# Mapping Evapotranspiration Under Current and Future Climate Models

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## 1 Abstract

The evapotranspiration process is key to understanding crop water demands. Using the established FAO-56 method for assessing baseline values using a reference crop, we can use climatic variables to asses changes in irrigation demands across different regions and times. The climate data used comes from WorldClim 2.1. The historical values can then be used to build and quantify the performance of a random forest model, using only the subset of variables that are also in future climate models This makes it possible to predict changes in $ET_0$ under future climate models. Allowing us to understand potential changes in the water demand for growing regions.


## 2 Introduction

Evapotranspiration is the sum of process by which water goes from the surface to the atmosphere via Evaporation out of the soil and transportation in which is water moving through plants to the atmosphere. This process is key to understanding the water needs of the agricultural industry and there are many proposed methods for its approximation. The first to see widespread adoption was the Penman equation. Established in 1948, it combined radiative energy balance with aerodynamic mass transfer methods to produce a approach that didn't require surface temperature. In 1998 a simplified equation was proposed by the Food and Agriculture Organization of the United Nations in the form of FAO-56. Where they established the Penman-Montheith equation using a reference grass crop to simplify the equation to just climatic variables. Allowing for comparison of different climates. Further methods have been developed as well as novel techniques like the use of thermal satellite imagery for more accurate results on the geographic scale.

#### 2.0.1 FAO-56

Established an equation for Reference evapotranspiration, Explaining the need for a reference crop in order to make comparisons, analyzed different methods and issues with variability in their results. Then establishes the baseline crop that is still widely used today.

#### 2.0.2 Practical and Theoretical Benefits of an Alternative to the Penman-Monteith Evapotranspiration Equation

As with any standard their are some critiques this paper highlights some issues with the performance of the Penman-Montheith equation under limiting cases that effect results at night and in cold environments. Though interesting their methods were not used due to complexity and not allowing for comparisons to other studies.

### 2.0.3 Version 3 of the Global Aridity Index and Potential Evapotranspiration Database

This work established methods for using WorldClim 2.0 data to calculate baseline values for evapotranspiration using the Penman-Monteith equation.

### 2.0.4 Projecting potential evapotranspiration change and quantifying its uncertainty under future climate scenarios: A case study in southeastern Australia

This paper compared the effectiveness of different methods using a simplified set of inputs comparing four other 0-models for $ET_0$ (Jensen-Haise, Makkink, Abtew, and Hargreaves) to a random forest model using the Penman-Monteith equation as a judge. They found random forest models to be more effective then alternatives.

### 2.0.5 Satellite-Based Energy Balance for Mapping Evapotranspiration with Internalized Calibration (METRIC)—Model

For a completely different approach, this papers proposes methods for using short and long wave satellite images from Landsat and MODIS along with ground based weather data in order to produce ET values and has other practical values over traditional methods.

## 3 Methods

### 3.0.1 Data Sources

Using values defined in FAO-56 standard for the Penman-Monteith equation gives standard values for non climatic variables crop height, albedo, and aerodynamic surface resistance. The rest of the variables come from climate models. In this case the climate data came from WorldClim v2.0 with historical data averaged over 1970-2000 to establish baseline values and build the model, and the future data coming from the HadGEM3-GC31-LL climate model under SSP245 for years 2041-2060, in which only a subset of climatic variables are provided, so a random forest regression model was used to make predictions.

| **variable** | historical climate | HadGEM3-GC31-LL |
|---|---|---|
| minimum temperature (°C) | X | X |
| maximum temperature (°C) | X | X |
| average temperature (°C) | X | |
| precipitation (mm) | X | X |
| solar radiation (kJ m-2 day-1) | X | |
| wind speed (m s-1) | X | |
| water vapor pressure (kPa) | X | |

### 3.0.2 Calculating $ET_0$

Calculating values of $ET_0$ was done using the methods in (Zomer et al., 2022) using a 12 cm grass reference crop, which are as follows.

$$ET_o = \frac{0.408\Delta(R_n - G) + \frac{900}{T_{avg}+273} * u_2 * (e_s - e_a)}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)}$$

$ET_o$ = Reference Evapotranspiration
$\Delta$ = Slope of vapor pressure curve (kPa $^{\circ}C^{-1}$)
$R_n$ = Net irradiance (MJ m$^{-2}$ day$^{-1}$)
$G$ = Ground heat flux (MJ m$^{-2}$ day$^{-1}$)
$\gamma$ = Psychrometric constant (kPa $^{\circ}C^{-1}$)
$e_s$ = Saturation vapor pressure (kPa)
$e_a$ = Actual vapor pressure (kPa)
$e_s - e_a$ = Saturation vapor pressure deficit (kPa)
$r_s$ = Bulk surface resistance (m s$^{-1}$)
$r_a$ = Aerodynamic resistance (m s$^{-1}$)

