



## Updates on the International Land Surface Interactions with the Atmosphere over the Iberian Semi-Arid Environment (LIAISE) Field Campaign

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economy of Western North America. To fulfill it, CW3E has reached an agreement with SDSC that provides the Center with exclusive access to the SDSC's petascale "Comet" supercomputer—which can perform nearly three quadrillion operations per second and has a storage of 12 Petabytes, thanks to a newly-purchased filesystem by CW3E. For reference, the computer will carry out over one billion core hours of work over three years, which is roughly equivalent to one year of the National Science Foundation's well-known "Cheyenne" supercomputer. This will enable CW3E researchers and collaborators to leverage Comet's computing resources, which are substantially larger than what typically is available for the development of a regional numerical weather prediction system. The goal is to significantly improve weather and hydrological forecasts to enhance the decision-making process associated with reservoir management over California, which could result in increased water supply and reduced flood risk over the region.

The CW3E Supercomputing Advisory Group (CSAG) includes scientists from CW3E and SIO, as well as recognized experts from the National Centers for Environmental Prediction (NCEP), European Centre for Medium-Range Weather Forecasts (ECMWF), National Center for Atmospheric Research (NCAR), Jet Propulsion Laboratory, University of Arizona, University of Colorado at Boulder, and Northern Illinois University. The CSAG operates as a directed research effort to aid CW3E in the selection of allocation requests. Projects are recommended by CW3E members plus CSAG and use a variety of community models and an array of promising technical approaches.

Some of the ongoing computational projects include CW3E's large ensemble (200 members), run at high-resolution (9 km horizontally, 60 vertical levels) based on CW3E's version of the Weather Research and Forecasting model ("West-WRF"), which is tailored to improve forecasts of ARs and extreme precipitation over the West; testing of the NCEP's experimental Global Forecast System v16 and its limited-area regional modeling capability; a high-resolution (2 km, 100 vertical level) 40-year reanalysis based on West-WRF downscaling of ECMWF Reanalysis Version 5; nature runs with NCAR's Model for Prediction Across Scales to perform predictability studies; high-resolution, high-top subseasonal-to-seasonal ensemble predictions with NCAR's Community Earth System Model Version 2; high-resolution hydrodynamic modeling for flood and inundation risk analysis with the University of Bristol's LISFLOOD-FP; and ocean-atmosphere coupled modeling experiments with the Massachusetts Institute of Technology's general circulation model (ocean) and WRF (atmosphere).

The program is well underway, producing unique modeling outputs relevant to water cycle extremes. CW3E solicits requests semiannually from center members, affiliates, and collaborators for use of Comet's computing resources. Stay tuned for future announcements (<https://cw3e.ucsd.edu>), including potential opportunities to participate.

## Updates on the International Land Surface Interactions with the Atmosphere over the Iberian Semi-Arid Environment (LIAISE) Field Campaign

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### Introduction

The overall objective of the Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment (LIAISE) project is to improve the understanding of land-atmosphere-hydrology interactions in a semi-arid region characterized by strong surface heterogeneity owing to contrasts between the natural landscape and intensive agriculture. It is known that irrigation can potentially impact the local atmospheric boundary layer (ABL) characteristics, thereby modifying near surface atmospheric conditions within and downwind of irrigated areas (e.g., Lawston et al., 2020) and potentially the recycling of precipitation. The understanding of the impact of anthropization and its representation in models have been inhibited due to a lack of consistent and extensive observations. In recent years, land surface and atmospheric observation capabilities have advanced while irrigated surfaces have been increasing, leading to a renewed need for dedicated field campaigns over contrasting (climate) regions. For example, the Great Plains Irrigation Experiment (GRAINEX) in the summer of 2018 focused on the impact of irrigation on coupled surface-atmosphere processes over a mesoscale region in eastern Nebraska (Rappin et al., 2021). In this paper, we present a summary of the LIAISE field campaign intensive phase, which took place over the Catalan counties of Urgell and Pla d'Urgell within the Ebro basin in northeastern Spain this summer (after a one year delay owing to the COVID-19 pandemic). In contrast to the GRAINEX experimental zone, LIAISE is located in a semi-arid hot, dry Mediterranean climate, with a very sharp delineation between a vast, nearly continuous intensively-irrigated region and the generally much more dry rain-fed zone to the east of the study domain. There are discussions underway to further expand this irrigated zone owing to its economic importance, but there is an urgent need to improve the prediction of the potential changes to the regional water cycle since water resources are limited (most of the water comes from reservoirs located in the Pyrenees Mountains to the north). The consensus of current

climate projections predicts a significant warming and drying over this region in upcoming years. The science questions and main objectives of the LIAISE project were described in Boone et al. (2019); thus, this paper focuses on a short summary of the intensive field campaign this past summer.

