COMPARISON OF GROUND AND SATELLITE BASED MEASUREMENTS OF THE FRACTION OF PHOTOSYNTHETICALLY ACTIVE RADIATION INTERCEPTED BY TALL-GRASS PRAIRIE

p.17

T.H. Demetriades-Shah, E.T. Kanemasu, I. Flitcroft,
Department of Agronomy, University of Georgia College of Agric.
Georgia Station, Griffin, GA 30223.

and H. Su
Evapotranspiration Laboratory, Waters Annex
Department of Agronomy, Kansas State University
Manhattan, Kansas 66506, U.S.A.

ABSTRACT

The fraction, of photosynthetically active radiation intercepted by vegetation, F_{ipar}, is an important requirement for estimating vegetation biomass productivity and related quantities. This study was as an integral part of a large international effort; the First ISLSCP Field Experiment (FIFE). The main objective of FIFE was to study the effects of vegetation on the land surface-atmosphere interactions and to determine if these interactions can be assessed from satellite spectral measurements. The specific purpose of this experiment was to find out how well measurements of F_{ipar} relate to ground, helicopter, and satellite based spectral reflectance measurements.

Concurrent measurements of F_{ipar} and ground, helicopter and satellite based spectral measurements were taken at thirteen tall-grass prairie sites within a 15x15km area in Kansas, U.S.A.

(NASA-CR-187595) COMPARISON OF GROUND AND SATELLITE BASED MEASUREMENTS OF THE FRACTION OF PHOTOSYNTHETICALLY ACTIVE RADIATION INTERCEPTED BY TALL-GRASS PRAIRIE (Georgia Univ.) 17 p — N91-14539
CSCL 02C G3/43 — Unclas 0320000

The sites were subjected to various combinations of burning and grazing managements. The ground and helicopter based measurements were taken on the same day or few days from the time of the overpass of Landsat and SPOT satellites. Ground-based reflectance measurements and sun photometer readings taken at the times of the satellite overpasses were used to correct for atmospheric attenuation (Fraser et al, 1989). A Hand-held radiometer was used to measure the normalized difference. These spectral indices were strongly correlated with helicopter and satellite based values (r=0.94 for helicopter, 0.93 for Landsat Thematic Mapper, and 0.86 for SPOT). However the ground, the helicopter and the satellite based normalized difference spectral vegetation indices showed low sensitivity to changes in F_{ipar}. Spectral measurements were only moderately well correlated with measurements of F_{ipar} (r=0.82 for hand-held radiometer, 0.84 for helicopter measurements, and 0.75 for Landsat TM and for SPOT). Improved spectral indices which can compensate for site differences are needed in order to monitor F_{ipar} more reliably.

Introduction

There is interest in the measurement of the fraction, F_{ipar} of photosynthetically active radiation (PAR) intercepted by vegetation canopies for estimating vegetation biomass production (Daughtry et al 1983), and indirectly for modeling land-atmosphere energy and mass exchange (Sellers et al 1986)

F_{ipar} can be measured on the ground by measuring PAR above and below the canopy. However, in order to use satellite data for the study of land surface-atmosphere interactions, or to be able to monitor vegetation productivity over large areas, it is necessary to relate such ground measurements to satellite measurements. Previous studies (e.g. Asrar et al, 1984) have shown that F_{ipar} is well correlated with ground based spectral reflectance measurements of the vegetation canopy. The purpose of this experiment was to compare concurrent measurements of F_{ipar} with near-ground and satellite spectral measurements over prairie vegetation subjected to different burning and grazing managements.

Materials and Methods

This study was conducted during the summer of 1989 and was located on and around the Konza Prairie Natural Research Area about 10km south of Manhattan, Kansas ($39^0 9'$N, $96^0 40'$W). The experiment was an integral part of a large international experiment - the First ISLSCP* Field Experiment (FIFE) which is supported by NASA (Sellers et al, 1988). Thirteen sites were selected within a 15x15km area, and each site was marked out in the form of a 100^0 sector of a circle of radius of 100m (WAB, site area of $8726m^2$). The most likely wind direction in this area is a south-south-westerly (190^0). The sites were orientated such that the radials bisecting the 100^0 sectors pointed to the 190^0 compass bearing. Various energy and mass flux measuring instruments were located at the apex of each site so that the flux measuring instruments were generally down-wind of the study area where

* International Satellite Land Surface Climatology Project.

various biophysical measurements were taken.

