Development of an Interactive Crop Growth Web Service Architecture to Review and Forecast Agricultural Sustainability

University of Idaho

ASA, CSSA, and SSSA International Annual Meeting – Nov2nd-5th, 2014 – Long Beach, CA

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Evapotranspiration plays a large role in agricultural practices. In cropping systems, simultaneous evaporation and transpiration occur in varying degrees, with variation largely based on the amount of solar radiation that reaches the cropping surface (Allen et al, 1998). As a crop grows, its' crop canopy changes with development, and, as such, variably limits the amount of solar radiation reaching the surface. With accurate climatic variables, elevation, and crop type – an overall crop evapotranspiration value can be calculated – and then compared to observational crop yield values. This study aims to examine this relationship of evapotranspiration and crop yield across the Inland Pacific Northwest (IPNW).

The study area for this effort is known as the Palouse region of Eastern Washington and Western Idaho (Figure 1). The region is typically dominated by medium to large scale agricultural practices - growing spring and winter wheat, barley, lentils, peas, garbanzo beans, and smattering of other crop types (Hall et al, 1999). Wheat is the predominant crop for the region, with the area producing over 10% of the nation's wheat yields. Whitman County additionally ranks consistently as the #1 wheat production county in the United States (Winter Wheat Facts, 2008-2009).

Project Goals

Given our proposed research statements, the specific goals of this study were to:

1. Develop a modular technology architecture for climatic analysis and data integration;
2. Test the usage of the above architecture by calculating reference evapotranspiration (ET) rates across the entire study area. The Penmen-Monteith equation was been selected, due to its incorporation of crop variability thru the use of a crop coefficient (Allen et al, 1998); and
3. Compare historical cropping yield rates with ET rates for the area within the study area. Are there significant correlations that would allow for effective inferences about future crop yield?

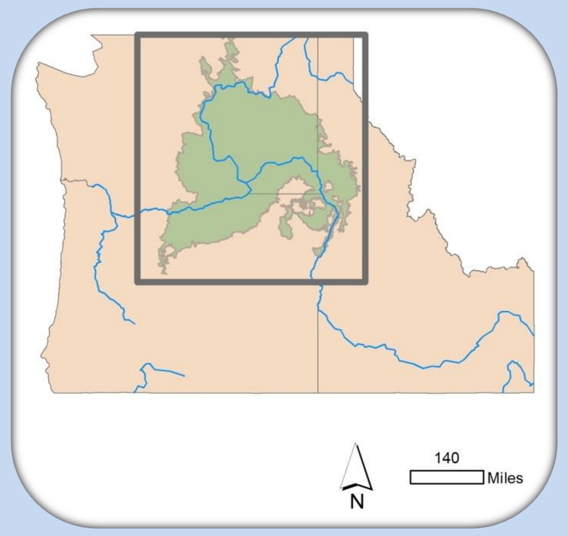


Figure 1. Study Area

Climatic Response Data Repository Framework

The climatic response data repository framework (CRRF) will outline a proposed data architecture that will work in an integrated fashion with other developed modeling and geoprocessing frameworks.

Hypothesis: What are the effects of evapotranspiration on the stages of growth for winter wheat and spring wheat, across multiple years

Evapotranspiration

For this study, we used the Penman-Monteith equation for calculating Reference Evapotranspiration (ETo) (Allen et al, 1998).

$$ET_o = \frac{0.408\,\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1+0.34\,u_2)}$$

where

ET_o	reference evapotranspiration [mm day^{-1}],
R_n	net radiation at the crop surface [MJ m^{-2} day^{-1}],
G	soil heat flux density [MJ m^{-2} day^{-1}],
T	mean daily air temperature at 2 m height [°C],
u_2	wind speed at 2 m height [m s^{-1}],
e_s	saturation vapour pressure [kPa],
e_a	actual vapour pressure [kPa],
e_s-e_a	saturation vapour pressure deficit [kPa],
Δ	slope vapour pressure curve [kPa °C^{-1}],
γ	psychrometric constant [kPa °C^{-1}].

