Chapter 3

SUNSPOT ANALYSIS TECHNIQUES

3.1. Sunspot Properties.

3.1.1. Sunspots. Sunspots are regions in the photosphere where intense magnetic fields cause the temperature and radiation to be less than in the surrounding, hotter, brighter photospheric gases. They consist of one or more dark cores (called "umbrae"), often surrounded by a less dark area ("penumbra"). In umbrae, very intense, longitudinally (line-of-sight) oriented magnetic fields cause the photospheric gases to become very cool, and thus dark (in fact, black), compared to the overall photosphere. In penumbra, the magnetic fields are less intense and are more horizontal in orientation. As a result, the temperature (and brightness) of these areas is closer to that of the overall photosphere. The horizontal fields in a penumbral area also tend to line up small, dark filamentary features in a radial pattern surrounding the umbra. Sunspots vary in size from less than 10 millionths of the solar hemisphere to sunspot groups of more than 5000 millionths.

3.1.2. Sunspot Groups. Sunspots tend to appear in magnetically bipolar groups. Even a unipolar spot group really has dual polarity; the magnetic field strength of the other polarity isn't intense enough to cause a visible spot. In each group there are normally two major spots, oriented roughly east-west, called the "leader, preceding, or western" spot, and the "trailer, follower, or eastern" spot. The leader spot is usually larger in size, has a stronger magnetic field strength, first to form, first to develop penumbra, and last to dissipate. It also tends to lie slightly closer to the equator than the trailer spot. This "tilt" in the spot group's major axis occurs in both hemispheres.

3.1.3. Sunspot Motions. Sunspots exhibit "proper motion", i.e., motion relative to Carrington longitude. This proper motion may be due to either the growth/expansion of the magnetic flux loops in emerging magnetic regions, and/or differential solar rotation. The sun does not rotate as a solid body like the earth. Instead, the Polar Regions rotate slower than the equatorial regions. Because the leader sunspot usually lies at lower latitude than the trailer, over time differential rotation widens the longitudinal separation between these spots (Figure 3.1). Once a sunspot group has reached its maximum longitudinal extent, it usually stabilizes or starts to decay as the magnetic field strengths weaken. Sunspots within a region will, on occasion, move relative to each other (e.g., converge or revolve about each other), or a major spot may rotate about an axis. These motions tend to cause intensified magnetic field gradients and/or shearing and increase the potential for flare activity.

3.1.4. Spot Growth and Decay. Individual spots may last a few hours to a few weeks, while a sunspot group may persist several months. Sunspot formation is preceded by the appearance of short-lived darkening called "pores", so small that it takes good sight for them to be visible. If the magnetic fields strengthen and continue to emerge, the pores become more persistent and mature into sunspots.

3.1.4.1. The rate at which individual spots within a group grow and decay is quite variable. Growth is generally more significant in its effect on flare activity than decay for equivalent rates of change. Growth (or decay) is identified by an increase (or decrease) in umbral darkness, in penumbral area, and/or in the number of intermediate spots. The more rapid the growth or decay, the more significant it is. Growth in one segment of a group, accompanied by decay in another segment, is also significant.

3.1.4.2. "Light bridges" appear as bright material extending across an umbra. They usually form slowly and may last up to several days. Rapid formation of light bridges often precedes rapid spot fragmentation and increased flare activity.

3.2. White Light Seeing Categories.

3.2.1. Seeing = 1 (Very poor).

3.2.1.1. Extreme limb motion observed. Faculae are not visible.

3.2.1.2. Spots on the disk appear as a blur with no definite shape. Separation between umbral areas in large spots is not detectable. Penumbrae are very ill defined.

3.2.1.3. No pores, granulation, or small spots are visible.

3.2.2. Seeing = 2 (Poor).

3.2.2.1. Moderate limb motion observed. Faculae and spots near the limb are lacking in definite outline.

3.2.2.2. Spots on the disk are badly blurred. Small spots are visible, but those closely spaced tend to merge. No details are detectable in penumbral areas, and umbrae lack definite outlines.

3.2.2.3. No pores or granulation are visible.

3.2.3. Seeing = 3 (Fair).

3.2.3.1. Image motion is observed on the limb and disk. Faculae near the limb have definite outline, but are slightly blurred.

3.2.3.2. Small spots are blurred; large spots are only slightly blurred. Umbrae and penumbrae are well separated, but with very little fine structure visible.

3.2.3.3. Pores and granulation are occasionally visible.

3.2.4. Seeing = 4 (Good).

3.2.4.1. Only slight limb motion is detectable. Faculae near the limb are sharply defined. Small umbrae near the limb are detectable.

3.2.4.2. Small details are visible within the large penumbral areas on the disk. Boundaries of penumbral and umbral areas are well defined. Light bridges, if any, are detectable.

3.2.4.3. Spots, pores, and granulation are visible, but show slight motion.

3.2.5. Seeing = 5 (Excellent).

3.2.5.1. Limbs are extremely stable. Faculae and small spots near the limb are very clearly defined and stable.

3.2.5.2. Boundaries of penumbrae and umbrae are very sharply defined and show no motion. Very fine detail is observable within penumbral areas on the disk.

3.2.5.3. Spots on the disk appear as a blur with no definite shape. Separation between umbral areas in large spots is not detectable. Penumbrae are very ill defined.

3.2.5.4. Small spots, pores, and granulation are very sharply defined and show no motion.

3.3. Modified-Zurich Sunspot Classification System. This classification system, developed by Patrick McIntosh while he was at the National Oceanic and Atmospheric Administration's Space Environment Laboratory, is based on a sunspot group's appearance in white light. There are three components to the system: sunspot class, penumbral class, and sunspot distribution (Figure 3.2).

3.3.1. Unipolar and Bipolar Groups.

3.3.1.1. A unipolar group is a single spot or a compact cluster of spots with the greatest separation between spots less than 3º. In the case of a group with penumbra (Class H), the greatest separation is measured between the center of the attendant umbra and the nearest border of the penumbra surrounding the main spot. Due to the width of the principal spot, such a group may have an overall length (along its major axis) of up to 5º. If the overall length is more than 5º, classify the group as bipolar.

3.3.1.2. A bipolar group has two or more spots forming a group with a length (along its major axis) of 3º or greater. Usually there is a space near the middle of the group, dividing it into two distinct parts (corresponding to opposite magnetic polarities).

3.3.1.3. The definitions above are based on white light observations only. Magnetograph, or inversion line, analysis may indicate that a group is unipolar even though its length is 3º or greater, or bipolar even though its length is less than 3º. In such a case, report the sunspot class based on the magnetograph or inversion line observation, and flag the unusual situation with a PLAIN language remark appended to the coded SPOTS report.

Figure 3.1. Longitudinal Sunspot Motions.