The sites were subjected to various combinations of burning and grazing treatments. Burning on the prairie is usually done in spring (about late April) to promote new growth of high quality feed and increase productivity of the tall-grass prairie. Full details of the exact locations of the 13 sites and the management treatments imposed on them are given in the FIFE experiment plan (Sellers and Hall, 1989). The prairie is dominated by three C_4 species of grass, Big Bluestem (Andropogon gerardii Vitmin), Little Bluestem (Andropogon scoparius Michx) and Indiangrass (Sorghastrum mutan L. Nash). There are also substantial proportions of various small C_3 shrubs. The soils at the sites were predominantly silty loams or silty clay loams and ranged in color from dark gray (Munsell color chart, 10YR 4/1) when dry to almost black (Munsell color chart, 10YR 2/1) when moist.

Near-ground measurements of spectral reflectance, and direct measurements of F_{ipar} were taken mostly within the 100^0 sectors. These areas were important because they contributed most to the fluxes sensed by instruments at the apexes of the sites (see FIFE experiment plan, Sellers and Hall, 1989). Measurements were usually taken within 2-3 hours of solar noon.

Two replicate measurements of F_{ipar}, about 10-20cm apart were taken usually at 25 to 50 locations within the WAB area of each site. Ground-based measurements of spectral reflectance were taken at the locations where F_{ipar} measurements were taken and also at

25 to 50 additional locations per site. Two replicate measurements 10-20cm apart were taken at each location within the sites. Prairie vegetation is inherently variable and a large number of measurements are necessary to obtain a reliable mean value. By averaging values over the WAB, comparisons could be made with Landsat data which give an average value over a 30x30m pixel, as well as SPOT data, which have a pixel size of 20x20m in the bands used for this study. A few measurements were also taken just outside of these areas but within 50m of the apex of the site.

F_{ipar} measurements were taken using a hemispherically viewing point PAR quantum sensor (Model LI-190SB, LI-COR Inc.) and a 50cm long line PAR quantum sensor. The line PAR quantum sensor was built from approximately 100 GaAsP photodiodes (CP-1511C, from Centronic Inc.) connected in parallel. The array of diodes was mounted in a 0.9 x 0.9cm x 50cm long aluminum bar. The window of the line quantum sensor was covered with 1.6mm thick white Plexiglas to act as a diffuser. The point quantum sensor was supported above the vegetation canopy and was used for monitoring the incoming PAR. The transmitted PAR was measured using the line quantum sensor which was slid into the base of the canopy. Both sensors were leveled before simultaneously recording their outputs on a data logger (Omnidata Polycorder). All the readings for a particular site were combined for calculating the mean value for F_{ipar}, for a particular day.

Ground-based spectral reflectance measurements were taken with a hand-held four channel band-pass radiometer (Exotech Inc. , model

100AX) with a 15^0 field of view (FOV). The instrument was fitted with filters to match the spectral bands 1 to 4 on the Landsat Thematic Mapper (TM). Reflectance readings were taken with the radiometer looking vertically down from a height of about 1.25m above the canopy. All four channels were logged simultaneously on a data logger (Omnidata Polycorder). The signal from the vegetation was referenced against a barium sulfate panel. All the readings for a particular site were combined for calculating the mean reflectance value for a particular day. The helicopter based spectral reflectance measurements were taken with an eight channel band-pass radiometer (Barnes Engng. Co., Multi-band Modular Radiometer). The instrument was filtered to match the spectral bands of Landsat TM. It had an instantaneous field of view of 1^0 and was operated from a height of about 300m. A minimum of 25 measurements within the WAB were averaged to obtain a mean value for a particular site. Reflected signals were referenced against a barium sulfate standard panel.

Satellite spectral data for Landsat TM bands 3 & 4 (wavebands 0.622-0.699μm, and 0.771-0.905μm) and for SPOT bands 2 & 3 wavebands 0.615-0.658μm and 0.773-0.865μm), for the FIFE sites, were obtained from the FIFE Information System (FIS) data base (Sellers and Hall, 1989). Radiometric corrections and geometric corrections using ground control points were applied by FIS staff. FIS staff also corrected the satellite signals for atmospheric attenuation using the algorithm of Fraser et al, (1989) and sun photometer measurements taken over the FIFE area at the time of the satellite overpass. Suitable satellite spectral data for this study were available for August 4 and 9. Landsat-5 and SPOT satellites overpassed the FIFE area on August 4. On this day SPOT overpassed at an off-nadir view-angle of 18 degrees and sun photometer readings indicated relatively low and stable values for aerosol optical thickness (Halthore et al, 1990). On August 9, only SPOT data at 24 degrees off nadir were available.

