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Ground-based Solar Observations in the Space Instrumentation Era
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The Need for Synoptic Solar Observations from the Ground

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Abstract. Synoptic observations are indispensable in studies of long-term effects pertinent to variation in solar radiative output, space weather and space climate, as well as for understanding the physics of global processes taking place on our nearest star. Synoptic data also allow putting the Sun in the context of stellar evolution. Historically, the main-stay of such observations has been groundbased although the improving longevity of space-borne instruments puts some space missions into the category of synoptic facilities. Space- and groundbased (synoptic) observations are complementary to each other; neither is inferior or superior to the other. Groundbased facilities can have a long-term (50 years+) operations horizon, and in comparison with their space-based counterparts, they are less expensive to operate and have fewer restrictions on international collaboration and data access. The instruments can be serviced, upgraded, and cross-calibrated to ensure the continuity and uniformity of long-term data series. New measurements could be added in response to changes in understanding the solar phenomena. Some drawbacks such as day-night cycle and the variable atmospheric seeing can be mitigated e.g., by creating global networks and by employing adaptive optics. Furthermore, the groundbased synoptic observations can serve as a backbone and a back-up to spacebased observations.

Here I review some existing groundbased synoptic facilities, describe plans for future networks, and outline the current efforts in strengthening the international collaboration in synoptic solar observations from the ground.

1. Introduction

The Sun is a variable star, which activity waxes and wanes with an approximately 11 year cycle. Because of Earth's proximity to the Sun, its activity determines space weather conditions in and near Earth's space environment and plays an important role in Earth's climate. The Sun is also a G-type (G2V) main-sequence star, and thus, it serves as a reference for comparison with other stars. The desire and need for long-term observations of the Sun come from a scientific curiosity and from the applied side of modern heliophysics. From a scientific perspective we want to understand the physics of solar and stellar processes and their change with time (e.g., long-term variability and solar cycle). We also want to understand the physics of Sun-planetary connections and its long-term trends (space climate). From an applied science perspective, routine synoptic observations are necessary for successful space weather forecasting. The intended use of data determines the data products and their characteristics (e.g., cadence, spatial resolution). In general, data intended for exploratory scientific research are not well-defined, and the observing programs have no clear end-date (continue for as long as possible). On the other hand, data intended for space weather forecast are well-defined,

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and these programs tend to be more limited in their duration (continue for as long as needed).

1.1. Early Synoptic Observations

From the beginning of scientific observations of the Sun the emphasis was made on maintaining the long-term records of solar activity. Regular drawings of sunspots made by many early scientists throughout Europe facilitated the discovery of solar rotation and the solar cycle itself. In 1848, Rudolf Wolf started a time series of sunspot numbers, which now represents the longest time series of direct measurements of solar activity. In 1981, the responsibilities for sunspot number time series were transfered from Zürich to the Royal Observatory of Belgium (`http://www.sidc.be/silso/home`), and the sunspot number time series was recently re-calibrated (Clette et al. 2014).

In 1874, the Royal Greenwich Observatory (RGO) started the photographic observations of the Sun with daily photoheliograms takes in several observatories (Willis et al. 2013). After 1976, the dataset of sunspot area is maintained by Debrecen Heliophysical Observatory using its own observations supplemented by photographic data or hand drawings from several other observatories (Abastumani, Ebro, Helwan, Kanzelhöhe, Kiev, Kislovodsk, Kodaikanal, Mount Wilson, Rome, Tashkent, Tokyo, Valasske Mezirici, and SOHO/MDI, Gyori et al. 2005).

Full disk (synoptic) spectroheliograms in the chromospheric Ca II K spectral line were taken in Kodaikanal Observatory (India) from 1907–1999 and at Mount Wilson Observatory (USA) from 1915–1985. Shorter in duration synoptic observing programs of CaK line spectroheliograms were conducted in several other observatories including Observatoire de Paris/Meudon, France (1893–present), Kislovodsk Mountain Astronomical Station (1953–present), Arcetri Astrophysical Observatory (1926-1974), the Astronomical Observatory of the Coimbra University, Portugal (1926-present, Garcia et al. 2011), the National Solar Observatory at Sacramento Peak, U.S.A. (1960–2002), the National Astronomical Observatory of Japan (1917–1970), Baikal Astrophysical Observatory of the Institute of Solar-Terrestrial Physics, Russian Federation (1995–present). The daily full-disk, photometric images of the Sun in Ca II K line (393.4 nm) wavelengths are also taken at the San Fernando Observatory (USA) since 1988 (white light images in 672.3 nm are taken since 1985, Chapman et al. 1992).

First measurements of magnetic field strengths in sunspots were taken at Mount Wilson Observatory in 1915, with synoptic measurements starting in 1917 (Hale & Nicholson 1938). These measurements continue till present. From mid-1950s, a similar program of daily measurements of sunspot field strengths was conducted in seven observatories in the former Soviet Union (Pevtsov et al. 2011).

1.2. Synoptic Observations in Modern Era

Although the effects of solar activity on Earth's natural (atmosphere, ionosphere, weather, climate) and technological (e.g., radio communications) systems was known, the importance of solar-terrestrial connections was further emphasized after World War II. In part, this was related to military development of radars and other early warning systems, exploration of high latitude Arctic and Antarctic regions, and the beginning of space exploration. New dedicated solar observatories were created in several countries: High Altitude Observatory (started as Climax station with first instrument, a coronagraph built in 1940, `https://www2.hao.ucar.edu/history-hao`) – Kislovodsk

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Mountain Astronomical Station (1948, Gnevyshev 1983), Sacramento Peak Observatory (first sunspot drawing is dated 1 September 1947, Evans (1956)).

