International research workshop of the Israel Science Foundation

Eco-hydrology of semiarid environments: Confronting mathematical models with ecosystem complexity

19-23 May 2013

Ben-Gurion University of the Negev, Israel

"It doesn't matter how beautiful your theory is, it doesn't matter how smart you are.
If it doesn't agree with experiment, it's wrong."

Richard P. Feynman

Scientific Committee

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OPENING ADDRESS

Drylands, including arid and semiarid areas as well as some of the dry subtropical regions, cover approximately one third of the total land area of the world. These areas are currently supporting in excess of two billion people, and this part of the global population will continue to grow. It is now becoming evident that drylands are vulnerable biomes, with some estimates placing about 10-20% of dryland areas to have already undergone degradation or irreversible desertification. Virtually every scientific report, including the Millennium Ecosystem Assessment, repeatedly stated that biophysical and socioeconomic monitoring and assessment of desertification and land degradation is first priority for desertification science.

While all aspects of desertification are well beyond the scope of a single workshop, a common theme to all scientific investigations of dryland regions are water regime and its impact on vegetation biomass and productivity. One aspect of the water-vegetation interactions is the self-organization of vegetation into regular patterns interspersed by sparsely vegetated or bare soils. These patterns have been observed in dry ecosystems worldwide and can be predicted via mathematical models. However, numerous knowledge gaps still exist between model predictions and reality. The aim of this workshop is to bring together hydrologists, ecologists, Earth scientists and soil physicists to explore the main factors affecting water-vegetation interactions at multiple spatial and temporal scales, and to determine the steps required (on a theoretical and experimental level) to improve the predictive skills of mathematical models in eco-hydrology.

This workshop hosts 75 participants with 30 oral presentations, 3 round table discussions and 15 poster presentations, all discussing most recent research on the following themes:

OPENING ADDRESS

Eco-hydrological processes and vegetation patterns • Flow processes and water regime in soils • Mathematical modeling in eco-hydrology • Coupling water to carbon fluxes and biomass • Novel experimental methods.

Papers related to the presentations will be submitted to a Special Issue in Water Resources Research and we envision that the exchange of ideas will form the basis for similar initiatives.

This workshop would not have been possible without the support of many institutions and individuals. We gratefully acknowledge their support and deeply thank them all. The Israel Science Foundation provided the prime financial support for the workshop and Ben-Gurion University hosted the event while President Carmi, Rector Hacohen and the Dean Newman provided additional financial support. The Minerva Center of Movement Ecology also partially supported the event. We received great help from Rachel Zimmermann who solved every administrative issue, coordinated all efforts and actually directed the event. Roni Bluestein-Livnon acted as the graphic editor and shared with us her experience in organizing academic events. Galia Barshad was the administrative assistant and Jeny Maktaz from Interia designed and implemented the workshop website. We also thank the students of the Geographic Information Laboratory in BGU for on-going help and Prof. Shaul Krakover who encouraged us to launch this initiative.

Scientific committee

Tal Svoray Ben-Gurion University of the Negev, Israel
Shmuel Assouline Agricultural Research Organization, Volcani Center, Israel
Gabriel Katul Duke University, N. Carolina, USA

PROGRAM

Sunday-Wednesday
19-23 May 2013

PROGRAM

Sunday | Monday

Sunday | 19.5.2013

Arrival	BGU Hotel, Beer Sheva
19:00	Ice Breaker

Monday | 20.5.2013

8:30 **Registration and Coffee**

9:00 **Opening address**

Prof. Zvi Hacohen Rector, Ben-Gurion University of the Negev

Prof. David Newman Dean, Faculty of Humanities and Social Sciences, Ben-Gurion University of the Negev

Prof. Pua Bar Head, Department of Geography and Environmental Development, Ben-Gurion University of the Negev

9:30 **Presentation of the workshop**
Tal Svoray

10:00 **Session I: Eco-hydrological processes and vegetation patterns I**
Chair: **Paolo D'Odorico**

The role of plants as ecosystem engineers in controlling eco hydrological processes and resilience to global changes
Moshe Shachak

PROGRAM

Monday

Vegetation-environment feedbacks from local to global scales
Max Rietkerk

11:00 **Coffee Break**

11:30 Assessing vegetation structure in Mediterranean drylands
Sonia Kefi

Vegetation as a filter of interannual climate variability
Simone Fatichi

Eco-hydrological patterns and processes induced by environmental fluctuations
Paolo D'Odorico

13:00 **Lunch Break**

14:00 **Session II: Eco-hydrological processes and vegetation patterns II**
Chair: Roni Avissar

Vegetation patterns in semiarid river basins: drivers of organization and metabolic implication
Ignacio Rodríguez-Iturbe

A connectivity-map approach to model plant invasive spread in heterogeneous environments
Ran Nathan

Evolution of vegetation spatial patterns in drylands: interaction of dispersal processes and climatic variation
Sally Thompson

PROGRAM

Monday | Tuesday

15:30 **Coffee Break**

16:00 Patch-size distribution and hydrological fluxes in real semiarid hillslopes
Tal Svoray

Sustainable use of soil and water resources in semiarid, managed ecosystems
Amilcare Porporato

Using the Ocean-Land-Atmosphere Model (OLAM) to assess the sensitivity of semiarid regions ecohydrology to climate variations
Roni Avissar

Tuesday | 21/5/2013

8:30 **Gathering and Coffee**

9:00 **Round table discussion**

How far are we from understanding the eco-hydrological processes that determine vegetation patterns?
Chair : **Amilcare Porporato**
Discussants: **Paolo D'Odorico, Jost von Hardenberg**

10:30 **Session III: Flow processes and water regime**
Chair: **Jean-Yves Parlange**

Infiltration in soils with a saturated surface
Jean-Yves Parlange

PROGRAM

Tuesday

What controls evaporation dynamics from porous surfaces?
Dani Or

Two water worlds? Isotope evidence shows that trees and streams return different pools of water to the hydrosphere in seasonally-arid environments
Jeffrey J. McDonnell

Ecohydrology of the Savanna region in Burkina Faso
Marc Parlange

12:30 **Lunch Break**

13:30 Impact of soil surface sealing on the ecohydrology of semiarid areas
Shmuel Assouline

Water-vegetation feedbacks in sealed environments.
Shai Sela

Canopy edge flows
Uri Shavit

15:00 **Coffee Break**

15:30 **Round table discussion**

To harness the theory of flow processes to water available for vegetation
Chair: **Dani Or**
Discussants: **Marc Parlange, John Selker**

PROGRAM

Tuesday | Wednesday

17:00 **Poster session**

Oren Ackermann | Yardena Bohbot-Raviv | Li Chen | Tomer Duman | Gordon E. Grant | Ran Holtzman | Dilia Kool | Yair Mau | Noa Ohana | Rakefet Shafran-Nathan | Koen Siteur | Christina Tague | Ana Trakhtenbrot | Yuval Zelnik | Royi Zidon

Wednesday | 22/5/2013

8:30 **Gathering and Coffee**

9:00 **Session IV: Mathematical modeling in ecohydrology**

Chair: **Antonello Provenzale**

Diversity and dynamics of water-limited vegetation landscapes: universal and non-universal aspects
Ehud Meron

Vegetation patterns and evapotranspiration fluxes in drylands.
Jost von Hardenberg

Climate-vegetation interaction in water-limited environments
Antonello Provenzale

The role of spatial heterogeneity of soil depth in vegetation pattern formation
Hezi Yizhaq

11:00 **Coffee Break**

PROGRAM

Wednesday

11:30 **Session V: Coupling water to carbon fluxes and biomass**
Chair: **Dan Yakir**

Spatiotemporal feedback between canopy conductance and soil moisture at the scale of individuals reflects native and imposed variation in canopy density
Ram Oren

The economics of leaf-gas exchange in a fluctuating environment and their upscaling to the canopy-level using turbulent transport theories
Gaby Katul

Contributions of soil properties tree hydraulics and leaf physiology to the ecohydrology of a semi-arid pine forest
Dan Yakir

Flux-variance similarity theory applied to water vapor and carbon dioxide exchange in a semiarid ecosystem
Todd Scanlon

13:30 **Lunch Break**

14:30 **Session VI: Novel experimental methods**
Chair: **Maxim Shoshany**

Observations of complex ecohydrologic processes at appropriate temporal and spatial scales with fiber optics
John Selker

PROGRAM

Wednesday

Water use efficiency, patch pattern properties and biomass in shrublands across Mediterranean climatic gradient
Maxim Shoshany

The eco-hydrology of the Devils Hole pupfish: when the ecology and the hydrology won't agree to the same story
Scott W. Tyler