### Salient Weather Features

An intensive observation period (IOP) was defined a priori as being a relatively clear day characterized by a well-mixed atmospheric boundary layer with weak synoptic scale forcing so that surface-induced local to regional scale circulations are most likely to be present and detectable. In late July, synoptic scale winds are typically light and from the west, and a thermal (heat) low pressure area generally forms over the region with daily maximum temperatures in the mid-to-upper 30s °C, though it is not unusual for them to be upwards of 40–42 °C for several-day periods. This thermal situation has a strong impact on surface winds. Formation of some shallow cumulus is possible, but moist convection, if present, is generally confined to the surrounding mountain ranges. Owing to the proximity to the Mediterranean Sea to the east, sea breeze (SB) formation is quite frequent, but its inland progression is slowed by the presence of the Catalan pre-coastal and coastal ranges that separate the Ebro basin from the sea. The intensity of the westerlies and strength of the heat low are also contributing factors to the SB front propagation and intensity. Generally speaking, the SB front usually arrived sometime between 16:00 and 19:00 local time over the study zone with the dry zone sites impacted earliest. The SB passage was seen in the observations as a low level wind shift (to winds with a significant easterly component) over the entire region, while in the east, horizontally-scanning lidar observations also revealed a significant increase in low-level moisture with its arrival. The sea breeze generally coincided with a collapsing ABL in the late afternoon. Days with a predicted early arrival of the SB were not designated as IOPs during the daily briefings. Finally, one rain event did occur on July 26, which was associated with the passage of a synoptic scale trough: local precipitation totals of around 30 mm were recorded over the irrigated zone; however, the convective cells propagated to the northeast and the dry zone received relatively little rainfall, thereby reinforcing the wet-dry zone contrast during the subsequent days of the SOP.

### Observing Period Strategy

The observation strategy consisted of three periods:

1. The long observation period (LOP) monitored slowly-evolving land surface state variables (such as soil moisture, crop evapotranspiration, and temperature) and relatively autonomous surface flux measurements at five sites characterized by different but regionally-representative land cover types, covering the growing season of summer cultivars (ending in October or November).
2. The special observation period (SOP) occurred from July 15–29, when contrasts between irrigated and natural surfaces are generally at or near their maximum. Intensive surface-based and airborne measurements of the atmo-

spheric boundary layer were made, along with intensive ecophysiological observations and remotely-sensed high spatial resolution mesoscale measures of surface variables from aircraft and unmanned aerial vehicles (UAVs). Two additional local-scale energy budget and soil moisture sites were added for the SOP, since they were used to evaluate remote sensing data from aircraft.

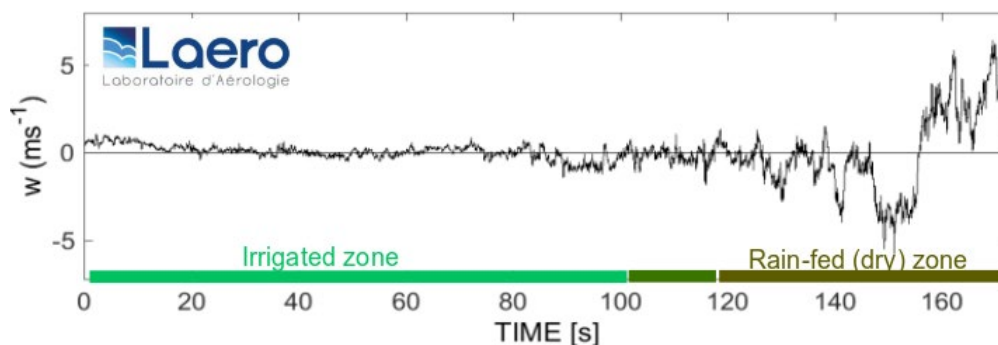
3. IOPs were defined as days within the SOP for which sufficiently good meteorological conditions occurred to justify the full complement of measures mentioned in item 2). Fortunately, the weather during the SOP was nearly ideal and enabled 11 IOP days.

