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Final Report

GROWTH/REFLECTANCE MODEL INTERFACE FOR WHEAT AND CORRESPONDING MODEL

DR. GWYNN H. SUITS
RUSSELL SIERON
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FINAL REPORT

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INTRODUCTION

The reception of signals by high altitude sensors is the end link in a formidible chain of radiometric events. One of the intermediate links in this chain is the reflection of daylight from materials covering the terrain. When that covering material is an agricultural crop - such as, wheat - the influence of the intermediate link is governed by the condition of the crop at the time of observation. If the signals received from a wheat field are clearly caused by reflection from dead plant material at a time in the growing season when the crop should be green and alive, one can infer that the crop under observation is in serious trouble and that the yield of such a crop will be nearly zero. On the other hand, if the signals received are those which reflect from large quantities of healthy green plants, one can infer that the crop is on schedule and is doing well. Yield should be high.

The characteristics of received signals are symptomatic indicators of crop condition. The signals are used diagnostically just as a medical doctor uses overt symptoms of human patients to infer the condition of the health of a patient. The possibility of disease is "remotely" detected within the patient. The symptoms are used to infer the presence or absence of certain classes of diseases from outside the patient. In order to make a correct diagnosis, the connection between certain symptoms and the class of disease that causes them must be known.

In the same way, remotely detected signals offer the opportunity to establish the connection between symptomatic signals and remotely located crop conditions. It is quite clear that correct diagnostic inferences are possible at least in the extreme crop conditions - alive or dead. The question remains as to the degree of refinement of diagnostic inference which can be made for crops under a variety of intermediate conditions of vigor.

It is the purpose of this research using modeling to explore the possibility of discovering new and useful symptoms which might be available from the Thematic Mapper and to connect these symptoms to the biological causes in the crop. A crop growth model is used to predict the day to day growth features of the crop as it responds biologically to the various environmental factors. A reflectance model predicts the character of the interaction of daylight with the predicted growth features. An atmospheric path radiance is added to the reflected daylight to simulate the radiance appearing at the sensor. Finally, the digitized data which are sent to a ground station are calculated. The sensor considered here is the Thematic Mapper. The crop under investigation here is wheat.

THE RITCHIE WHEAT GROWTH MODEL

A wheat growth model developed by Ritchie [1981] in 1979 is used to simulate the biological growth of wheat as it responds to the various environmental factors during the growing season. This model is in the form of a computer program which provides day by day estimates of the number of tillers, number and size of green leaves and, at maturity, the expected grain yield of the crop in response to a time sequence of weather and soil conditions under the influence of certain underlying genetic controling parameters. The growth model estimates provide a basis for the physical description of the ground cover as it changes day by day.

The completion of the physical description of the canopy of wheat is done using scaling factors derived from wheat field measurements by Jackson and Pinter [1981] and by accounting for dead leaf and stem material which the growth model no longer considers to be significant in the production process.

CANOPY REFLECTANCE MODEL

The canopy reflectance model which was used to calculate the interaction of sunlight with the growing wheat canopy was the extension of the uniform canopy model to include row effects by G. Suits [1983].

The density of foliage in the direction across rows changes throughout the growing season. As the crop first emerges, the foliage is concentrated along the row with bare soil exposed between rows. As the wheat progresses into the tillering stage some of the inter-row bare soil becomes occupied by foliage. During the period of rapid vegetative growth both the height and the lateral extent of foliage increases. The effect of row structure on reflectance reaches a maximum when the height of the crop is about the same as the row spacing. Row spacing was taken to be about 7 inches in this model canopy. As vegetative growth continues the lateral extension of foliage into the inter-row space approaches the uniform canopy condition.

The lateral distribution of foliage density was approximated as being

$$D = 1 + Am * \cos(2 * Pi * X/P)$$

where X = distance from row center,
P = row spacing,
Am = density modulation amplitude, $0 \le Am \le 1$.

When Am=0 the canopy is uniform.

The plant materials were modeled as the ensemble of various components - new green leaf, mature green leaf, dead leaf, green stem, dead stem, green heads, and dead heads. The reflectance and transmittance of each component type were obtained from measurements on the Beckman DK II.

The amount of each component to be used in the reflectance model was derived from the output of the growth model using Jackson and Pinter [1981] field measurements for scaling purposes. The geometrical arrangement was determined from photographs and drawings of wheat as a function of the Feekes stage of development.

For this wheat the canopy was divided into three layers. Layer 1, the top layer was made empty until the appearance of the flag leaf. The flag leaf was placed first in layer 1. Layer 2 contained the bulk of the vegetative growth of green leaf and stem. Layer 3, the bottom layer, contained the senescent leaf material which was discarded by the growth model program but which should still be present in the wheat field.

At the time of head extension the wheat heads and attached stem portion were also placed in layer 1 along with the flag leaf. As heads were extended beyond the level of the flag leaves, the flag leaves were re-assigned to the layer 2 until all flag leaves were in layer 2 and all heads and extended stem portions occupied layer 1.

During senescence, the loss of green leaf predicted by the growth model was introduced into reflectance model as a transfer of leaf area from the green leaf category to the dead leaf category. In the same way, green heads and stem were transferred to the dead head and stem categories.

The changes in wheat growth with time as predicted by the growth model were introduced into the reflectance model as a running average over several days of growth model output. The assumption is that the growth model output represents the expected values for a particular growth stage. In an actual field all plants do not achieve the same growth stage at the same time. There is some distribution of stages represented in a field at any one time.

The soil reflectance was obtained from measurements of a local sample and was adjusted for wheat belt soil albedo values. The soil moisture in the exposed top layer of soil was modeled empirically using moist soil spectral measurements. A precipitation of over 0.01 inches was taken to be sufficient to bring the visible top few millimeters of soil to the field capacity reflectance. Soil moisture from this top layer was made to dry asymptotically to yield the reflectance at an air-soil moisture equilibrium. A trace of water absorption is still evident in the reflectance spectrum at equilibrium. Soil moisture in the root zone computed by the growth model was assumed to have no visible effect at the surface.

The direction of the sun was taken to be the direction at the time of a Landsat overpass and the direction of view was the nadir. Wheat row direction was North-South.

CHOICE OF WHEAT FIELD LOCATIONS

Two different locations were chosen in the mid-west wheat belt - Wichita, Kansas, 37 degrees 41 minutes North latitude 97 degrees 20 minutes West longitude, and Sioux Falls, South Dakota, 43 degrees 32 minutes North latitude 94 degrees 44 minutes West Longitude. Both locations are suitable for planting winter wheat of the same variety.

The growing years were chosen on the basis of yearly total precipitation - a dry year, an average year and a year with above average precipitation.

ADDED PATH RADIANCE

The search for possible diagnostic signals in the Thematic Mapper requires the incorporation of a realistic estimation of atmospheric interference with the radiation arriving at the satellite. The primary interference is that due to path radiance. The path radiance caused by backscattering of direct sunlight passing through the atmosphere adds to the terrain radiance. Although path radiance changes from day to day, the best estimate of path radiance found by Eric Crist [1984b] for the Thematic Mapper bands was used in this calculation. The estimated mean spectral radiances in each band are listed in Table 1.

TABLE 1
Mean Spectral Radiances of the Atmosphere in the Thematic Mapper Bands According to Crist

Band	Spectral Radiance mW/sqcm sr um
TM1	3.35
TM2	1.68
TM3	1.03
TM4	0.49
TM5	0.04
TM7	0.00

GAINS AND OFFSETS

The last link in the radiometric chain of events is the detection of the radiation at the satellite and the conversion of signals to digital counts which are telemetered to the ground station. The relation between the radiance observed at the satellite and the digital counts of signal requires a gain and an off-set value. The gains and off-sets used in the calculation were those used by Crist [1984a]. These are listed in Table 2.

TABLE 2
TM Band Limits, Gains and Offsets

Band	λ_1 nm	λ_2 nm	Gain	Offset
TM1	450	520	15.777	0.82
TM2	520	600	8.038	0.81
TM3	630	690	10.571	-0.04
TM4	760	900	10.866	0.69
TM5	1550	1750	79.568	2.64
TM7	2080	2350	149.197	3.16

SUMMARY OF WHEAT GROWTH PREDICTIONS

The six growing conditions which were selected were three for the Sioux Falls, South Dakota region for the years 1950-51, 1957-58, and 1965-66 abreviated hereafter as S50-51, S57-58 and S65-66 and Wichita, Kansas region for the same years abreviated hereafter as W50-51, W57-58 and W65-66. Actual weather data for these regions and years were used to drive the Ritchie wheat growth model. Table 3 shows the leaf area index predicted for Feekes scale of development from 5 through 11 for each case. According to R. F. Peterson [1965] Feekes 5 is the final stage of tillering. Feekes 6 through 10 are the stages of stem extension with Feekes 10 the "boot" stage. Feekes 10.1 through 10.5 are the stages of heading. Feekes 11 is the ripening stage.

TABLE 3
Feekes Scale, LAI, Final Yield and
Brightness at Feekes 7

Feekes	S50-51	S57-58	S65-66	W50-51	W57-58	W65-66
5	0.058	0.047	0.015	0.137	0.082	0.090
6	0.71	0.74	0.69	0.68	0.83	0.888
7	1.85	1.79	1.76	1.57	1.95	1.91
8	2.81	2.78	2.68	2.31	2.87	2.93
9	3.59	3.62	3.59	3.06	3.67	3.77
10	4.21	4.30	4.33	3.58	3.80	4.47
11	4.27	4.33	4.41	3.62	3.66	4.48
Yield kg/HA						
	1401	1721	2641	780	1011	1319
BRIGHTNESS at Feekes 7						
	120.7	117.1	122.7	108.7	116.5	112.3

ANALYSIS

Some interesting observations can be made concerning the wheat growth predictions for these two regions. One can see that the Wichita area produces poorer yield than the Sioux Falls area on a consistent basis. Even when the LAI of the Wichita Area for W65-66 exceeds that of the poorest yielding year of the Sioux Falls area S50-51, the yield of the Wichita area is still less than that of the Sioux Falls area.