It was not possible to take all the ground and helicopter based measurements at all thirteen sites on the same day as the satellite overpass. However since the prairie vegetation does not change greatly over about a 4 day period, ground and helicopter based measurements which were taken up to 4 days from the date of the satellite overpass were used as 'ground truth' data.

Results and discussion

In this discussion we examine the relationship between ground, helicopter, and satellite based normalized difference (ND) spectral vegetation index and F_{ipar}. The normalized difference is given by:

$$ND=(IR-R)/(IR+R)$$

where IR and R are the reflectances in the near-infrared and red wavelength bands (which are bands 3 and 4 of the Landsat TM and bands 2 and 3 of SPOT). The radiation transport model of Shultis and Myneni (1988) shows that ND has a near-linear relationship to F_{ipar} which does not appear to be strongly influenced by variations in canopy geometry (Kanemasu et al, 1990). A weakness with the use of ND for monitoring F_{ipar} is that the relationship between ND and F_{ipar} does show some sensitivity to soil background variations (Kanemasu et al, 1990). However, soil background variation is a major problem with most broad-band spectral indices. Fig. 1 shows ground-based ND measurements against F_{ipar} measurement. All ground-based measurements collected during the experiment are shown here. These include ground measurements for which there were no corresponding satellite data available. Each point on the graph is the average of 25 to 50 ND and F_{ipar} values for one site for one particular day. Additional spectral reflectance measurements at locations for which no corresponding F_{ipar} measurements were taken were excluded when calculating site averages for this graph. Least squares linear regressions showed a slope of 0.46 for the burned sites and a slope of 0.32 for the unburned sites. The intercept was 0.31 for the burned sites and o.39 for the unburned sites, which is consistent with the organic content of these sites. Unburned sites usually had substantial amounts of light-colored dead plant material from previous years covering the soil. Burned sites had very little dead plant matter covering the soil. Variations in the soil background spectral properties cause major difficulties in the interpretation of spectral vegetation indices (Hall et al, 1990). Grazed sites had less biomass, and the type and growth habit of the vegetation appeared to be different on different sites (Nellis and Briggs, 1989). Also on the unburned sites there was sometimes standing dead vegetation. Burned sites had very little dead material standing within the canopy. These site variations were thought to be an important part of the reason why the relationship between ground-based ND and F_{ipar} in Fig. 1, was not as good as may be expected under more uniform soil-backgrounds and vegetation canopies.

In Fig. 2, ND values calculated from helicopter and satellite reflectances are plotted against ground based measurements of ND for August 4 and August 9. About 50 to 100 point measurements per site with the hand-held radiometer were averaged to obtain each ground-based ND value. For the Landsat data correction for atmospheric attenuation is based on regression against the ground-based reflectance measurements, instead of sun photometer readings. The uncorrected Landsat data showed a very high level of correspondence with ground-based reflectance measurements even though there was a bias due to the effects of the atmosphere. Landsat data, which had been corrected for atmospheric attenuation using the sun photometer readings were totally unrelated to ground-based measurements. The reasons for the poor performance of the sun photometer based atmospheric correction of the Landsat data is not known. No problems were encountered with the sun photometer based atmospheric corrections of SPOT data.

Figure 2 shows that helicopter and satellite measurements are strongly correlated with ground-based ND values (r=0.94 for helicopter, 0.93 for Landsat TM and 0.86 for SPOT). Differences between near-ground and satellite measurements can be caused by the effects of the atmosphere, by sampling error when taking point ground measurements, and by differences of solar angle and view angles which when combined with the non-Lambertian behavior of vegetation give different ND values. The ground measurements were taken looking vertically down, usually within two hours of noon. Landsat overpassed at around 11.35 A.M. CDT (viewing the FIFE sites at an angle of about 5^0) and SPOT overpassed at around 12:35 P.M. CDT (viewing the sites at an angle of about 18^0 on August 4 and at about 24^0 on August 9). Our results however show that these problems can be mostly overcome and that satellite measurements can be directly related to spectral measurements taken on or near the ground.

