

Chapter 49

Automated Solar Feature Detection for Space Weather Applications

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ABSTRACT

The solar surface and atmosphere are highly dynamic plasma environments, which evolve over a wide range of temporal and spatial scales. Large-scale eruptions, such as coronal mass ejections, can be accelerated to millions of kilometers per hour in a matter of minutes, making their automated detection and characterisation challenging. Additionally, there are numerous faint solar features, such as coronal holes and coronal dimmings, which are important for space weather monitoring and forecasting, but their low intensity and sometimes transient nature makes them problematic to detect using traditional image processing techniques. These difficulties are compounded by advances in ground- and space- based instrumentation, which have increased the volume of data that solar physicists are confronted with on a minute-by-minute basis; NASA's Solar Dynamics Observatory for example is returning many thousands of images per hour (~1.5 TB/day). This chapter reviews recent advances in the application of images processing techniques to the automated detection of active regions, coronal holes, filaments, CMEs, and coronal dimmings for the purposes of space weather monitoring and prediction.

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INTRODUCTION

Astrophysics seeks to determine the physical properties of celestial bodies, primarily by studying the light they emit. This is achieved using remote observations as the distances are generally too great to allow in-situ measurements. Our Sun is the closest of all stars, by many orders of magnitude, and allows scientists to perform long-baseline synoptic studies at size scales which are impossible with other stellar objects. The Sun is also the source of life on Earth, making the study of the Sun-Earth interaction extremely important, especially in our technology-dependent society of today. The study of space weather focuses on disturbances produced by the Sun and the effects that they have on the environment near Earth, the other planets, and throughout the heliosphere. Those disturbances can affect satellites, airplane communications, long metallic oil pipe lines and electrical distribution grids, to name a few. More directly, it can affect the health of air crews and passengers on polar flights and astronauts. Accurate forecasting of those disturbances and their effects allows us to prepare for their arrival. The Sun is routinely observed by numerous ground- and space-based observatories and the study of features in real time (i.e., those currently on the solar surface) provides a better insight into what may happen at a later time elsewhere in the heliosphere.

When Galileo Galilei turned his telescope to look at the Sun in the early 17th century he became one of the first scientists to look in detail at the solar atmosphere. He pointed out that sunspots are features on the surface of the Sun and used them to study solar rotation. Since then, many observatories have studied, counted, and classified sunspots as they emerge and evolve on the Sun. These observations have been used to understand more than how the Sun rotates; historical data have made important contributions in studying the 11-year solar activity cycle and even some possibly-related Earth climate changes (e.g., the

“little ice age” in Europe during the latter half of the 17th century occurred in the Maunder minimum, an almost 60-year period in which the Sun seemingly produced few sunspots, (Eddy 1976; Lockwood et al. 2010). Images were drawn by hand and classified by eye in those early observations, initially using pencil drawings before photographic plates became common use. The invention in 1969 of the Charge-Coupled Device (for which Willard S. Boyle and George E. Smith won the 2009 Nobel prize in physics) was the start of a new era for solar physics. The ability to directly digitize images at their acquisition allowed telescopes to rapidly acquire data. Shortly thereafter, space-based missions started taking observations in different wavelengths, providing a more complete view of the Sun. The many different types of instruments on-board spacecraft (i.e., imaging, spectrograph, and in-situ detectors) have also provided invaluable information for a recent field of study called “space weather”. Space weather generally refers to the combined effect that all forms of solar activity have on objects within the heliosphere (including planets, their atmospheres, and satellites.) The ultimate aim of space weather research is to accurately forecast the arrival time of events which affect the heliosphere. To achieve this we need a better understanding of the different features that appear on the Sun and the resulting different forms of solar activity.

In general the solar atmosphere is stratified into temperature layers, each of which can be distinguished by the dominant type of radiative emission. The coldest, and lowest, layer emits mostly visible light (i.e., the photosphere, approximately 6,000 K) while the hottest, and highest, layer emits mostly in extreme ultraviolet (EUV) and X-ray wavelengths (i.e., the corona, more than 1 MK; Stix, 2004). Fortunately for human life, the Earth’s upper atmosphere blocks most of the high energy solar radiation. However, this makes it impossible to observe the hottest layers from ground-based facilities. The observation of these layers is achieved with the use of instruments

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