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JORNEX: A REMOTE SENSING CAMPAIGN TO STUDY PLANT COMMUNITY RESPONSE TO HYDROLOGIC FLUXES IN DESERT GRASSLANDS

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ABSTRACT: The Jornada Experimental Range (Jornada) in southern New Mexico provides a unique opportunity to use remote sensing techniques to study the responses of vegetation to changing hydrologic fluxes and atmospheric driving forces. Research and measurements at the Jornada have been continuous since 1912 by the United States Department of Agriculture Forest Service and USDA Agriculture Research Service. The site was chosen as a National Science Foundation Long-Term Ecological Research site in 1981. These long-term investigations at Jornada have yielded a wealth of ground data about the basin vegetation characteristics, ecosystem dynamics, and vegetation response to changing hydrologic and atmospheric inputs. To complement the programs of ground measurements, a campaign called JORNEX (JORNada EXperiment) began in 1995 to collect remotely sensed data from aircraft and satellite platforms to provide spatial and temporal data on the physical and biological state of the Jornada rangeland. In conjunction with these studies, data were measured on the ground along established transects with detailed vegetation surveys (cover, height, composition, species)and with hand-held and yoke mounted spectral and thermal radiometers; from aircraft with spectral and thermal radiometers, multispectral digital video, and laser altimetry; and from space with Landsat Thematic Mapper, NOAA-AVHRR, and GOES satellites. Surface energy balance estimates are made from a combination of parameters and state variables estimated from aircraft and ground data. Surface roughness was evaluated with the laser altimetry data and used to estimate aerodynamic roughness. Fractal analyses of the laser data found differences between vegetation types. These different platforms allow the evaluation of the landscape at different scales. These measurements are being used to quantify the hydrologic budgets and plant response to change in components in the water and energy balance at the Jornada.
KEY TERMS: Remote Sensing; Desert Grasslands; Hydrology; Hydrologic Fluxes; Rangeland.

INTRODUCTION

Arid lands, semiarid grasslands and woodlands occupy about one-third of the Earth's land surface. Changes in the boundaries between semiarid and arid lands and the potential expansion of arid lands is a candidate index of environmental change due to either human impacts or regional climatic changes. The United States Department of Agriculture (USDA), Agriculture Research Service (ARS), Jornada Experimental Range (Jornada) in southern New Mexico provides a unique opportunity to integrate information about different scales and changes in vegetation types, cover, and distribution related to hydrologic-atmospheric fluxes and surface states at the interface between desert grassland and desert shrub ecosystems. The Jornada Experimental Range was established in 1912 under the jurisdiction of the USDA Bureau of Plant Industry. The USDA Forest Service assumed control in 1915 with climatic and vegetation records having been maintained since that time. In 1954, the Jornada was transferred to the Agricultural Research Service for research purposes. In 1981 the National

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Science Foundation (NSF) selected the Jornada as a Long-Term Ecological Research (LTER) site. Thus, the Jornada is a site of long-term ecological research programs to investigate the processes related to desertification and range management. These ongoing investigations within the ARS and the LTER research programs have yielded a wealth of ground data about the basin vegetation characteristics, ecosystem dynamics, and vegetation response to hydrologic, atmospheric, and human inputs.

In concert with the ongoing programs of ground measurements, a large-scale campaign named JORNEX (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 were measured on the ground along preestablished transects with detailed vegetation surveys (cover, composition, height), with hand-held and yoke mounted spectral and thermal radiometers, from aircraft with hyperspectral and thermal radiometers, infrared thermal radiometer, multispectral video, and laser altimeter, and from space with Landsat Thematic Mapper (TM), NOAA AVHRR, and GOES satellites. These different platforms (ground, aircraft, and satellite) will allow the evaluation of landscape patterns and states at different scales. These measurements will be used to quantify the hydrologic budget and plant response to changes in components in the water and energy balance at different scales and to evaluate techniques of scaling data. Coupling a mechanistic understanding of hydrologic and ecosystem processes are key to good land management. This paper discusses preliminary results from the 1995 to 1997 measurement campaigns.