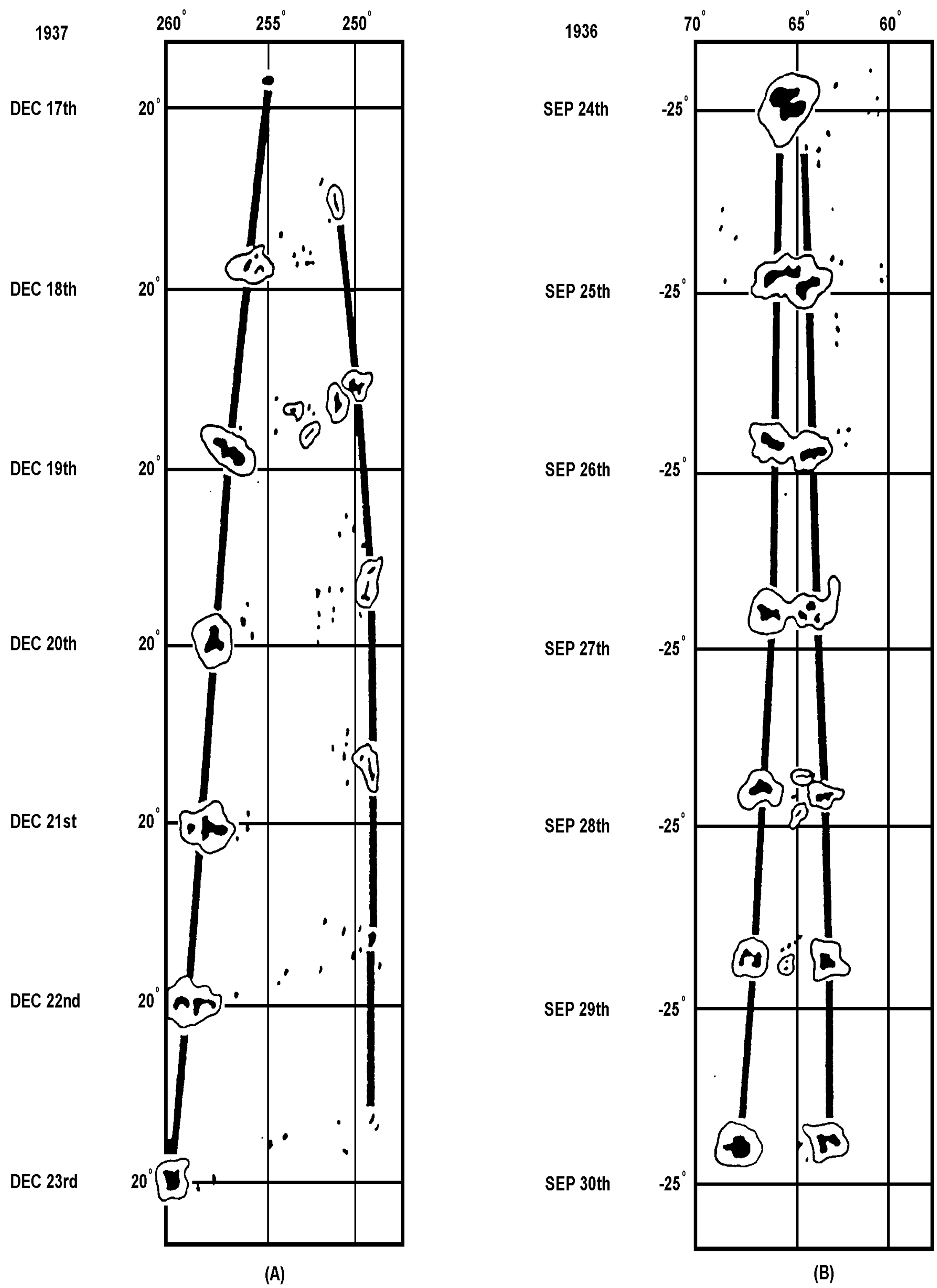
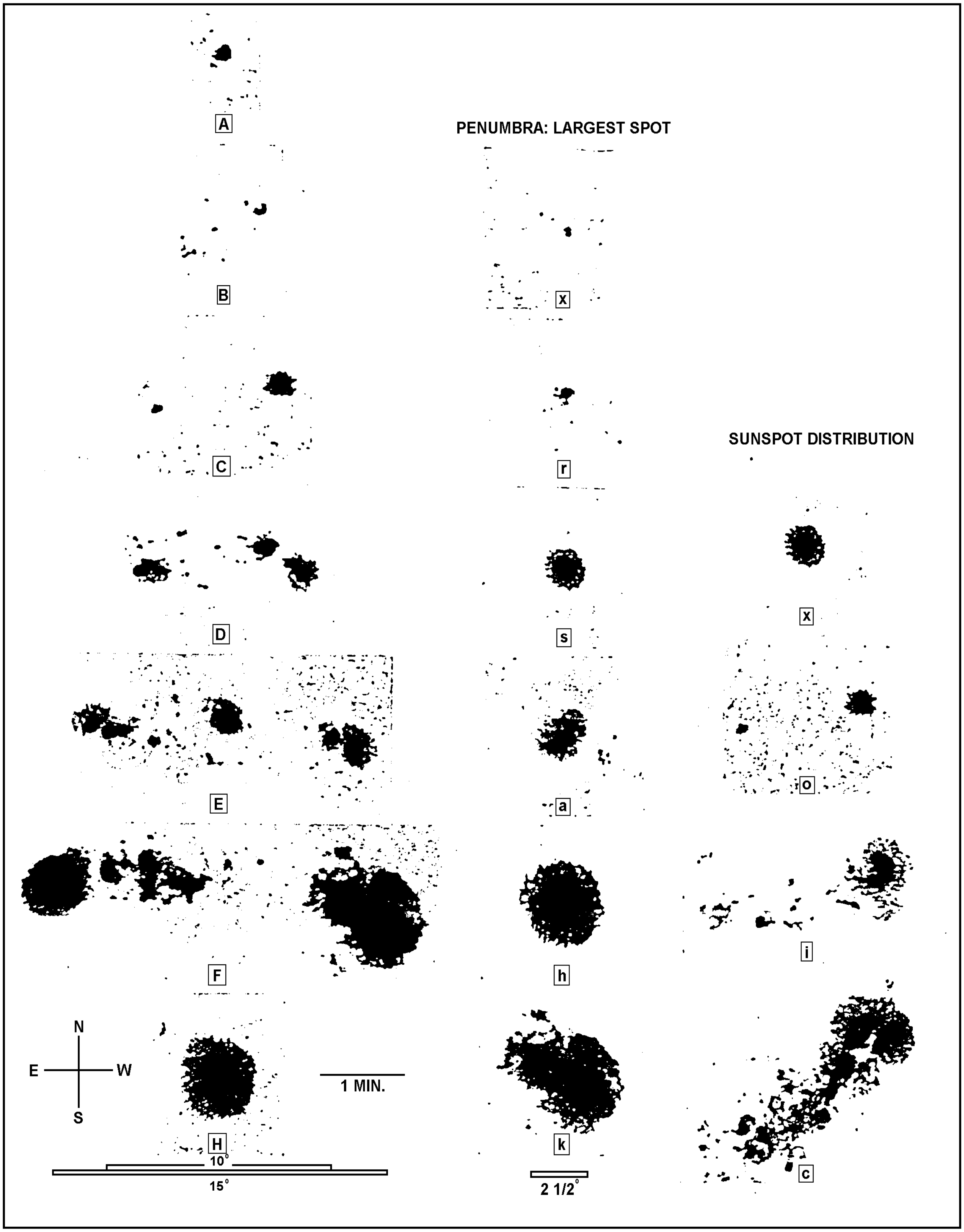


Figure 3.2. Modified-Zurich Sunspot Classification System.



3.3.2. Sunspot Class. There are seven classes in this component of the system. Each class represents an evolutionary stage that a sunspot group may go through during the course of its development and decay. When determining sunspot class, use the length of a sunspot group (often called "longitudinal extent") between the outermost extremities of the group's leading and trailing ends. Measure this length along the group's major axis (Figure 3.3). **NOTE:** Since the major axis may not be parallel to the latitude lines, the term "longitudinal extent" is misleading because it implies a strictly east-west measurement.

3.3.2.1. **A** - Unipolar group with no penumbra; length is (normally) less than 3 heliographic degrees.

3.3.2.2. **B** - Bipolar group with no penumbra; length is (normally) 3 heliographic degrees or greater.

3.3.2.3. **C** - Bipolar group with penumbra on spots of one polarity only, usually the spots at one end of an elongated group.

3.3.2.4. **D** - Bipolar group with penumbra on spots of both polarities. The group's length is less than or equal to 10 heliographic degrees.

3.3.2.5. **E** - Bipolar group with penumbra on spots of both polarities. The group's length is greater than 10, but less than or equal to 15, heliographic degrees.

3.3.2.6. **F** - Bipolar group with penumbra on spots of both polarities. The group's length exceeds 15 heliographic degrees.

3.3.2.7. **H** - Unipolar group with penumbra. The principal spot is usually the leader spot remaining from an old bipolar group.

3.3.3. Penumbral Class. Penumbra is the gray area bordering the black umbra. If an apparent gray area is too indistinct to be drawn, it should not be reported. To determine penumbral class, use the symmetry and size of the largest penumbra of a sunspot in a group. When using the penumbral diameter criteria below, measure across the north-south (N-S) axis of the spot. **NOTE:** A N-S measurement minimizes the effect of geometric foreshortening. Foreshortening depends on radius vector, and increases in magnitude as one approaches the limb in any radial direction from the sun's center. Since most sunspot groups are located less than 40º latitude, the N-S spot diameter should be the least affected by foreshortening. Taking a N-S measurement doesn't compensate exactly for foreshortening, but it does standardize how our approximate correction is applied.

3.3.3.1. **x** - No penumbra.

3.3.3.2. **r** - Rudimentary penumbra. Incomplete, irregular penumbra. It is brighter than mature penumbra and has a mottled or granular (vice filamentary) fine structure.

3.3.3.3. **s** - Small symmetric penumbra. Mature, dark, circular or elliptical penumbra with filamentary fine structure, and a N-S diameter across the penumbra of 2.5 heliographic degrees or less. This class includes penumbrae that appear elliptical due to the effect of geometric foreshortening. Symmetric penumbra usually contains either a single umbra or a compact cluster of umbrae near the center.

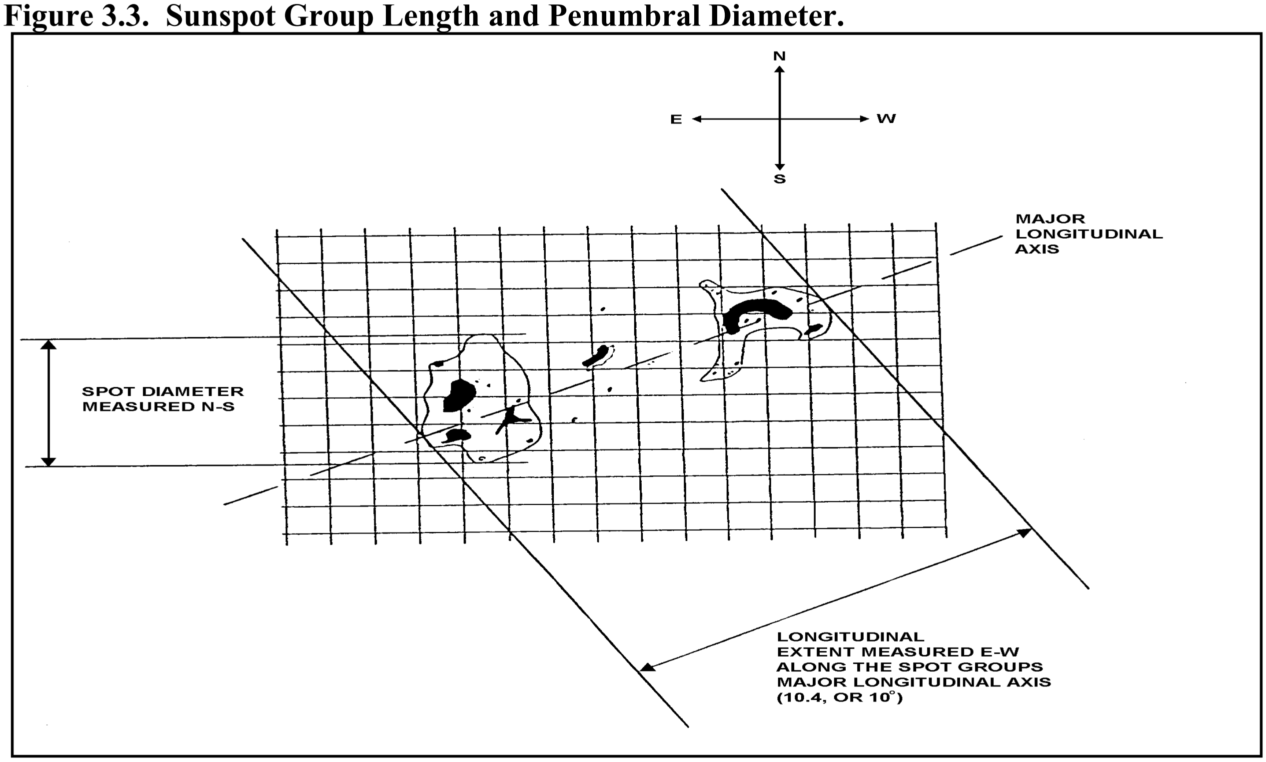
3.3.3.4. **a** - Small asymmetric penumbra. Mature, dark, irregular (clearly not circular or elliptical) penumbra with filamentary fine structure, and a N-S diameter across the penumbra of 2.5 heliographic degrees or less. The asymmetry is "real", not just due to foreshortening effects. Asymmetric penumbra usually contains two or more umbrae scattered within it.

