FERMILAB-UPC-158

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Doubler Dipole Data: A Perspective from the Cross Gallery

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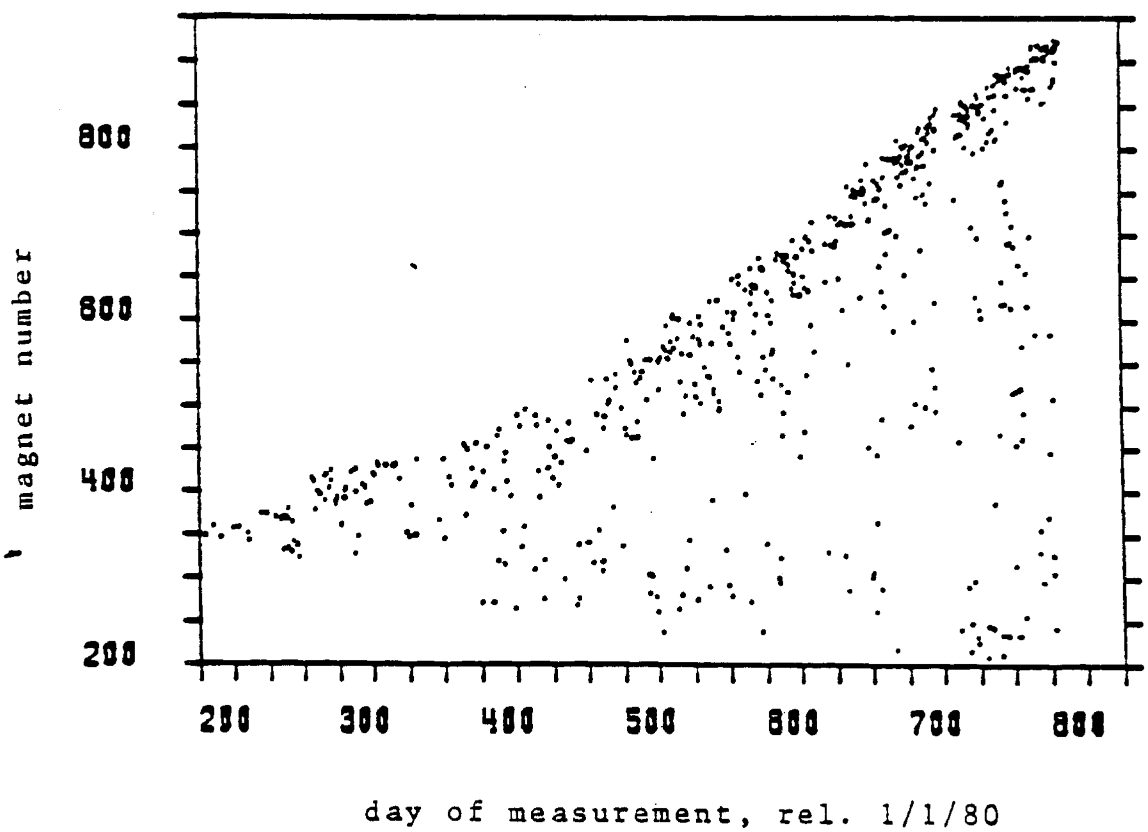
A number of anomolous symptoms have been appearing recently in the magnetic field data of Doubler dipoles. Some of these are real; others only reflect problems that have arisen with the measurement system — problems that MTF people are aware of and are working to correct. We shall present both kinds here, with a minimum of comment. To roughly unravel the real from the illusory, data will be shown in scatterplots sorted in two ways: according to (1) magnet number and (2) date of measurement. Clusters in the latter plots that are not present in the former will be taken as evidence of measurement errors rather than phenomena in the magnets. As seen below, early magnets are still being measured with regularity, so such separations are possible. The date above each plot marks the day on which it was made.

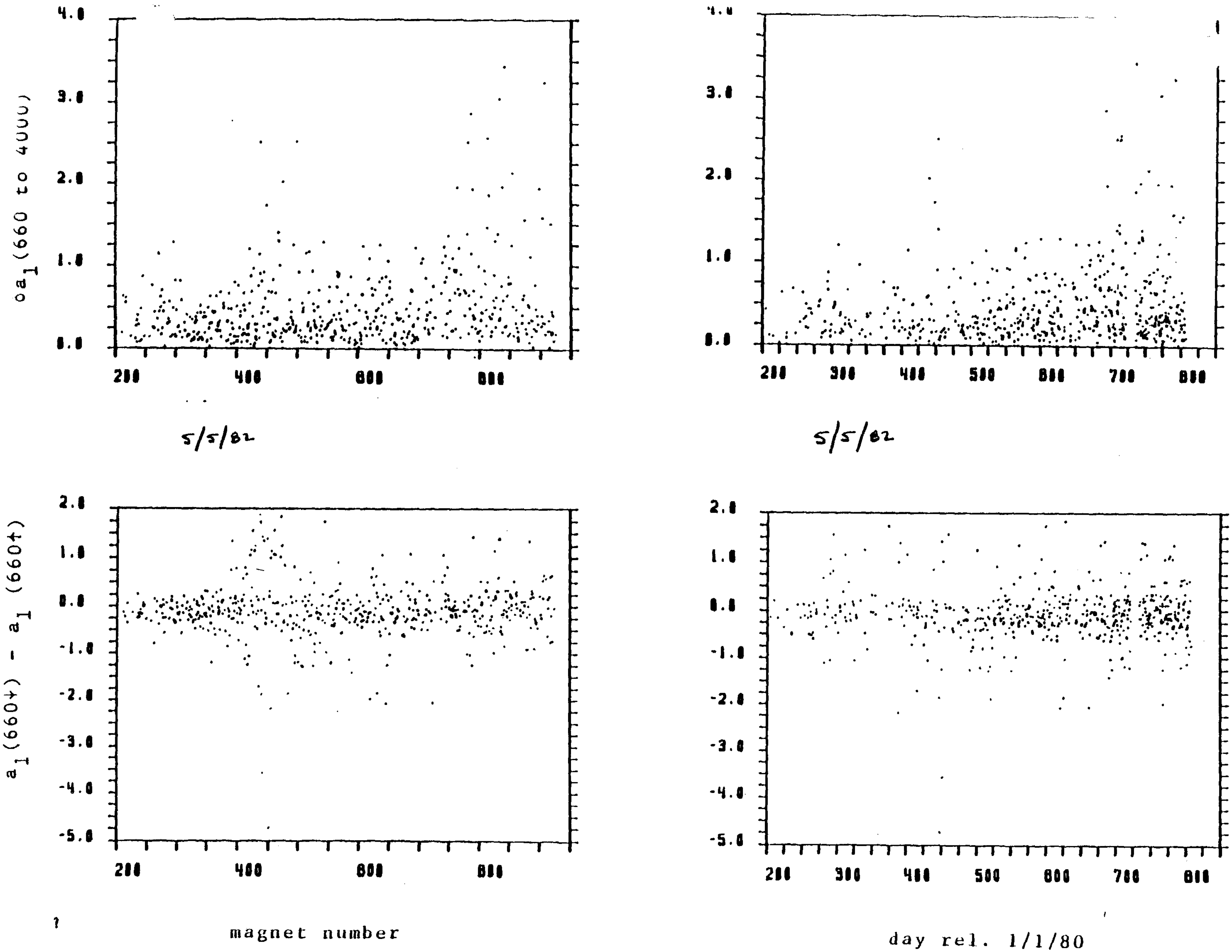
5/11/82



1. a_1: current dependence and hysteresis

At the January 14 X-rated magnet meeting the acceptable upper bound for δa_1, the total variation in a_1 between 660 and 4000 amps, was raised from 1.0 to 1.5 units. This was reasonable: sufficient statistics had been accumulated to argue that dipoles with $1.0 < \delta a_1 < 1.5$ were not outliers but merely on the edge of the distribution. Since then, beginning somewhere around magnet number 760, a number of dipoles have come through the system whose a_1 current dependence was far in excess of 1.5, the largest being TC0840 with $\delta a_1 = 3.4$. This seems to be a <u>real</u> phenomenon, not a measurement error. The only hint that it may be an artifact lies in the two 3-clusters seen in the plot of δa_1 vs. date. That is refuted rather strongly by the fact that the only recently measured, low numbered magnet with large δa_1 was TC0500, which fits nicely into a cluster with three other dipoles numbered between 400 and 500. If large δa_1 were an illusion one would expect to see it occur more regularly in low numbered magnets now being measured.