STUDY AREA

The Jornada is 37 km north of Las Cruces, New Mexico on the Jornada del Muerto Plain of the Chihuahuan Desert. The Jornada del Muerto basin is typical of the Basin and Range physiographic province of the American Southwest and the Chihuahuan Desert. The Jornada lies between the Rio Grande floodplain (elevation 1186 m) on the west and the crest of the San Andres mountains (2833 m) on the east in the northern part of the Chihuahuan Desert.

The climate is characteristic of the northern region of the Chihuahuan desert and is the most arid of the North American grasslands. There is abundant sunshine, low relative humidity, wide ranges of daily temperature, and variable precipitation. The average maximum temperature ranges from 13°C in January to 36°C in June. Annual average precipitation is 241 mm. 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 between 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 is approximately 10 times the average precipitation.

The Jornada is on the La Mesa geomorphic surface of middle Pleistocene age (>400,000 ybp). The ancestral Rio Grande river deposited sediments on this Plain. The 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 gently sloping surfaces. Throughout the Jornada, soil development is strongly influenced by topographic position, parent material, and climatic fluctuations during the Quaternary (Gile et al. 1981). Coppice dune areas are common. 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 close to the surface. Most 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 (Gile et al. 1981).

The vegetation is characteristic of a subtropical ecosystem in the hot desert biome. Grasses are entirely C4 and principal 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 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.). More than 500 plant species have been identified on the Jornada Experimental Range.

Grass communities dominated by black grama have been susceptible to encroachment by shrubs during the last century. Vegetation surveys made in 1915, 1928, and 1963, show that grass cover had decreased from 90 percent in 1858 to only 25 percent in 1963 (Buffington and Herbel 1965). Most of the shrub increases have occurred since 1928. Droughts, grazing by livestock and native fauna, and shrub seed dispersals have all contributed to the spread of shrubs. The vegetation surveys and aerial photographs made in 1938, 1942, 1973, and 1977, provide good documentation of vegetation change through time (Gibbens et al. 1993). 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 changes are reversible without substantial external inputs that could not be regarded as sustainable. Our study area encompasses an ecotone between a remnant black grama grassland and a honey mesquite coppice duneland that developed in the past 80 years. Without subsequent intervention further desertification of this grassland is anticipated during the next century.

Three specific sites in the Jornada were chosen for intensive studies. Sites were selected to represent grass, shrub (mesquite), and grass-shrub transition areas. Black grama dominates the grass site and is next to exclosure where grazing has been excluded. Honey mesquite on coppice dunes dominates the shrub site. The dunes vary in height from 1 to 4 m with honey mesquite on each dune. Bare soil dominates the area between the coppice dunes. The transition site has vegetation components from both the grass and shrub sites. Dunes are developing but are usually less than 1 meter in height. The sites will be referred to as grass, shrub, and transition in this paper.

METHODS[2]

Intensive ground and airborne campaigns have been made at the Jornada in May 1995, 1996, and 1997 (dry season), September 1995, 1996, and 1997 (wet season) and February 1996 (winter or dormant season). These campaigns included collection of ground, aircraft, and satellite data.

Ground Data

Vegetation measurements were made along 150-m transects established at each site using vertical line intercept techniques (Canfield, 1941; Eberhart, 1978) for measuring vegetation composition(species), cover, and height. Permanent markers were geopositioned and the same transects were remeasured each campaign. Along each transect three 30-m segments were measured for vertical line intercepts at 10-cm intervals for a total of 900 points per transect. Measurements were recorded by species. In support of the laser altimeter data, heights of the tallest vegetated structure (i.e., herbaceous culm, woody liter, leaf canopy) at each intercept point were also measured. Height measurements (nearest cm) were made for both live plant material and standing litter.

Surface landscape (soil and vegetation) temperatures were measured with an Everest thermal infrared radiometer (IRT) with a band pass of approximately 8-13 µm. Landscape surface temperatures were measured with IRTs during each aircraft overflight for each study period at the grass and shrub sites. These temperature measurements were collected at 5-m intervals over a gridded pattern approximately 30 m^2 during all campaigns.

