08:45:24 OCA PAD AMENDMENT - PROJECT HEADER INFORMATION 01/23/92

Active

Project #: G-35-618 Cost share #: Rev #: 1
Center # : 10/24-6-R7308-0A0 Center shr #: OCA file #:
Work type : RES
Contract#: NA16RC0448-01 Mod #: BUD REV 920115 Document : GRANT
Prime #: Contract entity: GTRC

Subprojects ? : N CFDA: 11.431
Main project #: PE #:

Project unit: E & A SCI Unit code: 02.010.140
Project director(s):
JUSTUS C G E & A SCI (404)894-3890

Sponsor/division names: US DEPT OF COMMERCE / NATL OCEAN & ATMOS ADM
Sponsor/division codes: 110 / 004

Award period: 910901 to 920831 (performance) 921130 (reports)

Sponsor amount	New this change	Total to date
Contract value	0.00	60,000.00
Funded	0.00	60,000.00
Cost sharing amount		0.00

Does subcontracting plan apply ?: N

Title: CLIMATE RELATED MEASUREMENTS WITH NEW 1.6 UM AVHRR CHANNEL

PROJECT ADMINISTRATION DATA

OCA contact: Brian J. Lindberg 894-4820

Sponsor technical contact	Sponsor issuing office
DAVID GOODRICH (301)427-2474	DEWAYNE K. WYNN (301)427-2922
U.S. DEPARTMENT OF COMMERCE, NOAA OFFICE OF GLOBAL PROGRAMS, R/OGP 1335 EAST WEST HWY, 4TH FLOOR, SSMC1 SILVER SPRING, MD 20910	U.S. DEPARTMENT OF COMMERCE, NOAA GRANTS OPERATIONS BRANCH,ATTN: OA321 1325 EAST WEST HWY, ROOM 5410, SSMC2 SILVER SPRING, MD 20910

Security class (U,C,S,TS) : U ONR resident rep. is ACO (Y/N): N
Defense priority rating : N/A N/A supplemental sheet
Equipment title vests with: Sponsor GIT X

Administrative comments -
BUDGET REVISION TO PURCHASE COMPUTER AS APPROVED BY SPONSOR IN LETTER DATED 12/17/91.

SR0243

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| Project Number G-35-618                            Doc Header Id 31319          |
| Project Title CLIMATE RELATED MEASUREMENTS WITH NEW 1.      Status T            |
| Award Period: From 01-SEP-1991  To 31-AUG-1993                                  |
| PDPI JUSTUS               CARL           Sponsor US DEPT OF COMMERCE/NATL OCE |
| Contract No NA16RC0448-01                                                       |
| Prime Contract No                                                               |
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| OCA File No 02.110.004.92.006                        BOA No                     |
| Security Class U          Unclassified                                          |
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Title of the project.
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GTA

G35-618
#1

CLIMATE RELATED MEASUREMENTS WITH THE NEW 1.6 μm AVHRR CHANNEL

C. G. Justus, Principal Investigator

School of Earth and Atmospheric Sciences

Georgia Institute of Technology

Atlanta, GA 30332-0340

October, 1991

QUARTERLY PERFORMANCE REPORT

Report Period: September 1, 1991 - September 30, 1991

PREPARED FOR THE

UNITED STATES DEPARTMENT OF COMMERCE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Under Grant No. NA16RC0448-01

Dr. Arnold Gruber, Technical Monitor

Georgia Tech Project G-35-618

PROGRESS TO DATE

Activity during the first reporting period concentrated in two areas: (1) converting all satellite simulation programs and data bases to our new RS/6000 workstation system, and (2) doing a literature survey for papers on data analysis or model studies applicable to the interpretation of 1.6 μm signals from either Landsat Thematic Mapper or NOAA KLM/AVHRR.

Program converted to the RS/6000 system include: **SATSIM**, the spectral radiative transfer model to simulate signals from scanning sensors on polar orbiting satellites (e.g. Landsat or AVHRR sensors); **GOESIM**, a program similar to SATSIM which simulates the time variation of signals from sensors on geostationary satellites; **SPECTRL**, a spectral radiative transfer model to simulate shortwave or longwave irradiances at the top and bottom of a cloudless atmosphere; **CIE**, a special version of SPECTRL developed for the International Commission on Illumination, for computing solar spectral irradiances; and **SPECLD**, a spectral radiative transfer model to simulate shortwave irradiances at the top and bottom of an atmosphere with uniform cloud layer.

Data files converted to the RS/6000 system for use in these programs include: spectral albedo files for a variety of surfaces, spectral filter files for a variety of sensors, surface bidirectional reflectance files at several wavelengths for a variety of surfaces, and the spectral absorption coefficient files for the UV spectrum (250 - 400 nm), the solar spectrum (0.3 - 4 μm) and thermal IR spectrum (3 - 60 μm).

In addition to references already given in the project proposal, additional relevant papers were identified, and are listed in the references section below.

PLANS FOR THE COMING PERIOD

Model simulation studies will begin for assessing the response characteristics of the AVHRR 1.6 μm channel under a variety of atmospheric, surface and cloud conditions.

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G 35-618
#2

CLIMATE RELATED MEASUREMENTS WITH THE NEW 1.6 μm AVHRR CHANNEL

C. G. Justus, Principal Investigator

School of Earth and Atmospheric Sciences

Georgia Institute of Technology

Atlanta, GA 30332

January, 1992

QUARTERLY PERFORMANCE REPORT

Report Period: October 1, 1991 - December 31, 1991

PREPARED FOR THE

UNITED STATES DEPARTMENT OF COMMERCE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Under Grant No. NA16RC0448-01

Dr. Arnold Gruber, Technical Monitor

Georgia Tech Project G-35-618

PROGRESS TO DATE

In addition to spectral model studies to develop potential algorithms for working with the 1.6 μm AVHRR channel (to measure such properties as vegetation moisture, soil moisture, cloud ice/water phase, cloud-cover/snow-cover discrimination, etc.), it is planned that a limited number of scenes of Landsat Thematic Mapper (TM) data will be obtained and analyzed. TM has a 1.6 μm band similar to that being planned for AVHRR.

The EROS Data Center coordinates an archive of Federally Owned Landsat Data (FOLD), from which data can be obtained by Federal agencies (and Federal contractors), at reproduction costs (typically about $100 per tape). A complete catalog of the FOLD archive has been obtained and scanned for appropriate TM scenes that could be used in this study. The FOLD archive contains a total of 326 scenes of TM data from Landsats 4 and 5. Of these, a total of 57 scenes have been selected as possible candidates for use in this study, as given in Table 1. These scenes span a wide range of seasons, locations and cloud fractions. Emphasis in the selection of candidate scenes was placed on availability of multiple scenes from the same location, to assess differences that occur in the 1.6 μm signal under different atmospheric and/or surface conditions.

As shown in Table 1, all but two of the candidate scenes are on data tapes resident at NASA Goddard. Contacts will be initiated there with

Mr. Locke Stuart
Landsat Science Office
NASA/GSFC Code 920
Greenbelt, MD 20771
FTS 888-5411

to determine details of availability of the candidate data as well as possible auxiliary field measurements that might have been collected. For the two USGS candidate scenes, the contacts are

USGS/EDC:

Mr. Paul Severson
Customer Services Section
EROS Data Center
Sioux Falls, SD 57198
FTS 753-7507

USGS/ISD:

Ms. Lynda Bellisime
Information Systems Division
U.S. Geological Survey
2255 N. Gemini Drive
Flagstaff, AZ 86001
FTS 765-7105

Final decisions about how many of these sets to request (through the NOAA Grant Monitor's office) will be made after complete details have been obtained from these contact people.

Table 1

List of Candidate Landsat Thematic Mapper Scenes from the Federally Owned Landsat Data (FOLD) Archives

Scene ID	Path	Row	Date	CC%	Latitude	Longitude	Location	Quads
Y5001315045X0	14	34	03/14/84	20%	N 372400	W 751700	NASA	Q1-Q4
Y5012415091X0	14	34	07/03/84	20%	N 372900	W 754600	NASA	Q1-Q2
Y5014015093X0	14	34	07/19/84	0%	N 372900	W 754700	USGS/EDC	Q1-Q4
Y4003815102X0	14	42	08/23/82	50%	N 255900	W 784900	NASA	Q1-Q4
Y4018215123X0	14	42	01/14/83	40%	N 260000	W 785400	NASA	Q1-Q4
Y4019815130X0	14	42	01/30/83	20%	N 260000	W 785500	NASA	Q1-Q4
Y5004415110X0	14	42	04/14/84	20%	N 260000	W 785200	NASA	Q1-Q4
Y5020415135X0	14	42	09/21/84	90%	N 260100	W 790000	NASA	Q1-Q4
Y5028415135X0	14	42	12/10/84	20%	N 255900	W 784900	NASA	Q1-Q4
Y4010915135X0	15	33	11/02/82	10%	N 385300	W 764600	NASA	Q1-Q4
Y5002315112X0	15	33	03/24/84	10%	N 385000	W 763000	NASA	Q1-Q4
Y5009915143X0	15	33	06/08/84	30%	M 385400	W 765400	NASA	Q1-Q4
Y5017915162X0	15	33	08/27/84	10%	N 385500	W 770300	NASA	Q1-Q4
Y5045115163X0	15	33	05/26/85	0%	N 385400	W 765300	NASA	Q1-Q4
Y5056315154X0	15	33	09/15/85	10%	N 385400	W 765400	NASA	Q1-Q4
Y5001115254X0	17	38	03/12/84	10%	N 314200	W 814200	NASA	Q1-Q4
Y5001115260X0	17	39	03/12/84	80%	N 301500	W 820600	NASA	Q1-Q4
Y5021615361X0	18	36	10/03/84	10%	N 343800	W 825200	NASA	Q1-Q4
Y4018515411X0	19	36	01/17/83	0%	N 343700	W 842200	NASA	Q1-Q4
Y5001415443X0	20	33	03/15/84	60%	N 385600	W 844900	NASA	Q1-Q4
Y4060815463X0	20	37	03/15/84	0%	N 331200	W 862200	NASA	Q1-Q4
Y5001415460X0	20	37	03/15/84	0%	N 331300	W 862900	NASA	Q1-Q4
Y5001415463X0	20	38	03/15/84	10%	N 314700	W 865300	NASA	Q1-Q4
Y4060815472X0	20	39	03/15/84	20%	N 301900	W 870800	NASA	Q1-Q4
Y5001415465X0	20	39	03/15/84	40%	N 302000	W 871600	NASA	Q1-Q4
Y5005415465X0	20	39	04/24/84	10%	N 301700	W 865900	NASA	Q1-Q4
Y5001415474X0	20	41	03/15/84	60%	N 272800	W 880000	NASA	Q1-Q4
Y4060916212X0	27	16	03/16/84	10%	N 625200	W 841700	NASA	Q1-Q4
Y5004616324X0	28	30	04/16/84	0%	N 431100	W 953300	NASA	Q1-Q4
Y5015816350X0	28	30	08/06/84	0%	N 431200	W 954100	NASA	Q1-Q4
Y5031816370X0	28	33	01/13/85	0%	N 385400	W 965700	NASA	Q1-Q4
Y5047816365X0	28	33	06/22/85	0%	N 385400	W 970000	NASA	Q1-Q4
Y5054216362X0	28	33	08/25/85	40%	N 385400	W 970000	NASA	Q1-Q4
Y5012917075X0	33	37	07/08/84	10%	N 331100	W 1062100	NASA	Q1-Q4
Y5019317092X0	33	37	09/10/84	10%	N 331200	W 1063000	NASA	Q1-Q4
Y5024117091X0	33	37	10/28/84	10%	N 331100	W 1062200	NASA	Q1-Q4
Y5035317094X0	33	37	02/17/85	0%	N 331100	W 1062100	NASA	Q1-Q4
Y5044917092X0	33	37	05/24/85	10%	N 331100	W 1062100	NASA	Q1-Q4
Y5054517084X0	33	37	08/28/85	20%	N 331100	W 1062300	NASA	Q1-Q4
Y4049018031X0	42	36	11/18/83	40%	N 343700	W 1195000	NASA	Q1-Q4
Y5004818014X0	42	36	04/18/84	10%	N 343700	W 1195000	NASA	Q1-Q4
Y5028818043X0	42	36	12/14/84	0%	N 343600	W 1194900	NASA	Q1-Q4
Y4016818143X0	44	34	12/31/82	20%	N 372800	W 1220400	NASA	Q1-Q4
Y4020018150X0	44	34	02/01/83	30%	N 372900	W 1221000	NASA	Q1-Q4

Table 1 continued

Scene ID	Path	Row	Date	CC%	Latitude	Longitude	Location	Quads
Y4039218150X0	44	34	08/12/83	40%	N 372800	W 1220500	NASA	Q1-Q4
Y4039218152X0	44	34	08/12/83	0%	N 372800	W 1220500	NASA	Q1-Q4
Y5006218131X0	44	34	05/02/84	20%	N 372800	W 1220200	NASA	Q1-Q4
Y5012618143X0	44	34	07/05/84	40%	N 372900	W 1220700	NASA	Q1-Q4
Y5023818160X0	44	34	10/25/84	10%	N 372900	W 1220800	NASA	Q1-Q4
Y5004418231X0	46	28	04/14/84	0%	N 460200	W 1222100	NASA	Q1-Q4
Y5014018245X0	46	28	07/19/84	0%	N 460200	W 1222300	NASA	Q1-Q4
Y5015618252X0	46	28	08/04/84	10%	N 460300	W 1222800	NASA	Q1-Q4
Y5038018262X0	46	28	03/16/85	10%	N 460200	W 1222200	NASA	Q1-Q4
Y5033119570X0	55	116	01/26/85	40%	S 780700	E 1632200	USGS/ISD	Q1-Q4
Y5035903524X0	132	115	02/23/85	50%	S 770300	E 485800	NASA	Q1-Q4
Y5015205150X0	139	216	07/31/84	0%	N 460100	W 1220200	NASA	Q1-Q4
Y5036005161X0	139	216	02/24/85	90%	N 460200	W 1215400	NASA	Q1-Q4

G 35-618
#3

CLIMATE RELATED MEASUREMENTS WITH THE NEW 1.6 μm AVHRR CHANNEL

C. G. Justus, Principal Investigator

School of Earth and Atmospheric Sciences

Georgia Institute of Technology

Atlanta, GA 30332

April, 1992

QUARTERLY PERFORMANCE REPORT

Report Period: January 1, 1992 - March 31, 1992

PREPARED FOR THE

UNITED STATES DEPARTMENT OF COMMERCE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Under Grant No. NA16RC0448-01

Dr. Arnold Gruber, Technical Monitor

Georgia Tech Project G-35-618

The attached summary of project objectives, progress to date and future plans, was prepared and submitted for the NOAA Climate and Global Change Programs Operational Measurements Science Review meeting, scheduled for May 27-28 in Washington, D.C.

Some model studies of the effects of the AVHRR 1.6 μm channel (Channel 3) on vegetation index analysis are presented in Figures 1 and 2. NDVI(x,y) stands for the normalized-difference vegetation index from reflectances measured in channels x and y. Thus

$$\mathrm{NDVI}(1,2) = \frac{R_2 - R_1}{R_2 + R_1}$$

is the usual vegetation index measured by NOAA from the current AVHRR channels 1 and 2. Figure 1 shows that NDVI(2,3) is sensitive to the amount of moisture present in both vegetation and in various soil types. Figure 2 shows that NDVI(1,3) is somewhat more sensitive to soil moisture but is less sensitive to vegetation moisture than is NDVI(2,3).

A listing of several Thematic Mapper (TM) data sets available from NASA Langley Research Center has been obtained. This list along with the one obtained earlier from NASA Goddard is being examined to determine a few TM scenes to order.

