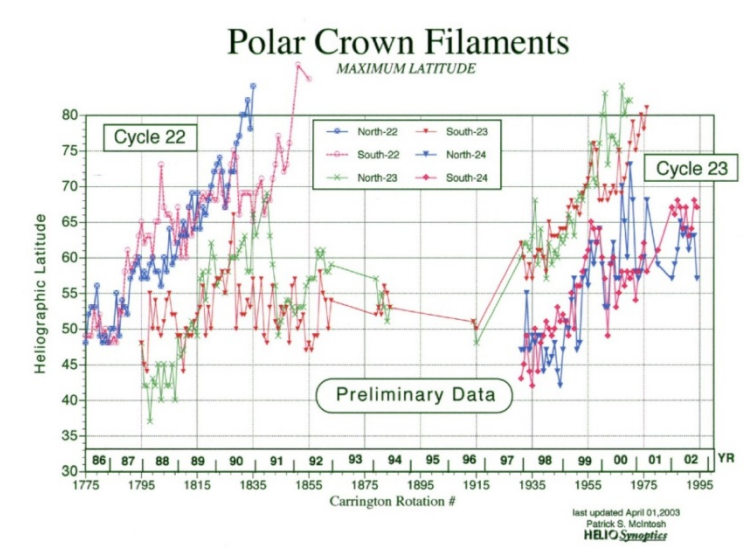

Figure 1. Location of the maximum latitude of PCFs during SCs 22 and 23 taken from McIntosh synoptic maps,

A variety of scientific discoveries have depended on the use of the synoptic maps (see McIntosh, 2003, for a review). For example, the maps have been used to describe the drift of polar crown filaments (PCFs) to higher and lower latitudes, the disappearance and reappearance of polar CHs, and the reversal of the polar magnetic field (e.g., Webb et al., 1978; 1984). *Figure 1* shows the location of the maximum latitude for the PCFs as traced on these synoptic maps, including the "secondary" PCF that appears at lower latitudes and replaces the "true" PCF after the solar magnetic field reverses. The lifetime of a PCF is about 15 years (McIntosh 1992). These motions give clues about the fluid dynamics of the Sun and its dynamo processes. McIntosh's maps have also been used to study the morphology and global context of coronal cavities, as part of a study of the nature of coronal mass ejection magnetic precursors (Gibson et al., 2010), and the global context of solar activity during the last solar minimum (Thompson et al., 2011; Webb et al., 2011).

The Hα synoptic maps have proved to be unique tools for studying the structure and evolution of the large-scale solar fields and polarity boundaries, because: 1) they have excellent spatial resolution for defining polarity boundaries, 2) the organization of the fields into long-lived, coherent features is clear, and 3) the data are relatively homogeneous back to the start of cycle 20 in 1964 (McIntosh & Wilson 1985). Time series zonal "stackplots" of the maps are invaluable in identifying and tracking large-scale features over solar-cycle time scales, including polarity boundaries, CHs, and active longitudes. An atlas of stackplots of the Hα synoptic charts covering two full solar cycles, from 1966-1987, was published by NOAA (McIntosh et al., 1991). Decadal stackplots have demonstrated the evolution of the polar crown gaps, polarity reversals and longitudinal pattern drifts that circle the Sun over a cycle (McIntosh & Wilson, 1985; McIntosh 2003). Their analysis led to the development of a model of flux emergence and surface evolution (McIntosh & Wilson 1985; Wilson & McIntosh 1991).

3. Implementation

To preserve the full archive of maps in a form readily accessible to the community, the best-available version of all the maps are being scanned into an initial electronic format. As part of the effort we are establishing a standard and searchable final format for the maps that utilizes 14 IDL

colors with specified RGB values to identify specific features. The features include filaments, large-scale positive and negative polarity regions, CHs of each polarity, CH boundaries, PILs, major sunspots, and plage areas. Over half of the maps in SC 23 have already been produced in colorized digital format; an example is shown in *Figure 2* for a CR during SC 23 maximum in March 2002. The polar CHs are visible, as well as several equatorial CHs. Filaments and the PIL are observed throughout the disk as are numerous sunspot and plage areas within active regions. The standard format for the final, processed maps will be based on a similar color-coding scheme for identifying solar features.