Multispectral measurements were made using an Exotech 4-band radiometer with interchangeable filters. Filters corresponding to the first four bands of the Landsat Thematic Mapper (TM) were installed for 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) bands. A backpack-type apparatus (called a "yoke") equipped with an Exotech and IRT was used to make measurements over an area equivalent to Landsat TM pixels (120 m in the thermal, 30 m in the visible) at the grass site in September 1995 and 1996 and May 1996. 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.

Radiometric plant canopy and soil reflectance measurements were made at the grass and transition sites

[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.

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 (520 - 600 nm), visible red (630 - 699 nm), and NIR (760 - 900 nm) 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).

Radiometric plant canopy and soil reflectance measurements were made using an Analytical Spectral Devices (ASD) full range (350-2500 nm) spectroradiometer along each of the 150-m vegetation transects in May 1997 and September 1997. ASD measurements were made at 5 m intervals along the vegetation transects and at the gridded temperature sites. Separate radiometric measurements were also made for the dominate plant species at each site.

Leaf-area index (LAI) measurements were made with a portable LICOR LAI instrument along the same 150-m transects used for the vegetation measurements at each site. Measurements were made at 1-m intervals along these transects.

Surface energy fluxes were monitored continuously from May 1995 to May 1997 using the Bowen ratio-energy balance method and periodically (during intensive field campaigns) with eddy correlation systems at the grass and the shrub sites. In addition, a third site with a 30 m tower was monitored at the transition site during the May 1997 campaign. Eddy correlation instruments were positioned at two heights on the tower.

Surface energy balance system (SEBS)were installed at the grass and mesquite 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 continued to September 1997.

Net radiation 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 soil temperature, and three platinum resistance thermometer probes were buried to measure the change in soil temperature. 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 mesquite. Soil moisture was measured over a 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 soil heat flux. 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 vertical windspeed (w) and air temperature (T), and a KH20 krypton hygrometer to measure vapor density (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 and 2.25 m above the mesquite surface. The EC sensors at both sites were periodically reoriented (due to variable wind directions) to maintain undisturbed air flow past the sensors. 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 evaporative 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 in 1997. 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 eddy-correlation were scanned at 10 hz with intermediate calculations of the covariances 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 sensible heat (H) and λE.

Aircraft Data

An aircraft platform (ARS Aerocommander from Weslaco Texas) was used to collect spectral, thermal, multispectral video and laser altimeter data. Airborne campaigns were scheduled to make measurements for a three (3) day intensive study period centered on the overpass of Landsat-5. Aircraft flightlines were made to run parallel to or perpendicular to the ground vegetation transect.

A Global Positioning System (GPS) navigation system (Trimble Transpack II) is integrated with the systems on the airplane. The navigation system receives data from GPS satellites and continuously calculates and displays the flight direction (bearing), altitude, time, ground speed, latitude, and longitude coordinates. A video insertion system (Compos model LP-701) transfers the GPS information to annotate the video tapes. The latitude and longitude coordinates correspond to the approximate center of the ground measurements and have an accuracy of ±100 m. Data collections from all instruments on the aircraft are synchronized to the GPS time.

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) (400 - 1100 nm) light sensitive. For this experiment the three cameras are equipped with visible yellow-green (YG, 555 - 565 nm), red (R, 623 - 635 nm), and NIR (845 - 857 nm) filters. The computer is a 486-DX50 system that has an RGB image grabbing board (640 x 480 pixel resolution). In addition, the signals of cameras are also subjected to a color encoder that provides an analog CIR composite stored on the S-VHS recorder. The video system was mounted in the floor (port) of the Aerocommander aircraft. Imagery was acquired at altitudes of 300 and 1000 m between 1000 and 1530 hrs under sunny conditions.