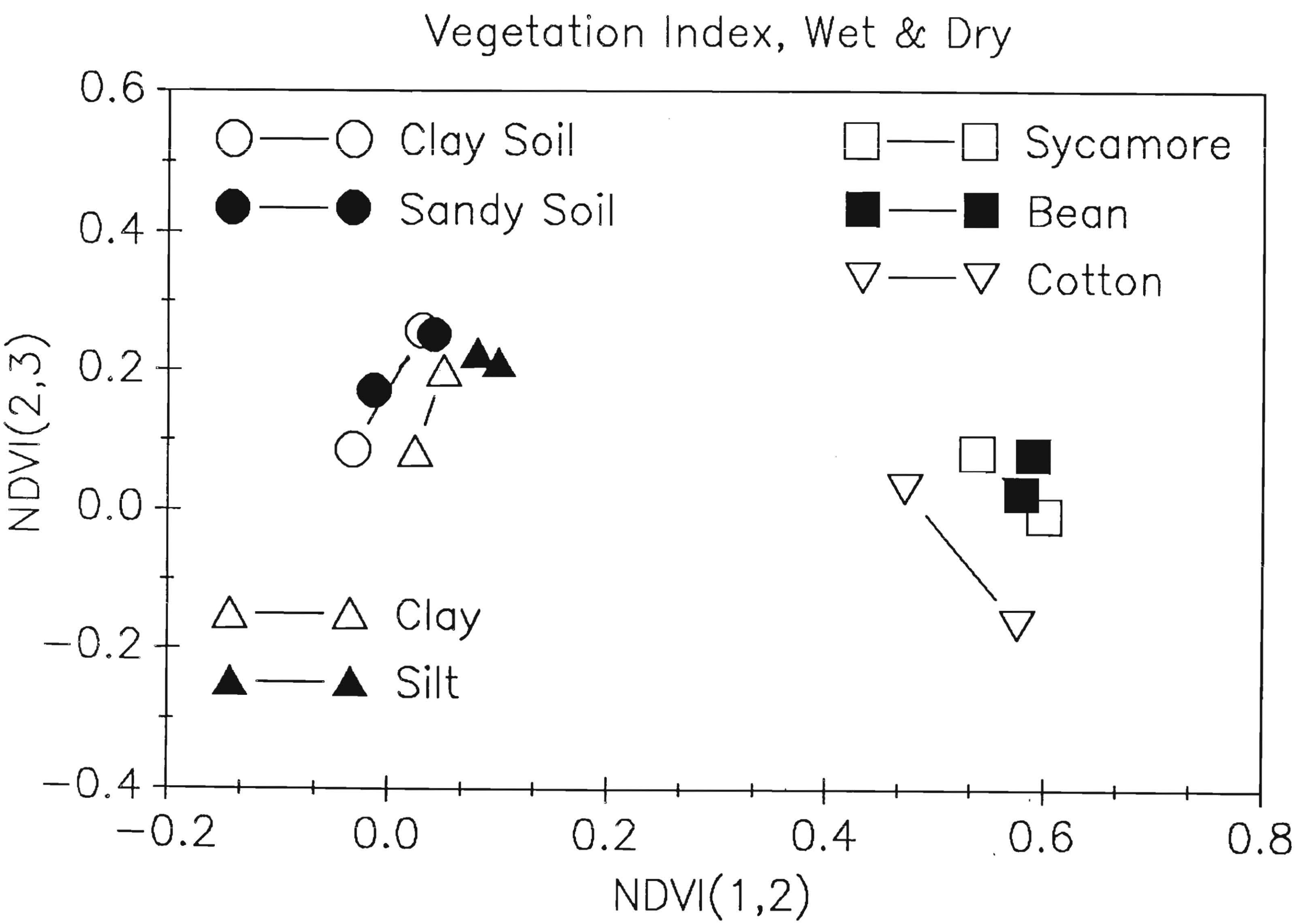
Vegetation Index, Wet & Dry
Clay Soil
Sandy Soil
Sycamore
Bean
Cotton
Clay
Silt
NDVI(2,3)
NDVI(1,2)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.2
0.0
0.2
0.4
0.6
0.8

Figure 1

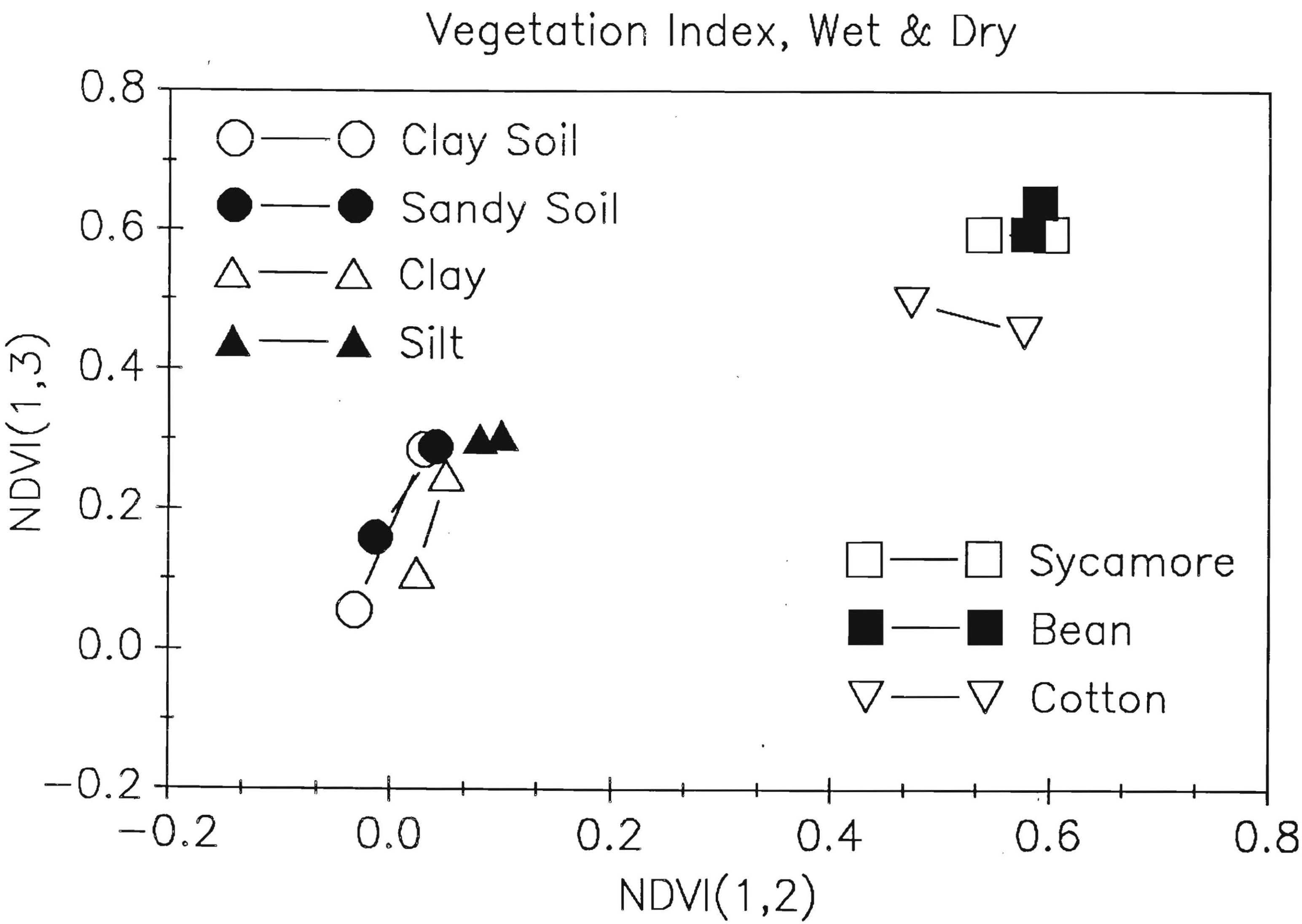
Vegetation Index, Wet & Dry
0.8
0.6
0.4
0.2
0.0
−0.2
NDVI(1,3)
Clay Soil
Sandy Soil
Clay
Silt
Sycamore
Bean
Cotton
−0.2
0.0
0.2
0.4
0.6
0.8
NDVI(1,2)

Figure 2

CLIMATE-RELATED MEASUREMENTS WITH THE NEW 1.6 μm AVHRR CHANNEL

C. G. Justus
Georgia Institute of Technology

LEVEL OF FUNDING: $60,000/year

OBJECTIVES

1. Development and Testing of AVHRR Products Using the New 1.6 μm Channel. Potential applications include improved interpretation for snow and clouds, aerosols, and vegetation and soil moisture.

2. Validation of the New AVHRR Products with the NOAA Global Mapped Data Set. The potential for production of global climate-related data products will be determined.

PROGRESS TO DATE

1. Conversion of Spectral Radiative Transfer Programs to RS/6000 Workstation System. Programs converted include: SATSIM, GOESIM, SPECTRL, SPECLD and CIE.

2. Conversion of Spectral Data Bases to RS/6000 Workstation System. Data bases converted include: spectral albedo files, spectral filter files, surface bidirectional reflectance files, and spectral absorption coefficient files for the UV, solar and thermal IR spectral regions.

3. Literature Review. A bibliography has been prepared from the literature review for papers relevant to measurement, interpretation or modeling of satellite signals at 1.6 μm wavelength.

4. Review of the FOLD Archive. A review of the catalog of the Federally Owned Landsat Data archive was conducted, and several candidate scenes selected for order (at essentially no cost) from the FOLD archives at NASA Goddard.

5. Simulation of AVHRR Products Using the 1.6 μm Channel. The effects of moisture content on several types of vegetation, and of soil moisture, on several soil types have been examined. Normalized-difference vegetation index values using 1.6 μm - visible channel combination are more sensitive to soil moisture. The 1.6 μm - near-IR combination is more sensitive to vegetation moisture.

FUTURE PLANS

1. Continued Model Simulation for Development of 1.6 μm AVHRR Products

2. Analysis of Selected Thematic Mapper 1.6 μm Scenes for Validation of the AVHRR Products

CLIMATE RELATED MEASUREMENTS WITH THE NEW 1.6 μm AVHRR CHANNEL

C. G. Justus, Principal Investigator

School of Earth and Atmospheric Sciences

Georgia Institute of Technology

Atlanta, GA 30332

April, 1992

QUARTERLY PERFORMANCE REPORT

Report Period: January 1, 1992 - March 31, 1992

PREPARED FOR THE

UNITED STATES DEPARTMENT OF COMMERCE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Under Grant No. NA16RC0448-01

Dr. Arnold Gruber, Technical Monitor

Georgia Tech Project G-35-618

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$$\mathrm{NDVI}(1,2) = \frac{R_2 - R_1}{R_2 + R_1}$$

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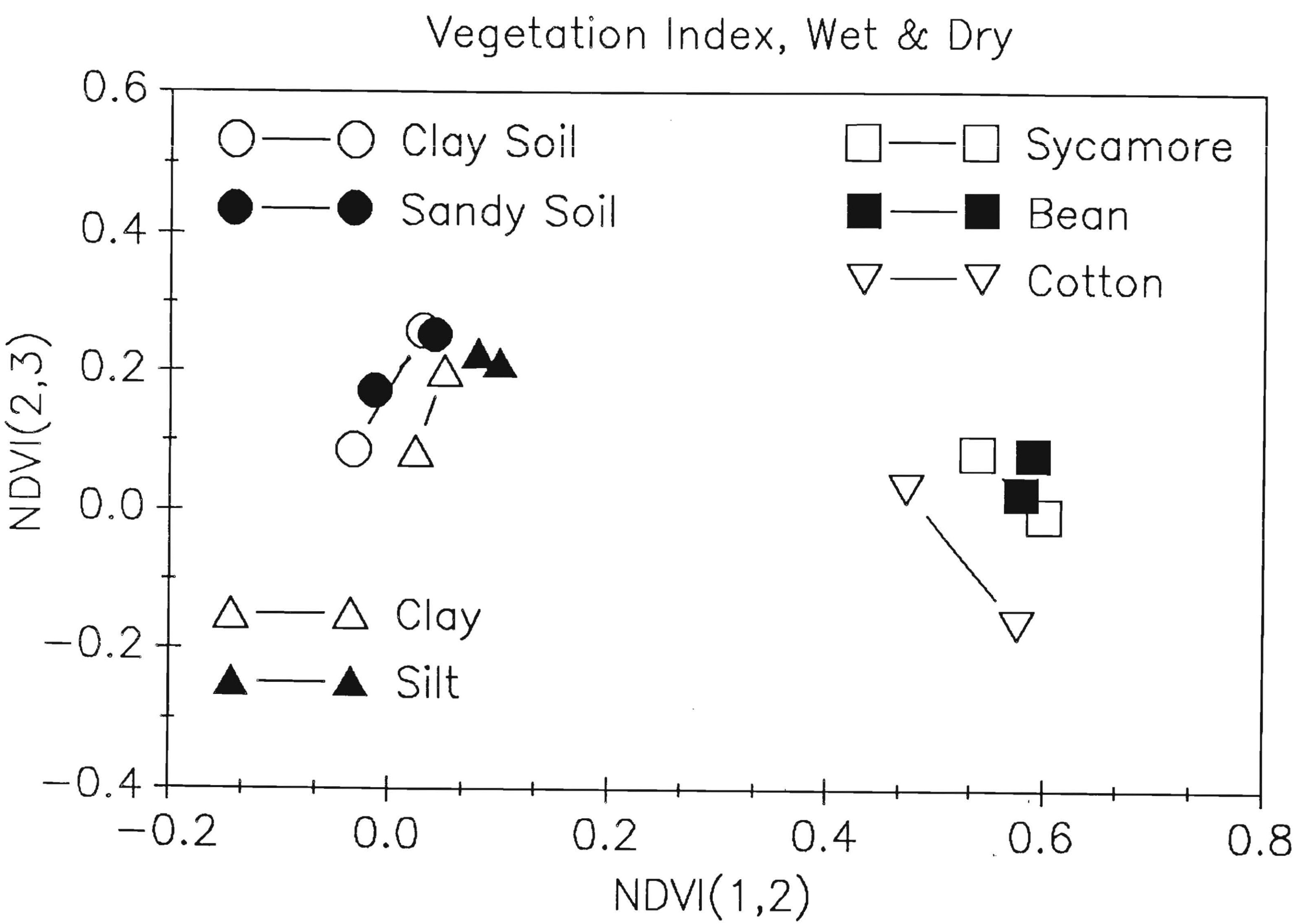

Vegetation Index, Wet & Dry
Clay Soil
Sandy Soil
Sycamore
Bean
Cotton
Clay
Silt
0.6
0.4
0.2
0.0
−0.2
−0.4
NDVI(2,3)
−0.2
0.0
0.2
0.4
0.6
0.8
NDVI(1,2)

Figure 1

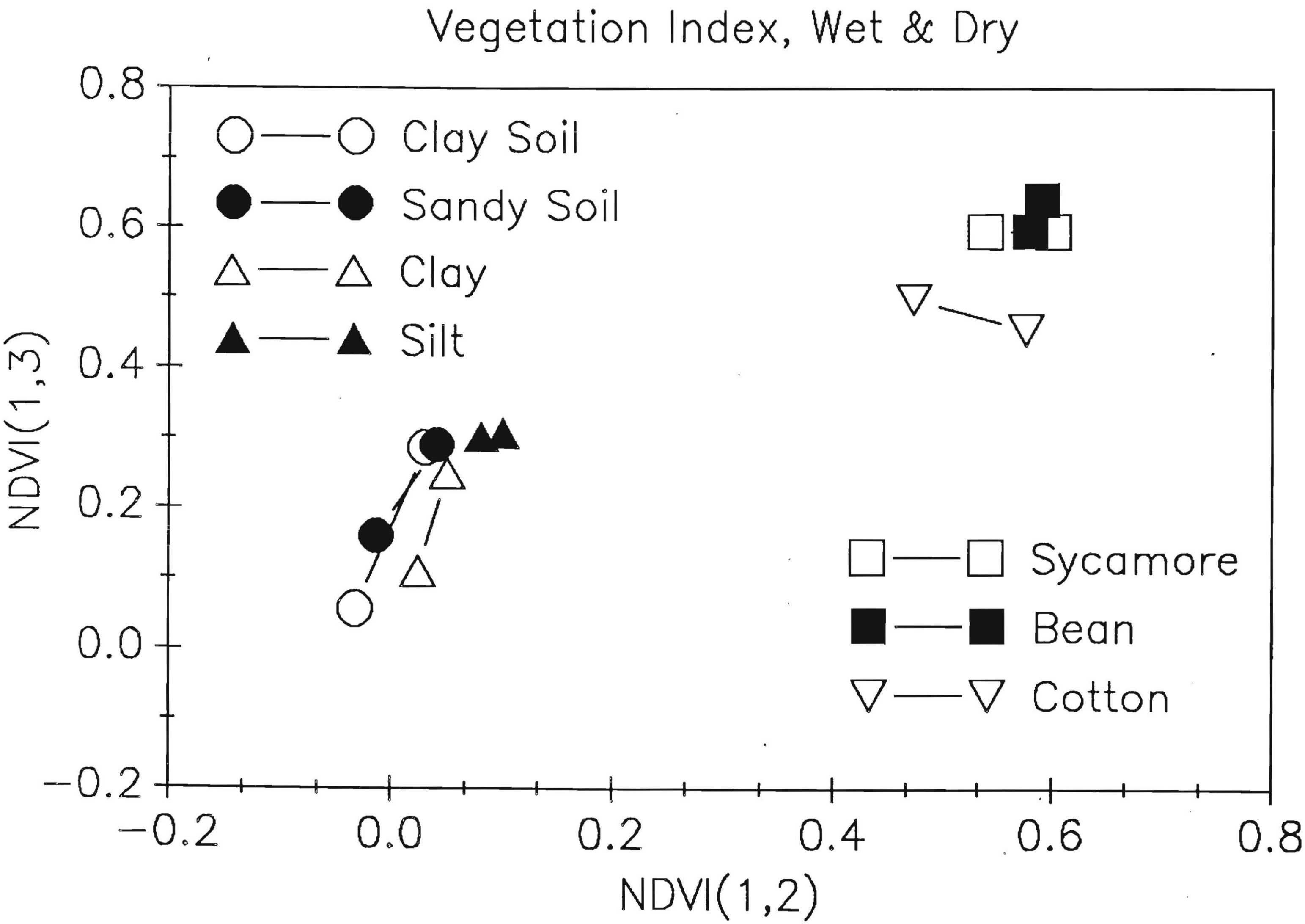
Vegetation Index, Wet & Dry
0.8
0.6
0.4
0.2
0.0
−0.2
NDVI(1,3)
Clay Soil
Sandy Soil
Clay
Silt
Sycamore
Bean
Cotton
−0.2
0.0
0.2
0.4
0.6
0.8
NDVI(1,2)

Figure 2

CLIMATE-RELATED MEASUREMENTS WITH THE NEW 1.6 μm AVHRR CHANNEL

C. G. Justus
Georgia Institute of Technology

LEVEL OF FUNDING: $60,000/year

OBJECTIVES

1. Development and Testing of AVHRR Products Using the New 1.6 μm Channel. Potential applications include improved interpretation for snow and clouds, aerosols, and vegetation and soil moisture.

2. Validation of the New AVHRR Products with the NOAA Global Mapped Data Set. The potential for production of global climate-related data products will be determined.

PROGRESS TO DATE

1. Conversion of Spectral Radiative Transfer Programs to RS/6000 Workstation System. Programs converted include: SATSIM, GOESIM, SPECTRL, SPECLD and CIE.

2. Conversion of Spectral Data Bases to RS/6000 Workstation System. Data bases converted include: spectral albedo files, spectral filter files, surface bidirectional reflectance files, and spectral absorption coefficient files for the UV, solar and thermal IR spectral regions.

3. Literature Review. A bibliography has been prepared from the literature review for papers relevant to measurement, interpretation or modeling of satellite signals at 1.6 μm wavelength.

4. Review of the FOLD Archive. A review of the catalog of the Federally Owned Landsat Data archive was conducted, and several candidate scenes selected for order (at essentially no cost) from the FOLD archives at NASA Goddard.

5. Simulation of AVHRR Products Using the 1.6 μm Channel. The effects of moisture content on several types of vegetation, and of soil moisture, on several soil types have been examined. Normalized-difference vegetation index values using 1.6 μm - visible channel combination are more sensitive to soil moisture. The 1.6 μm - near-IR combination is more sensitive to vegetation moisture.