### Forecast Support/Decisions

A daily briefing was held each morning (09:00 to 12:00 local time), which consisted of a review of the previous day's scientific activities and potential technical issues, a forecast briefing, and a final discussion to propose an IOP day 2 days in advance, to confirm 1 day in advance and potentially to cancel it on the morning of the IOP (in the case of a significant and poorly-anticipated degradation of weather conditions or technical issues). Daily forecast briefings were provided by a team of forecasters from the Meteorological Service of Catalonia (SMC) and three students from the Météo-France National Meteorological School (ENM). Forecasts were based on operational model outputs from a version of the Weather Research and Forecast (WRF) model used by the SMC, the European Center for Medium Range Prediction (ECMWF), Research Actions from small to large scales (ARPEGE) and Application of Research at the Operational Mesoscale (AROME) models. The operational WRF-ARW configuration uses grid nesting with a cascade from 9 to 3 km spatial resolution, but outputs from a research version running at 1.5 km was also used. AROME (the domain covers most of Spain) is run operationally at 1.3 km. The other two models are global (resolutions less than about 10 km over the area). These forecasts were used to coordinate aircraft flight timing and paths, the different surface-based atmospheric monitoring operations, and for coordination with different teams making surface measurements for calibration and evaluation of data from airborne sensors.

### Aircraft

Eight flights were made on IOP days by the French Office of Aircraft Instrumented for Environmental Research (SAFIRE) ATR-42, which consisted of two legs. During the first leg, the goal was to explore the properties of the convective boundary layer and measure the turbulence (at five vertical levels ranging from 300 m to several km in altitude) over roughly 15 km transects within both the irrigated and rain-fed zones. In the second leg, 16 km transects crossing between the two zones at a constant height for which airborne high spatial resolution measures were made of atmospheric state variables (Fig. 1), soil moisture, vegetation water content, photosynthesis and biomass from the GNSS-R dual polarization airborne instrument (the Global navigation satellite system Reflectometry Instrument, GLORI), and solar-induced fluorescence (SIF) from the HyPlant imaging spectrometer. NASA flew the Scanning L-band Active Pas-



**Figure 1.** Vertical velocity measured by the ATR32 on July 21 at a height of 1240 m moving from NE to SW across the irrigation transition to rain-fed surfaces starting at 13:47 UTC (on the left).

sive (SLAP) sensor on a B200 King Air to provide soil moisture over both irrigated and non-irrigated zones. Most flights were low altitude (300 m), providing a unique opportunity for small 100x200 m footprints. Two flights were at medium altitude (~800 m) to provide wider context. Data products will include passive brightness temperature, active backscatter coefficient, and soil moisture (from the passive). Thermal infrared (IR) data will also be available. Nine science flights were conducted, and conditions were favorable, including observations of irrigation events and precipitation followed by a dry down. A third aircraft, the Flying Laboratory of Imaging Systems (FLIS) airborne infrastructure operated by Czechglobe, performed five successful flights: visible and near-infrared and longwave infrared hyperspectral imaging sensors were utilized for data acquisition of target areas under different viewing angles. The study was focused mainly on research of the Bidirectional Reflectance Distribution Function (BRDF) effect.

The drone activities in July 2021 had four top priorities: a) analysis of the vegetation activity by SIF imaging (six flights), b) identification of stress situations of the vegetation by multispectral and thermal imaging (26 flights), c) meteorological vertical profiling of wind, temperature, and humidity (36 flights), and d) supporting flights providing high-precision maps and digital elevation models (5 flights). Some of the flights, i.e., the SIF flights, were closely correlated to manned aerial flights. The drones proved to be a valuable and complementary tool with respect to the ground-based and other airborne (balloons, manned aircraft) systems and instruments.