a_1 hysteresis at 660 amps has continued to occur at a fairly steady, reasonably small rate, since magnet number 500. Between 400 and 500 its incidence was alarmingly large, while no magnet below 350 exhibits the effect. Again, there is no evidence that this is an MTF artifact, and some evidence that it is not. For example, if it were connected with the more recent anomolies in b_2, b_4 and b_6 hysteresis (see later section) one would expect to see it occuring in some of the dipoles numbered between 200 and 400.


4.0
3.0
2.0
1.0
0.0
σa1(660 to 4000)
200
400
600
800
5/5/82
4.0
3.0
2.0
1.0
0.0
200
300
400
500
600
700
800
5/5/82
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
a1(660+) - a1 (660+)
200
400
600
800
magnet number
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
200
300
400
500
600
700
800
day rel. 1/1/80

2. NMR data

During the same January 14 X-rated magnet meeting a new criterion was established for the magnitude of the dipole field. Because of the problems experienced with $\int B d\ell$ measurements and because NMR measurements were comparatively reliable, it was decided to adopt an NMR window 9.982 $\leq$ avg. NMR $\leq$ 10.002 kG/kA and to reduce the significance of the DCX ($\int B d\ell$) measurements. Since that time the incidence of dipoles with average NMR smaller than 9.982 has been on the rise. In fact, on the whole, NMR seems to be slowly decreasing. Its secular wanderings are more strongly evident in Fig. 2a than Fig. 2b, supporting the contention that this is a real effect. A drift in calibration is not impossible, but not indicated. Based on the numbers recorded in the data base, which are all an outsider has to go by, there is no window of width 0.02 which does not exclude an uncomfortably large number of dipoles. The present window is definitely not centered on the distribution for the most recently built dipoles. We can thus expect many more to fall below its lower bound, which will tend to make the criterion more and more meaningless in the weeks and months to come.

It is amusing (is it?) to note that, with only two exceptions, no magnet measured before the "data gap" ending near day 500 had a large σ_{NMR}. (Was there an algorithmic change?)

Comment: Dots appearing below the plot's border come from evaluated dipoles for which no NMR measurements appear in the data base.

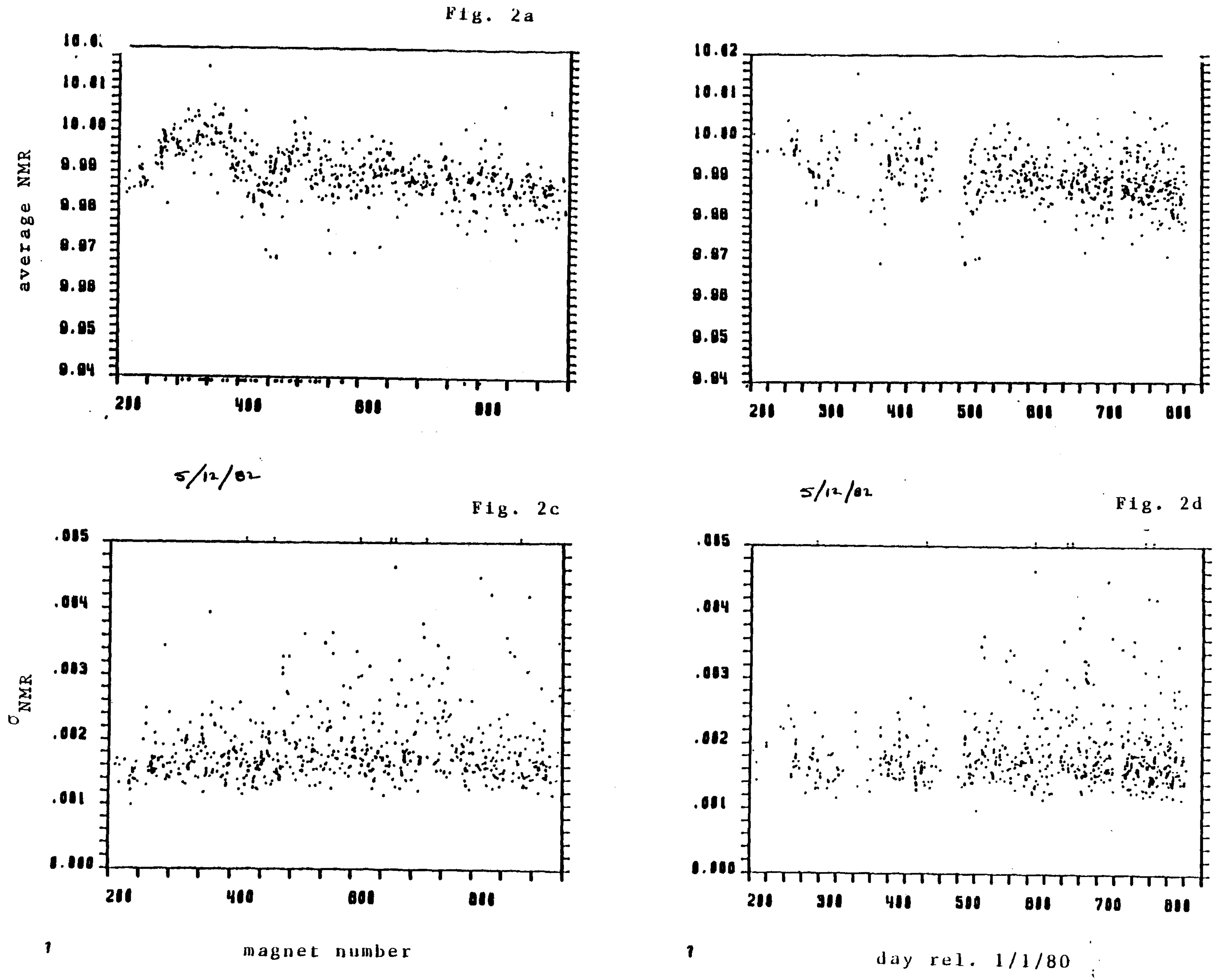


Fig. 2a
average NMR
10.01
10.00
9.99
9.98
9.97
9.96
9.95
9.94
200
400
600
800
10.02
10.01
10.00
9.99
9.98
9.97
9.96
9.95
9.94
200
300
400
500
600
700
800
5/12/82
Fig. 2c
5/12/82
Fig. 2d
σ_{NMR}
.005
.004
.003
.002
.001
0.000
200
400
600
800
magnet number
.005
.004
.003
.002
.001
0.000
200
300
400
500
600
700
800
day rel. 1/1/80

3. Hysteresis: b_2, b_4, b_6

By symmetry, the first higher order moment expected to exhibit hysteresis is the normal sextupole, b_2, followed by b_4 and b_6. (Interestingly, b_6 generally has greater hysteresis than b_4.) Data on these quantities indicate the sudden onset of measurement errors somewhere around early November, 1981 - errors that have persisted to the present. This is seen most dramatically in Fig. 3d, which shows b_4 hysteresis vs. time. It is present also in Fig. 3b but not as dramatically; to be convinced that the smaller values of b_2 hysteresis are indeed not real, compare Fig. 3b to Fig. 3a. Standing alone, b_6 hysteresis seems uninteresting, but when it is plotted versus b_2 hysteresis, as is done in Section 6, a striking, though illusory, correlation becomes evident.

