Proceedings of the Second

International Airborne Remote Sensing Conference and Exhibition

Technology, Measurement & Analysis

Volume II

24-27 June 1996
San Francisco, California
USA

JORNEX: AN AIRBORNE CAMPAIGN TO QUANTIFY RANGELAND VEGETATION CHANGE AND PLANT COMMUNITY-ATMOSPHERIC INTERACTIONS[1]

J.C. Ritchie[a], A. Rango[a], W.P. Kustas[a], T.J. Schmugge[a], K. Brubaker[a], X. Zhan[a], K.M. Havstad[b], B. Nolan[b], J.H. Prueger[c], J.H. Everitt[d], M.R. Davis[d], F.R. Schiebe[e], J.D. Ross[f], K.S. Humes[g], L.E. Hipps[h], K. Ramalingam[h], M. Menenti[i], W.G.M. Bastiaanssen[i], H. Pelgrum[i]

[a]USDA-ARS Hydrology Laboratory, Beltsville, MD 20705; [b] USDA-ARS Jornada Experimental Range, Las Cruces, NM 88003; [c]USDA-ARS National Tilth Laboratory, Ames, IA 50011; [d]USDA-ARS Remote Sensing Research, Weslaco, TX 78596; [e]Site-Specific Technology Development Group Inc., 2228 W. 12th. Street, Stillwater, OK 74074; [f]USDA-ARS National Agricultural Water Quality Laboratory, Durant, OK 74702; [g]Department of Geography, University of Oklahoma, Norman, OK 73069; [h]Department of Soil Science and Biometerology, Utah State University, Logan, UT 84321; [i]DLO-Winand Staring Centre, P.O. Box 125, 6700 AC Wageningen, The Netherlands

ABSTRACT

The Jornada Experimental Range in southern New Mexico provides a unique opportunity to integrate hydrologic-atmospheric fluxes and surface states, vegetation types, cover, and distribution, and vegetation response to changes in hydrologic states and atmospheric driving forces. The Jornada Range is the site of a long-term ecological research program to investigate the processes leading to desertification. In concert with ongoing ground measurements, remotely sensed data are being collected from ground, airborne, and satellite platforms during JORNEX (the JORNada EXperiment) to provide spatial and temporal distribution of vegetation state using laser altimeter and multispectral aircraft and satellite data and surface energy balance estimates from a combination of parameters and state variables derived from remotely sensed data. These measurements will be used as inputs to models to quantify the hydrologic budget and the plant response to changes in components in the water and energy balance. Intensive three day study periods for ground and airborne campaigns have been made in May 1995 (dry season) and September 1995 (wet season), February 1996 (Winter) and are planned for wet and dry seasons of 1996. An airborne platform is being used to collect thermal, multispectral, 3-band video, and laser altimetry profile data. Bowen ratio-energy balance stations were established in shrub and grass communities in May 1995 and are collecting data continuously. Additional energy flux measurements were made using eddy correlation techniques during the September 1995 campaign. Ground-based measurements during the intensive campaigns include thermal and multispectral measurements made using yoke-based platforms and hand-held instruments, LAI, and other vegetation data. Ground and aircraft measurements are acquired during Landsat overpasses so the effect of scale on measurements can be studied. This paper discusses preliminary results from the 1995 airborne campaign.

INTRODUCTION

The Jornada Experimental Range in southern New Mexico provides a unique opportunity to integrate hydrologic-atmospheric fluxes and surface states, vegetation types, cover, and distribution, and vegetation response to changes in hydrologic states and atmospheric driving forces. As a National Science Foundation (NSF) Long-Term Ecological Reserve (LTER) and a United Nations (UN) Man and the Biosphere (MAB) site, the Jornada Experimental Range is the site of long-term ecological research programs to investigate the processes related to desertification. The ongoing investigations within

---

[1] Presented at the Second International Airborne Remote Sensing Conference and Exposition, San Francisco, California, 24-27 June 1996

the LTER have yielded a wealth of ground data about the basin vegetation characteristics, ecosystem dynamics, and vegetation response to hydrologic-atmospheric inputs.

In concert with the ongoing programs of ground measurements, a campaign named JORNEX (the JORNada EXperiment) was begun in 1995 to collect remotely sensed data from ground, airborne, and satellite platforms to provide spatial and temporal data on the physical and biological state of the rangeland. Data on distribution of vegetation state were measured on the ground with detailed vegetation surveys (cover, composition, height) at preestablished transects and with hand-held and yoke mounted radiometers and infrared thermal radiometers, from an aircraft with radiometers, infrared thermal radiometer, multispectral video and a laser altimeter, and in space with Landsat Thematic Mapper satellite data. Surface energy balance estimates are made from a combination of parameters and state variables estimated from remotely sensed and ground data. Different platforms (ground, aircraft, and satellite) allow the evaluation of landscape patterns and states at different scales. These measurements will be used as inputs to quantify the hydrologic budget and plant response to changes in components in the water and energy balance. This paper will discuss preliminary results from the 1995 and 1996 airborne campaigns.

STUDY AREA

The Jornada Experimental Range, the largest Agricultural Research Service (ARS) field station (783 km^2), is located 37 km north of Las Cruces, New Mexico. Most of the Experimental Range is on the Jornada del Muerto Plain of the Chihuahuan Desert. It lies between the Rio Grande Valley on the West and the San Andres Mountains on the east in the northern part of the Chihuahuan Desert. The crest of the San Andres mountain roughly coincides with the eastern boundary of the Experimental Range.

The climate is characteristic of the northern region of the Chihuahuan desert, the most arid of the North American grasslands. By definition, the Chihuahuan Desert is an area above 1100 m elevation where the ratio of long term average annual precipitation (mm) / (long term average temperature C + 10) is less than 10. Annual averages for precipitation and temperature are 241 mm and 15 C, respectively. Approximately 55% of the annual precipitation occurs as localized thunderstorms during July, August and September. Droughts (<75% of average annual precipitation) are common, and have occurred in 18 years from 1915-1995. The frost free period averages 200 days, but the effective growing season, especially for perennial grasses, is limited to the summer months. High temperatures, low humidities, and frequent winds (annual average wind movement is 17,346 km) result in large water losses by evaporation. Potential evaporation rates are approximately 10 times the average precipitation.