The GREENNESS-BRIGHTNESS and WETNESS-BRIGHTNESS plots for these growing seasons are shown in Figures 1 through 12 where Feekes stage number is indicated on the plot. Feekes 10 and 11 are indicated by the letter A. Composites by location are shown in Figures 13, 14, 15, and 16 where the solid, long dash, and short dash curves are for 50-51, 57-58, and 65-66 respectively. These results are predicted by the combined models. In almost all cases the GREENNESS and WETNESS are comparable but the BRIGHTNESS of the Wichita area is consistently lower than for the Sioux Falls area.

The row structure of the wheat fields in both areas were still distinct up to about Feekes 7. Thereafter, the field rapidly became uniform due to foliage extension across rows. Since the difference in BRIGHTNESS is consistent before and after Feekes 7, the row structure cannot be responsible for the differences.

During the growing season, precipitation produced changes in soil reflectance. However, the effect of soil moisture does not appear to be significant in the tasseled cap plots.

One might suspect that BRIGHTNESS value might be a symptom of yield. However, Table 3 shows that within one location there is no consistent relation between BRIGHTNESS at Feekes 7 and yield. The symptom seems to be dependent upon geographic location and, hence, sun angle at over pass time. The fact that the growth model predicts location dependent yield may be entirely coincidental.

Two interesting features can be observed in the tasseled cap plots. The first is the transition from Feekes 3 to 5 where an increase in BRIGHTNESS is clearly evident inall growth sequences except for W50-51. In the W50-51 sequence the LAI at Feekes 5 is significantly greater than the LAI of any other sequence at that stage. However, at Feekes 6, evidently the growth model predicted a favorable early growth period followed by an unfavorable incident which produced long term damage to the crop. The result can be seen in the low BRIGHTNESS of the tasseled cap and the low LAI in the table for succeeding Feekes stages. The weather data for the period between Feekes 5 and 6 does not indicate any unusual circumstances other than about a week without precipitation. The lowest temperature was 1 degree C and the highest was 16 degrees C.

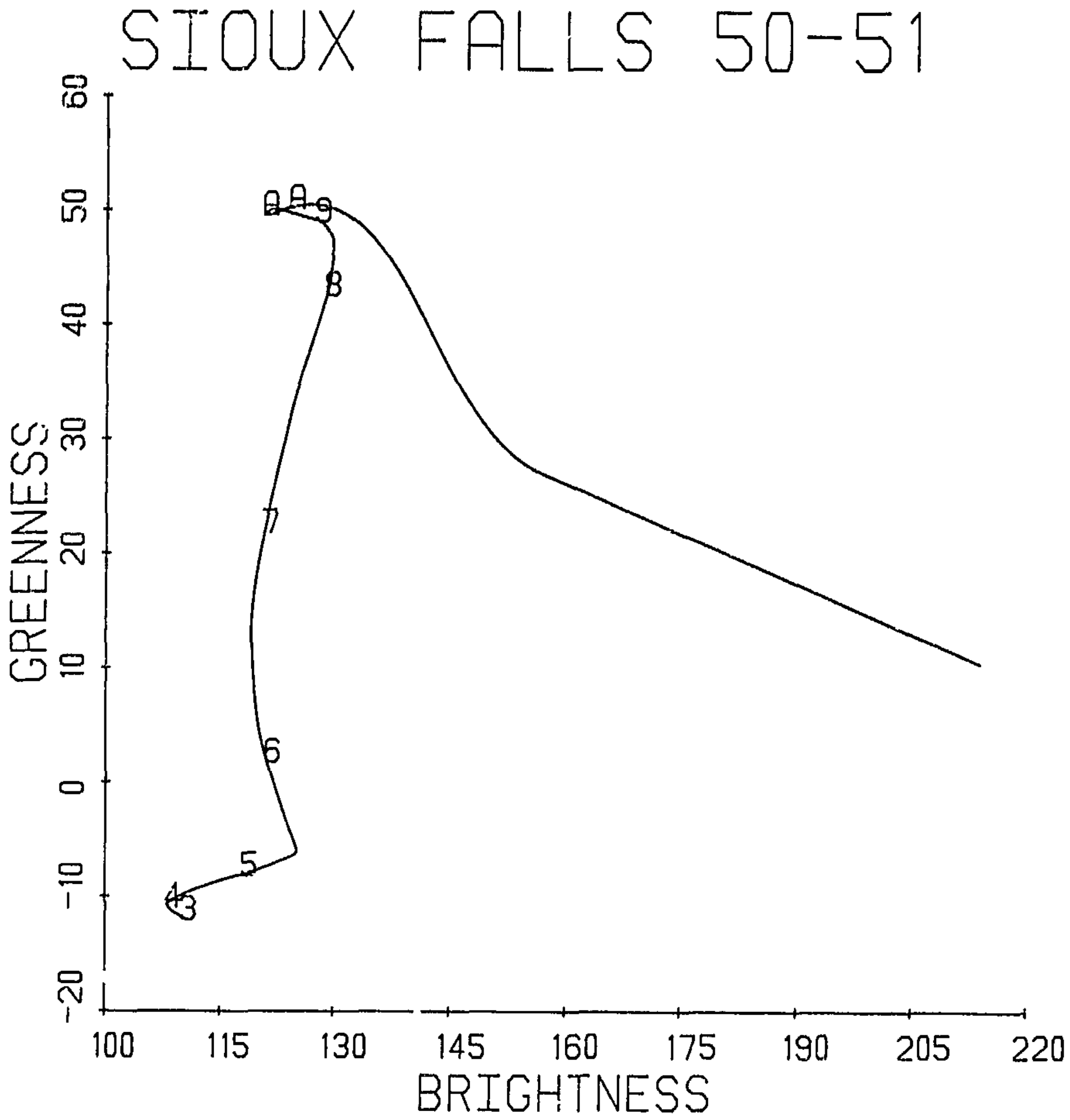
The second interesting feature is the loop at the top of the GREENNESS-BRIGHTNESS tasseled cap for W57-58. This loop is cause by the early achievement of maximum LAI near Feekes 9 while all other sequences achieved maximum between Feekes 10 and 11. The yield for W57-58 is neither unusually large nor small so that this feature is evidently not a symptom of anything important.

The WETNESS-BRIGHTNESS plots do not seem to offer any notable features beyond the obvious variations in BRIGHTNESS which were already evident. We had hoped to see possible new diagnostic features appearing in the Thematic WETNESS variable. The fact that identical soils and North-South row directions were used for both locations may be the primary reason why no large differences resulted.

CONCLUSIONS

The use of a combined growth and reflectance model for wheat was used to explore the possibility of discovering new and useful diagnostic signals in the Thematic Mapper bands. The results of this particular modeling effort have not revealed anything new. Whatever diagnostic features that may exist lie beyond the scope of these models.