Desert rain storms and flash floods: Insights gained from space-time characterization and modeling of convective rain cells
Efrat Morin

17:00 **Coffee Break**

17:30 **Round table discussion**

Confronting mathematical models with field observations
Chair: **Ehud Meron**
Discussants: **Ignacio Rodríguez-Iturbe, Jeffrey McDonnell**

18:30 **Closing**
Gaby Katul

Presenting Special Issue to WRR
Shmuel Assouline

20:00 **Gala Dinner**

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LECTURES

Impact of soil surface sealing on the hydrology of semi-arid areas

Shmuel Assouline[1]
Shai Sela[2]
Li Chen[3]
Tal Svoray[2]

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2 Ben-Gurion University, Israel
3 Desert Research Institute, USA

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Bare soil surfaces in semi-arid areas are prone to sealing, which involves the formation of a more compacted and less permeable layer at the vicinity of the soil surface. This new interface of the soil-atmosphere system affects flow processes such as infiltration and evaporation. It therefore shapes the local and regional rainfall-runoff relationship; influences the intensity of soil erosion; and determines the amount of water in the soil profile available for the development of vegetation. At the hillslope scale, soil surface sealing affects spatial and temporal distribution of key components of the water budget. The role of soil surface sealing in shaping the hydrological response of a semi-arid hillslope in Southern Israel is described on a quantitative basis using a modeling approach that links the seal hydraulic properties to the physical characteristics of the hillslope. It is shown that, depending on rainfall intensity and soil depth, the seal layer can act as a positive factor that suppresses evaporation and conserves water stored in the profile to the benefit of the vegetation, or as a negative one that reduces infiltration and increases water losses through runoff.

A two-dimensional surface runoff model is applied to represent the joint impact of the seal layer, the microtopography and the vegetation patches on spatial and temporal features of the rainfall-runoff relationship. The seal layer and the vegetation patches affect runoff generation, while microtopography affects mainly overland flow patterns. More water is supplied to the vegetation patches via runoff re-infiltration under soil surface sealing conditions. ■

The impacts of water table depth on ecohydrological processes and their effects on weather and climate at the regional and global scales

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David Medvigy[2]

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The global water table depth produced by Fan, Li and Miguez-Macho (2013) was introduced into the Ocean-Land-Atmosphere Model (OLAM), a state-of-the-art Earth System Model developed in our research group, to investigate the hydroclimatological effects of land-atmosphere interactions at multiple spatial and temporal scales. Particularly, we studied the effects of deforestation of tropical regions and desertification of arid areas on the local, regional and global weather and climate. Insights from the different experiments emphasize the needs for specific modeling and experimental capabilities and the benefits of modern, multi-scale Earth System Models for such simulations.

Ecohydrology of a mixed savanna-agrosystem in Burkina Faso

Natalie Ceperley[1]
Theo Mande[1]
Scott Tyler[2]
Nick van de Giessen[3]
Marc B. Parlange[1]

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The ecohydrology of a semi arid watershed in Southeastern Burkina Faso is studied through field campaigns that have been ongoing since 2009. A distributed sensor network of wireless meteorological stations, eddy covariance flux towers and sap flow probes have been arranged across cultivated rice and millet fields, natural savanna, fallow fields, and agroforestry trees, to understand diurnal and seasonal variations in evapotranspiration and stream flow discharge. Normalized difference vegetation indexes taken from weekly MODIS images as well as personal field observations were used to inform seasonal and spatial variations in albedo, rate of transfer to ground heat flux, and roughness length. Samples from rain, ground, surface, soil, and xylem water were collected for analysis of isotopic δO18 and δDH fractions, and ground water, stream temperature, and discharge at two locations were monitored.

The talk will focus on results on the dynamics of an ephemeral stream in the watershed and the diurnal stream flow patterns that are observed. The diurnal stream flow pattern in the early part of the wet season (when it is a losing stream) is influenced in the early season by variations in stream temperature (range of 10 degrees c) and changes in the viscosity. Later in the season when it fed by the ground water (gaining stream) the evaporation along the stream edge near the outlet apparently controls the diurnal stream pattern. The isotope measurements support that the early season stream flow is rainfall dominated and later in the season ground water dominated.

Ecohydrological patterns and processes induced by environmental fluctuations

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Environmental systems are forced by a number of climatic and anthropogenic drivers, which are not constant in time but fluctuate. Part of this variability is random because of the uncertainty inherent to climate dynamics and episodic disturbances. Relatively strong fluctuations are a distinctive feature of dryland precipitation, particularly in very arid climates. What role does environmental variability play in the dynamics of these ecosystems? Research on environmental change typically considers ecosystem response to shifts in mean climate conditions. There is, however, some evidence of ongoing changes in the variance of hydrologic drivers. What is the effect of changes in this variance? Random environmental fluctuations are generally expected to induce disorder. However, they can also lead to the emergence of organized spatiotemporal patterns in ecosystem dynamics. We discuss some of the major mechanisms of noise-induced organization in nonlinear dynamical systems affected by stochastic drivers and explore the applicability of these models to eco-hydrologic processes in arid regions. We show how an increase in environmental variability may enhance the resilience of dryland ecosystems, increase biodiversity, or induce vegetation pattern formation. ■

Vegetation as a filter of interannual climate variability

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Interannual variability of climate, precipitation in particular, can influence the components of hydrological budget, affecting them directly and indirectly through vegetation structure and function.

In this study, we investigate the effects of fluctuations of annual precipitation on ecohydrological dynamics. Specifically, we use an Advanced WEather GENerator, AWE-GEN, to simulate 200 years of hourly meteorological variables obtained by imposing four types of precipitation annual processes: an AR1 process with the observed coefficient of variation of annual precipitation, an ARFIMA process with the observed coefficient of variation, and AR1 processes with coefficients of variation increased and decreased of 0.1.

The obtained long-term hourly meteorological time series are used to force a mechanistic ecohydrological model, Tethys-Chloris. Simulations of the hydrological and vegetation dynamics are performed for three locations characterized by different vegetation cover and climate conditions: (i) shrubs in a semi-arid desert of Arizona, (ii) grasses in Mediterranean California, and (iii) temperate deciduous forest in northern Michigan.

Long-term water fluxes mediated by energy transfer in the processes of transpiration and carbon assimilation are essentially unaffected by the imposed climate fluctuations; the only exception is represented by the water-limited environment. This finding support previous evidence of interannual “insensitivity” of evapotranspiration and the strong dependence of the Horton index on the Humidity index, demonstrated for many catchments. Vegetation tends to use the largest proportion of available water, implying that interannaul fluctuations of precipitation mostly affect variability of deep leakage/recharge.

With the exception of the semi-arid site, vegetation also tends to filter out the long-term correlation in annual precipitation. Short-term correlation can be detected in grass productivity dictated by the memory of carbon pools (fine roots, carbohydrate reserves), rather than from climate conditions.

Integrated metrics of vegetation drought stress, such as root available soil moisture, are also marginally affected by the imposed interannual variability, emphasizing how the process is dictated by sub-year anomalies rather than by long-term fluctuations. Finally, this study also allows quantifying which is the representativeness of 5-15 year time series (typically available in monitoring networks) of energy fluxes and vegetation productivity with respect to the long-term quantities. While evapotranspiration and vegetation productivity have narrow range of variability within a 5-15 year period, this is not the case for deep recharge that requires a long-term period for accurate estimation of the mean, climate-driven flux. ■

The economics of leaf-gas exchange in a fluctuating environment and their upscaling to the canopy-level using turbulent transport theories

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Global climate models predict decreases in leaf stomatal conductance (gs) and transpiration due to increases in atmospheric CO_2. The consequences of these reductions are increases in soil moisture availability and continental scale run-off at decadal time-scales. Thus, a theory explaining the differential sensitivity of stomata to changing atmospheric CO_2 and other environmental conditions such as soil moisture at the ecosystem scale must be identified. Here, stomatal responses to environmental fluctuations are first investigated using an optimality theory applied to stomatal conductance. An analytical model for gs is first proposed based on (a) Fickian mass transfer of CO_2 and H_2O through stomata; (b) a biochemical photosynthesis model that relates intercellular CO_2 to net photosynthesis; and (c) a stomatal model based on optimization for maximizing carbon gains when water losses represent a cost. The optimization theory produced three gas exchange responses that are consistent with observations across a wide-range of species: (1) the sensitivity of gs to vapour pressure deficit (D) is similar to that obtained from a previous synthesis of more than 40 species, (2) the theory is consistent with the onset of an apparent 'feed-forward' mechanism in gs, and (3) the emergent non-linear relationship between the ratio of intercellular to atmospheric [CO_2] (ci/ca) and D agrees with the results available on this response. A simplified version of this leaf-scale approach recovers the linear relationship between stomatal conductance and leaf-photosynthesis employed in numerous climate models that currently use a variant on the 'Ball-Berry' or the 'Leuning' approaches provided the

marginal water use efficiency increases linearly with atmospheric CO_2. The model is then up-scaled to the canopy-level using novel theories about the structure of turbulence inside vegetation. This up-scaling proved to be effective in resolving the complex (and two-way) interactions between leaves and their immediate microclimate. Extensions of this optimality approach to drought, salt-stressed cases, and for plants within protected environments are briefly presented. ■

