COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 07-140 **PD 04-7381** **07/09/07**	**FOR NSF USE ONLY**
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) **DEB - ECOSYSTEM SCIENCE CLUSTER**	**NSF PROPOSAL NUMBER** **0743678**

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
07/09/2007	**12**	**08010000 DEB**	**7381**	**065391526**	**07/09/2007 5:25pm**

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN) **546001796**	SHOW PREVIOUS AWARD NO. IF THIS IS ☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE

University of Virginia Main Campus

AWARDEE ORGANIZATION CODE (IF KNOWN)

0037457000

ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE

University of Virginia Main Campus
P.O. BOX 400195
CHARLOTTESVILLE, VA. 229044195

NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE

PERFORMING ORGANIZATION CODE (IF KNOWN)

ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions)
☐ SMALL BUSINESS ☐ MINORITY BUSINESS
☐ FOR-PROFIT ORGANIZATION ☐ WOMAN-OWNED BUSINESS
☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **Collaborative research: Do vegetation-microclimate feedbacks promote shrub encroachment in the Southwestern United States?**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ **264,981**	**36** months	**03/01/08**	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

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☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
☐ HISTORIC PLACES (GPG II.C.2.j)
☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.D.1)
☐ VERTEBRATE ANIMALS (GPG II.D.5) IACUC App. Date ________
PHS Animal Welfare Assurance Number ________

☐ HUMAN SUBJECTS (GPG II.D.6) Human Subjects Assurance Number ________
Exemption Subsection ______ or IRB App. Date ________
☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)
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☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

PI/PD DEPARTMENT

Environmental Sciences

PI/PD FAX NUMBER

434-982-2137

PI/PD POSTAL ADDRESS

P.O. Box 400123
291 McCormick Rd.
Charlottesville, VA 229044123
United States

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME **Paolo D'Odorico**	**PhD**	**1998**	**434-924-7241**	**paolo@virginia.edu**
CO-PI/PD **Stephan F De Wekker**	**PhD**	**2002**	**434-924-3324**	**sfd3d@virginia.edu**
CO-PI/PD **Jose D Fuentes**	**PhD**	**1992**	**434-982-2654**	**jf6s@virginia.edu**
CO-PI/PD				
CO-PI/PD				

Electronic Signature

CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the Authorized Organizational Representative or Individual Applicant is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), nondiscrimination, and flood hazard insurance (when applicable) as set forth in the NSF Proposal & Award Policies & Procedures Guide, Part I: the Grant Proposal Guide (GPG) (NSF 07-140). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

Conflict of Interest Certification

In addition, if the applicant institution employs more than fifty persons, by electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.A; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Drug Free Work Place Certification

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Exhibit II-3 of the Grant Proposal Guide.

Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Debarment and Suspension Certification contained in Exhibit II-4 of the Grant Proposal Guide.

Certification Regarding Lobbying

The following certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

Certification Regarding Nondiscrimination

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Certification Regarding Flood Hazard Insurance

Two sections of the National Flood Insurance Act of 1968 (42 USC §4012a and §4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the:

(1) community in which that area is located participates in the national flood insurance program; and
(2) building (and any related equipment) is covered by adequate flood insurance.

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant located in FEMA-designated special flood hazard areas is certifying that adequate flood insurance has been or will be obtained in the following situations:

(1) for NSF grants for the construction of a building or facility, regardless of the dollar amount of the grant; and
(2) for other NSF Grants when more than $25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME **Sandra A Schluge**	**Electronic Signature**	**Jul 9 2007 4:38PM**

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER
434-924-4275	**sas2u@virginia.edu**	**434-982-3096**

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COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 07-140

NSF 07-140

FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)

DEB - Ecosystem Studies

FOR NSF USE ONLY

NSF PROPOSAL NUMBER

0743737

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
07/09/2007	12	08010209 DEB	1181	868853094	07/09/2007 5:26pm

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)

856000642

SHOW PREVIOUS AWARD NO. IF THIS IS
☐ A RENEWAL
☐ AN ACCOMPLISHMENT-BASED RENEWAL

IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE

University of New Mexico

ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE

SCHOLES HALL RM 102
ALBUQUERQUE, NM 87131-0001

AWARDEE ORGANIZATION CODE (IF KNOWN)

0026633000

NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE

ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE

PERFORMING ORGANIZATION CODE (IF KNOWN)

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions)
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TITLE OF PROPOSED PROJECT **Collaborative research: Do vegetation-microclimate feedbacks promote shrub encroachment in the southwestern United States?**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 289,008	36 months	02/01/08	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

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____
☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

PI/PD DEPARTMENT
Biology

PI/PD POSTAL ADDRESS
MSC03 2020

Albuquerque, NM 87131
United States

PI/PD FAX NUMBER
505-277-0304

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME Marcy Litvak	PhD	1998	505-277-5580	mlitvak@unm.edu
CO-PI/PD Scott L Collins	PhD	1981	505-277-6303	scollins@sevilleta.unm.edu
CO-PI/PD William T Pockman	PhD	1996	505-277-2724	pockman@unm.edu
CO-PI/PD				
CO-PI/PD				

Electronic Signature

CERTIFICATION PAGE

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(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.

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(2) for other NSF Grants when more than $25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME **Gloria Cordova**	**Electronic Signature**	**Jul 9 2007 5:04PM**

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER
505-277-2968	**gcordova@unm.edu**	**505-277-4185**

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PROJECT SUMMARY

Background. Woody plant encroachment into grasslands is a global phenomenon that results from a variety of global change drivers. Over the last 150 years the southwestern United States has undergone dramatic changes in the composition and structure of vegetation due to invasion by *Larrea* spp. and *Prosopis* spp in southwestern deserts. Concern about the encroachment of woody vegetation is motivated by economical losses associated with the conversion of rangelands into woodlands, regional carbon dynamics and the occurrence of erosion-driven loss of nutrient-rich soil particles in response to the decrease in grass cover, with consequent loss of ecosystem services and functioning. The relatively abrupt character of grassland-to-shrubland transitions suggests that arid and semiarid rangelands may be bistable systems, with stable states characterized by either grass or shrub dominance. Due to the presence of alternative stable states, aridland ecosystems may have limited resilience and in some cases even small changes in environmental drivers (grazing intensity, fire, rainfall patterns) cause abrupt state transitions from grassland to shrubland. Bistable dynamics are induced by positive feedbacks between external drivers and the current system state. What remains unclear is whether feedbacks between land cover change and atmospheric boundary layer dynamics may contribute to shrub encroachment in the southwestern US.

Intellectual Merit. The proposed research will develop field and modeling activities to investigate and quantify the feedbacks between encroachment by a native C_3 shrub, *Larrea tridentata,* into native C_4 grassland, and the consequent changes in surface energy balance in a northern Chiuhuahuan desert ecosystem. To this end, the project will (1) test the hypothesis that *Larrea* encroachment leads to decreases in surface albedo and increases in thermal energy storage in soils with the overall net effect of increasing nighttime air temperatures capable of favoring the establishment and viable growth conditions for *Larrea* plants; (2) assess whether and where this vegetation-microclimate feedback can induce conditions of ecological bistability in the dynamics of aridland ecosystems thereby limiting their resilience.

