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MAGNETOGRAPH GROUP SUMMARY

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Introduction.

The Magnetograph Group evolved from the Energy Buildup and Storage Group, chaired by T. Tarbell at the 1988 Max '91 Workshop in Kansas City. The suggestion was advanced at the 1988 Workshop that observing campaigns specifically designed to obtain magnetic field measurements from many participating sites should be conducted as part of the FLARES 22/Max '91 program. It was felt that such campaigns would provide cross-calibration of instrumentation, would allow studies of active region evolution over periods of several days, and would permit extrapolation of coronal fields and inference of magnetic energy content.

The discussion at the 1989 Max '91 Workshop at Laurel, Md. began with oral presentations by Harvey, who discussed a much earlier magnetograph comparison program conducted by J. Beckers under IAU sponsorship early in the 1970's; by Zirin, who discussed the successful two-station magnetograph network with Big Bear Solar Observatory and Huairou Solar Observatory in China; by Jones, who discussed a recent cooperative observing effort during the International Solar Month (Sep. 1988); and by Chapman who described new instrumental developments at the San Fernando Observatory.

Open informal discussion followed the oral presentations. The intent of the original agenda was to develop specific guidelines and action items for further magnetograph campaigns. However, actual attention focussed on the techniques and many practical problems of interleaving ground-based measurements of magnetic fields from diverse sites and instruments to address the original scientific objectives.. The predominant view of the discussion group was that present instrumentation and analysis resources do not warrant immediate, specific plans for further worldwide campaigns of cooperative magnetograph observing. The several reasons for this view, together with many caveats, qualifications, and suggestions for future work are presented in the following summary of the Magnetograph Group discussion.

The IAU Campaign.

Under sponsorship of the IAU, Jacques Beckers coordinated a program to compare then extant magnetographs. Observations began with a pilot study in 1970, continued with a primary campaign in 1971, and ended with an unsuccessful attempt to observe active regions in June, 1972. A brief summary of the results appears in *IAU Transactions* XVA (1973), p.108, and an extensive unpublished report was also prepared. Target regions were observed by the participating instruments in the FeI 5250 Å line; data were prepared at each site on punched cards in a common fixed format and were sent to Beckers for analysis. Eventually, both point-by-point and "scatterplot" comparisons of data from pairs of instruments were prepared. All the instruments were longitudinal field magnetographs, mostly of more or less conventional Babcock design.

The initial studies showed some large discrepancies (factors of order 2) which led to better understanding of calibration procedures and correction of several errors. One discrepancy in algebraic sign was not firmly resolved until in-situ measurements of the interplanetary field at 1 A.U. were correlated with the polarity of fields at the solar surface. After correction of the calibration errors, general agreement at roughly the ± 25% level was found between instruments for the 5250 Å line in weak-field regions. The agreement in strong-field areas near sunspots was much worse, almost certainly because of "saturation" effects induced by line-profile changes. Harvey pointed out that, although the full report was not published, the studies did identify calibration problems and induced a healthy appreciation of the observable effects of line-profile variations on the relation between Zeeman shifts and measurements of intensity differences in polarized light. The preparation and intercomparison of the data were extremely laborious, particularly for the coordinator.

The Big Bear-Huairou Network

More recent and quite successful efforts at cooperative magnetograph observing have been conducted using video magnetographs at Big Bear Solar Observatory and the Huairou Observatory near Beijing. Long-term magnetogram movies displayed at the discussion session and elsewhere unmistakably demonstrate the advantage of nearly continuous coverage of magnetic evolution over periods of days--the natural time scale of the phenomenon. Movement of many magnetic patterns can be easily followed in the time series of networked magnetograms which would be impossible to identify across the night-time interruptions at a single site. As a general rule, Zirin felt that eight-hour coverage is clearly not adequate for these studies while sixteen-hour coverage is nearly sufficient.