### 3.0.3 Reference $ET_0$ Under Future Climate Models

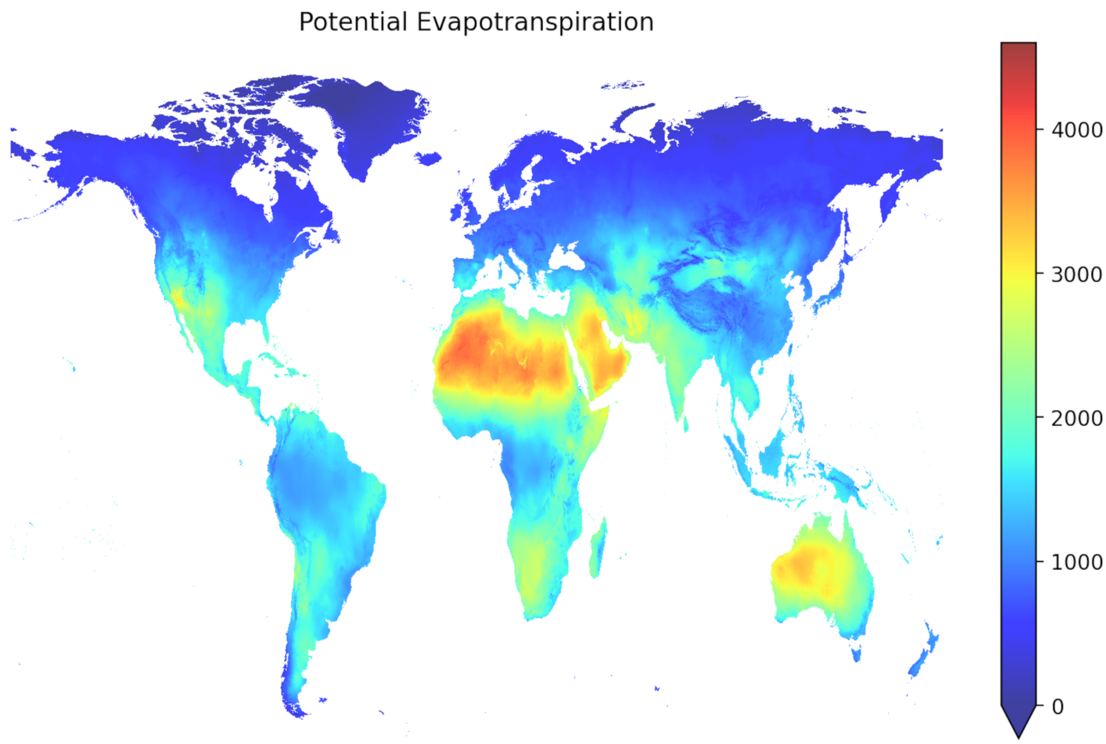
In order to attempt understanding how crop irrigation needs might change under future climate scenarios, and given only a subset of the required climatic variables, further estimations are needed. In order to reduce complexity, the data was first clipped to the CONUS using maps from the US Census. Where Random Forest Regression was used to build a model to predict values of $ET_0$ using values from the historical model that are available under the future climate model. This could then be applied and analysed.

### 3.0.4 Changes In Agricultural Areas

Data from USDA quick stats was used to acquire acres of harvested land in 2017. This was used in conjunction with Census state and county maps to look at changes in counties where at least 25% of the land was harvested. Allowing us to focus on changes in key agricultural regions.