Broader Impacts. Quantifying vegetation-atmospheric feedbacks during *Larrea* invasion into grassland will provide comprehensive information on atmosphere-ecosystem interactions and feedbacks associated with regional climate warming. Identifying differences in the thermodynamic and radiative characteristics of the atmospheric boundary layer above *Larrea* and grassland vegetation will contribute to understanding the potential feedbacks between land cover change and microclimate, and will provide useful information on processes controlling shrub encroachment in the desert southwest. As part of the academic training, two Ph.D. students will develop their dissertation research. A new course on *Land Surface Processes in Arid Lands* will be developed and offered at the University of Virginia. A short course will be offered to high-school teachers on current issues in hydrometeorological research. Data and information from this project will also be linked to a GK12 program that connects research at the Sevilleta LTER to middle school science classes in nearby Belen and Socorro, New Mexico.

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.C.

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

1. Introduction and Motivation

Over the last 150 years the southwestern United States has undergone dramatic changes in the composition and structure of vegetation due to woody plant invasion into the Sonoran and Chihuahuan deserts (Buffington and Herbel, 1965; Archer et al., 1988; Archer, 1989; Van Auken, 2000). Commonly known as "shrub encroachment", this phenomenon involves a decrease in grass cover and an increase in density of shrub species that have existed in the region (at much lower densities) for the last several thousands of years (Van Auken, 2000).

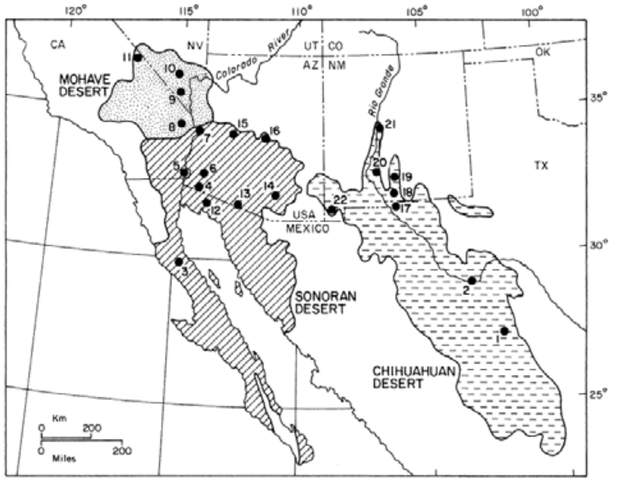


Figure 1. Extent of *Larrea tridentata* in the Southwestern U.S. and Western Mexico. Shaded areas represent deserts where *Larrea* vegetation is found: Chihuahuan, Sonoran, and Mohave Deserts. (after Hunter and Betancourt, 2001).

Shrub encroachment has been observed in many regions of the world, including Southern Africa, South America, and Australia (e.g., Van Auken, 2000). The widespread character and relatively rapid pace of this process poses important questions on the nature of its drivers. In the case of the North-American deserts (Figure 1), the encroachment of mesquite (*Prosopis glandulosa*) and creosotebush (*Larrea tridentata*) has been explained as an effect of "climate warming", increased atmospheric carbon dioxide (CO_2) concentrations, overgrazing, fire management, and other processes that favor C_3 shrubs over C_4 grasses (e.g., Buffington and Herbel, 1965; Archer 1990; 1994). However, no conclusive evidence exists that any one process serves as a universal driver of shrub encroachment globally or regionally (Knapp et al. 2007).

Changes in regional climate might facilitate shrub encroachment. The southwestern US is undergoing a warming trend (SRAG 2000, Han and Roads 2004, Leung et al. 2004), and is becoming drier overall, although the region may also experience a greater frequency of El Niño events in the future (IPCC 2007, Cook et al. 2004, Seager et al. 2007). This warming phenomenon, however, is not occurring evenly throughout the day. Rather, global nighttime temperatures have increased twice as fast as daytime temperatures over the last 50 years (Houghton et al. 2001) a trend that is apparent in the northern Chihuahuan Desert over the past century (Fig 2). Nighttime warming can have important consequences for plant communities. For example, higher nighttime temperature since 1970 in semiarid shortgrass prairie is correlated with a decrease in dominant species and an increase in invasive forbs (Alward et al. 1999). In the Southwestern US, creosotebush is adapted to extremely hot and dry conditions and its northern distribution is limited by tolerance to freezing temperatures (Wells and Shields 1964, Beatley 1974, Pockman and Sperry 1997). Thus, as climate change continues, creosotebush should be released from its thermal constraints and could potentially continue its northward migration at the expense of native grassland .

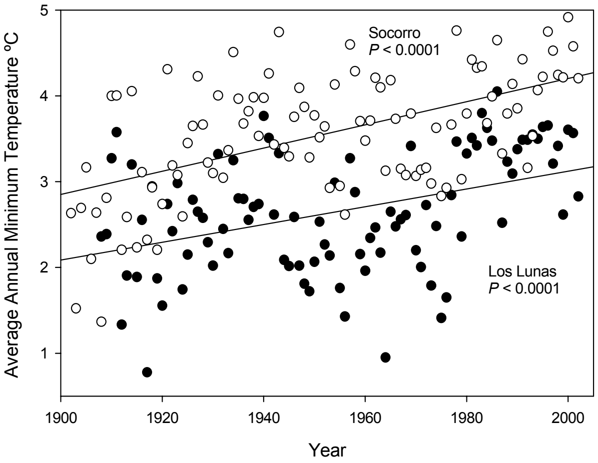


Figure 2. Historical increases in annual minimum temperatures in Socorro and Belen, central New Mexico. The average of the slopes shows an increase of 0.019C per year suggesting an increase of 1-2 C over the next 50-100 years if these trends continue. Data are from the U.S. Historical Climatology Network www.ncdc.noaa.gov/oa/climate/research/ushcn/ushcn.html.

Woody plant encroachment has not only ecological but key economic consequences. Economic losses are associated with the conversion of grazed grasslands into unproductive woodlands, and the occurrence of erosion-driven loss of soil nutrients in response to the decrease in grass cover, with consequent loss of ecosystem services and functioning (Schlesinger et al. 1990, Geist and Lambin 2004).

Also of interest, however, is that shrub encroachment is occurring at rates greater than climate change. Thus, other factors must facilitate this transition. One such factor yet to receive much consideration is a potential positive feedback between shrub encroachment, changes in regional energy balances (albedo effects) and increased regional warming (Laliberte et al. 2004), similar to that observed with changes in albedo in the boreal forest-tundra transition zone (Chapin et al. 2005). In the southwest, the relatively abrupt character of the grassland-to-shrubland transition, as observed elsewhere, suggests that these arid and semiarid ecosystems may be bistable (Noy-Meir, 1975; Westoby, 1979; Walker et al., 1981; Walker and Noy-Meir, 1982), with either grass- or shrub-dominated states. Due to the presence of alternative stable states, these aridlands have only limited resilience (e.g., Holling, 2000) and in some cases even small changes in environmental drivers (fire, grazing, climate change) could cause an abrupt shift of grass-dominated system to the shrubland state (e.g., Andeires et al., 2002; van Langevelde et al., 2003).