3.3.3.5. **h** - Large symmetric penumbra. Has the same characteristics as a small symmetric (s) penumbra, but with a N-S diameter across the penumbra greater than 2.5 heliographic degrees (normally corresponding to an area greater than about 250 millionths of the solar hemisphere).

3.3.3.6. **k** - Large asymmetric penumbra. Has the same characteristic as a small asymmetric (a) penumbra, but with a N-S diameter across the penumbra greater than 2.5 heliographic degrees (normally corresponding to an area greater than about 250 millionths of the solar hemisphere).

3.3.4. Sunspot Distribution. This component of the Modified-Zurich Sunspot Classification System indicates the density of a group's internal spot population. The "o", "i", and "c" distribution classes are limited to bipolar groups. For example, the distribution of a unipolar H group with a small satellite umbral spot should be an "x", rather than "o". These and other logical restrictions on combining sunspot class, penumbral class, and sunspot distribution limit the number of possible classifications in the Modified-Zurich Sunspot Classification System to 60. Table 3.1 summarizes the allowed combinations.

Figure 3.3. Sunspot Group Length and Penumbral Diameter.



3.3.4.1. **x** - Undefined for a single spot or unipolar spot group.

3.3.4.2. **o** - Open. Few, if any, spots between the leader and trailer spots. Any interior spots are very small umbral spots or pores.

3.3.4.3. **i** - Intermediate. Many spots lie between the leading and trailing portions of the group, but none of them possesses mature (i.e., more than rudimentary) penumbra.

3.3.4.4. **c** - Compact. The area between the leading and trailing ends of the spot group is populated with many strong spots, with at least one interior spot possessing mature penumbra. An extreme case has the entire spot group enveloped in one continuous penumbral area.

Table 3.1. Allowed Types of Groups in the Modified-Zurich System.

Sunspot Class	Penumbral Class	Spot Distribution	Number of Combinations
A	X	x	1
B	X	o, i	2
C	r, s, a, h, k	o, i	10
D, E, F	r	o, i	6
D, E, F	s, a, h, k	o, i, c	36
H	r, s, a, h, k	x	5

		Total Allowed Types:	60

3.4. Mount Wilson Magnetic Classification System.

3.4.1. Information for assigning the Mount Wilson magnetic class may be obtained from computer generated magnetic maps, manual inversion line analysis, or any other applicable observing technique. The magnetic polarities of individual sunspots in a group, and the distribution of surrounding plage, form the basis for this system. The three major classes are Alpha (unipolar), Beta (bipolar), and Gamma (complex). A special magnetic subclassification, the Delta configuration, exists when an inversion line separates umbrae of opposite polarity within the same penumbral area. An example of each class below is shown in Figure 3.4.

3.4.2. **Alpha (α)**. A single spot, or unipolar spot group, around which the distribution of plage is fairly symmetrical. Magnetic field measurements show that unipolar groups are often accompanied by an area of opposite polarity in which sunspots are not visible.

3.4.2.1. **Alpha p**. The magnetic field polarity in and around the spot(s) corresponds to the polarity for leader spots in the hemisphere for the current solar cycle. The spot(s) and adjacent plage are followed by an elongated area of plage or faculae of the opposite polarity. Not reported at USAF observatories.

3.4.2.2. **Alpha f**. The magnetic field polarity in and around the spot(s) corresponds to the polarity for trailer spots in the hemisphere for that cycle. The spot(s) and adjacent plage are preceded by an elongated area of plage or faculae of the opposite polarity. Not reported at USAF observatories.

3.4.3. **Beta (β)**. A bipolar group in which magnetic field strengths and spot areas indicate a balance between the leader and trailer spots. The polarities show a clear separation.

3.4.3.1. **Beta p**. A bipolar group in which the magnetic field strengths and spot areas indicate that the leader spots are dominant. Not reported at Air Force observatories.

3.4.3.2. **Beta f**. A bipolar group in which the magnetic field strengths and spot areas indicate that the trailer spots are dominant. Not reported at USAF observatories.

3.4.4. **Beta-gamma (βγ)**. A spot group that has Beta (bipolar) characteristics, but is lacking a well defined dividing line between regions of opposite polarity. This class includes cases in which spots of the opposite or "wrong" polarity accompany the leader or trailer regions.

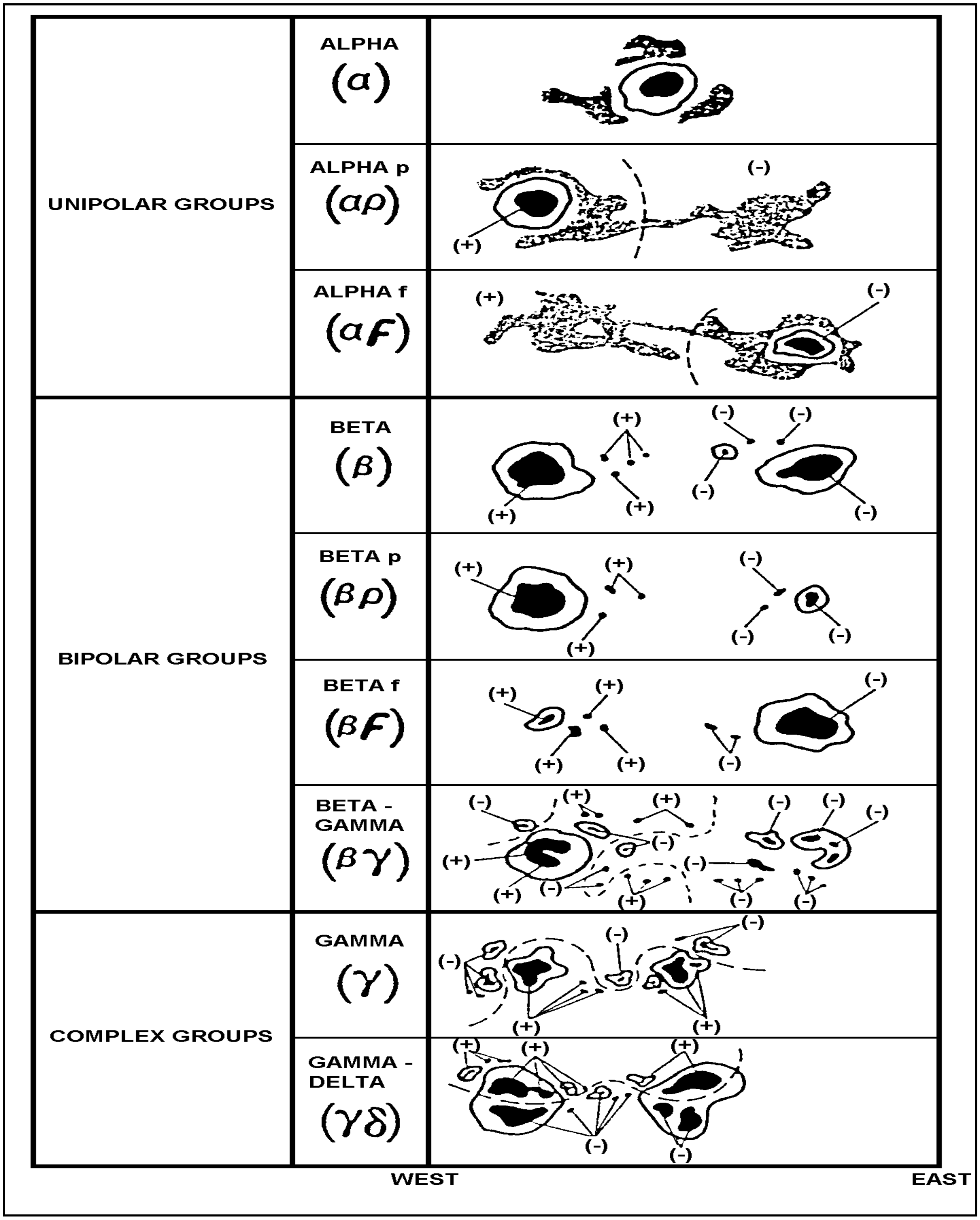
3.4.5. **Gamma (γ)**. A spot group in which the polarities are completely intermixed.

3.4.6. **Beta-delta (βδ)**. A spot group, which has Beta characteristics, but has umbrae of opposite polarity inside the same penumbra.

3.4.7. **Beta-gamma-delta (βγδ)**. A spot group, which has Beta-gamma characteristics, but has umbrae of opposite polarity inside the same penumbra.

3.4.8. **Gamma-delta (γδ)**. A spot group, which has Gamma characteristics, but has umbrae of opposite polarity inside the same penumbra.

Figure 3.4. Mount Wilson Magnetic Classification System.



3.5. Sunspot Drawing Procedures.

3.5.1. Complete the legend block of the AFWA Form 21, Sunspot Analysis Worksheet, and align the worksheet on the white light projection board for the correct P-angle.