FUTURE PLANS

1. Continued Model Simulation for Development of 1.6 μm AVHRR Products

2. Analysis of Selected Thematic Mapper 1.6 μm Scenes for Validation of the AVHRR Products

G35-618

#4

CLIMATE RELATED MEASUREMENTS WITH THE NEW 1.6 μm AVHRR CHANNEL

C. G. Justus, Principal Investigator

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July, 1992

QUARTERLY PERFORMANCE REPORT

Report Period: April 1, 1992 - June 30, 1992

PREPARED FOR THE

UNITED STATES DEPARTMENT OF COMMERCE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Under Grant No. NA16RC0448-01

Dr. Arnold Gruber, Technical Monitor

Georgia Tech Project G-35-618

PROGRESS FOR THE QUARTER

At the recent NOAA Climate and Global Change Program Operational Measurement Science Review meeting, it was suggested by Jeff Dozier that additional literature review would yield some relevant early results from the study of Landsat TM. An e-mail request to Dr. Dozier for a bibliography of the reports to which he referred produced the attached response.

This list of references has been scanned and copies of the relevant papers obtained. A preliminary scan of these indicated no specific results on the use of Landsat TM 1.6 μm band for the quantitative estimation of soil moisture or vegetation moisture, two of the primary properties being investigated in this project.

PLANS FOR THE COMING QUARTER

Reports and a CD-ROM data set for the FIFE program have been obtained that includes Landsat TM data in conjunction with surface-based measurements done under the FIFE program. These data will be read and evaluated as a source of ground truth observations for the present study.

Possibilities for obtaining Landsat TM scenes from NASA Langley and from the FOLD archive will continue to be explored. So far, other than the FIFE data set, no Landsat scenes have been identified which have coincident surface-based observations.

Date: Sat, 30 May 92 09:21:52 PDT
From: dozier@crseo.ucsb.edu (Jeff Dozier)
To: justus@eas.gatech.edu
Subject: Re: bibliography

Jere:

I'm signed on at home, so have just scanned your bibliography. Here is a list from me, but there may be many that are already on your list.
Cheers,
Jeff

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G 35-618

#5

CLIMATE RELATED MEASUREMENTS WITH THE NEW 1.6 μm AVHRR CHANNEL

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September, 1992

QUARTERLY PERFORMANCE REPORT

Report Period: July 1, 1992 - August 31, 1992

PREPARED FOR THE

UNITED STATES DEPARTMENT OF COMMERCE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Under Grant No. NA16RC0448-01

Dr. Arnold Gruber, Technical Monitor

Georgia Tech Project G-35-618

Progress to Date

The CD-ROM of the First ISLSCP Field Experiment (FIFE) Collected Data (Strebel et al., 1991) and software were received from the NASA Pilot Land Data System FIFE Information System. Official user status was established by returning the FIFE Information System User Registration form.

Initially some hardware and software problems were encountered with the SONY CD-ROM drive (improper interface software and a CD sensor defect). The drive was returned to SONY for replacement and shipment of the proper interface software.

After proper installation of the replacement CD-ROM drive, the FIFE Collected Data software was installed and scanned. There is one (spatially degraded) Thematic Mapper (TM) scene on the CD, made up of eight bands (including the 1.6 μm band). The TM image contains 512 x 512 pixels. Each pixel is 8 bits. There are also 40 AVHRR-LAC images, one SPOT image and 2 days of NS001 images taken from the NASA C-130 aircraft.

In addition to the satellite image data, a large collection of soil moisture data (e.g. from gamma ray and neutron probe sensors) and other atmospheric and surface parameters are also on the CD.

Plans for the Coming Period

A set of data from the FIFE Collected Data CD will be extracted and compared with spectral model simulations of the expected satellite radiance at 1.6 μm and other wavelengths. Possibilities will continue to be explored for obtaining TM data from the Federally Owned Landsat Data (FOLD) database at NASA Goddard, and from other TM holdings at NASA Langley.

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G 35-618
#6

CLIMATE RELATED MEASUREMENTS WITH THE NEW 1.6 μm AVHRR CHANNEL

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Georgia Institute of Technology

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March, 1993

SEMI-ANNUAL PERFORMANCE REPORT

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Under Grant No. NA16RC0448-01

Dr. Arnold Gruber, Technical Monitor

Georgia Tech Project G-35-676

Progress to Date

A major source of Landsat TM data with ancillary surface measurements has been identified and obtained. This is the First International Land Surface Climatology Project (ISLSCP) Field Experiment (FIFE) data set, available on CD-ROM (Sellers et al 1992) and over Internet with SQL data base query routines.

Preliminary analysis has identified several days and sites with Landsat TM and soil moisture information. Table 1 shows data on reflectances (%) for TM bands 3 (0.6-0.7 µm), 4 (0.7-0.9 µm) and 5 (1.6-1.8 µm). These data will be used as surrogates for NOAA K-L-M AVHRR channels 1 (0.6-0.7 µm), 2 (0.7-1.0 µm) and 3A (1.6 µm) data. Tables 2-4 show examples of FIFE data on average soil moisture at various sites as determined by the gamma ray method, the gravimetric method and the neutron probe method, respectively.

FIFE data such as in Tables 1-4 will be used to study whether normalized-difference vegetation index (NDVI) values based on AVHRR channels 1 and 3A and channels 2 and 3A respond to soil moisture and vegetation moisture as indicated in the model study results shown in Figures 1 and 2 (discussed in earlier reports). It is anticipated that NDVI (1, 3A) and NDVI (2, 3A) algorithms will provide a useful addition to quantitative methods for studying soil moisture and vegetation moisture (Nemani et al, 1993).

Figure 3 shows a good example of potential applications of the 1.6 µm AVHRR band for determination of cloud properties. This is a Landsat TM band 5 image of Hurricane Andrew obtained on August 24, 1992 near Naples, FL (EOSAT, 1992). There are indications that variations in 1.6 µm brightness may be a good discriminator of ice phase versus water phase clouds. Unfortunately the $4400 price to acquire original digital data of this image probably precludes obtaining it for this project.

Plans for the Coming Period

A final report and paper will be prepared giving details of the NDVI (1, 3A) and NDVI (2, 3A) algorithms developed. Although the Principal Investigator, Dr. Justus, will be retiring from Georgia Tech on May 1, he will retain an adjunct/emeritus status and will continue to supervise the work on this project until completion.

References

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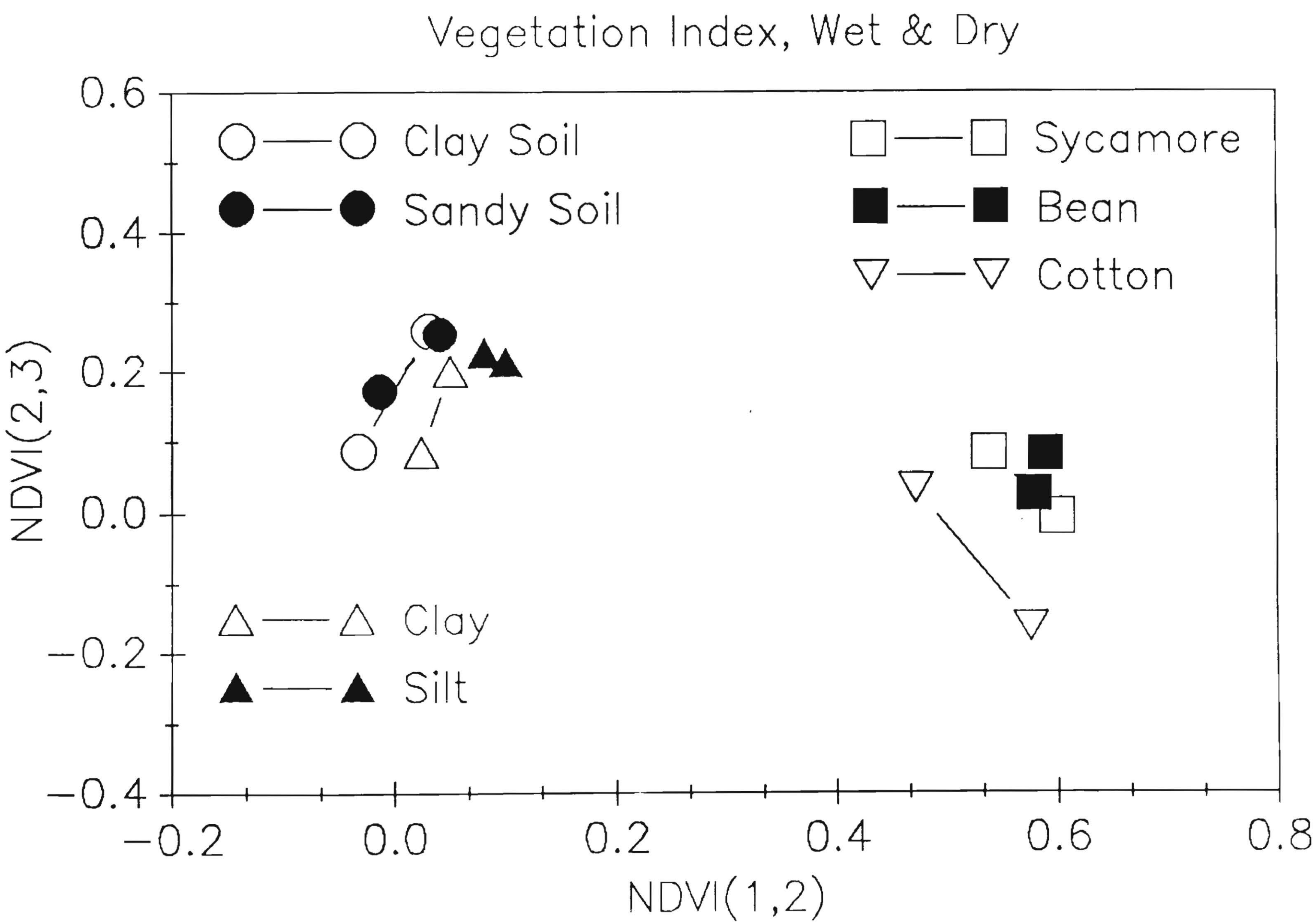
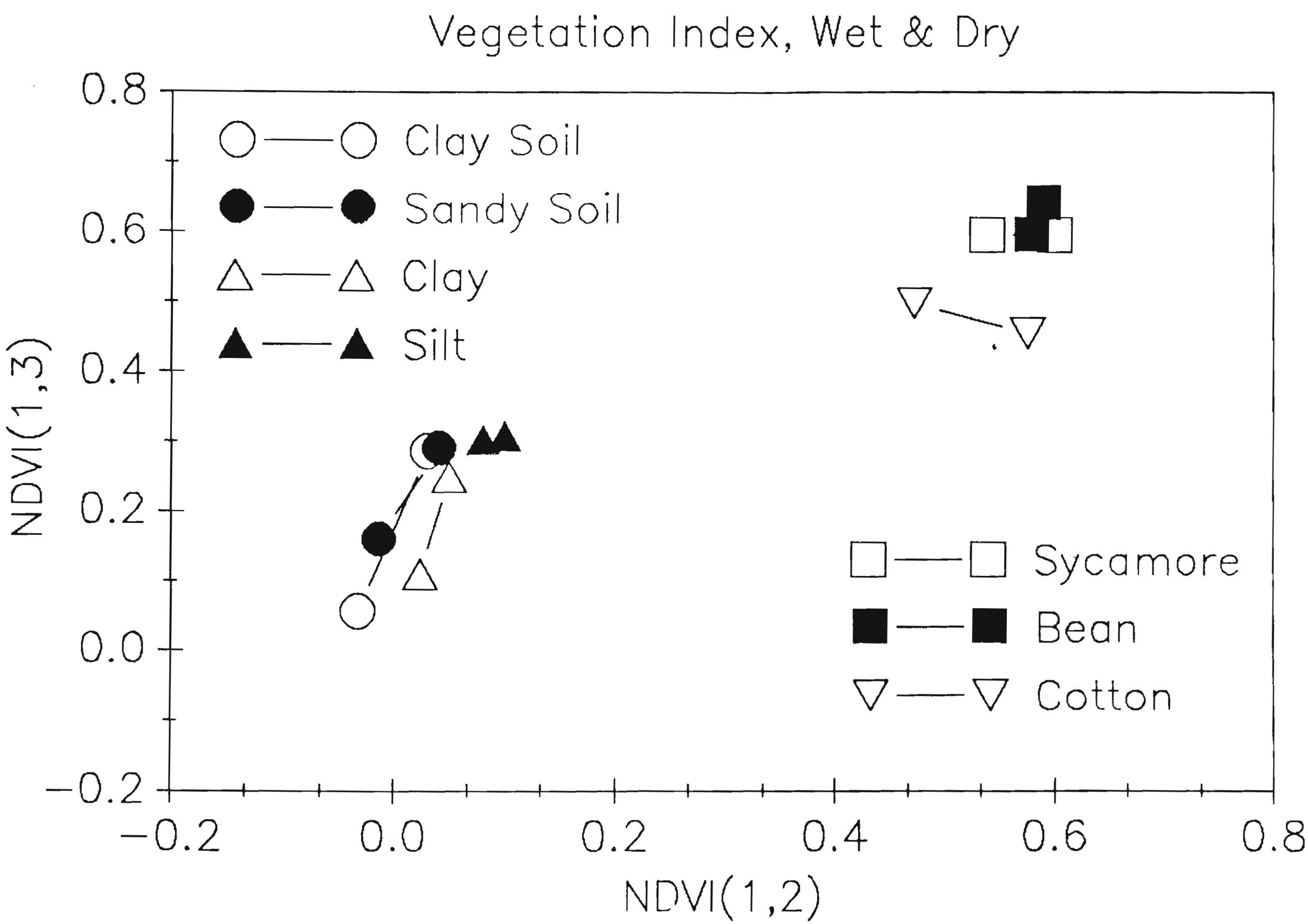


Vegetation Index, Wet & Dry
Clay Soil
Sandy Soil
Sycamore
Bean
Cotton
Clay
Silt
NDVI(2,3)
NDVI(1,2)
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.2
0.0
0.2
0.4
0.6
0.8

Fig. 1



Vegetation Index, Wet & Dry
Clay Soil
Sandy Soil
Clay
Silt
Sycamore
Bean
Cotton
NDVI(1,3)
NDVI(1,2)
0.8
0.6
0.4
0.2
0.0
−0.2
−0.2
0.0
0.2
0.4
0.6
0.8

Fig. 2

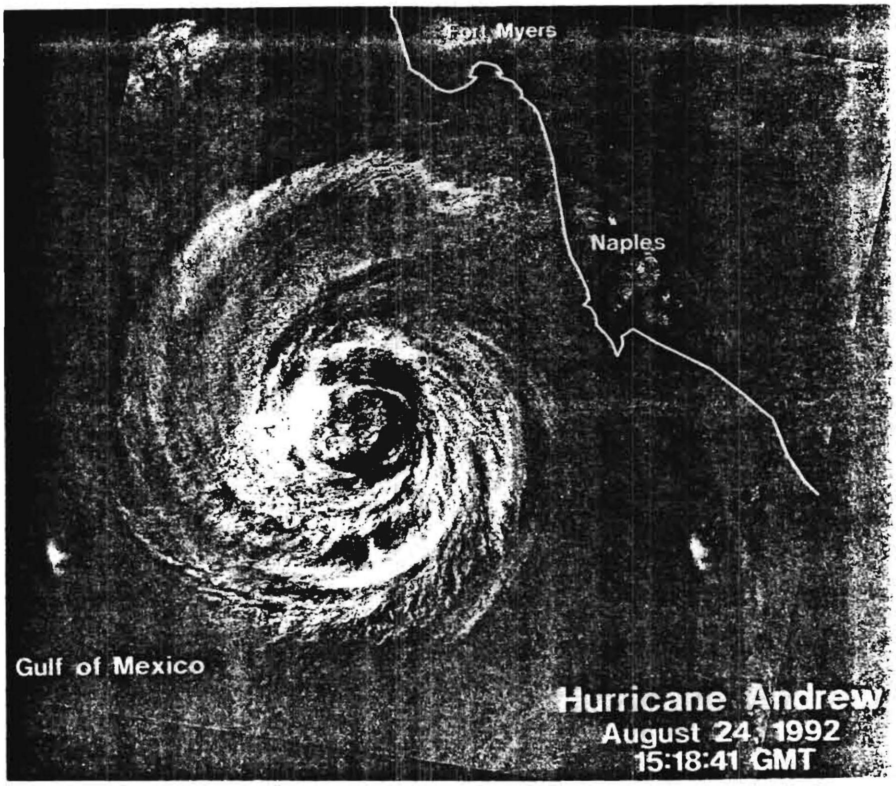

Fort Myers
Naples
Gulf of Mexico
Hurricane Andrew
August 24, 1992
15:18:41 GMT

Fig. 3

Table 1 - Reflectances (%) in TM bands 3, 4 and 5 for various observation dates and station ID's.