Bistable dynamics are often induced by positive feedbacks between external drivers (climate, disturbance regime, ecosystem management) and the state of the system (e.g., Wilson and Agnew, 1992). While the role of a few feedback mechanisms has been well documented (e.g., Schlesinger et al., 1990; Rietkerk and Van de Koppel, 1997; van Langevende et al., 2003; D'Odorico et al., 2006), it is still unclear whether interactions between land cover change and atmospheric boundary layer (ABL) dynamics may contribute to the process of shrub encroachment (e.g., Schlesinger et al., 1990). In fact, feedbacks between vegetation cover and microclimate conditions are difficult to assess without detailed measurements of the different component of the surface energy balance. Indeed, minimum annual temperatures recorded at two stations at similar elevation in central New Mexico located a 30 km north (black dots) and south (white dots) of the current location of the shrub encroachments front show considerably higher annual low temperatures in the region dominated by shrubs (white dots) compared to the region dominated by grasses (black dots). Only a small part of this difference can be attributed to latitude. Therefore, is the large temperature difference a result or a cause of the different vegetation at the two sites?

One could argue that the warming trend has favored the grassland-to-shrubland conversion. Alternatively, one could think that changes in the land cover have enhanced the warming at the site that is currently dominated by shrubs. In this case, the positive feedback between microclimate and vegetation cover could play a crucial role in the process of shrub encroachment. Indeed, in this region, extensive freezing-induced embolism for most of the winter suggests that creosote may strongly benefit from increased minimum temperatures (Martinez-Vilalta and Pockman 2002).

Only a few authors have investigated the effect of shrub encroachment on ABL properties in the American Southwest. Beltran-Przekurat and co-workers (pers. comm.) used a mesoscale atmosphere-biosphere model to assess the effect of land cover change on surface fluxes and near-surface air temperature in the northern Chihuahuan Desert. These authors found that mesquite (*Prosopis glandulosa*) and creosotebush (*Larrea tridentata*), the two major shrub species in the Chihuahuan and Sonoran deserts, have different impacts on near-surface microclimate: the encroachment of *Prosopis* would increase the albedo and consequently lead to surface cooling while the conversion to *Larrea* would decrease the albedo and increase the storage of energy in the soil. This could result in higher near-surface air temperature above surfaces occupied by *Larrea* plants. Hayden et al. (1998) reported that in areas encroached by *Larrea* the nighttime minimum temperatures are higher (by 4-6 °C) than in the adjacent grasslands. These results, which are in agreement with long-term temperature records from nearby areas in the Chihuahuan desert (Balling 1988; 1998; Bryant, 1990; Small and Kurc, 2003) and with some preliminary model simulations, need to be adequately validated by field observations capable of explaining the underlying processes. The overarching goal of our research is to quantify the feedbacks between *Larrea* encroachment, ABL dynamics, and the surface energy balance in the Southwestern U.S.

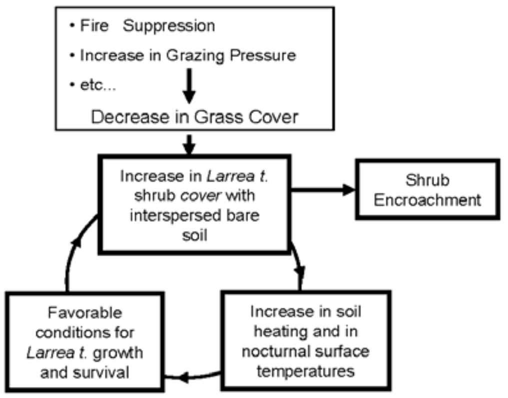


Figure 3. Schematic representation of the land-atmosphere feedback investigated in this proposal.

Results from limited micrometeorological measurements (Carr, 2005) suggest that changes in the landscape albedo associated with *Larrea* encroachment lead to warmer conditions during the nighttime (Hayden, 1998). Because *Larrea* is seldom found in regions with low minimum nighttime temperatures (e.g., Pockman and Sperry, 1997), a positive feedback may exist between *Larrea* encroachment and changes in surface micrometeorological conditions. This feedback could play an important role in enhancing *Larrea* encroachment, in that, as they migrate northward, *Larrea* shrubs would be able to create microclimate conditions favorable to their own survival in cooler environments. Therefore, this proposal will utilize field observations and modeling to clarify the role of this feedback in the process of shrub encroachment.

2. Objectives and Hypotheses

This project will address three major research objectives:

1) We will first **test the hypothesis that the encroachment of *Larrea tridentata* into desert grassland decreases surface albedo and increases thermal energy storage in soils with the overall net effect of increasing nighttime air temperatures that favor establishment and growth of creosotebush;.** We will test this hypothesis with *field measurements* (§4.2, 4.4) interpreted with a process-based *mesoscale atmospheric model* (§ 4.3) to assess the mechanisms underlying the hypothesized feedback. We will then investigate the environmental implications of these interactions between land cover and surface energy exchanges. To this end, we will:
2) assess whether and where vegetation-microclimate feedbacks (Fig. 3) are able to **induce bistability in the dynamics of aridland ecosystems,** in a way that both the grassland with cooler surface conditions, and shrubland with warmer (nighttime) conditions are stable states of the system. We expect this bistability (if any) to exist at the grassland-to-shrubland transition similar to the results from other transitional areas prone to positive biosphere-climate feedbacks, such as some desert margins (e.g., Zeng and Neeling, 2000; Wang and Eltahir, 2000). The existence of this bistability would suggest that anthropogenic disturbances (overgrazing, changes in fire regime) or changes in environmental conditions (e.g., warming, increased atmospheric CO_2) could trigger transitions to a stable state characterized by shrub dominance. Due to the stability of the shrubland state, the system would not revert back to grassland even after the disturbance ceases, consistent with low observed mortality among established, *Larrea* adults (Bowers et al., 1995). Thus, vegetation-climate feedbacks could contribute to explain the irreversibility of the process, in addition to other feedbacks (not addressed in this study) associated with vegetation-soil erosion coupling (Schlesinger et al., 1990), and fire dynamics (e. g., Anderies et al., 2002). We will assess these dynamical properties of the system through numerical *model simulations* based on a regional climate model (§ 4.6) coupled with a vegetation dynamics model (§ 4.5). Both models will be evaluated and parameterized using data from our field measurements (§ 4.2, 4.3) and from the literature (see section 4).
3) We will also determine **the maximum extent of the geographical region** in the Southwestern U.S., where, under the current climate conditions, **vegetation-microclimate feedbacks could allow for the successful establishment of creosotebush**. The fact that the encroachment of *Larrea* is an ongoing process suggests that the southwestern dryland landscape will eventually reach a steady state. This part of the project will provide an assessment of the steady state the system would be converging to under the current climate conditions. Simulations with the *coupled regional climate-vegetation model* combined with physiological measurements will be used to address this objective.

The last two objectives assume that, as has been shown for many desert plants (Nobel 1980 2003), minimum temperature is the major microclimatic parameter controlling the northern range boundary of *Larrea*. Temperatures associated with complete loss of water transport in a Sonoran desert population corresponded to the northern limit of *Larrea* across Sonoran and Mojave deserts (Pockman and Sperry, 1997). A follow-up study (Martinez-Vilalta and Pockman 2002) showed that adults in the Chihuahuan desert retained xylem function to somewhat colder temperatures. This project will build on these observations in adult plants by assessing the freezing responses of seedlings from across the northern limit of Larrea. This information is critical if we are to understand the likely affect of changing climate on the distribution of this species as mediated by establishment and growth of juvenile plants.