The growth model is a disease free, insect free, and weed free model. The translation of the growth model predictions to the detailed predictions of the above ground canopy contents and structure were necessarily stylized by scaling factors derived from the Jackson-Pinter data. A growth model designed expressly for agronomic use to predict yield does not contain all of the needed descriptors for the above ground canopy which must be controlled biologically and environmentally just as much as the ultimate yield. The scaling factors may be too insensitive to those controls.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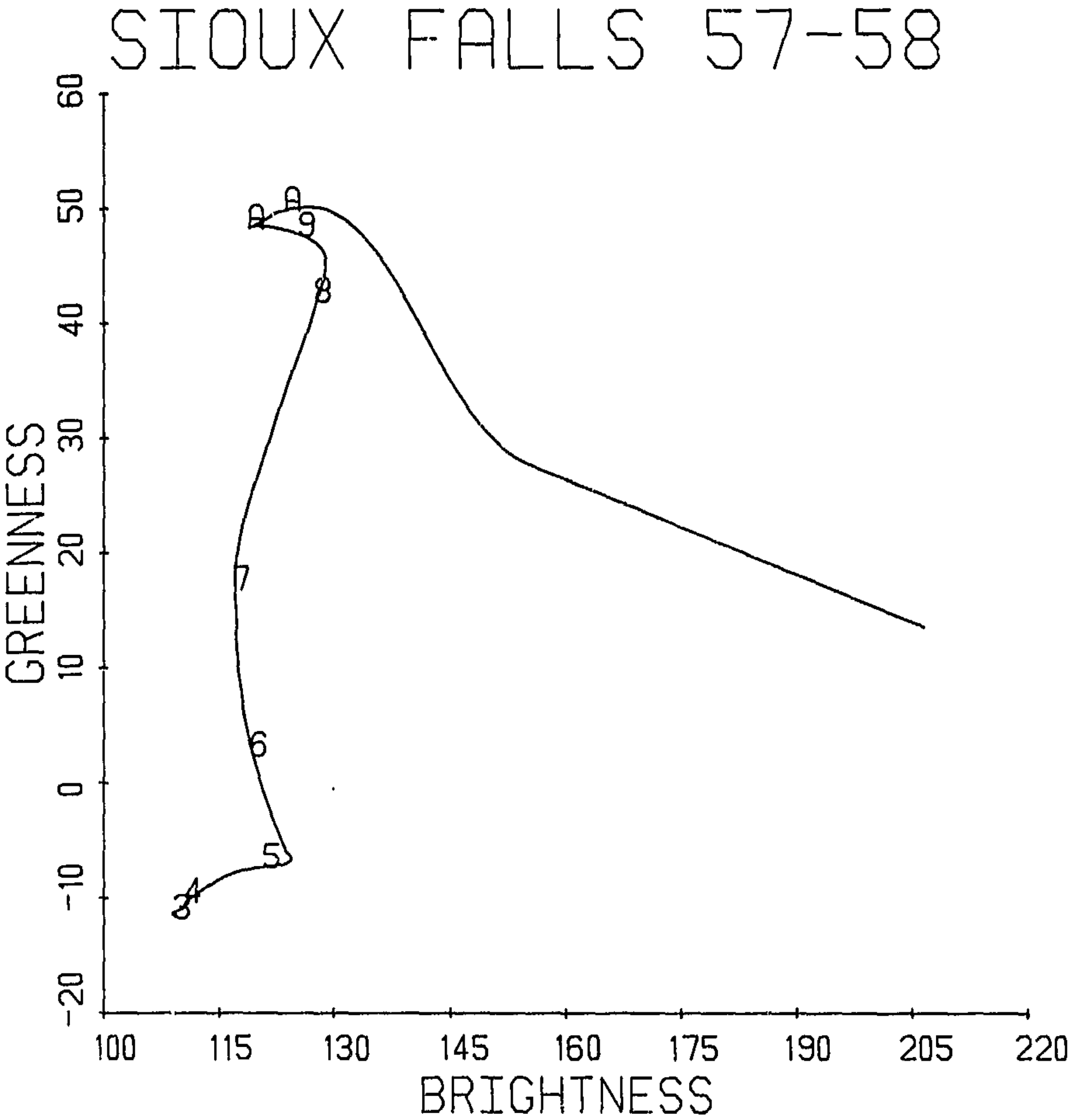
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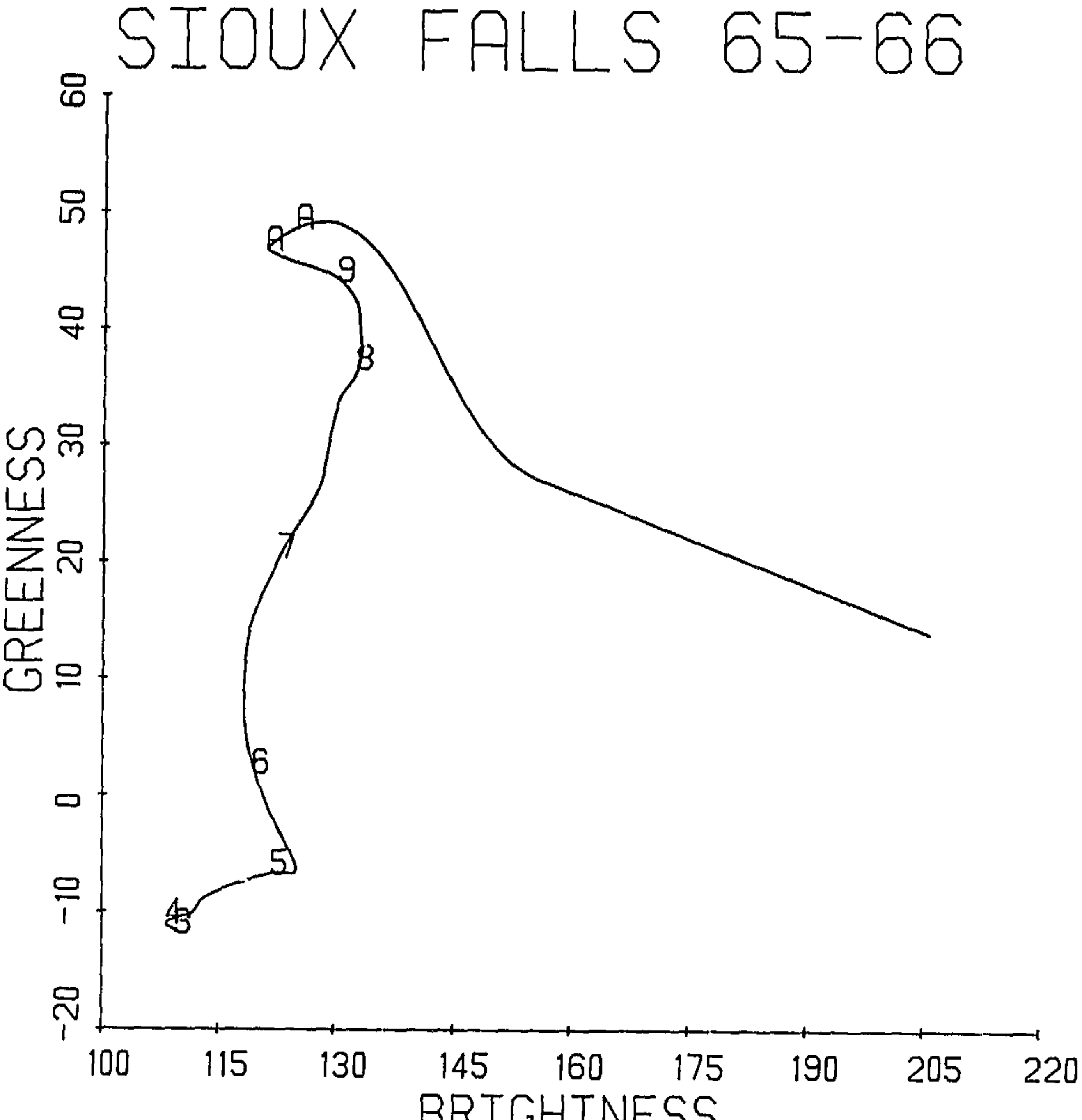
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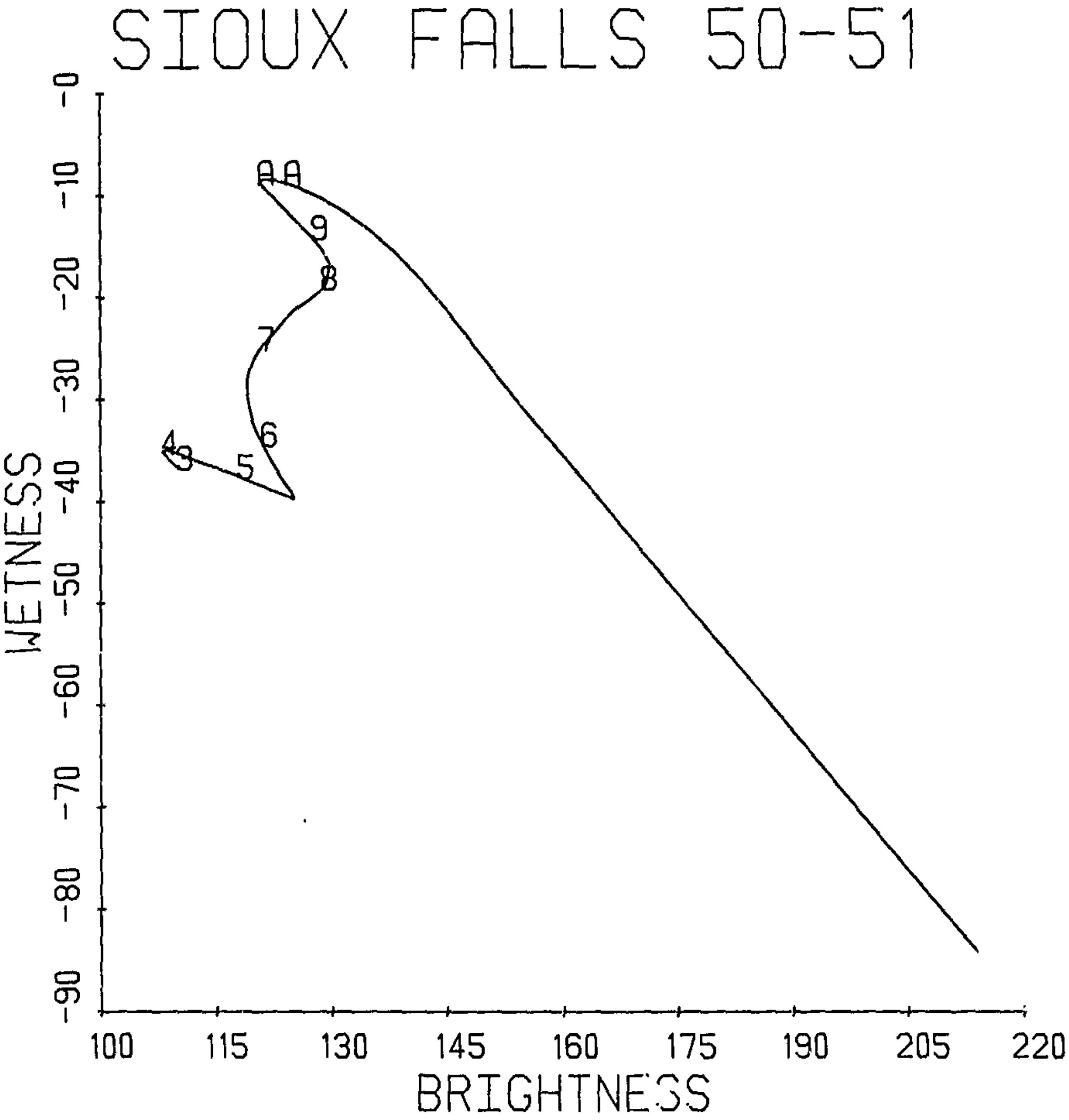
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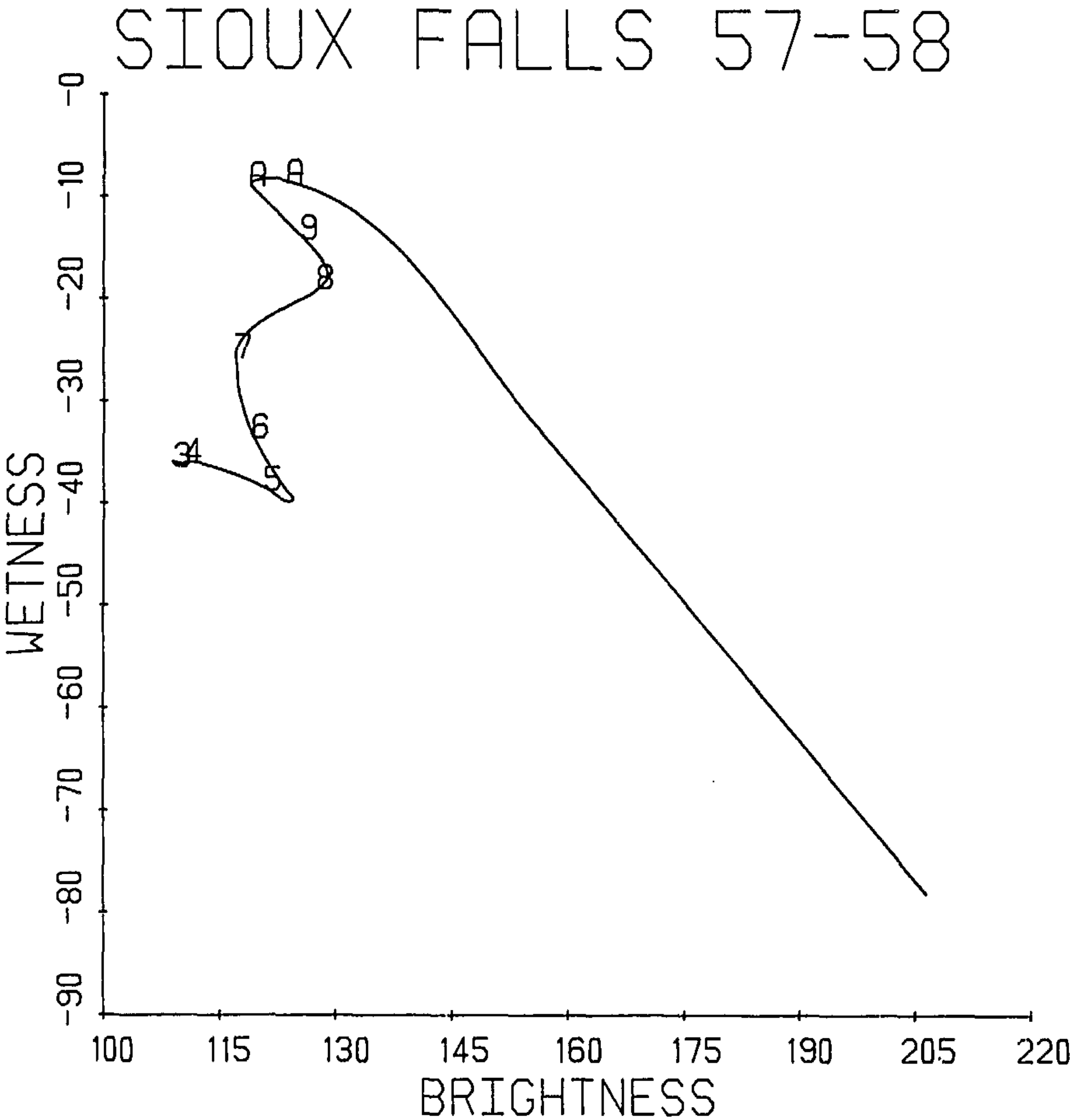