Post-World War II years also saw a rapid development of radioastronomy. For the synoptic observations of the Sun, a notable development was the beginning of observations in 2.8 GHz (λ = 10.7 cm). Beginning 1946, the data were taken via a radiotelescope located near Ottawa, Canada. In 1990, the program was relocated to the Dominion Radio Astrophysical Observatory (DRAO) near Penticton, British Columbia. A number of radio-telescope facilities were built around the globe, with many taking the solar observations. One of these radio facilities for solar synoptic observations is the Siberian Solar Radio Telescope (SSRT) located about 220 km from Irkutsk, Russian Federation. It is a crossed interferometer, consisting of two arrays of 128x128 parabolic antennas 2.5 meters in diameter each, spaced equidistantly at 4.9 meters and oriented in the E-W and N-S directions (Figure 1). The length of each linear baselines of the interferometer is 622.3 meters; the instrument's working wavelengths λ = 5.2 cm (5.7 GHz). The SSRT was commissioned in 1984, and its regular synoptic observations started in 1998 (Kochanov et al. 2013). Figure 2 shows an example of SSRT synoptic observations.

Figure 1. View of N–S arm of Siberian Solar Radio Telescope (SSRT). The colored figure can be found in the electronic version. Courtesy of A. Kochanov.

Early magnetographic observations started in late 1950s, with routine synoptic observations of full disk line-of-sight (LOS) magnetograms starting in early 1970s at the Mount Wilson Observatory (MWO), National Solar Observatory at Kitt Peak (NSO/KP, Livingston et al. 1976), and Wilcox Solar Observatory (WSO, Hoeksema & Scherrer 1986). The magnetograph at MWO was rebuilt at the end of 1981 (Howard et al. 1983),

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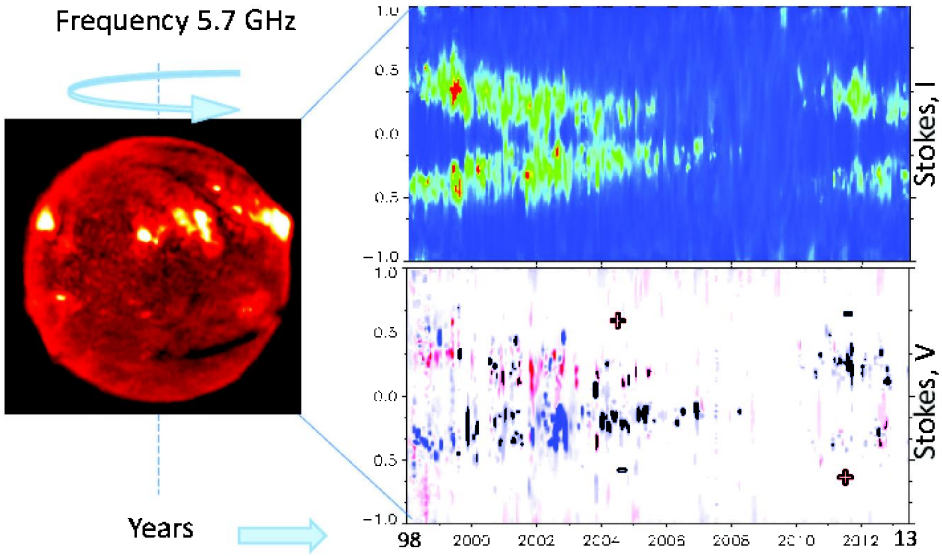

Figure 2. Full disk image of the Sun in 5.7 GHz (left) and synoptic maps of Stokes I (non-polarized flux) and V (circular polarization) derived from SSRT synoptic observations. Light/dark gray (red/blue in colored figure) corresponds to positive/negative circular polarization (Kochanov et al. 2015). The colored figure can be found in the electronic version.

and again in 2002 (Ulrich et al. 2002). NSO/KP 512-magnetograph operated from 1974–1992, when it was replaced by NASA/NSO Spectromagnetograph (SPM, Jones et al. 1992). In 2003, the SPM was replaced by the Vector Stokes Magnetograph (VSM) on Synoptic Optical Long-term Investigations of the Sun (SOLIS) platform (Keller et al. 2003; Balasubramaniam & Pevtsov 2011). Current data products from SOLIS include: full disk LOS and vector magnetic field maps (photosphere and chromosphere, cadence 1–2 per day), full disk narrow band images (Hα, He1083.0 nm. cadence 10 seconds), Sun-as-a-star spectra in 8 wavelength bands. Derived products include synoptic maps of radial and LOS magnetic field in the photosphere and chromosphere and their uncertainties, emission index, line asymmetry and other proxies derived from spectral line profiles (see `http://solis.nso.edu`).

Beginning late 1960, a number of vector and longitudinal magnetographs operated in a synoptic mode taking daily observations. These include the vector magnetographs at Marshall Space Flight Center, USA (1979–2003, Hagyard et al. 1982), the Okayama Astrophysical Observatory Solar Telescope, Japan (1982–1995, Makita et al. 1985), the Mitaka Solar Flare Telescope, Japan (1992–2007, SFT, Sakurai et al. 1995), the Big Bear Solar Observatory Videomagnetograph (Varsik 1995), the Haleakala Stokes Polarimeter, USA (HSP, 1989–2000 Mickey 1985), Huairou Solar Observing Station, China (starting 1988, Ai & Hu 1986; Bao et al. 2000), Sayan Observatory, Russian

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Federation (1966-mid-1990s, Grigoryev et al. 1985), the Potsdam vector magnetograph (Staude et al. 1991), Ondřejov Observatory, Czech Republic (1990–2001, Klvaňa & Bumba 1994), and Crimean Astrophysical Observatory (since late-1950s, Severny 1965).