OBS_DATE	STATION_ID	EXOATM_REFL3	EXOATM_REFL4	EXOATM_REFL5
09-APR-87	2	14.30	28.60	30.80
09-APR-87	3	14.00	20.00	28.50
09-APR-87	4	6.60	7.10	7.10
09-APR-87	5	14.60	22.70	31.00
09-APR-87	7	13.10	19.10	27.40
09-APR-87	8	5.30	5.20	6.00
09-APR-87	9	16.50	24.70	33.90
09-APR-87	10	5.30	5.90	6.30
09-APR-87	12	10.80	16.50	22.80
09-APR-87	14	10.60	17.20	25.60
09-APR-87	15	10.40	22.60	24.30
09-APR-87	16	15.80	22.40	30.40
09-APR-87	20	14.30	20.90	28.70
09-APR-87	22	15.40	25.10	33.40
09-APR-87	23	15.00	24.30	32.10
09-APR-87	24	12.80	22.40	28.60
09-APR-87	26	13.80	20.90	30.30
09-APR-87	27	12.20	16.70	23.70
09-APR-87	28	14.50	24.70	31.30
09-APR-87	30	16.10	23.40	32.50
09-APR-87	31	14.50	21.60	30.30
09-APR-87	34	14.10	22.40	32.50

09-APR-87	36	12.00	23.80	27.70
09-APR-87	38	13.10	21.60	29.30
09-APR-87	39	15.10	22.60	29.30
09-APR-87	40	17.50	25.20	32.60
09-APR-87	41	13.50	22.00	28.80
09-APR-87	42	15.00	21.60	30.50
09-APR-87	44	11.30	21.10	25.40
09-APR-87	52	15.10	22.40	29.30
09-APR-87	60	14.40	22.50	29.90
09-APR-87	807	14.80	21.60	29.50
09-APR-87	810	15.20	22.40	32.30
09-APR-87	812	12.30	18.30	23.70
09-APR-87	814	14.00	20.50	30.70
09-APR-87	817	15.20	24.50	33.80
09-APR-87	831	12.70	21.90	28.80
09-APR-87	842	13.50	22.70	30.30
09-APR-87	908	13.80	21.30	30.70
09-APR-87	912	5.30	5.20	6.00
09-APR-87	946	11.30	21.10	25.40

OBS_DATE	STATION_ID	EXOATM_REFL3	EXOATM_REFL4	EXOATM_REFL5
11-MAY-87	2	8.50	34.00	20.90
11-MAY-87	3	11.10	22.50	23.80
11-MAY-87	4	8.00	27.50	18.60

11-MAY-87	5	11.10	25.30	25.40
11-MAY-87	7	11.30	24.10	22.80
11-MAY-87	8	8.30	25.90	19.00
11-MAY-87	9	8.00	16.90	18.60
11-MAY-87	10	7.30	25.60	17.70
11-MAY-87	12	7.80	31.80	18.90
11-MAY-87	14	8.20	29.70	18.00
11-MAY-87	15	10.20	20.80	23.00
11-MAY-87	16	7.60	27.60	19.10
11-MAY-87	20	9.10	22.20	19.40
11-MAY-87	22	10.00	29.90	25.10
11-MAY-87	23	8.20	23.20	21.80
11-MAY-87	24	9.30	28.50	24.20
11-MAY-87	26	8.90	28.00	21.60
11-MAY-87	27	8.80	21.00	17.70
11-MAY-87	28	9.10	30.20	21.60
11-MAY-87	30	7.80	23.60	18.90
11-MAY-87	31	11.70	25.70	25.40
11-MAY-87	34	9.40	29.50	21.60
11-MAY-87	36	9.60	30.10	22.40
11-MAY-87	38	10.80	26.70	23.40
11-MAY-87	39	8.60	20.50	20.40
11-MAY-87	40	9.50	23.30	19.00
11-MAY-87	41	8.10	28.30	19.70
11-MAY-87	42	8.00	24.90	18.60

11-MAY-87	44	8.90	28.30	20.40
11-MAY-87	52	8.60	22.80	19.60
11-MAY-87	60	11.80	25.10	24.40
11-MAY-87	807	12.20	24.00	25.30
11-MAY-87	810	13.10	24.20	28.00
11-MAY-87	812	8.80	27.00	19.40
11-MAY-87	814	13.30	25.10	27.10
11-MAY-87	817	10.00	28.40	25.70
11-MAY-87	831	7.80	25.10	18.80
11-MAY-87	842	10.00	25.50	22.70
11-MAY-87	908	9.50	30.70	23.10
11-MAY-87	912	8.30	25.90	19.00
11-MAY-87	946	8.90	28.30	20.40

OBS_DATE	STATION_ID	EXOATM_REFL3	EXOATM_REFL4	EXOATM_REFL5
12-JUN-87	2	6.60	31.20	17.50
12-JUN-87	3	7.70	28.10	19.50
12-JUN-87	4	6.00	39.70	15.70
12-JUN-87	5	6.90	34.00	19.10
12-JUN-87	7	7.80	27.40	19.60
12-JUN-87	8	6.40	35.50	16.10
12-JUN-87	9	6.60	26.50	19.10
12-JUN-87	10	5.90	41.80	16.30
12-JUN-87	12	5.50	37.00	17.70

12-JUN-87	14	6.60	33.80	16.30
12-JUN-87	15	10.20	20.30	24.20
12-JUN-87	16	6.10	36.10	15.90
12-JUN-87	20	6.70	30.30	16.50
12-JUN-87	22	8.10	31.20	21.50
12-JUN-87	23	6.20	35.60	17.20
12-JUN-87	24	8.20	30.80	20.10
12-JUN-87	26	7.40	28.70	19.60
12-JUN-87	27	7.40	23.80	17.80
12-JUN-87	28	6.60	34.00	19.50
12-JUN-87	30	7.80	25.00	19.00
12-JUN-87	31	7.80	32.00	19.90
12-JUN-87	34	7.30	32.70	19.10
12-JUN-87	36	7.70	30.70	19.20
12-JUN-87	38	7.50	30.90	20.00
12-JUN-87	39	7.20	25.40	19.70
12-JUN-87	40	8.10	30.30	19.30
12-JUN-87	41	6.40	32.70	18.20
12-JUN-87	42	6.20	32.30	16.00
12-JUN-87	44	7.80	30.40	17.60
12-JUN-87	52	7.20	30.00	18.00
12-JUN-87	60	7.20	34.50	19.60
12-JUN-87	807	7.40	30.00	20.20
12-JUN-87	810	6.70	33.90	19.50

12-JUN-87	812	7.00	33.00	16.80
12-JUN-87	814	6.60	37.80	18.30
12-JUN-87	817	8.80	28.40	23.00
12-JUN-87	831	8.00	26.80	19.60
12-JUN-87	842	7.70	28.40	20.50
12-JUN-87	908	6.40	38.90	19.10
12-JUN-87	912	6.40	35.50	16.10
12-JUN-87	946	7.80	30.40	17.60

OBS_DATE	STATION_ID	EXOATM_REFL3	EXOATM_REFL4	EXOATM_REFL5
14-JUL-87	2	6.80	29.60	18.90
14-JUL-87	3	7.40	28.00	19.50
14-JUL-87	4	6.50	36.20	16.20
14-JUL-87	5	7.40	31.10	18.90
14-JUL-87	7	7.50	27.90	18.40
14-JUL-87	8	7.10	31.00	16.80
14-JUL-87	9	7.70	26.20	20.00
14-JUL-87	10	7.10	35.80	16.30
14-JUL-87	12	6.40	32.60	16.30
14-JUL-87	14	6.10	32.90	17.30
14-JUL-87	15	13.30	28.60	28.10
14-JUL-87	16	6.40	35.30	15.30
14-JUL-87	20	6.60	31.30	15.30
14-JUL-87	22	8.40	29.00	22.60

14-JUL-87	23	6.60	38.70	16.70
14-JUL-87	24	7.10	34.40	18.40
14-JUL-87	26	7.30	28.00	20.10
14-JUL-87	27	6.50	18.00	11.10
14-JUL-87	28	7.30	35.00	20.20
14-JUL-87	30	8.00	26.60	20.10
14-JUL-87	31	8.20	31.80	20.20
14-JUL-87	34	7.50	30.80	18.80
14-JUL-87	36	8.40	29.40	22.20
14-JUL-87	38	6.30	25.50	14.90
14-JUL-87	39	7.10	27.80	18.60
14-JUL-87	40	9.30	28.90	20.40
14-JUL-87	41	6.80	33.60	17.30
14-JUL-87	42	6.40	32.10	16.40
14-JUL-87	44	7.50	30.70	19.10
14-JUL-87	52	7.50	28.30	19.30
14-JUL-87	60	7.50	32.90	19.80
14-JUL-87	807	7.80	29.30	18.80
14-JUL-87	810	7.30	35.60	19.00
14-JUL-87	812	7.10	30.60	17.10
14-JUL-87	814	7.40	36.80	19.10
14-JUL-87	817	9.00	28.20	23.50
14-JUL-87	831	8.50	26.80	21.40
14-JUL-87	842	7.10	32.10	18.00
14-JUL-87	908	6.60	38.30	18.40

14-JUL-87	912	7.10	31.00	16.80
14-JUL-87	946	7.50	30.60	19.10

OBS_DATE	STATION_ID	EXOATM_REFL3	EXOATM_REFL4	EXOATM_REFL5
15-AUG-87	2	8.30	22.40	22.30
15-AUG-87	3	8.10	26.20	20.30
15-AUG-87	4	7.60	32.20	19.10
15-AUG-87	5	8.90	28.30	22.50
15-AUG-87	7	7.70	22.40	18.60
15-AUG-87	8	7.30	27.90	18.80
15-AUG-87	9	7.70	21.60	18.20
15-AUG-87	10	7.10	28.50	17.30
15-AUG-87	12	6.30	26.10	13.90
15-AUG-87	14	6.20	26.50	16.70
15-AUG-87	15	8.20	22.40	18.80
15-AUG-87	16	7.10	30.70	17.30
15-AUG-87	20	7.50	26.40	16.50
15-AUG-87	22	8.70	25.30	23.30
15-AUG-87	23	7.70	28.50	18.70
15-AUG-87	24	7.60	28.70	19.00
15-AUG-87	26	9.40	23.90	22.80
15-AUG-87	27	7.70	19.10	15.00
15-AUG-87	28	8.60	28.90	22.30
15-AUG-87	30	8.40	22.90	22.00

15-AUG-87	31	8.60	27.60	22.10
15-AUG-87	34	9.60	25.40	23.20
15-AUG-87	36	10.00	23.20	24.30
15-AUG-87	38	7.30	27.80	19.10
15-AUG-87	39	7.20	23.60	17.90
15-AUG-87	40	9.20	24.80	20.30
15-AUG-87	41	7.50	27.40	19.20
15-AUG-87	42	6.80	27.20	17.20
15-AUG-87	44	8.10	26.10	20.30
15-AUG-87	52	7.70	24.20	18.90
15-AUG-87	60	8.70	30.60	22.00
15-AUG-87	807	7.90	29.80	20.90
15-AUG-87	810	8.10	30.20	20.30
15-AUG-87	812	7.90	26.40	18.80
15-AUG-87	814	8.30	30.70	19.90
15-AUG-87	817	9.00	24.50	23.10
15-AUG-87	831	7.20	25.90	18.60
15-AUG-87	842	7.40	28.90	18.00
15-AUG-87	908	7.40	29.20	19.50
15-AUG-87	912	7.30	27.90	18.80
15-AUG-87	946	8.10	26.10	20.30

OBS_DATE	STATION_ID	EXOATM_REFL3	EXOATM_REFL4	EXOATM_REFL5
31-AUG-87	2	7.40	30.40	20.00

31-AUG-87	3	7.60	26.20	19.40
31-AUG-87	4	7.80	30.10	19.00
31-AUG-87	5	8.90	27.10	22.80
31-AUG-87	7	7.30	22.60	17.70
31-AUG-87	8	7.10	28.60	18.90
31-AUG-87	9	7.40	24.90	20.80
31-AUG-87	10	7.00	26.70	17.40
31-AUG-87	12	5.50	27.50	15.10
31-AUG-87	14	6.50	25.70	17.20
31-AUG-87	15	11.40	28.20	26.40
31-AUG-87	16	7.10	29.90	17.00
31-AUG-87	20	6.60	27.10	16.40
31-AUG-87	22	8.10	27.50	22.50
31-AUG-87	23	7.40	30.70	19.20
31-AUG-87	24	7.10	31.00	19.00
31-AUG-87	26	8.10	24.90	22.00
31-AUG-87	27	8.90	21.00	15.90
31-AUG-87	28	8.00	29.20	22.20
31-AUG-87	30	6.70	27.30	20.20
31-AUG-87	31	8.90	26.80	22.80
31-AUG-87	34	10.00	26.00	26.10
31-AUG-87	36	8.80	25.50	24.10
31-AUG-87	38	6.70	31.00	18.10
31-AUG-87	39	7.10	25.40	20.00

31-AUG-87	40	9.10	27.50	22.60
31-AUG-87	41	7.30	28.50	19.30
31-AUG-87	42	7.00	27.00	17.30
31-AUG-87	44	8.00	27.20	20.10
31-AUG-87	52	7.40	25.30	19.40
31-AUG-87	60	8.60	29.70	22.30
31-AUG-87	807	8.10	26.90	20.40
31-AUG-87	810	7.90	27.40	21.50
31-AUG-87	812	7.60	23.20	17.90
31-AUG-87	814	8.70	29.10	20.40
31-AUG-87	817	8.60	26.90	23.70
31-AUG-87	831	6.30	29.20	17.50
31-AUG-87	842	7.20	28.30	17.70
31-AUG-87	908	7.60	28.30	20.40
31-AUG-87	912	7.10	28.60	18.90
31-AUG-87	946	8.00	27.20	20.10

OBS_DATE	STATION_ID	EXOATM_REFL3	EXOATM_REFL4	EXOATM_REFL5
18-OCT-87	2	11.10	26.20	25.10
18-OCT-87	3	11.60	18.90	23.30
18-OCT-87	4	12.90	22.40	27.20
18-OCT-87	5	13.20	22.10	28.70
18-OCT-87	7	10.90	16.90	21.30
18-OCT-87	8	12.80	22.60	27.40

18-OCT-87	9	11.80	22.90	24.20
18-OCT-87	10	11.30	19.50	23.20
18-OCT-87	12	9.00	16.40	17.90
18-OCT-87	14	8.80	16.40	20.00
18-OCT-87	15	14.50	26.40	27.10
18-OCT-87	16	12.70	22.00	25.30
18-OCT-87	20	10.40	18.10	20.30
18-OCT-87	22	13.10	23.30	29.40
18-OCT-87	23	11.40	21.10	24.90
18-OCT-87	24	12.40	22.10	26.60
18-OCT-87	26	11.90	20.50	25.30
18-OCT-87	27	10.20	17.60	19.50
18-OCT-87	28	12.90	24.50	28.70
18-OCT-87	30	11.80	24.10	24.30
18-OCT-87	31	12.00	22.00	27.40
18-OCT-87	34	13.60	24.10	28.80
18-OCT-87	36	13.50	23.60	28.90
18-OCT-87	38	11.80	22.90	23.10
18-OCT-87	39	11.80	20.90	24.60
18-OCT-87	40	14.10	24.80	28.40
18-OCT-87	41	11.30	21.10	24.20
18-OCT-87	42	12.40	20.30	23.50
18-OCT-87	44	12.40	21.30	25.20
18-OCT-87	52	12.40	20.90	25.50
18-OCT-87	60	13.00	23.90	27.80

18-OCT-87	807	12.10	21.30	24.60
18-OCT-87	810	12.60	20.60	27.60
18-OCT-87	812	10.60	18.00	20.90
18-OCT-87	814	12.20	21.00	28.90
18-OCT-87	817	13.30	24.20	29.50
18-OCT-87	831	11.30	22.90	19.80
18-OCT-87	842	12.50	21.80	25.90
18-OCT-87	908	11.00	20.50	23.60
18-OCT-87	912	12.80	22.60	27.40
18-OCT-87	946	12.40	21.30	25.20

OBS_DATE	STATION_ID	EXOATM_REFL3	EXOATM_REFL4	EXOATM_REFL5
27-APR-88	2	9.30	29.40	21.50
27-APR-88	3	8.30	11.30	19.80
27-APR-88	4	8.90	14.20	20.20
27-APR-88	5	15.10	23.30	33.10
27-APR-88	7	6.10	7.90	14.80
27-APR-88	8	8.90	14.10	21.10
27-APR-88	9	10.30	18.40	24.40
27-APR-88	10	14.20	21.40	28.30
27-APR-88	12	6.40	10.10	17.20
27-APR-88	14	6.20	10.10	16.90
27-APR-88	15	10.50	16.80	24.80
27-APR-88	16	7.80	11.50	18.30

27-APR-88	20	14.30	23.00	27.60
27-APR-88	22	13.90	26.50	33.90
27-APR-88	23	8.30	14.00	23.80
27-APR-88	24	12.10	23.20	29.00
27-APR-88	26	12.80	22.70	28.60
27-APR-88	27	11.10	17.10	21.90
27-APR-88	28	9.70	16.10	25.20
27-APR-88	30	9.30	16.60	24.60
27-APR-88	31	14.00	22.50	31.10
27-APR-88	34	11.20	21.50	27.60
27-APR-88	36	10.60	26.20	26.90
27-APR-88	38	9.20	15.00	23.60
27-APR-88	39	12.40	21.50	26.90
27-APR-88	40	10.90	17.50	26.10
27-APR-88	41	13.40	25.40	30.50
27-APR-88	42	8.50	12.70	19.40
27-APR-88	44	9.70	18.80	23.00
27-APR-88	52	10.50	16.10	22.80
27-APR-88	60	6.40	8.50	16.10
27-APR-88	807	6.10	7.70	13.40
27-APR-88	810	14.70	21.80	32.10
27-APR-88	812	12.70	20.90	28.60
27-APR-88	814	15.20	21.90	31.80
27-APR-88	817	13.20	24.20	30.20

27-APR-88	831	8.70	15.30	22.50
27-APR-88	842	14.30	24.40	30.00
27-APR-88	908	6.50	9.10	18.70
27-APR-88	912	8.90	14.10	21.10
27-APR-88	946	9.70	18.80	23.00

OBS_DATE	STATION_ID	EXOATM_REFL3	EXOATM_REFL4	EXOATM_REFL5
13-MAY-88	2	8.00	33.80	20.00
13-MAY-88	3	8.30	18.20	21.20
13-MAY-88	4	6.90	22.60	17.30
13-MAY-88	5	14.90	23.30	31.60
13-MAY-88	7	7.10	14.50	18.40
13-MAY-88	8	7.40	19.60	18.20
13-MAY-88	9	8.20	24.60	21.30
13-MAY-88	10	11.50	23.30	24.50
13-MAY-88	12	6.80	18.60	19.60
13-MAY-88	14	7.20	17.00	19.60
13-MAY-88	15	13.00	20.30	29.20
13-MAY-88	16	6.70	21.60	18.00
13-MAY-88	20	9.60	18.80	21.60
13-MAY-88	22	12.10	29.20	28.80
13-MAY-88	23	7.80	21.80	21.50
13-MAY-88	24	10.30	28.50	25.40
13-MAY-88	26	10.30	26.60	24.90

13-MAY-88	27	9.40	22.70	20.60
13-MAY-88	28	8.30	23.00	24.50
13-MAY-88	30	7.90	23.20	20.60
13-MAY-88	31	12.60	23.60	28.50
13-MAY-88	34	9.30	26.90	24.30
13-MAY-88	36	8.70	28.60	23.50
13-MAY-88	38	7.50	24.80	20.20
13-MAY-88	39	10.20	25.10	25.00
13-MAY-88	40	10.10	22.70	23.50
13-MAY-88	41	11.10	26.90	25.80
13-MAY-88	42	7.70	19.30	18.30
13-MAY-88	44	8.90	22.20	23.50
13-MAY-88	52	9.20	22.70	22.00
13-MAY-88	60	7.40	16.90	20.20
13-MAY-88	807	6.70	14.30	17.70
13-MAY-88	810	13.70	23.10	30.60
13-MAY-88	812	10.90	26.60	25.10
13-MAY-88	814	14.10	23.60	28.70
13-MAY-88	817	10.80	26.40	27.70
13-MAY-88	831	8.00	22.10	20.10
13-MAY-88	842	13.00	26.30	29.10
13-MAY-88	908	6.90	17.70	20.50
13-MAY-88	912	7.40	19.60	18.20
13-MAY-88	946	8.90	22.20	23.50