3. Overview of methods

The research methods will include:

a) a set of grassland and shrubland flux tower *measurements* to determine how vegetation attributes affect energy flow and dynamics. Specifically we will measure near-surface air temperature profiles to determine the magnitude of the differences in minimum nighttime temperatures in these two land cover types. We will also use radiosonde balloons to determine differences in the cooling rate in the nocturnal boundary layer over the two land cover types (see § 4.1-4.2).

b) These micrometeorological and boundary layer measurements will be used to validate a *mesoscale model* of land-atmosphere interactions, which will be used to investigate differences in atmospheric boundary layer (ABL) dynamics at the two sites. This part of the project will shed light on the physical mechanisms determining the impact of land cover on the microclimate (see § 4.3).

c) Physiological measurements of seedlings grown in the UNM greenhouse will be used to understand the freezing response of young plants from populations in the warm deserts of North America. We will combine measurements of photosynthesis and chlorophyll fluorescence with measures of xylem function to assess loss of function associated with long term minimum temperatures and the moderating effect of warming climate. We will measure the freezing responses of these plants at high and low water stress because low water potentials favor xylem failure under more moderate freezing stress and precipitation regime is also expected to change in this region (see § 4.4).

d) These measurements will be used to parameterize a minimalist model of grass-shrub dynamics (hereafter called *vegetation model*) in which the rate of shrub encroachment depends on minimum nighttime temperatures (see § 4.5).

e) The vegetation model will be coupled with a *regional climate model* to investigate the effect of vegetation-climate feedbacks on the stability and resilience of plant communities located at the shrubland-grassland boundary. The following subsections will provide more details on the methods used in this study (see § 4.6).

4.1 Field Observations. The field investigations will take place at the Sevilleta National Wildlife Refuge (SNWR) approximately 80 km south of Albuquerque, New Mexico and is located in the northern Chihuahuan Desert of the Rio Grande Valley. Because the Sevilleta site shows a dramatic encroachment front of *Larrea tridentata* into native desert grassland it represents an ideal location to investigate differences in surface energy flows associated with the two different land covers***, both of which exist under the same regional climate conditions***. To this end, concurrent measurements will be made on two flux towers currently deployed over the *Larrea*-dominated shrubland and *Bouteloua*- dominated grassland. An additional portable flux tower will be used to investigate the surface energy balance at selected sites along the grassland-shrubland transition. The grassland (34.3402 N, -106.685420) and shrubland (34.3338 N, -106.734010 W) tower sites are in the McKenzie Flats area of the SNWR. The SNWR contains extensive semi-arid grassland dominated by C_4 perennial grasses (*Bouteloua gracilis*, *B. eriopoda*, *Sporobolis* spp., *Hilaria jamesii*,

Figure 4. Photographs showing the abrupt transition between *Bouteloua eriopoda*-dominated grassland and

Muhlenbergia spp.) located on relatively level topography along the western edge of the Los Piños Mountains. Total vegetation cover in grassland (live plus litter) averages 60% with 40% bare soil, whereas vegetation cover in creosotebush-dominated shrubland averages around 30% with 70% bare soil (Báez et al. 2006) Mean January minimum temperature (1999-2006) at the Deep Well meteorological station, a grassland site on the SNWR, was -6.3°C, with a mean absolute minimum temperature of -13.9°C and a mean January maximum of 12.0°C. In creosote-dominated vegetation near the grassland-shrubland boundary 2 km south of Deep Well, mean January minimum temperature (1999-2006) was -3.7°C, with a mean absolute minimum temperature of -10.5°C and a mean January maximum of 11.4°C. *These differences clearly demonstrate that areas where shrub encroachment has occurred have higher local mean and absolute minimum temperatures (-6.3°C and -13.9°C in grassland, respectively, vs. -3.7°C and -10.5°C in shrubland) in January but little difference in daytime high temperatures.* In addition, mean annual precipitation (1989-2005) at the SNWR is 250 mm, about 60% of which comes in isolated, short duration showers during the monsoon season (July – September); the remainder arrives with winter frontal systems, although with considerable year-to-year variation (Pennington and Collins 2007). Aboveground net primary production (ANPP) averages 51.1 g m^{-2} y^{-1} in *Bouteloua* grassland and 59.2 g m^{-2} y^{-1} in *Larrea* shrubland (Muldavin et al. 2007). More information about the Sevilleta is available at (http://sev.lternet.edu).

The eddy covariance instrumentation at both sites is identical. Covariances are obtained from 10 Hz measurements of vertical wind speed and gas concentration using 3-axis sonic anemometers (model CSAT-3, Campbell Scientific Inc., Logan, UT) and open-path gas analyzers (Model LI-7500, LiCor Inc., Lincoln, NB), respectively. Data loggers (model CR3000, Campbell Scientific Inc.) control all instrumentation at both sites. Additional equipment at both sites includes instruments to measure net radiation (model CNR1, Kipp & Zonen, Holland) at grassland site and REBS Q*7.1 at shrubland), air temperature and relative humidity (model HMP45C, Vaisala, Finland), photosynthetically active radiation (model LI-SZ190, LiCor), barometric pressure, surface temperature, and ground heat flux. In addition, the grassland site has 6 temperature and moisture soil profiles, and the shrubland site has 4 temperature and moisture profiles. We are asking for an additional CNR1 radiometer through this proposal so net radiation will be measured using identical instrumentation at both sites. Measurements of radiation and of turbulent fluxes of momentum and heat will allow for comparison of the energy balances over the grass and shrub-dominated sites and differences in these budgets to be identified. Based on preliminary field studies (Carre 2005), it is anticipated that the surface covered with *Larrea* vegetation will irradiate greater amounts of thermal energy than the grasslands in response to efficient energy storage in the soil. Measurements of soil heat flux, soil temperature, and soil moisture content will be taken in order to investigate the degree of energy storage and flow in and out of the soil

In addition to tower measurements, radiosonde balloons will be launched from the two sites at frequent intervals (every one or two hours) during several nights (about 20 balloon launches at each site) to determine more accurately the difference in nocturnal cooling rates in the ABL over grassland and over shrubland. The cooling rate in the nocturnal boundary layer (which can be several hundred meters deep) has also been suggested to be a better means for evaluation of the mesoscale model than the surface temperature (De Wekker and Whiteman, 2006) further demonstrating the need for balloon measurements.

Comparison of the meteorological data taken from the shrubland and grassland portions of the site will allow for determination of differences in the thermal structure of the air near the surface. Because of aerodynamic and energy balance considerations, it is anticipated that the thermal structure of the lower atmosphere over the *Larrea*-dominated vegetation will differ from that over grassland. Nighttime conditions will be of primary importance as the nocturnal boundary layer is highly stable and will allow for the air to remain relatively stagnant. We are particularly interested in minimum nighttime temperatures, as they determine the critical conditions that can be endured by *Larrea*.