The instrument used to make the airborne measurements of temperature was an Everest thermal infrared radiometer (IRT) with a band pass of approximately 800-1300 nm 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 (450-520 nm (blue), 530-610 nm (green), 620-690 nm (red) and 780-900 nm (near infrared)). The IRT and one Exotech were mounted looking nadir. A second Exotech is used either mounted on the aircraft or the ground looking toward the sky to measure irradiance. 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. Airborne data from these instruments were collected for two north-south flight lines that passed over the three study sites. Each flight line was approximately 10 km long. Flights were made at elevations of approximately 125 m and 300 m with two passes in opposite direction at each elevation on each flight line. Flights were made on the three days centered on a Landsat TM overpass. Morning (0900-1100 hours Local Time) and early afternoon (1230-1430 hours) flights were made on each of the three days, weather permitting.

Laser altimetry measurements were made on 4 north-south and 4 east-west flight lines, designed to cross the three study sites along the ground vegetation transects. 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, February 1996, and May 1997. Flights were made at an altitude of approximately 300 meters. The laser altimeter mounted in the Aerocommander measured 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, 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 minima being due to vegetation or man made structures.

A Cessna Citation aircraft under contract to NASA and DOE flew 2 flights lines on June 19, 1997 and September 30, 1997 over the Jornada Experimental Range. The aircraft carried the Thermal Infrared Multispectral Scanner (TIMS) and a 12 channel Daedelus multispectral scanner. The latter has bands from the visible to the thermal infrared. TIMS has 6 channels in the 800 to 1200 nm thermal band. Both instruments have 2.5 milliradian IFOV's and approximately ±40° swaths. For the June 19 flight the altitudes were 1.5 and 5 km affording 4 and 12.5 m resolution, respectively. On the September 30 flight the altitudes were 0.75 and 5 km producing 2 and 12.5 resolutions. In addition the NASA flew the AVIRIS instrument to collect hyperspectral data during the May 1997 campaign.

Satellite Data

Landsat Thematic Mapper (TM) has been purchased for the cloud free days during the campaigns to be used for scaling ground and aircraft measurements to larger areas. AVHRR and GOES data will also be used to make inferences about larger areas and to assess the value of different resolution data.

RESULTS

Radiance Measurements

Reflectance data are currently being analyzed to assess differences in plant species and difference in averaged reflectance from the vegetation transects. Assessment of reflectance spectra (Fig. 1)measured using the ASD along the different vegetation transect shows a difference in reflectance between the shrub, transition, and grass transects. Figure 1 shows averaged spectra (average of 10 spectra taken at 5 m intervals) from the different vegetation transects. Reflectance was highest in the visible and near infrared (NIR) along the shrub transect when compared with the transition and grass transects. Reflectance patterns along the grass and transition transects were similar.

Preliminary analyses show significant differences in ground reflectance measurements among different plant species at all sites (Everitt et al., 1997). Black grama has lower NIR reflectance than the other species, which supports its dark image response in the color infrared(CIR) video imagery. Visible and NIR reflectance values of soil at all sites were higher than those for the plant species. This concurs with the bright soil response on the CIR images at the shrub and transition sites.