The Experimental Range is located on the La Mesa geomorphic surface of middle Pleistocene age (>400,000 ybp). The ancestral Rio Grande river deposited sediments on this Plain. The three study sites are located on Typic Haplargid and Paleargid soils that have developed from alluvium in level basins below the piedmonts. Wind in this region commonly modifies these gentle sloping surfaces. The soils are loamy sands and fine loamy sands typical of the Onite, Pajarito, Pintura and Wink series. These soils are moderately deep, but have calcic horizons of varying thicknesses relatively close to the surface. Virtually all of the carbonate content of these soils originated from atmospheric additions. Surface colors are typically light brown and reddish brown, and were called Desert and Red Desert soils in earlier soil classifications.

The vegetation is characteristic of a subtropical ecosystem in the hot desert biome. Grasses are entirely C4 and principle dominants include black grama (*Bouteloua eriopoda* (Torr.) Torr.), mesa dropseed (*Sporobolus flexuosus* (Thurb. Ex Vasey) Rydb.), and three-awn (*Aristida purpurea* Nutt. and *Aristida pansa* Wooton & Standl.). Shrubs and suffrutescents are commonly C3 and include honey mesquite (*Prosopis glandulosa* Torr.), Western honey mesquite (*Prosopis glandulosa var. torreyana* (L. Benson) M. C. Johnston), fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.), Broom snakeweed (*Gutierrezia sarothrae* (Pursh) Britton & Rusby), and a soaptree yucca (*Yucca elata* (Engelm.) Engelm.). Seasonal rains can trigger flushes of both annual and perennial forbs such as spectaclepod (*Dithyrea wislizenii* Engelm.), Desert baileya (*Baileya multiradiata* Harv. & Gray) and leatherweed croton (*Croton pottsii* (Klotzsch) Muell.Arg.). Grass communities dominated by black grama have been susceptible to disturbances (such as prolonged drought and overgrazing) and encroachment by shrubs during the last century has been common.

Large areas of former grassland, including the northern portion of the study area are now dominated by honey mesquite. This conversion on these deep coarse texture soils characteristically resulted in formation of coppice dunes (Buffington and Herbel, 1965), increasing spatial heterogeneity of critically limited nutrients (especially N) required for plant growth (Schlesinger et al., 1990), and increased wind erosion (Gibbens et al., 1993). It is unlikely that these vegetation conversions are reversible without substantial external inputs that could not be regarded as sustainable. The study area encompasses an ecotone between a remnant black grama grass and a honey mesquite coppice duneland that developed in the past 80 years. Without subsequent intervention further desertification of this grass is anticipated during the next century.

Within the larger Jornada Experimental Range, three specific sites were chosen for intensive studies. Sites were selected to represent grass, shrub, and grass-shrub transition areas. Black grama dominates the grass site and is within a long term study are where grazing has been excluded. The site is relatively level. Honey mesquite on coppice dunes dominates the shrub site. The dunes vary in height from 1 to 5 m with a honey mesquite on each. Between dunes is usually bare soil. The grass-shrub transition site is a transition area between the grass and shrub with vegetation components from both. Some dunes are present but are usually less than 1 meter in height.

METHODS[2]

Intensive ground and airborne campaigns were made in May 1995 (dry season), September 1995 (wet season) and February 1996 (winter), and are planned for the dry (May) and wet (September) seasons of 1996. An airborne platform (Aerocommander) is being used to collect thermal, multispectral, video and laser altimeter data. A scanning laser was flown during the September 1995 campaign over the shrub and transition sites. Airborne campaigns are scheduled to make measurements for a three (3) day intensive study period centered on the overpass of Landsat-5. Landsat Thematic Mapper (TM) will be evaluated for scaling ground and aircraft measurements to larger areas. Extensive ground data are collected during these three day periods. AVHRR data will also be used to make inferences about larger areas.

Airborne data

Video Imagery

Video imagery was obtained with a three-camera multispectral digital video imaging system (Everitt et al., 1995). The system consists of three charge-coupled devices (CCD) analog video cameras, a computer equipped with an image digitizing board, a color encoder, and a super (S)-VHS portable recorder. The cameras are visible-near-infrared (NIR) (0.4 - 1.1 µm) light sensitive. For this experiment the three cameras are equipped with visible yellow-green (YG, 0.555 - 0.565 µm), red (R, 0.623 - 0.635 µm), and NIR (0.845 - 0.857 µm) filters, respectively. The computer is a 486-DX50 system that has an RGB image grabbing board (640 x 480 pixel resolution). The NIR, R, and YG image signals from the cameras are subjected to RGB inputs of the computer digitizing board, thus giving a color-infrared (CIR) composite digital image similar in color rendition to CIR film. The computer hard disk can store 1000 CIR composite images. In addition, the signals of cameras are also subjected to a color encoder that provides an analog CIR composite that is stored on the S-VHS recorder. The analog CIR imagery recording serves as a back up in the event the computer malfunctions.

A Global Positioning System (GPS) navigation system (Trimble Transpack II) is integrated with this system on the airplane. The navigation system constantly receives data from GPS satellites and calculates and displays continuously the flight direction (bearing), altitude, time, ground speed, and latitude-longitude coordinates. A video insertion system (Compix model LP-701) transfers the continuous GPS information on the last two lines of the R-filtered camera, which in

---

[2] Trade names are included for the benefit of the reader and do not imply an endorsement of or a preference for the product listed by the U. S. Department of Agriculture.

turn annotates the composite image on the video tape. The latitude and longitude coordinates correspond to the approximate center of each image and have an accuracy of ±100 m.

Video imagery was obtained using this system at the grass, shrub and the grass-shrub transition sites on September 24-25, 1995 and February 15-16, 1996. The video system was mounted in the floor (port) of the Aerocommander aircraft. Imagery was acquired at altitudes of 300, 750, and 1500 m between 1000 and 1530 hrs under sunny conditions.