Zirin identified three important elements in the success of this network in addition to the obvious fact that the observing sites are strategically dispersed in longitude. First, the instruments are similar (the Huairou design being based on the Big-Bear video magnetograph) and comparatively simple. Second, the observing campaigns are most successful when there is interchange of scientific staff between sites. Finally, a powerful image processing system and a dedicated expert to run it are available to reduce and interleave the observations into a coherent single time series. This very considerable data reduction and analysis capability is necessary even though the geometric and scaling corrections are minimized by the similarity of the instruments.

Cooperative Magnetograph Observations during the International Solar Month.

In response to the "charge" developed at the 1988 Max '91 workshop, Jones noted that the International Solar Month--a period of observing campaigns originally planned for simultaneous observation of the Sun from the Soviet Phobos mission, the Solar Maximum Mission, the VLA, and many ground-based observatories--provided an early opportunity to use an existing infrastructure for communication and target selection to obtain comparative magnetograph observations.

Accordingly, under the auspices of the National Solar Observatory, an exploratory letter was sent to many observatories with appropriate instrumentation. The primary goals were to identify potential participants, to establish communications links, to identify peculiarities in data sets, and, in general, to learn how to organize better campaigns. Responses expressing interest in the project were received from eleven groups; however, communications were too slow for actual participation in many cases, and several instruments were either not ready for observations or were undergoing repairs and renovation. A target region near disk center was selected for intensive observation on 16 and 17 September, 1988, and was announced over the standard e-mail communications network used by the organizers of the International Solar Month. By the time of the Laurel workshop, data from five groups were available (Hawaii-Mees Observatory (MO); Mount Wilson Observatory (MW); Lockheed Palo Alto Research Laboratories (LPARL) operating the Solar Optical Universal Filter and Polarimeter (SOUP) breadboard instrument at the Swedish Telescope on La Palma; the San Fernando Observatory (SFO) of California State University at Northridge (CSUN); and the National Solar Observatory/Kitt Peak (NSO/KP). Observations from the San Fernando Observatory were of two regions (NOAA ARs 5105 and 5106) on a different date (11 August 1988) but could be compared with NSO/KP full-disk data. A summary of relevant observing parameters is shown in Table I.

With some difficulty, the various data sets (all on standard magnetic tape) were read at the National Optical Astronomy Observatories (NOAO) central computing facilities in Tucson and were coverted to IRAF (Interactive Reduction and Analysis Facility) format. One can identify common features in grey scale displays of the various magnetograms without great difficulty, but the large disparities in field of view (82 X 82 arc-seconds to full-disk) and pixel size (1/6 to 20 arc-seconds) are immediately obvious. The images were interpolated onto grids of square pixels where necessary and were rotated (approximately) to "standard" heliographic orientation with solar north at the top, west to the right.

Table 1.

Observatory	Instrument	Line	Region	Time	Pixel Size (arc-sec)	FOV (arc-sec)
LPARL La Palma	SOUP/OSL Breadboard	6303	AR5148	09/17/88 16:36	0.16x0.16	82x82
MO	Stokes Polarimeter	6303	AR5148	09/17/88 17:39	5.6x5.6	196x140
MW	150-ft Tower Magnetograph	5250	AR5148	09/17/88 19:20	12.7x20.2	Full Disk
NSO/KP	512-Channel Diode Array Magnetograph	8688	AR5148	09/17/89 16:10-22:10 (every 5 min.)	1.0x1.0	256x512
			AR5105, AR5106	08/11/89 16:10	1.0x1.0	Full Disk
CSUN/SFO	Dual Reticon Magnetograph	6303	AR5105	08/11/89 22:05	1.9x1.9	486x480
			AR5106	08/11/89 22:22	1.9x1.9	486x477