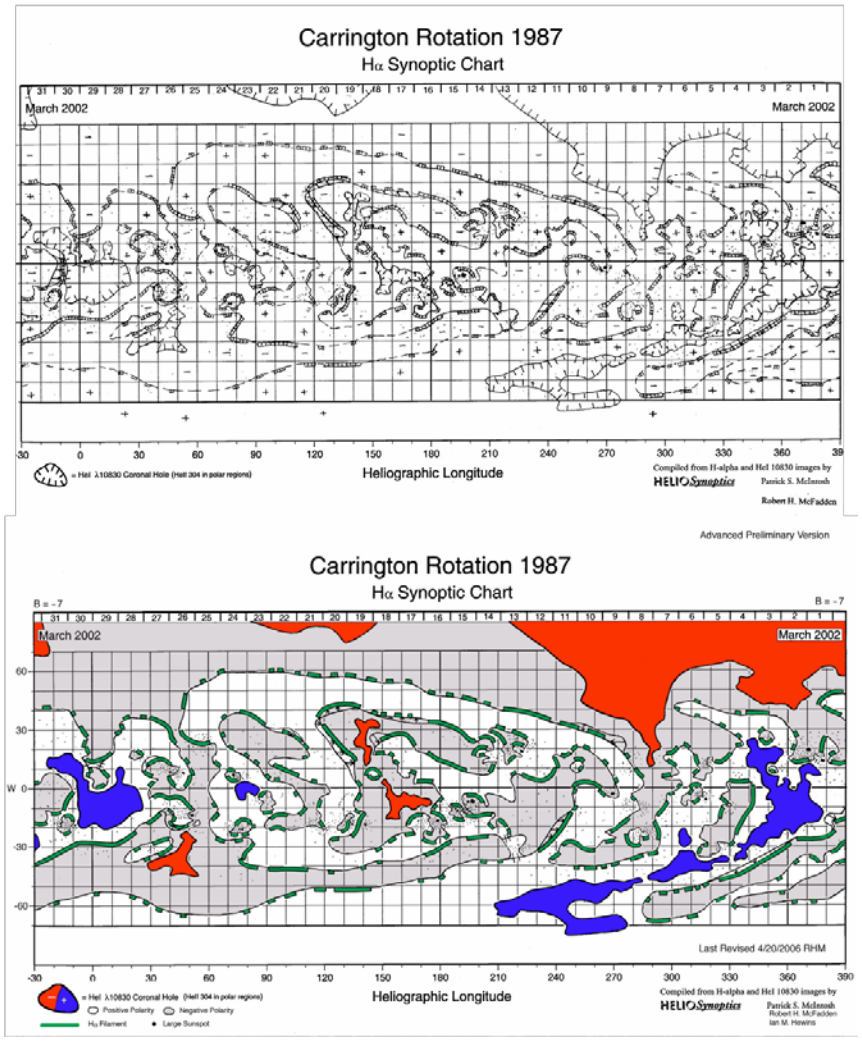

Figure 2. Top: scanned copy of original synoptic map, created by Pat McIntosh, from March 2002. Bottom: processed colorized map, with negative (red) and positive (blue) CHs, filaments (green), PIL (black) and negative (grey) and positive (white) polarity quiet Sun.

McIntosh's assistants Ian Hewins and Robert McFadden are doing most of the work to assure consistency over time. The original maps vary in size, but all are being scanned into a uniform format. We have begun the processing of the electronic maps with the most recent data (SC 23), and then we will work backwards in time and SC number. The processing consists of using Adobe Photoshop to remove any unnecessary notes, marks, or symbols, and to colorize the maps, and to output the maps using IDL to a standard grid in heliolongitude and heliolatitude (0.09 degrees default for the .gif files). The next step is to output these processed maps as arrays of numbers, which reproduce color-coded solar features for each rotation. We have written a general computer IDL code, plotfinal.pro, to produce gif images using FITS files for each CR. These have up to 16 permutations of the mapping variables that are output as "final" gif files depending upon keyword settings. We will also produce codes to make efficient searches of the map arrays and to organize the information for scientific purposes, such as investigations of how the various features vary with time. We will make these codes publicly available, or the user can produce his/her own codes for a given purpose.

Finally, the final digital files for each CR map created in each of three process steps stored at the National Centers for Environmental Information (NCEI), NESDIS, NOAA, U.S. Department of Commerce. with the assistance of project collaborator William Denig.

4. Personnel Experience and Responsibilities

The PI of this grant, David Webb, is managing the project, assuring that the work plan is completed so that the resulting maps comprise a useful archive for the public and the scientific community, and is also working on the development of analysis software for searching and effectively utilizing the archived data.

Ian Hewins and Robert McFadden were trained in the mapping by Patrick McIntosh and have preserved all the mapping paperwork and some of the digital files, and are ensuring consistency and continuity with the original technique. Their work involves organizing and scanning (where necessary) the full archive, and processing and digitizing the maps to the final, standardized format. Barbara Emery-Geiger, recently retired from NCAR/HAO, is doing some of the project management administration, and is helping with the digital processing and metadata data archiving requirements of the proposed effort.

Sarah Gibson is the primary interface between the PI - Boston College and HAO/NCAR, and is assisting with all aspects including the IDL processing and analysis software.

5. Plan of Work

The work plan is to collate, scan and process the approximately 574 maps in the order of priorities listed below.

1) First, collect and process (as in steps 2-3) a few CR maps in different current formats (e.g., black-and-white on paper, black-and-white electronic, colorized electronic…) to test the techniques and identify any problem areas. Establish a standard, searchable final format for the maps (.fits was chosen).

2) Collect initial electronic reproductions of the best available unprocessed maps for the full time period (SCs 20-23) by scanning originals. Our goal here is to achieve consistent initial electronic versions of all the maps to consistent resolutions. (0.09 solar degrees was chosen as the default for the .gif files, with 0.25 solar degrees for the .fits files.)

3) Process to final format the electronic maps with Photoshop, starting from the recent data (SC 23) and working backwards in time and SC number. Output processed maps as arrays of numbers, which reproduce color-coded feature patterns for each rotation (similar to Fig. 2). We estimate this process will take 4-6 hours for each map.

4) Write codes to permit efficient searches of these map arrays and to organize the information for scientific purposes, such as of analysis of how the various features vary with time.

This work is initially being done under an NSF RAPID grant and is funded Through March 2017. This limited effort does not allow enough time to complete all the above tasks for the full time period, but we will be able to complete Tasks 1 and 2 for all the maps, Task 3 for all of SC 23 and perhaps 100 more maps, and Task 4. Further accomplishment of Task 3 for the maps for SC 20-22 will be done as the limited funding and time of this and future grants permit.

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