4.2 Data analysis. The flux data will be analyzed to provide comparative results concerning the energy flows for shrubland and grassland surfaces. Both available energy (i.e., net radiation) and soil heat fluxes will be directly estimated from raw measurements provided by net radiometers and heat flux plates. Radiometer measurements will provide the necessary information to derive the magnitude of the surface albedo for both surfaces. Additionally, radiometric measurements will be analyzed to derive the surface emissivity and thus quantify the variability in surface properties responsible for the changes in thermal energy flow. The turbulent momentum, sensible and latent heat flux densities will be derived from the eddy covariance measurements. Wind speed measurements made at several levels above the surface will be utilized to derive the surface roughness length. It is crucial to investigate how much this variable changes across the landscape so that numerical models can use this information to parameterize and quantify the exchange of energy between the landscape and atmosphere.

4.2.1 Data Processing. Covariance terms are corrected for density fluctuations due to temperature and water vapor using the WPL procedure (Webb et al., 1980), and frequency response corrections will be applied using the method of Massman (2000). Half-hourly averages of the covariances are computed. 'Natural wind' coordinate rotations (Lee et al., 2004) are applied to 30-min averages of the covariances to correct for anemometer tilt with respect to the terrain.

Eddy covariance measurements of Net Ecosystem Exchange (NEE) at the two sites will be used to determine the temperature and soil moisture controls on shrub and grass growth and will provide input for parameterization of the vegetation dynamics model. Eddy covariance underestimates nocturnal NEE when inversions, low turbulence and advection prevent CO_2 generated by the ecosystem from being detected by eddy covariance systems. We will correct for this underestimate following Aubinet et al. (2002). A friction velocity (u*) filter will be used to reject data obtained when turbulence is low. Data gaps created by the u* filter will be filled following procedures outlined by Reichstein et al. (2005), which will also be used to calculate ecosystem respiration (R_e) during the daytime. Daytime gaps in *NEE* will be filled using non-rectangular hyperbolic light response functions following the procedures of Gilmanov et al. (2003). Gross primary production (*GPP*) will be calculated as $NEE - R_e$ (Flanagan et al., 2002). Half-hourly values of *NEE*, R_e, and *GPP* will be summed to obtain daily and seasonal totals. Data gaps in water vapor flux (*E*) will be filled by interpolation for small time intervals, and using relationships between *E* and $R_n - G$ (soil heat flux) for larger time intervals. Thirty-minute averages of *E* will be totaled to obtain daily and seasonal totals.

Latent heat flux will be calculated by multiplying *E* from eddy covariance by latent heat of vaporization (L) at air temperature. Sensible heat flux (*H*) will be determined from eddy covariance using sonic anemometer measurements of air temperature. The Schotanus et al. (1983) humidity correction will be applied to sonic-derived *H*. Soil heat flux (*G*) will be measured by soil heat flux plates and calorimetry (Liebethal et al., 2005). Heat flux plates (HFT-3, REBS) will be installed at a depth of 5 cm below the soil surface, and the storage flux in the 0-5 cm will be calculated from the time-rate-of-change in soil temperature at depth as measured by thermocouple probes. Soil water content will be measured using Campbell Scientific CS616's. We will also account for energy storage in photosynthesis as outlined by Meyers and Hollinger (2004).

Energy balance closure can be an issue with eddy covariance (Wilson et al., 2002), and comparisons of energy fluxes among sites can be problematic as a result, especially when determining if differences in water use exist among sites. We will close the energy balance by partitioning the missing energy between *LE* and *H* using eddy covariance measurements of the Bowen ratio as outlined by Twine et al. (2000) and used by Scott et al. (2004).

4.3 Effect of *Larrea* encroachment on the near-surface atmosphere: mesoscale model. To investigate the effect of shrub encroachment and consequent changes in land-atmosphere interactions on the regional climate we will carry out a number of simulations with the Regional Atmospheric Modeling System (RAMS, Pielke et al.,1992, Cotton et al., 2003). RAMS solves a set of dynamic equations in their nonhydrostatic, compressible form, a thermodynamic equation, and a set of cloud microphysical equations. It predicts the three velocity components, potential temperature, mixing ratio, and subgrid-scale turbulence kinetic energy (TKE) in a terrain-following coordinate system. RAMS is coupled with a Land Ecosystem Atmosphere Feedback model, version 2 (LEAF-2; Walko et al., 2000), which has multiple soil layers and accounts for the effects of several different vegetation functional types. Ground observations and published data will be used to determine parameters characteristic of each functional type, including albedo, emissivity, leaf area index, mean root depth, and roughness length. In the model, the turbulent exchange at the surface is based on Monin-Obukhov similarity theory. The computed surface fluxes for the soil and vegetation must be averaged to provide the grid-averaged surface flux. These fluxes serve as the lower boundary for the sub-grid diffusion scheme for the atmosphere. The three-dimensional simulations will be made over a large domain covering the Southwestern US, with the domain consisting of four nested grids. The innermost grid is approximately 200x200 km with a horizontal grid spacing of 500 m and is centered on the LTER field site across the encroachment front. The first model level will be as close to the ground as possible to allow the detailed investigation of the nighttime temperatures and cooling rates. Simulations will be made for the duration of the intensive balloon measurements at the LTER site and initialized with analysis field provided by numerical weather prediction models (i.e., the National Centers for Environmental Prediction Eta Data Assimilation System (NCEP EDAS) fields). The five outermost lateral boundary points in the domain will be nudged toward NCEP EDAS objective analysis fields at 3-hour intervals to allow changes in large-scale conditions to influence the model simulations. Nudging towards objective analysis fields will only be applied to the outermost grid; no interior nudging will be applied which allows an investigation of the physical processes affecting the land-surface atmosphere feedback mechanisms in the study area. Vegetation distribution and topography will be derived from a 30 arcsecond (~ 1 km) resolution data set from the United States Geological Survey (USGS). Multiple simulations will be carried out in which the distribution of grassland and shrubland will be varied to investigate its impact on ABL dynamics, and in particular the hypothesized positive feedback mechanism between shrub encroachment and ABL dynamics. To study the interaction using the mesoscale model, it is particularly important that the model simulates properly the nocturnal cooling over vegetated surfaces. The measurements that are going to be taken as part of the study (tower and balloon measurements) will be crucial to evaluate the model's performance given the common problems in simulating nocturnal boundary layers (e.g. Mahrt, 1999).

After we have adequately simulated the ABL over grass- and shrub-dominated areas and assessed model limitations, model simulations will be run with different surface cover scenarios. Each of these boundary conditions will affect the surface energy balance as well as the regional patterns of atmospheric circulation. The resulting surface air temperatures will be used to determine if the near-ground microclimate is favorable for *Larrea* survival using the same criteria as in section 4.4

4.4 Physiological measurements. To understand the effect of increased minimum temperatures observed in a *Larrea*-encroached landscape, we must understand the conditions under which freezing leads to mortality or a shift in plant carbon balance. To this end, we will measure the response of gas exchange and water transport to freezing. Because of the importance of seedlings to any northward expansion of the range as temperatures increase, our measurements will focus on seedlings, from several sites across the northern limit of *Larrea* (Sevilleta, Camp Verde Valley, AZ and Eureka Valley, NV, see fig. 1). Because water status affects xylem response to freezing (Davis et al 1999), we will measure these responses at high and low plant water potential using plants grown from seed, raised in the UNM research greenhouse and acclimated in growth chambers prior to treatment. From each field site, we will collect some data on adult freezing responses for comparison with seedling data using the methods of Pockman and Sperry (1997) and Martinez-Vilalta and Pockman (2002). Briefly, seedlings will be exposed to freezing conditions using an insulated chamber linked to a temperature controlled bath with carefully controlled rates of freezing and thawing based on field measurements of wood temperature. The root system will be held at near freezing temperatures to reflect the difference between above- and below-ground temperature regimes. After freezing, some plants will be returned to the greenhouse for extended measurements of photosynthesis and transpiration while other plants will be used for measurements of xylem hydraulic conductance. The results will be represented in models using the temperature at which freezing damage begins (T_i) and the temperature at which *Larrea* xylem loses all conducting capacity (T_0). Moreover, our water availability treatment will provide some index of the change in response under different soil water levels. Although this is a simplistic approach, it is consistent with the freezing response observed in *Larrea* adults in which freezing damage increased linearly with minimum freezing temperature (Pockman and Sperry 1997).