It proved easier to "stretch", rotate, and register the three higher resolution magnetograms (LPARL, NSO, SFO). As of the workshop and this writing, pixel-by-pixel and scatterplot comparisons have only been carried out for these three sites. The NSO/KP magnetograms have been used as the "standard" primarily because of the relatively high spatial resolution and long historical record of the instrument. Figure 1 shows the comparison of a sample line from the LPARL (at full spatial resolution) and the NSO data (magnified by interpolation to the same pixel size and masked to the same field of view). Allowing for the different spatial resolution, the overall correspondence between the two data sets appears reasonably good except that the reported field strength of the LPARL data seems systematically higher. This effect is shown somewhat better in the pseudo scatter-plot of Figure 2. A direct point-by-point scatterplot would simply show a saturated black area due to the large number of points in the images. Thus Figure 2 shows instead a half-tone rendering of log(1+N) where N is the two-dimensional histogram (20 x 20 Gauss bins) of the images. The mean (solid curve) and $\pm$ 1 σ (dashed curves) of the one-dimensional slices of the histogram at each bin of the NSO data are plotted to give a more quantitative view of the systematic variation and the spread of the data. A substantial portion of the spread of points may be attributed to the large discrepancy in spatial resolution (many localized features in the LPARL data are not seen in the NSO magnetograms) and errors in spatial registration. The instruments also seem to respond rather differently to strong umbral fields. The negative spike at zero field in the NSO data is an artifact of boundary interpolation during the image rotation process. The systematic correlation between the data sets is