4/21/82

Fig. 3a

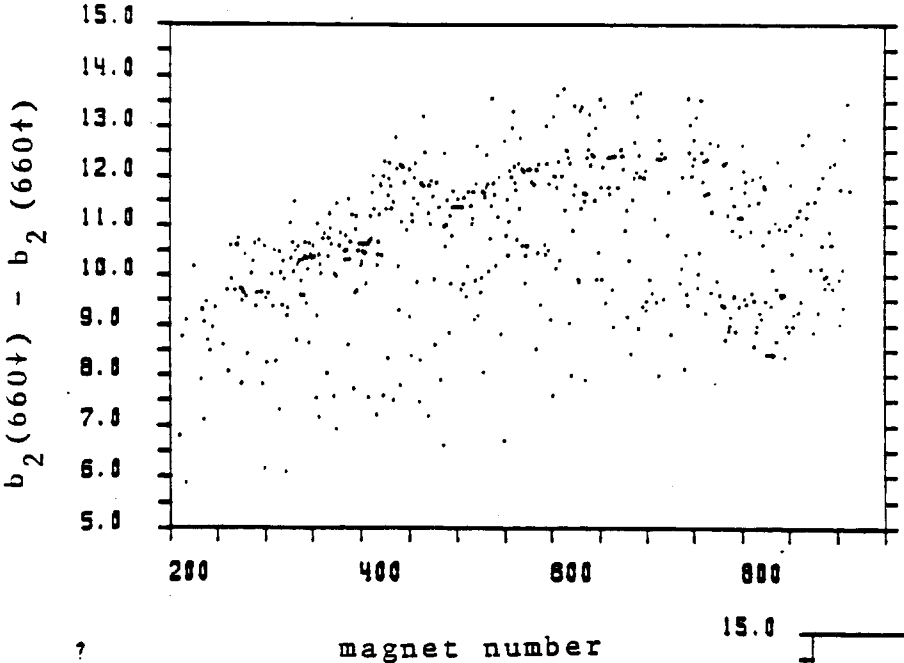


Fig. 3b

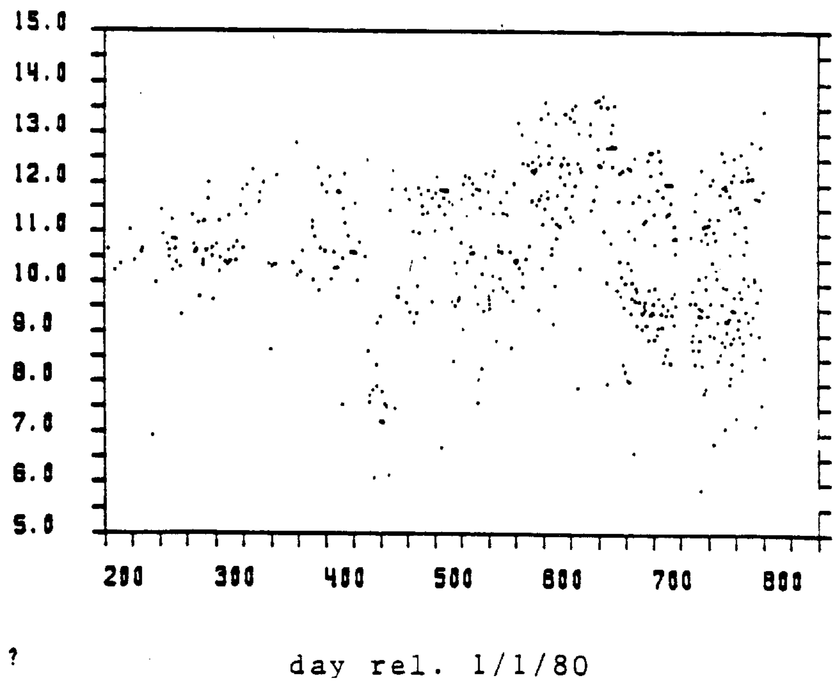


Fig. 3c

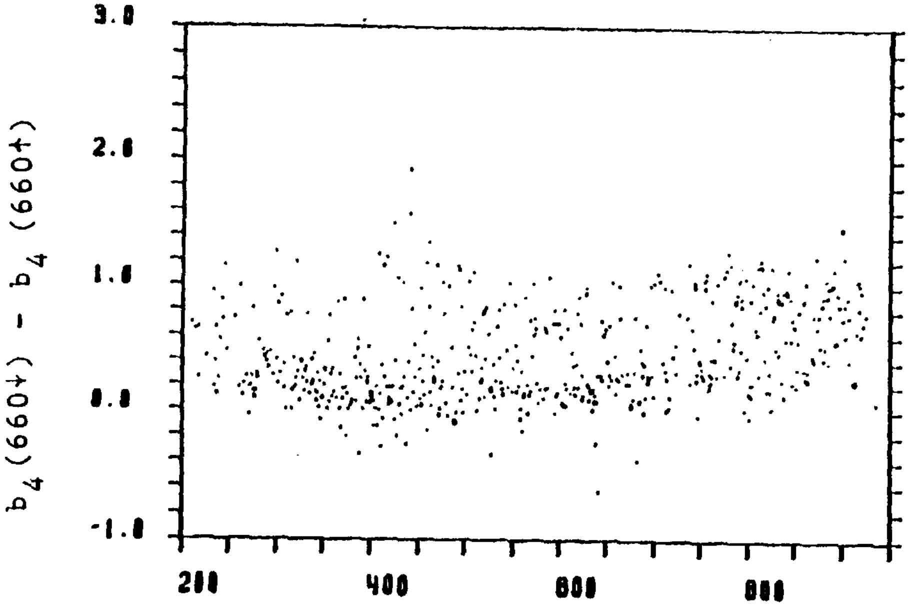
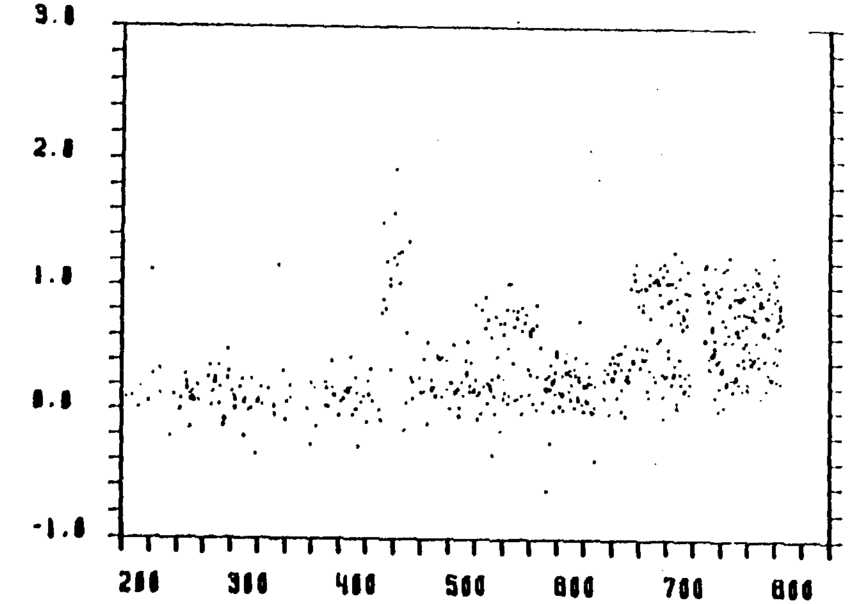
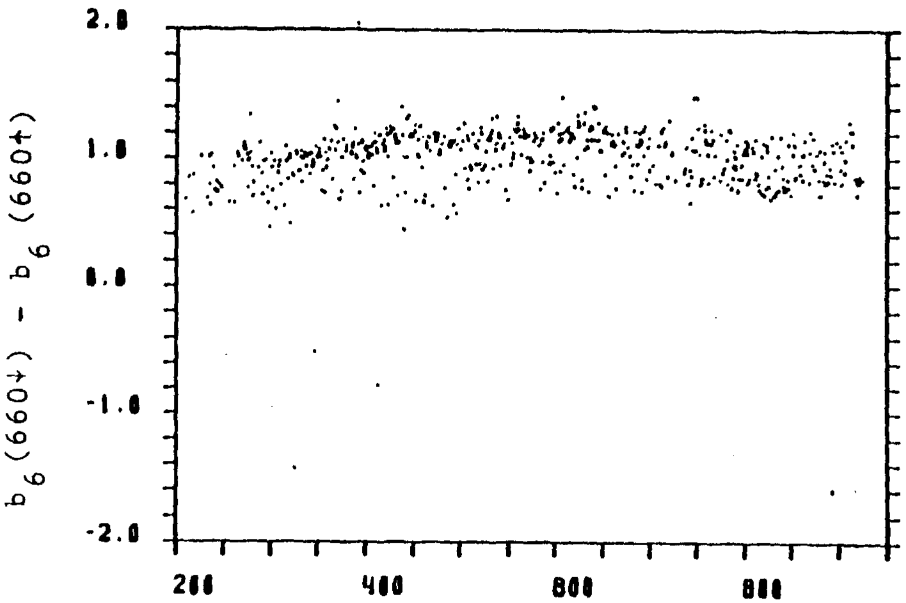