4,5 Vegetation model This part of the project will develop and parameterize a simple model of vegetation dynamics accounting for changes in the fractional cover and leaf area index (LAI) of two functional types, namely shrubs and grasses. The model will calculate changes in shrub and grass fractional cover at the annual time scale and will run coupled with the regional climate model described in the following section: at the end of each year the output of the regional climate model will be used to calculate changes in grass and shrub cover. In turn, the newly updated vegetation cover will be used to calculate the input parameters (i.e., surface roughness, albedo, emissivity, etc.) for the regional climate model. These parameters will be used to simulate the regional climate dynamics in the following year, and so on. A similar approach in the modeling of vegetation and climate dynamics can be found in other models of biosphere-atmosphere interaction (e.g., Brovkin et al., 1999; 2002). Thus the climate dynamics model will run at the annual time scale in a spatially extended domain having the same resolution as the regional climate model.

Grass and shrub productivity depends in general on a number of factors including soil moisture availability, temperature, soil nutrients, and fire regime. Although both grasses and *Larrea* respond to soil moisture fluctuations, a tighter coupling exists between grass productivity and summer soil moisture, while *Larrea* shrubs are more sensitive to winter moisture (Muldavin et al., 2007). The rainfall climatology typical of the Northern Chihuahuan desert exhibits two distinct rainy seasons, with about half of the mean annual rain falling on average in the summer months and the other half in the winter months. Winter precipitation is used by *Larrea* shrubs, while summer precipitation may be used both by grasses and shrubs, though grasses are limited by summer soil moisture fluctuations much more than shrubs, which have access to deeper soil moisture contributed by winter rainfall. Thus, the relative importance of winter vs summer rainfall determines the balance between grass and shrub productivity (Muldavin et al., 2007). Shrubs are hardly killed by drought conditions but they are sensitive to freeze-induced embolism, while there is no evidence that grasses are limited by minimum winter temperatures. We model the dynamics of shrubs and grasses as two logistic laws (e.g., Tsoularis and Wallance, 2000), with carrying capacities dependent on the limiting resources and disturbance regime (i.e., summer soil moisture for grasses, and winter soil moisture and minimum temperatures, for shrubs). Both soil moisture and temperatures will be calculated by the regional climate model. Thus, the dynamics of the fractional covers of shrub (S) and grass (G) biomass will be expressed as

$$\frac{dS}{dt} = \alpha S\,(C_S - S)$$

$$\frac{dG}{dt} = \beta\, G\,(C_G - \gamma\, S - G)$$

with α and β determining the time scales of growth of each group. C_S and C_G are the carrying capacities, and γ represents the fraction of the carrying capacity for grasses that is accessible to shrubs. To account for temperature limitations on shrub growth/survival, C_S will be expressed as a function of the minimum nighttime temperature, T_n, with C_s, rapidly tending to zero when the minimum nighttime temperature is smaller than the limit value for max freezing-induced stress. The productivities of grasses and shrubs will be also expressed as a function of model-simulated summer and winter average soil moisture, respectively. These soil moisture values will be averaged throughout the root depth of each functional type. Linear relations will be used, consistently with the data shown in Muldavin et al., (2007).

The model will be parameterized and validated using data on vegetation density available from field observations to determine the carrying capacity for shrubs, grasses, and the parameter γ, which depends on the amount of grass vegetation able to grow in shrub interspaces. To this end, we will use historical data from the literature to determine the rates of growth/establishment and encroachment of *Larrea* under different climate conditions. Although historical photo records are limited at the Sevilleta, estimated rates of shrub encroachment at the Jornada Basin to the south of SNWR suggest rapid increases in shrub cover and declines in grass cover from the mid-1930's to the mid-1970's (Goslee et al. 2003, Laliberte et al. 2004). For the parameterization of the dependence of C_s on winter hydrological/climate conditions, will benefit from and complement an on-going manipulative experiment on the impact of increasing night time temperatures, and winter rainfall on creosote invasion (see Collins et al. 2006).

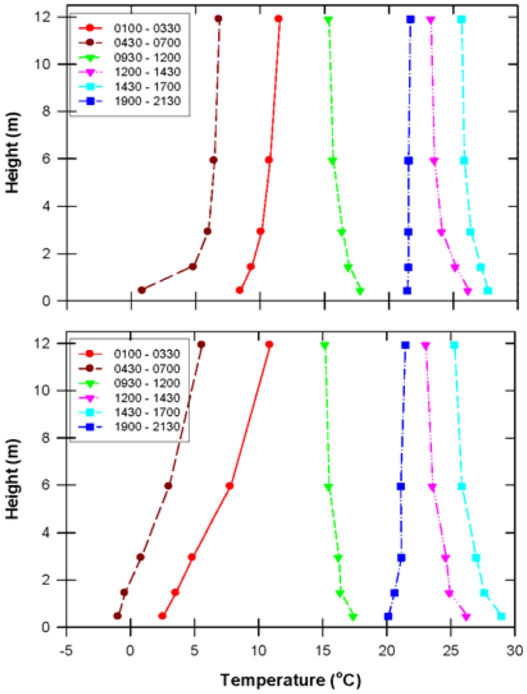
We acknowledge that this model is an oversimplification of the processes contributing to shrub encroachment in that it ignores some other important factors (e.g., land use change, grazing, fire dynamics and fire management, changes in rates of grass establishment, etc.). However, this simplistic approach will allow us to investigate the extent to which feedbacks between vegetation and microclimate may affect the process of shrub encroachment, when all the other factors remain constant. Plus, such a model can serve as a starting point from which we can add complexity to determine how other factors (resource competition, shifts in seasonal precipitation (Peters 2002) affect grass-shrub dynamics and landscape-scale patch structure.

4.6 Coupled regional climate-vegetation model. The regional climate model that we will use is based on the mesoscale model RAMS (see section 4.3). The vegetation model will be run off-line using output from the regional climate model to investigate the interaction and feedback processes between climate and shrub encroachment. RAMS will be run in a coarser resolution than for the investigation of the vegetation heterogeneity on the ABL (section 4.3) to accommodate the length of the simulation. We anticipate that with the current resources we have available (16 CPU linux cluster and 4TB file server), a 10-year simulation can be easily achieved for the study area using a resolution of about 5km). For initial and boundary conditions, analysis fields from the NCEP/NCAR 40-year reanalysis project will be used (Kalnay et al., 1996). If the 10-year simulation does not appear to be sufficient to study bush encroachment, we can extend the simulation with multiple years using additional resources (such as the linux clusters at NCAR) to which we have access. Thus, the regional climate model will be run for one year at a time and will provide the microclimate variables (including winter nighttime temperature and soil moisture) necessary to run the vegetation model. The output from the vegetation model (grass/shrub cover) is then fed back to the regional climate model which will run for one year using the updated landcover information, and so on.