Data Preparation and Processing

Data methodology for preparing, transforming and organizing data for study effort

Crop Yield

For this study, crop yield values were acquired thru survey efforts conducted by University of Idaho researchers Kate painter and Hilary Donlan (Painter and Donlan, 2012)

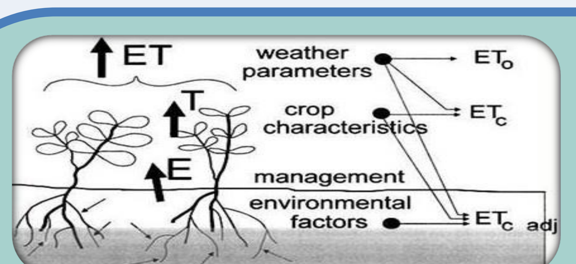


Figure 2. Crop Evapotranspiration (citation)

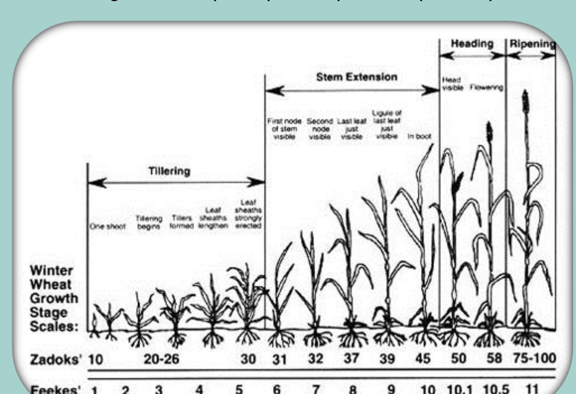
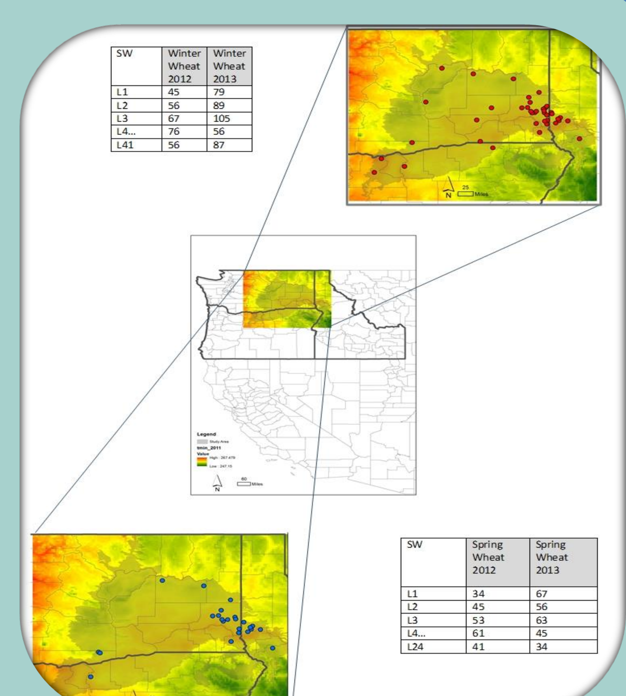


Figure 3. The Feekes and Zadoks growth stage scales for winter wheat (citation)

As part of this study, climatic parameters (temperature, humidity, wind speed, solar radiation) were acquired in order to calculate evapotranspiration for each day, for each cell location (Abatzoglou, Brown, 2011). In addition, observational crop yield values were acquired (Painter, Donlan, 2012) across the Palouse for 2012 and 2013 – winter wheat and spring wheat (Figure 4).

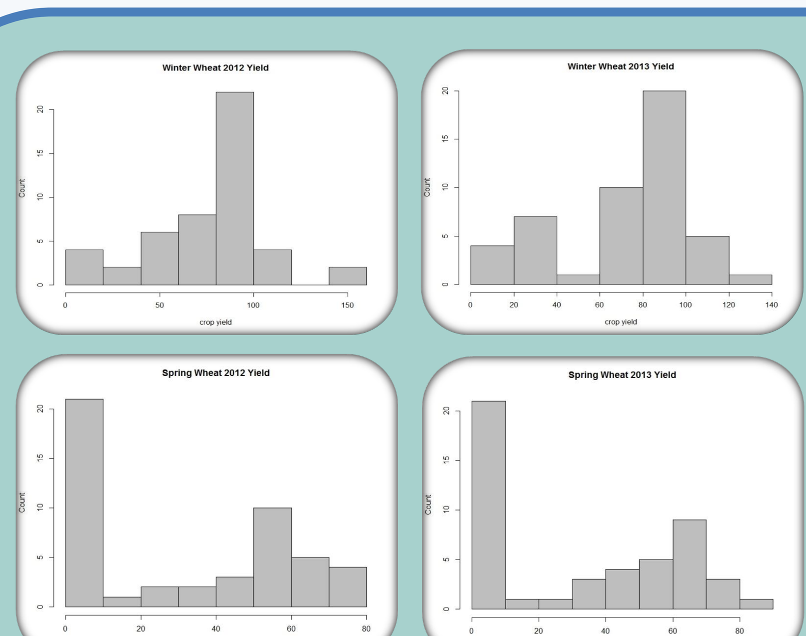
We are categorizing our time variable in crop development stages (1-4), which correspond to a particular number of days within the seasonal growing cycle for winter or spring wheat By using these crop stage categories, we can use a mixed design model (both analysis within stages and between locations) to examine the variance of evapotranspiration between locations and within stages across a particular location.