3.5.2. Check the focus and size of the projected solar image prior to starting the drawing. **NOTE:** If necessary, adjust the white light focusing knob and projection board position to ensure an 18 cm diameter image is in focus on the board. There is a seasonal variation in image size due to changes in the earth-sun distance. The frequency of these adjustments will be greatest (up to daily) near solar perihelion and least (every few weeks) near aphelion. Movement of the white light focusing knob may also affect image dimension at the guider assembly. To ensure accurate tracking and positioning, run the system calibration check (CALCK) program and, if necessary, run the image calibration (ICAL) program after focusing.

3.5.3. Use a short, finely pointed, hard lead pencil. Ensure the pencil has a good eraser. Avoid hitting the surface of the mirror with the pencil since the eraser will leave a mark.

3.5.4. Note the time the drawing is started. Carefully outline each umbra and penumbra with a fine line. Precisely blacken in the umbrae.

3.5.5. Move a white card back and forth over the worksheet to aid in defining spots and eliminating the effect of tiny imperfections in the worksheet. This act also allows comparison of the actual and drawn images.

3.5.6. Note the time the drawing is finished. The time of the observation is the midpoint of the drawing process.

3.6. Data Reduction Procedures.

3.6.1. Assign local and SEC sunspot numbers.

3.6.1.1. Start the local number sequence with 001 for the first new sunspot group observed after the beginning of a new calendar year.

3.6.1.2. Carefully maintain numbering continuity from day-to-day. However, use a new local number when a previously numbered spot group disappears, then later reforms.

3.6.1.3. Include SEC assigned region numbers, when available. **NOTE:** Check other spot reports and all SEC messages for information on newly assigned SEC regions.

3.6.2. Assign a quality of observation by referring to the white light seeing categories in paragraph 3.2.

3.6.3. Determine each sunspot group's location and length using the appropriate Stoneyhurst overlay. When selecting a Stoneyhurst overlay, round the B-angle (also known as B_O) up if it is x.5° or greater, and round it down if it is x.4° or less.

3.6.3.1. To determine the sunspot group's location (latitude and longitude), use the geometric center of the group. Label the coordinates for each sunspot group on the sunspot analysis worksheet.

3.6.3.2. Measure the length of a group (often called "longitudinal extent") between the outermost extremities of the group's leading and trailing ends. Express the results in heliographic degrees. Make the measurement along the group's major axis (Figure 3.3). **NOTE:** Since the major axis may not be parallel to the latitude lines, the term "longitudinal extent" is misleading because it implies a strictly east-west measurement.

3.6.3.2.1. If the major axis is inclined less than (roughly) 45º to the latitude lines: Lay a ruler or the edge of a piece of paper along the major axis and note its length or mark the length on the paper. Rotate the ruler or paper edge, about the center of the group, so the ruler or paper edge is parallel to the latitude lines. Read the group's (approximate) length directly off the Stoneyhurst overlay in heliographic degrees.

3.6.3.2.2. If the major axis is inclined more than (roughly) 45º to the latitude lines: Visualize a right triangle formed by the major axis, the latitude lines, and the longitude lines. Measure the change in latitude in degrees, and the change in longitude in degrees. Then use the Pythagorean theorem ($c^2 = a^2 + b^2$) to compute the group's length. **NOTE:** The terms "a" and "b" correspond to the increment in latitude and longitude, expressed in degrees.

3.6.4. Determine the total (penumbral and umbral) uncorrected area of each sunspot group using the sunspot area overlay.

3.6.4.1. Place the sunspot area overlay on top of a drawn spot. Using a "best fit" method, select the overlay circle or ellipse whose outline matches the outline drawn for penumbral areas and/or encloses individual umbra without penumbra. For very irregular penumbra, it may be necessary to break it down into imaginary circles or ellipses to make the measurement. If the area is less than 10 millionths, determine the area by estimating how much of the 10 millionths circle it fills.

3.6.4.2. Repeat the step above for each spot in a group. Add the areas of all the spots in the group to get the total uncorrected group area.

3.6.5. Determine the total corrected area of each sunspot group using the limb foreshortening overlay.

3.6.5.1. Center the limb foreshortening overlay on the sunspot drawing and rotate it so that the line runs from the sun center through the geometric center of the group. The "hash mark" across the group's center represents a limb foreshortening correction factor.

3.6.5.1.1. If the group's center is between two hash marks use the smaller correction factor no matter which hash mark is closest to the center.

3.6.5.1.2. If the group's center lies below the 1.1 hash mark, give it a correction factor of 1.

3.6.5.1.3. If the group's center lies beyond the 3.0 hash mark, give it a correction factor of 3.

3.6.5.2. To get each group's corrected spot area (in millionths of the solar hemisphere), multiply the total uncorrected spot area by the foreshortening correction factor. Report each group's area in whole increments of 10 millionths of the solar hemisphere.

3.6.6. The number of spots in a sunspot group is the number of umbrae (or dark cores) visible. For example, two umbrae surrounded by the same penumbral area count as two spots.

3.6.7. Determine the Modified-Zurich Classification (spot class, penumbra type, and distribution) from the spot drawing. Use the length of the sunspot group (measured as specified in this chapter) in determining spot class.

3.6.8. Determine the magnetic classification using any means of magnetic field analysis available. Particularly useful is the technique of overlapping a magnetic map on a Mg-b_2 image.

3.6.9. As a final check before transmitting an encoded SPOTS report IAW AFMAN 15-124 compare the sunspot locations against data from other observatories and the AXXX02 KBOU Joint USAF/NOAA Solar Region Summary bulletin. If a significant deviation exists, recheck the location with the white light projection board and Stoneyhurst overlay (correct P-angle and B_o used). Serious errors can also be introduced when the H-alpha and white light imaging systems are not colinear. The lack of colinearity can be detected by performing two image rotator checks: one at the white light board, and the other on the H-alpha monitor. It can also be detected by comparing the sunspot analysis worksheet coordinates for a particular spot with the coordinates obtained by the DALAS location (DALO) program.

Chapter 4

ACTIVE REGION AND MAGNETIC ANALYSIS TECHNIQUES

4.1. Active Region Analysis.

4.1.1. An active region is an area where a localized intensification of the solar magnetic field has concentrated atmospheric plasma to make it denser, hotter, and thus brighter, than the surrounding atmosphere. These regions are observed in the upper photosphere as white light faculae, in the chromosphere as plage, and in the corona as coronal condensations. The complex, enhanced magnetic field in active regions is responsible for nearly all flare activity and most disk and limb activity.

4.1.2. Faculae. Faculae are bright patches (also known as "white light plage") in the upper photosphere, located in areas of enhanced magnetic fields associated with sunspots. They are normally visible only near the limb, where limb darkening provides a favorable contrast. Since magnetic fields associated with active regions diverge with height, facular structure is finer than in chromospheric plage.

4.1.3. Plage. Plage is the chromospheric aspect of an active region and is visible in H-alpha. Tables 4.1 and 4.2 list the criteria for determining plage compactness and intensity.

4.1.3.1. Each plage compactness class corresponds roughly to an evolutionary stage that a plage region may go through during the course of its development and decay. New, young regions tend to be compact. As the region ages, the magnetic field lines tend to spread over a wider area, causing the plage to become more scattered.

4.1.3.2. Since a much smaller magnetic field strength is required to produce an area of plage than a sunspot, plage generally develops before, and dissipates after, any associated sunspot(s). Not all plage have spots develop beneath them. In H-alpha observations, plage will often obscure any underlying sunspot(s).

Table 4.1. Plage Compactness Descriptions.

Compactness	% Area of an Enclosed Circle
Widely Scattered	< 20
Scattered	≥ 20 to < 40
Scattered to Broken	≥ 40 to < 60
Broken	≥ 60 to < 80
Compact	≥ 80 to 100

Table 4.2. Plage Intensity Descriptions.

Intensity	Description
1	Faint Plage. (Barely visible with diffuse edges; i.e., just above the contrast sensitivity detection threshold.)
2	Moderate Faint. (Clearly visible and moderately distinct with good seeing and light level. Visible to about ± 0.2 Angstrom off-band.)
3	Normal. (Visible to about ± 0.35 Angstrom off-band.)
4	Bright. (Visible to about ± 0.5 Angstrom off-band. Generally associated with new emerging regions with strong magnetic gradients along complex neutral lines. May reach intensities equal to faint flares in strong or rapidly emerging regions.)
5	Flare Bright. (Generally visible to ± 0.5 Angstrom off-band. Distinguished from flares by slow rise time and long duration. Normally confined to only points or segments within a region.)

4.1.3.3. Point Brightenings. Very localized point enhancements in plage intensity that collectively, at any one moment, do not reach the minimal area needed to declare a flare (i.e., their total corrected area is less than 10 millionths of the solar hemisphere). Point brightenings may be of faint, normal, or brilliant intensity. They generally rise in intensity and return to their pre-enhanced level in a short period of time, typically 10 minutes or less. They may occur as single points, or as a series of continuously rising and falling points. At times they brighten rapidly and remain at, or near, flare intensity for up to several hours. **NOTE:** "Point brightenings" are a plage, not flare, characteristic. As such, they are reported in a PLAIN, not FLARE, code report. Do not confuse point brightenings with the flare characteristics "brilliant points", "bright points", or "several eruptive centers". These flare characteristics are defined in the chapter on flare analysis.

4.1.3.4. Plage Fluctuations. Plage fluctuations differ from flares primarily in their lower intensity (seldom greater than 50% above background), and slower rate of intensity change (no flash phase). Also, they are usually less well defined than flares, and are not identifiable beyond about ± 0.5 Angstrom off-band in H-alpha. Occasionally they do rise (slowly) to flare intensity and may remain at, or near, that level for several hours. At times portions of these fluctuations can exhibit flash phase characteristics and should be classified as flares. The most enhanced, extensive and long-lived fluctuations occur in magnetically intense, complex areas, and their effects (X-ray emissions, etc.) can be similar to those of a flare.