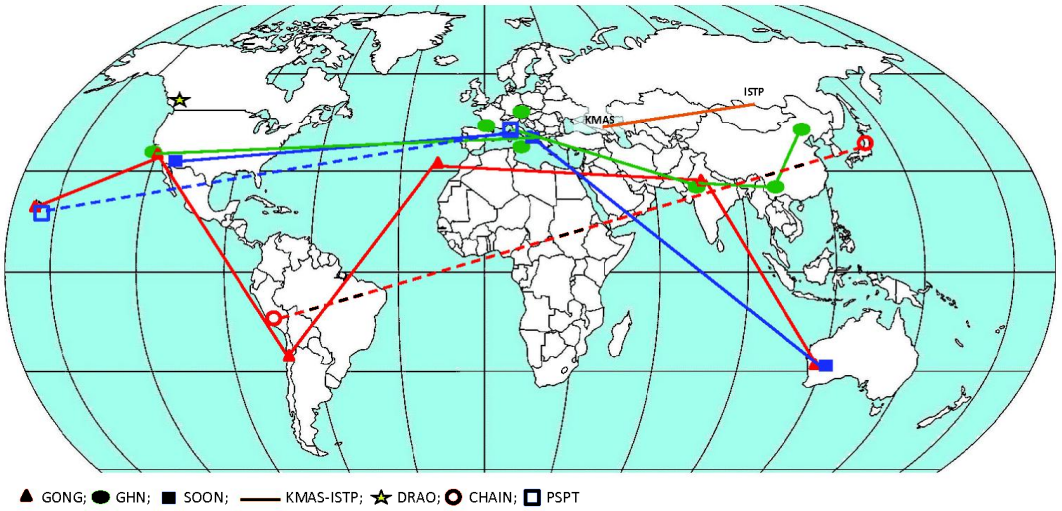

Figure 3. Existing world-wide networks for solar synoptic observations. The colored figure can be found in the electronic version.

1.3. Networks

Figure 3 shows the approximate location of solar synoptic networks that are currently in operation or under construction.

Arguably, the first network began operations in April 1874, with the measurements of the area and position of sunspots being conducted from the Royal Greenwich Observatory (RGO). In 1874–1885 period the RGO observations were supplemented by photographs obtained from other observatories (Harvard College, the Melbourne Observatory, Dehra Dûn in India, and the Royal Alfred Observatory, Mauritius) to fill many of the gaps in the early Greenwich series. From 1886 to 1909, the contributing stations were Greenwich, Dehra Dûn, Mauritius, and later Kodaikanal); after 1910, the contributing observatories were Greenwich, the Royal Observatory at the Cape of Good Hope (South Africa), Dehra Dûn and the Kodaikanal Observatory in India with some occasional data provided by the US Naval and the Mount Wilson Observatories.

In 1977, the US Air Force (USAF) started compiling data on sunspot areas, active regions and their flare activity using the observations from its Solar Optical Observing Network (SOON). Currently, only three SOON stations continue their operations: Holloman AFB, New Mexico, USA; RAAF Learmonth, Australia and San Vito dei Normanni Air Station, Italy. SOON stations in Massachusetts, Hawaii, and Puerto Rico were shut down, and early plans for Improved SOON (ISOON, Balasubramaniam & Pevtsov 2011) network were canceled.

In 1932, a network of synoptic solar observatories, named "Solar Service" was created in the Soviet Union (see CIA Report 1955). At its peak, the "Solar Service" included 16 observatories located across eleven time zones in U.S.S.R. and a solar telescope in Cuba (Nikonov et al. 1984). The network stations were equipped with identical or near identical telescopes to take daily observations of the Sun in the photosphere and

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chromosphere (some stations were also taking coronagraphic and radio observations). The backbone of the "Solar Service" was formed by the Main (Pulkovo) Astrophysical Observatory and its Kislovodsk Mountain Astronomical Station, Crimean Astrophysical Observatory (CrAO), Shamakhy Astrophysical Observatory, Astronomical Observatory of Ural State University, Astronomical Institute of Uzbek Academy of Sciences, Sayan Solar Observatory of the Institute of Solar-Terrestrial Physics, and Ussuriysk Astrophysical Observatory. Sever decline in funding that followed the disintegration of the Soviet Union resulted in discontinuation of "Sun Service" operations in about 1997. Some stations (e.g., KMAS, `http://en.solarstation.ru/`; CrAO) continued synoptic operations, and recently, there were attempts to re-start the "Sun Service" program using observatories in the Russian Federation. As part of this development, a new network of full disk low resolution LOS magnetographs has been initiated. The instruments are based on a previous design of the Solar Telescope of Operational Prognosis (STOP, Demidov et al. 1998). Currently, two magnetographs are in operation at the Baikal Astrophysical Observatory of the Institute of Solar-Terrestrial Physics (ISTP) and at Kislovodsk Mountain Astronomical Station (KMAS) of Pulkovo Observatory. Figure 4 shows photographs of the telescope interior and provides examples of full disk magnetograms from the two sites.