OBS_DATE	STATION_ID	EXOATM_REFL3	EXOATM_REFL4	EXOATM_REFL5
06-JUN-88	2	7.00	26.70	18.40
06-JUN-88	3	7.00	27.00	18.50
06-JUN-88	4	6.00	35.00	16.00
06-JUN-88	5	8.80	27.20	23.70
06-JUN-88	7	6.50	26.20	17.10
06-JUN-88	8	6.50	27.60	16.60
06-JUN-88	9	6.40	31.10	17.70
06-JUN-88	10	6.60	31.40	17.50
06-JUN-88	12	5.60	32.00	16.50
06-JUN-88	14	5.90	30.70	16.50
06-JUN-88	15	12.40	21.40	28.50
06-JUN-88	16	5.90	33.80	15.70
06-JUN-88	20	7.10	29.30	17.30
06-JUN-88	22	8.40	29.00	23.90
06-JUN-88	23	6.40	30.20	18.00
06-JUN-88	24	7.30	29.20	19.70
06-JUN-88	26	7.70	27.80	20.20
06-JUN-88	27	7.50	26.10	17.30
06-JUN-88	28	8.00	28.20	22.70
06-JUN-88	30	6.70	27.40	18.90
06-JUN-88	31	7.90	29.40	21.60
06-JUN-88	34	7.90	29.80	19.50
06-JUN-88	36	7.80	29.50	21.10

06-JUN-88	38	5.80	36.00	16.10
06-JUN-88	39	7.40	28.50	19.80
06-JUN-88	40	8.90	27.80	20.70
06-JUN-88	41	6.80	31.00	19.20
06-JUN-88	42	6.10	30.10	15.70
06-JUN-88	44	7.20	27.50	20.10
06-JUN-88	52	7.00	29.50	19.00
06-JUN-88	60	6.20	32.60	17.80
06-JUN-88	807	6.10	27.70	16.20
06-JUN-88	810	7.70	28.20	21.20
06-JUN-88	812	7.00	30.80	18.90
06-JUN-88	814	7.10	31.30	20.00
06-JUN-88	817	8.90	27.20	24.10
06-JUN-88	831	7.20	26.20	17.90
06-JUN-88	842	9.10	28.20	24.10
06-JUN-88	908	5.70	35.00	17.80
06-JUN-88	912	6.50	27.60	16.60
06-JUN-88	946	7.20	27.50	20.10

OBS_DATE	STATION_ID	EXOATM_REFL3	EXOATM_REFL4	EXOATM_REFL5
01-AUG-88	2	7.90	22.90	20.60
01-AUG-88	3	9.00	27.10	18.00
01-AUG-88	4	8.30	29.50	17.90
01-AUG-88	5	8.80	29.40	21.40

01-AUG-88	7	7.70	25.80	16.40
01-AUG-88	8	7.50	26.20	17.30
01-AUG-88	9	7.50	27.60	18.10
01-AUG-88	10	8.10	27.60	19.10
01-AUG-88	12	6.40	29.70	15.10
01-AUG-88	14	6.40	30.30	16.30
01-AUG-88	15	12.20	28.90	26.40
01-AUG-88	16	8.30	27.60	17.70
01-AUG-88	20	8.10	24.30	17.20
01-AUG-88	22	10.40	27.00	24.60
01-AUG-88	23	8.00	25.10	18.70
01-AUG-88	24	7.70	28.30	19.60
01-AUG-88	26	8.70	26.00	21.80
01-AUG-88	27	8.60	23.50	16.60
01-AUG-88	28	9.90	23.70	24.80
01-AUG-88	30	7.70	26.50	17.30
01-AUG-88	31	8.00	31.00	18.80
01-AUG-88	34	9.20	26.50	21.50
01-AUG-88	36	10.70	25.20	26.10
01-AUG-88	38	7.70	28.80	17.00
01-AUG-88	39	9.10	24.20	21.50
01-AUG-88	40	9.70	25.50	20.60
01-AUG-88	41	8.70	26.80	20.80
01-AUG-88	42	6.90	27.70	16.40

01-AUG-88	44	9.70	23.70	23.40
01-AUG-88	52	8.60	26.70	18.20
01-AUG-88	60	8.10	30.00	18.40
01-AUG-88	807	7.60	28.00	17.00
01-AUG-88	810	7.70	33.00	18.10
01-AUG-88	812	7.90	26.20	15.90
01-AUG-88	814	8.20	32.40	18.80
01-AUG-88	817	10.60	25.20	25.10
01-AUG-88	831	8.50	24.60	20.80
01-AUG-88	842	7.80	29.60	18.80
01-AUG-88	908	6.90	35.10	16.20
01-AUG-88	912	7.50	26.20	17.30
01-AUG-88	946	9.70	23.70	23.40

OBS_DATE	STATION_ID	EXOATM_REFL3	EXOATM_REFL4	EXOATM_REFL5
25-AUG-88	2	7.10	20.30	19.10
25-AUG-88	3	6.50	25.70	17.80
25-AUG-88	4	6.50	26.50	17.70
25-AUG-88	5	7.80	25.50	21.90
25-AUG-88	7	6.20	25.70	15.60
25-AUG-88	8	6.40	26.40	17.30
25-AUG-88	9	6.20	27.90	17.90
25-AUG-88	10	6.70	25.90	18.40
25-AUG-88	12	5.50	26.50	14.10

25-AUG-88	14	5.40	29.50	14.70
25-AUG-88	15	7.00	26.80	20.60
25-AUG-88	16	6.80	25.40	17.30
25-AUG-88	20	7.00	21.80	20.20
25-AUG-88	22	8.60	24.90	24.40
25-AUG-88	23	7.20	22.00	19.60
25-AUG-88	24	7.00	25.30	20.00
25-AUG-88	26	7.80	23.10	21.00
25-AUG-88	27	6.60	21.40	14.80
25-AUG-88	28	8.90	21.80	25.60
25-AUG-88	30	7.10	23.90	19.40
25-AUG-88	31	7.20	27.00	19.60
25-AUG-88	34	9.30	25.50	22.60
25-AUG-88	36	9.40	22.00	25.60
25-AUG-88	38	6.30	26.30	16.50
25-AUG-88	39	8.20	21.70	20.80
25-AUG-88	40	9.10	25.30	21.90
25-AUG-88	41	8.10	24.10	22.10
25-AUG-88	42	5.90	25.20	15.70
25-AUG-88	44	8.60	22.00	23.30
25-AUG-88	52	7.10	25.70	17.50
25-AUG-88	60	6.30	28.60	17.80
25-AUG-88	807	6.60	25.50	15.90
25-AUG-88	810	7.10	29.10	19.10
25-AUG-88	812	6.10	26.80	15.90

25-AUG-88	814	7.40	29.30	19.80
25-AUG-88	817	8.50	24.20	23.90
25-AUG-88	831	7.30	22.80	21.10
25-AUG-88	842	6.80	28.20	17.90
25-AUG-88	908	5.90	30.20	17.70
25-AUG-88	912	6.40	26.40	17.30
25-AUG-88	946	8.70	21.90	23.30

OBS_DATE	STATION_ID	EXOATM_REFL3	EXOATM_REFL4	EXOATM_REFL5
26-SEP-88	2	9.20	18.30	22.50
26-SEP-88	3	8.60	23.50	18.00
26-SEP-88	4	9.70	24.80	21.60
26-SEP-88	5	10.70	23.60	24.60
26-SEP-88	7	7.90	21.50	16.70
26-SEP-88	8	8.60	23.90	20.80
26-SEP-88	9	8.20	23.30	20.00
26-SEP-88	10	9.10	20.70	20.60
26-SEP-88	12	7.00	21.70	15.10
26-SEP-88	14	6.80	21.50	14.60
26-SEP-88	15	8.10	26.80	19.50
26-SEP-88	16	9.20	22.70	20.10
26-SEP-88	20	9.00	21.70	18.80
26-SEP-88	22	10.10	23.60	26.20
26-SEP-88	23	8.20	21.30	19.90

26-SEP-88	24	9.10	23.40	21.40
26-SEP-88	26	9.60	20.00	21.50
26-SEP-88	27	8.00	20.40	13.50
26-SEP-88	28	9.70	20.90	24.90
26-SEP-88	30	9.30	21.40	21.70
26-SEP-88	31	9.50	23.50	22.50
26-SEP-88	34	10.60	25.20	24.50
26-SEP-88	36	11.50	21.60	27.50
26-SEP-88	38	8.40	24.60	19.00
26-SEP-88	39	9.60	19.30	21.00
26-SEP-88	40	10.20	25.10	23.80
26-SEP-88	41	9.60	21.30	23.40
26-SEP-88	42	8.00	21.30	17.30
26-SEP-88	44	9.60	21.90	23.70
26-SEP-88	52	9.40	22.90	19.10
26-SEP-88	60	9.50	25.90	20.80
26-SEP-88	807	8.70	23.80	17.10
26-SEP-88	810	9.30	22.80	21.70
26-SEP-88	812	7.80	20.20	18.00
26-SEP-88	814	9.00	21.30	21.30
26-SEP-88	817	10.90	23.50	25.90
26-SEP-88	831	10.10	16.10	20.50
26-SEP-88	842	8.70	22.20	20.50
26-SEP-88	908	7.70	24.70	16.70

26-SEP-88	912	8.60	23.90	20.80
26-SEP-88	946	9.60	21.90	23.70

OBS_DATE	STATION_ID	EXOATM_REFL3	EXOATM_REFL4	EXOATM_REFL5
04-AUG-89	2	8.10	17.60	21.90
04-AUG-89	3	9.00	21.50	21.00
04-AUG-89	4	7.60	22.60	17.60
04-AUG-89	5	7.80	21.20	18.10
04-AUG-89	7	8.00	19.90	17.90
04-AUG-89	8	7.90	20.30	17.70
04-AUG-89	9	8.60	22.00	21.00
04-AUG-89	10	8.00	20.30	19.70
04-AUG-89	12	6.80	21.50	16.70
04-AUG-89	14	7.20	22.60	17.20
04-AUG-89	15	11.40	25.00	27.20
04-AUG-89	16	6.50	27.60	15.00
04-AUG-89	20	7.60	22.50	16.60
04-AUG-89	22	11.00	22.90	28.50
04-AUG-89	23	7.00	26.20	18.00
04-AUG-89	24	8.60	23.00	22.40
04-AUG-89	26	7.60	22.40	19.20
04-AUG-89	27	7.80	19.10	17.20
04-AUG-89	28	8.30	22.10	22.10
04-AUG-89	30	6.70	27.20	17.40
04-AUG-89	31	8.20	25.90	19.90

04-AUG-89	34	8.10	25.70	20.60
04-AUG-89	36	8.80	23.10	22.60
04-AUG-89	38	7.60	23.30	18.40
04-AUG-89	39	8.30	19.70	20.80
04-AUG-89	40	10.30	21.50	23.10
04-AUG-89	41	8.00	24.10	21.20
04-AUG-89	42	7.80	21.10	19.20
04-AUG-89	44	9.70	22.70	24.70
04-AUG-89	52	8.80	20.90	20.60
04-AUG-89	60	7.50	24.20	18.50
04-AUG-89	807	8.40	20.20	18.60
04-AUG-89	810	7.60	25.20	19.00
04-AUG-89	812	7.20	23.50	17.50
04-AUG-89	814	8.50	24.20	19.60
04-AUG-89	817	11.10	21.40	27.50
04-AUG-89	831	9.60	20.30	20.20
04-AUG-89	842	8.00	25.40	19.70
04-AUG-89	908	7.30	27.40	18.70
04-AUG-89	912	7.90	20.30	17.70
04-AUG-89	946	9.70	22.70	24.70

Table 2 - Soil moisture by gamma-ray method (%), standard deviation (%), and number of observations, at various dates and station ID's

DATE	ID	SM(%)	SD(%)	N
4-AUG-89	601	34.6	3.3	6
4-AUG-89	602	30.0	3.8	7
4-AUG-89	603	24.7	5.6	5
4-AUG-89	604	22.7	6.8	4
4-AUG-89	605	27.7	1.9	4
4-AUG-89	606	31.4	2.5	4
4-AUG-89	607	33.9	2.4	3
4-AUG-89	608	30.4	2.3	3
4-AUG-89	609	25.8	7.0	4
4-AUG-89	610	23.5	6.1	6
4-AUG-89	611	33.3	0.1	2
4-AUG-89	612	32.2	0.9	5
4-AUG-89	613	31.5	6.1	6
4-AUG-89	614	26.4	2.5	3
4-AUG-89	615	32.1	8.8	6
4-AUG-89	616	33.0	3.6	4
4-AUG-89	617	31.1	3.2	4
4-AUG-89	618	32.1	2.7	3
4-AUG-89	619	30.3	2.9	5
4-AUG-89	620	28.3	3.1	4
4-AUG-89	623	31.4	2.6	6
5-AUG-89	601	30.7	5.3	6
5-AUG-89	602	33.7	2.7	7
5-AUG-89	603	27.2	6.0	5
5-AUG-89	604	25.3	7.7	4
5-AUG-89	605	28.9	2.8	4
5-AUG-89	606	30.9	1.7	4
5-AUG-89	607	34.1	3.3	3
5-AUG-89	608	34.8	2.7	3
5-AUG-89	609	31.3	2.9	4
5-AUG-89	610	24.6	8.6	7
5-AUG-89	611	32.8	0.3	2
5-AUG-89	612	30.9	1.0	5
5-AUG-89	613	30.5	5.6	6
5-AUG-89	614	22.4	4.1	3
5-AUG-89	615	27.2	6.8	6
5-AUG-89	616	30.8	3.7	4
5-AUG-89	617	31.3	2.9	4
5-AUG-89	618	29.6	4.7	3
5-AUG-89	619	30.8	3.9	5
5-AUG-89	620	24.9	4.8	4

5-AUG-89	621	26.4	3.1	4
5-AUG-89	622	29.4	3.0	4
5-AUG-89	623	30.5	1.2	4

Table 3 - Soil moisture by gravimetric method (%), standard deviation (%), and number of observations, at various dates and station ID's

DATE	ID	SM(%)	SD(%)	N
14-AUG-87	10	36.6	2.2	5
14-AUG-87	12	37.8	5.9	5
14-AUG-87	14	41.2	2.9	5
14-AUG-87	30	33.1	1.5	5
14-AUG-87	34	39.8	1.2	5
14-AUG-87	36	36.4	2.7	5
14-AUG-87	38	38.6	1.4	5
15-AUG-87	2	32.2	2.4	5
15-AUG-87	4	43.2	2.5	4
15-AUG-87	6	37.6	1.9	5
15-AUG-87	8	39.5	1.5	5
15-AUG-87	10	34.4	2.1	5
15-AUG-87	11	37.9	2.3	10
15-AUG-87	12	34.6	3.8	5
15-AUG-87	14	32.6	3.1	5
15-AUG-87	20	33.3	5.0	5
15-AUG-87	22	33.5	2.0	5
15-AUG-87	24	38.6	1.5	5
15-AUG-87	26	34.2	3.3	5
15-AUG-87	28	37.5	3.9	5
15-AUG-87	30	26.5	1.4	5
15-AUG-87	34	37.9	1.6	5
15-AUG-87	36	31.9	2.7	5
15-AUG-87	38	31.9	3.1	5
15-AUG-87	40	33.3	2.8	5
15-AUG-87	42	37.9	3.5	5
15-AUG-87	44	36.4	3.9	5
26-APR-88	802	19.8	1.5	5
26-APR-88	805	32.3	6.0	5
26-APR-88	807	34.4	2.9	5
26-APR-88	808	25.2	3.2	5
26-APR-88	811	34.9	0.8	2
26-APR-88	827	22.0	4.5	5
26-APR-88	831	39.4	7.4	5
28-APR-88	811	25.3	3.1	3
28-APR-88	820	23.8	2.5	5
28-APR-88	829	22.3	3.6	5
28-APR-88	836	20.1	1.8	5
28-APR-88	840	24.7	4.1	5
06-JUN-88	817	20.0	2.6	5
06-JUN-88	819	17.7	1.1	5
06-JUN-88	821	13.4	1.2	5

06-JUN-88	823	16.3	3.1	5
06-JUN-88	825	16.3	1.7	5
07-JUN-88	802	14.6	1.7	5
07-JUN-88	805	20.1	2.6	5
07-JUN-88	806	30.5	1.9	10
07-JUN-88	807	22.8	3.2	5
07-JUN-88	808	20.4	1.2	5
07-JUN-88	812	24.9	3.1	10
07-JUN-88	827	16.9	0.5	5
07-JUN-88	831	26.6	2.4	5
07-JUN-88	836	19.4	1.8	5
02-AUG-88	811	12.4	2.3	5
02-AUG-88	817	11.5	1.5	5
02-AUG-88	819	16.5	1.2	4
02-AUG-88	820	14.9	2.3	5
02-AUG-88	821	10.6	0.6	5
02-AUG-88	823	9.5	1.4	5
02-AUG-88	825	12.2	1.8	5
02-AUG-88	836	11.3	2.2	5
25-AUG-88	817	20.5	3.8	5
25-AUG-88	819	19.1	1.0	5
26-AUG-88	820	18.3	2.3	5
26-AUG-88	821	11.0	1.3	5
26-AUG-88	823	10.4	0.4	5
26-AUG-88	825	16.4	1.1	5
26-SEP-88	811	19.6	3.8	5
26-SEP-88	827	17.3	2.3	5
26-SEP-88	836	16.6	2.0	5
03-AUG-89	902	17.6	2.1	5
03-AUG-89	906	25.4	1.4	5
03-AUG-89	908	29.0	2.3	5
03-AUG-89	910	33.6	4.6	5
03-AUG-89	912	32.5	2.2	5
03-AUG-89	913	36.4	1.6	5
03-AUG-89	916	35.2	3.1	5
03-AUG-89	919	31.4	2.1	5
03-AUG-89	925	42.9	7.0	5
03-AUG-89	926	34.1	4.9	5
03-AUG-89	936	35.5	2.8	5
03-AUG-89	938	32.0	4.2	5
03-AUG-89	944	27.9	4.8	5
04-AUG-89	902	14.6	0.9	5
04-AUG-89	906	22.8	2.5	5
04-AUG-89	908	22.4	2.6	5
04-AUG-89	910	32.6	6.0	5
04-AUG-89	912	27.3	1.9	5
04-AUG-89	913	34.1	0.9	5
04-AUG-89	916	36.3	2.9	5
04-AUG-89	919	26.1	4.1	5