4.2. H-alpha Seeing Categories.

4.2.1. Seeing = 1 (Very Poor).

4.2.1.1. Image motion is usually obvious with rippling waves sweeping across the disk.

4.2.1.2. Only gross features such as plage and large filaments are visible. Plage brightness appears as a homogeneous glob. Only gross changes may be detected in large prominences.

4.2.1.3. Small (around 10 millionths of the solar hemisphere) faint and normal subflares are usually not discernible.

4.2.1.4. When viewing off-band, the observer can't distinguish between umbrae and penumbrae, even in large spots.

4.2.2. Seeing = 2 (Poor).

4.2.2.1. Image motion is observed.

4.2.2.2. Brightness variations between plage areas may be seen. Point brightenings may be observed, but appear as small, ill-defined patches of fluctuating plage.

4.2.2.3. Filament channels begin to appear. Minor limb activity, such as small Active Surge Regions (ASRs), may not be observed.

4.2.2.4. Small, faint subflares occasionally may not be observed.

4.2.3. Seeing = 3 (Fair).

4.2.3.1. Some image motion may be observed on both the disk and limb.

4.2.3.2. Arch Filament Systems (AFS) are plainly visible. Narrow active region filaments may be seen.

4.2.3.3. Filament channels are generally sharply defined. Minor limb activity is visible.

4.2.3.4. Fibril structure is moderately distinct around strong spots. When viewing off-band, umbrae and penumbrae are distinguishable from each other.

4.2.4. Seeing = 4 (Good).

4.2.4.1. AFSs are well defined. Narrow active region filaments are sharply defined. Plage point brightenings appear as sharp, well-defined points.

4.2.4.2. The individual spikes in small ASRs are clearly separated from each other.

4.2.4.3. Chromospheric fine structure is moderately distinct at H-alpha line center and off-band.

4.2.5. Seeing = 5 (Excellent).

4.2.5.1. No limb motion is observed.

4.2.5.2. Fine hairline filaments are sharply visible.

4.2.5.3. Active region fibril structure and chromospheric fine structure are sharply defined.

4.2.5.4. When viewing off-band, both umbrae and penumbrae are sharply defined.

4.3. Computer Generated Magnetic Maps.

4.3.1. Use the SOON telescope's magnetograph subsystem to make magnetic maps (called magnetograms) for use in analyzing the magnetic complexity of active regions (i.e., inversion line locations; field polarities, intensities, and gradients; and the Mount Wilson sunspot classification). The spectrograph (SPEC) program is used to acquire magnetograms.

4.3.2. The magnetograph uses the Zeeman effect, the splitting of magnetically sensitive spectral lines. It analyzes the line's components to determine the "longitudinal" (or line-of-sight) magnetic field. The separation of the two components indicates the magnetic field strength, while their polarization indicates the polarity (positive or negative) of the magnetic field. Since magnetograms display only the line-of-sight portion of the magnetic field, geometric foreshortening causes magnetograms to lose their resolution and quantitative accuracy near the limbs. Thus, even if a region's magnetic field strength remained constant during its entire disk passage, it would appear to strengthen as it approached the central meridian and weaken as it moved on toward the west limb.

4.3.3. Preliminary steps required before running the program SPEC.

4.3.3.1. Ensure a good MAGR videometer box exists. magnetic reference region (MAGR) will be located as near as possible to disk center; minimum 150 x 150 arc seconds in size; and is as completely devoid of features (e., plage, filaments, etc.) as possible. The program SPEC will use this region for magnetic calibrations, initial Doppler cube centering, and phase plate optimization.

4.3.3.2. Define an H-alpha videometer sequence (e.g., VM) to include up to six regions for which maps will be made. The sequence provides region identifications and locations to the program SPEC.

4.3.3.3. Place the calibration polaroid over the objective lens.

4.3.3.4. Ensure the following items are properly adjusted:

4.3.3.4.1 Confirm the proper setting for the right hand edge of the large scale SG lens.

4.3.3.4.2. Slit jaw micrometer is set at 1.25 mm (125 microns).

4.3.3.4.3. Slit carriage assembly is in the PE position, and "NORM" is selected on the slit function knob.

4.3.3.4.4. Set the Grating, Focus, and Shift dial to locally established values. **NOTE:** The final rotation of the Grating dial should be a counterclockwise move to allow for any play in the linkage.

4.3.3.4.5. Spectrograph filter wheel is set at filter 11.

4.3.3.4.6. Magnetograph slide assembly beam-splitter lever is in the "up" position, and the 10830 Angstrom beam-splitter is pulled out.

4.3.3.4.7. Magnetograph slide assembly is in the full "in" position.

4.3.3.5. Ensure all servo modules are in the "AUTO" position, and the SG lens control is in the "COMP" position. Set the DZA gain to the locally determined value required to achieve a proper photodiode plot.

4.3.4. Run the program SPEC IAW guidance contained in the SOON COM. Select the following options:

4.3.4.1. **"C".** Adjust the calibration lens so that the calibration polaroid lies over the junction of the slit and the photodiodes, as seen on the monitor.

4.3.4.2. **"O".** Select the appropriate optical setups (normally the default values). Running the "O" option is necessary to start the high voltage chop. **NOTE:** If it becomes necessary to run "OF,SPEC,1" or a power outage occurs, run "RU,KTEST,,1" to shut off the KD*P chop voltage. It is preferable, however, to off ("OF") the subroutine in progress, so that the SPEC menu will appear and an orderly exit can be made from SPEC.

4.3.4.3. **"P".** Plots the profile of the light on the photodiodes. If there isn't a dip in the profile plot on each side of the vertical line, do the following:

4.3.4.3.1. Move the slit carriage assembly to the Spectra/White Light (S-WL) position. Place the trinocular eyepiece switch in the TV position. Route the SG output to monitor 4 by selecting "SG" on the "Master" switcher. A split image of the spectral line, with lateral horizontal displacement, should be visible. **NOTE:** If not, check and adjust the scanner mirrors to send light to the SG, the function knob on the slit carriage, the filter wheel in front of the SG TV camera, and the prism in the SG front end.

4.3.4.3.2. Move the slit carriage until one side of the slit jaw opening is visible. Use the SG zoom optics to bring the slit image into sharp focus. Then use the Focus dial to focus the spectral line in relation to the slit.

4.3.4.3.3. Set the Doppler "CUBE" servo module to "MANUAL" and its potentiometer to "500".

4.3.4.3.4. Adjust the 8468 Angstrom spectral line position with the grating dial so the spectral line in the top half of the split image lies on one side of the slit, and the line in the bottom half lies to the other side of the slit. It will be necessary to move the slit carriage so that first one edge of the slit jaw opening, and then the other, can be seen. The spectral line segments should be positioned as equally as possible on each side of the slit.

4.3.4.3.5. Return the "CUBE" servo module to the "AUTO" position, and the slit carriage to the "PE" position.

4.3.4.3.6. Run the SPEC program's "P" option again.

4.3.4.3.7. If the dips in the profile plot now appear on each side of the vertical line, proceed to the next paragraph, Option “S”. If not, repeat the above steps for Option “P”.

4.3.4.4. **"S".** Select the appropriate videometer sequence. The magnetograph will now run.

4.3.5. After all magnetograms are acquired, remove the calibration polaroid from the objective lens.

4.4. Magnetic Inversion Line Analysis.

4.4.1. An inversion line (also called a transition, dividing, zero, or neutral line) marks the division between areas of opposite "longitudinal" (line-of-sight) magnetic polarity. The terms zero or neutral line are misleading since they imply an absence of magnetic field; whereas there is actually a "transverse" field (horizontal or parallel to the sun's surface), often a strong one. Inversion lines are very useful in determining the magnetic complexity of active regions (and thus flare potential), or in locating boundaries between large solar areas with predominately positive or negative polarity (i.e., Solar Sector Boundaries (SSBs).

4.4.2. Manual inversion line analysis, based on inference techniques, can be used to supplement computer magnetograph analysis when: the magnetograph is inoperative, in areas where the magnetic field strength is below the detection threshold of the magnetograph, or when features are smaller in scale than can be resolved by the magnetograph. For example, magnetograph accuracy declines with increasing radial distance from the sun's center because the longitudinal magnetic fields become less line-of-sight. In addition, magnetograph analysis is often ineffective for full disk analysis. Excellent background material can be found in AWS-TR-76-262, *Development and Decay Potential of Active Solar Regions from a Full-Disk Neutral-Line Analysis*.

4.4.3. Inference Techniques. In the absence of magnetograms, H-alpha features such as filaments, fibril structure, AFSs, and plage corridors can be used to infer the location of inversion lines. These features, and their relationship to inversion lines, are discussed below.

4.4.3.1. Filaments. Filaments are long, cloud-like structures suspended by magnetic fields (usually a saddle configuration) in the sun's atmosphere. They may develop where magnetic field lines are transverse (i.e., parallel to the sun's surface) and can support high density, charged plasma. These transverse fields normally are found at magnetic inversion lines (Figure 4.1). Filaments may develop between large scale areas (solar sectors) of opposite polarity ("quiescent filaments"), or between areas of opposite polarity within an active region ("plage filaments"). Plage filaments are much shorter, narrower, and lower in the sun's atmosphere than quiescent filaments. Since the supporting magnetic field structure in an active region changes on a much shorter time scale, plage filaments vary in size, shape, and darkness (i.e., density) more rapidly than quiescent filaments. Against the bright solar disk, filaments appear as dark absorption features. Filaments seen at the limb appear bright against a dark background and are called "prominences". Filaments are the most useful chromospheric feature for locating magnetic inversion lines due to their large size and easy identification.

4.4.3.1.1. Filaments located some distance from the center of the disk are actually viewed from the side, and often display legs or feet, which approach the sun's surface. (Large electric currents flowing up these feet interact with the magnetic field to provide the buoyancy or suspension force.) The inversion line is located at the base of these feet; not at the smooth, unscalloped side of the filament (Figure 4.2).