Fig. 3d



4/22/82

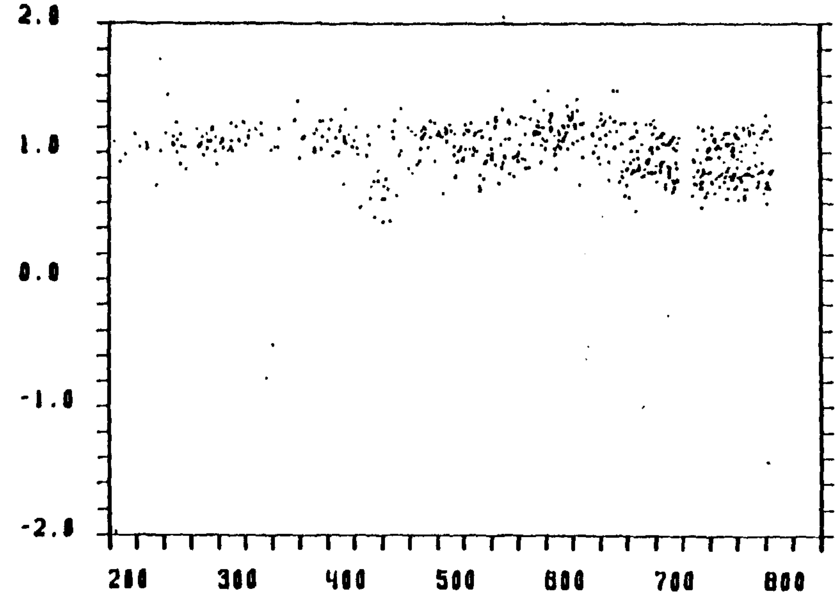
Fig. 3e



magnet number

4/22/82

Fig. 3f



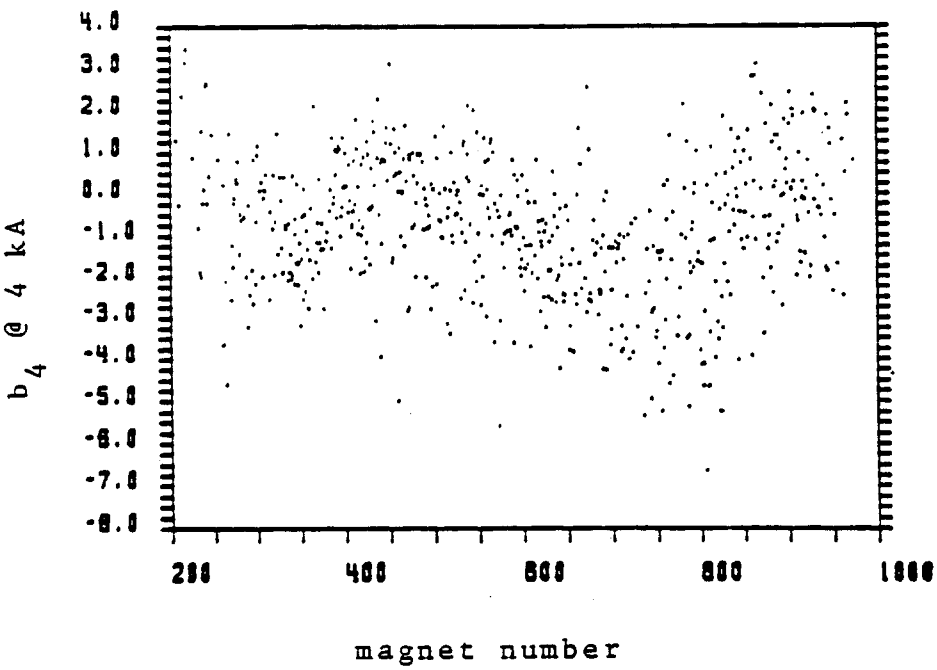
day rel. 1/1/80

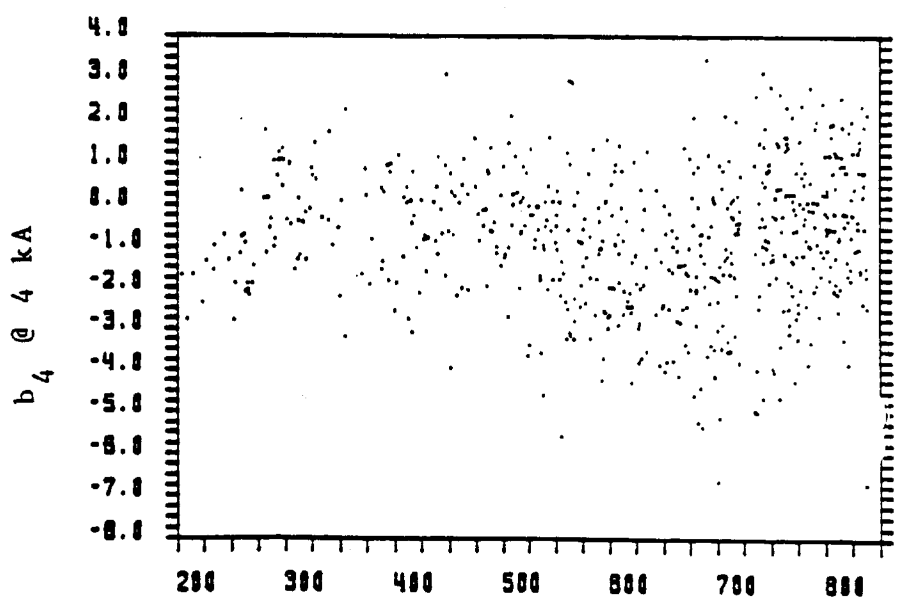
4. b_4 and its current dependence

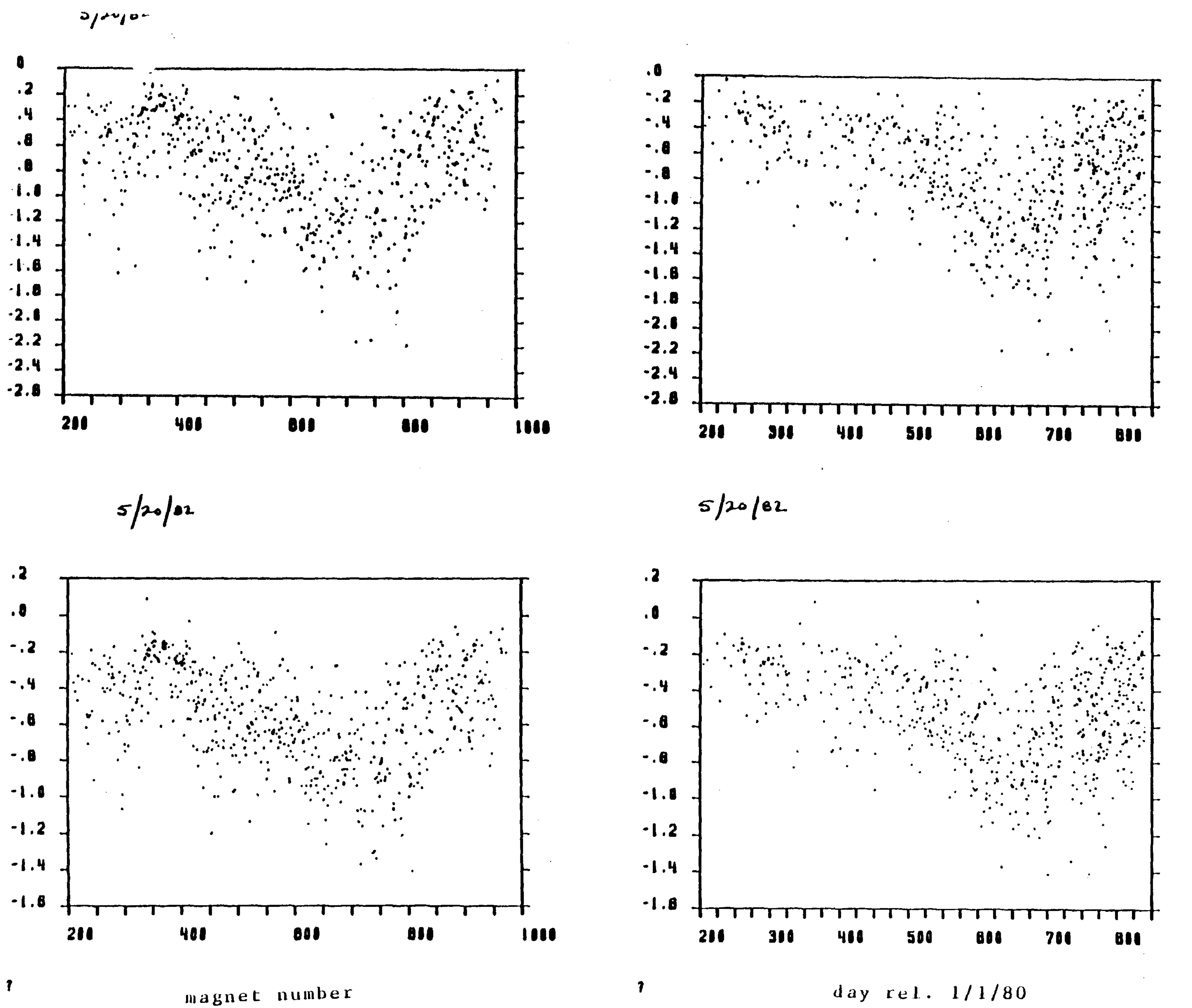
The history of b_4 data shows an interesting "sag" between magnet numbers 600 and 850. Both the value of b_4(at 4 kA) and its current dependence degraded alarmingly within this region. I issued a warning at the onset of this trend that a disaster loomed if it continued. It did not. In fact, the situation seems to have corrected itself, nicely illustrating the sometime wisdom of benign neglect. (Or were deliberate changes in production responsible for the improvement?)

Whether to include the normal decapole resonances ($5\nu_H$, $3\nu_H + 2\nu_V$, and $\nu_H + 4\nu_V$) in magnet shuffling remains an open question; currently this is not done.

5/20/82






5/20/82
5/20/82
5/20/82
magnet number
day rel. 1/1/80

5. The 18-poles: b_8, a_8

In recent times the value of a_8 has significantly increased in magnitude. This has been attributed by MTF personnel to a difficulty in separating the skew and normal components because of an angular error in the construction of the harmonics probe. (The explanation is that some of the normal component, b_8, is being interpreted as the skew component, a_8). Of course, this