5. Expected Results

We expect notable differences to be present in the low level atmospheric thermal structure between the two vegetation sites. Similarly, values of nighttime mixed boundary layer potential temperature and moisture content are expected to be elevated over the *Larrea* vegetation compared to grassland.

Figure 5 shows some preliminary results of averaged temperature profiles measured above the two sites in April 2005. To demonstrate variations in the atmosphere's thermal structure throughout the day, temperatures were averaged over intervals of 2.5 hours. Daytime temperatures are fairly similar between the two sites due to the relatively high convective mixing and horizontal wind from solar heating. After sunset, temperature rapidly decreases and the residual convective energy is lost to the overlying atmosphere; winds decrease allowing the formation and growth of the nocturnal stable boundary layer. The nocturnal stable boundary layer grows more quickly over the grassland (Fig. 5b) as compared to the *Larrea* site (Fig. 5a). In addition, near surface temperatures above *Larrea* remained higher than above grassland throughout the night and this difference was stronger when the wind speeds were small. Albedo values at the *Larrea* site were consistently lower than over the grassland throughout the observation period. Albedo was determined by measuring the ratio of the incoming and outgoing (reflected) shortwave radiation. Figure 5 provides an example of daily variability of albedo at the two sites. These results indicate that shrubs are able to more effectively absorb and utilize incoming solar radiation. Moreover, due to the presence of bare soil, more solar radiation is absorbed at the *Larrea* site, which is then released to the overlying atmosphere at night as terrestrial thermal energy.



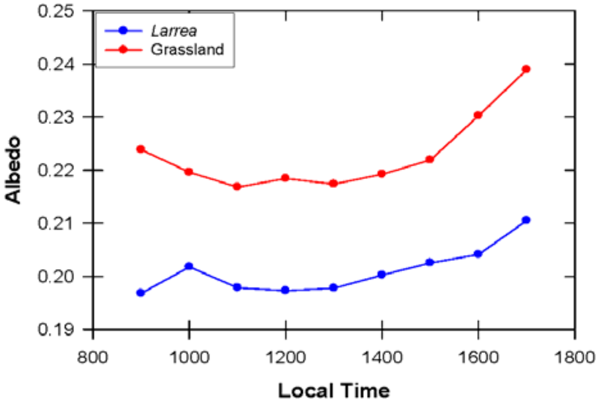


Figure 5 (left): An example of averaged vertical temperature profiles on a springtime day (Apr. 13, 2005) over shrubland (Top) and over grassland (Bottom).

Figure 6 (above): Albedo measured at the same sites.

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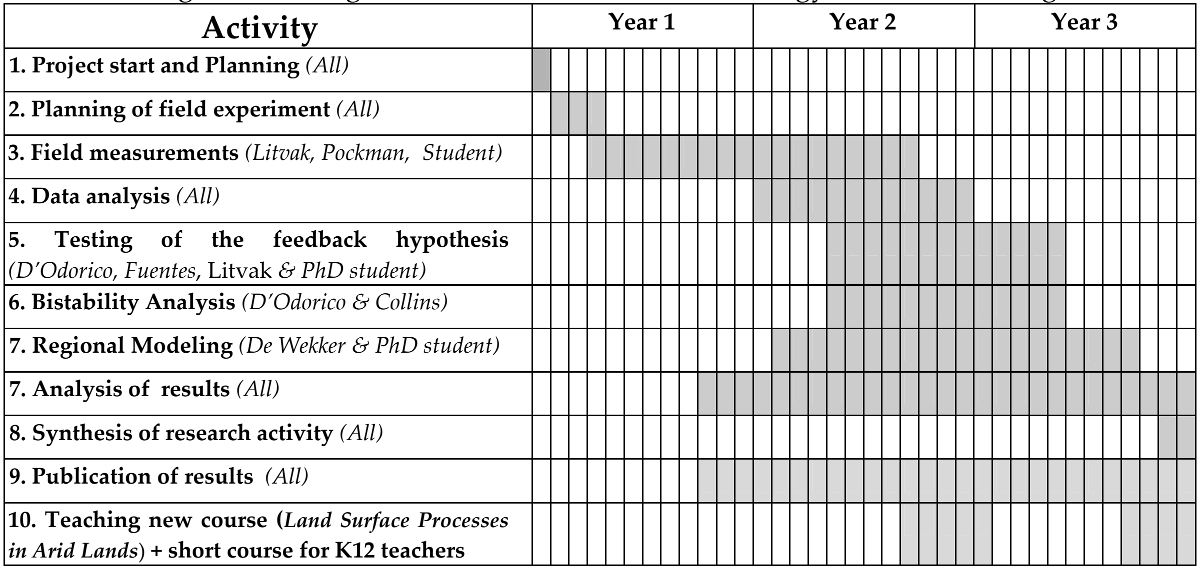
6. Coordination of the research among the PIs

The research will be developed jointly by groups at the University of Virginia (UVA) and University of New Mexico (UNM). The research team responsibilities are as follows:

1. Paolo D'Odorico (UVA) will supervise the graduate student at UVA funded by this project. He will contribute to the experimental design and to the analysis of the data, to the evaluation of feedbacks and non-linear system dynamics.
2. Stephan De Wekker (UVA) will supervise the modeling of the regional dynamics of land-atmosphere interactions using a regional atmospheric-land surface model. He will assist the student in setting up and interpreting the simulations.
3. Jose D. Fuentes (UVA) will contribute to the analysis of field data from flux towers and balloon launching and investigate the differences in surface energy fluxes and storage over the two land covers. He will also, supervise the student in the evaluation of the research hypothesis.
4. Marcy Litvak (UNM) Marcy Litvak will supervise the flux tower measurements, processing of the tower data, and will contribute to the investigation of differences in surface energy fluxes and near-surface microclimate conditions between the grassland and shrubland sites.
5. Scott Collins (UNM) will contribute to the experimental design with site selection and to the evaluation of the vegetation-microclimate feedback with his expertise in grassland vegetation dynamics. He will also contribute to the design/parameterization of the vegetation model.
6. William Pockman (UNM) will lead the physiological study of *Larrea tridentata* and *Bouteloua eriopoda* the microclimate conditions controlling the establishment, survival and growth of *Larrea* in the Chihuahuan desert.



Activity	Year 1												Year 2												Year 3											
1. Project start and Planning *(All)*	▨																																			
2. Planning of field experiment *(All)*		▨	▨	▨																																
3. Field measurements *(Litvak, Pockman, Student)*				▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨															
4. Data analysis *(All)*													▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨												
5. Testing of the feedback hypothesis *(D'Odorico, Fuentes,* Litvak *& PhD student)*																	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨							
6. Bistability Analysis *(D'Odorico & Collins)*																	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨							
7. Regional Modeling *(De Wekker & PhD student)*														▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			
7. Analysis of results *(All)*										▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
8. Synthesis of research activity *(All)*																																			▨	▨
9. Publication of results *(All)*										▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
10. Teaching new course (*Land Surface Processes in Arid Lands*) + short course for K12 teachers																					▨	▨	▨	▨	▨								▨	▨	▨	▨

Table I. Schedule of principal research activities to be achieved as part of this proposal.