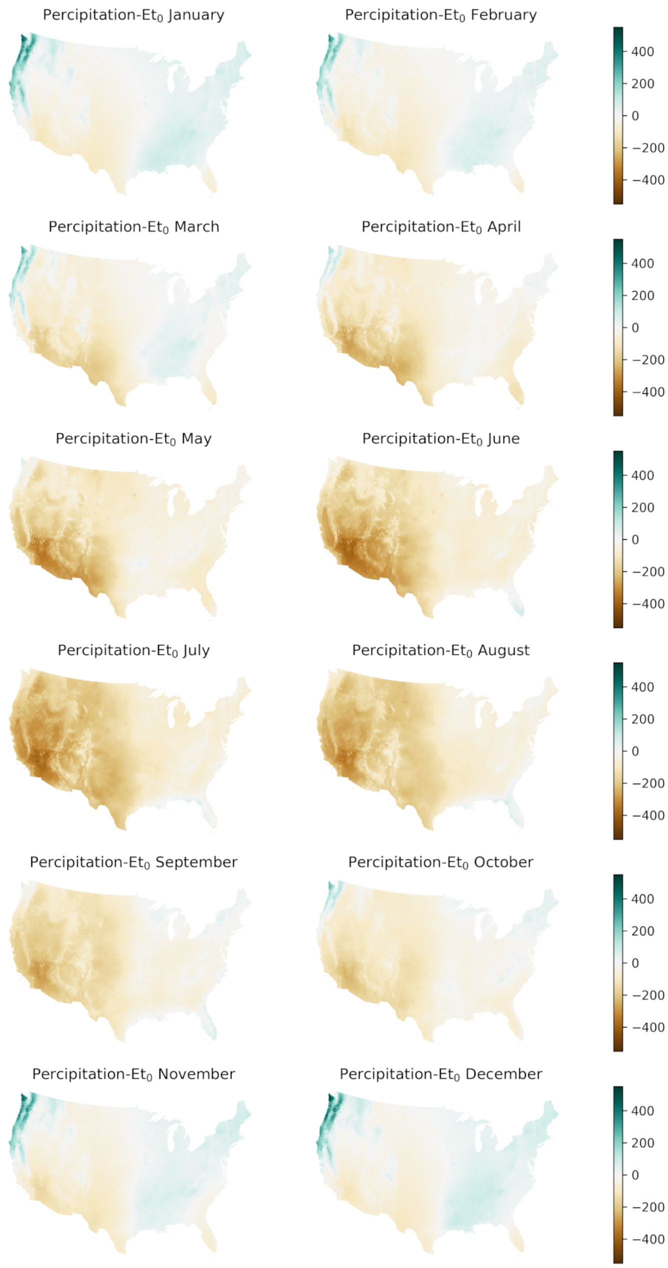
# 4 Results

Using the methods discussed above we can begin visualizing and understanding the current state of evapotranspiration cycle and how it is likely to change. changes in our reference grass surface across the world. The map bellow shows cumulative values of $ET_0$ over the average year in our historical model. Note Antarctica is removed and values below zero have been clipped, these are predominantly polar and high elevation regions where climatic models start to break down (McColl et all.,2020).



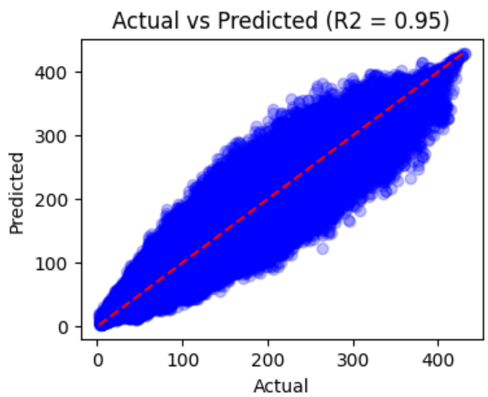
### 4.0.1 Focusing on the Continental United States

Restricting our domain to the continental United States will allow us to integrate agricultural data sources This first figure shows the net gain and loss across the year. Where the expected seasonality and climatic difference between the arid west and humid east can be clearly seen.



### 4.0.2 Model Performance

The random forest model was built on the baseline using values for minimum and maximum temperature, as well as precipitation to predict $ET_0$ values. As those are the values available in the future climate models. Training the model produced the following test statistics.