Assessing vegetation structure in Mediterranean drylands

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Characteristics of vegetation spatial patterns may be used as early-warning signs of degradation in drylands. A variety of spatial metrics have been proposed in the literature based on theoretical models. Empirical verification, however, has not been able to keep in pace with the rapid growth in theoretical studies. Here, after reviewing the state of the art of spatial early-warning signals of degradation, I would like to present analyses of vegetation spatial patterns in Mediterranean drylands based on aerial images exploring and comparing these spatial early-warning signs. ■

Two water worlds? Isotope evidence shows that trees and streams return different pools of water to the hydrosphere in seasonally-arid environments

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Ecohydrological coupling in seasonally-arid environments is poorly understood. This talk presents a number of field-based studies that expose some of the puzzles and paradoxes in ecohydrological regimes where hydrology (i.e. rain input) and ecology (transpiration output) are out of phase. Here I present work that analyzes stable isotopes of oxygen ($\delta^{18}O$) and hydrogen (δD) in water to quantify spatial and temporal changes in precipitation, evaporation, soil water, tree water and stream discharge. I show for seasonally-arid systems in Oregon USA (i.e. the HJ Andrews Experimental Forest and the Alsea Forest) and Veracruz Mexico (i.e. a tropical montane cloud forest) a common finding of two isotopically distinct and separate pools of water held within the soil: one a mobile pool held at relatively low matric tension, making it more subject to gravitational transport to streams when more water is added to the system. The other pool is water held under higher matric tensions and has a longer residence time within the soil, and a higher propensity to be taken up by plants. In each case, as the dry season progressed, plants relied on deeper soil water as surface soils dried out. Evaporation from the soil surface resulted in a distinct isotopic signature on tightly bound soil water. Our isotope data indicate that most water taken up by plants during the time of seasonal aridity was affected by evaporation at some point, including soil water deeper than 30 cm. In contrast, mobile water reaching the stream and forming stream water did not show any evidence of an evaporation signature even though discharge rates showed distinct diurnal cycles driven by transpiration. During the wet up, soil lysimeter water and stream water were consistent with meteoric water signatures but with damped temporal dynamics with a several week lag period. Overall, our isotopic data provided insights into ecohydrological coupling that we had not expected based on our previous hydrometric-based hydrological analysis and physiologically-based tree analysis. These findings expose a key gap between mathematical models and ecosystem complexity characterizing seasonally-arid ecosystems. ■

Diversity and dynamics of water-limited vegetation landscapes:Universal and non-universal aspects

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Water-limited landscapes are spatially extended nonlinear system showing complex patterns of vegetation and soil water in space and time. Modeling such systems and relating model predictions to experimental observations pose a great challenge. Luckily, the mathematical theory of spatially extended nonlinear systems – pattern formation theory – is pretty well developed. An important result of this theory is the common universal behavior that different, and even disparate, systems show, provided they share certain mathematical constructs, such as instabilities, multiplicity of stable states and global constraints.

In this talk I will present four examples of such constructs: (A) a stationary non-uniform instability of a uniform state, (B) bistability of uniform and periodic-pattern states, (C) global constraints induced by fast transport processes, and (D) spatial resonances associated with periodic external modulations. I will then discuss the universal behaviors associated with these constructs in the context of water-limited vegetation. These include a universal sequence of ordered vegetation states along environmental gradients: bare soil, spots, stripes, gaps and uniform vegetation (construct A), a multitude of additional disordered states (construct B), gradual desertification dynamics (construct B), scale-free vegetation patterns (construct C), and resonant vegetation responses to the application of water harvesting methods of vegetation restoration (construct D).

These universal aspects of water-limited vegetation can be studied with relatively simple models that capture the mathematical constructs of interest. While powerful, this approach is not a substitute for the study of detailed models tailored to describe specific systems. I will conclude the talk with a discussion of the additional non-universal information that detailed models provide. ■

Desert rain storms and flash floods: Insights gained from space-time characterization and modeling of convective rain cells

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The occurrence of an extreme flash-flood at a given catchment is the final and powerful result of several meteorological and hydrological processes. Rain storm properties, including rain accumulations, rain intensities and space-time distributions, are most important in determining flash flood magnitudes. Catchment properties are also of major importance as they define the catchment-dependent sensitivity of flash-flood generation to rain properties. The presented study looks into these relationships focusing on catchments in the semi-arid and arid regions of the south-eastern Mediterranean. A special attention is given to the space-time rainfall patterns that are derived from meteorological radar data and allow a better view of the rainstorm structure, evolvement and movement in relation to the flooded catchment. The study is conducted through analysis of the highest recorded flash-flood events for which radar data are available. Past studies and new analyses are synthesized to provide more insights into the storm-catchment hydrological interactions during extreme flash flood events. In addition, a better understanding of these interactions is gained by implementing a rain cell model of convective rain cells. The rain fields are used as an input to a hydrological model to test the catchment response to spatial and temporal characteristics of the rain cells. As a case study we tested an extreme storm event over a semi-arid catchment in southern Israel. It was found that the catchment is very sensitive to the rain cell's location, speed and direction and that relatively small changes of these properties may increase the flood peak discharge by three-fold. ■

A connectivity-map approach to model plant invasive spread in heterogeneous environments

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Predicting plant spread in future environments is an important challenge given the rapid shift in near-surface temperature projected across the globe. Using a mechanistic invasion-by-extremes model, we estimate the spread of wind-dispersed plant species in different biomes given long-term analysis of trends in surface windspeed. We then analyze the variation is the ability of wind-dispersed plant species at various biomes to track the projected climate range shift projected for these areas. ■

What controls of evaporation dynamics from porous surfaces?

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Evaporation dynamics from porous media reflect interactions between internal liquid and vapor transport, energy input for phase change, and mass transfer across air boundary layer. The roles of two key interfaces controlling evaporation dynamics are studied: (1) interactions of wet evaporating surfaces with air boundary layer; and (2) capillary flow from a receding drying front. At a critical drying front depth, determined by the porous medium pore size distribution, capillary liquid continuity essential to supplying surface evaporation is disrupted and evaporation rate transitions from high and relatively constant rate during stage-1 to lower and diffusion-controlled stage-2 evaporation. This characteristic length is modified by evaporation rate, hence reflecting the interplay of capillary, gravity and viscous forces. Existence of nonlinear interactions between evaporating porous surfaces and the air boundary layer above are evidenced by often nearly constant stage-1 evaporation rate while surface water content continuously decline (and drying front recedes). We show that enhanced vapor fluxes per pore from remaining active pores as they become increasingly isolated (with surface drying) are responsible for maintaining a nearly constant evaporation rate. Experiments show that such compensation and constant evaporation rates are sustainable only for low atmospheric demand (typically <5 mm/day), whereas evaporative fluxes under high atmospheric demand exhibit a continuous decrease with surface drying even when internal capillary flow is not limiting. Details of vapor diffusion field above porous surfaces show that flux compensation due to increased pore spacing may

fully compensate for reduced evaporative surface area (water content) for low demand with thick boundary layer, but is far less efficient for high demand with a thin air boundary layer. Consequently, for high atmospheric demand, surface evaporative flux continually decreases with surface drying irrespective of internal supply. Measurement aspects of these interfacial processes and implications for hydrological estimates of evaporative losses from heterogeneous surfaces will be presented. Results may also permit certain conclusions regarding evaporation from leaf surfaces and the role of stomatal spacing and patchiness on water losses from plants. ■

Spatiotemporal feedback between canopy conductance and soil moisture at the scale of individuals reflects native and imposed variation in canopy density