Thermal and multispectral data

The instrument used to make the airborne measurements of temperature was an Everest thermal infrared radiometer (IRT) with a band pass of approximately 8-13 μm and a 15° field of view. An Exotech 4-band radiometer with interchangeable filters was used to make radiance measurements corresponding to the first 4 bands of the Landsat Thematic Mapper (0.45-0.52 μm (blue), 0.53-0.61 μm (green), 0.62-0.69 μm (red) and 0.78-0.90 μm (near infrared)).

The IRT and one Exotech were mounted looking nadir. A second Exotech was mounted looking toward the sky. Thus, measurements of the incoming and reflected radiation were measured simultaneously. A video camera, borehole-sighted with the IRT and Exotech, records an image of the flight line. Each video frame is annotated with GPS data (time, latitude, longitude, etc.). Data collections from the IRT and Exotech are synchronized to the GPS time. Airborne data from these instruments were collected for two (2) north-south flight lines that passed over the three study sites. Each flight line was approximately 10 km. Flights were made at elevations of approximately 125 m and 300 m with two (2) passes in opposite direction at each elevation on each flight line. Flights were made on the three days centered on the Landsat TM overpass. Morning (0900-1100 hours) and early afternoon (1230-1430 hours) flights were made on each of the three days, weather permitting.

Laser Altimeter

Laser altimetry measurements were made on 4 north-south and 4 east-west flight lines. These flight lines were designed to cross the three study sites. Two of the lines were the same flight lines used for the thermal and radiance flights. Laser altimetry flights were made in May 1995, September 1995, and February 1996.

The laser altimeter mounted in the Aerocommander was used to measure the distance from the airplane to the landscape surface. The altimeter is a pulsed gallium-arsenide diode laser, transmitting and receiving 4000 pulses per second at a wavelength of 904 nm. The field-of-view of the laser is 0.6 milliradians that gives a "footprint" on the ground that is approximately 0.06% of the altitude. The timing electronics of the laser receiver allow a vertical resolution of 5 cm for each measurement.

Digital data (distance from the airplane to the landscape surface) from the laser receiver along with data from a gyroscope and an accelerometer mounted on the base of the laser platform are recorded with a portable personal computer. A video camera, borehole-sighted with the laser, records an image of the flight line. Sixty video frames are recorded per second and frame are annotated with consecutive numbers, clock time, and GPS data. Each video frame number is recorded with digital laser data by the computer to allow precise location of the laser data on the landscape with the video data for these studies.

Landscape surface elevation was calculated for each laser measurement based on known ground elevations along a flight line. The minimum elevations measured along a flight line are assumed to be ground surface elevation with measurements above these minimums being due to vegetation or man made structures.

Ground Data

Ground-based data collected during each of the three-day intensive campaigns include thermal and multispectral measurements made using hand-held and backpack-mounted instruments, geometric and radiometric vegetation measurements, and surface energy flux measurements.

Thermal and multispectral measurements

Ground temperatures were measured with an Everest thermal infrared radiometer (IRT) with a band pass of approximately 8-13 μm and a 3° field of view. The multispectral measurements were made using an Exotech 4-band radiometer with interchangeable filters. Filters corresponding to the first 4 bands of the Landsat Thematic Mapper (TM) were installed 0.45-0.52 μm (blue), 0.53-0.61 μm (green), 0.62-0.69 μm (red) and 0.78-0.90 μm (near infrared).

A backpack-type apparatus (called a "yoke") equipped with an IRT and an Exotech was used to make measurements over an area equivalent to Landsat TM pixels (120 m in the thermal, 30 m in the visible). Measurements were taken at 5 m intervals between center points of a grid of sixteen 30-m squares, as the observer walked in a pattern designed to minimize self-shading. The yoke-mounted Exotech was looking nadir, and a second (stationary) Exotech was mounted looking skyward. Thus, the incoming and outgoing radiation were measured simultaneously. Yoke measurements of temperature and radiance were made at the grass site during the September 1995 experimental period, during the aircraft overflight and during the Landsat overpass.

At the other study sites, landscape surface temperatures were measured with hand-held IRTs, during each aircraft overflight for each study period. These temperature measurements were collected at 5 m intervals over a gridded pattern approximately 30 m on a side.

Vegetation measurements

Total basal vegetative cover in this environment is low. The standard technique for measuring vegetation cover and composition is the vertical line intercept method (Canfield, 1941; Eberhart, 1978). Vegetation measurements were selected near the study sites to represent grass, shrub and grass-shrub transition site, and specific locations were based on prior supervised classification of the vegetation communities in this area. A single 150 m transect was established at each site. The lines were placed to correspond to one flight line within the site. Permanent markers were geopositioned and the same transect placement was remeasured each sampling period Within each line three 30 m segments were measured for vertical line intercepts at 10 cm intervals for a total of 900 points per site. Measurements were recorded by species. In support of the laser altimeter data, vertical heights of the tallest vegetated structure (i.e., herbaceous culm, woody liter, leaf canopy) at each intercept point were also collected. Height measurements (nearest cm) were made for both live plant material and standing litter.

Radiometric plant canopy and soil reflectance measurements were made at the grass and transition site on September 24, 1995. Reflectance measurements were made of western honey mesquite, soaptree yucca, broom snakeweed, black grama, and bare soil at the desert grass site. For the transition site, measurements were made on western honey mesquite, broom snakeweed, four-wing saltbush, and bare soil. These plants are the dominant species on each study site. Reflectance measurements consisted of 15 randomly selected plant canopies (each species) and soil surfaces with a Barnes' modular multispectral radiometer (Anonymous, 1980). Measurements were made in the visible green (0.52 - 0.60 μm), visible red (0.63 - 0.69 μm), and NIR (0.76 - 0.90 μm) spectral bands with a sensor that had a 15 ° field-of-view placed 1 to 1.5 m above each canopy/soil surface. Reflectance measurements were made between 1130 and 1400 hours under sunny conditions. Radiometric measurements were corrected to reflectance at a common solar irradiance reference condition (Richardson, 1981).