In the early 1990s, the Global Oscillation Network Group (GONG) developed a six-station network to study the internal structure of the solar convection zone. GONG instruments are located at Big Bear Solar Observatory (USA), Learmonth Solar Observatory (Australia), Udaipur Solar Observatory (India), Observatorio del Teide (Canary Islands, Spain), Cerro Tololo Interamerican Observatory (Chile), and Mauna Loa Observatory (Hawaii, USA). Original GONG instruments included Doppler imager and full disk longitudinal magnetograph. In 2010, all GONG instruments were upgraded with full disk Hα imagers. While initially the GONG network was oriented on helioseismic studies, the recent emphasize is on providing routine data for space weather monitoring and forecast. Current data products from GONG include the full disk LOS magnetograms in the photosphere, white light and Hα images (20 second cadence), and full disk Dopplergrams for helioseismology. Derived data products include 10-minute average magnetograms and their variances, synoptic (Carrington) maps of radial magnetic field, Potential Field Source Surface (PFSS) coronal field extrapolation, and farside helioseismic maps every 12 hours.

In 1996-97, the National Solar Observatory developed a network of the Precision Solar Photometric Telescopes (PSPT) for obtaining solar images with the differential photometry with high 0.1% accuracy. The PSPT take full-disk images in the blue (409.4nm) and red (607.1nm) continuum, Ca II K line core (393.4 nm) and wing (393.6 nm) with a narrow and wide spectral bandpasses. Currently, two PSPT instruments are in operation: Mauna Loa Solar Observatory (MLSO, Hawaii, USA) and the Osservatorio Astronomico di Roma (Italy).

The Global high resolution Hα Network (GHN) is a collaboration of full disk Hα telescopes located at Big Bear Solar Observatory (USA), Kanzelhöhe Solar Observatory (Austria), Catania AstrophysicalObservatory (Italy), Royal Observatory of Belgium/Uccle (Belgium),Observatoroir de Paris/Meudon and Observaroire Midi/Pyrénées (France), Yunnan Astronomical Observatory and Huairou Solar Observing Station in China. In addition, a large number of observatories operate Hα telescopes, which are not formally associated with GHN. Some examples include MLSO (USA), Hα Solar Telescope of Argentina (HASTA), ChroTel (The Kiepenheuer Institute for Solar

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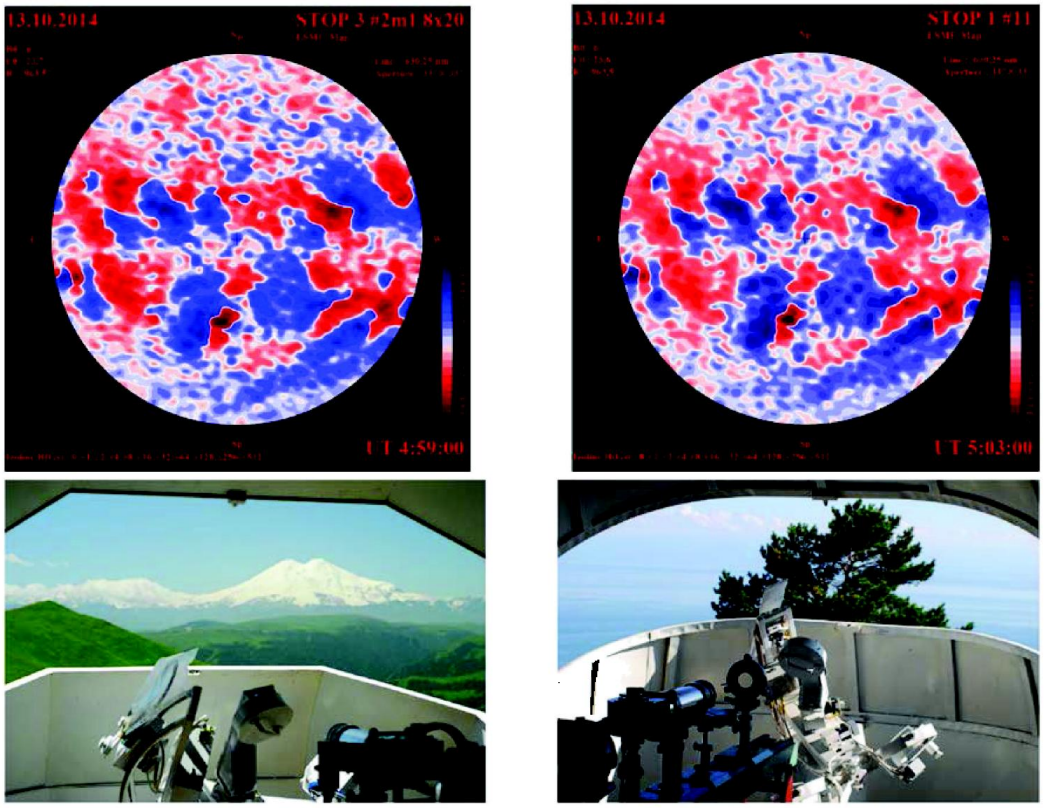

Figure 4. Example of LOS magnetograms taken by two synoptic telescopes located at (right) Baikal Astrophysical Observatory (Lat. 52N Long. 104E) and (left) KMAS (Lat. 44N Long 42E). Light and dark gray (red and blue in the colored version) correspond to magnetic fields of positive and negative polarity. Low panel shows the interior of two telescopes and the outside views. The double-peaked mountain is Mount Elbrus, Europe's highest mountain (5,642 m).The telescope on the low-right panel faces the shores of lake Baikal, the world's deepest body of fresh water. The colored figure can be found in the electronic version. Courtesy of M.Demidov.