Fig. 3 shows ground, helicopter, and atmospherically corrected satellite based ND values against F_{ipar} measured with the line quantum sensor. Both the near-ground as well as the satellite based ND values show low sensitivity to measurements of F_{ipar}. The near-infrared to red reflectance ratio (IR/R) was also tested. IR/R was more responsive to changes in F_{ipar} but the relationship showed greater scatter and gave slightly lower correlation coefficients than those obtained for ND. Also the satellite measurements of ND are not as strongly correlated with F_{ipar} as are the near-ground ND measurements. One reason for this may be due to the within-site variability of the prairie biomass. Leaf area data from previous measurements on these sites showed that the coefficient of variation within the sites was about 50%. Since we took 25 to 50 point measurements of F_{ipar} per site, the average may be out by about 15 to 20% from the true mean value. About half of the ground-based spectral reflectance measurements and F_{ipar} were taken over the same locations within the sites. Thus within-site variability should not be as important when comparing ground-based ND values to measurements of F_{ipar}. However the satellite measurements were an average of several pixels (usually about 5), so there could be a difference between satellite and ground measurement due to sampling error in the F_{ipar} measurements. Had we taken more measurements of F_{ipar} the sampling error could have been reduced, but as discussed above the major problem with estimation of F_{ipar} using near-ground or satellite spectral measurements is the sensitivity of current spectral indices to soil background and other site variations.

Conclusions

The results show that, satellite spectral reflectance measurements are in good agreement with spectral reflectance measurements taken near the ground. The near-ground and satellite based ND values were only moderately well correlated with measurements of F_{ipar}. This was probably due to differences between burned and unburned sites. Unburned sites frequently had a thick layer of light-colored dead plant material covering the soil. Other differences such as, the spectral properties of the canopy elements (leaves, stems, etc.), and canopy architecture could also be important. Better spectral indices which can compensate for such site differences are needed in order to improve the reliability of spectral estimates of F_{ipar}. Satellite ND measurements were slightly less well correlated to F_{ipar} than near-ground ND values. This may be due to incomplete correction for atmospheric effects, to differences of solar angle and view zenith angle at the time of the ground and satellite measurements or due to the large within-site variability.

Acknowledgements

We thank the FIFE Information System (FIS) staff at NASA GSFC for processing the satellite data, and Dale Reed for the maintenance and repair of electronic equipment. This work was financed by a grant from NASA under contract NAG5-389.

References

Asrar, G. Fuchs, M. Kanemasu, E.T. and Hatfield, J.L. 1984. Estimating absorbed photosynthetic radiation and leaf area index from spectral reflectance in wheat. Agron. Journ. 76:300-306.

Fraser, R.S.; Ferrari, R.A; Kaufman, Y.J.; and Mottoo, S. 1989. Algorithm for atmospheric correction of aircraft and satellite imagery. NASA Technical Publication 100751.

Daughtry, C.S.T. Gallo, K.P. and Bauer, M.E. 1983. Spectral estimates of solar radiation intercepted by corn canopies. Agron. Journ. 75:527-531.

Hall, F.G. Huemmrich, K.F. and Goward, S.N. 1990. Use of narrow-band spectra to estimate the fraction of absorbed photosynthetically active radiation. Rem sensing Environ.

Halthore, R.N. Brugge, C.J. and Markham, B.L. 1990, Aerosol optical thickness measurements during FIFE'89. AMS Symposium on the First ISLSCP Field Experiment (FIFE) p121-125. Feb 7-9, 1990, Anaheim Calif. American Meteor. Soc. Boston, Massachusetts.

Kanemasu, E.T. Demetriades-Shah, T.H. Su, H. and Lang A.R.G. 1990. Estimating grassland biomass using remotely sensed data. In Applications of Remote Sensing in Agriculture. Edited by M.D. Steven and J.A. Clark. Butterworths, London.

Nellis, M.D. and Briggs, J.M. 1989. The effects of spatial scale on Konza landscape classification using textural analysis. Landscape Ecology 2:93-100.