7. Significance and impacts of the proposed activity

7.1 Intellectual Merit. Changes in plant community composition not only affect species diversity and productivity, but also may impose dramatic changes on land-atmosphere interactions, through changes in regional albedo with subsequent effects on regional temperatures. Unless such feedbacks are understood and incorporated into climate models, model forecasts are likely to underestimate the impacts of climate change. In the southwestern US, where models predict and warmer and dryer future (Seager et al. 2007) changes in land-atmosphere interactions subsequent to grassland-to-shrubland conversions remain poorly investigated and characterized (e.g., Bhark and Small, 2003).

Changes in land cover conditions modifying albedo (Charney, 1975), surface roughness (e.g., Sud et al., 1988), and soil moisture (Shukla and Mintz, 1982), with consequent effects on surface energy and water vapor fluxes, and boundary layer dynamics. A number of modeling studies have investigated how these factors may determine the effect of land cover change on surface climate in regions of the world affected by desertification (Xue and Shukla, 1993; Xue, 1996; Wang and Eltahir, 1999), deforestation (Dickinson and Henderson-Sellers, 1988), and ecosystem succession (Bonan, 2002). However, the effect of shrub encroachment on boundary layer dynamics and the possible existence of positive microclimate-vegetation change feedbacks remain poorly investigated. This is somewhat surprising given that grassland-to-shrubland conversions are occurring at a relatively rapid pace in a many arid and semiarid regions worldwide. There are good indications that this process may be enhanced by any interactions between vegetation and the near surface atmosphere. However, no field investigations combined with model-based analyses have conclusively tested the existence of a positive feedback between shrub encroachment and surface energy balance.

7.2 Broader Impacts.

Shrub invasion, particularly by *Prosopis* and *Larrea*, has been increasing in semi-arid grasslands in the American southwest during the past century (Gardner 1951, Buffington and Herbel 1965, Archer 1994, Schlesinger et al. 1990, Cross and Schlesinger 1999, Asner et al. 2003, Goslee et al. 2003). It is estimated that 19 million ha of native grassland in southwestern North America is now dominated by creosotebush (Van Auken 2000; Fig 1). Invasion by *Larrea* reduces species diversity (Báez et al. 2006), increases soil erosion, and decreases infiltration and soil fertility (Bhark and Small 2003, Whitford et al. 2001). Once established *Larrea* adults experience extremely low mortality (Bowers et al. 1995). Consequently, land does not revert back to grassland following creosote invasion. Quantification of vegetation-atmosphere feedbacks of *Larrea* invasion in New Mexico will yield new insights into vegetation-atmosphere interactions in this region. Identifying differences in the thermodynamic and radiative characteristics of the atmospheric boundary layer above shrub- and grass-dominated vegetation will contribute to the understanding potential feedbacks between land cover change and microclimate and will provide useful information on processes controlling shrub encroachment,which affects ecosystem functioning and services in aridland ecosystems worldwide with detrimental impacts on local societies.

7.2.1 Benefits to Society. The proposed research combines empirical and theoretical approaches by an experienced research team with ongoing collaborations to explore an important open problem related to the role of vegetation-microclimate feedbacks in the process of shrub encroachment in the southwestern U.S. These feedbacks may be responsible for numerous impacts on land surface cover, landscape dynamics, soil productivity, ecosystem dynamics, and near-surface climate conditions over large areas of the US and the world. With successful completion of this research, better understanding of the interactions between changes in land cover and surface air temperatures will result in a better prediction of the stability, resilience, and spatial extent of areas expected to be prone to shrub encroachment under the current climate conditions.

7.2.2. Advance discovery while promoting teaching, training, and learning. Two **Ph.D. students** will be trained during this project, one in vegetation-atmosphere modeling (UVA) and another in ecophysiology and vegetation dynamics modeling (UNM). These students will gain general understanding of the methods of scientific research, learn specific tools required for this project, develop collaboration skills, and gain experience in preparing papers and giving presentations.

The PIs are committed to integrating research with teaching goals. A **new course** (*Land Surface Processes in Arid Lands*) will be developed by the PI at UVA and offered in the hydrometeorology of arid environments. The course will present an analysis of arid and semiarid environments from a broad and interdisciplinary perspective. The proposed research will provide tools and case studies, which will be used to show connections existing between atmospheric and land surface processes, as well as the impact of land cover on surface energy balance. This course will include lecture sessions and critical analysis of the current literature on this subject and be offered as a research seminar and webcast to UNM so that undergraduate (senior) and graduate students from UVA and UNM can enroll and participate.

A goal of this project is to stimulate high school science education by providing high school teacher training and research experience. A **short course** will be offered to **high-school teachers** on current issues in hydrometeorological research. This short course will be offered for teachers at UVA and at UNM through the Sevilleta LTER E-MRGE (Ecohydrogeology in the Middle Rio Grande Environment) GK12 program (Collins is PI). One of the foci of educational programs at both participating universities is the training of school teachers and the offering of courses in the natural and earth sciences. These offerings are developed in coordination with local school officials to gauge the interests and needs of the K12 community of school teachers. These teachers usually receive a certificate and graduate credit from the relevant host university. Through the involvement of public school science teachers this research will have a significant impact on middle and high school science education**.**

7.2.3. Provide Research Opportunities for Underrepresented Groups. All PIs are committed to integrating diversity in into their research groups and will welcome students of different gender, ethnicity, and race. Indeed, they actively try to seek to recruit students and postdocs from underrepresented groups. The PIs at UVA are volunteers for faculty-student mentoring program of the Office of African-American Affairs at University of Virginia. Their research group currently provides a diverse academic environment to about 10 students, including 5 minority students from the U.S., and 3 international students. UNM is a certified Hispanic serving institution with a relatively large population of Native American students. The Department of Biology has over 1200 undergraduate majors of which 33% re Hispanic, 10% Native American, 7% Asian and 2% African American. Thus, by our regular day-to-day activities UNM faculty work with, encourage, mentor, and train a large number of minority students on a daily basis. In that regard, we serve a much broader goal of recruiting minority students into ecological research. The SEV LTER is involved in education and outreach through our Schoolyard LTER, the SNWR, a GK-12 program, a summer mini-IGERT program, an ESA SEEDS Chapter, and our everyday classroom teaching activities.

8. Results from previous NSF support

Grants NSF EAR-0409305 (UVA) and 0408869 (EIU). Grant Period: 09/01/04 – 08/31/06. Funding: $140,672 (UVA) and $73,581 (EIU). *Title*: "*Collaborative Research: The Effect of Atmospheric Humidity on the Susceptibility of Dry Soils to Wind Erosion*". We have tested the major hypotheses of the project both at the lab [*Ravi et al.*, 2006a] and at the field scale [*Ravi and D'Odorico*, 2005]. We have found that air humidity affects the surface soil moisture and the threshold velocity for wind erosion. Publications: *Ravi and D'Odorico*, 2005; *Ravi et al.*, 2006a,b; Ravi et al., 2007a,b,c; *D'Odorico and Porporato*, 2006a,b.

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