Physics, Germany), SMART (Hida Observatory, Kyoto University) and Mitaka Solar Observatory in Japan, Kislovodsk Mountain Astronomical Station (Russian Federation), Baikal and Sayan Astrophysical Observatories, and Crimean Astrophysical Observatory. Full disk Hα images are also taken by Full Disk Patrol (FDP) telescope on SOLIS.

Recently, the solar group at Kyoto University begun development of the Continuous H-alpha Imaging Network (CHAIN, Ueno et al. 2010). The focus of this network is to provide a continuous 3-D structure of the velocity field in the solar atmosphere in relation to filament eruptions and post-flare/CME shock waves. The network will have operations at Hida Observatory (Japan), Ica University (Peru), King Saud University (Saudi Arabia), and a site in Algeria. Currently, only the instrument at Hida Observatory operates on a daily basis. The instrument at the Peru site was installed in 2010, and is in the commissioning state. The telescope at the Saudi Arabia site is under construction.

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The above lists are not inclusive, as the complete description of all existing observing facilities is outside the scope of this paper. For additional information about these groundbased facilities, we refer the reader to the web page maintained by the IAU inter-Division B and E working on "Coordination of Synoptic Observations of the Sun" at `http://www.nso.edu/IAU-Com12/resources`.

1.4. Historical Archives of Solar Synoptic Observation

Early observations of solar phenomena were taken in the form of hand drawings and photographic data. The digitization of these data is a critical step in increasing their scientific usage.

Digitized sunspot drawings from several observatories are available from NGDC at `ftp.ngdc.noaa.gov/STP/space-weather/solar-data/solar-imagery/photosphere/sunspot-drawings`. There is also the Hungarian historical solar drawings collection (1872–1919, `fenyi.solarobs.unideb.hu/HHSD.html`). The 1932–1979 data from the "Catalogues of solar activity" of the Russian "Solar Service" program are available at `www.gao.spb.ru/\database/csa/main_e.html`. The Debrecen Photoheliographic Data archive is available in digital form at `fenyi.solarobs.unideb.hu/deb_obs_en.html`. Sunspot drawings from MWO were digitized (see, `ftp://howard.astro.ucla.edu/pub/obs/drawings`). A project is underway to transfer the heliographic position of sunspots, their umbral areas, and the field strengths to a digital format (Tlatova et al. 2015).

Ca K line spectroheliograms from MWO (1915–1985) were selectively digitized by Foukal (1996) using a 8-bit, 512-pixel format (four images per months). Later, the entire data set was re-digitized at UCLA using a higher pixel resolution (3000x3000) and 12-bit digitizer (Bertello et al. 2010). Unfortunately, the final calibrated data may be lost due to a recent failure of data server; likely, the raw scanned data were not affected. Ca K line spectroheliograms from Kodaikanal Observatory (1907–1999) were first digitized with 8-bit density resolution and 1400-pixel resolution (Tlatov et al. 2009). A re-digitization program with 16-bit density and higher pixel resolution has recently been completed (Priyal et al. 2014). Spectroheliograms taken at Evans facility at NSO/Sacramento Peak in different wavelengths from 1965–2002 are digitized and available on-line from the NSO Digital Library at `diglib.nso.edu/ftp.html`. Ca K line spectroheliograms were also partially digitized by Foukal (1996) similar to his digitization of MWO data. These data are also available via the NSO Digital Library. The digitized archives of Ca K line spectroheliograms are also available for Arcetri Astrophysical Observatory (1926-1974, `www.oa-roma.inaf.it/solare/cvs/arcetri.html`), National Astronomical Observatory of Japan (1917–1970, `solarwww.mtk.nao.ac.jp/en/db_ca.html`), Observatoire de Paris/Meudon (1893-1999, `bass2000.obspm.fr/gallery2/\main.php?g2_itemId=9081`).

Full disk Hα observations from Big Bear Solar Observatory and NSO/Sacramento Peak were digitized in the framework on the solar film digitization project at NJIT (`http://sfd.njit.edu/`). NSO/SP flare patrol data (1960–2002, 1 minute cadence) are available at `ftp://vso.nso.edu/flare_patrol_h_alpha_sp/`.

While significant progress was made in digitizing the historical solar synoptic data, there are still major data sets that need to be preserved. These observations include the data from the NSO/Sacramento Peak and several observatories in the former Soviet Union, which may hold rich collections of full disk daily observations in Hα and other

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wavelengths. The effort should also be made to make all the digitized data freely available to the international research community.

2. Groundbased vs. Spacebased Observations

Historically, the main-stay of synoptic observations of the Sun has been groundbased although the improving longevity of space- borne instruments puts some space missions into the category of synoptic facilities. Table 1 compares two type of operations on the basis of some general parameters.

Table 1. Comparison of Spacebased and Groundbased Observatories

Critical Parameter	Spacebased	Groundbased
Day-night / weather cycle/ atmospheric seeing	No, but may have orbital effects (for example, see, Figure 5).	Yes, but can be mitigated via use of networks and adaptive optics.
Wavelength coverage	Visible, IR, radio, EUV, X-ray, γ-ray, *in situ*	Visible, radio, limited IR, UV proxies may exist.
Longevity	< 10 years, critical failures may limit mission duration.	Long-term (50 yrs+) instruments can be repaired and upgraded.
Cost	High	Low-medium
Flexibility of measurements/ instrument upgrades	Measurements are fixed.	New measurements can be added.
International collaboration	Limited in instrument/ technology development.	Mostly unrestricted.
	Data analysis is largely unrestricted. Requires central coordination.	Can run under a loose coordination.