04-AUG-89	925	36.4	6.4	5
04-AUG-89	926	27.7	4.0	5
04-AUG-89	936	31.0	5.1	5
04-AUG-89	938	26.3	2.2	5
04-AUG-89	944	24.6	2.5	5
05-AUG-89	902	29.8	4.5	5
05-AUG-89	906	31.2	1.3	5
05-AUG-89	908	34.4	1.6	5
05-AUG-89	910	31.7	10.2	5
05-AUG-89	912	37.9	6.3	5
05-AUG-89	913	35.8	3.3	5
05-AUG-89	916	43.2	8.4	5
05-AUG-89	919	26.4	3.9	5
05-AUG-89	925	42.7	4.0	5
05-AUG-89	926	25.9	4.1	5
05-AUG-89	936	36.3	4.4	5
05-AUG-89	938	32.4	3.6	5
05-AUG-89	944	35.1	5.0	5

Table 4 - Soil moisture by neutron method (%), standard deviation (%), and number of observations, at various dates and station ID's

DATE	ID	SM(%)	SD(%)	N
14-AUG-87	1	38.5	0.6	5
14-AUG-87	2	42.8	6.0	5
14-AUG-87	3	35.3	3.6	5
14-AUG-87	4	45.9	1.1	4
14-AUG-87	5	33.0	2.6	5
14-AUG-87	7	29.8	1.7	5
14-AUG-87	10	36.1	2.2	5
15-AUG-87	28	37.4	2.8	5
15-AUG-87	40	33.2	4.4	5
15-AUG-87	42	31.2	3.3	5
15-AUG-87	44	34.4	2.1	5
17-OCT-87	23	38.4	3.3	5
17-OCT-87	25	29.3	6.3	5
17-OCT-87	27	42.0	3.1	5
17-OCT-87	36	12.9	3.6	5
18-OCT-87	1	33.9	1.7	5
18-OCT-87	2	15.2	2.8	5
18-OCT-87	3	34.7	2.5	5
18-OCT-87	4	10.4	1.8	4
18-OCT-87	5	30.7	1.8	5
18-OCT-87	7	32.3	1.8	5
18-OCT-87	10	10.6	1.9	5
19-OCT-87	9	32.6	2.5	5
19-OCT-87	13	33.1	2.1	5
19-OCT-87	15	25.1	3.2	5
19-OCT-87	20	15.1	5.5	5
19-OCT-87	28	13.1	2.3	5
19-OCT-87	29	28.9	2.9	5
19-OCT-87	31	29.2	2.1	5
19-OCT-87	44	11.7	3.0	5
26-APR-88	802	19.3	1.9	5
27-APR-88	805	27.8	3.3	5
28-APR-88	811	27.0	4.8	5
28-APR-88	820	23.7	2.6	5
28-APR-88	829	22.0	2.0	5
28-APR-88	836	19.5	1.0	5
05-JUN-88	817	20.1	2.1	5
05-JUN-88	819	17.4	1.2	5
05-JUN-88	821	14.3	1.3	5
05-JUN-88	823	17.2	3.7	5
07-JUN-88	802	15.9	1.9	5
07-JUN-88	805	18.3	2.6	5

07-JUN-88	836	19.5	2.2	5
25-AUG-88	817	21.7	3.2	5
25-AUG-88	819	20.4	1.3	5
26-AUG-88	820	16.2	3.5	5
26-AUG-88	821	11.0	1.3	5
26-AUG-88	823	10.8	0.8	5
26-SEP-88	811	17.6	3.1	5
26-SEP-88	836	17.3	2.6	5

G-35-618
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CLIMATE RELATED MEASUREMENTS WITH THE NEW 1.6 μm AVHRR CHANNEL

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Georgia Tech Project G-35-618/G-35-676

Abstract

An analysis is performed with simulated AVHRR data including the 1.6 μm channel (3A) that will become available on NOAA-K to show that the AVHRR "tasseled cap" transform variables are effective measures of soil moisture and vegetation moisture. Observed soil moisture and vegetation moisture data from the First International Satellite Land Surface Climatology Project (ISLSCP) Field Experiment (FIFE) are examined and shown to verify that the AVHRR tasseled cap transform variables (as represented by Landsat Thematic Mapper surrogate data) provide effective measures of soil moisture change and vegetation moisture content. It is recommended that tasseled cap transform variables be produced from AVHRR data including the new 1.6 μm channel and it id suggested that these quantities will provide useful adjuncts to soil and vegetation moisture determined from microwave sensors. Additionally, it is suggested that the tasseled cap transform AVHRR variables will be useful for other applications such as snow/cloud discrimination, discrimination of water-phase clouds from ice-phase clouds and in the determination of optical properties of cirrus clouds and atmospheric aerosols.

Introduction

Beginning with NOAA-K, the AVHRR instrument is to have a new 1.6 μm channel. This new channel, designated 3A, will be switched over from the normal 3.7 μm (channel 3) during the daylight portion of the orbit. The primary purpose of the new channel 3A is to improve the ability to distinguish between snow and clouds (especially low clouds that have about the same brightness temperature as the surface; see Figures 9-11 of Justus and Paris, 1986).

The purpose of this study is to examine the potential climate-related measurements that might be made on a global scale using the AVHRR data from the new 1.6 μm channel 3A, especially the measurement of soil moisture and vegetation moisture parameters. In addition to these vegetation-moisture and soil-moisture applications documented here, experience with Landsat TM multispectral analysis has shown that the availability of a 1.6 μm channel (such as Band 5 of TM) can be of great value in the quantitative analysis of vegetation status (Tucker, 1978; Perry and Lautenschlager, 1984; Ehrlich et al, 1993) and in the monitoring of fire damage to tropical forests (Pereira and Setzer, 1993). Theoretical spectral model studies have also shown that multispectral analysis including a 1.6 μm channel on AVHRR will have value in the measurement of cirrus clouds (Masuda and Takashima, 1990), in allowing the discrimination between water-phase clouds and ice-phase clouds (Pilewskie and Twomey, 1986), and in the refinement of the determination of aerosol optical properties (Justus and Paris, 1987). The addition of the 1.6 μm channel on AVHRR is therefore expected to provide significant improvement in the global-scale analysis of a variety of climate-related parameters during the period until even more advanced spectral sensors such as MODIS become available (Townsend et al., 1991).

Study Results

The basis for the application of a 1.6 μm sensor wavelength in the determination of soil moisture and vegetation moisture, as well as in snow/cloud discrimination and water-phase-cloud/ice-phase-cloud discrimination, is illustrated in Figures 1 and 2. These figures show spectral reflectance curves taken from Bowker et al. (1985). These figures illustrate that the spectral absorption feature caused by water, normally centered at 1.4 μm if the water is in the vapor phase, is spectrally shifted to 1.5 μm or longer wavelengths if the water is in more solid phase such as snow, ice or moisture content in soil or vegetation.

Normal vegetation index values are based on the difference between reflectance in the visible (0.5-0.7 μm: AVHRR channel 1) and near-IR (0.7-1.0 μm: AVHRR channel 2). Information about the spectral reflectance near 1.5 μm (such as provided by the channel 3A AVHRR at 1.6 μm) is much more sensitive to moisture than the conventional channel 1-channel 2 vegetation index analysis.

Multispectral analysis capabilities can be put on a much more quantitative basis by using the spectral reflectances of Bowker et al. (1985) in a spectral radiative transfer model to simulate the response of the AVHRR sensor in each of its spectral channels, under a variety of observing conditions. For clear-atmosphere cases, the spectral model of Justus and Paris (1985) was used for this study. For simulation of scenes with cloud cover, the model of Paris and Justus (1988) was used. These models have been recommended by the International Commission on Illumination (CIE, 1989) for the calculation of solar spectral irradiances.

Figure 3 shows results for sensor reflectance simulations for AVHRR channels 1 and 2, using the Justus and Paris model for the various surface spectral reflectances of Bowker et al. (including a variety of vegetation and soil types as well as water and snow surfaces). Clouds of a variety of optical depths were simulated with the Paris and Justus model. This figure shows the familiar "vegetation branch", in which vegetation is characterized by high values of sensor-band reflectance in channel 2 and low values of channel 1 reflectance.

The addition of channel 3A at 1.6 μm adds a third dimension to the simulated results, as shown in the two different perspective views of Figures 4 and 5. While the addition of this third dimension allows for a variety of analysis approaches, a popular and effective method is to use a form of principal component analysis know as the "tasseled cap" transform (Kauth and Thomas 1976; Crist and Cicone, 1984; Crist 1985; Crist and Kauth, 1986). The tasseled cap transform allows the three input values of reflectances in AVHRR channels 1, 2 and 3A (here measured in reflectance units) to be transformed into three empirically orthogonal parameters (similar in interpretation to eigenvectors of the covariance matrix of the reflectance data). The transformed variables are thus simple linear combinations of the input reflectances. Tasseled cap transform analysis of the data in Figures 4 and 5 yielded the following results for the transformed variables (B, G and D) from the original AVHRR sensor-band reflectances (CH1, CH2 and CH3A):

$$
\begin{aligned}
B &= 0.784\,CH1 + 0.556\,CH2 + 0.276\,CH3A \\
G &= -0.517\,CH1 + 0.831\,CH2 - 0.205\,CH3A \\
D &= -0.343\,CH1 + 0.018\,CH2 + 0.939\,CH3A.
\end{aligned}
\qquad (1)
$$

The transform variables B and G are conventionally labeled "Brightness" and "Greenness" because B corresponds approximately to the radial direction along the soil-cloud-snow branch of Figure 3, while G corresponds approximately to an orthogonal direction increasing along the vegetation branch of Figure 3. Figure 6 illustrates this property by plotting the CH1-CH2 data of Figure 3 after transformation and as seen in the B-G plane. The third tasseled cap transform variable (D), illustrated by the three dimensional plot of Figure 7, can be interpreted as "Dryness" (i.e. a parameter whose value increases as the moisture content decreases). Frequently a third tasseled cap parameter called "Wetness" is defined. If the coefficient values in the D component of equation (1) are reversed in sign, then such a "Wetness" parameter would result (i.e. Wetness values would increase as the moisture content increases).

Several of the surface spectral data sets of Bowker et al. (1985) consist of "wet-dry" pairs, that is spectral reflectance curves for the same surface type under conditions of high and low moisture content. These wet-dry pairs contain both vegetation and soil type representatives. That the tasseled cap transform parameters for the AVHRR reflectances represent a strong signal of both the vegetation moisture and the soil moisture content is illustrated by plotting the results for the Dryness versus Brightness (D-B) for the Bowker wet-dry pair data, as shown in Figure 8. In all cases, the dry member of the wet-dry pair is the one at the larger dryness value in Figure 8. The success of the AVHRR tasseled cap transform in measuring soil and vegetation moisture is not surprising in view of the fact that Landsat TM data (using all 7 TM bands) shows a good ability to measure soil moisture and vegetation moisture (Crist et al., 1986; Musick and Pelletier, 1988) through the use of tassseled cap transform variables.

We now examine the ability of the 3-channel AVHRR data to quantitatively estimate the soil moisture and vegetation moisture through the use of the tasseled cap transform variables. For this purpose we use observed soil moisture and vegetation moisture data from the First International Satellite Land Surface Climatology Project (ISLSCP) Field Experiment (FIFE). An overview of the FIFE project is provided by Sellers et al. (1992). The FIFE data are available in a 5-volume CD-ROM data set (Strebel et al., 1991). As a surrogate for the AVHRR with 1.6 μm, the FIFE Landsat imagery from Thematic Mapper band 3 (0.62-0.70 μm), band 4 (0.77-0.90 μm) and band 5 (1.6-1.8 μm) were used in place of AVHRR channels 1, 2 and 3A, respectively. The TM values (in reflectance units) were processed trough the AVHRR tasseled cap transform relations of equation (1) to yield Brightness (B), Greenness (G) and Dryness (D) parameters.

FIFE soil moisture data from either neutron probe or gravimetric technique (or an average of the two if both were available) were used from sites and times where simultaneous (same day) TM observations were available. Because of variability among the different soil types at the various sites, the Dryness values were not found to be uniquely related to soil moisture content. However, when data were examined with different soil moisture values observed at the same site on different days (each with a corresponding TM observation), then it was found that there is a close relationship between the observed changes in soil moisture content (in percent) and the change in

Dryness between the two days (in percent). The observed relationship is illustrated in Figure 9. The regression relation shown in Figure 9 is

$$\delta \text{ Soil Moisture } (\%) \quad = \quad 1.48 \quad - \quad 6.496 \ \delta \text{ Dryness}(\%) \qquad (2)$$

This regression relation explains 68.9% of the original variance among the data points of Figure 9, with an rms residual error of 6.9% in the fitted values of soil moisture change.

Similarly, FIFE data on vegetation moisture were compared with observations of the TM-surrogate AVHRR Dryness parameter, as shown in Figure 10. The vegetation moisture content is expressed as a percent of dry vegetation weight. As a more relevant measure of the total amount of vegetation moisture in the satellite scene, the vegetation moisture values are multiplied by the measured values of leaf-area-index (LAI). Figure 10 shows good correspondence between LAI × Vegetation Moisture and tasseled cap Dryness parameter. The regression

$$\text{LAI} \times \text{Vegetation Moisture } (\%) \quad = \quad 376.4 \quad - \quad 17.46 \text{ Dryness } (\%) \qquad (3)$$

explains 79.4% of the original variance in the data points of Figure 10, with a residual error of 21.6% in the fitted values of LAI × Vegetation Moisture.

Discussion and Recommendations

The spectral model results of Figure 8 and the FIFE observational data using TM-surrogate data for AVHRR with the 1.6 μm channel 3A, indicate that the tasseled cap transform variables using AVHRR reflectance data will be very effective in the quantitative measurement of soil moisture and vegetation moisture. Since the AVHRR data have nominal 1 km resolution (LAC data) or 4 km resolution (GAC data), these soil moisture and vegetation moisture observations with AVHRR will serve as useful adjuncts to be used in combination with soil moisture or vegetation moisture derived from (perhaps more accurate, but lower spatial resolution) microwave sensors.

Recently, Nemani et al. (1993) have shown that there is value in combining AVHRR-derived surface temperature measurements with normalized vegetation index values to estimate soil moisture. Improvements over the use of AVHRR tasseled cap Dryness parameter alone are also likely with the addition of satellite-derived surface temperature information. The FIFE data would also provide a good set of observations (Jedlovec and Atkinson, 1992) against which to test this hypothesis.

Figures 6 and 7 show that the AVHRR tasseled cap transform variables are also useful in discriminating snow and clouds, and in distinguishing vegetation from soils. The tasseled cap transform variables, forming an empirical orthogonal set as they do, tend to maximize the variance (and minimize the covariance) among the transformed data values. This feature should lead to improved discrimination among all types of phenomena. Hence, the AVHRR tasseled cap transform parameters of Brightness, Greenness and Dryness, as provided by equation (1), should also be useful in distinguishing water-phase clouds from ice-phase clouds, in determining the presence and optical properties of cirrus clouds and in providing additional optical information about atmospheric aerosols.

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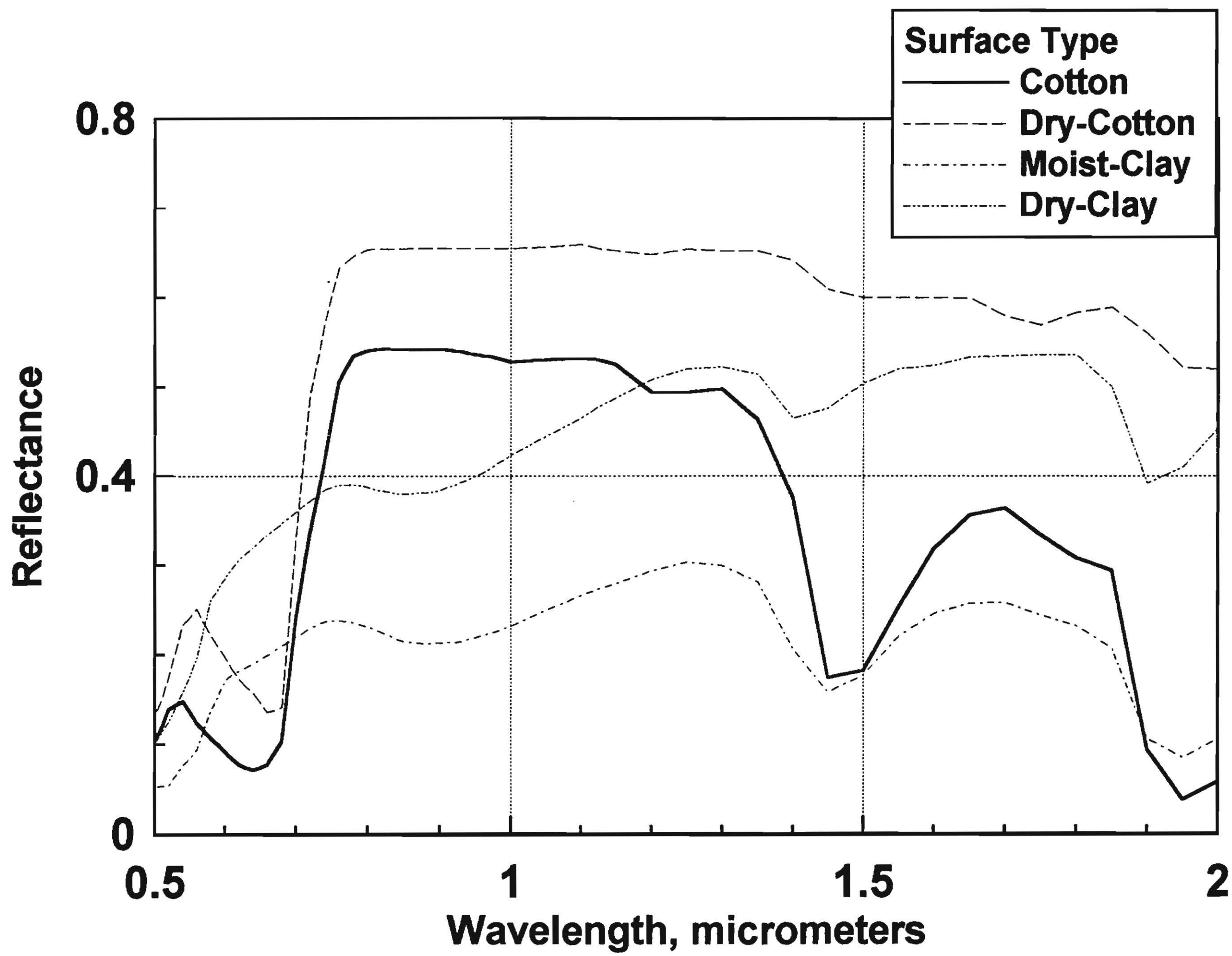

Figure 1 - Spectral reflectance curves (Bowker et al., 1985) for moist and dry cotton and moist and dry clay.