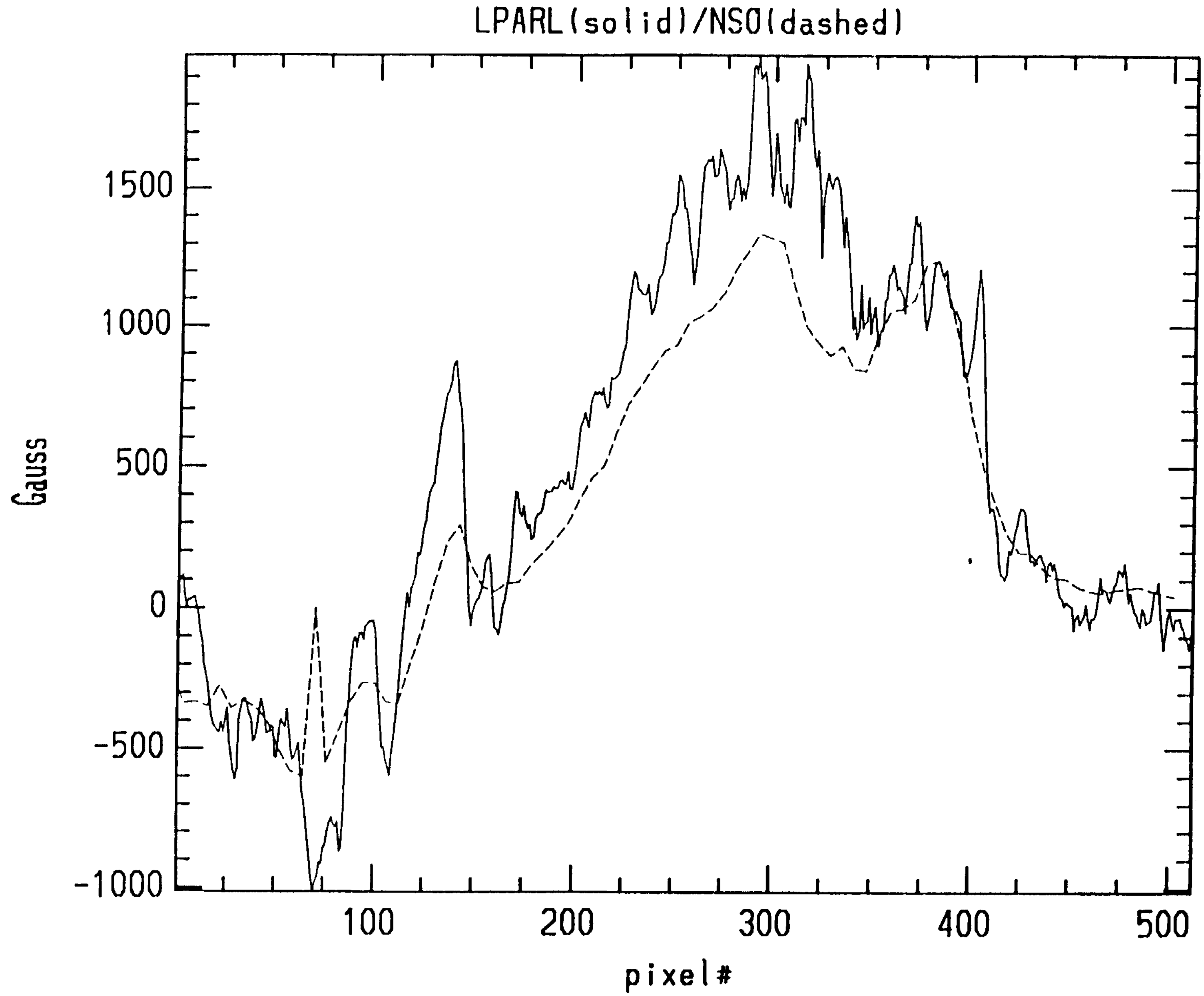

Figure 1. - Longitudinal magnetic fields from a sample line of regstered images of AR 5148 from LPARL (solid) and NSO/KP (broken).