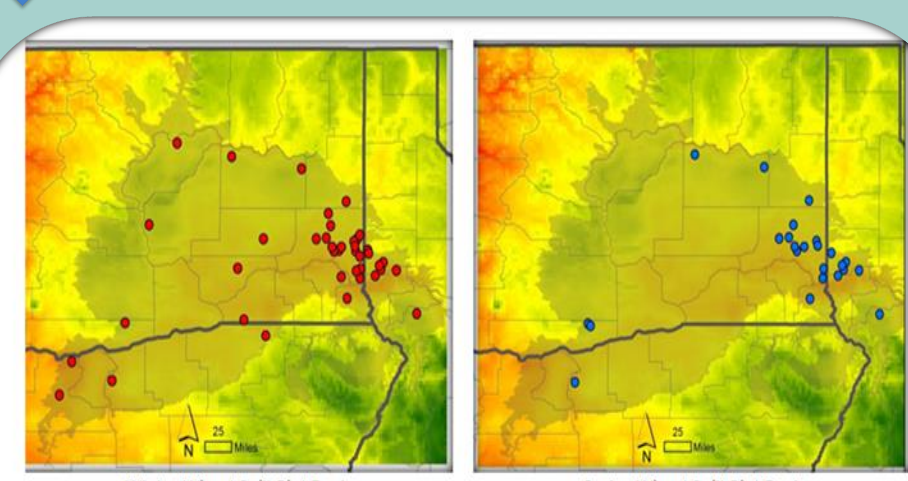


SW	Winter Wheat 2012	Winter Wheat 2013
L1	45	79
L2	56	89
L3	67	105
L4...	76	56
L41	56	87

SW	Spring Wheat 2012	Spring Wheat 2013
L1	34	67
L2	45	56
L3	53	63
L4...	61	45
L24	41	34

Figure 4. Overview of the study area, with winter wheat and spring wheat locations delineated. The background raster is minimum temperature for 2011.





Winter Wheat Split Plot Design

	WW12				WW13			
	1	2	3	4	1	2	3	4
L1	ET1	ET2	ET3	ET4	ET1	ET2	ET3	ET4
L2	ET1	ET2	ET3	ET4	ET1	ET2	ET3	ET4
L3	ET1	ET2	ET3	ET4	ET1	ET2	ET3	ET4
L4...	ET1	ET2	ET3	ET4	ET1	ET2	ET3	ET4
L41	ET1	ET2	ET3	ET4	ET1	ET2	ET3	ET4

L1-L41 = Sample Locations. n= 41.

Spring Wheat Split Plot Design

	SW12				SW13			
	1	2	3	4	1	2	3	4
L1	ET1	ET2	ET3	ET4	ET1	ET2	ET3	ET4
L2	ET1	ET2	ET3	ET4	ET1	ET2	ET3	ET4
L3	ET1	ET2	ET3	ET4	ET1	ET2	ET3	ET4
L4...	ET1	ET2	ET3	ET4	ET1	ET2	ET3	ET4
L24	ET1	ET2	ET3	ET4	ET1	ET2	ET3	ET4

L1-L24 = Sample Location. n= 24.