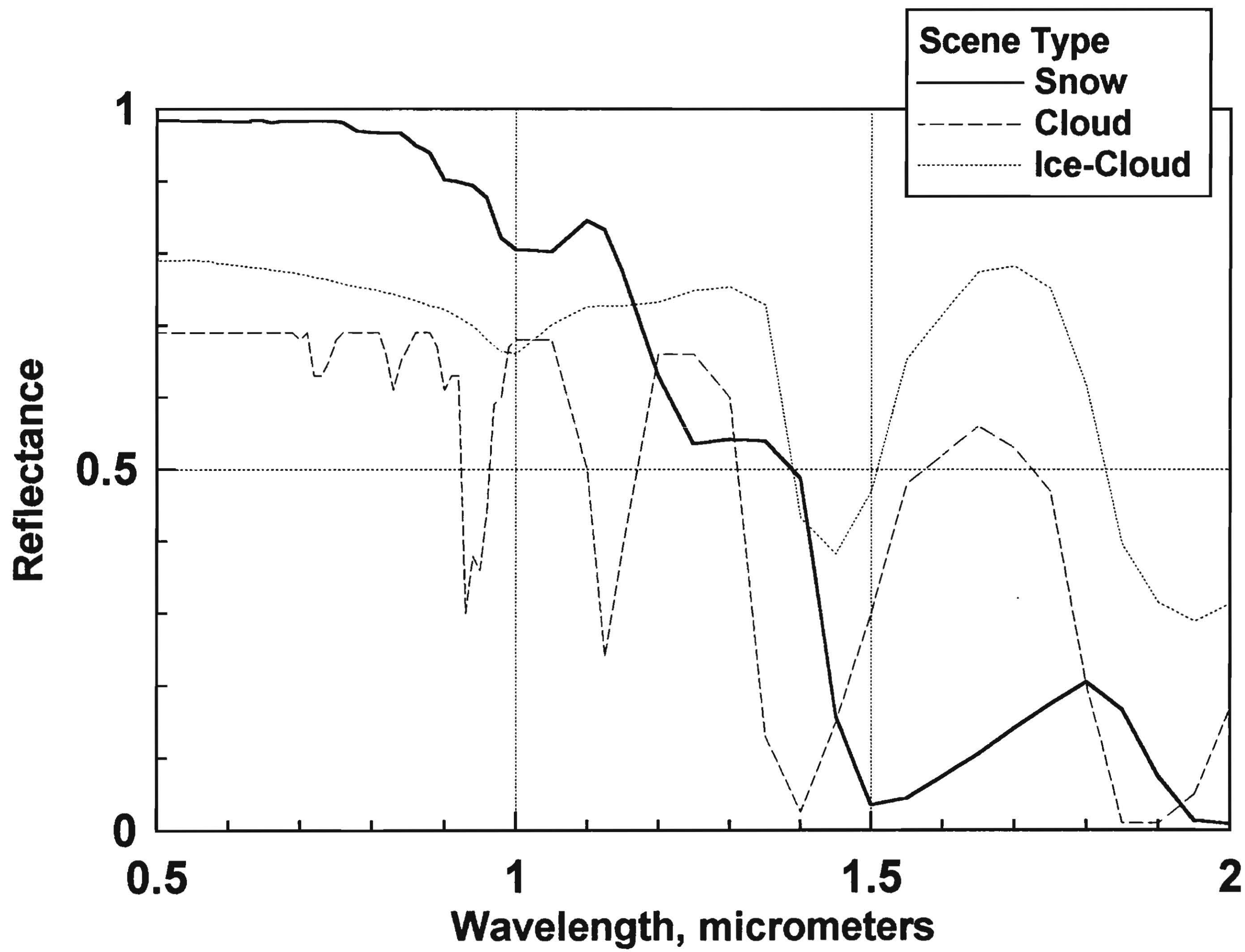

Figure 2 - Spectral reflectance curves (Bowker et al., 1985) for fresh snow, water-phase cloud and ice-phase cloud.

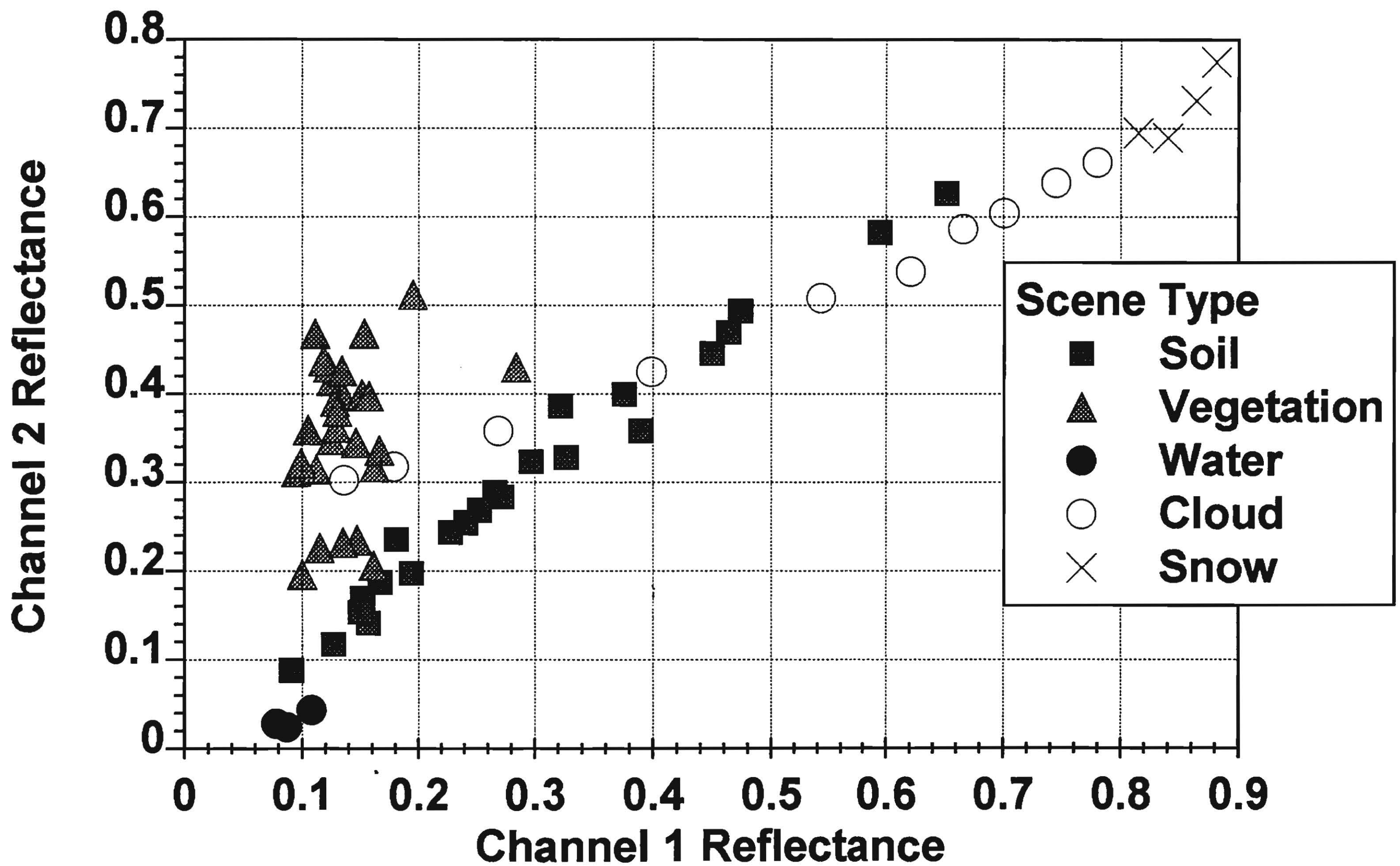

Figure 3 - Simulated AVHRR sensor-band reflectances for a variety of surface reflectances and cloud optical depths.

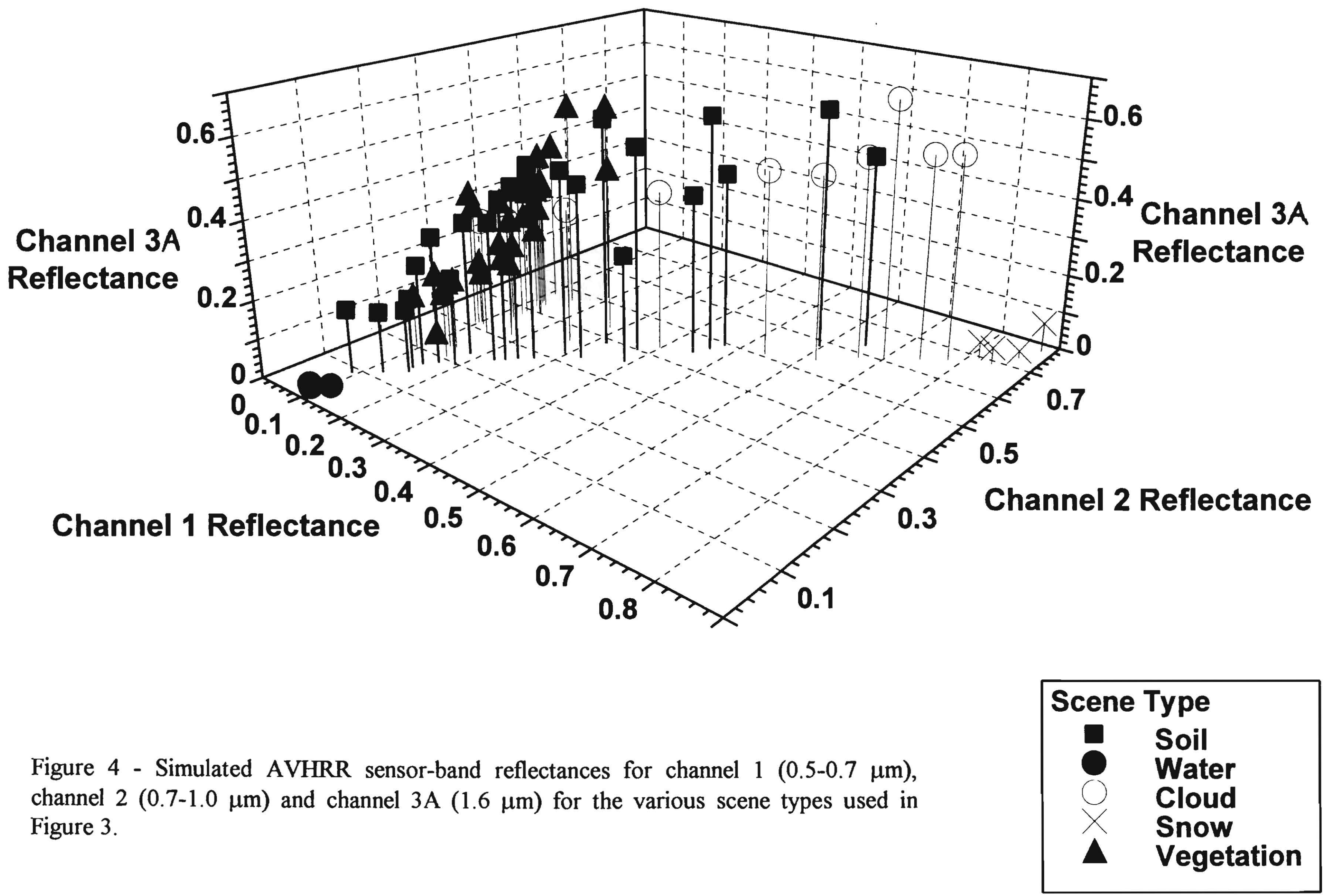

Figure 4 - Simulated AVHRR sensor-band reflectances for channel 1 (0.5-0.7 µm), channel 2 (0.7-1.0 µm) and channel 3A (1.6 µm) for the various scene types used in Figure 3.

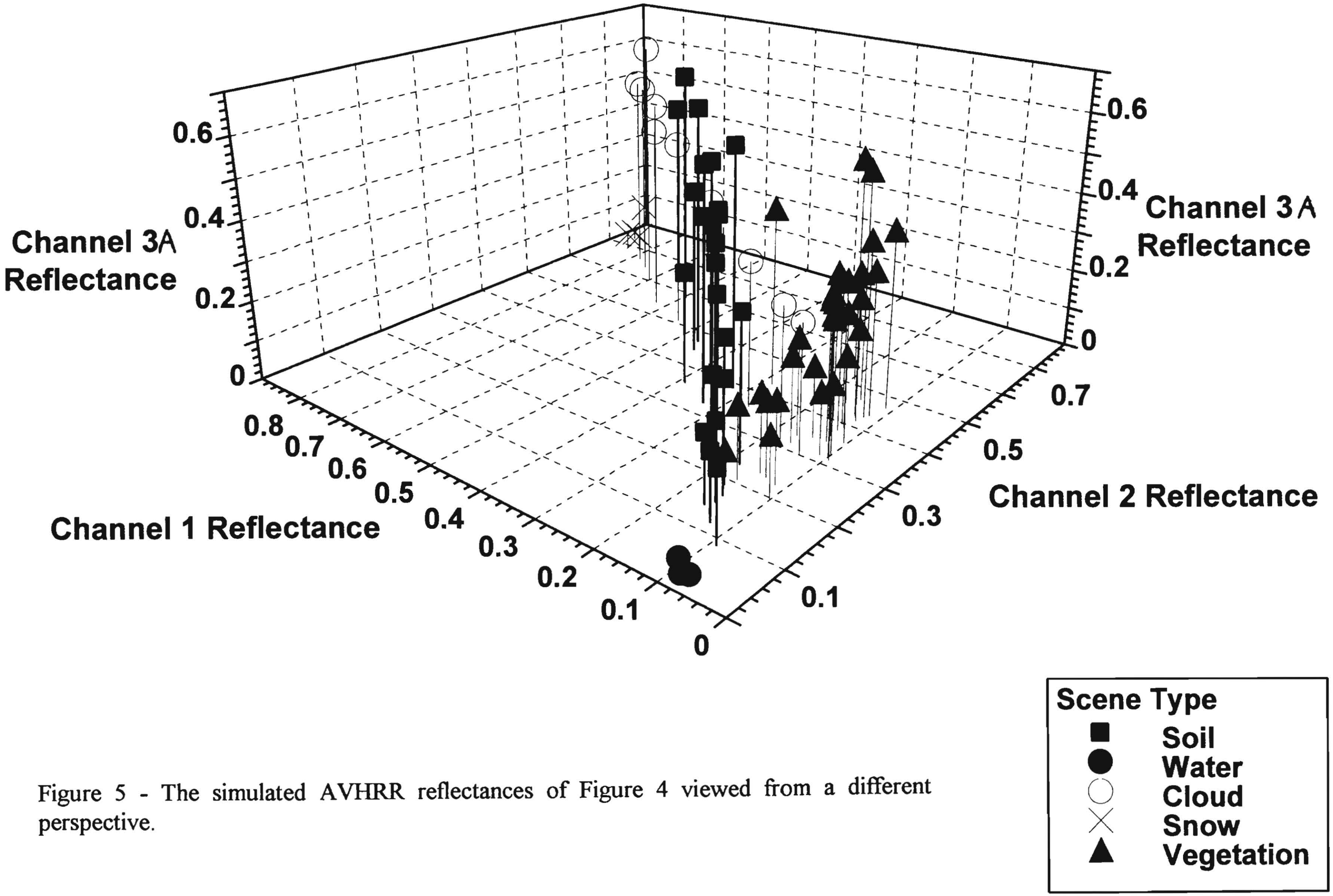

Figure 5 - The simulated AVHRR reflectances of Figure 4 viewed from a different perspective.