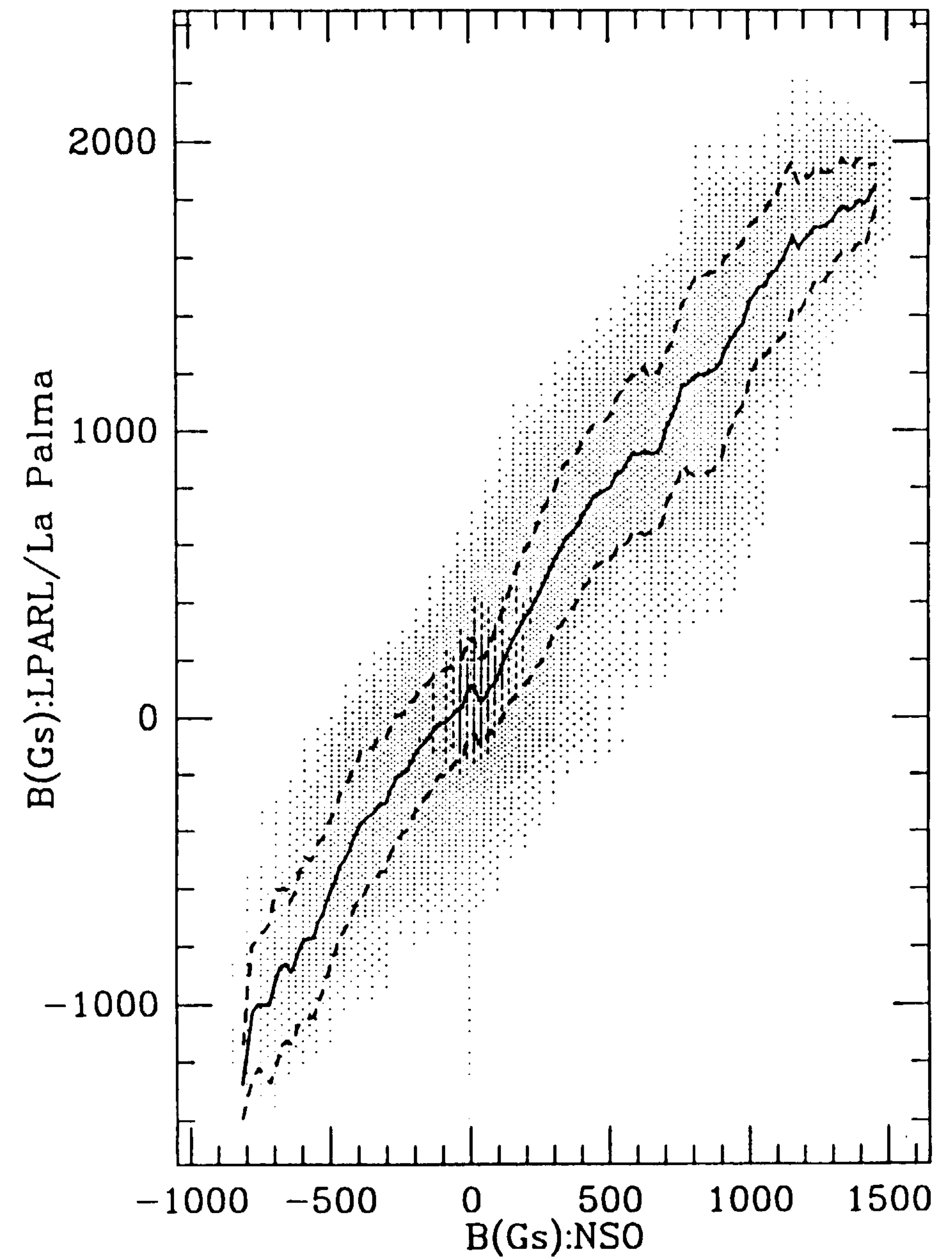

Figure 2. - "Scatterplot" diagram of LPARL and NSO/KP magnetic fields from registered images of AR 5148. The density of plotted points is determined from the two-dimensional histogram (see text), and the curves show the mean ± 1 σ of histogram slices.

quite linear, but the slope (LPARL vs. NSO) is 1.2.

Figure 3 compares sample image lines from the SFO and NSO data for one of the observed active regions, and Figure 4 shows the corresponding "scatterplot". There is a similar anomalous negative spike at zero NSO field, but the overall spread of points is reduced when compared to the LPARL-NSO plots, presumably because of the similar spatial resolution of the two instruments. However, the SFO instrument saturates at smaller field values than the NSO magnetograph, and the slope (SFO vs. NSO) is approximately 0.75.

Both the LPARL and SFO instruments are new so that it is perhaps not surprising to find calibration constants in disagreement. The specific reasons for the discrepant slopes are not clear, however, and further investigation of the calibration procedures will be undertaken. Loosely speaking, the spread in field values is consistent with the ± 25% found in the IAU study. Thus, the basic quantitative correlation properties between magnetographs, when the data are compared pixel by pixel, have not changed much between the previous and current generations of instruments. Since the instruments which have been compared so far are still basically Babcock magnetographs which are sensitive to line profile effects, this is a result which might be anticipated. On the other hand, the visual correspondence between actual magnetogram images is quite good which suggests that networks of similar instruments can in principle be used for long-term studies of magnetic field evolution. Moreover, it should be noted that "today's pixel" typically has much greater spatial resolution, linearity, uniformity of response, sensitivity, and dynamic range than could be found in data from fifteen or twenty years ago.

Finally, although media for interchange of digital data and image processing hardware and software are vastly improved in the last fifteen years, actual reduction, analysis, and comparison of diverse data is still laborious and time-consuming, particularly in the exploratory stages. The rotation and magnification of dissimilar images for precise registration can be particularly difficult and may require several iterations by an intelligent and knowledgeable analyst. Once the rotation and magnification parameters have been established, sequences of similar images may be shifted in a more automated fashion to complete the registration process.

New Magnetograph Instrumentation at the San Fernando Observatory

G. Chapman presented preliminary data from two new instruments at the San Fernando Observatory operated by the California State University at Northridge (CSUN). The first of these is a Babcock magnetograph using dual Reticon arrays to span segments of the solar image (similar to the NSO/Kitt Peak magnetograph); the second is a Video Spectra-Spectroheliograph which records full long-slit spectra from a two-dimensional CCD detector on video tape. Some analysis of sunspot Stokes V-profiles derived from the latter instrument was discussed. In particular, the discussion emphasized that the wavelength separation of the extrema in Stokes V is more a reflection of line width than field strength. More importantly in the context of the group discussion, the instrumentation is representative of a new generation of both line-of-sight and vector magnetographs which are likely to be completed in the next year or two--a circumstance which considerably influenced subsequent discussion of the desirability and timing of future magnetograph campaigns.

Discussion

The open discussion centered less on the desirability of the scientific goals mentioned in the introduction and more on the practicality of achieving them with Max '91 campaigns scheduled in the next year or so.