### Surface Network

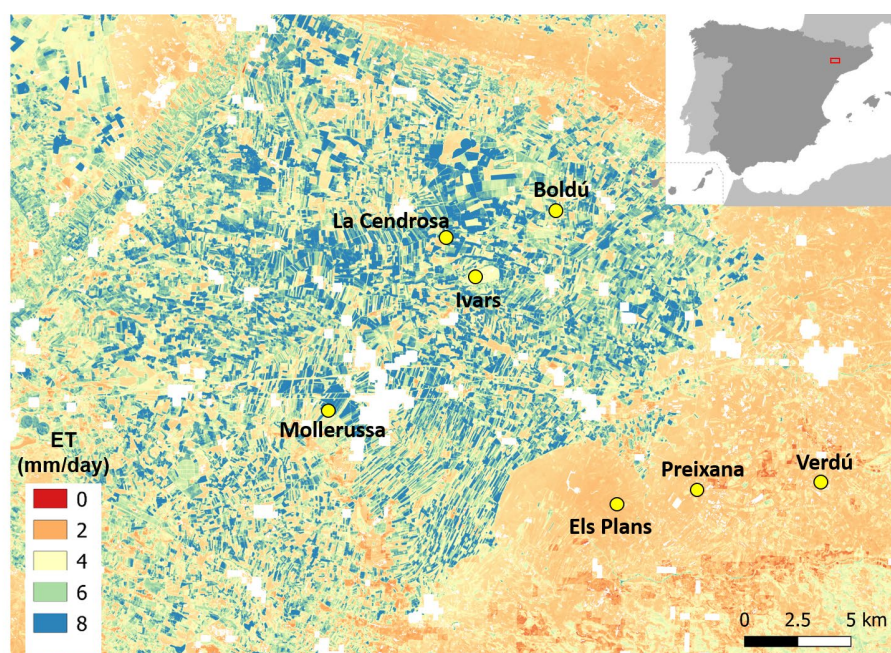
The study zone covered approximately a 30x30 km square (Fig. 2), which is divided by a boundary (from southwest to northeast) between the irrigated and rain-fed zone (southeastern part). Seven observing sites were installed with nine surface energy budget (SEB) observing stations (one site, Mollerussa, included three SEB stations over different vegetation types) and two weighing lysimeters in apple trees. All of the SEB stations used eddy covariance to compute turbulent fluxes in addition to including the main components of the surface radiation balance. The study zone location allowed the project to benefit from the dense local meteorological station and radar data from SMC, along with an existing extensive observation site run by the Institute of Agri-food Research and Technology (IRTA) and SMC in Mollerussa.

Three of the locations were over cultivars within the irrigated zone, three were located within the dry zone (one was drip irrigated), and the final location is a lake within the irrigated zone. Leaf-level and canopy-level ecophysiological data were collected for five vegetated SEB sites. Field scale turbulence estimates from scintillometers were made at three of the sites. Finally, two of the sites (La Cendrosa and Els Plans) were complemented by extensive measurements of the lowest part of the atmosphere using captive balloons, frequent radio-sounding releases, UHF wind profilers, and lidars. Ecophysiological measurements were conducted both at leaf- and canopy level at all of the field sites within the LIAISE domain with the objective of: providing vegetation-specific parameters for land surface models, providing leaf-level and canopy-level traits as ground-truth for remote sensing and eddy covariance measurements, quantifying diurnal patterns in leaf-level transpiration in response to drought stress, and quantifying partitioning of evaporation versus transpiration and photosynthesis versus soil respiration. A summary of the sites is given below where wet zone and dry zone indicate sites within the irrigated or rain-fed parts of the study domain, respectively.

### La Cendrosa Site: Irrigated Alfalfa (Wet Zone)

The La Cendrosa supersite was irrigated just before and once during the SOP using the flood/gravity method. The crop was cut just before the start of the SOP, and was ready for cutting by the end with a height of about 70 cm. A 50 m mast was installed with a SEB station that measured meteorological variables at three levels and enabled turbulent flux computations at two. A distributed temperature-sensing Raman scattering optical cable was also mounted along the tower and across the field which provided high frequency temperature measurements every 12–25 cm. A laser scintillometer was installed for estimating parcel-scale sensible heat flux. Hourly radiosondes (up to ~3 km) and tethered balloon flights (at levels ranging from 50 to 600 m) were carried out on IOP days roughly from sunrise through early evening, and a total of 152 radiosondes were released. A UHF wind profiler (wind and certain turbulence measures from 200 m to 3000 m) and a vertical profiling lidar (40 to 250 m) were in operation throughout the SOP. A Parsivel2 disdrometer was also installed near the 50 m mast. A great deal of ecophysiological measures at the plant and leaf level were made, which included in situ measurements of vegetation fluorescence (passive and active fluorescence and gas exchange), CO<sub>2</sub> assimilation (A-PAR), stomatal conductance,





**Figure 2.** The LIAISE study zone in Catalonia (NE Spain) with surface site locations plotted over a map of crop evapotranspiration corresponding to 17<sup>th</sup> July 2021, obtained through a Two-Source Energy Balance (TSEB) model using images from Sentinel-2 and Sentinel-3. Prepared by IRTA.

photochemical yield, fluorescence (fraction of absorbed photosynthetically active radiation, or F-PAR), chlorophyll content, vegetation height, leaf reflectance, leaf area index, and water and carbon isotopes. SIF was also observed remotely from UAVs with RGB and multi-spectral instruments.