Leaf-area indexes (LAI) measurements were made with a portable LI-COR instrument along the same 150 m transects used for the vegetation measurements and along supplemental transects in the same communities. Measurements were made at 1 m intervals along the transects during the September and February study periods.

Flux measurements

Surface energy fluxes have been monitored continuously since May 1995 using the Bowen ratio-energy balance method and periodically (during intensive field campaigns) with eddy correlation systems at primarily two locations. One is located at the grass site (site 1) and the other at the shrub site (site 2) on dunes 1 to 2 m in height and 10-20 m in width. In addition, a third site contained a 10 m tower during the September field campaign at the transition site (site 3). Eddy correlation instruments were positioned at two heights on the tower.

Theory of flux measurements

Bowen Ratio/Energy Balance Approach

To evaluate the energy balance over non-forested land surfaces and under non-advective conditions requires the determination of four flux components, which are related by:

$$R_n - G - H - \lambda E = 0 \qquad (1)$$

where R_n is net radiation, G is soil heat flux, H is sensible heat flux, E is evaporative flux, and λ is latent heat of vaporization. Under daytime convective conditions, typically R_n, G, H and λE are positive. At the grass and shrub sites, R_n and G were measured using thermopile devices, and the turbulent fluxes (H and λE) were measured using the BREB (Bowen-ratio energy balance) method.

The BREB method is based on the assumption that the eddy diffusivities for H and λE in the atmospheric surface layer are equal (Bowen, 1926). The Bowen ratio, β, which is the ratio of H to λE, can then be measured as:

$$\beta \doteq \frac{\gamma \Delta T}{\Delta e} \qquad (2)$$

where γ is the psychometric constant, ΔT is the temperature difference between two elevations above a plant canopy, and Δe is the vapor-pressure difference between the same two elevations. Combining Eq. (1) with the definition of β leads to:

$$\lambda E = \frac{R_n - G}{1 + \beta} \qquad (3)$$

H is then calculated from Eq. (1). Calculated values of λE and H are dependent on measurements of R_n, G, ΔT and Δe, and on the validity of the advection and eddy-diffusivity assumptions. Net radiation (R_n) is measured using thermopile type, shielded net radiometers. Soil heat flux at the surface (G) is measured using the combination method (Tanner, 1960), which involves burying heat flux plates at a depth of several centimeters to measure soil heat flow (G_d), and measuring the change in soil temperature above the plates to compute the soil heat storage term (S). The BREB method has been tested by many investigators and it is thought to have an uncertainty of 10% for λE under ideal conditions (Sinclair et al., 1975). For heterogeneous surfaces, however, the uncertainty probably increases to 20 to 30% (Nie et al., 1992).

Eddy Correlation Technique

The Eddy correlation (EC) method uses high-frequency measurements of vapor density (ρ_v), air temperature (T), and vertical windspeed (w) to compute λE and H independently. Assuming the mean vertical windspeed ($\overline{w}$), is zero, the fluxes are:

$$\lambda E = \lambda \overline{w' \rho'_v} \qquad (4)$$

and

$$H = \rho c_p \, \overline{w' T'} \qquad (5)$$

where ρ is air density, C_p is the specific heat capacity of air, primes denote deviations from mean values, and overbars denote mean covariances during a measurement period. The quantities $\overline{w' \rho_v'}$ and $\overline{w' T'}$ are covariances. The feasibility of this method was demonstrated more than 40 years ago by Swinbank (1951) with continuous refinements being made (Dyer, 1961; Hicks, 1970; Miyake and McBean, 1970; Webb et al., 1980; Tanner et al., 1985; Shuttleworth et al., 1988) An accuracy of 5-10% in the measurement of H and λE is generally assumed for measurements made over a uniform surface with an adequate fetch.

The surface energy balance system (SEBS)were installed at sites 1 and 2 to measure energy flux, weather and supplementary data. The SEBS is an integrated system of sensors designed for the U.S. Department of Energy's Atmospheric Radiation Measurements (ARM) program by Radiation and Energy Balance Systems Inc. (REBS). The collection of Bowen-ratio, weather, and supplementary data began in May of 1995 and will continue through at least September of 1996.

R_n is measured using the REBS Q7 net radiometer positioned between 2 and 3 m above the surface. Three REBS HFT-3 soil-heat-flux plates were buried at 5 cm to measure G_4, and three platinum resistance thermometer probes were buried to measure the change in soil temperature for computing S. Each probe measured the mean temperature between the surface and the 5-cm depth.

Air temperature and vapor pressure differences were measured with modified Vaisala HMP35A temperature-humidity probes with a 2 m separation. The mechanism, designed by REBS, exchanged sensor positions every 15 min, allowing 2 min for equilibration after each exchange. The position of the lower sensor is 10 to 20 cm above the surrounding vegetation. Measurements from two 15-min periods were averaged to produce a 30-min Bowen ratio.

Wind speed and directions were measured using a Met One anemometer and a wind vane located at a nominal height of 3 m above the local topography. Atmospheric pressure was measured using a Met One barometric pressure sensor at site 2. Soil moisture was measured over the 5 cm depth, using three soil moisture resistance sensors (REBS SMP-2). This value of soil moisture was used with an estimate of bulk density to compute the soil heat capacity that is then used with time rates of change in soil temperatures in calculating S. All sensors on the REBS installation were scanned every 30 sec, with 15-min and 30-min means recorded on a Campbell Scientific CR10 data logger.

Eddy-correlation measurements were made using a one-dimensional (1-D) Campbell Scientific CA27 sonic anemometer (with a fine wire thermocouple) to measure w and T, and a KH20 krypton hygrometer to measure ρ_v (Tanner et al., 1985; Tanner, 1988). These sensors were co-located with the BREB systems and deployed approximately 1.8 m above the grass surface at site 1 and 2.25 m above the mesquite/dune surface at site 2. The EC sensors at both sites were periodically reoriented to maintain undisturbed air flow past the sensors due to variable wind directions. At the grass and shrub sites measurements of net radiation and soil heat flux in addition and independent to those made at the BREB sites were also conducted using the REBS Q7 net radiometer and HFT-3 soil heat flux sensors. Temperature and relative humidity measurements necessary for correcting for oxygen and density effects on the λE flux (Webb et al., 1980) were made using a Vaisala HMP-35 temperature /humidity probe at 2 m above the surface.

