the coupling to runoff and the improved treatment of terrain heterogeneity are amongst the main challenges that SVAT modeling faces currently.

ET determination in numerical models is now facing the transitioning of weather models into convection permitting models that experience far more fast fluctuations near the land surface than models in which convection is parameterized. A thorough review is needed of whether conventional concepts, such as the Monin-Obukhov Similarity Theory (MOST), need to be improved for the next-generation models. Furthermore, models have to continuously improve their performances related to forecasting, data assimilation, trend analysis and climate projections.

Fourth Challenge: Estimating ET Remotely and at the Catchment Scale

Satellite remote sensing ET estimates normally use the approaches of PM, Priestley-Taylor or the residual method and make a number of further assumptions to obtain H, G or R_n, usually imposing the closure of the SEB. As mentioned above, parameterizing ET essentially as a function of solar radiation is also an option. The resulting values are compared with in situ ET estimates and calibrated accordingly.

To obtain the actual ET, normally a function is derived that varies between wet conditions-corresponding to ETp-and dry conditions when sensible heat flux prevails. Quantities like albedo, land surface temperature, surface roughness, soil moisture or some vegetation index are used. For heterogeneous vegetated surfaces, two-source energy balance (TSEB) approaches are common. There exist also purely empirical algorithms trained by data, using, for example, neural networks.

Satellite estimates of ET are given at the scale of the pixel, and some applications require information at much higher resolutions, such as the hectometer and subdaily scale. This is leading to the development of downscaling methods for most satellites.

The scale issue has a specific hydrological side, since hydrologists have traditionally analyzed the water budget at the catchment level, looking for closure at relatively large time scales (typically annual) and using the water balance as the basic methodology, with ET=precipitation–runoff, assuming that storage changes might be neglected at annual time scales. However, hydrological numerical models require estimations of ET at a higher time-space resolution. Annual catchment water budgets may be used as a calibration or validation method for other approaches.

To reflect on these ET-related subjects, a workshop is being organized for 7–9 October 2019 in Sydney, Australia, hosted by the University of New South Wales. It is intended to bring together specialists from different disciplines and provide a space for interaction and scientific progress on the subject. More information will be available at *https://www.gewexevents.org/events/determining-evapotranspiration/*.

Land Surface Interactions with the Atmosphere over the Iberian Semi-Arid Environment (LIAISE)

Aaron Boone[1], Martin Best[2], Joan Cuxart[3], Jan Polcher[4], Pere Quintana[5], Joaquim Bellvert[6], Jennifer Brooke[2], Guylaine Canut-Rocafort[1] and Jeremy Price[2]

[1]CNRM–Université de Toulouse, Météo-France/CNRS, France; [2]UKMO, Exeter, UK; [3]University of the Balearic Islands, Palma, Mallorca, Spain; [4]Laboratoire de Météorologie Dynamique, CNRS/IPSL, Ecole Polytechnique, France; [5]Observatori de l'Ebre, Spain; [6]Efficient Use of Water in Agriculture Program, IRTA, Lleida, Spain

Introduction

One of the largest challenges facing environmental science is understanding future changes in the terrestrial water cycle and the subsequent impact on water resources. It has also been recognized by international organizations such as the World Climate Research Programme (WCRP) that human activities are playing a key role in modifying the continental water cycle, and therefore must be accounted for in projections. As highlighted by the WCRP Grand Challenge on "Water for the Food Baskets of the World," this issue is especially critical in bread basket regions where water resources are already limited, such as the Mediterranean basin. Understanding the processes that drive the hydrological cycle in this region is a key aim of the international HYdrological cycle in the Mediterranean Experiment (HyMeX). Climate projections from the Coupled Model Intercomparison Project phase 5 (CMIP5) predict that the Mediterranean region will be a so-called climate change "hot spot" during the twenty-first century (Diffenbaugh and Giorgi, 2012). However, semi-arid regions are also hot spots for biases in climate model variables, in particular land surface temperature (LST) and components of the surface energy balance. The Mediterranean basin is also characterized by highly heterogeneous land cover in terms of both natural and anthropized surfaces, largely driven by the limited availability of soil moisture and the nature of the precipitation. Since rainfall is essentially limited to winter and mountainous areas, human management of the natural river systems is required to provide water for crops and an ever-increasing population. Dams and extraction for irrigation modify the amount and timing of the water flowing into the ocean. Irrigation is also known to significantly impact local atmospheric boundary layer (ABL) growth and structure, in addition to modifying near surface atmospheric conditions and increasing convective activity and clouds downwind of irrigated areas (e.g., Lawston et al., 2015). It also greatly enhances the aforementioned land surface (flux) heterogeneity.