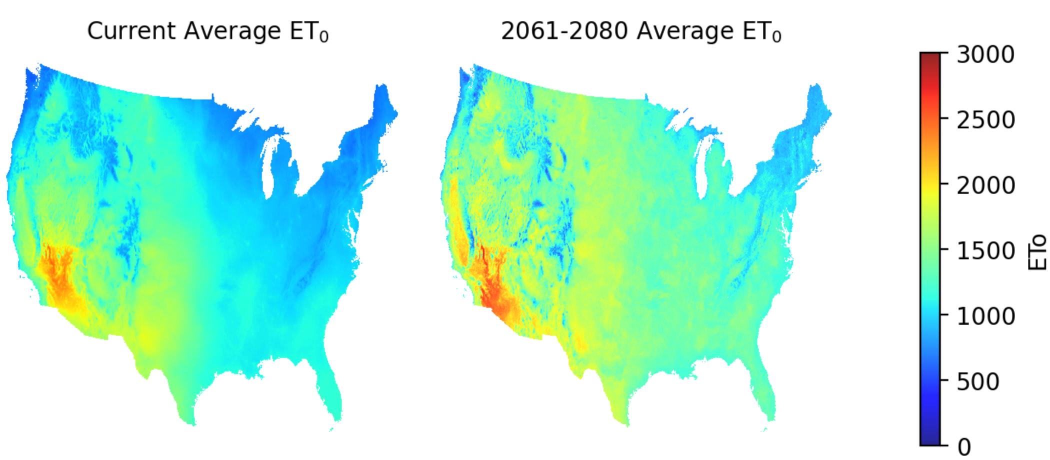



| Test | Value |
|---|---|
| minimun | 2.91 |
| maximum | 429.94 |
| $R^2$ | 0.95 |
| MAE | 9.95 |
| RMSE | 15.9 |

These results are promising, producing a surprisingly good fit and moderate error. The model should preform well enough on future climate models to give us a reasonable approximation of growing conditions under future climate scenarios.

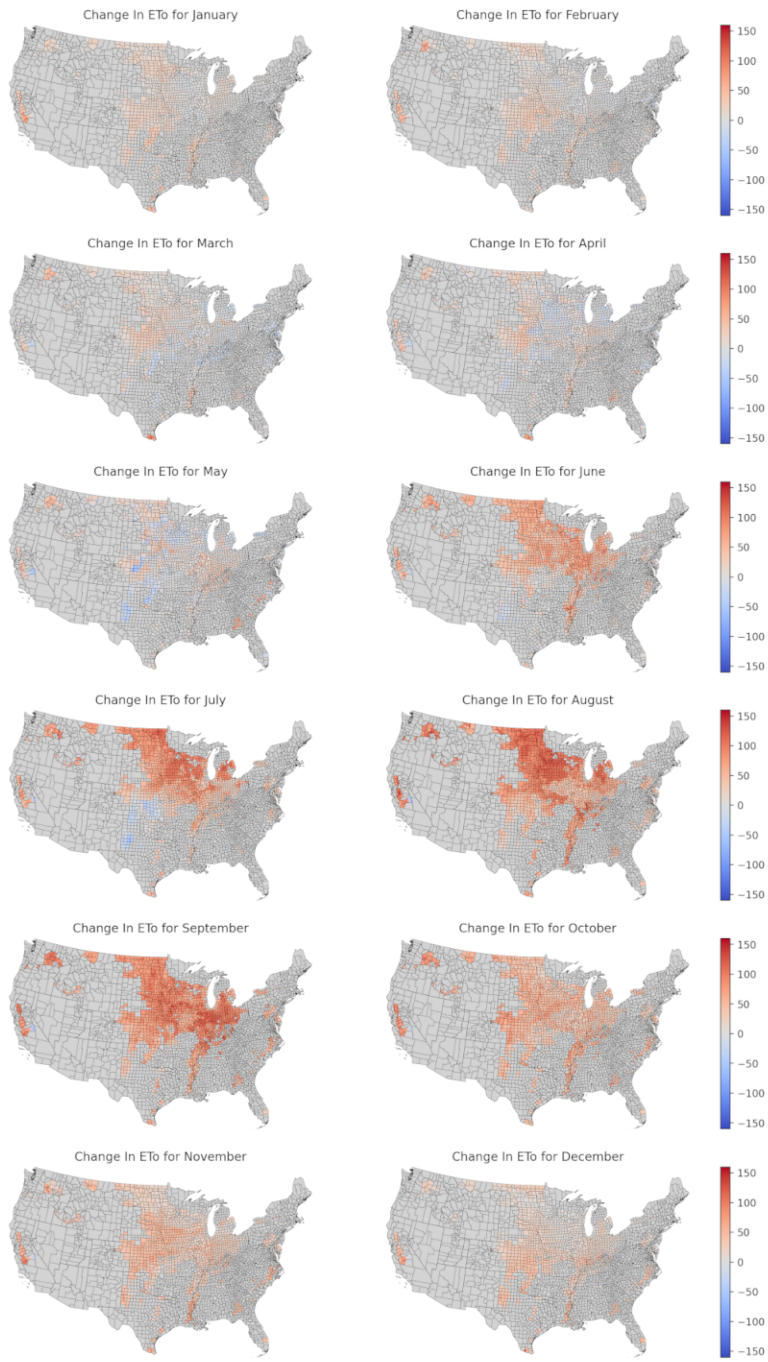
### 4.0.3 Future scenarios

This plot shows $ET_0$ under our current climate and for the years 2061-2080 using values from the HadGEM3-GC31-LL climate model fed into the $ET_0$ prediction model. The results show increases in values for our reference grass surface across the CONUS.