It is clear that despite some obvious drawbacks (i.e., day-night cycle, atmospheric seeing, limitations in wavelength coverage), groundbased observations have several notable advantages. Even with a ten-year duration space missions, groundbased facilities have the advantage of a much longer operation horizon. Groundbased operations are less expensive. As the public funding available for scientific research is declining, broad international collaborations may provide a solution for maintaining the important synoptic data sets. In that respect, the groundbased facilities have fewer restrictions on international participation and the data access as compared with the spacebased operations. It is also much easier for Nations with limited resources or politically-imposed restrictions to participate in groundbased collaborative projects e.g., by providing data from their National facilities, contributing an instrument or providing a site support for the international network. In addition, the groundbased instruments can be serviced, upgraded, and cross-calibrated to ensure the continuity and uniformity of long-term data series. New measurements could be added in response to changes in understanding the solar phenomena.

Some drawbacks such as day-night cycle and the variable atmospheric seeing can be mitigated e.g., by creating global networks and by employing adaptive optics. Fur-

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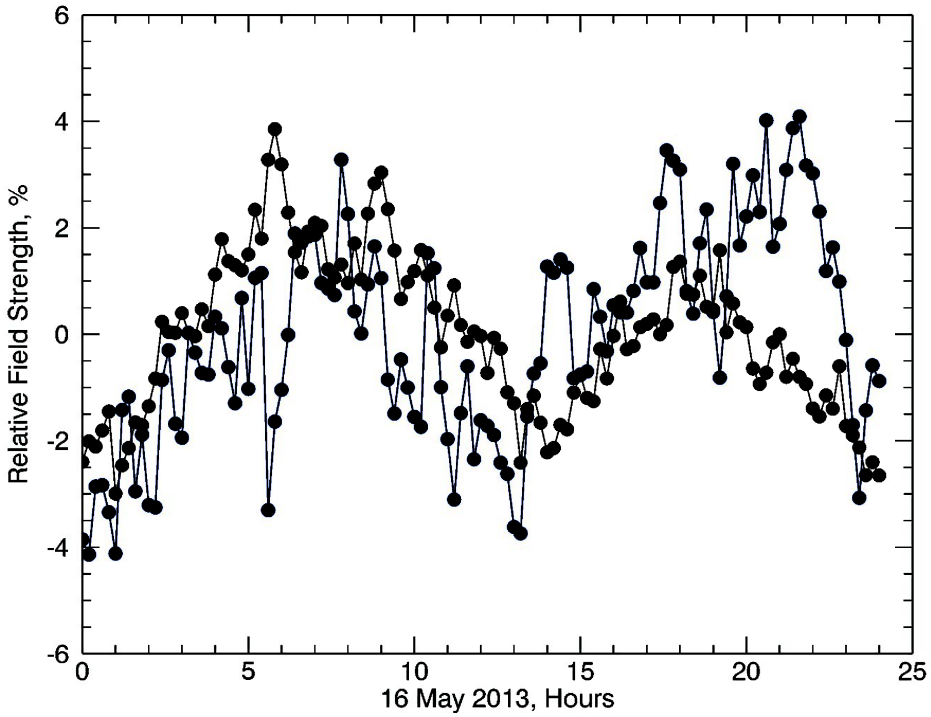

Figure 5. Example of 12-hour variations in maximum field strength in two sunspots observed by SDO/HMI on 16 May, 2013. Changes are shown as percentage relative to mean field strength in each spot for this day. This variations are the results of orbital motions of SDO (Smirnova et al. 2013). The colored figure can be found in the electronic version.

thermore, lack of access to certain wavelength ranges could be partially compensated by developing proxy observations. For example, images in the 160-170 nm UV range currently taken by AIA on Solar Dynamics Observatory (SDO), can be replaced by groundbased observations in the chromospheric spectral lines (see, Figure 6).

Despite the effects of the atmospheric seeing, with proper care, the groundbased facilities can return data very similar to those from spacebased instruments on spatial scales down to telescope resolution limits (Figures 7 and 8). A direct comparison of longitudinal magnetograms from HMI/SDO and VSM/SOLIS validate the strong correlation between the two when the higher spatial resolution HMI data are degraded to account for difference in spatial resolution (Pietarila et al. 2013).

While spacebased observations can provide observations free of atmospheric distortions and in the wavelength bands not available from the ground, they have their own limitations. These limitations may result in lack of continuity and uniformity of data sets, limitations on the amount of data and their completeness, high cost of development and launch and the need for additional (also costly) operations.

With the exception of operational missions (e.g., GOES spacecraft operated by NOAA), it is often difficult if possible to re-fly the same instruments on successive missions. In combination with a limited lifetime of missions, this may result in a mis-