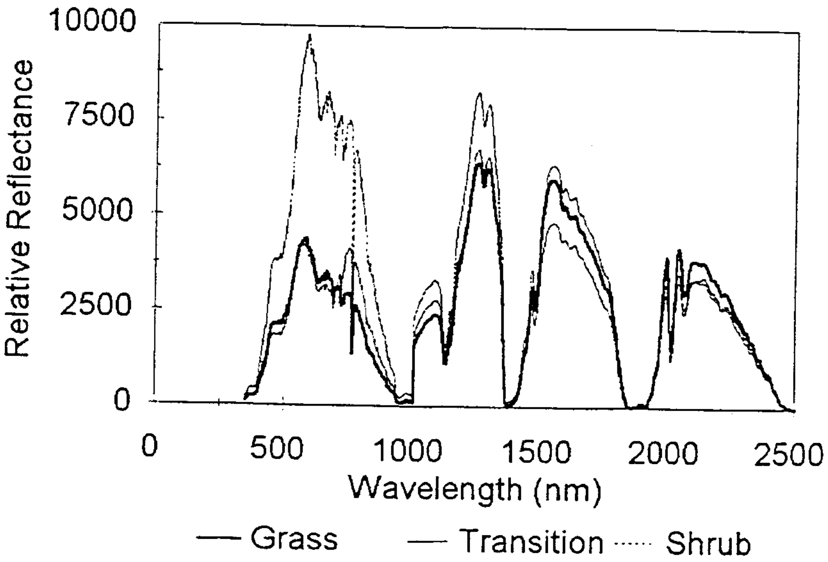

Figure 1. Relative reflectance measured along the shrub, transition, and grass site vegetation transects in October 1997. Each trace is an average of 10 measurements along each transect.

CIR composite video imagery shows differences in image tones among plant species (cover types) at all sites (Everitt et al., 1997). However, contrast was 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 honey mesquite and soaptree yucca. At the transition and shrub sites, honey mesquite appears as distinct red clumps that give it a conspicuous geometric shape. Soils at the transition site are brighter than those at the grass site. This characteristic also enhances the detection of honey mesquite on the CIR video images. At the shrub site there was also good contrast between the honey mesquite and the soils.

Thermal Measurements

A morning and afternoon measurement along the same transect of radiometric ground surface temperature from a nadir-viewing Infrared Thermometer (IRT) with a 15° field of view (FOV) on board the Aerocommander aircraft shows the day time increase in temperature (Fig.2). The aircraft flew at nominal height of 300 m yielding an IRT sensor footprint diameter of 80 m. The transects were flown on October 9, 1997 in the morning (10:30 am MDT) and afternoon (1:30 pm MDT). These data are georeferenced to allow direct comparison of 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. The transect begins over a grass area, passes over a transition area and ends over a mesquite dune area. Temperatures are in the same range as those measured on the ground.

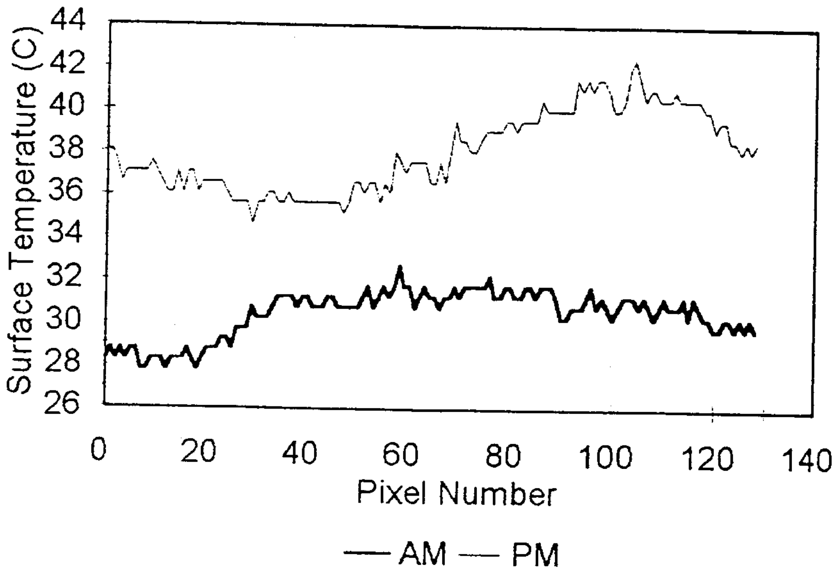

Figure 2. Ground surface temperature measured in the morning (lower line) and afternoon (upper line) on October 9, 1997 with an infrared thermometer mounted on the Aerocommander aircraft.