Sellers, P.J. and Hall, F.G. 1989. FIFE 1989 Experiment Plan. NASA GSFC, Greenbelt, MD.

Sellers, P.J. Hall, F.G. Asrar, G. Strebel, D.E. and Murphy, R.E. 1988. The First ISLSCP Field Experiment (FIFE). Bulletin of the Amer. Meteor. Soc. 69:22-27.

Sellers, P.J. Mintz, Y. Sud, Y. and Dalcher, A. 1986. A simple biosphere model (SiB) for use within general circulation models. J. Atmos. Sci. 43:505-531.

List of Figures

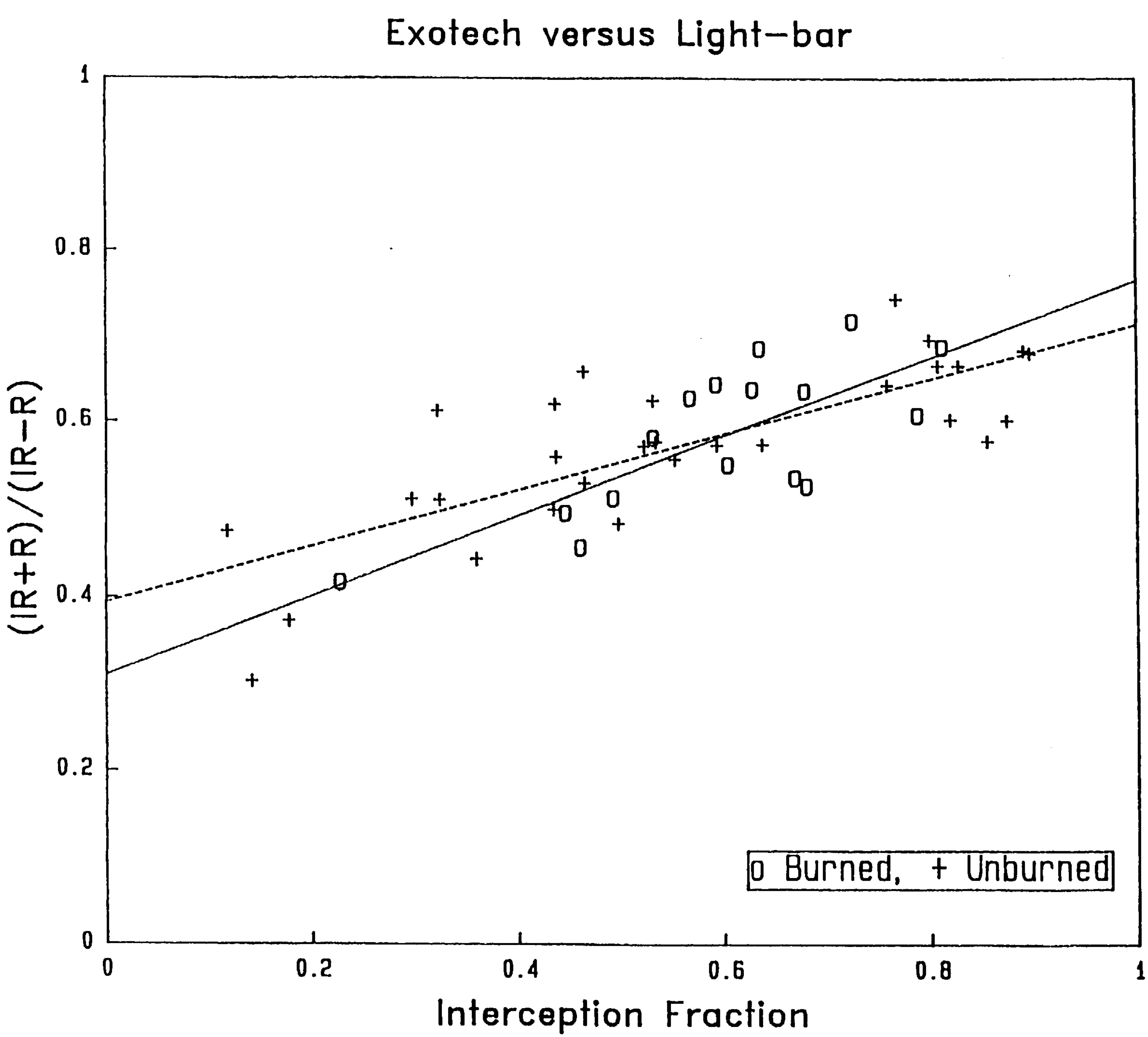
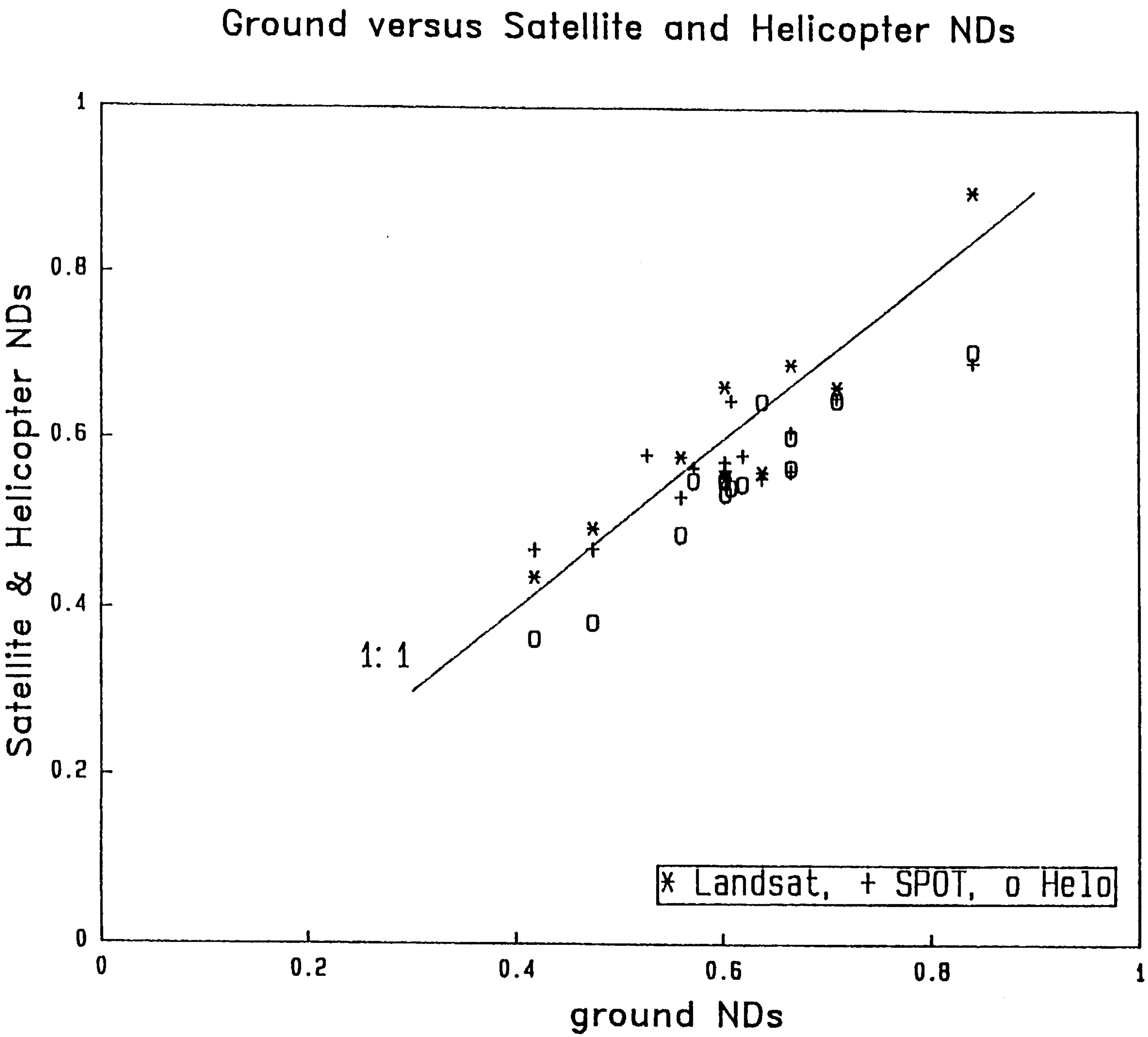

Exotech versus Light-bar
(IR+R)/(IR-R)
Interception Fraction
o Burned, + Unburned
0
0.2
0.4
0.6
0.8
1

Fig. 1



Ground versus Satellite and Helicopter NDs
Satellite & Helicopter NDs
ground NDs
1: 1
* Landsat, + SPOT, o Helo
0
0.2
0.4
0.6
0.8
1

Fig 2.