should be happening to the other harmonics as well, but the effect is presumably most pronounced for the eighteen pole simply because b_8 is so large: typically, $b_8 \approx -17$. The fact that this phenomenon is so much more pronounced in Fig. 5d corroborates the idea that we are observing a measurement error. It is also true that b_8 is slowly decreasing in magnitude while a_8 increases. However, the combination $b_8^2 + a_8^2$ also seems to be slowly decreasing rather than remaining constant as one would expect if it were merely an angular error.

The importance of the 18-pole rests on its use in computing the shifts by which "raw" harmonic data are converted to "corrected" harmonic data. Let $c_n = b_n + ia_n$ represent the raw and $c_n' = b_n' + ia_n'$ the corrected harmonics. Then we have

$$\sum_n c_n (z + \delta)^n = \sum_n c_n' z^n,$$

where the shift is δ. This gives us

$$c_n' = \sum_{k=n}^{14} c_k \binom{k}{n} \delta^{k-n}$$

with $\binom{k}{n}$ being the usual binomial coefficient. The rationale for choosing δ is to zero c_7' assuming that the major contribution comes from c_8.

We thus get

$$\delta = -c_7/8c_8$$

$$= \frac{1}{8}|c_7/c_8|e^{i(\phi_7-\phi_8+\pi)}$$

Errors in determining $\phi_7 - \phi_8$ feed errors in the corrected harmonics c_n'. To complete the analysis, we have to calculate in detail the sensitivity of the lower harmonics to such errors.