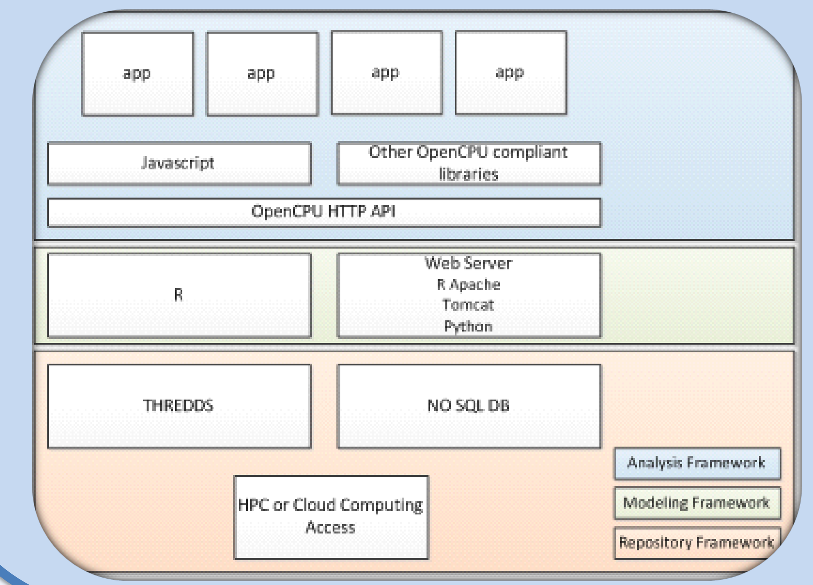
Figure 5 – Above: Distributions of crop yield for 2012 and 2013 for winter and spring wheat, across the Inland Pacific Northwest (Painter and Donlan, 2012)

Figure 6 – Right: Split Plot ANOVA design to examine the variation of ET by crop stage, across all locations.

Development of Climatic Response Data Repository Framework

The proposed effort will develop grouping of technology frameworks to estimate climatic response variability. The strategies that will be used to build out these frameworks include:

Modularity. The intention of the proposed framework is to allow components to be reused, and combined with other technology structures;
Reusability. The proposed frameworks will be developed with the explicit intent to enable their re-use and potential re-deployment in a different location;
Mesh-network functionality. A key component of the proposed frameworks is the ability to enable node to node interaction between deployed frameworks;
Open Access. An important aspect of this effort is ensure that all technologies developed are built upon open source methods, and are freely available.



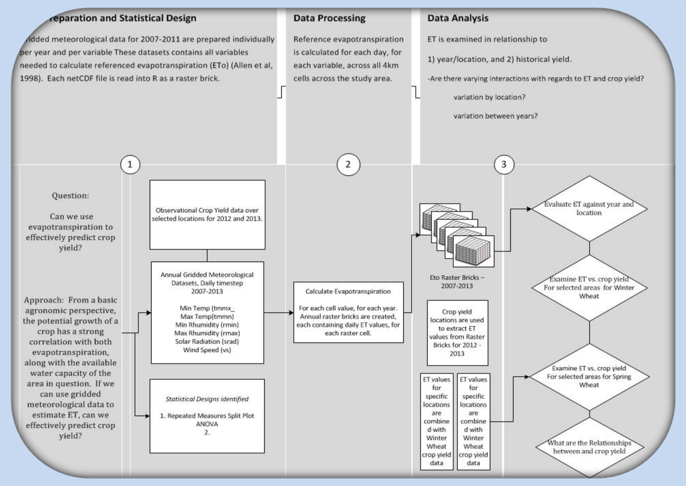
The climatic response data repository framework approach will build out a modular statistical and data model to evaluate climatic response variations over time and location. The CRF will utilize:

- Python for overall framework structure
- R statistical package for dynamic statistical interactions
- RApache – a R-integrated Apache web server
- OpenCPU – a HTTP API that allows integration between R and Javascript, for web server analytic deployment in a web environment

Data Preparation, Processing, and Analysis

Data preparation includes the collection of all the climate and crop datasets for the time period, evaluation of the accuracy and precision of the data, and working with the data to ensure that it is fit to use for calculation and analysis purposes.

The climate input datasets were in netCDF format (Rew and Davis, 1990, Rew and Davis, 1993), with yearly dataset containing variables for latitude, longitude, day, and a singular climatic variable. No manipulation was needed for the input data values or column headers, and each netCDF file was read directly into the R statistical package.