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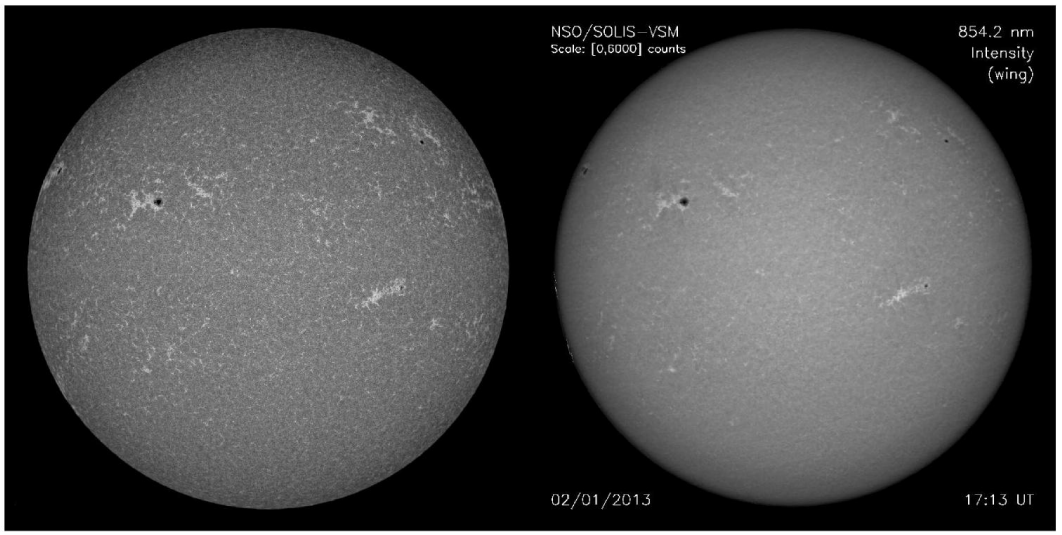

Figure 6. Comparison of near simultaneous full disk images taken on 1 February 2013 by left: AIA/SDO (170.0 nm, 1718 UT) and right: FDP/SOLIS (wing of Ca II 854.2 nm, 1713 UT). A close examination shows that all major brightenings are present on both images.

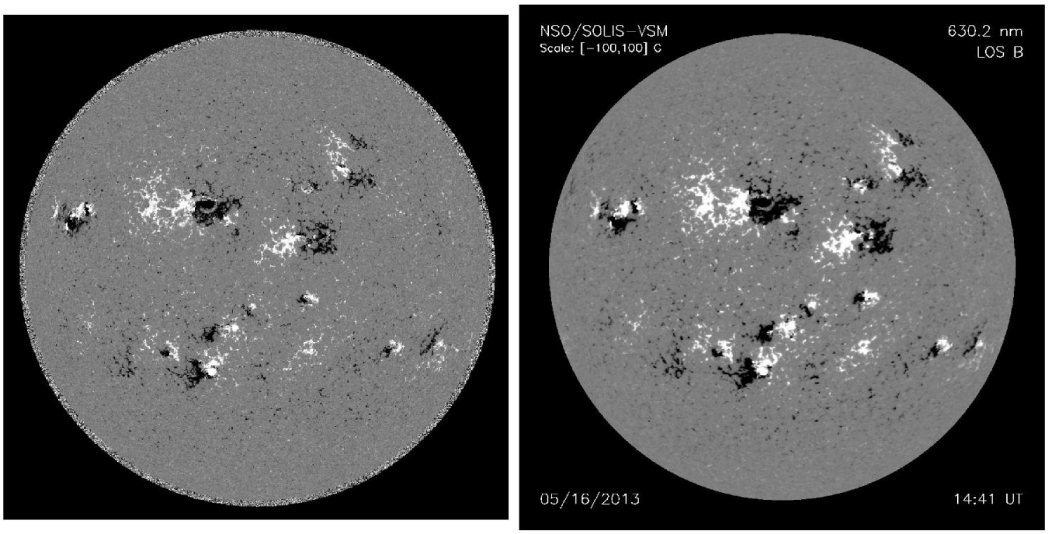

Figure 7. Comparision of SDO/HMI (left) and SOLIS/VSM (right) full disk longitudinal magnetograms taken on 16 May 2013 at 14:48 UT (HMI) and 14:41 UT (VSM). White/black halftones represent line-of-sight magnetic field of positive/negative polarity.

match of data sets even from the missions with similar scientific goals. One example of such mismatch is the measurements of the total solar irradiance (TSI) from different radiometers (Fröhlich 2006). It is also not uncommon to have gaps in time series because of lack of overlap between successive missions. The continuity of dataset is better for the operational missions, but those tend to concentrate on daily space weather forecast, not the long-term research.

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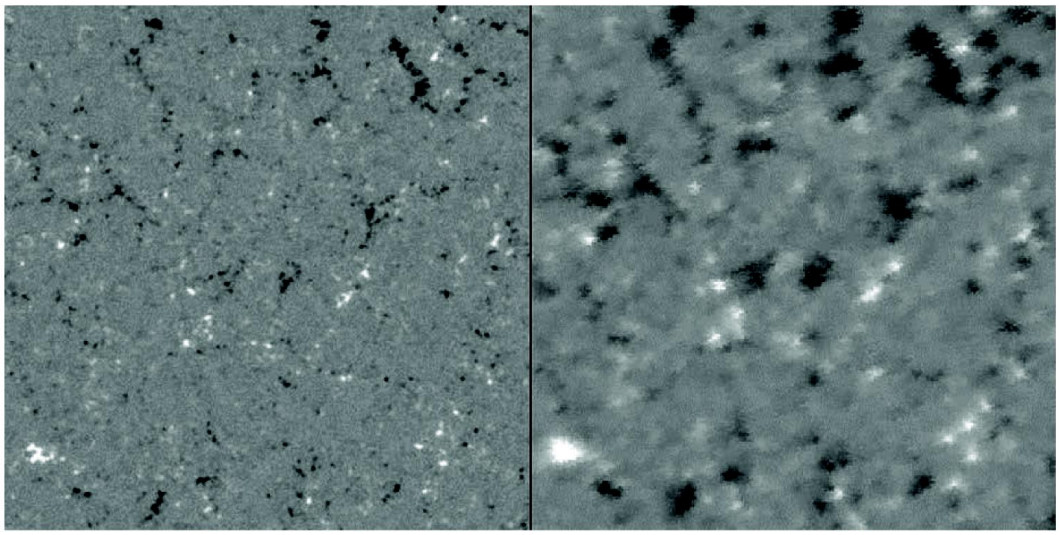

Figure 8. Central part of magnetograms shown in Figure 7: HMI (left) and SOLIS/VSM (right). Each panel shows an area of approximately 200 by 200 arcseconds in size near the disk center.