#### **Els Plans Site: Winter Crops and Seasonal Bare Soil (Dry Zone)**

At the Els Plans supersite, a naturally rain fed area, a 50 m mast was deployed and included meteorological parameters and flux measurements at a number of heights, surface canopy measurements and subsurface moisture, surface temperature, and thermal imaging. On 7 IOP days, boundary layer profiles were made between sunrise and 19:00 local time. On 4 evenings, the soundings were extended to 23:00 local to capture the ABL evening transition. A total of 116 radiosonde releases were achieved to a maximum height of 8 km. The evening transition soundings were extended into the stable boundary layer by deployment of a tethered balloon. Finally, a lidar setup was installed near this site, pointing northward with a swath across the transition zone between the irrigated and rain-fed zones which provided measures of state variables and turbulent fluxes. A series of soil evaporation experiments were made, for example, by small mobile lysimeters.

#### **Ivars Site: Lake (Wet Zone)**

The lake has a surface of approximately 1x2 km, and is on the order of 1–2m deep. A floating SEB station was anchored near the center of the lake during the entire LOP. Lake water temperature measurements at depths of 5, 10, 30, 50, 100,

and 150 cm were measured, along with periodic measures of lake turbidity. Two screen-level meteorological measurement stations were installed on opposite sides of the lake in proximity to an optical large aperture and a microwave scintillometer (operational during the SOP). Turbulent flux measurements over the lake can thereby be compared with those from the floating SEB station. Finally, several UAV flights were made to map the surrounding topography for high resolution modeling studies.

#### **Preixana Site: Almond Orchard (Dry Zone)**

A SEB station was installed in a rain-fed almond tree grove near Preixana within the dry zone. The measurement of the turbulent fluxes is done from the top of a scaffolding 2 m above the trees. The system was complemented by soil temperature and moisture measurements.

#### **Mollerussa Site: Irrigated Apple Orchard, Corn Field and Short Grass (Wet Zone)**

The Mollerussa site is located at the IRTA experimental facility, southwest of the town, and includes three separate SEB stations each over contrasting vegetation types and two weighing lysimeters. Here, there was a particular focus on evapotranspiration (ET) estimates (contributing directly to the GEWEX ET initiative: Cuxart et al., 2019). The first site is within a drip-irrigated apple orchard irrigated under two different irrigation strategies (full-irrigation and stressed) during the IOP campaign. A SEB station was installed over the weighing lysimeter located in the fully-irrigated part of the orchard in order to give ET estimates using two different approaches. Two sets of soil sensors were deployed on both sides of the irrigation line, each consisting of temperature measurements at multiple levels and a heat flux plate and a water content reflectometer just below the soil surface. Infrared temperature sensors were also installed above apple trees in order to monitor continuous canopy transpiration. An automatic weather station from the SMC network is maintained a few meters north of the apple orchard, and a second SEB station was installed within an irrigated cornfield. Finally, for the LIAISE campaign, a complete SEB station was installed over a well-irrigated short grass surface to monitor the so-called reference ET<sub>0</sub>. An optical microwave scintillometer was set up to provide field scale turbulent fluxes. The lower atmosphere was monitored using a radio acoustic sounding system (RASS) sodar to provide vertical profiles of the wind and virtual temperature between 40 and 300 m above the ground, and a UAV made lower atmospheric profiles. Several flights were also conducted with an UAV equipped with multispectral and Thermal-IR cameras in order to evaluate the performance of the thermal-based Two-Source Energy Balance (TSEB) model for estimating daytime ET and its partitioning components. Numerous ecophysiological measurements were

also made, many the same as at La Cendrosa; however, several specific experiments were designed to contrast certain processes over well-irrigated versus sparsely-irrigated plots, such as stomatal conductance at the apple orchard.