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The degree of occupation of tracts of land by individuals is commonly evaluated in terms of the total amount of available resources acquired by all individuals combined (e.g., absorbed photosynthetically active radiation, canopy evapotranspiration) and the resultant effects of competition and competition-related mortality on the cycling of sequestered resources (e.g., carbon, nitrogen). However, it is also recognized that the density of the canopy near individuals affect their performance by modifying the light available to the individual and that canopy density varies appreciably over short distances even within so-called uniform vegetation. Less recognized is the effect of such variation in canopy density on the dynamics of water utilization. Until recently, studies concentrated on the effect of average canopy density on stand transpiration. We show in a furrow-irrigated vineyard (*Vitis vinifera*) in arid northwest China, that inter-vine variation of crown-scale stomatal conductance under standard conditions was determined by leaf-to-sapwood area ratio. However, spatial variation of canopy density along the vineyard row sections, induced by imprecise summer canopy hedging, resulted in a faster decrease in soil moisture between irrigation events where leaf area index was higher, leading to a faster decrease in stomatal conductance. We demonstrate a similar process occurring in a less organized plantation of larch (*Larix principis–rupprechtii*) in a moister portion of northwest China. The non-linear relationship between stomatal conductance and soil moisture translates (in a modeling experiment) to lower stand-scale photosynthesis in heterogeneous in compare to homogeneous vegetation of a similar average leaf area index. ■

Infiltration in soils with a saturated surface

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William L. Hogarth[2]
David A. Lockington[3]
David A. Barry[4]
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An accurate analytical solution of Richards equation is obtained and used to obtain an infiltration equation which requires no curve fitting. The shape of the infiltrating profiles is described in details especially at the wetting front. Comparisons of predictions with numerical results using COMSOL show the great precision of the analysis. ■

Sustainable use of soil and water resources in semiarid, managed ecosystems

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Ecosystems can be viewed as open systems out of thermodynamic equilibrium, where water, energy, carbon and nutrient fluxes sustain biomass growth and related ecosystem services. Efforts to manage their dynamics for agricultural and other societal purposes altering such fluxes should balance the need to reduce variability to maximize productivity with that of maintaining natural variability and conditions thus preserving natural ecosystem services. Such a problem is one of optimal stochastic control of complex systems, which becomes particularly challenging in arid and semi-arid regions with seasonal and interannual rainfall variability. In this work we introduce a quantitative framework, based on stochastic eco-hydrologic models of soil-plant system, to address optimal irrigation, fertilization and harvesting aimed at optimizing sustainability of soil and water resources, profitability and productivity. ■

Climate-vegetation interaction in water-limited environments

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We discuss some of the interactions between terrestrial vegetation, soil and atmosphere in water-limited environments, focusing on the role of evapotranspiration fluxes and the possibility of multiple equilibria in the climate-vegetation system. We address the role of vegetation in modulating the intensity of summer droughts at continental latitudes, the role of precipitation intermittency and the competition between grass and shrubs in a simple model of savanna dynamics. We also discuss a simple ecohydrological model of an ideal sandy planet where vegetation favors the insurgence of a water cycle, and discuss some general issues on the scales of interaction between climate and terrestrial vegetation. ■

Vegetation-environment feedbacks from local to global scales

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In semi-arid ecosystems, a variety of mechanisms induce positive and negative feedbacks at disparate spatial scales between vegetation and environment such as water and nutrients. Such feedbacks explain a high diversity of spatial patterns on landscapes and determine how sensitive these systems are for human disturbance and droughts. The spatial scales at which those feedbacks operate vary from local (square meters) to regional (square kilometers). I will present how such feedbacks determine vegetation patterns and dynamics at local, regional and global scales by the use of simple to intermediate complexity models. ■

Vegetation patterns in semi-arid river basins: Drivers of organization and metabolic implication

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The spatial organization of vegetation in river basins is of fundamental importance in their ecosystem services and runoff prediction. Semi-arid watersheds are specially sensitive to the impact of ongoing climate change and it is of great importance to predict in a quantifiable manner the expected changes that their vegetation structure will experience in terms of functional vegetation types and their spatial patterns inside the basin. We show that maximum productivity, as an expression of maximum entropy production at the basin scale, provides an effective principle for the organization of the vegetation structure in the watershed. Moreover,this principle leads to an organization of vegetation throughout the basin that links the basin metabolic activity with the structure of the drainage network. ■

Flux-variance similarity theory applied to water vapor and carbon dioxide exchange in a semiarid ecosystem

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The tight coupling between water and carbon cycles is nowhere more evident than in semiarid and arid ecosystems, where intermittent rainfall events exert a strong influence on biomass dynamics, soil biogeochemical processes, and land-atmosphere exchange. The latter is explored through the application of flux-variance similarity theory, which predicts a perfect correlation between high-frequency time series of water vapor and carbon dioxide concentrations measured over vegetated surfaces. Departures from theoretical expectations, however, are typically encountered in field settings due to the physiologically and spatially distinct processes involved in the exchange of carbon dioxide (photosynthesis and respiration) and water vapor (transpiration and direct evaporation) between the land surface and the atmosphere. Using eddy covariance data collected over savanna vegetation in the Kalahari region of southern Africa, flux-variance theory is applied to evaluate the impact of transient events (e.g. fire, rainfall) on the partitioning of carbon dioxide and water vapor fluxes. Such information is useful, for example, for the parameterization of land surface models and for characterizing water use strategies of the savanna vegetation. ■

Eco hydrological feedbacks between surface sealing and woody vegetation in dry climates

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Recent studies highlighted the significant effect that the presence of a seal layer, a frequent phenomenon in dry climates, has on vegetation soil water availability. Using data from high resolution lysimiter experiments and a physically based model, feedbacks and interactions between *Sarcopoterium spinosum* (a dwarf shrub, most dominant in semiarid parts of Israel) and soil water content availability resulting from the presence of a seal layer at the soil surface are studied. The role of the seal layer in modulating available water and consequently, its effect on evapotranspiration fluxes is analysed. By using a synthetic water content threshold, representing the onset of vegetative water stress conditions, different climatic scenarios are considered, allowing insights on temporal and spatial trends of future desertification processes at the studied hillslope. ■

Observations of complex ecohydrologic processes at appropriate temporal and spatial scales with fiber optics

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The timing and abundance of the provision of water to ecosystem is a fundamental control on type, density, and patterns of vegetation in water-stressed environments. The use of point sensors of soil water content has been a fundamental limitation in observation of these systems. For instance, observation of the spatial dynamics of water abundance patterns following a rainfall event require measurement across transects in space. In this talk we consider the technologies that might be useful to address these observations, specifically considering technologies that might provide time-lapse observations of spatially varying processes through the soil. We will briefly review the opportunities and limitations presented by ground penetrating radar, electrical resistance tomography, and electromagnetic induction for the observation of temporal and spatial patterns in soil water. We will then introduce the opportunity for soil-water observation provided by Actively Heated Fiber Optics (AHFO) in the context of Distributed Temperature Sensing (DTS – see CTEMPs.org). Current DTS is capable of recording temperature approximately each 10 cm along a multi-km fiber optic cables. By observing the thermal response due to an injection of heat (via electrical resistance heating along the fiber) one can estimate the thermal properties at tens of thousands of points along linear transects. We then discuss the estimation of soil water content from these data, and the challenges for calibration of this method. We will present data from field tests in Oregon and Oklahoma. ■

The role of plants as ecosystem engineers in controlling eco hydrological processes and resilience to global changes

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In many drylands eco hydrological processes are controlled by two ecosystem engineers, soil microphytes and shrubs. Soil microphytes adhere the soil surface particles by secreting polysaccharides, thus forming biogenic soil crusts. Shrubs engineer the environment above and below ground by modifying soil properties in relation to water flow. The two engineering creates a source-sink system with multiple feedbacks where the crust is a source of soil, water, organic matter and nutrients while the shrub patch is the sink for material and source of organisms.

As a result of hydro ecological feedbacks most of the biological productivity and diversity of the system is concentrated in the shrub sink patches. Global changes such as the increase in frequency and severity of droughts and land use that modifies the relationships between the two ecosystem engineers may affect the functions and feedbacks of the two phase mosaic made of crust and shrub patches. This can for example transform a shrub land into crust land by increasing leakage of resources and decreasing productivity and diversity (desertification).

Based on long term research at LTER sites in the Northern Negev, Israel, I present two models depicting how changes in feedbacks due to natural and anthropogenic disturbances can cause state changes in the hydro-ecological system and how the specific mode of shrub and crust engineering can enhance or prevent this transition. My main proposition is that understanding the resilience of the hydro ecological system to global changes depends on the properties and interaction between the ecosystem engineers and their control over hydro-ecological feedback processes. ■

Canopy edge flows

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Classical studies of transport phenomena within and above canopies focused on ideal, nearly fully developed flow conditions. The main reason was that under such conditions the transport equations are greatly simplified. Kaimal and Finnigan (1994) describe how micrometeorologists scoured the countryside in the 1950s and 1960s searching for flat uniform sites. However in real environments, such fully-developed conditions are the exception rather than the rule. Forest canopies, stream vegetation and urban areas are patchy and the flow is forced to penetrate and leave these canopy patches along its path.