Depending on the spacecraft orbit, some datasets may show periodic cycles in observations (similar to day-night cycle) due to for example, Earth eclipses or a spacecraft passage over the South Atlantic Anomaly. The degradation of EUV instruments requires conducting regular launches of duplicate instruments on sounding rockets followed by calibration of the instruments against laboratory sources (Béland et al. 2014).

Because of emphasis on wavelength ranges not accessible from the ground, the instruments operating in the visible wavelength range may have a lower priority for space missions. Limitations on size, weight and telemetry often lead to simplifications of instruments and/or observables, which in their turn may limit the amount of information available from these data. For example, it is not uncommon to reduce the spectral sampling or the spectral bandpass of data. Such reduced sampling may have negative effects on physical parameters derived from these data (Figure 5).

This brief comparison of space- and groundbased synoptic observations indicates that the two programs are complementary to each other; neither should be seen as inferior or superior to the other.

3. Critical Evaluation of Existing Synoptic Programs

A critical look at a plethora of groundbased instruments and synoptic programs indicates several potential issues. First, there is a lack of coordination between the national programs and individual observatories. As the result, there is a significant overlap in some areas (e.g., "everybody observes Hα" syndrome), while some data are provided from a single source (e.g., 10.7 cm radio flux). The overall goals of synoptic programs are not well-defined, and as the result, there is no critical evaluation of what needs to be observed or what could be missing. Even in formal networks, there could be a significant non-uniformity in the data (e.g., Hα telescopes comprising GHN may differ significantly in spatial resolution, filter bandpasses, and the data processing).

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Lack of long-term planning for replacing the aging facilities and for the data preservation are also outstanding issues.

In the past, the approach for synoptic observations was to continue taking data for several observables that historically were considered to be good/useful proxies of solar activity. New observations were rarely added. Perhaps a better approach would be to identify several clear goals for synoptic observations and revisit these goals on a regular basis. Then, specific questions could be identified to address the goals, which would help defining the observables. The CHAIN-network may be one example of such an approach.

As an example, one of the key questions for a synoptic program could be to understand how energy flows through the solar atmosphere. Answering this question is important for understand the physics of the chromospheric and coronal heating and the flare activity, and it will require studying both rapid processes on small spatial scales (e.g., jets, flare triggers) and the large-scale connectivity and remote eruption triggering.

For long-term synoptic programs we also need to revisit such requirements as the wavelength ranges, cadence, the spatial and spectral resolution, the derived parameters (magnetic field/vector or LOS, Doppler velocities), and identify which of these data are necessary and which are supplementary.

3.1. New Synoptic Initiatives

Several new initiatives pursue the replacement of aging synoptic networks and building new instruments. One of these initiatives is the Solar Physics Research Integrated Network Group (SPRING) operated as part of Joint Research Activities of Solarnets working program. Solarnet is an Integrated Activity (IA) funded by the European Union's Capacities Programme under Framework Programme 7. The objectives of SPRING is to develop "the instrumentation for large field-of-view observations of a network of small aperture solar telescopes in support of observations with existing high-resolution solar telescopes" (see, `http://www2.mps.mpg.de/projects/seismo/HELASVI/talks/T8_Roth.pptx`). The SPRING network is envisioned as a replacement for the aging GONG network with the multi-wavelength helioseismology and the additional capabilities for measuring the vector magnetic fields.

Other initiatives include a development of a network of automatic Hα and Ca II K line telescopes–spectroheliographs for small university observatories (KMAS, A. Tlatov, private communication). There is also an ongoing project to develop the Brazilian Solar Magnetograph (Vieira et al. 2015).

One of the objectives of synoptic programs in solar physics is to provide the data for space weather modeling and forecast. Thus, it is important to develop closer ties between traditional solar and space physics synoptic observations and magnetospheric and ionospheric synoptic programs. One of recent developments in this direction is the PROTEAS project initiated by the National Observatory of Athens (Kontogiannis et al. 2015).

There is a need for a strong international collaboration in all these new projects.

3.2. New Data Products

The advances in modeling and observations call for developing new data products for synoptic observations. For example, some synoptic instruments (e.g., VSM/SOLIS) take observations of full line profiles of selected photospheric and chromospheric spectral lines with high spectral sampling. These spectral line profiles can be used to derive

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a 3D distribution of thermodynamic parameters in the solar atmosphere (Beck et al. 2015). This technique was recently successfully applied to construct a full disk map of the temperature distribution in the solar chromosphere at the range of the Ca II 854.2 nm spectral line formation.

Other possible data products can include synoptic maps of free magnetic energy derived from non-linear force-free field modeling (see Figure 4 in Tadesse et al. 2014) or synoptic maps of vector magnetic fields (Gosain et al. 2013).

The IAU inter-division B and E working group on Coordination of Synoptic Observations of the Sun provides a forum for discussion of all issues relevant to synoptic long-term observations including coordination between synoptic programs in different countries and a proper calibration of historical data from different sources (e.g., sunspot drawings, CaK plage indices, magnetic field measurements etc). The reader is encouraged to visit the current web site of this IAU working group at `http://www.nso.edu/IAU-Com12`.

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