During the September 1995 study period 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. Such temperature differences are typical of those measured during all study periods. Combining this temperature data with information on relative vegetation cover obtained from the video images should enable us to estimate the temperatures measured by the IRT on the airplane. An example of the hand-held IRT measurements from May 1996 of the mesquite and interdune vegetation versus interdune bare soil and mixtures of mesquite and bare soil areas are illustrated in Figure 3. The plot indicates that temperature differences between vegetation and bare soil can reach 15-20° C. These temperatures are in the same range as those measured from the aircraft

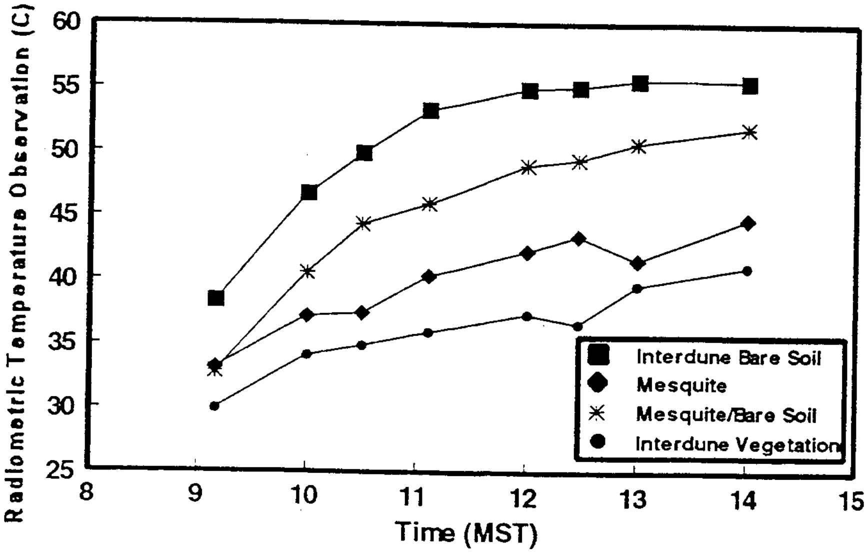

Figure 3. An example of hand-held radiometric temperature observations of vegetation, bare soil and mixtures of bare soil and mesquite (mesquite/bare soil) measured at the shrub site in May 1996.

during the same time period. Difference between morning and afternoon temperature is similar for the ground and aircraft data.

The TIMS coverage for June 19, 1997 from the 5 km altitude flight shows differences in temperatures between grass, shrub, and transition sites that are similar to those measured on the ground. The resolution is 12.5 m per pixel and by combining the data into an image using TIMS channel 5 (λ = 10.7µm) on the red gun, channel 3 (λ = 9.2 µm) on the green gun and channel 1 (λ = 8.4 µm) on the blue gun produces an image of the surface landscape emissivity. On such an image, the red areas are those where channel 5 has a higher emissivity than the others and are typical of quartz sand. White areas on these images are typically dormant vegetation where all 3 channels have a high response. Exposed soils are reddish color in color on the images. Using these images along with information on vegetation cover we will be able to map emissivity and land surface temperature.

Laser

Laser altimeter measured transects at the grass, shrub, and transition sites show differences in surface topography and roughness at the sites (Figs. 4, 5, and 6). The grass site (Fig. 4) is relatively uniform in surface

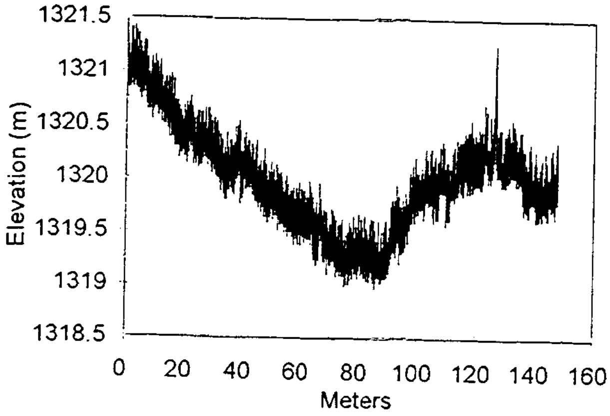

Figure 4. Laser altimeter measurement of topography and surface roughness at the grass site. Data were collected May 19, 1995.