4.4.3.1.2. Near a large, well-developed sunspot a filament may curve toward and point directly into the spot. The inversion line departs from the path of the filament near the ends of the radial fibril structure and extends around the spot at right angles to the fibrils (Figure 4.3).

4.4.3.2. Fibril Structure and Filament Channels. Fibrils are narrow, linear absorption features visible in H-alpha. Near filaments and sunspots with strong magnetic fields they become aligned with the horizontal magnetic lines of force near the sun's surface (much like iron filings near a magnet). Overall fibril patterns show little change over a period of hours, although the lifetime of individual fibrils is only 10 to 20 minutes.

4.4.3.2.1 Systems of parallel, curving fibrils typically connect closely spaced regions of opposite polarity, giving the impression that the regions are "stitched" together. Fibrils may also extend radially from large, strong sunspots, forming extensions of the radial pattern seen in the penumbra. In such a situation, the inversion line lies at the outer edge of the radial pattern, perpendicular to the fibrils (Figure 4.3).

4.4.3.2.2. Near filaments, fibrils are usually aligned at a small angle to the filament and form a feather-like pattern, with the inversion line along its rib (Figure 4.3). A "filament channel" is an extension of this feather-like pattern into an area where a filament could be supported, but no filament is observed. A filament channel normally develops before the filament itself, and often persists long after a filament disappears.

4.4.3.3. Arch Filament Systems (AFS). These are dark, linear absorption features usually observed only in young, developing bipolar plage regions, or in Emerging Flux Regions (EFR). An AFS appears as one or more short, dark arches connecting plage of opposite polarity (Figure 4.4). The legs of individual arch filaments are inclined less than 30º to the sun's surface and the tops of the arches lie at a low altitude, rarely more than 10,000 km. Due to their low altitude, arch filaments, like fibrils, represent only the horizontal component of the magnetic field near the sun's surface. As a result, AFS are aligned parallel to the fibril pattern between the plage of opposite polarity. Arch filaments are not "true" filaments, since they lie across (rather than along) magnetic inversion lines, and are lower in the chromosphere than plage filaments (Figure 4.5). The inversion line therefore bisects the AFS at right angles to the AFS strands.

4.4.3.4. Plage Corridors. Polarity changes do not occur within an area of bright plage itself. Usually there is a distinct division (dark lane) between plage segments of opposite polarity. The division is called a "plage corridor", and an inversion line normally lies within this corridor (Figure 4.6). Plage filaments and filament channels may lie along a plage corridor, while arch filaments may lie across a corridor. The width of a plage filament, filament channel, and/or plage corridor increases as the magnetic field gradient across the inversion line decreases. Thus in young active regions (with abrupt polarity changes) they are narrow and often difficult to observe. They are noticeably wider between the weak magnetic fields in old active regions.

4.5. Magnetic Polarities in Active Regions.

4.5.1. All active regions are magnetically bipolar, just like the sunspots that may form within these active regions. Usually the positive and negative magnetic field strengths within a spot group are not equal in intensity. (**NOTE:** This fact explains why EFRs and old regions appear unipolar: for an EFR, the other polarity simply has not yet achieved a detectable intensity; while for an old region, it has declined below detectability.) In spot groups there are normally two major spots, the leader and the trailer spot. The leader spot usually is larger in size, has a stronger magnetic field strength, is the first to form, the first to develop penumbra, and the last to dissipate. The reason for these characteristics is that the leader spot almost always has the same polarity as that possessed by the nearer pole at the start (i.e., minimum) of an 11-year Solar Sunspot Cycle.

4.5.2. The general solar magnetic field is very weak (about one gauss) and dominates the Polar Regions. Unlike the earth, the general magnetic field is not due to an internal dipole field; rather it is the net result of many small surface fields in sunspots, pores, and the magnetic network associated with plasma convection cells in the photosphere. Also unlike the earth, the sun undergoes differential rotation (i.e., lower latitudes rotate more quickly than higher latitudes). The effect of differential rotation on the general solar magnetic field imbedded in its surface causes the development of active regions and sunspot groups, as well as a reversal of the general solar magnetic field polarity approximately 11 years. **NOTE:** Solar cycles may be as short as seven years or as long as 17 years, but average 11 years. Furthermore, the rise from solar minimum to maximum occurs in roughly four years, while the decline to minimum again occurs in roughly seven years.

Figure 4.1. Magnetic Field Support for a Prominence.

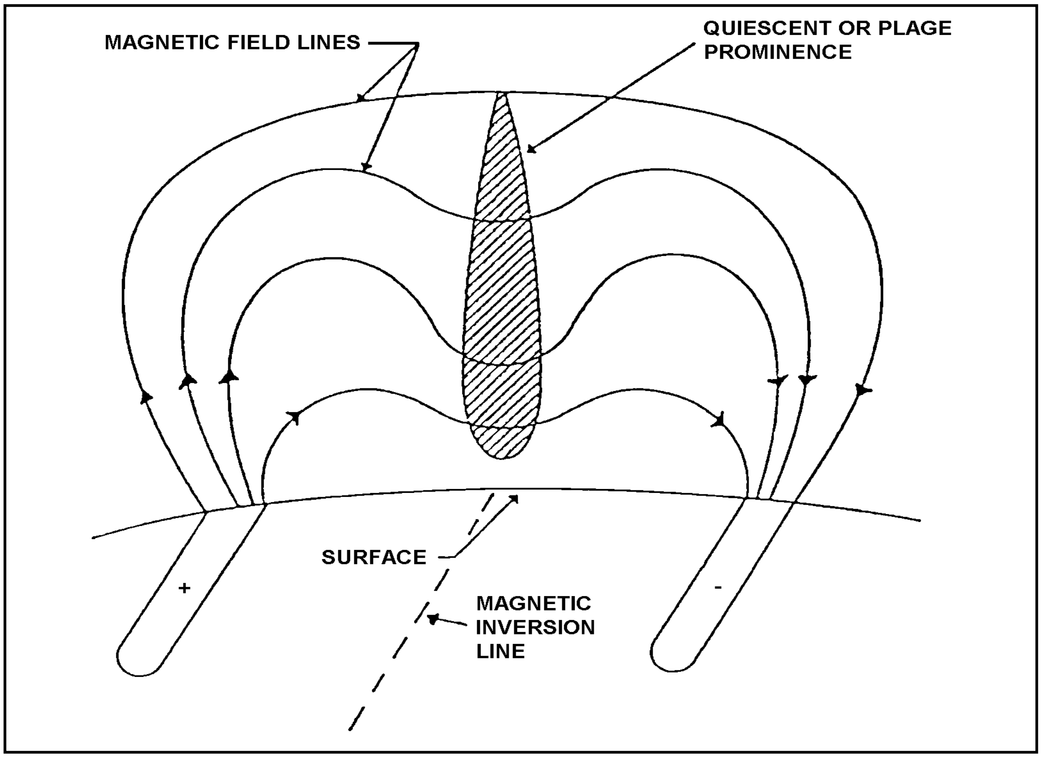


Figure 4.2. Full Disk Magnetic Inversion Lines. (Inversion lines are inferred at the base of filaments on the side where the "feet" are visible.)

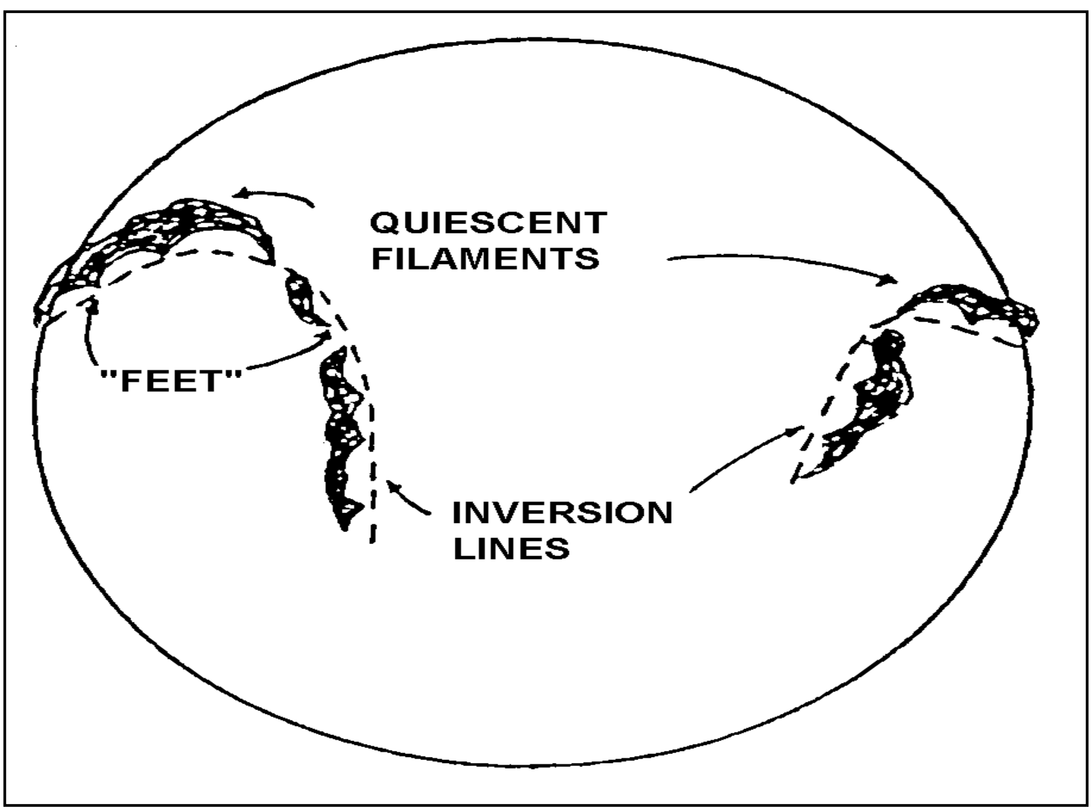


Figure 4.3. Active Region Magnetic Inversion Line.