When flow encounters a canopy patch, it experiences large changes. Streamlines bypass the patch, a complex pressure field is formed, Reynolds stresses starts to develop at the upper corner and dispersive stresses become highly significant. While the study of such flows must cover both the sub-filter and the average scales, the large spatial variations of the edge region pose both theoretical and technical difficulties when applying the theory of volume averaging.

Recently, we used extensive particle image velocimetry to map the subscale flow field in model canopies made of glass cylinders and glass thin plates. The velocity fields, as a function of space and time, were used to calculate a large variety of flow properties. These include mean velocities and pressure, velocity RMS and turbulent kinetic energy, Reynolds and dispersive stresses, length and time scales, energy dissipation and spectrum. The momentum equation was analyzed and an order of magnitude comparison between the different forces, including mean drag, was derived. It was found, for example, that normal streamwise dispersive stresses are large in the vicinity of the canopy edge and should not be ignored.

The talk will present the flow problem and its complexity. Using some of our results we will attempt to provide an intuitive physical understanding of the flow phenomena and its spatially average representation. An emphasis will be given on the relationships between the subscale and the average quantities in an attempt to better understand the mechanism of momentum transfer in these complex regions. ■

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Water Use Efficiency, patch pattern properties and biomass in shrublands across Mediterranean climatic gradient

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Studying the eco hydrology along gradients between sub-humid and arid climate regions is important for the understanding the consequences of desertification due to global climate and of the growing human disturbance to the natural eco-systems. Water Use Efficiency (WUE) is a key eco hydrological element which determines biomass productivity and CO_2 assimilation in plants and thus influence atmospheric chemistry and climate. Life-forms and plant cover greatly vary along climatic gradients due to frequent droughts and extensive human disturbances from fires, wood cutting and grazing pressures. The resulting vegetation patterns then influence these ecosystems' Water Use Efficiency. In an earlier study there was developed a mathematical model relating shrublands biomass to precipitation and WUE as parameterized on the basis of shrub cover proportion and an edge ratio describing the relative area of shrubs' margins from their total area. This model was tested with reference to data derived from photographs taken from an ultra-light aircraft flying at a height of 60 meters above the ground resulting images with a spatial resolution at the scale of 2 centimeters. Extending the model to wide regions necessitated up-scaling it to air photographs scale and to Landsat TM scale. It was found that this model can be simply modified to work with the fractal dimension as derived for these two different scales. This allowed us to map the Water Use Efficiency over the whole climatic gradient region together with the shrublands biomass. With the recent availability of Landsat time series we have assessed the changes in biomass productivity across this important transition zone with reference to desertification processes. ■

Patch-size distribution and hydrological fluxes in real semiarid hillslopes

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Climate-vegetation interactions and feedbacks are the subject of many rangeland studies and recently, the rainfall-plant-soil interplay in the hillslope scale is in the foci of ecohydrology. As most of the models in this scale rely on synthetic environments, there is a need for studies that use remotely sensed and in-situ data to examine the effect of hillslope hydrological processes on ecosystem functioning and plant population spread in a more realistic manner. A major problem is the difficulty encountered in quantifying water budget and measuring vegetation at the individual shrub level. In this research, a typical hillslope was chosen offering variations in slope decline and orientation, soil depth and vegetation cover, at the LTER Lehavim site in the center of Israel. The annual rainfall is 290 mm, the soils are brown lithosols and arid brown loess and the dominant rock formations are Eocenean limestone and chalk with patches of calcrete. The vegetation is characterized by scattered dwarf shrubs (dominant species *Sarcopoterium spinosum*) and patches of herbaceous vegetation, mostly annuals, are spread between rocks and dwarf shrubs. Eight areal photographs of the slope, between the years 1978-2005, were acquired, georeferenced and shrub cover was estimated based on supervised classification of the airphotos. An extensive spatial database of soil hydraulic and environmental parameters (e.g. slope, radiation, bulk density, soil depth) was measured in the field and interpolated to continuous maps using geostatistical techniques and physically-based modeling. This spatio-temporal database was used to characterize 1187 spatial cells serving as an input to a numeric hydrological model (Hydrus 1D) solving the flow equations to predict soil water content at the single storm and seasonal scales. The model was verified by sampling soil moisture at 63 random locations at the research site, during three consecutive storms in the 2008-09 rainy seasons. The results show that shrub-grass ratio reached a steady state phase with 20% cover in 1992 (after 14yr). This recovery rate is in agreement with previous field studies. Patch size distribution in the slope scale had shown that the size of patches in the field varies with soil moisture conditions of the last 30 yrs. Quantification of the factors affecting shrub establishment was done using stepwise regression, showing that slope decline, radiation, soil texture, and rockiness are the leading physical factors. ■

Evolution of vegetation spatial patterns in drylands: interaction of dispersal processes and climatic variation

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Minimalist modeling of plant dispersal processes in dryland environments has traditionally represented motion as a diffusive process. This introduces several kinds of artifact into dispersal modeling: firstly the rate of dispersal becomes dependent upon the local biomass gradient, rather than being connected directly to biological factors such as fecundity and dispersal adaptation; secondly, the dispersal process is intrinsically localized; and finally migrating is treated as a continuous field, rather than a collection of discrete particles in motion. Previous work has demonstrated that refining models to avoid diffusive representations of spread improves the ability of models to represent disordered spatial patterns in biomass, and to avoid generating artifacts (such as upslope migration bias on hillslopes). Here we present new work addressing the transients associated with shrub (*Baccharis* species) encroachment in California, a process strongly influenced by interactions of climatic variation, changing patterns of herbivory and wind dispersal, and with potential implications for water balance dynamics. ■

The ecohydrology of the Devils Hole pupfish: when the ecology and the hydrology won't agree to the same story

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Devils Hole, a groundwater fed fracture in the Mojave Desert of southern Nevada, is home to a unique desert ecosystem that includes the only population of endangered Devils Hole pupfish (*Cyprinodon diabolis*). The pupfish survive in what is considered to be the smallest known habitat for a vertebrate species (~50 m^2) and live near the thresholds of survivability of fish for both temperature (~33.5 °C) and dissolved oxygen (~3 mg l^{-1}). The ecosystem has been open to the atmosphere for ~60,000 years, yet there is little evidence of surface water connectivity to other pupfish species. Furthermore, warming during the mid-Holocene is likely to have further warmed the habitat beyond the temperature limitations of the modern population. The presence of the pupfish therefore represents an ecohydrologic conundrum: their presence requires hydrologic connection, yet the hydrologic and climatologic evidence precludes such a connection and survivability. In this talk, we combine physical measurements of the Devils Hole habitat using high resolution Distributed Temperature Sensing (DTS) with CFD simulation of the thermal regime of their habitat through the past (~60 kyr) climate fluctuations to try to resolve this conundrum and to define the ecohydrological conditions that have supported the pupfish. Through numerical simulations of the habitat, we speculate on their timing of their and cohabitating aquatic invertebrate origins by noting the physical response of the environment to thermal bottlenecks such as the mid-Holocene warming as well as reviewing the genetic divergence data from other closely related species. The computational model is also used to predict the habitat response to several scenarios of 21st century climate change in order to better develop management plans for this most unique of species. ■

Vegetation patterns and evapotranspiration fluxes in drylands

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The formation of spatial patterns in dryland vegetation is the product of complex water-vegetation feedback mechanisms, and is often observed in connection with the existence of multiple stable states. While the self-organization of vegetation has been widely explored, the impact of spatial vegetation patterning itself on local atmospheric-soil water fluxes has yet to be determined in detail. In particular it remains to be assessed to what extent different vegetation patterns affect the intensity of local evapotranspiration fluxes, particularly in the presence of intermittent precipitation episodes. To explore this issue, we introduce a new explicit-space mathematical model for vegetation dynamics in water-limited ecosystems, inspired by previous approaches to vegetation pattern dynamics. The model includes two separate soil layers, including deep soil percolation, and separates the effects of evaporation, active only in a thin surface layer, and transpiration, conveying water from deeper soil thanks to root action. The model has been developed to represent adequately evapotranspiration in the presence of intermittent rainfall conditions. We use the model to explore the spatial self-organization of vegetation, the formation of multiple stable states and to examine if evapotranspiration fluxes depend only on bulk vegetation characteristics, such as biomass density or vegetated fraction, or rather also on the detailed spatial vegetation pattern dynamics. In particular we find that transpiration fluxes in the days following a rainfall event depend on the type of vegetation pattern and that bulk fluxes from fixed vegetation (such as cultivated areas) can be very different from those above

dynamically evolving vegetation, even when the fraction of space covered by vegetation and the average biomass density are the same. We discuss the relevance of these results for the problem of upscaling vegetation dynamics and determining adequate parametrizations and models for vegetation also in large-scale climate models, where small-scale vegetation patterns cannot be explicitly resolved. ■