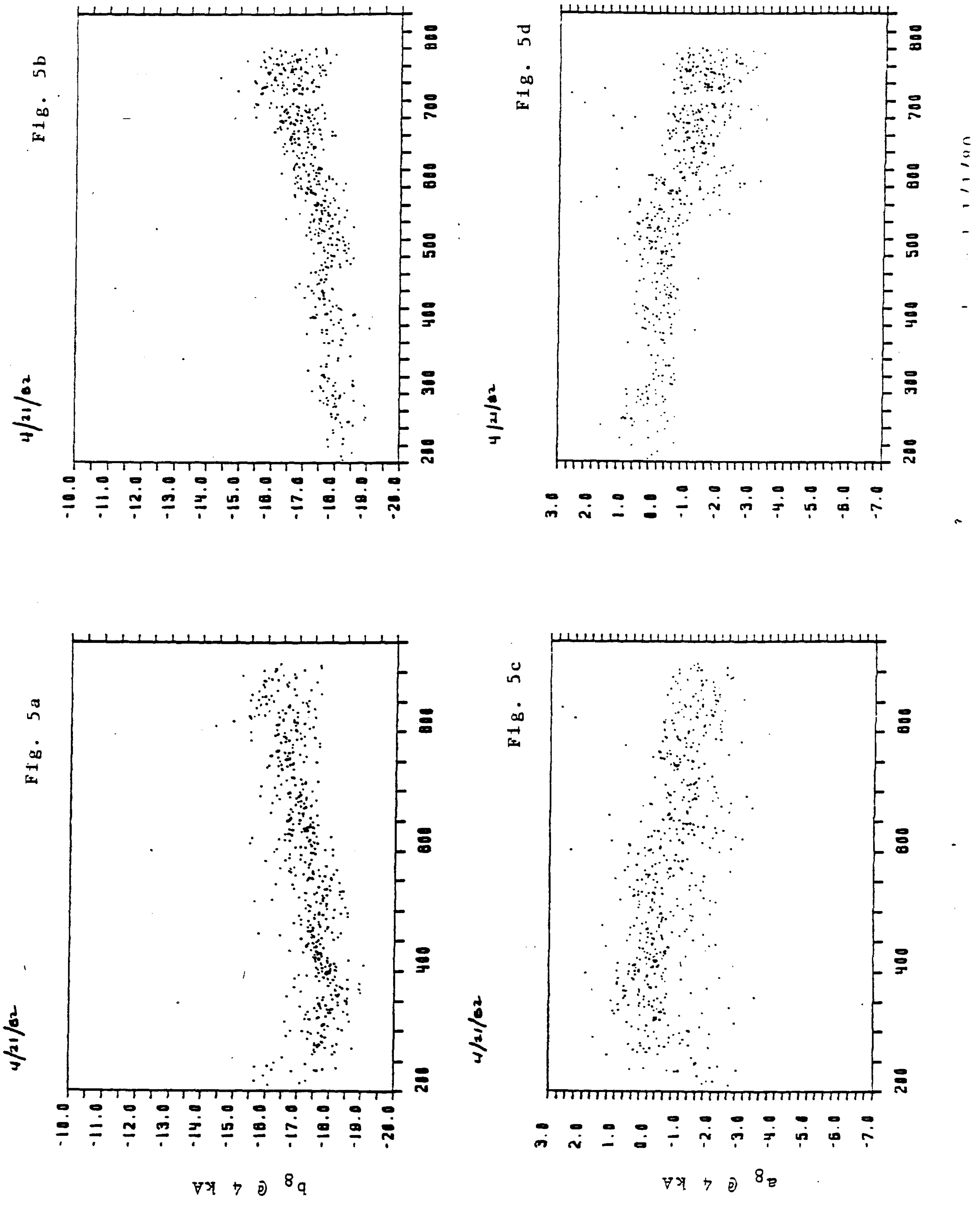


Fig. 5a
Fig. 5b
Fig. 5c
Fig. 5d
4/21/82
b_8 @ 4 kA
a_8 @ 4 kA
200
300
400
500
600
700
800
-10.0
-11.0
-12.0
-13.0
-14.0
-15.0
-16.0
-17.0
-18.0
-19.0
-20.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0