At the transition site, 1-D sonic and krypton hygrometer sensors were deployed at 2 and 10 m on a steel tower. The differential heights on the tower were selected to represent two distinct source areas of latent heat as a function of different vegetative cover. All EC sensors were scanned at 10 hz with intermediate calculations of the covariances in Eq. 4 and 5 computed every 10 min. At the end of every 30 minutes the 10 min. covariances were averaged and recorded on a Campbell Scientific 21X data logger as 30-min fluxes of H and λE.

RESULTS

Multispectral Video

Videographic and reflectance data are currently being analyzed. Qualitative assessment of the CIR composite video imagery shows differences in image tones among plant species (cover types) at both sites. However, contrast is greater at the grass site where black grama has a distinct dark signature that can be readily separated from the red to magenta tones of western honey mesquite and soaptree yucca. At the transition site, western honey mesquite appears as red clumps that give it a conspicuous geometric shape. Soils at the transition site are brighter than that at the desert grass site. This characteristic also enhances the detection of western honey mesquite.

Preliminary results show significant differences in ground reflectance measurements among plant species at the grass site. Black grama has lower NIR reflectance than the other species at the grass site, which supports its dark image response in the CIR video imagery. Visible and NIR reflectance values of soil at the transition higher than those for the plant species. This concurs with the bright soil image response at this site.

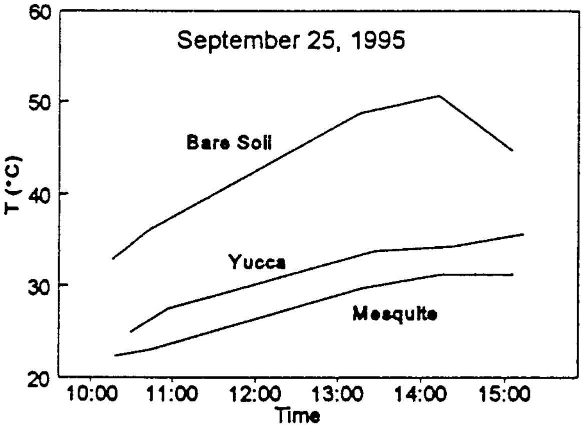

Figure 1. Surface temperatures measured at the transition site on September 25, 1995.

Thermal

During the September 1995 study period the ground measurements of surface temperature showed considerable difference between vegetation and bare soil surfaces. At the shrub and transition sites, a 30 °C difference was measured. The data for the different flight times for the shrub site are shown in Table 1. Passage of clouds sometimes reduced the maximums. These temperatures along with the images of the site for obtaining relative vegetation cover should enable us to estimate the temperatures measured by the IRT on the airplane. Similar data for one day for the transition site are shown in Figure 1. Temperature ranges are similar at both sites. Temperature of the bare soil was approximately 10° C higher that of the vegetation. The Yucca with broad leaves had a higher temperature that the smaller leafed Mesquite.

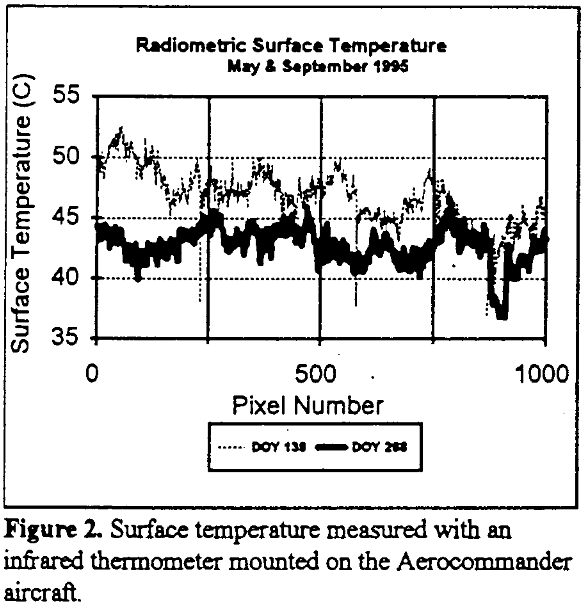

Figure 2. Surface temperature measured with an infrared thermometer mounted on the Aerocommander aircraft.

Figure 2 illustrates two transects of radiometric surface temperature from a nadir-viewing IRT with a 15° field of view (FOV) on board the Aerocommander aircraft. The aircraft flew at nominal height of 300 m yielding an IRT sensor footprint diameter of 80 m. The transects were flown on May 20, 1995 (DOY 139) between 1200 and 1230 local time and September 25 (DOY 268) between 1400 and 1430 local time over the study area. These data will be georeferenced to interpret the surface features causing the spatial and temporal variation in the observations. In both transects the surface temperatures are relatively high due to the sparse vegetation cover and dry soil surface conditions. There also may be some larger scale features that cause the surface temperature to oscillate or show periodicity. Temperatures are in the same range as those measured on the ground.

Fluxes

Examples of the surface energy balance components estimated using the BREB method for a day during the May (Day 144) and September (Day 268) campaigns of 1995 are illustrated (Figs. 3-6). Note for site 1 (Figs. 3&4), the significant difference in the partitioning of the available energy $(R_N - G)$ into H and λE between the May campaign when the grass was senescent and September where summer precipitation revived, to some extent, the dormant grass vegetation. However, there has been a drought at the Jornada Experimental Range that started in 1994 and continues through 1996 with little precipitation recorded in the winters of 1994/1995 and 1995/1996. Thus the differences observed between May and September are not as marked as one might see for a normal precipitation year. The contrast in the partitioning of H and λE between May and September for site 2 (Figs.5 & 6) is similar to site 1, but not as dramatic. Whether vegetation differences

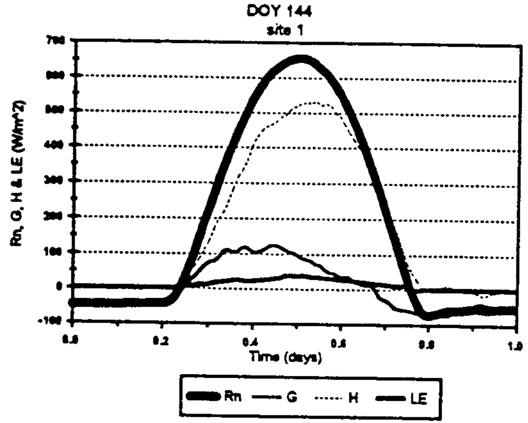

Figure 3. Surface energy balance for grass site for Day 144 in May 1995.