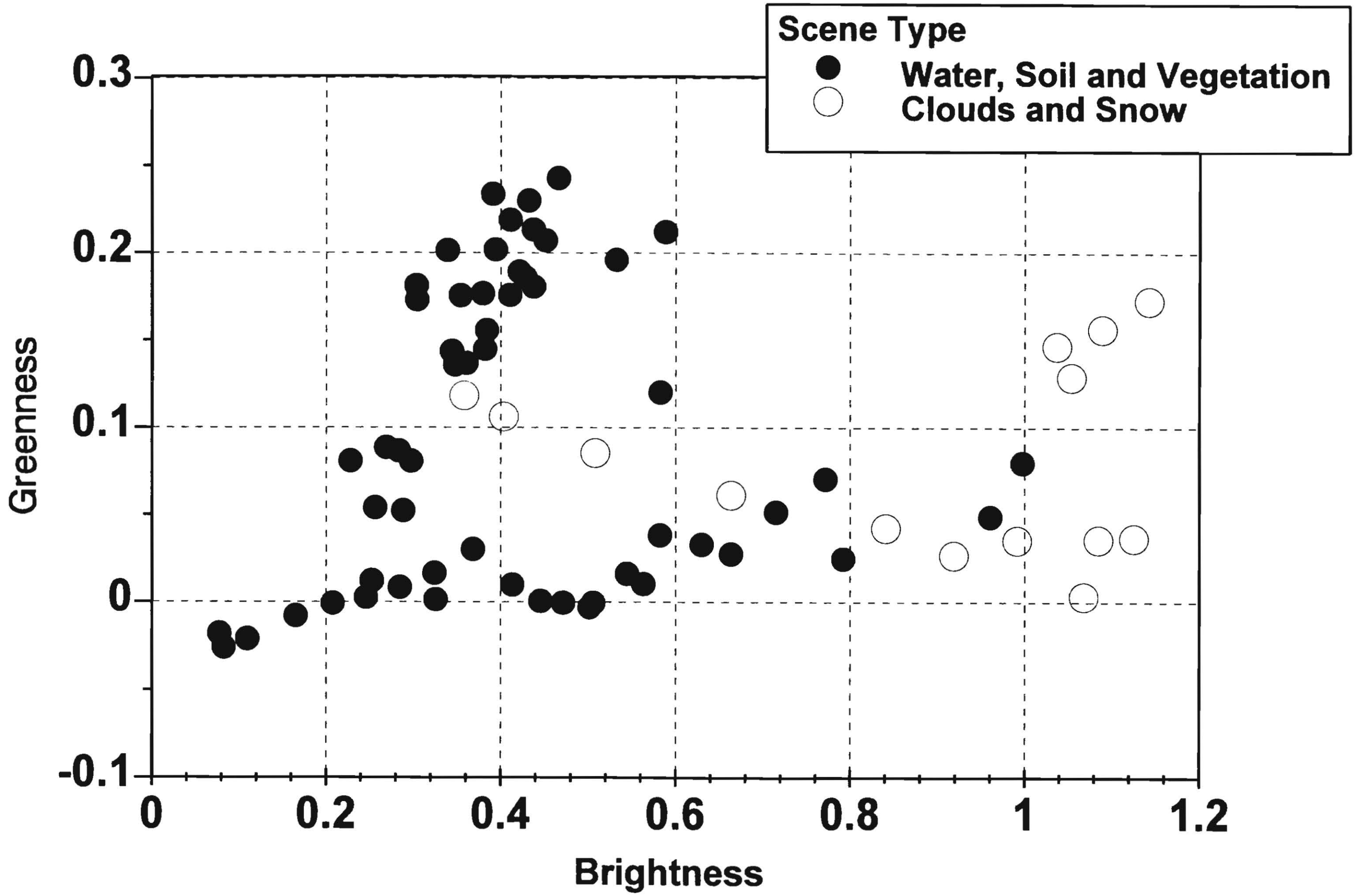

Figure 6 - The Brightness-Greenness (B-G) plane of the tasseled cap transform data from Figure 3.

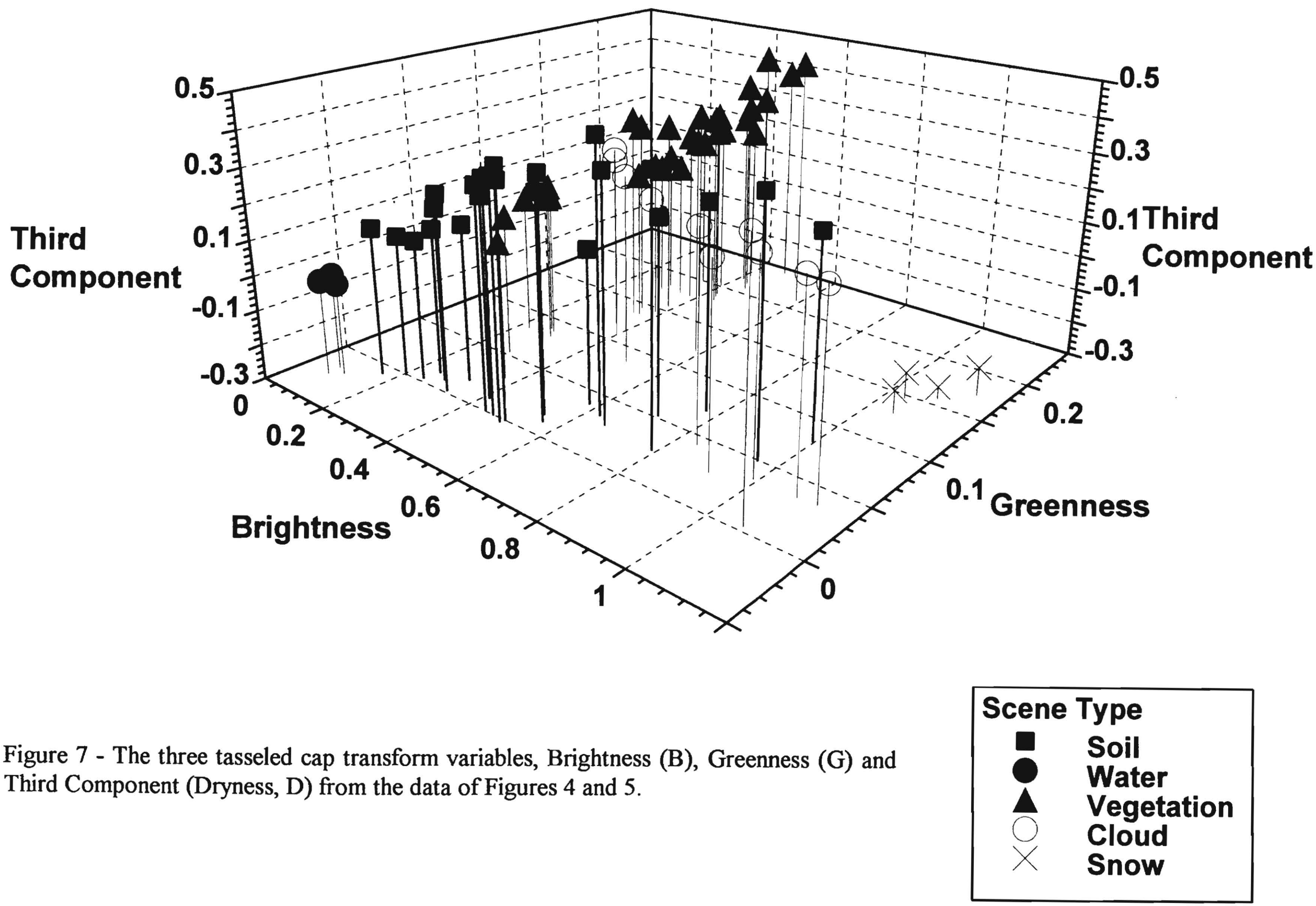

Figure 7 - The three tasseled cap transform variables, Brightness (B), Greenness (G) and Third Component (Dryness, D) from the data of Figures 4 and 5.

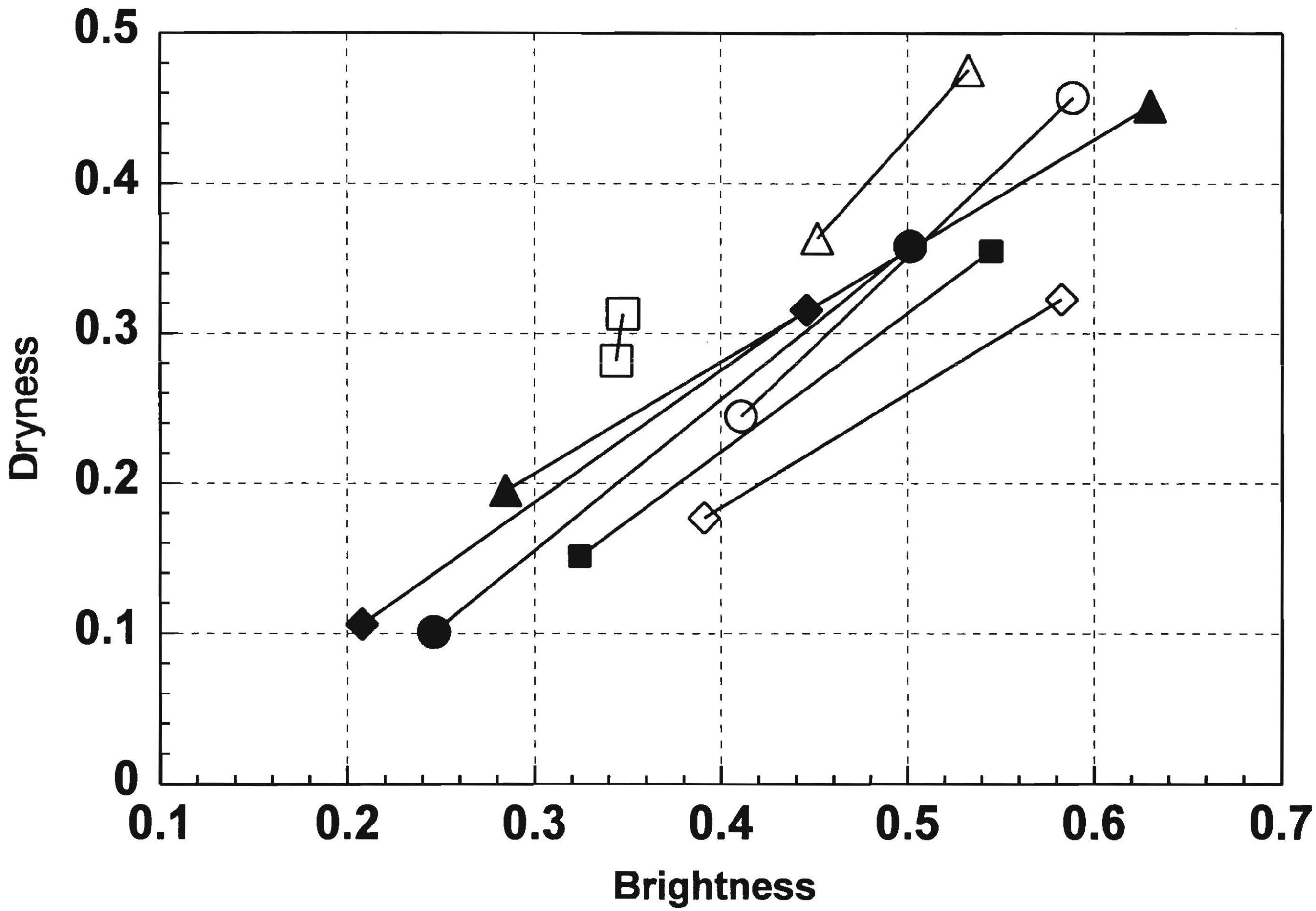

Figure 8 - Dryness versus Brightness (D-B) for various wet and dry soil types (open symbols) and vegetation types (solid symbols) from the Bowker et al. (1985) spectral reflectances: □ = clay, ❍ = clay soil, ◊ = sandy soil, Δ = silt, ■ = beans, • = cotton, ♦ = pine, ▲ = sycamore.

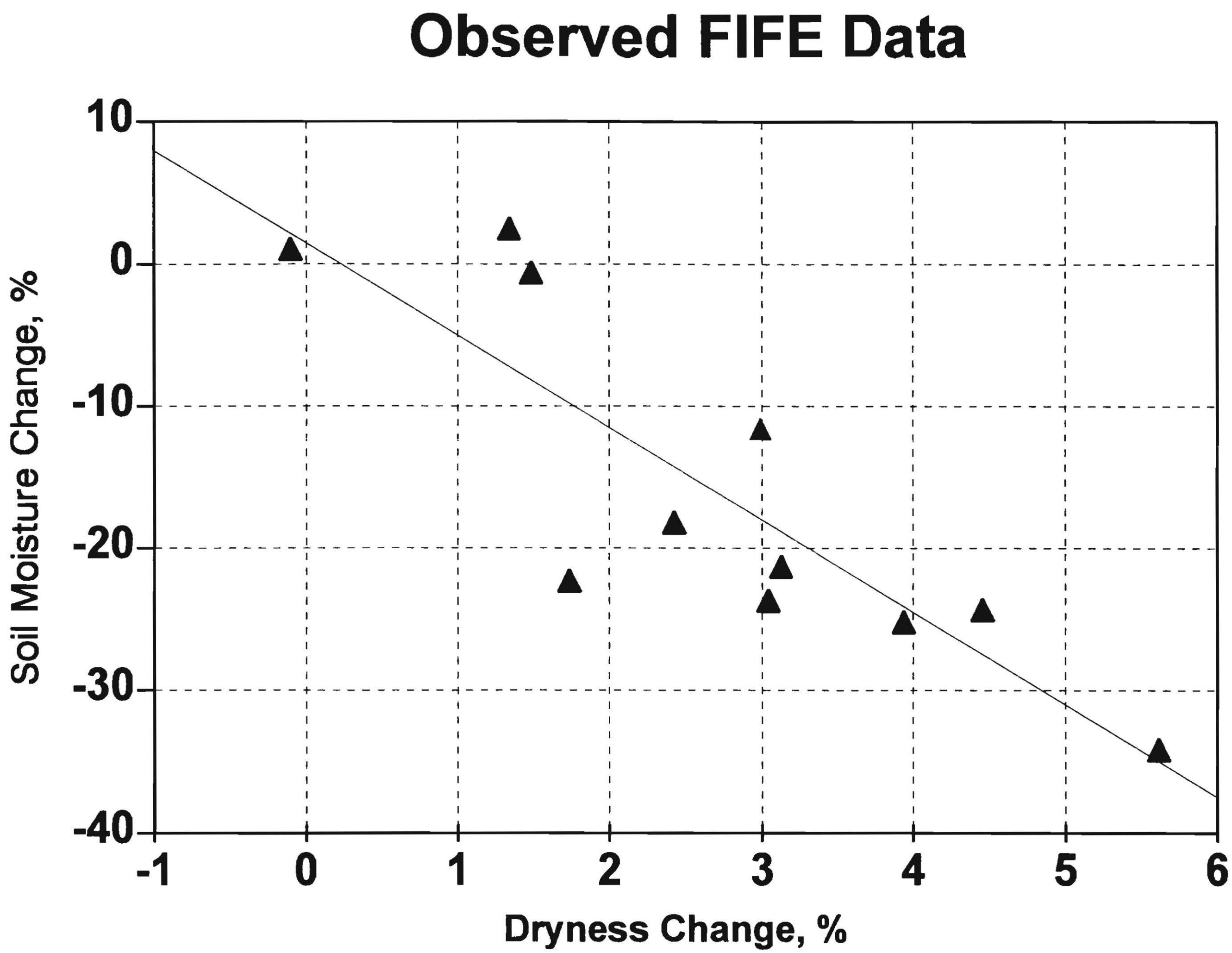

Figure 9 - Observed FIFE soil moisture change between observations versus observed TM-surrogate AVHRR Dryness value change between observations.

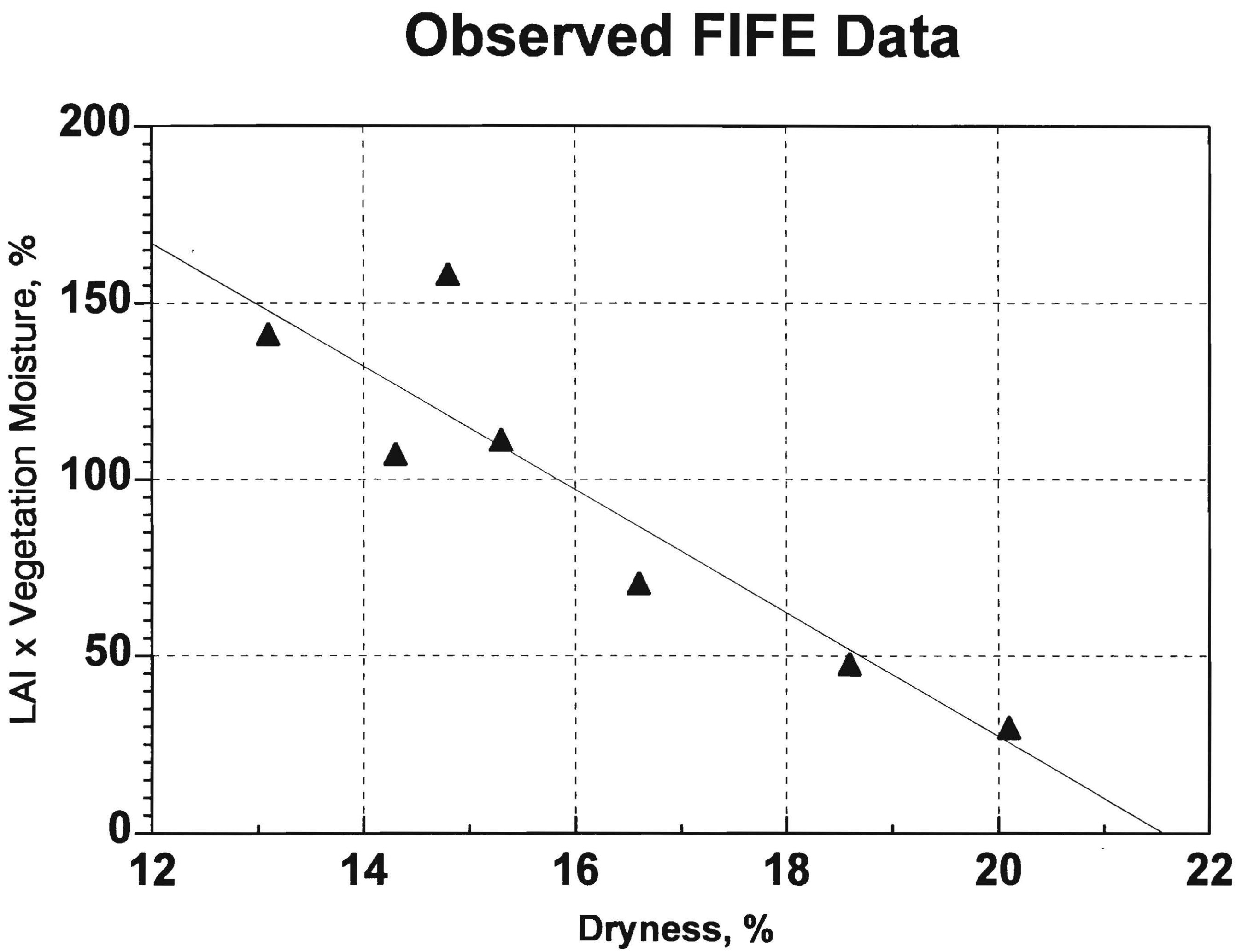

Figure 10 - Observed FIFE data for the product of vegetation moisture (% dry weight) times leaf-area-index (LAI) versus the observed TM-surrogate AVHRR Dryness parameter.