Interactions of soil properties, tree hydraulics, and leaf physiology on the ecohydrology of a semi-arid pine forest

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The survival and success of the semi-arid Yatir forest in southern Israel is a puzzle. Average precipitation is 283±88 mm yr^{-1}, but drought years occur regularly, and precipitation as low as 138 mm yr^{-1} has been recorded since the planting of the forest. The rain season is short, leading to seasonal droughts, with near-hygroscopic surface soil water content levels during the long summer (~5% m^3 m^{-3} from June to November). Groundwater is deep (~300 m). Yet, the forest turned out to be a carbon sink of ~2.3 t C Ha, not very different from the FLUXNET global mean of about 2.6. The forest productivity is associated with distinct phenology, tight water budget (with over 90% of precipitation measured as ET). It also shows a 'closed' energy budget, with cooler canopy surface (even though latent heat is a minor flux) that emits large fluxes of sensible heat. Leaf physiology indicates isohydric characteristic, with a very narrow safety margin, between stomatal closure and development of xylem cavitation. But recovery from cavitation is efficient and fast, and can occur twice daily. Variations in soil characteristics (water retention) with depth reduce water loss to depth providing a key element in the forest ecohydrology. Only the inclusion of these leaf, stem, and soil characteristics allowed successful numerical simulation of the forest hydrological budget using an ecosystem-scale model (MuSica). Understanding the water dynamics within the forest is key to unraveling Yatir puzzle, and help predict the future of forests across the Mediterranean and other regions undergoing drying trends. ■

The role of soil depth spatial heterogeneity in vegetation pattern formation

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The majority of mathematical models for eco-hydrology vegetation patterns are based on the principal assumption of symmetry braking mechanism acting in homogenous systems. This assumption is based on positive feedbacks operating at small scales, leading to de-stabilized uniform states. These states consequently lead to larger scale regular or irregular patterns, thus creating self-organized heterogeneity. However, ecological systems are rarely homogenous and exhibit spatial heterogeneity at different scales and in different abiotic variables. This noticeable gap between model realizations and real ecological systems limits the applicability of such models and their validation with field data. This study is a first step towards addressing the research gap, by applying heterogeneity of soil profile depth and discussing its role on vegetation pattern formation. This is achieved using the model of Rietkerk et al. (2002) and extensive soil depth measurements collected at Lehavim LTER, located in the semiarid environment in northern Negev of Israel. Soil depth is a key factor affecting soil water storage, and consequently hydrological processes such as infiltration or runoff initiation. Our results indicate that soil depth significantly affects the conditions for vegetation growth, as reflected in the emerging vegetation patterns, bringing them closer to field observations. ■

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Sarcopoterium Spinosum from mosaic structure to matrix: impact of calcrete (Nari) on vegetation in a Mediterranean semi-arid landscape

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Sarcopoterium spinosum L. (S.p.) is a common type of dwarf shrub in the eastern Mediterranean area. This study focuses on the semi-arid south-western Judean foothills (Shephelah) in Israel, characterized by a hilly landscape with variable coverage of hard calcrete rock outcrops (Nari) on chalk.

The following research questions were addressed: 1) What is the effect of calcrete rock outcrops on S.p. and the spatial composition of the vegetative landscape? 2) What are the landscape conditions in which S.p. dominates the vegetation? 3) What is the spatial structure and occupation strategy of S.p. in relation to rocky and non-rocky landscape surfaces?

A field study was conducted to measure visual surface coverage of five components: S.p., shrub (excluding S.p. and including other dwarf shrubs, trees and annuals), rock, and bare soil. The results show that rock, an abiotic component, plays an important role in the semi-arid landscape of the research area. When rocky coverage is more than 14% of the surface, its presence contributes to high heterogeneity and advanced ecological niches, and governs the appearance and distribution of biotic components such as S.p. and others. Among the studied components, the relationship between rock and S.p. was found to be the strongest. Furthermore, rock and S.p. seem to fill interchangeable functions. As rock presence decreases, S.p. distribution increases. When rock cover is less than 14%, S.p. becomes the dominant landscape component, covering 37%-78% of the surface, characterized by large patches with a high level of homogeneity along the entire slope. Our results show that the rock/S.p. ratio controls changes in the landscape structure varying from stable heterogenic mosaic to stable homogeneous S.p. matrix. ■

Note: The presentation is based on: Ackermann, O., Zhevelev, H. M., & Svoray, T. 2013. *Sarcopoterium spinosum* from mosaic structure to matrix structure: Impact of calcrete (Nari) on vegetation in a Mediterranean semi-arid landscape. *Catena*, *101*, 79–91. doi:10.1016/j.catena.2012.10.001.

A Lattice Boltzmann model (LBM) and Particle Image Velocimetry (PIV) measurements of the turbulent flow within and above a finite modeled canopy

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The flow through and above forest canopies which cover much of the Earth's surface is abundantly non-uniform and complex. Since it is an essential ingredient to multi-scale transport-modeling, such as material evaporation, transport and dispersion, simplified flow models which can incorporate additional physics are advantageous. In this talk we present a two dimension lattice-Boltzmann study of the volume-Reynolds average Navier-Stokes (VRANS) equations which we derive for a finite canopy model. The approach can be used to efficiently study and model the effects of leaf-area-density (LAD), turbulence intensity and boundary conditions on the flow through non-uniform canopies. We compare several solutions with detailed flow measurements obtained by a Particle Image Velocimetry (PIV) at various regions along the finite canopy, and reveal the importance of the dispersive stresses to the average momentum at the canopy-edge. ■

A Modeling approach for rainfall-runoff processes in complex arid environments

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Water resources are vital for dryland ecosystems. Temporal and spatial distribution of water resources may significantly affect the development and sustainability of these ecosystems. The rainfall-runoff process in complex arid environments plays a key role in the water resource distribution in these regions while has not been fully understood yet due to interactions among water, vegetation patches, topography and soil characteristics. This study aims to better quantify the interplay of soil surface sealing, microtopography and vegetation in arid region hydrology. A modeling approach is developed to couple a two-dimensional surface runoff model and a two-layer conceptual infiltration model with elaborate numerical treatment. The model can be used to study the rainfall-infiltration-runoff process on heterogeneous surfaces with the co-existence of spatially varying soil and landscape properties mentioned above. The model has been validated for a field site in the semiarid field plot of Lehavim LTER, Israel. The mechanisms that a seal layer, microtopography and vegetation affecting dryland runoff processes and water resources distribution have been analyzed based on modeling results. ■

The effects of time-dependent turbulent kinetic energy dissipation rate on particle trajectory models in canopy flows

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A ubiquitous feature defining turbulence is intermittency in fluctuating velocity gradients. It has been recognized for some time that the Eulerian probability density function of velocity gradient quantities is characterized by stretched exponential tails, indicating rare and intense events embedded in a relatively quiescent flow (Frisch, 1995). More recently (La Porta et al., 2001), advances in optical measurements revealed that the three-dimensional time-resolved trajectories of tracer particle accelerations are also highly intermittent exhibiting extremely large accelerations. To account theoretically for such intermittent patterns in particle trajectory models, the use of the so-called 'superstatistical approach' is gaining attention (Reynolds, 2003). The premise behind such an approach is that the Lagrangian time scale can be treated as a random variable, where its variation is primarily attributed to intermittency in the turbulent kinetic energy dissipation-rate. Although conventional Lagrangian trajectory models (Thomson, 1987) have been used extensively for calculating concentrations (and flux footprint) of gases, aerosols, particles, pollen, and seeds in both atmospheric and canopy flows (Nathan et al., 2002), these models are based on the assumption of a 'layer-wise' constant but vertically inhomogeneous Lagrangian time-scale formed by the *mean* turbulent kinetic energy and its dissipation rate. In this work, the conventional Lagrangian trajectory approach (Thomson, 1987) is expanded to include a stochastic model for the instantaneous dissipation rate proposed elsewhere (Pope, 2000). This novel approach is first shown to satisfy the so-called well-mixed condition (Thomson,

1987) and is then employed to conduct trajectory simulations in highly inhomogeneous atmospheric turbulent flows. Using multi-level field measurements from a pine forest (Katul and Albertson, 1998), it is demonstrated that the relative variability in the mean turbulent kinetic energy dissipation rate far exceeds those reported in Direct Numerical Simulation studies at moderate Reynolds number (Pope, 2000), and (empirically) suggests that incorporating the variability in the turbulent kinetic energy dissipation rate is warranted for such type of canopy and atmospheric flow systems.