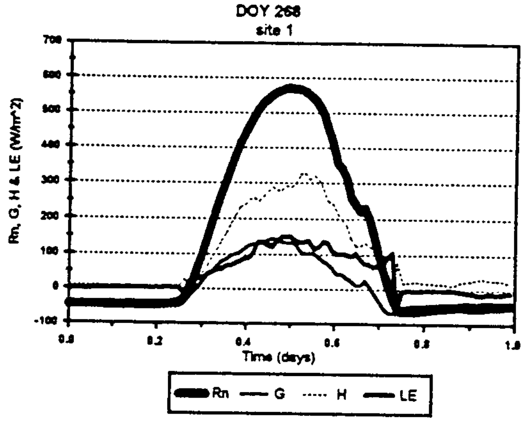

Figure 4. Surface energy balance for grass site for Day 268 in September 1995.

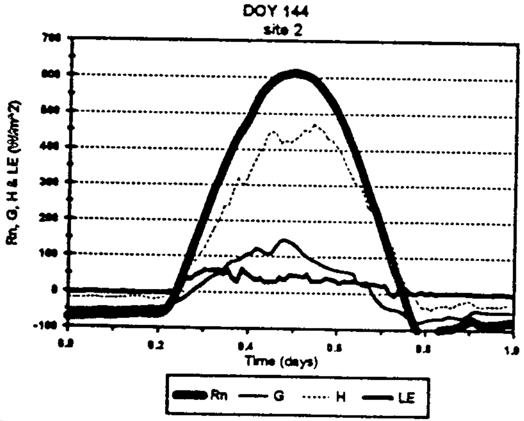

Figure 5. Surface energy balance for the shrub site for Day 144 in May 1995.

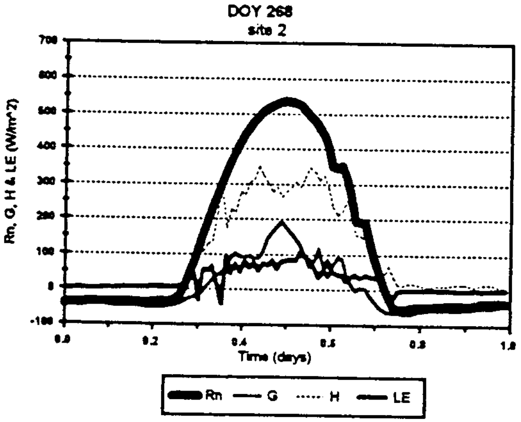

Figure 6. Surface energy balance for shrub site for Day 268 in September 1995.

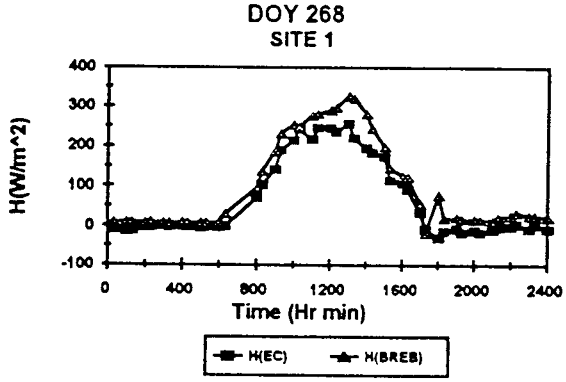

Figure 7. Comparison of sensible heat flux (H) measured by the Bowen ratio (BRED) and Eddy Correlation (EC) methods at the grass site.

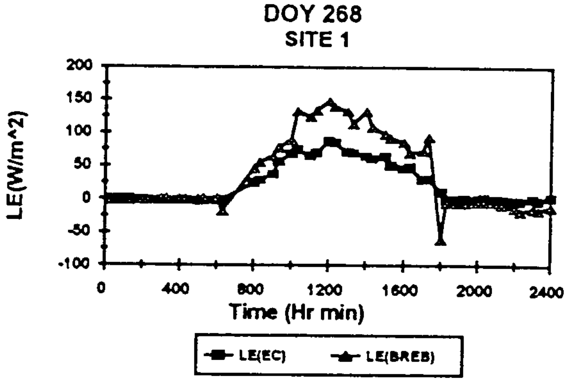

Figure 8. Comparison of latent heat flux (λE) measured by the Bowen ratio (BREB) and Eddy Correlation (EC) methods at the grass site.

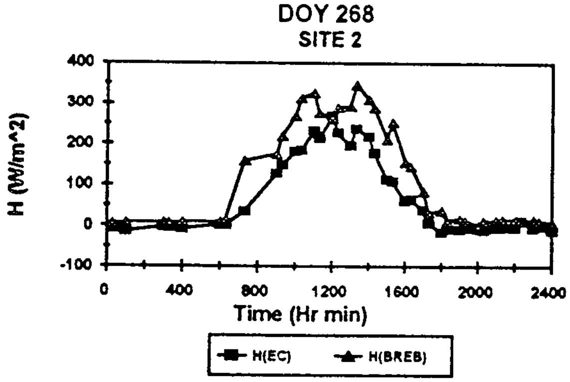

Figure 9. Comparison of sensible heat flux (H) measured by the Bowen ratio (BRED) and Eddy Correlation (EC) methods at the shrub site.