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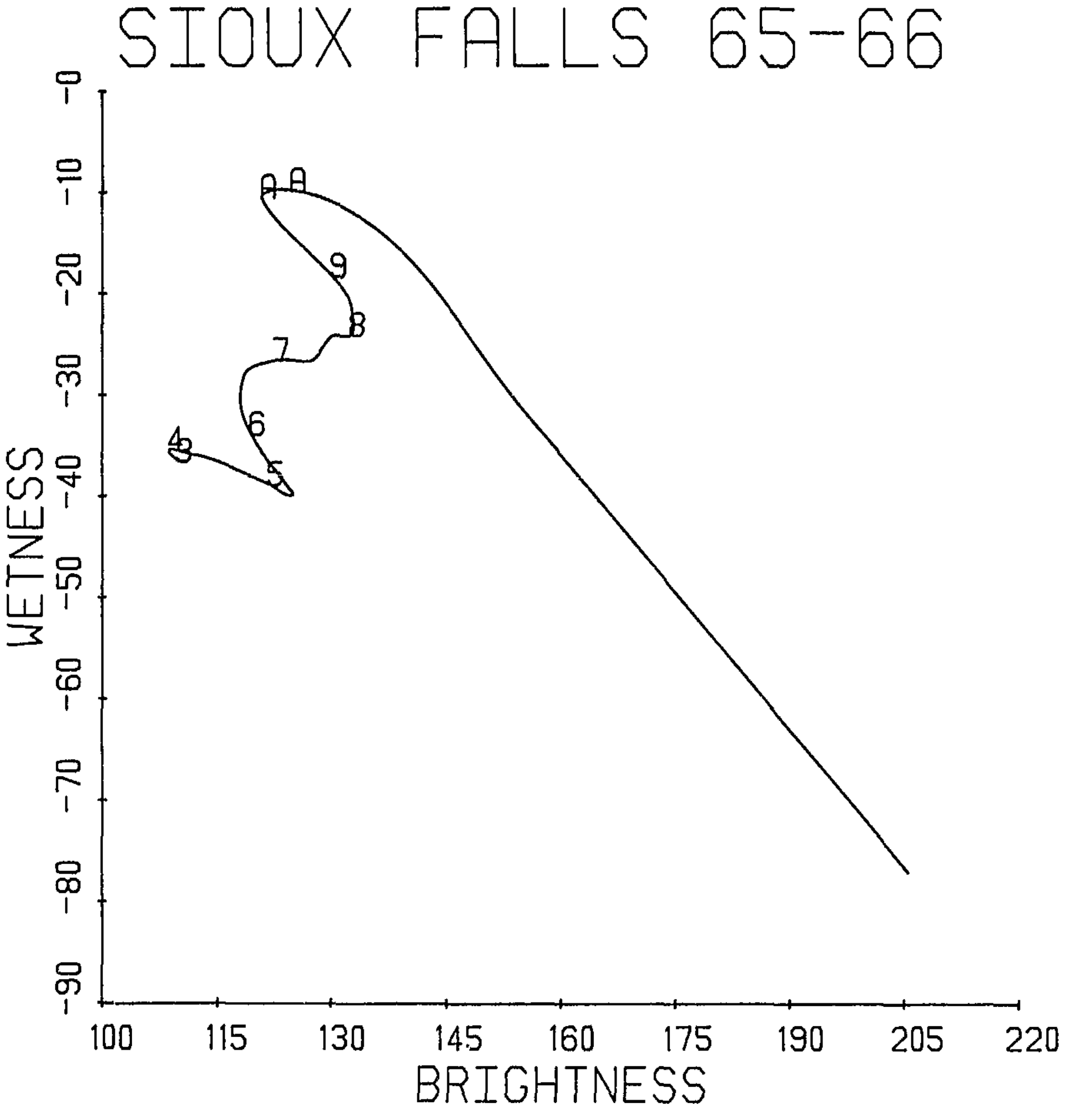
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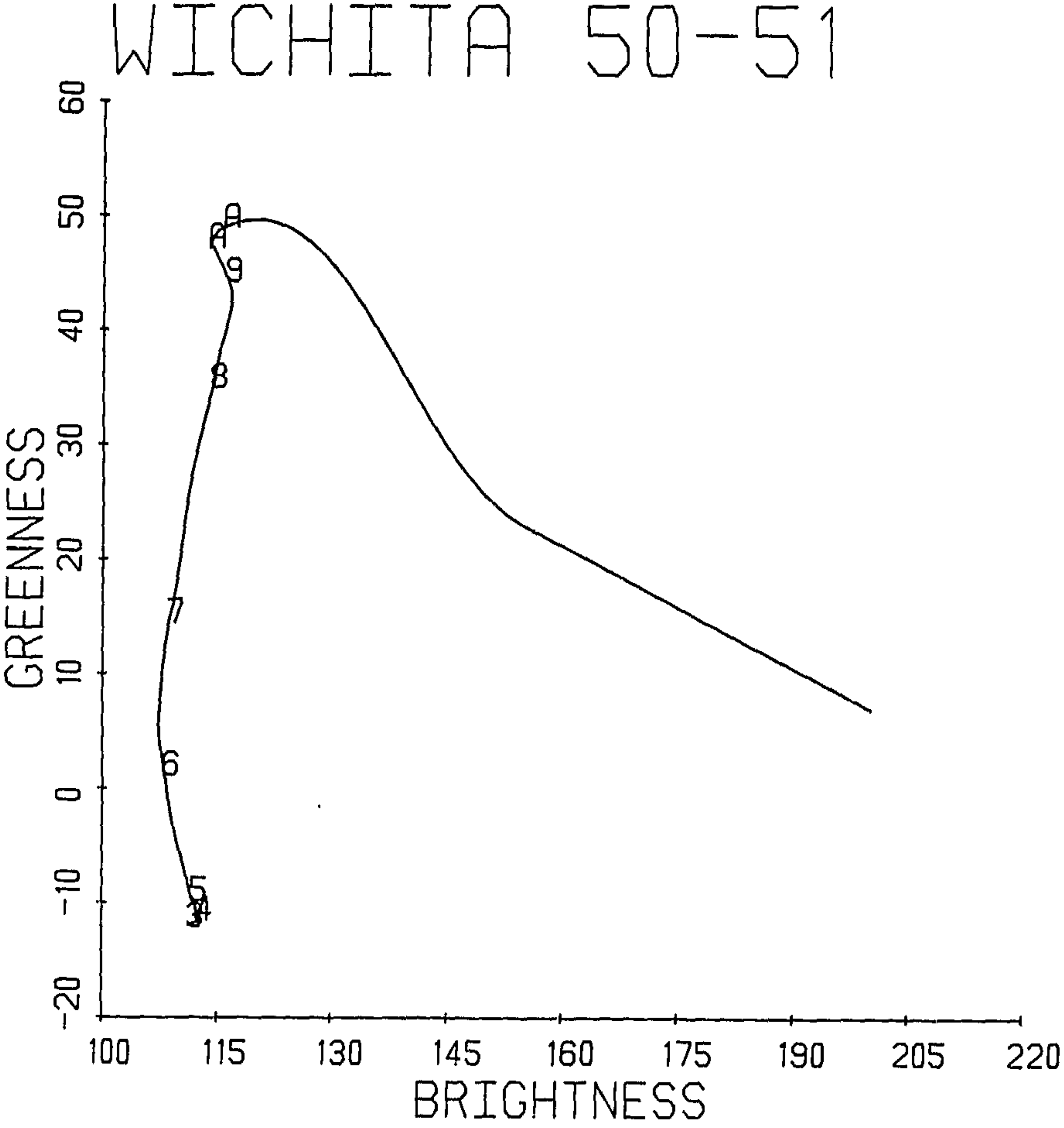
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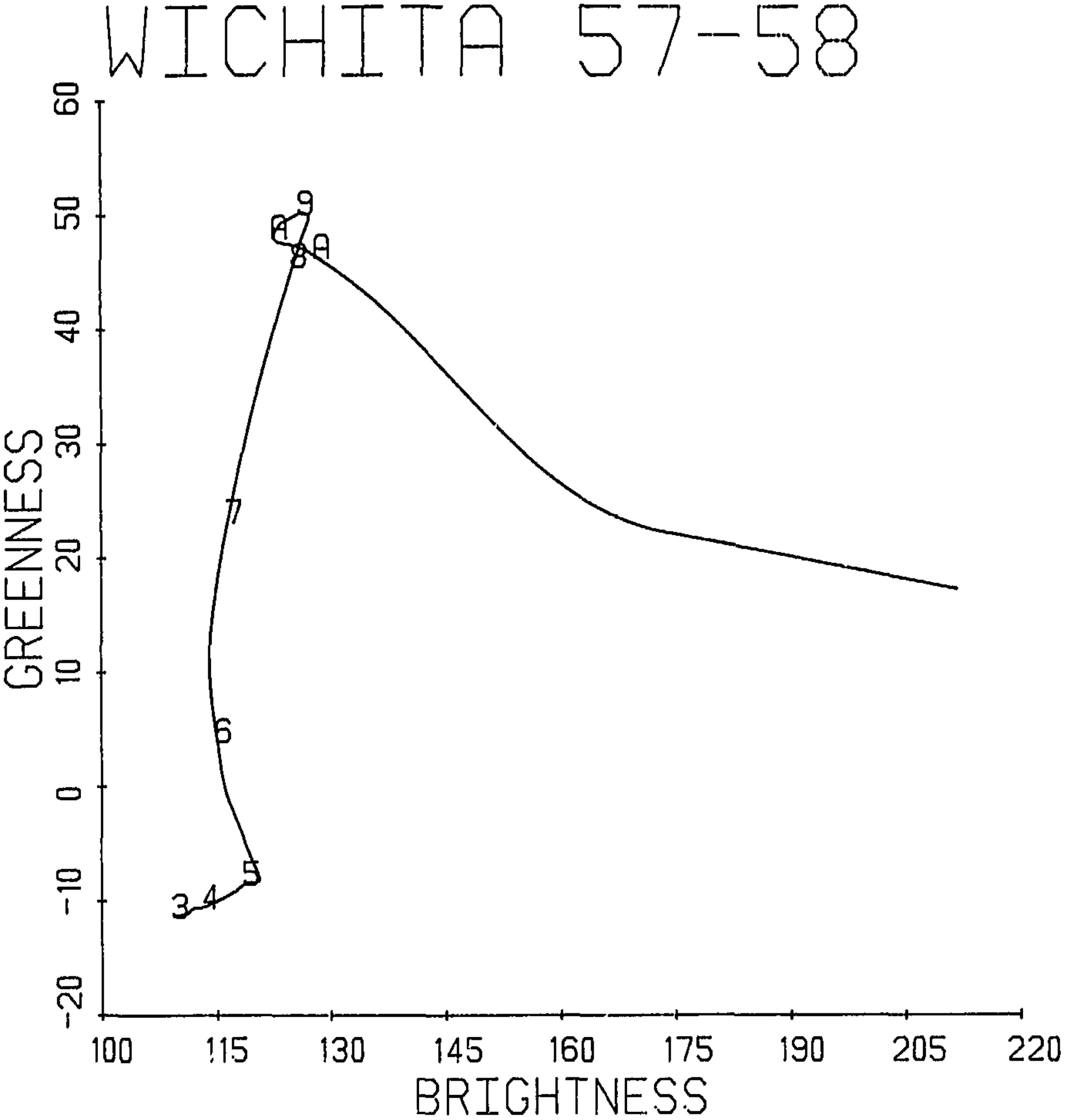
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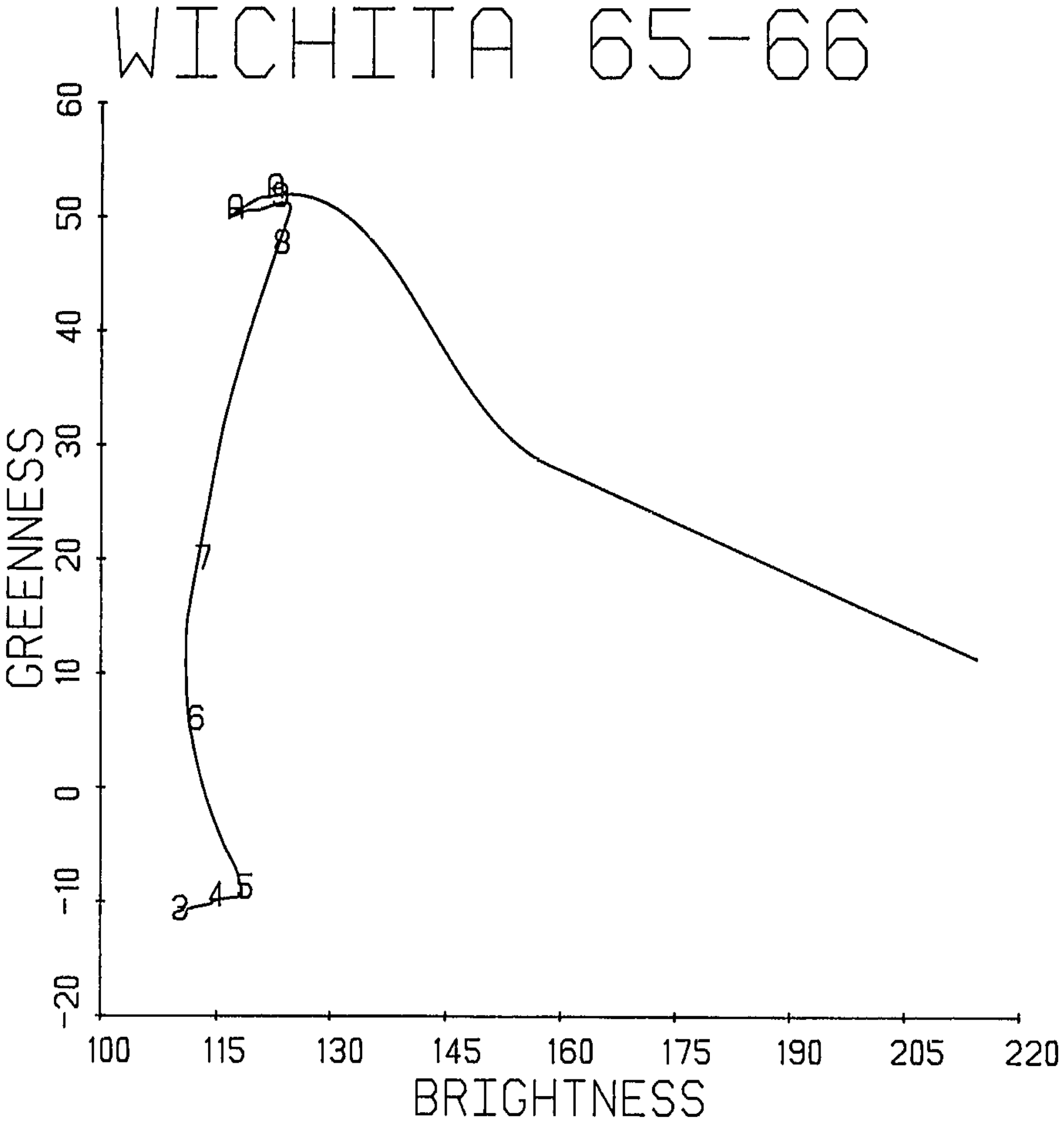
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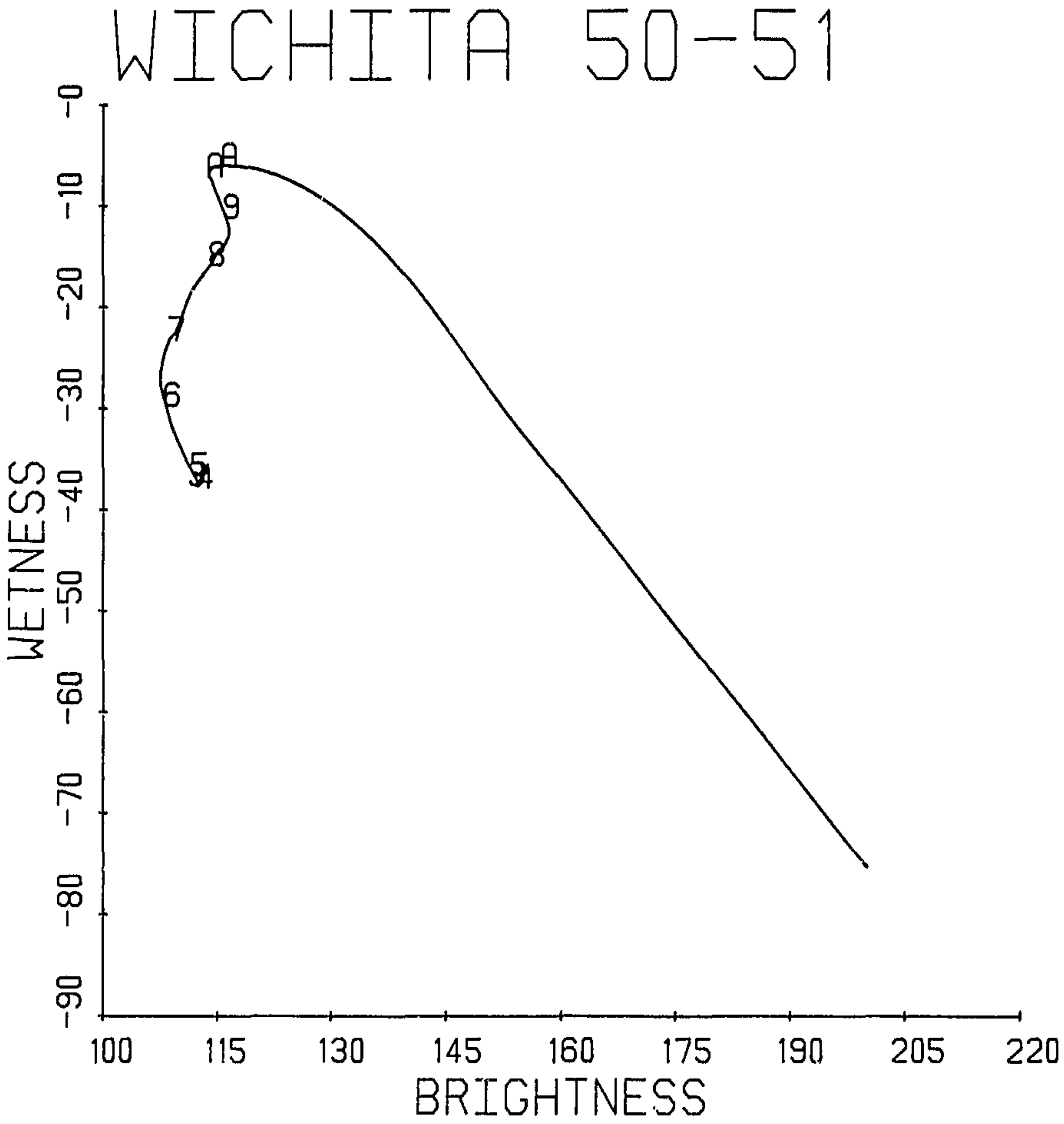