4/21/82

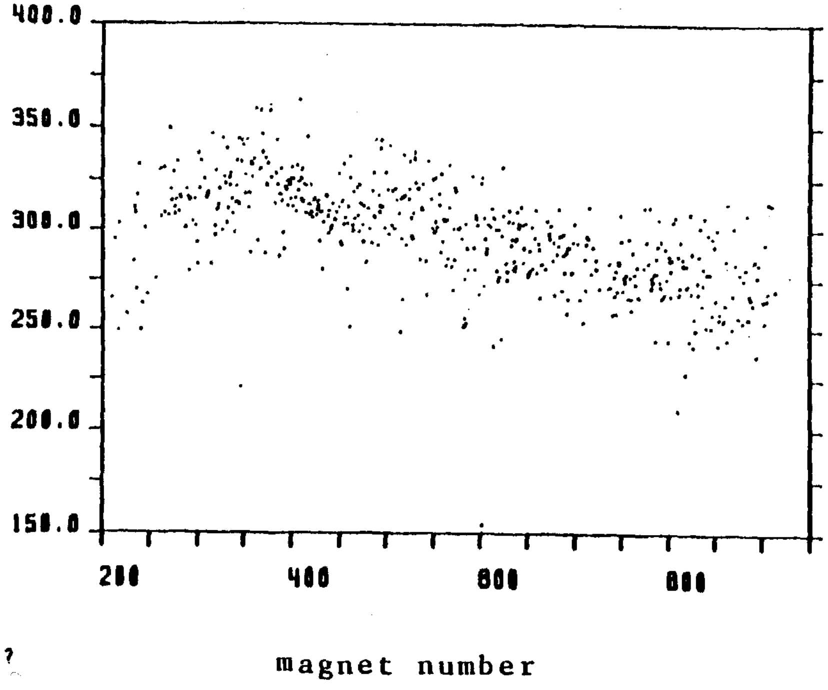


Fig. 5e

4/21/82

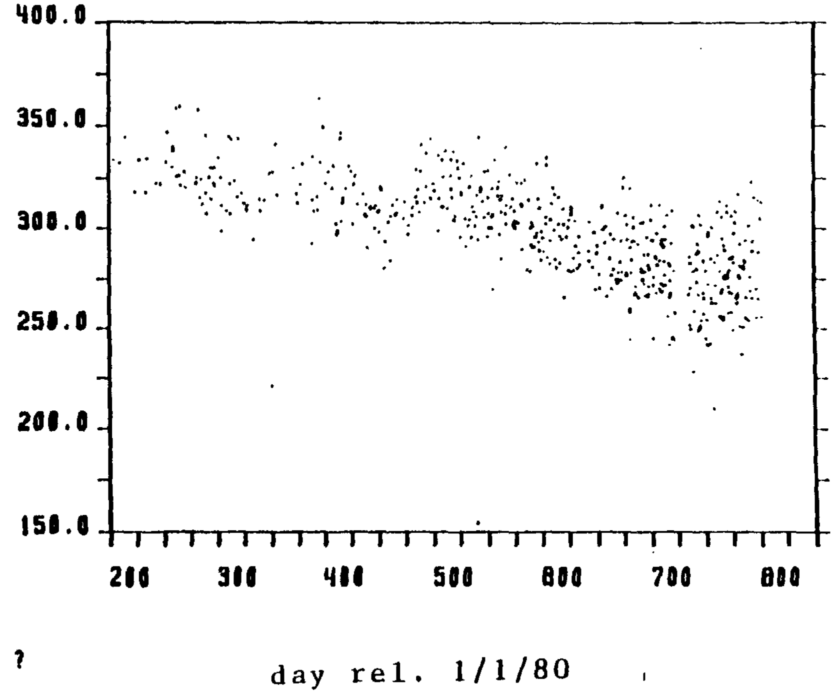


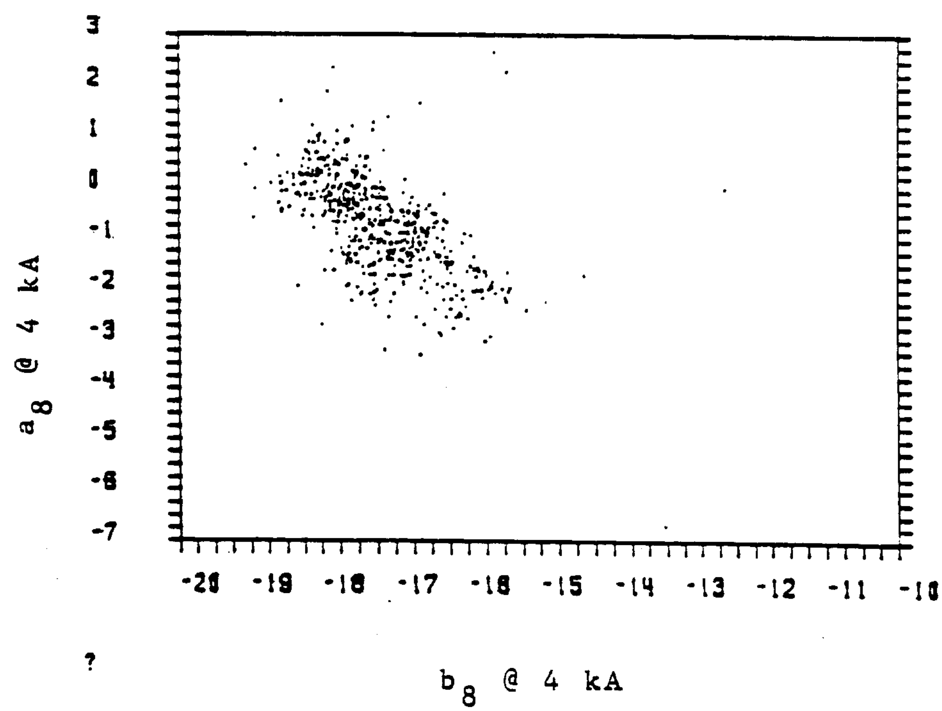
Fig. 5f

6. Some correlations.

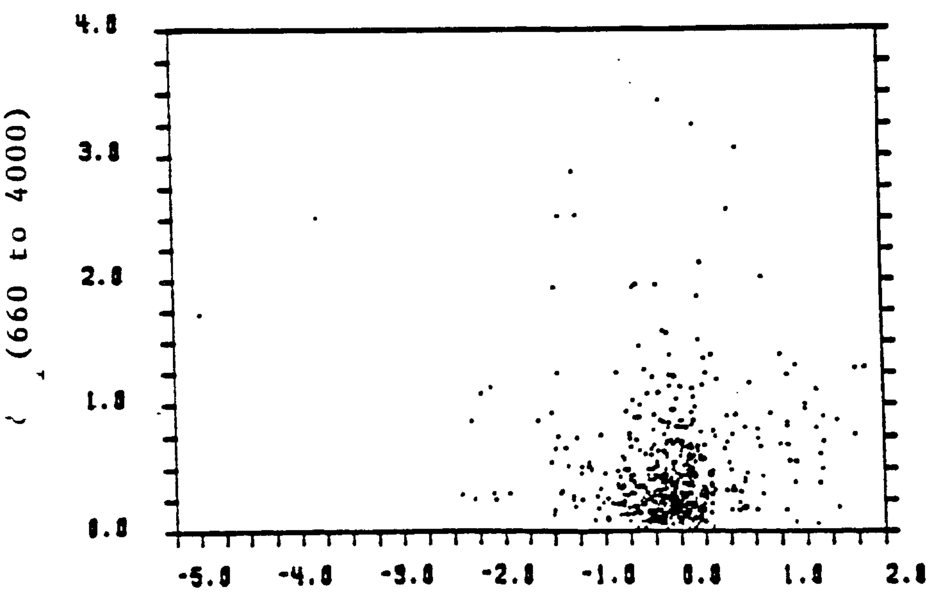
Presented here are a few scatterplots of one magnetic variable against another. Correlations are most striking for b_2, b_4, and b_6 current dependence (between 3 and 4 kA) and for b_2 vs. b_6 hysteresis. (Recall that the latter is not considered to be a real phenomenon.) There is almost no evidence for a connection between a_1 current dependence and hysteresis.

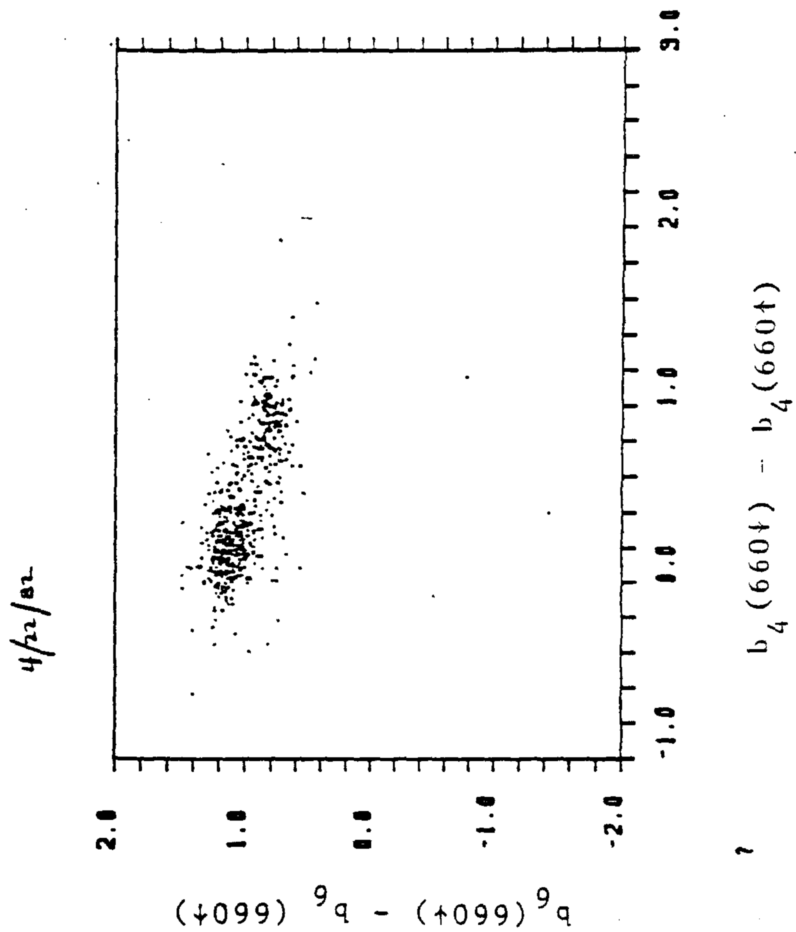
Make of these what you will.