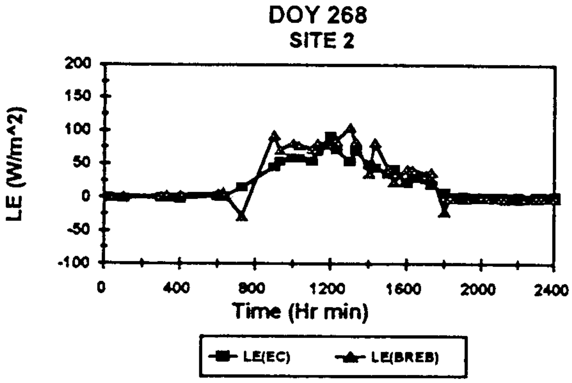

Figure 10. Comparison of latent heat flux (λE) measured by the Bowen ratio (BRED) and Eddy Correlation (EC) methods at the shrub site.

or difficulties cause by using the BREB method in complex terrain are being investigated with the EC data.

Eddy correlation data were collected during the September campaign (Figs. 7-10) with EC units co-located at the BREB sites and two EC units located 2 and 10 m on the tower located at the transition site. A comparison for Day 268 of H and λE from both systems at the grass site (Figs. 7 & 8) and the shrub site (Figs. 9 & 10) indicate that the H-values and λE-values estimated by the BREB method are generally higher than those by the EC method Factors causing these discrepancies in the flux partitioning are being investigated with the remotely sensed data. Differences in flux estimates between EC and BREB methods over heterogeneous terrain is not unusual. For example, similar discrepancies were observed in FIFE (Fritschen et al., 1992).

Finally, a comparison in λE-values from the 2 and 10 m measurement heights for Day 268 is shown in Figure 11. There are consistent differences in λE-values that may be caused largely by different vegetation types within the source-area footprints for the 2 and 10 m measurements (Schuepp et al., 1990; Schmid and Oke, 1990). The aircraft remote sensing data will be critical for evaluating the surface properties within each of the source-area footprints.

Laser

Laser altimeter measured transects at the grass and shrub sites show differences in surface topography and roughness at the sites (Figs. 12 & 13). The grass site is relatively level with an occasional shrub or taller vegetation on the surface. The shrub site has evidence on many dunes present on the underlying landscape.

Fractal analysis of the four transects of laser altimetry data at grass and shrub sites supports the possibility of distinguishing between these landscapes using fractal properties of the laser data. Results show that a specific range of scales has to be selected to use the fractal dimension for distinguishing between grass and shrub landscapes. Calculation of fractal dimensions from log-log plots involves the slope and intercept parameters. Whereas the slope is used directly to calculate the fractal dimension, the intercept represents an important measure of the vertical range or amplitude and is another parameter characterizing. This value defines such parameters of the surface roughness as the crossover length, topothesy, etc. This parameter can be included into distinguishing procedure. It remains to be determined whether seasonal changes of the vegetation modify or change the scaling laws of the surface roughness. All these questions represent exciting horizons to explore (Pachepsky et al., 1996).

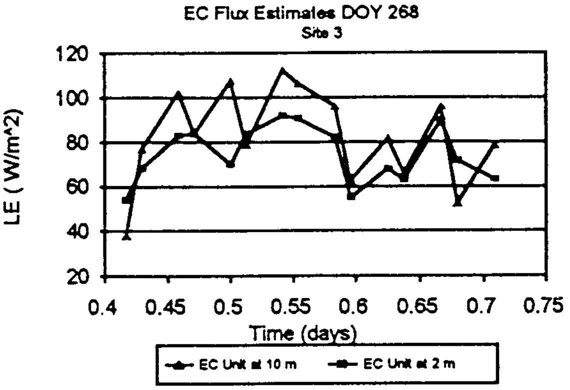

Figure 11. Eddy correlation estimates of latent heat (λE) at 2 and 10 meters for Day 268 in September 1995

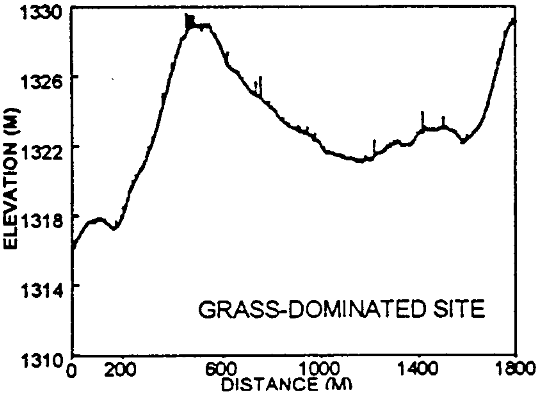

Figure 12. Laser altimeter measurement of topography and surface roughness at the grass site. Measurement was made in May 19, 1995 and are displayed using a 12-measurement block average.

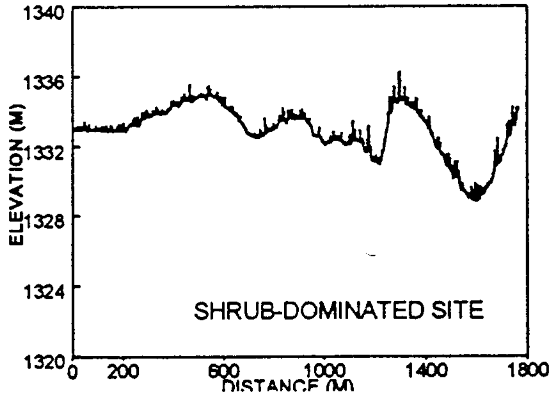

Figure 13. Laser altimeter measurement of topography and roughness at the shrub site. Data were collected May 19, 1995 and are displayed using a 12-measurement block average.