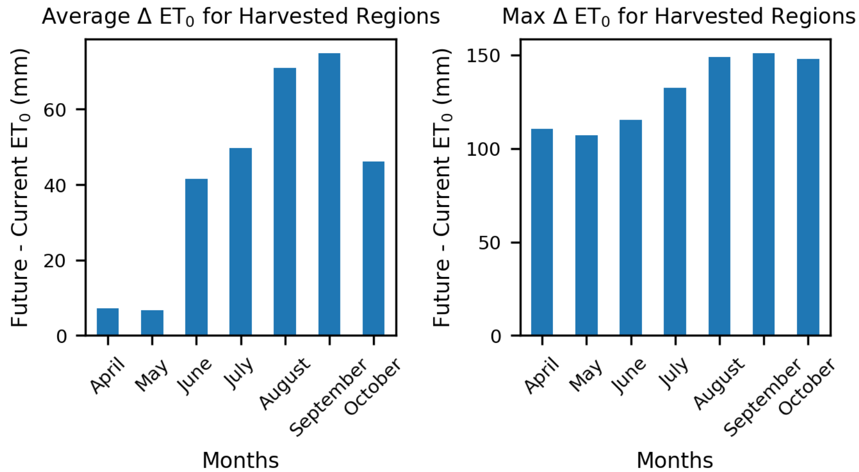


### 4.0.4 Effect on growing regions

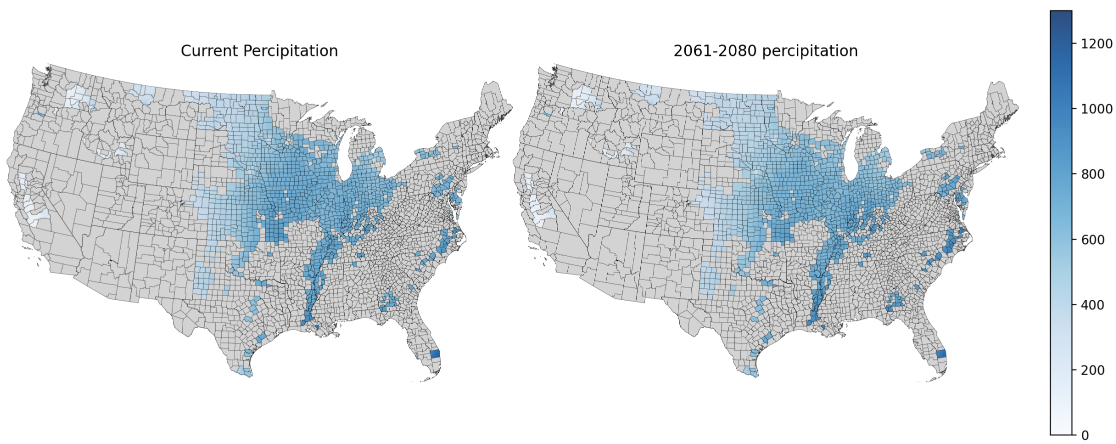
Next in looking at changes for each month (current - future), and restricting to counties where at least 25% of the land was harvested. Changes can be seen throughout core growing months with the most drastic changes in July to September where monthly losses due to evapotranspiration can be expected to increase by over 150 mm (5.9 in) a month.



This figure looks more specifically at the growing regions, over the key months and shows the expected average and maximum losses due to increases in evapotranspiration.




It is also worth looking at changes in precipitation as well, the figure bellow shows that changes in precipitation will not compensate for change in evapotranspiration. With a neglagable predicted loss in Precipitation over growing regions of -0.006 mm/acre.



# 5 Conclusion

This study attempted to use readily available data and a standard evapotranspiration model, in order to understand changes in water demands of crops under future climate scenarios. The use of Random Forest regression model used showed promise in predicting $ET_0$ values using the restricted set of variables available in future climate models. Results from this model highlight the need for addressing the water demands of crops as part of facing climate change. Further work is merited refining the model and broadening the analysis.

# 6 Refrences


Allen et al. Crop evapotranspiration —guidelines for computing crop water requirements. FAO Irrigation and drainage paper 56. Food and Agriculture Organization, Rome (1998).

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