Considerable attention was given to formats and image projection protocols which might facilitate data handling and comparison. The FITS format is convenient for image processing at NSO so long as the "standard" is rigidly observed (fixed 2880 byte blocks, header keywords blank-padded to eight characters, partial trailing blocks padded to full fixed size, etc.) but has a block length which is too small for efficient transfer of large images and which is wasteful of space on new high-density media such as heliscan video tape cartridges (e.g., Exabyte). The Lockheed group has developed an efficient storage format for Exabyte cartridge tapes, and a

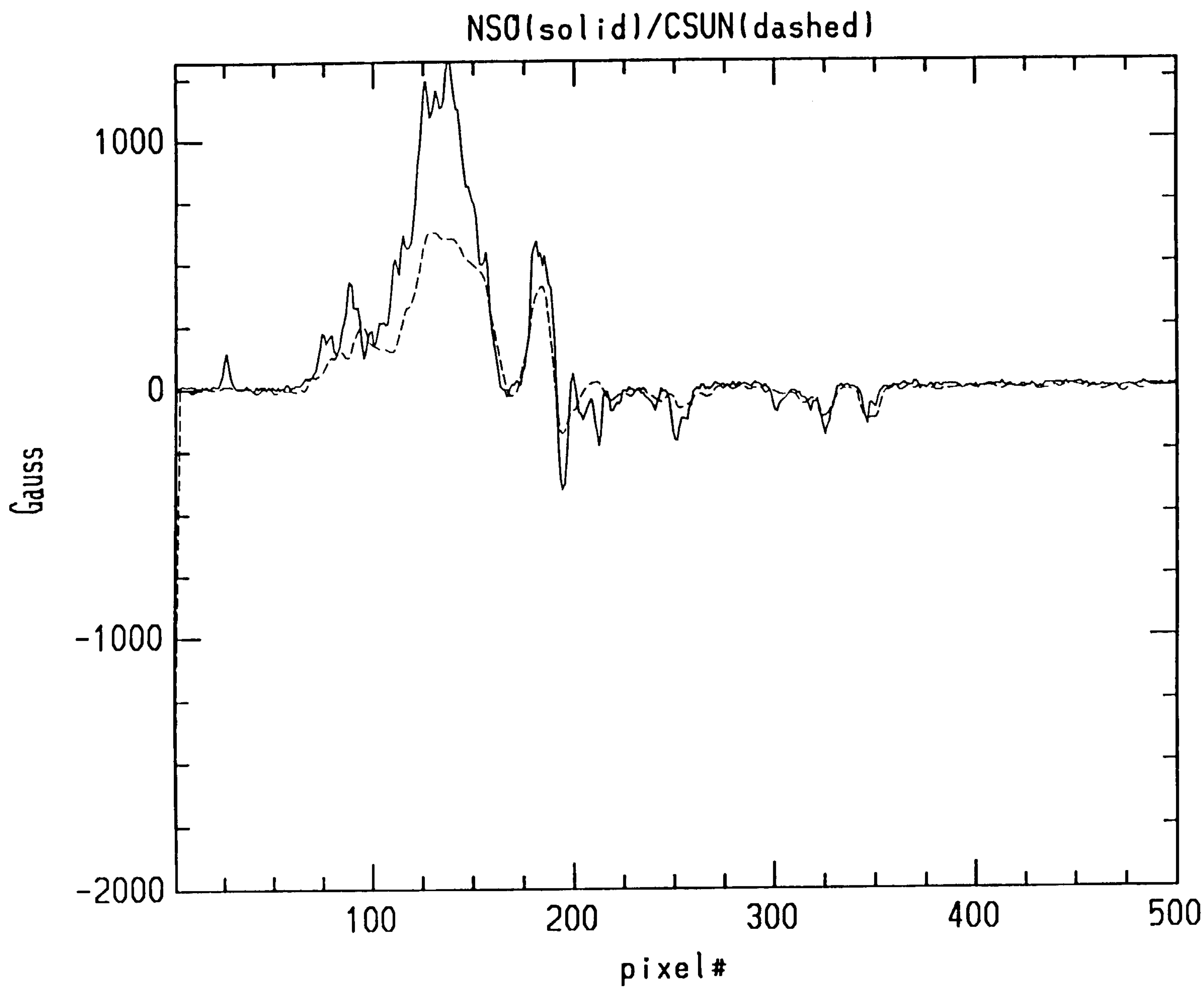

Figure 3. - Longitudinal magnetic fields from a sample line of regstered images of AR 5105 from NSO/KP (solid) and SFO (broken).