The proposed model demonstrates that the addition of dissipation rate variability amplifies two types of motion governing the spatial evolution of the mean concentration with increasing distance from an elevated source. The first is connected to strong sweeping motion that enhances the decay rate of the mean concentration with increased downwind distance, and the second is linked to strong intermittent ejections of particles from the canopy immediately adjacent to the source. Shortly after their release, these particles escape the low-velocity region within the canopy volume to the high-velocity region in the free air above the canopy via a strong ejection motion. This ejective phenomenon increases the probability of single particles to reach far regions, creating a heavy tail in the mean concentration very far from the scalar source. Implications of these events to dispersal, spread, and invasion by extremes are being explored. ■

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Watering the forest for the trees: An emerging priority for water management on forest lands

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Forests utilize prodigious amounts of water for evapotranspiration. In the US, for example, total volume of water flux due to ET is at least 10% greater on forest lands than irrigated agriculture, the next highest land use. Widespread threats to forests due to drought stress prompt re-thinking of priorities for water management on forest lands. In contrast to the widely held view that forest management should emphasize providing water for downstream uses, we argue that maintaining forest health in the face of environmental change may require focusing on the forests themselves and strategies to reduce their vulnerability to increasing water stress in the context of a changing climate. Management strategies would need to be tailored to specific landscapes but could include: a) thinning; 2) encouraging drought-tolerant species; 3) irrigation; and 4) strategies that make more water available to plants for transpiration. Hydrologic modeling reveals that specific management actions could reduce tree mortality due to drought stress. Adopting water conservation for vegetation as a priority for managing water on forest lands would represent a fundamental change in perspective and potentially involve tradeoffs with other downstream uses of water. ■

Fingering and fracturing in granular media

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Here, we describe the phenomenon of capillary fracturing in granular media. We study the displacement of immiscible fluids in deformable, non-cohesive granular media. Experimentally, we inject air into a thin bed of water-saturated glass beads and observe the invasion morphology. The control parameters are the injection rate, the bead size, and the confining stress. We identify three invasion regimes: capillary fingering, viscous fingering, and "capillary fracturing", where capillary forces overcome frictional resistance and induce the opening of conduits. We derive two dimensionless numbers that govern the transition among the different regimes: a modified capillary number and a fracturing number. The experiments and analysis predict the emergence of fracturing in fine-grained media under low confining stress, a phenomenon that likely plays a fundamental role in many natural processes such as primary oil migration, methane venting from lake sediments, and the formation of desiccation cracks. ■

Below canopy evaporation dynamics: Implementing variable boundary conditions in HYDRUS 2D/3D

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Evaporation from the soil surface (E) can be a significant water balance component in arid areas. Whereas plant water uptake through transpiration is generally the desired component where water is used to enhance plant productivity, E is considered a loss as water is permanently removed from the system. E is hypothesized to be particularly high in sparsely vegetated systems with large areas of exposed soil or under very wet conditions; such as flood irrigated crops and wetlands. In irrigated crops, especially crops under deficit irrigation, accurate understanding of the productive and unproductive allocations of water is highly relevant. E is expected to be a function of soil, climate, irrigation regime/ precipitation patterns, and plant canopy development and will therefore change dynamically at both daily and seasonal time scales. The objective of this research was to quantify E in an isolated, drip irrigated vineyard under arid conditions with a specific focus on spatial and temporal variations of E across the inter-row using measurements and models. Vineyards are a high-value crop with large areas of exposed soil, where the magnitude of E even under drip irrigation could be potentially large.

An experiment was conducted in an isolated commercial desert vineyard, with a mean annual precipitation of 90 mm. Continuous measurements above the canopy included evapotranspiration, solar radiation, air temperature and humidity and wind speed and direction. Short-term intensive measurements below the canopy were conducted at ground level, along transects between adjacent vine rows. Measurements included actual E using micro-lysimeters, potential E (Ep) with micro-pans, and solar radiation using pyranometers. Results show a clear effect of shading on below canopy Ep, with distinctly different high and low daytime Ep at different positions within the rows. Actual E was affected by available water in the soil and concentrated mostly along the drip line, with an obvious effect of shading on the timing of peak evaporation. A new module allowing variable boundary conditions at the soil surface was added to HYDRUS 2D/3D, a widely used numerical model for water flow in the soil. The consequences of below canopy observations for whole (vineyard) system water and energy budgets will be highlighted as well as the potential to model spatial variation in below canopy *E* using HYDRUS 2D/3D.

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Rehabilitation through spatial forcing

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In recent years there has been much interest in studying the rehabilitation of damaged ecological systems. The first step of rehabilitation is recovery of vegetation, which can be achieved in drylands by the harvesting of runoff water in hill slopes. A common water-harvesting practice is the construction of parallel contour ditches – termed Shikim – which accumulate runoff water from the uphill areas, and along them trees are planted. An important factor in the success of rehabilitation in this kind of practice is the fact that vegetation in water limited regions can self-organize in patterns.

These patterns are result of symmetry breaking processes induced by feedbacks between the biomass and a limited resource of the system (e.g. water, nutrients). In a hill slope the stripes orient themselves to parallel bands perpendicular to the slope direction and migrate uphill. The understanding of the interplay between the natural patterns of a vegetation system and human-made landscape modifications is essential for devising successful rehabilitation practices of damaged dryland regions. We study the response of a simplified vegetation model to a one-dimensional spatial periodic forcing. One- and two-dimensional resonant patterns are presented, and the interplay between them is investigated. We compare the vegetation model to a simpler pattern-forming system subjected to spatial forcing (the parametrically forced Swift-Hohenberg equation), and we discuss the similarities and differences between these two systems. ■

Effects of land-cover change on rainfall-runoff relationships: A case study of the Yarkon-Ayalon watershed, Israel

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Temporal changes and spatial patterns are often studies by analyzing land cover changes (LCCs) using spaceborne images. LCC is an important factor, affecting run-off regime within watersheds through processes such as urbanization, agricultural activities, quarries and afforestation. This study focuses on the Yarkon-Ayalon watershed, located in central Israel. This watershed drains an area of about 1800 km^2 and is characterized by a mean annual precipitation of about 600 mm. The watershed area is divided by the borderline between Israel and the West Bank – Palestinian Authority, both political regions experience LCCs. These changes affect runoff characteristics and are studied for each of the sub-basins within the Yarkon-Ayalon watershed. The objective of this research is to estimate the effects of temporal and spatial changes in land cover on rainfall-runoff relations in an extreme rainfall event, throughout the watershed and its sub-basins. A classification map of six different land cover types was created for the year 1989, using a maximum likelihood supervised classification of a Landsat TM satellite image. The classification map was used as an input for the Kinematic Runoff and Erosion (KINEROS2) hydrological model along with precipitation data of an extreme rainfall event that occurred during the winter season of years 1991-1992. This extraordinary rainfall event lasted five days and has led to a total of 170 mm of rain and peak discharges of 370 and 490 million cubic meters (mcm)/second in the Ayalon and Yarkon rivers, respectively. Model calibration was performed by using total runoff volume data based on hydrometric measurements taken during this rainfall event. Validation of the

model performance was performed by comparing the model results to measured data in order to receive output accuracy estimation. A similar procedure was then conducted using a 2009 land cover classification map, derived from a Landsat TM image, as an input to KINEROS2 model, along with the same precipitation data and calibration parameters, in order to understand the possible outcomes of a rainfall event of such magnitude and duration after 20 years of LCCs in the Yarkon-Ayalon watershed. The results show a slight increase in runoff volume and peak discharge values between the examined time periods as a result of LCCs. In addition, a strong relationship was spotted between vegetation cover along the six sub-basins and the runoff volume. The LCCs that had the most pronounced effects on runoff volumes were related to urbanization and vegetation removal. Changes in land cover through a period of 19 years were found to have some effect on the runoff regime. ■

Annual vegetation, primary production potential and dryland ecosystems resilience

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With the increasing effect of ongoing climatic changes on ecosystem structure, many studies have suggested that spatial patterns of primary production may be a good indicator of the "health" of arid and semi-arid ecosystems. Those studies expressed the concern that a sudden loss of vegetation may not be followed by a full recovery thus implying on deterioration of the last patterns. The assumption that regular patterns appear under certain climatic conditions is suitable for perennial vegetation and shrubs but not for annuals which is the dominant formation in dryland environments. In particular, primary production patterns of annuals are only a "snapshot" of a certain yearly climate conditions and the spatial arrangements of local soil moisture sinks. In these environments there is usually no carry-over effect of soil moisture from previous years. Without the buffering effect of previous years, annual vegetation primary production patterns are an optimal subject to investigate the resilience (= capacity to produce in the following year) of semi-arid ecosystems to significant climatic fluctuations.