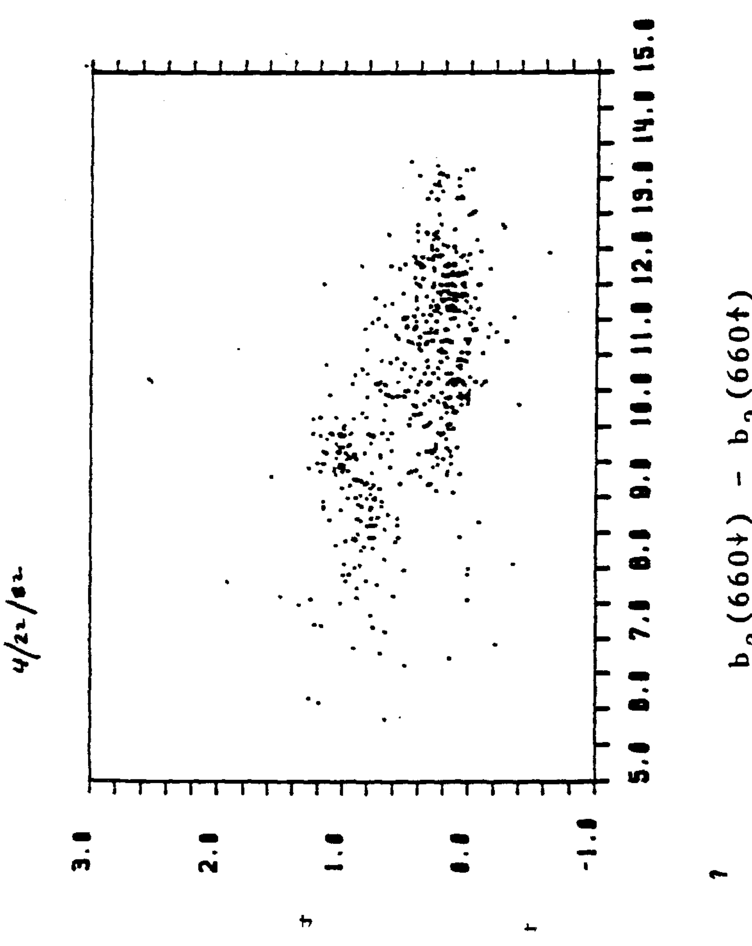
4/21/82

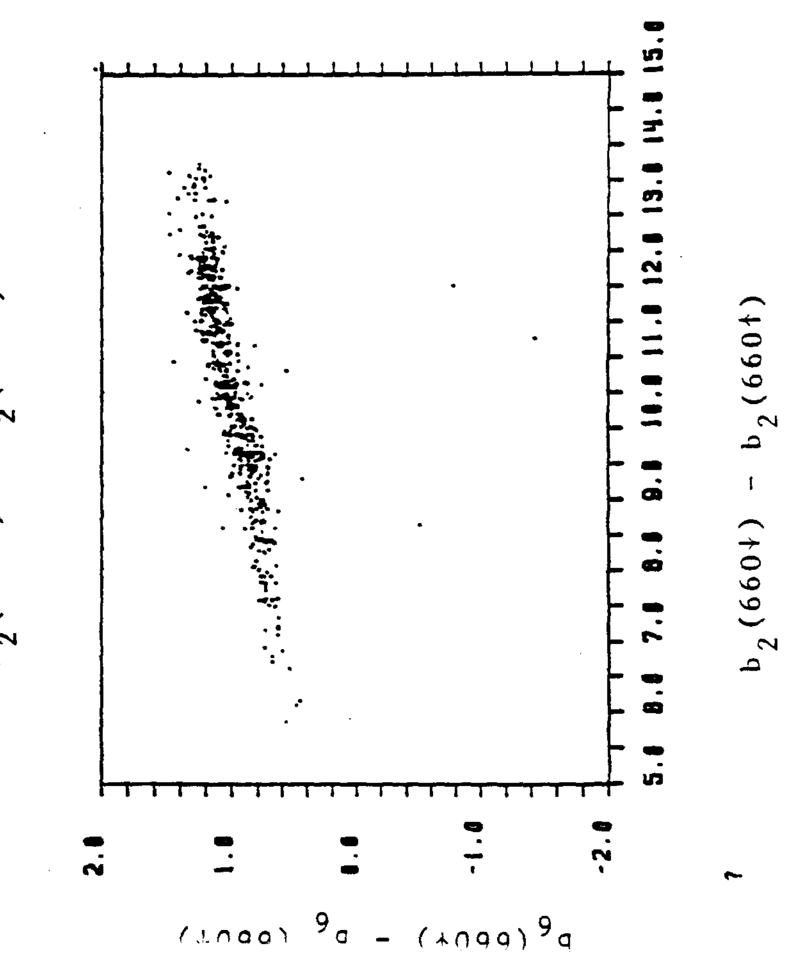


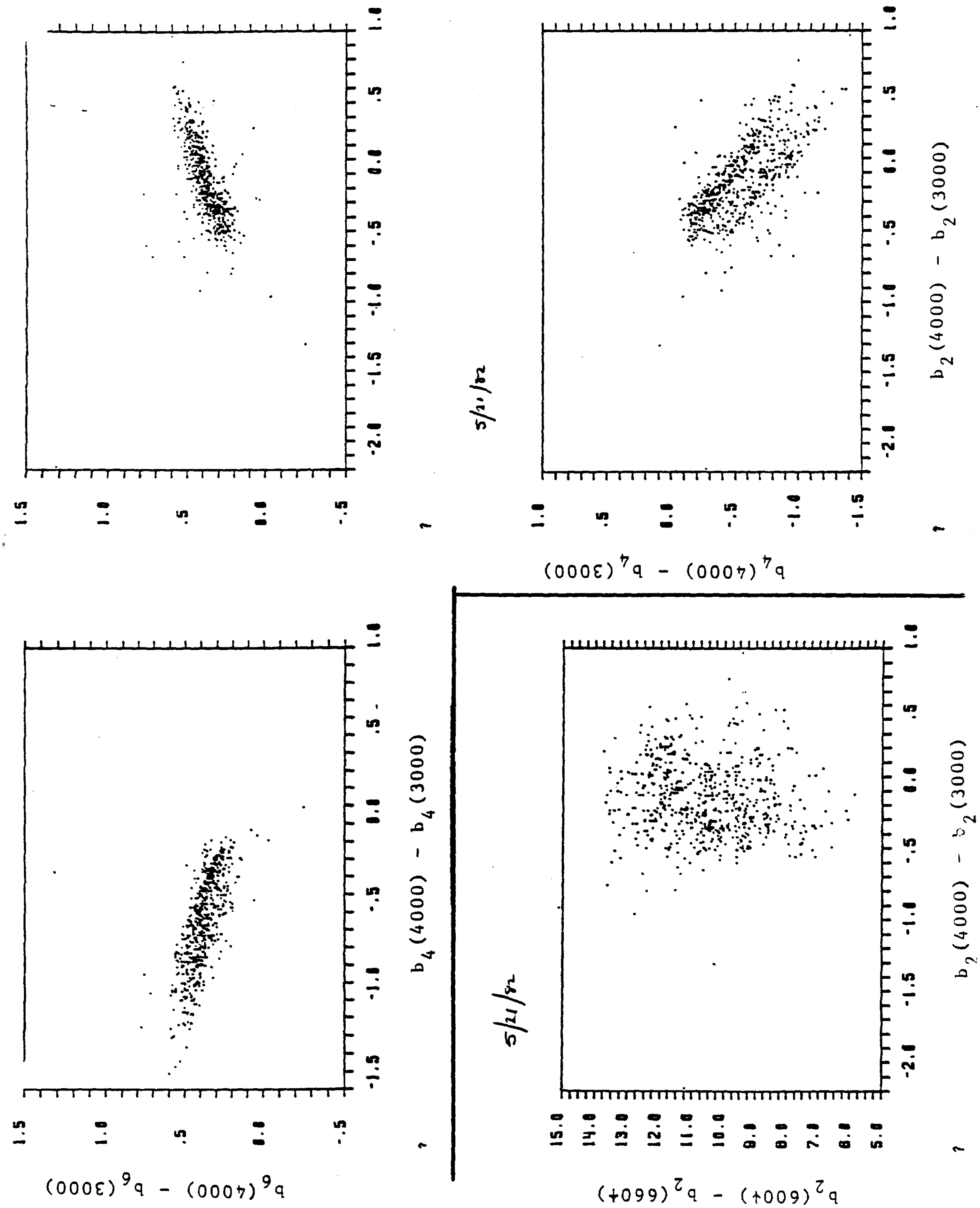
5/11/82




4/22/82
2.0
1.0
0.0
-1.0
-2.0
-1.0
0.0
1.0
2.0
3.0
$b_6(660+) - b_6(660+)$
$b_4(660+) - b_4(660+)$


4/22/82
3.0
2.0
1.0
0.0
-1.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
$b_2(660+) - b_2(660+)$


2.0
1.0
0.0
-1.0
-2.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
$b_6(660+) - b_6(660+)$
$b_2(660+) - b_2(660+)$



$b_2(4000) - b_2(3000)$
$b_4(4000) - b_4(3000)$
$b_4(4000) - b_4(3000)$
$b_6(4000) - b_6(3000)$
$b_2(4000) - b_2(3000)$
$b_2(600+) - b_2(660+)$
5/21/82
5/21/82