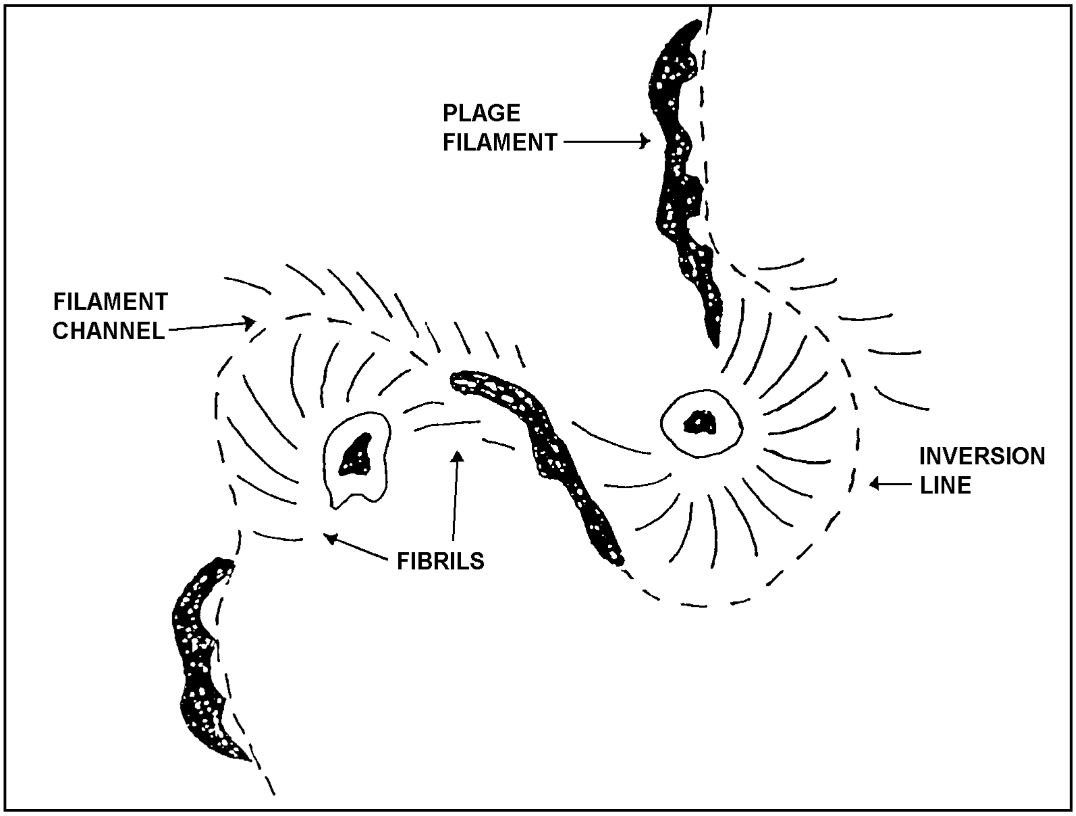


Figure 4.4. Arch Filament System (AFS).

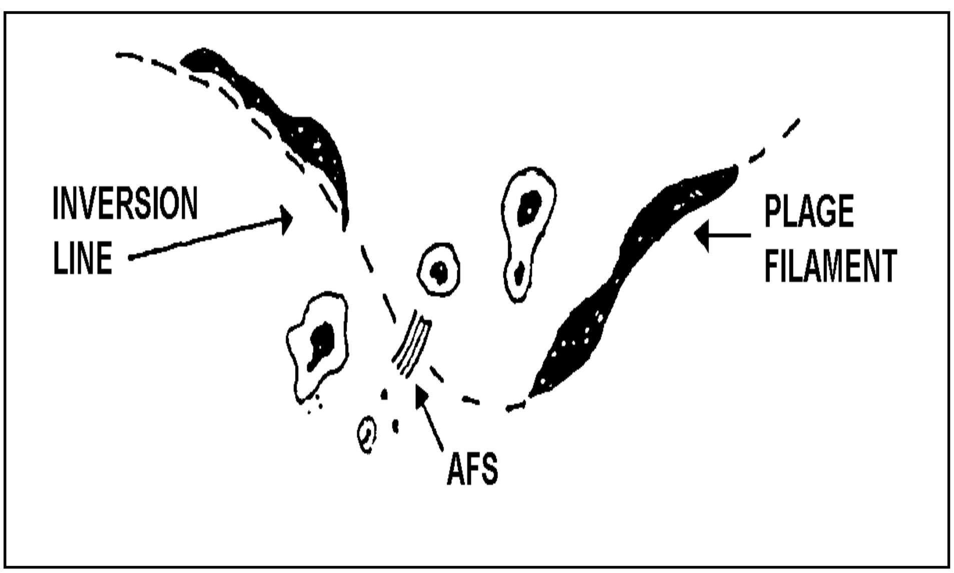


Figure 4.5. Arch Filament System Structure.

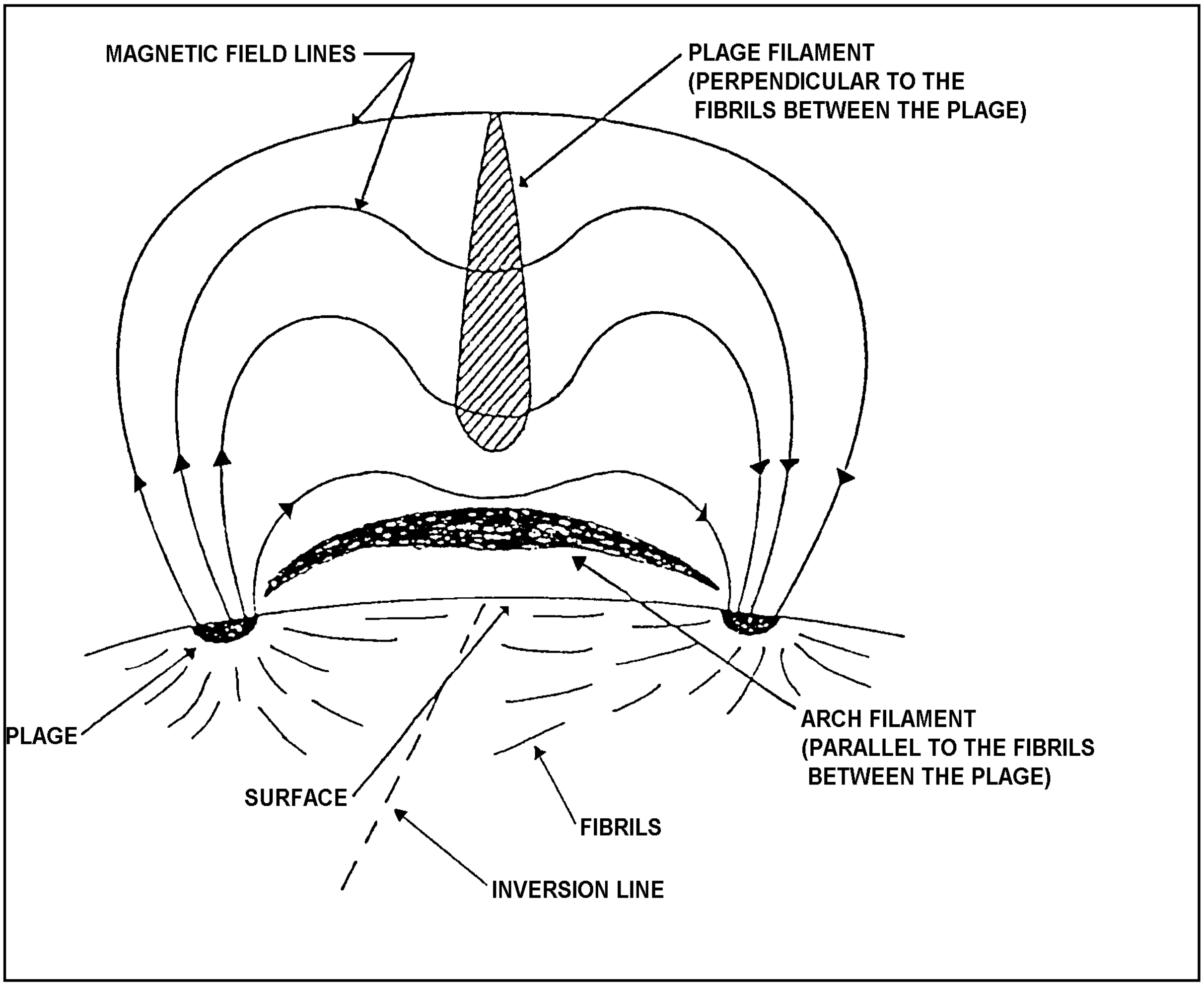
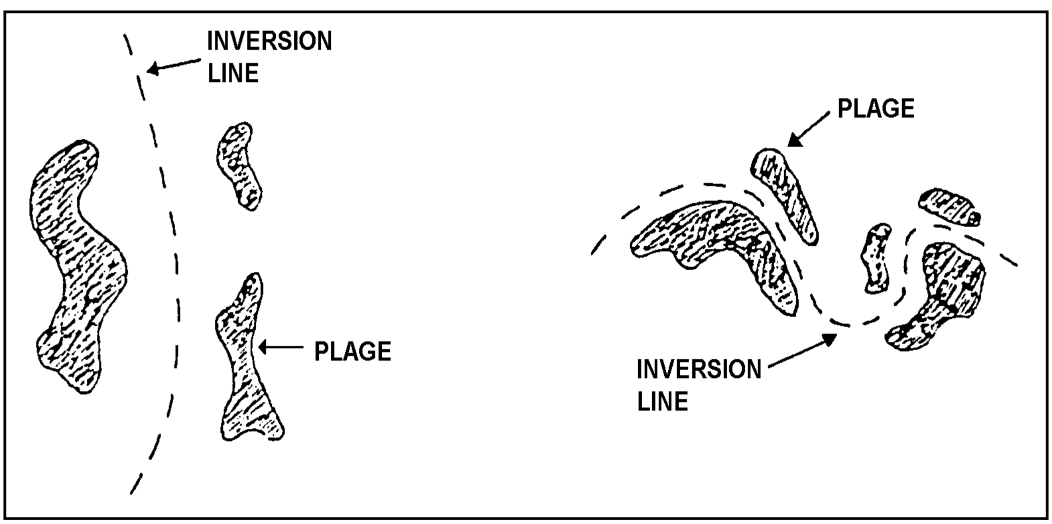


Figure 4.6. Plage Corridors (Plage corridors in old, decaying active regions are wide due to weak magnetic gradients, while those in a mature region are narrow due to tight gradients.)