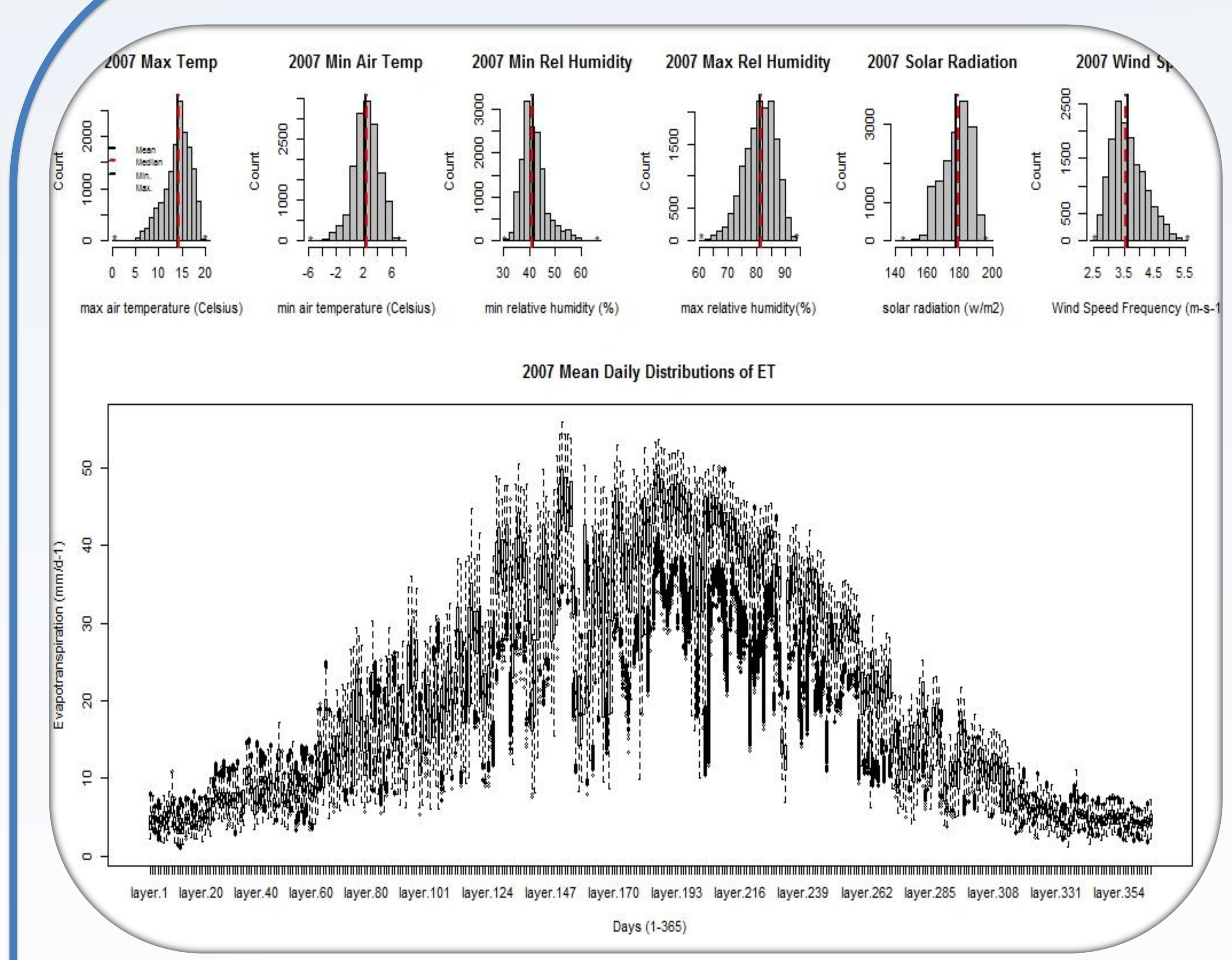


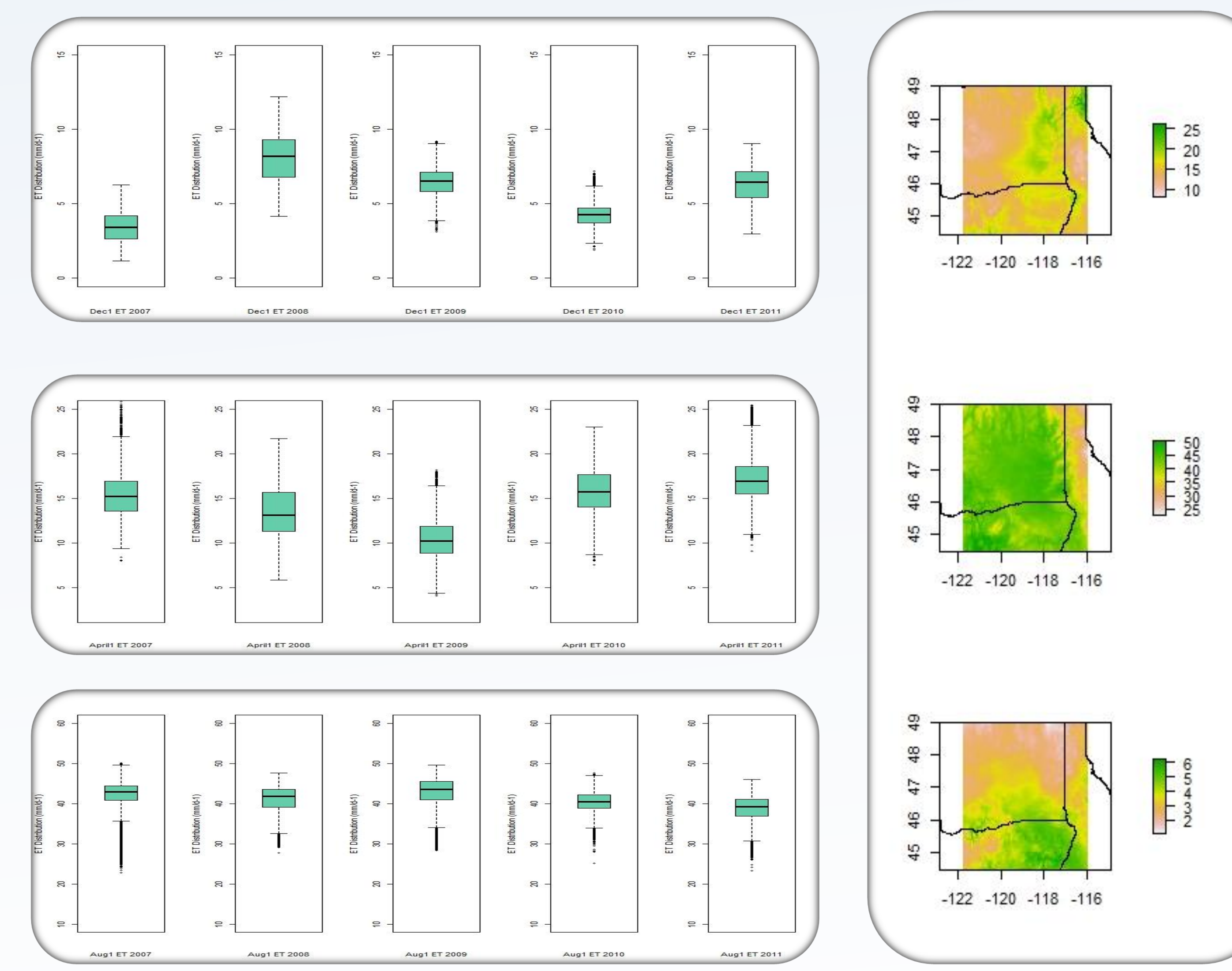
Initial Results and Interpretations

Evapotranspiration values were calculated for 2007-2011, for each day, for every cell within the study area extent. Overall, values ranged from near 0 to 60 millimeters per day (mm/d), with a expected normal distribution that aligns with the standard seasonal variations.

To further examine evapotranspiration values, we explored the distribution of ETo across 2007, in comparison to the input climatic variable distributions (Figure 8). Overall, ETo values for 2007 across this study area are less distributed in cooler months (November, December, January, February), and more distributed in warmer months, as noted in Figure 8.

To further compare evapotranspiration across the breadth of the dataset, we examined the distribution of ETo across all years (2007-2011) for three specific dates (April 1st, August 1st, and December 1st) (Figure 9). We found the same seasonal pattern of low ETo values for cooler month and higher values for warmer months. In addition, we saw some variations across the years for each date – with 2009 being an interesting year with lower ETo values for cooler months – as compared to other years within the 2007-2011 range.





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REACCH Data Management Partners

"Regional Approaches to Climate Change for Pacific Northwest Agriculture" is funded through award #2011-68002-30191 from the National Institute for Food and Agriculture

United States Department of Agriculture
National Institute of Food and Agriculture

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