In our study, the long-term trend in the spatial variation of annual primary production was tested in two dryland environments: dry mediterranean and semiarid - both dominated by annual vegetation. The study was applied on a database of 21 and 30 years, respectively. Change in productivity patterns along space as a result of annual weather conditions was examined by GIS-analysis of rasteric model (25 m^2 per cell), that predict annual vegetation daily primary production.

Long-term data gathered during the last three decades indicated that both environments have exhibited high resilience of productivity to rainfall variability. Both ecosystems demonstrate high resilience in their vegetation patterns over a long-term period, and showed recovery even after years of low productivity. Although large changes in the spatial pattern of productive areas were observed, narrowing of vegetative areas was not necessarily accompanied by a reduction in primary production potential, especially at the dry mediterranean site. In particular, primary production process continued at low-medium levels of productivity while reducing vegetation patterns. These results suggest that maintaining primary production potential at drought years keeps the system from shifting to aridity. ■

How will increases in rainfall intensity affect bistable patterned arid ecosystems?

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In arid ecosystems plants can improve soil structure, which on sloped terrains can result in the formation of spatially periodic vegetation bands perpendicular to the hillslope gradient. The formation of these bands allows plants to survive under harsher conditions, as during intense rain events surface water is 'harvested' from the bare interbands uphill. These banded arid ecosystems are however vulnerable: changing climatic conditions may push the system to a degraded state in which vegetation is absent. As a result of global warming, rain events are projected to become more intense in the coming decades. This could lead to increased runoff losses and decreased productivity of arid ecosystems, which may trigger a critical transition to a degraded bare state. Current conceptual models that describe vegetation pattern formation often only implicitly capture rainfall partitioning into infiltration and runoff. Therefore, these models cannot be used to study the role of rainfall intensity in these systems. In this paper we introduce a model in which rainwater partitioning is captured using simple conditional rules. From analysis of the model we conclude that increasing rainfall intensity, as projected for the coming decades, can induce and enhance bistability of arid ecosystems. The model predicts that periodic patterns resulting from surface water redistribution cannot exist in climatic regions with low mean rainfall intensity and that ecosystems in these areas are less likely to be bistable. An increase in rainfall intensity does not only affect the bistability of arid ecosystems, it can also push these ecosystems to a desert state, even if aggregated rainfall rates remain unchanged. Such a critical transition is not necessarily preceded by the formation of vegetation patterns. If the system is in a patterned state, desertification resulting from increasing rainfall intensity can only occur if the mean rainfall intensity exceeds the infiltration capacity of bare soil and is more likely to take place if the impact of plants on soil structure is low. A decline in mean rainfall intensity may as well result in a critical transition to the desert state. However, this can only occur if the system is in a patterned state. Finally, decreasing rainfall intensity can result in revegetation. This recovery process is facilitated by the water harvesting mechanism responsible for vegetation patterning. In future studies spatially explicit stochastic models in combination with realistic infiltration models could be used to verify the obtained results. ■

Climate change impacts on eco-hydrology in mountain environments: Why spatial patterns of soil and subsurface drainage matter

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In the mountains regions throughout the globe, the impacts of a warmer climate on ecohydrologic processes will reflect the complex spatial heterogeneity and temporal patterns of moisture and energy inputs. What is less often considered is the role that spatial patterns of geologically mediated drainage and soil storage properties play in shaping the geography of vegetation and streamflow responses to warming. We use case studies in the semi-arid Western US to demonstrate that soil-geology can be first order control on within and between watershed differences in the sensitivity of ecohydrologic processes to a warming climate. We use a spatially distributed model of coupled carbon-nitrogen cycling and hydrologic processes, RHESSys (http://fiesta.bren.ucsb.edu/~rhessys/) and data assimilation of remote-sensing and point-based flux-tower and sapflow measurements, to estimate watershed patterns of forest evapotranspiration, net primary productivity and risk of drought related die back under historic climate variability and moderate warming scenarios. We have adapted the model to include a semi-process based representation of drought-related vegetation mortality. Model estimates show that for many forests even moderate warming substantially increases the risk of drought related mortality. Increases in drought risk occur not only in the most currently water-limited areas but also in areas that receive substantial lateral inputs of moisture. Model estimates, however, also show that the magnitude of variation in eco-hydrologic responses associated with hillslope variation in soil and drainage characteristics is of similar magnitude to variation associated with inter-annual

precipitation patterns. Given these interactions we demonstrate the importance of thinking about eco-hydrology in the context of climate warming from a geomorphic perspective. We use these model-based results to illustrate how Critical Zone Observatories can be used to improve the representation of subsurface parameters and fine-scale heterogeneity in eco-hydrologic model applications. ■

Mechanistic modeling of the effectiveness of vegetation as a barrier to spread of wind-dispersed invasive species

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Wind-dispersed invasive and weedy plant species cause substantial damage both in natural and agricultural habitats. Although preventing new infestations was shown to be more effective than exterminating existing populations, approaches to contain the spread of these species are currently scarce. Since tall vegetation changes both the wind flow and the seed-vegetation collision probability, hereby negatively affecting the seed dispersal distances, it was previously suggested to use buffer zones of tall vegetation to contain the spread of wind-dispersed weeds. Our goal here was to construct a mechanistic modeling framework enabling the exploration of whether tall vegetation buffers could effectively block seed dispersal, particularly the rare long-distance dispersal (LDD) events which are considered as the primary driver of spread rate.

We used the coupled Eulerian-Lagrangian approach to simulate trajectories of seeds dispersing near vegetation transition zones. Towards this end, we applied a recently developed first-order closure model that employs a streamfunction-vorticity formulation to solve the mean wind and turbulent stress variables across transitions in canopy height (Banerjee et al., in press). As the simplest-case scenario, we examined the simulated dispersal kernels of seeds released upwind of a short-to-tall canopy edge with an infinitely long tall barrier.

Our preliminary results show that in many cases, the median dispersal distance drops as seeds are released closer to the edge. The trends in LDD (99-th percentile distance) are non-monotonic with distance from edge. The next logical step is to apply this model to test for the effects of the tall-vegetation properties – length, height, density; and of the seed motion capacity (terminal velocity and release height), on the effectiveness of the buffer zones in curbing seed LDD. ■

References:

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Regime shifts in spatially extended eco-systems

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The world we live in is ever changing. When encountered with the various vast eco-systems that exist around us, a major goal is to understand and predict their dynamics. We look at the transitions that eco-systems undergo, focusing on their response to climatic changes and anthropogenic disturbances, considering the specific effects of their spatial nature. When discussing eco-systems of dry-land vegetation, this naturally reflects on a major concern over the last decades relating to the desertification process that many habitats are undergoing. The possibility of abrupt (catastrophic) regime shift has been discussed extensively in the literature, and we investigate the validity of such results for explicitly spatial systems, to develop an understanding of transitions that are unique to spatial systems. The focus is thus on unique aspects to such spatial systems, and their relevance to the prevailing dynamics. This includes dynamics of fronts between alternative states of the system, existence and stability of localized states and the relevance of multiplicity of patterned states on the smoothness of transitions. ■

Utilizing a stochastic weather generator to study effects of climatic conditions on insect population dynamics: *Bemisia tabaci* as a case study

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Temperature is expected to increase by few Celsius degrees by 2100. The effect of these changes on insect pest populations is one of the principal challenges ecological and agricultural research is confronting. Here, we focus on the regional effects of current climate conditions and their forecasted change in the future, on population dynamics of the whitefly *Bemisia tabaci*. Apart from being the most devastating insect pest in the tropics and subtropics, we consider *B. tabaci* a future "key" global pest, as increasing temperatures will likely lead to population outbreaks and habitat expansion of insects with short development. Our work utilizes a new approach for studying insect population response to climate change by coupling a weather generator that produces realizations of temperature series under a given climate conditions with a model representing the insect population dynamics. The following research steps are taken: 1. downscaling synoptic data using stochastic weather generator to create realizations of local temperature time series under current climatic conditions, 2. predicting local climate changes, using general circulation models data and a stochastic weather generator by generating realizations of local temperature series under future climatic conditions, and, 3. predicting *B. tabaci* population response to climate conditions and their change using the produced realizations in steps 1 and 2 as input into an insect population dynamics model. Two sites in the Mediterranean climatic regimes and one site in the semi-arid climatic regimes of Israel have been selected for this study. Results from this ongoing research will be shown in our presentation, indicating so far an increase of two degree Celsius on average by 2100 and an increase of *Bemisia tabaci* population size as well as increased frequency of severe outbreaks. ■

Comments