The current representation of anthropization in land surface models (LSMs) and therefore within global climate models (GCMs) is in a relatively nascent stage and urgently needs attention if we are to make accurate future projections of water resources and modifications to the global water cycle

(Harding et al., 2015). The understanding of the impact of anthropization and its representation in models have been inhibited due to a lack of consistent and extensive observations. Here we present the plans for a project which will bring together ground-based and airborne measurements with modeling studies to improve our understanding of key natural and anthropogenic land processes and the subsequent feedbacks with the Mediterranean boundary layer and basin-scale hydrological cycle. These observations will provide the opportunity for a number of community modeling experiments to move forward within GEWEX, helping to highlight gaps in our knowledge and identify current model deficiencies within land surface processes and land/atmosphere interactions.

Objectives and Science Questions

The overall objective of this new activity, the Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment (LIAISE) project, is to improve our understanding of the impact of anthropization on the water cycle in terms of land-atmosphere-hydrology interactions, and the limitations of models to represent all aspects of the terrestrial water cycle in a semi-arid environment on the Iberian peninsula. These include: i) the influence of heterogeneity in land cover, including large irrigated areas, on area-averaged surface fluxes of momentum, heat and moisture; ii) the consequence of land/atmosphere interactions on local initiation of precipitation and boundary layer evolution; iii) the interactions between soil moisture, reservoirs and groundwater in both natural and irrigated regions; iv) the impact of changes in runoff generation owing to anthropogenic effects and its influence on stream flow and reservoir storage; and v) the ramifications of human influences on the future evolution of the water cycle. The main science questions can be summarized as:

1. What are the key natural and anthropogenic semi-arid surface processes that modulate or control infiltration and runoff and govern turbulent fluxes and their spatial heterogeneity?
2. How does anthropization impact boundary layer development, mesoscale circulations and potentially precipitation recycling over this region via feedbacks with the atmosphere?
3. What is the sustainability of ground water and reservoirs in the face of expanding agricultural and farming activities, especially in light of projected future warming and drying over this region?

The study domain for LIAISE is the Ebro basin in northeastern Spain, which is bound to the north by the Pyrenees and to the south by the Iberian System. Surface heterogeneity has grown due to the presence of human society, which has been altering the hydrological cycle and the landscape mainly through intense agricultural activity. The bulk of the basin runoff is generated in the Pyrenees region, therefore infrastructure has been built to store and transport water from the mountainous areas to the agricultural fields. Most of the water used for agriculture, approximately 75%, is stored in reservoirs while the rest is maintained by the snow pack in the mountains. This infrastructure has increased agricultural production and dramatically enlarged irrigated areas. In addition, agricultural fields in the headwater region have been abandoned, which leads to the expansion of forests, increasing evapotranspiration and decreasing river flow. Therefore, the human component of the Ebro system cannot be avoided in any study that aims to understand the water cycle of a basin driven by meteorological and hydrological processes.

Strategy

The overall strategy for LIAISE is to take a multidisciplinary approach consisting of utilizing a suite of LSMs and hydrological and meteorological models that will employ remotely-sensed data or data assimilation strategies to prescribe input parameters and conduct evaluations. It can be summarized as follows:

1. A network of surface energy budget (SEB) observing stations will be installed within an approximately 10 km radius centered over the Urgell and Plà d'Urgell (Lleida) region of the Ebro basin. This area is selected since it encompasses several representative Mediterranean land cover types: irrigated cereal crops (corn, alfalfa), non-irrigated crops (wheat and other cereals), irrigated fruit trees (pear, apple), irrigated poplar plantations, natural grasses and baresoil, non-irrigated fruit trees (olives, almonds) and a lake used for irrigation. The land sites will also include soil moisture, temperature and vegetation monitoring data. This location will also allow us to benefit from the dense local meteorological station and radar data from the Spanish State Meteorological Agency (AEMET) and the Meteorological Service of Catalonia (SMC), along with an existing extensive observation site run by the Institute of Agrifood Research and Technology (IRTA), which includes weighing lysimeters in apple orchards. This network will enable us to evaluate the ability of LSMs to simulate fluxes, especially evapotranspiration, over irrigated sites and to contrast the fluxes with those from natural surfaces. These sites will be maintained at least through entire growing season as part of the Intensive Observation Period (IOP) from early April through September 2020.
2. A 15-day Special Observation Period (SOP) is planned for mid July 2020, when contrasts between irrigated and natural surfaces are at their maximum. During the SOP, the SEB network will be complemented by extensive measurements of the lowest 4 km of the atmosphere using captive balloons, frequent radio-sounding releases, a UHF wind profiler, lidars and up to five flights by the French Office of Aircraft Instrumented for Environmental Research (SAFIRE)/ATR42 aircraft. Measured atmospheric fluxes and state variables will be used in conjunction with fully coupled, non-hydrostatic mesoscale models to study the impact of irrigation on the spatial variability of the ABL, the basin scale circulation and water budget and interactions between the irrigated and natural surfaces.
3. During the observational campaign, a 5-day period will be identified during the dry down of soil moisture in the spring. Throughout this period, radiosondes will be launched at regular periods to add to atmospheric and flux profiles along a 50 m mast. These data will be used to study the