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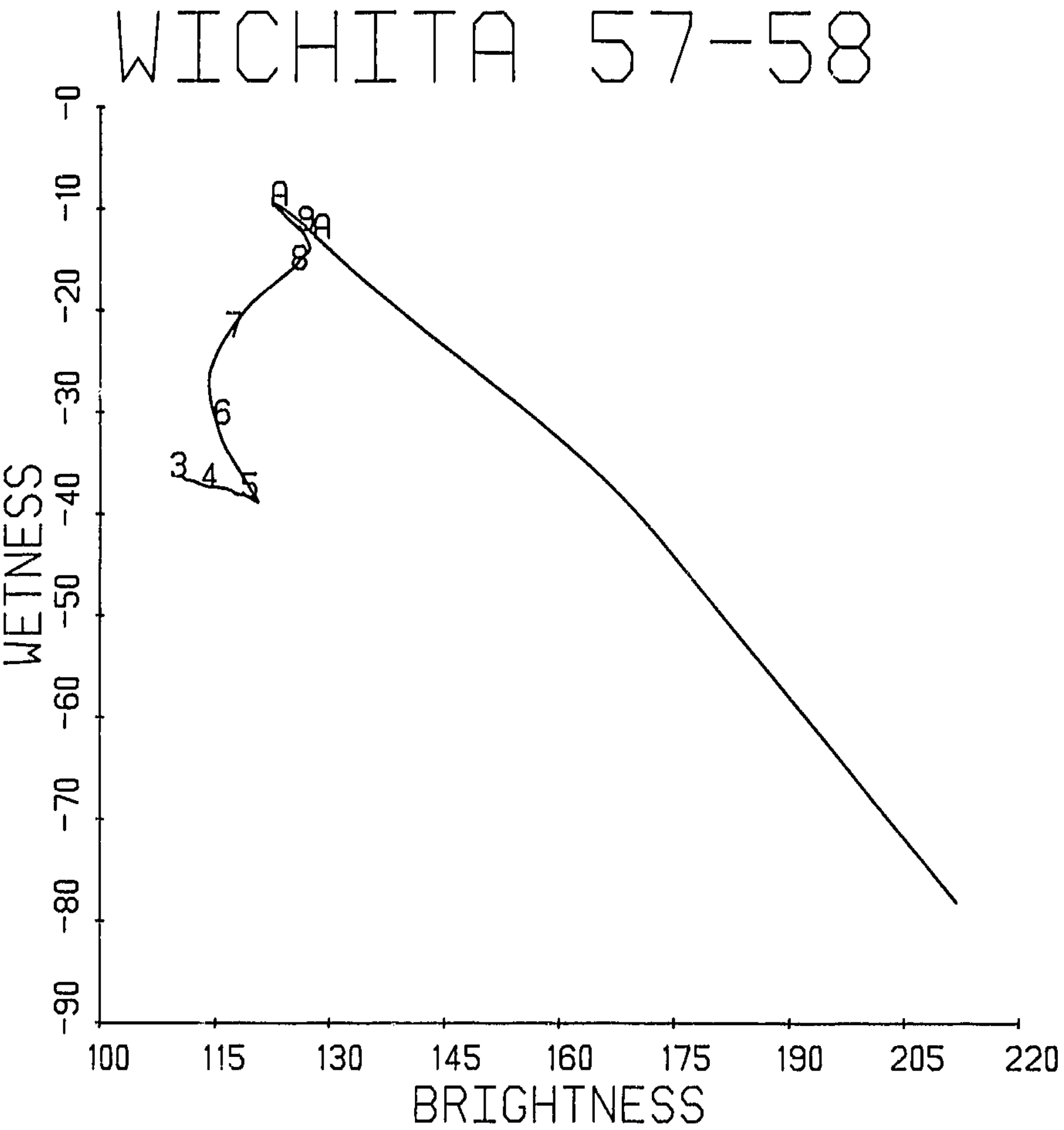
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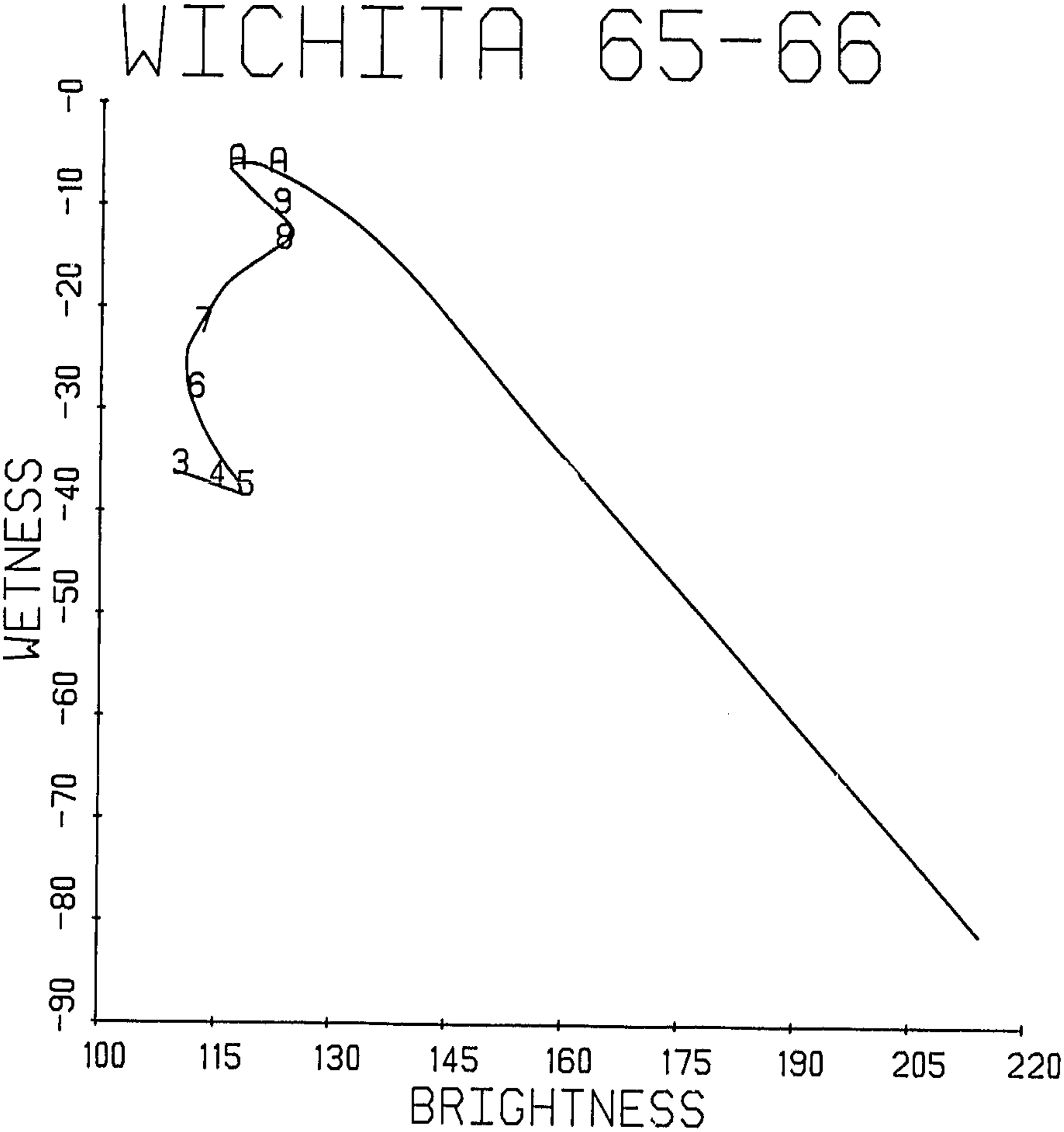
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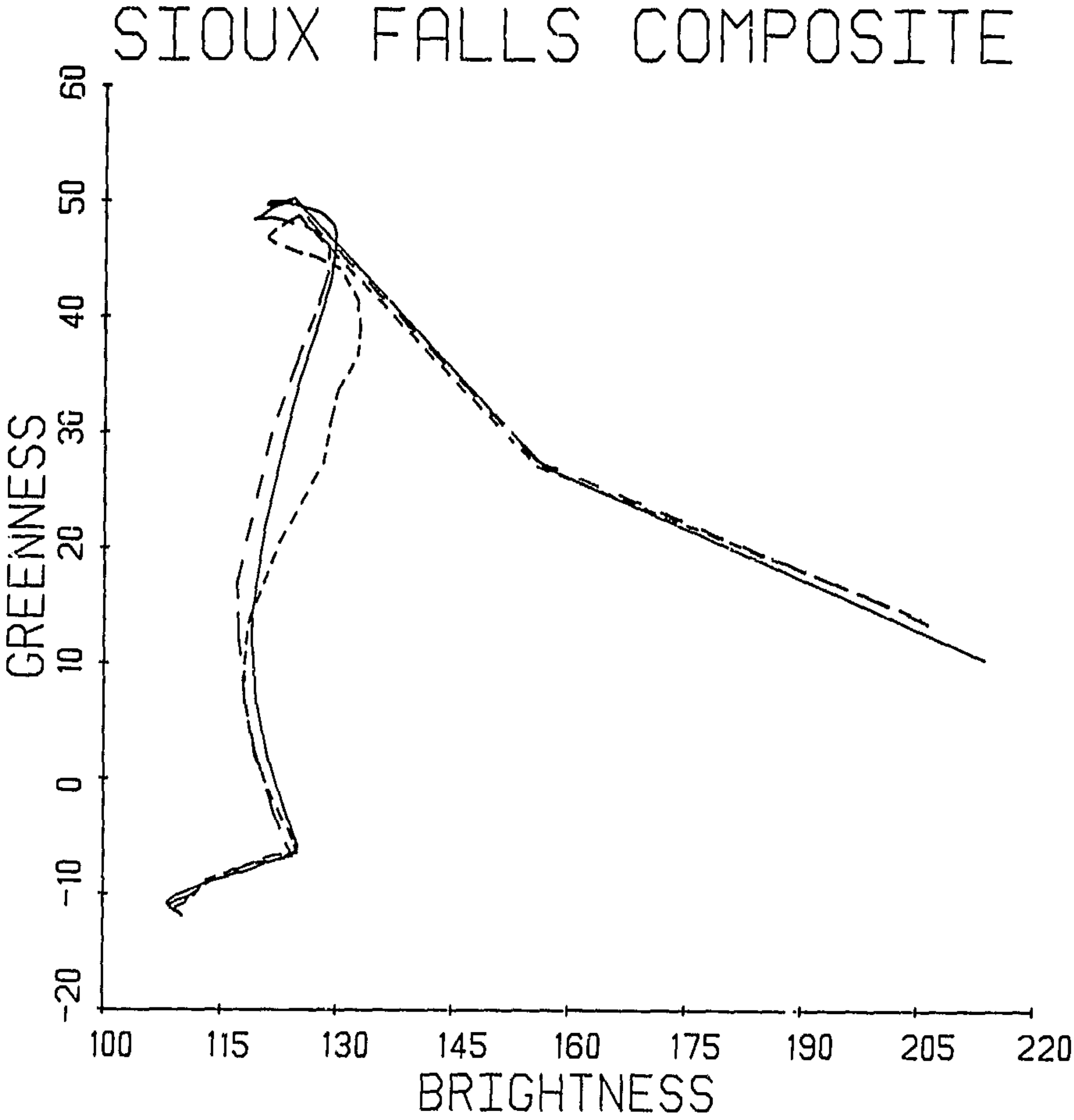
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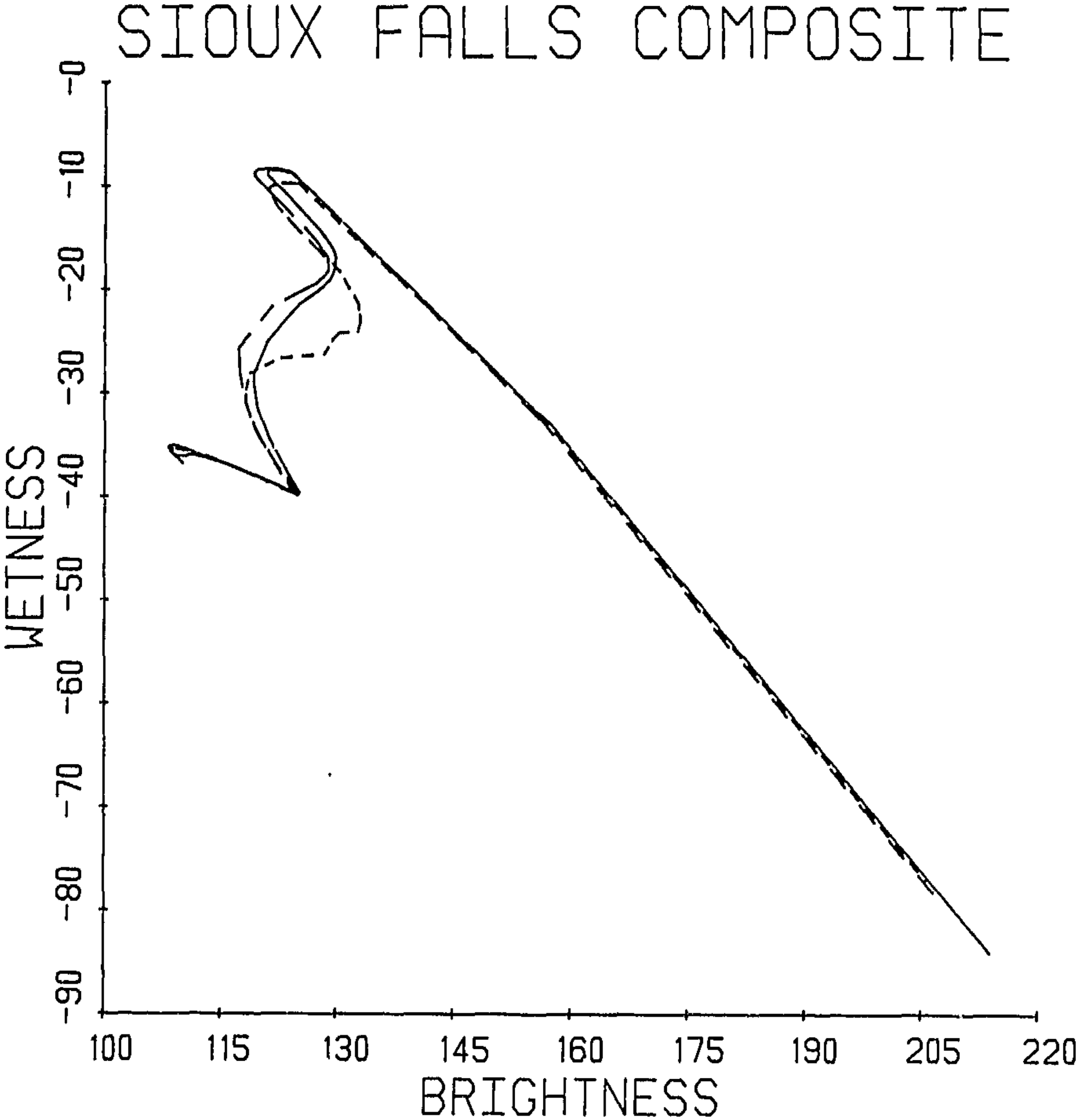
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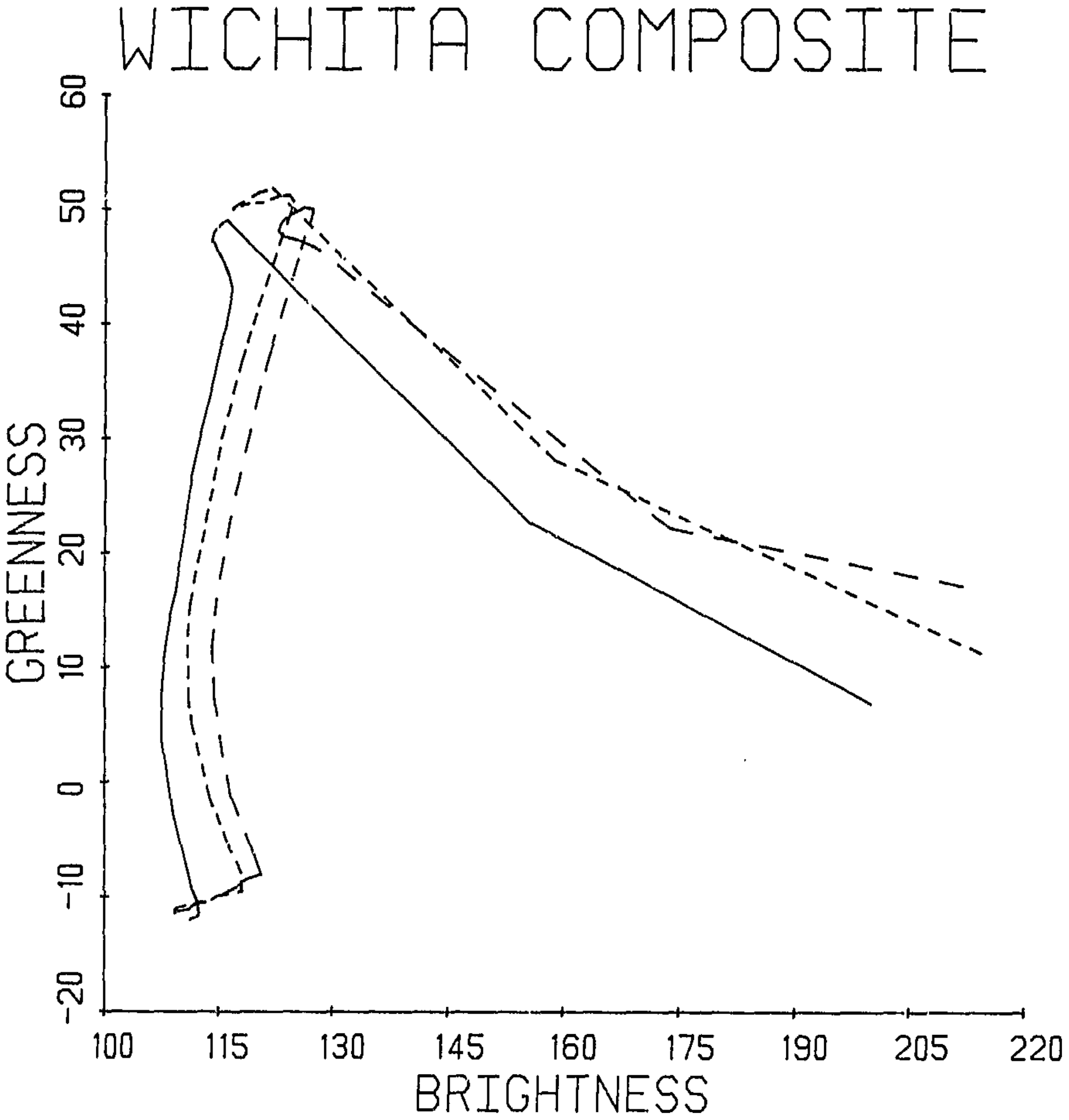