ACKNOWLEDGMENTS

The authors express appreciation to the USDA-ARS Remote Sensing Research Unit, Subtropical Agricultural Research Laboratory, Weslaco, TX for the use of their Aerocommander as the platform for flying the instrument. Special appreciation goes to M.R. Davis, pilot, USDA-ARS, Weslaco, TX, who flew the Aerocommander and was always willing to do "one more flight line." Sincere appreciation is due to the staffs of the USDA-ARS Jornada Experimental Range, Las

Cruces, NM, USDA-ARS Hydrology Laboratory, Beltsville, MD, USDA-ARS Remote Sensing Research Unit, Subtropical Agricultural Research Laboratory, Weslaco, TX, USDA-ARS National Tilth Laboratory, Ames, IA, and the USDA-ARS National Agricultural Water Quality Laboratory, Durant, Oklahoma, who provided logistical and ground support before, during, and after the airborne campaigns.

LITERATURE CITED

Anonymous. 1980. Modular-multiband radiometer model 12-1000. Barnes Engineering Co., Stamford, CT. Bull. 12-1000A. 7 pp.

Bowen, I.S. 1926. The ratio of heat losses by conduction and evaporation from any water surface. Phys. Rev. 27:779-787.

Buffington, L.C. and C.H. Herbel. 1965. Vegetational changes on a semidesert grassland range from 1853 to 1963. Ecol. Monographs 35:139-164.

Canfield, R.H. 1941. Application of the line intercept method in sampling range vegetation. J. Forestry 39:388-394

Dyer, A.J. 1961. Measurement of evaporation and heat transfer in the lower atmosphere by an automatic eddy correlation technique. Quart. Jour. Roy. Meteorol. Soc. 87:401-412.

Eberhardt, L.L. 1978. Transect methods of population studies. J. Wildlife Management 42:1-31.

Everitt, J. H., D. E. Escobar, I. Cavazos, J. R. Noriega, and M. R. Davis. 1995. A three-camera multispectral digital video imaging system. Remote Sens. Environ. 54:333-337.

Fritschen, L.J., P. Qian, E.T. Kanemasu, D. Nie, E.A. Smith, J.B. Stewart, S.B. Verma, and M.L. Wesely. 1992. Comparisons of surface flux measurement systems used in FIFE 1989. J. Geophys. Res. 97(D17):18697-18713.

Gibbens, R.F., K.M. Havstad, D.D. Billheimer, and C.H. Herbel. 1993. Creosotebush vegetation after 50 years of lagomorph exclusion. Oecologia 94:210-217.

Hicks, B.B. 1970. The measurement of atmospheric fluxes near the surface: a generalized approach. Jour. Appl. Meteorol. 9:386-388.

Miyake, M. and G. McBean. 1970. On the measurement of vertical humidity transport over land. Boundary-Layer Meteorol. 1:88-101.

Nie, D., E.T. Kanemasu, L.J. Fritschen, H.L. Weaver, E.A. Smith, S.B. Verma, R.T. Field, W.P. Kustas, and J.B. Stewart. 1992. An intercomparison of surface energy flux measurement systems used during FIFE 1987. J. Geophys. Res. 97(D17):18715-18724.

Pachepsky, Y.A., J.C. Ritchie, and D. Gimenez. 1996. Fractal modeling of airborne laser altimetry data. Remote Sens. Environ. (In review)

Richardson, A. J. 1981. Measurement of reflectance factors under daily and intermittent irradiance variations. Appl. Opt. 20:1336-1340.

Schlesinger, W.H., J.F. Reynolds, G.L. Cunningham, L.F. Huenneke, W.M. Jarrell, R.A. Virginia, and W.G. Whitford. 1990. Biological feedbacks in global desertification. Sci. 247:1043-1048.

Schuepp, P.H., M.Y. Leclerc, J.I. MacPherson and R.L. Desjardins. 1990. Footprint prediction of scalar fluxes from analytical solutions of the diffusion equation. Boundary-Layer Meteorol. 50:355-373.

Schmid, H.P. and T.R. Oke. 1990. A model to estimate the source area contributing to turbulent exchange in the surface layer over patchy terrain. Quar. Jour. Roy. Meteorol. Soc. 116:965-988.

Shuttleworth, W.J., J.H.C. Gash, C.R. Lloyd, D.D. McNeill, C.J. Moore and J.S. Wallace. 1988. An integrated micrometeorological system for evaporation measurements. Agric. For. Meteorol. 43:295-317.

Sinclair, T.R., L.H. Allen, Jr., E.R. Lemon. 1975. An analysis of errors in the calculation of energy flux densities above vegetation by a Bowen-ratio profile method. Boundary-Layer Meteorol. 8:129-139.

Swinbank, W.C. 1951. The measurement of vertical transfer of heat and water vapor by eddies in the lower atmosphere. Jour. Meteorol. 8:135-145.

Tanner, C.B. 1960. Energy balance approach to evapotranspiration from crops. Soil Sci. Soc. Amer. Proc. 24:1-9.

Tanner, B.D. 1988. Use requirements for Bowen ratio and eddy correlation determination of evapotranspiration. In: R.H DeLynn (Ed.), Planning Now for Irrigation and Drainage in the 21st Century, Irrigation and Drainage Division of the ASCE. pp. 605-616.

Tanner, B.D., M.S. Tanner, W.A. Dugas, E.C. Campbell and B.L. Bland. 1985. Evaluation of an operational eddy correlation system for evapotranspiration measurement. In: Advances in Evapotranspiration, Proc. of the National Conference on Advances in Evapotranspiration, American Society of Agricultural Engineers, St. Joseph, MI pp. 87-99.

Webb, E.K., G.I. Pearman, and R. Leuning. 1980. Correction of flux measurements for density effects due to heat and water vapor transfer. Quar. Jour. Roy. Meteorol. Soc. 106:85-100.

Table 1. Range of surface temperature measured at the shrub site in September 1995

DATE	TIME (MST)	° C (Low)	° C (High)
September 24, 1995	13:48 - 14:02	31.6	48.1
	14:10 - 14:25	31.5	51.8
September 25, 1995	13:36 - 13:57	28.8	51.4
	14:30 - 14:54	32.2	52.3
September 26, 1995	10:14 - 10:36	18.6	46.2
	10:42 - 11:06	20.1	47.2
	11:22 - 11:49	25.6	50.6
	12:12 - 12:34	26.2	56.8
	13:00 - 13:22	28.0	49.7