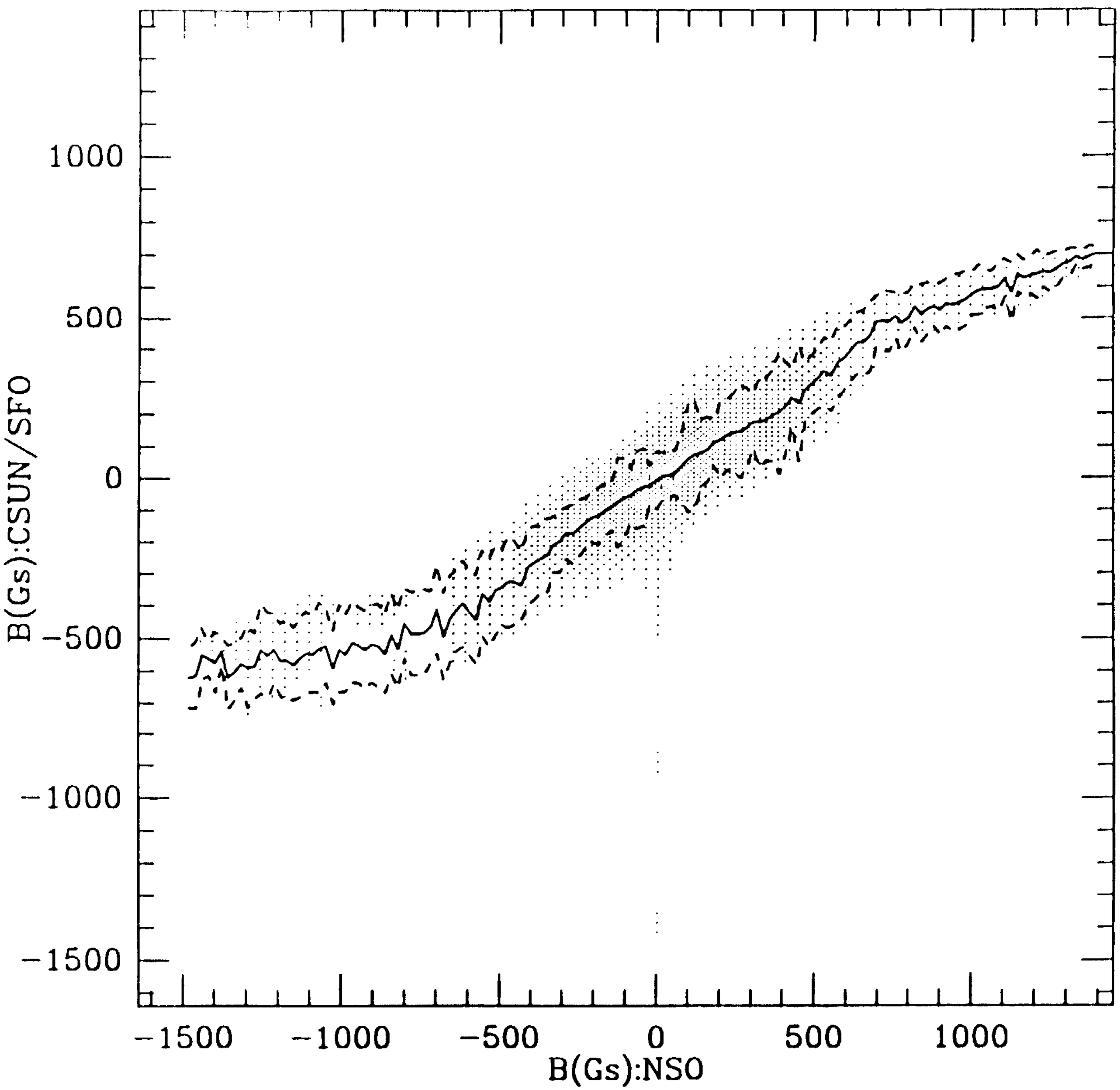

Figure 4. - "Scatterplot" diagram of SFO and NSO/KP magnetic fields from registered images of AR 5105.