impact on interactions with the lower part of the boundary layer and the contrast in the surface fluxes between the sites with natural dry down and the irrigated sites. A number of LSMs will be confronted with the data to help understand the limitations identified by Ukkola et al. (2016).

4. Several LSM-hydrological modeling platforms will be tested over this region. The improved understanding and representation of evaporation from irrigated surfaces and their high resolution mapping by satellite data will be incorporated into models, which include new parameterizations for dams, rivers and canals, groundwater and reservoirs. Extensive discharge and dam release data will be obtained from the basin authority, the Hydrographic Confederation of the Ebro, through its real-time data portal, Sistema Automático de Información Hidrológica (SAIH). The focus will be on better understanding the exchanges between the different components of the water cycle.

5. Two measurements from the ATR42, high resolution land surface temperature and soil moisture estimates from the GLObal navigation satellite system Reflectometry Instrument (GLORI), will be used alongside state-of-the-art soil moisture products based on downscaled data such as that from the Soil Moisture and Ocean Salinity (SMOS) and Soil Moisture Active Passive (SMAP) missions. This data will be used for assimilation into LSMs and/or evaluation alongside in situ soil moisture observations from an existing Ebro Observatory network and measurements from irrigation-monitoring companies. The use of high-resolution remotely-sensed data from both satellites and aircraft along transects crossing swaths of irrigated and non-irrigated land with concomitant surface observations will permit a multi-scale modeling approach going from the parcel to the regional scale. An example of the detection of irrigated zones over this region using remote sensing is shown in Figure 1 (*see cover*).

6. The improved coupled LSM-hydrological model systems that include anthropogenic effects will be used in conjunction with statistically downscaled new high-resolution regional climate data as part of the European-Mediterranean Coordinated Regional Climate Downscaling Experiment (EuroMed-CORDEX) project in order to provide estimates of the evolution of water resources over this region.

7. Field-scale actual and potential evapotranspiration will be evaluated using two-source energy balance (TSEB) models, which combine thermal observations from Sentinel-3 satellites and optical observations from Sentinel-2 satellites. The methodology for combining Sentinel-3 and Sentinel-2 data to obtain high-resolution ET is currently being researched in the Sentinels for Evapotranspiration (SEN-ET) project (*http://esa-sen4et.org/*).

Summary and Outcomes

To the authors' knowledge, this is the first international project which will focus on the human impact on the water and energy cycle in a semi-arid environment for which the models are advanced enough to explicitly account for dams, irrigation methodologies, river flow, ground water interactions, vegetation phenology and atmospheric feedbacks. These models are sophisticated enough to exploit remotely-sensed data as input or to use data assimilation strategies, but despite recent advances, water management is either quite simple or nonexistent in most LSMs. This was evident during the GEWEX Hydroclimatology Panel (GHP)-Global Land/Atmosphere System Study (GLASS) Workshop on Including Water Management in Large Scale Models (Harding et al., 2015). So we seek to improve the representation of anthropization in the LSM component of Earth system models. LIAISE addresses the GEWEX Science Questions and contributes to WCRP's Grand Challenges, notably how a warming world will affect available fresh water resources globally, specifically in the food basket regions, and how it will change human interactions with these resources and their value to society. Another key GEWEX Science Question addressed by LIAISE pertains to improving our understanding of the effects and uncertainties of water and energy exchanges in the current and changing climate and how to convey this information to society. The improvement of the representation of anthropogenic effects in models will form the foundation for water resource impact studies under future climate change. These results will be communicated to water management services within the Ebro basin. A comprehensive database, consisting of surface-based and aircraft measurements of surface and hydrological fluxes and states and properties of the ABL, will be integrated into the Mediterranean Integrated STudies at Regional And Local Scales (MISTRALS)/HyMeX database, which can accessed upon request by interested researchers. This database of observations will form the basis for a number of international modeling experiments that will cut across many areas of interest to GEWEX, ranging from the ability of LSMs to capture soil moisture dry down, the representation of heterogeneity and how this interacts with the atmospheric boundary layer, the impacts of human influence on land surface fluxes and land/atmosphere interactions and the impact of human influence of the terrestrial water cycle of semi-arid environments.

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