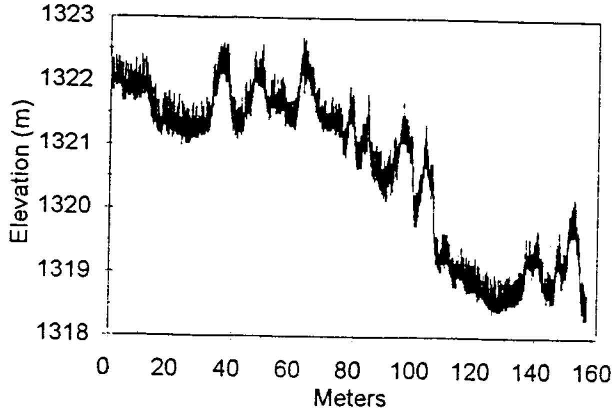

Figure 5. Laser altimeter measurement of topography and roughness at the shrub site. Data were collected May 19, 1995.

roughness with an occasional shrub or taller vegetation on the surface present on the underlying topography. The shrub site (Fig. 5) has evidence of dunes present on the underlying landscape with vegetation on top of the dunes. The transition site (Fig. 6) shows evidence of both the grass and shrub sites with the beginning of what appears to be small dunes. Fractional vegetation cover and vegetation height measured from the laser altimeter were comparable to the measurement made on the ground (Ritchie, 1996)

Fractal analysis of laser altimetry data from each of the grass, shrub, and transition sites (four transects at each site for February, May, and September) 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, shrub, and transition landscapes. The fractal dimensions tend to increase in a sequence from grass to transitional to

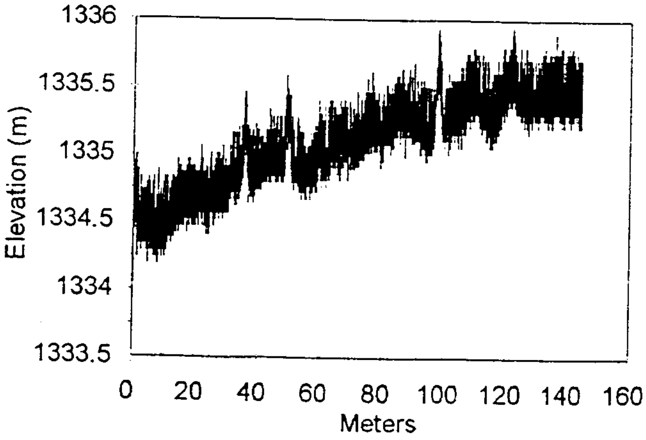

Figure 6. Laser altimeter measurement of topography and surface roughness at the transition site. Data were collected May 19, 1995.

shrub sites in this range of scales. The difference between fractal parameters of laser altimetry data for the grass, shrub, and transition landscapes supports the possibility of distinguishing between these landscapes using laser altimetry data. Results show that the fractal dimension is subject to seasonal changes and spatial variation in any specific range of scales. However, the pattern of the dependence of fractal dimensions on scale is specific to the land cover. More studies on spatial and temporal variability of the roughness are needed to select a formal way to quantify these patterns and to use the differences for distinguishing between land covers. A fractal technique for estimating cover type represents a new technical opportunity to quantify landscape roughness (Pachepsky et al., 1997).

Studies have also shown (Menenti and Ritchie, 1994) that the effective aerodynamic roughness at the shrub site can be estimated using the high resolution laser altimeter measurements of land surface roughness. Studies (De Vries et al., 1997) show that estimations of the effective aerodynamic roughness of the complex terrain consisting of coppice dunes with bare interdunal areas are plausible using simple terrain features computed from high resolution laser altimeter data. The estimates of aerodynamic roughness compare well with estimates made using measured wind profiles measured at the site (De Vries et al., 1997). The availability of high resolution altimeter data of the land surface would make it possible to estimate aerodynamic roughness for other landscapes where wind flow data are not available.

CONCLUSIONS

The Jornada Experimental Range in southern New Mexico provides a unique opportunity to integrate information about 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.

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