long-block FITS format is being developed at NOAO partly for archiving full-disk magnetograms on Exabyte tapes. Rabin (NSO) and Shine (LPARL) agreed to explore possibilities for a useful standard. It was also suggested that a standard coordinate system (e.g. Carrington) be adopted for data interchange and that local sites interpolate their data onto such a grid before export. Many reservations were expressed about both the practicality and need for such a standard, and no specific action was agreed upon.

Some discussion was devoted to the comparability of vector field measurements. The transverse component of the field is ordinarily much more difficult to measure since it has a weak linear polarization signature, and preliminary comparison of results between the Marshall Vector Magnetograph and the Hawaii Stokes polarimeter seem to reflect this. A new Advanced Stokes Polarimeter is being developed by the High Altitude Observatory and NSO/Sacramento Peak which should be less subject to some of the current measurement uncertainties since it will record full Stokes profiles at high spatial and spectral resolution. An alternative method for measuring vector fields which partly avoids the difficulties of weak polarization is to observe infrared lines whose widths are small compared to the magnetic splitting. Work is proceeding on two infrared magnetographs at the NSO McMath telescope. One will operate near the opacity minimum at 1.6 μm (Rabin *et al.*) while the other will make use of the 12 μm emission lines (Deming,*et al.*). Other characteristics of the infrared (improved seeing, less scattered light, simplicity of interpretation, linear dependence of source function on temperature, etc.) help to make this an attractive spectral regime, and the detector technology to make such devices possible is rapidly maturing. Both instruments are in fairly early stages of development, and their impact on studies during the current maximum of activity is uncertain.

Conclusions.

From the results of the oral papers and the tenor of the ensuing discussions, a general consensus developed that existing optical magnetographs do not yield measurements of solar magnetic fields which can be intercompared with high quantitative precision. Many of the reasons for this are known (line profile effects; seeing; different spatial resolution), and new instruments are nearing completion which should be less sensitive to at least some of the problems. Thus campaigns to calculate evolution of magnetic energy content in an active region volume using magnetograms from multiple sources are at present ill-posed. Extrapolation of photospheric fields to coronal heights, while still uncertain given the scatter in measurements by different instruments, may be a better posed problem simply because the dominant contribution is from low-order multipoles whose measurement is less sensitive to seeing, spatial resolution, and line profile effects.

Given the high degree of geometric fidelity achievable with modern detector systems, magnetograms taken at different locations with similar resolution have a very high degree of visual comparability and can be used to observe many elemental processes of magnetic field evolution (transverse motions of flux concentrations, flux emergence, subsidence, bipolar encounters, evolution of network boundaries, etc.). However, with the notable exception of the La Palma instrument, the magnetographs which participated in the International Solar Month are clustered in the American Southwest and are too narrowly dispersed in longitude for effective networking. Moreover, the elements which have led to the successful operation of the Big Bear-Huairou network (especially simplicity and similarity of instruments) will be difficult to develop for other existing magnetographs over a wide geographic distribution. Thus, although magnetograms will continue to be essential planning tools and will provide necessary data for Max '91 studies of solar activity, the current state of the art does not justify a near-term campaign organized around magnetographs. One limited "mini-campaign" was suggested--the intensive observation of the kinematics and dynamics of the polar field reversal. Zirin agreed to lead such an effort.

Cross-calibration of instrument pairs continues be a useful endeavor. J. Schmelz agreed to contact international observatories to see if further such comparisons might be undertaken with NSO data. Although the NSO magnetograph will be replaced with the new NSO/NASA

Spectromagnetograph which will use full line profiles instead of two-slit detection, both the old and new instruments will be operated together long enough to allow thorough cross-calibration between new and old standards. There was general agreement that all the issues should be revisited in about a year's time after many of the "next generation" instruments have become operational.