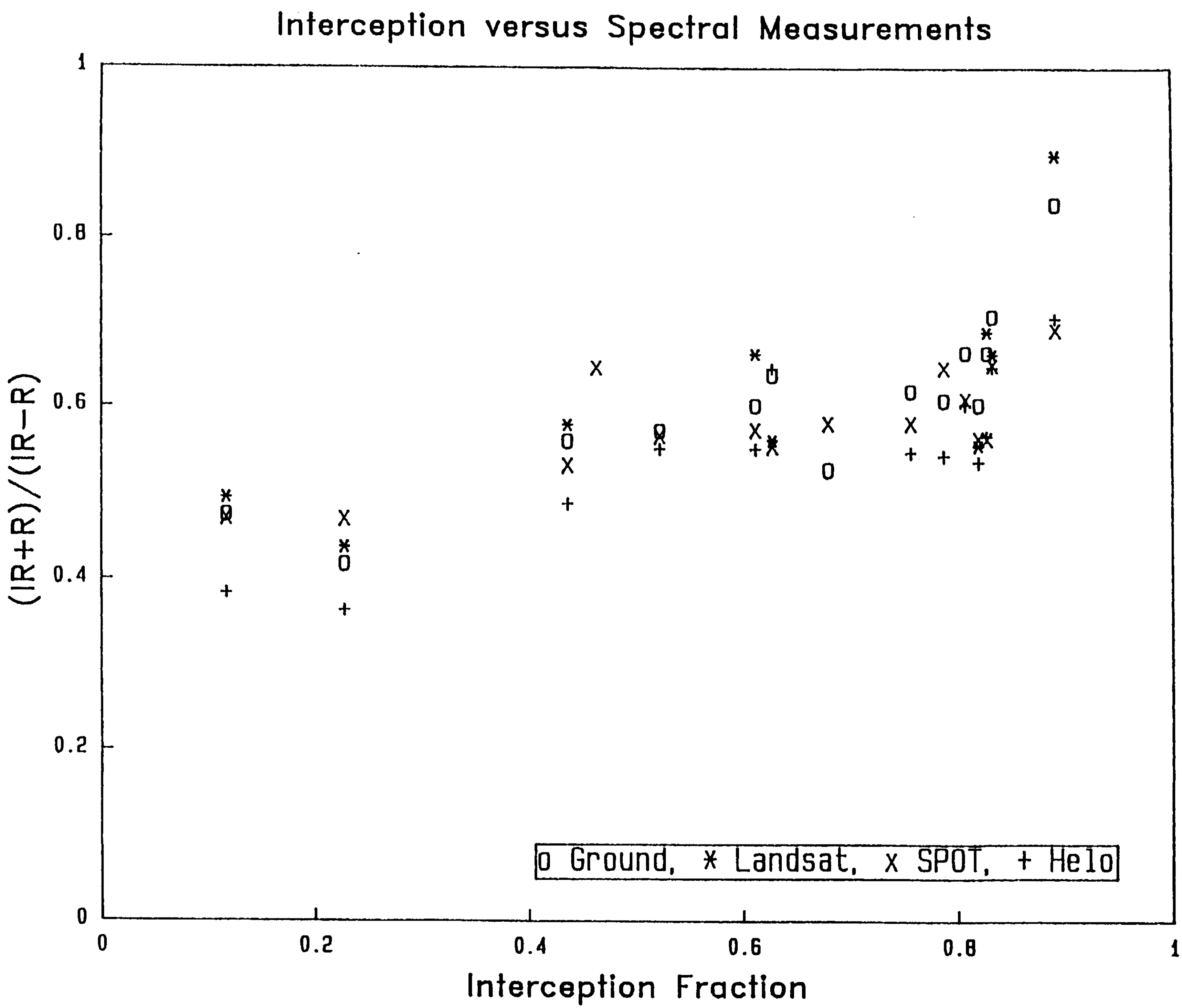

Interception versus Spectral Measurements
(IR+R)/(IR−R)
Interception Fraction
o Ground, * Landsat, x SPOT, + Helo
0
0.2
0.4
0.6
0.8
1

Fig 2