#### **Verdú Site: Irrigated Vineyard (Dry Zone)**

A SEB station was installed over a vineyard near the town of Verdú. The objective of this experiment is to provide flux, vegetation, and soil moisture measurements for use in an improved version of the Food and Agricultural Organization Irrigation and Drainage Paper No. 56 (FAO-56) model for rank tree crops (in collaboration with the European Space Agency). The vineyard row spacing is 4 m with no vegetation cover on the inter-row. The soil is very shallow (about 50 cm) and stony. The monitoring system includes a 4-band net radiometer, three soil heat flux plates, two SKYE Normalized Differential Vegetation Index (NDVI) sensors, three soil moisture sensors (5, 20 and 40 cm) on the row, and one surface soil moisture sensor on the inter-row. Three weather variables are also monitored: rainfall, temperature, and relative humidity. The experiment was supported by a weekly field survey of soil moisture and vegetation porosity.

#### **Boldú Site: Multiple Irrigated Crops (Wet Zone)**

A network of soil moisture sensors has been installed over different crops at Prat de Boldú in collaboration with a local irrigation consulting company, SAF-Sampling. The goal of this experiment is multi-purpose: first, to test an innovative low-cost soil moisture monitoring network; second, to provide validation data for the estimation of soil moisture by GLORI and the Sentinel-1 algorithm; and third, to improve an algorithm of irrigation retrieval from satellite data. In agreement with the Cooperative of Ivars, a network of two gateways and 14 soil moisture stations were installed. The site is characterized by cereal crops (barley, wheat, maize), vegetables (peas, broccoli), fodders (alfalfa), and apple trees. The irrigation methods are flooding, sprinkler (pivot, ramp, and full cover), and drip irrigation on broccoli. In addition, a full SEB station was installed in a corn field within the area that was flood-irrigated.

#### **Perspectives**

Data processing is ongoing, and data will be continuously uploaded to the LIAISE database (LIAISE-DB) maintained by Data and Services for the Atmosphere (AERIS). Currently, select quicklook images from the field campaign can be viewed at <https://liaise.aeris-data.fr/products/>, but over upcoming months and in 2022, processed data will be continuously updated. Simulations from modeling studies will also be contributed to the database in upcoming years. Field data will have an embargo period of three years; however, researchers may contact the LIAISE science principal investigators for specific instruments to obtain data sooner for research purposes on an individual basis. The data distribution policy is modeled after the GEWEX-supported Hydrological cycle in the Mediterranean Experiment (HyMeX) experiment and a final version will be posted on the LIAISE website by the end of 2021. It is planned that LIAISE data will be used for several planned GEWEX initiatives studying the re-

gional scale water and energy cycles in upcoming years (Best et al., 2020). The LIAISE multi-mesoscale-model intercomparison project ([http://turbulencia.uib.es/intercomp\\_liaise/](http://turbulencia.uib.es/intercomp_liaise/)) will contribute directly to the ongoing GEWEX ET initiative (Cuxart et al., 2019) and other LIAISE community modeling projects. The data also has the potential to help improve the retrieval of hydrology-related variables: at least two European Space Agency funded projects have plans to use the data set in order to improve our knowledge on the downstream impact of irrigation by water management agencies. More information on the project, workshop presentations, and information on the field campaign can be found at <https://www.hymex.fr/liaise/index.html>.

Two sites are being maintained over the longer term in order to cover the dry down, which was missed in 2021 due to travel restrictions. The Met Office 50 m mast will be deployed from June 2021 to July 2022, capturing the evolution of the surface and near-surface conditions over a 13-month period, including very dry conditions during the summer months, and soil moisture dry-down in the spring. Specific stable ABL experiments are also planned for the spring of 2022. The ET0 station and the RASS will also remain at Mollerussa for several years to complement research being done at IRTA and SMC.

Finally, a series of outreach actions have been planned in the Lleida region. During the campaign, presentations were made to local groups involved in viticulture, and classes were offered to a local high school (that graciously hosted the LIAISE forecast briefings) on land-surface interactions with emphasis on the objectives and results from the LIAISE campaign. A press conference was organized at IRTA during the SOP and interviews were presented on Catalan and Spanish television networks, and project summaries were published in regional and national newspapers and in Spanish agritech publications. More comprehensive outreach efforts are anticipated for 2022 led by IRTA and in conjunction with the first post-campaign LIAISE workshop.

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