4.5.2.1. In Sunspot Cycle 21, the North Pole had positive magnetic polarity, and the South Pole negative polarity. In Sunspot Cycle 22 the situation was reversed. The polarity reversal at the poles is gradual; the polar field starts to weaken shortly after solar maximum and the reversal is completed shortly before the onset of the new sunspot cycle at solar minimum. A return to the original polarity orientation for the general magnetic field takes two full sunspot cycles, and is known as the Hale 22-year Cycle.

4.5.2.2. Another result of differential rotation, and the fact that the sun's magnetic field is imbedded in the photosphere, is the preferred latitude band for new sunspot formation, which gradually drifts equatorward during the solar cycle. This phenomenon is often displayed as a Maunder Butterfly Diagram (Figure 4.7). At the start of a cycle (solar minimum), spots tend to form near 40º north and south latitude. As the cycle progresses, the favored latitudes move lower, to about 15º near solar maximum, and finally to about 5º just as the next cycle is about to begin. There is an overlap of about three years near minimum when old cycle, low latitude spots and new cycle, high latitude spots may co-exist.

4.5.3. Computer generated magnetograms indicate the polarity of the various portions of an active region. To confirm the accuracy of computer assigned polarities, an analyst can use the fact that the leading (western) portion of an active region, like its leader spot (if any), normally has the same polarity as the nearer pole possessed at the start of the cycle; while the trailing portion has the opposite polarity as the trailer spot (if any). For example, in Cycle 22 Northern Hemisphere spot groups had negative leaders and positive trailers, while Southern Hemisphere groups had positive leaders and negative trailers.

4.5.4. If a leader spot is observed to have the reversed polarity from that expected, recheck the magnetic field analysis. True leader spot polarity reversals do occur in rare, but significant, cases. They often involve complex or unusual region configurations, and their occurrence should be brought to the attention of the forecast centers.

4.6. Solar Sector Boundaries.

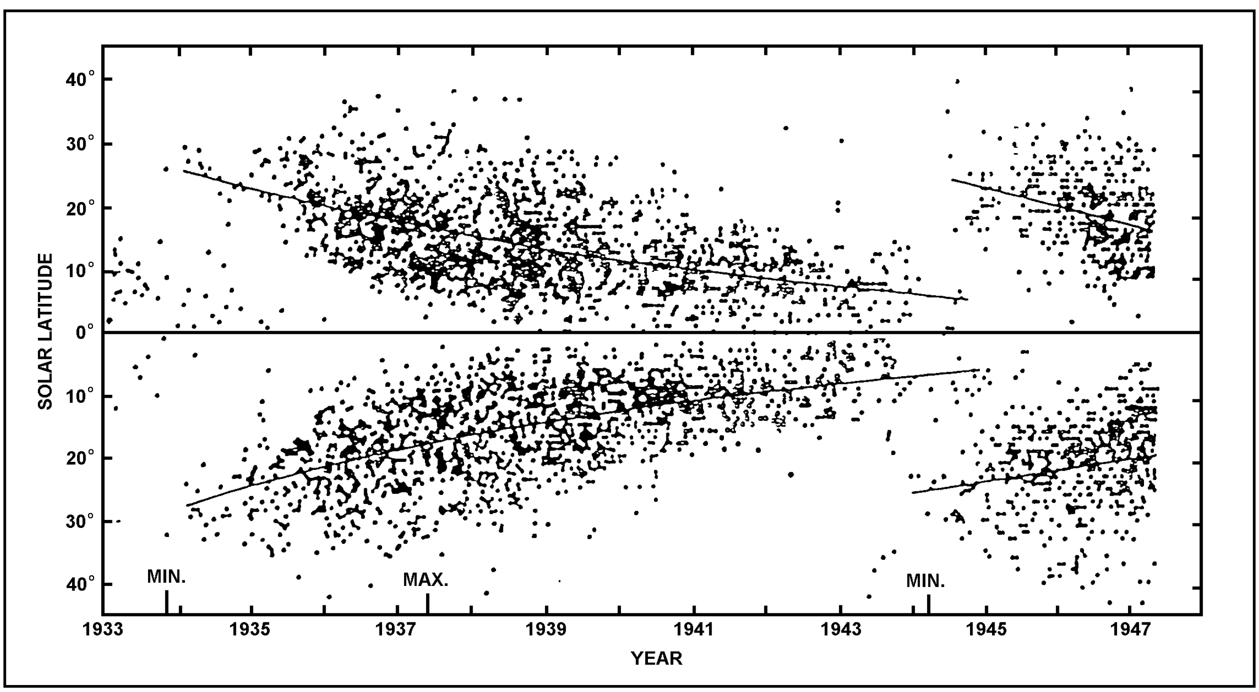
4.6.1. The general solar magnetic field dominates the Polar Regions, causing them to have opposite polarities. At mid to low latitudes, the general solar magnetic field still appears as expansive areas of predominately single polarity, but these areas (called "solar sectors") tend to be longitudinally oriented (Figure 4.8.). These sectors have an average width of approximately 100 degrees longitude, an overall arrowhead shape that points toward the west, and may persist for several solar rotations. The magnetic field strength of these sectors is weak, only one or two gauss, and represents the summation of all the high intensity (tens to several thousand gauss) fields in the active regions. SSBs are the magnetic inversion lines separating these expansive solar areas of opposite polarity. **NOTE:** SSBs are currently not reported by Air Force Solar Observatories.

4.6.2. Solar sectors and SSBs are important because of their connection with the Interplanetary Magnetic Field (IMF) and the solar wind. The origin of the IMF lies in the predominately single polarity, photospheric magnetic fields in the solar sectors. As a result, the IMF also displays a sector structure. The IMF guides the solar wind, which is a continuous out-gassing of charged solar particles, outward from the sun. Additional high-speed, high-density particle streams (often referred to as "Coronal Mass Ejections", CMEs) can be emitted by large solar flares, erupting filaments or prominences, and/or "coronal holes" (which are large coronal areas that have open, outward directed magnetic field lines). The outward motion of these high-speed, high-density particle streams will be influenced by the IMF's sector structure. To predict their potential influence on the earth, forecasters need to know the location of the particle stream's source region on the sun and information about the sector structure of the IMF.

4.6.3. The location on the sun of a particle stream's source region is important because of the IMF's spiral structure. This spiral structure causes solar particles from the sun's Eastern Hemisphere to pass behind the earth in its orbit. However, particles from the sun's western hemisphere are swept into the path of the earth, and are much more likely to cause disturbances in the earth's own geomagnetic field. In general, an IMF sector boundary passage at the earth tends to follow the solar central meridian passage of a SSB by about four to six days.

4.6.4. Quiescent filaments are the most useful solar feature for identifying portions of an inversion line associated with a SSB. The disappearance of a filament that previously defined a SSB may indicate changes in the strength, position, or size of adjacent sectors. It does not necessarily indicate the SSB has also disappeared. In fact, the filament may reform in (or very near) the original location at a later time since the underlying magnetic field structure may not have changed.

Figure 4.7. Maunder's Butterfly Diagram. (Latitudinal variation in distribution of sunspots with time.)



4.7. Coronal Condensations and Holes.

4.7.1. Coronal Condensations. The coronal aspect of an active region is a "coronal condensation", a region of enhanced density and radiation at visible (in certain spectral lines), ultraviolet, X-ray, and radio wavelengths. Coronal condensations are caused by the presence of closed magnetic loop structures. They are long-lived features, and may persist for a month or more after the underlying photospheric sunspots and chromospheric plage have dissipated.

4.7.2. Coronal Holes. Of greater importance to forecasting geomagnetic activity are "coronal holes". Coronal holes are regions of low density, low temperature, and open, diverging magnetic field lines. The open field lines allow the easy escape of charged solar particles, thus adding high-speed, high-density particle streams to the solar wind. The SOON telescope has the potential to observe coronal holes using the infrared Helium absorption line at 10830 Angstrom. Absorption at 10830 Angstrom requires a high temperature gas, so the presence of a hole is inferred by the lack of 10830 Angstrom absorption. A low temperature and lack of absorption can also be caused by the presence of a filament. However, quiescent filaments lie along sector boundaries, not within sectors. Thus a magnetic map can be used to distinguish between the two phenomena.

4.7.2.1. Coronal holes are related to expansive photospheric areas (solar sectors) of predominately single polarity. A coronal hole may form inside a solar sector when the sector has grown to at least 30º in longitude, and it generally disappears when the longitudinal extent of the sector decreases to less than 30º. Only those sectors possessing the same polarity as the nearer pole are possible source regions for coronal holes (Figure 4.8).

4.7.2.2. Coronal holes are perhaps the most persistent solar feature. They are semi-permanent features of the sun's polar caps. At lower latitudes they persist up to nine months, although three to six months is more common.

4.7.2.3. Near solar cycle maximum, coronal holes tend to be more numerous and at lower latitudes, but they are also much smaller and shorter-lived. Near solar minimum, holes tend to be fewer and at higher latitudes, but they are larger and longer-lived. During the years of solar minimum, coronal holes are the dominant cause of recurrent geomagnetic storms.

4.7.3. The SOON telescope is not presently used to observe either coronal condensations or holes.