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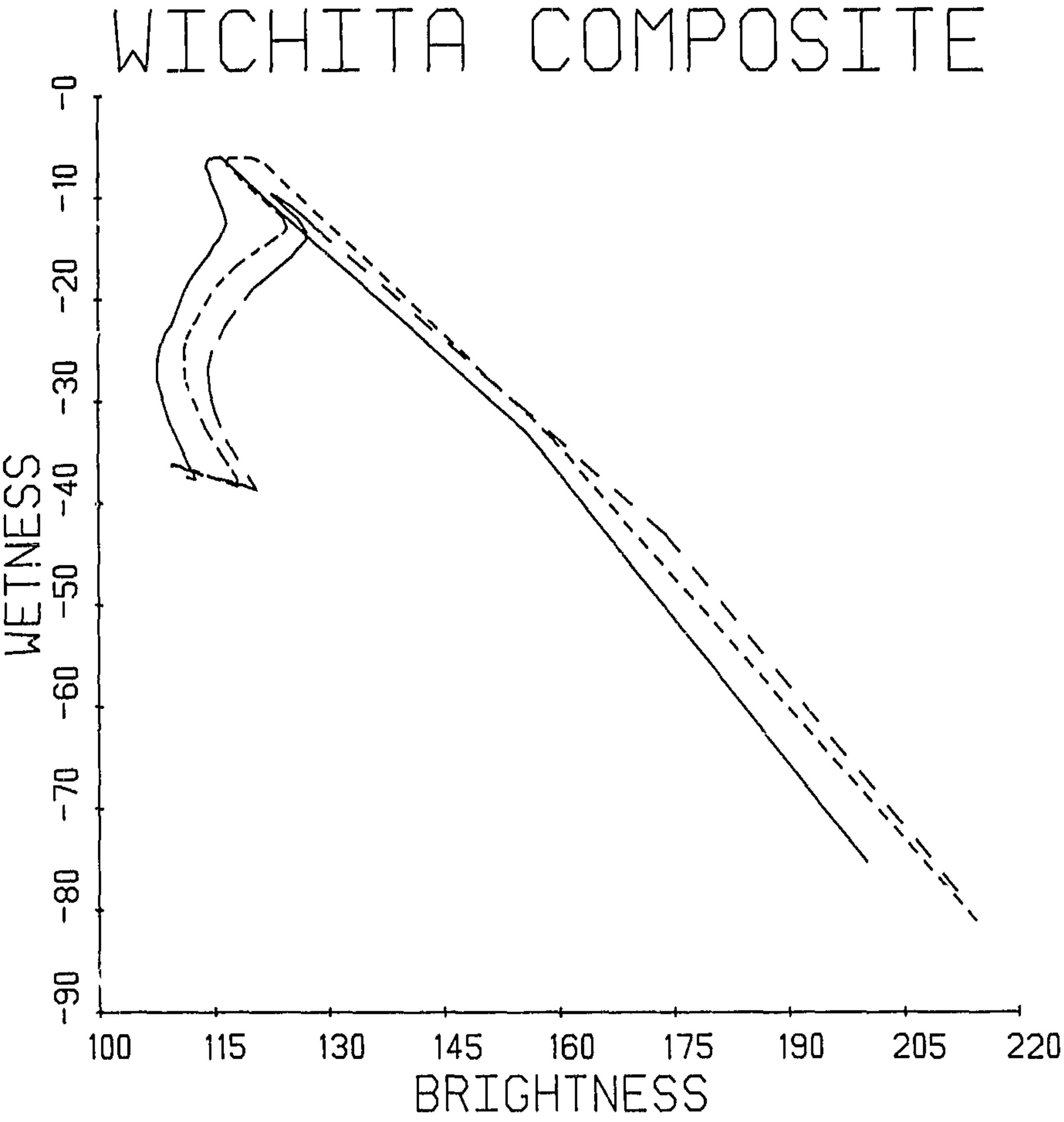
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BRIGHTNESS

Figure 16

REFERENCES

E. Crist [1984a], "Application of the Tasseled Cap Concept to Simulated Thematic Mapper Data," Photogrammetric Engineering and Remote Sensing, Vol. 50, p. 343, March 1984.

E. Crist [1984b], private communication of mean spectral radiances of the atmosphere in the Thematic Mapper bands.

R. F. Peterson [1965], "WHEAT," Interscience Publishers Inc., N. Y. 1965.

R. Jackson and P. Pinter [1981], private communication of Podura wheat field data for 1977-78 received at ERIM 1981.

J. Ritchie [1981], private communication of computer software and notes.

G. Suits [1983], "Extension of a Uniform Canopy Reflectance Model to Include Row Effects," Vol. 13, pp. 113-129, Remote Sensing of Environment 1983.