How do SPEI, PET, AET, and Soil Moisture relate to plant growth?

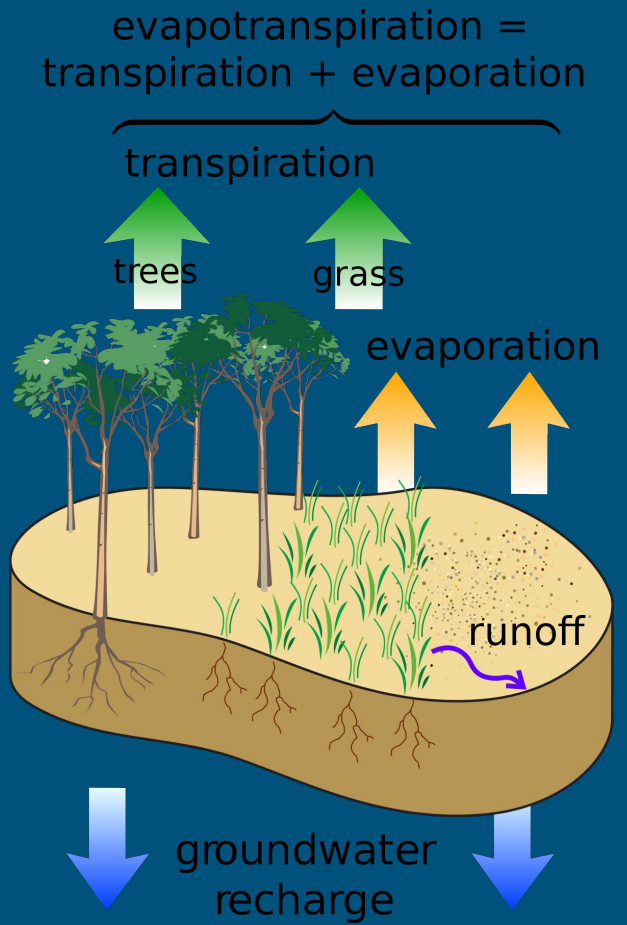
Andrew Chow, Wesley Noble, Amy Kou

Hypothesis

- We believe that there will be correlations between SPEI, PET, AET, Soil Moisture, MSI and Plant Growth
  - Positive relationship?
  - Among these, which is the best indicator of plant growth
  - Can a Moisture Stress Index (MSI) values averaged from Landsat imagery be used to predict plant growth? Soil moisture content?

Importance

- Measuring evapotranspiration is hard to do
  - This often requires knowledge of the weight change in plants during the study period as well as the amount of precipitation and change in soil water storage
- Therefore, potential evapotranspiration calculations can be used to get a sense of how a plant or vegetated area is transpiring without in-situ measurements hard to attain without disrupting the vegetation
- Evapotranspiration can be a great indication of not only water induced stress on plants but also the availability of and therefore amount of water storage in the soil
- When measurements are hard to attain, it is therefore useful to look into alternative measures to obtain accurate and informative relations and results related to evapotranspiration, field measurements, and climatological records



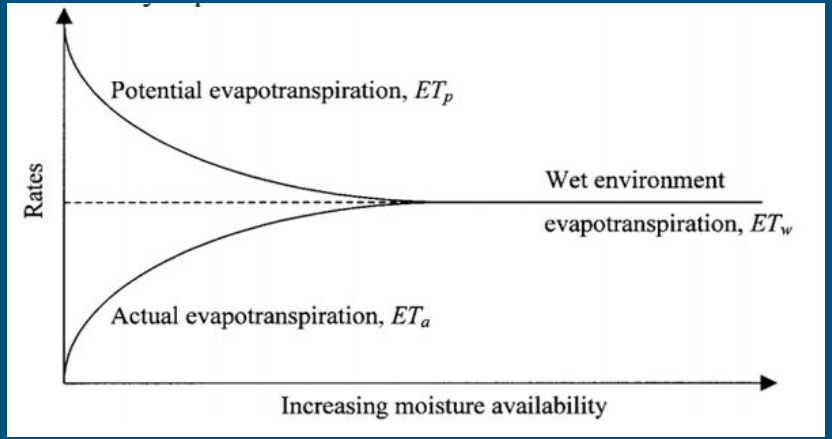
Background

- **What is the difference between potential evapotranspiration and actual evapotranspiration?**
- PE is the demand or maximum amount of water that would be evapotranspired if enough water were available (from precipitation and soil moisture). AE is how much water actually is evapotranspired and is limited by the amount of water that is available.
- Most frequently used elements for computing evapotranspiration includes mean air temperature, and some form of radiation and day length (Arkley & Ulrich, 1962)
- Example: PET = MF X T;
- MF = monthly evapotranspiration (mm), T = mean temperature (F°)
- Plant growth depends on 3 factors --- soil, climate & management
- When comparing different climates for plant growth, keep in mind that AET depends on the available water storage capacities (AWC) of the soils (Hargreaves, 1974).

Background

- Two different ways of calculating evapotranspiration
  - PET → FAO Penman Monteith uses standard climatological records of solar radiation (sunshine), air temperature, humidity and wind speed to represent the physical and physiological factors governing the computation of evapotranspiration
  - AET → Bowen Ratio measures vertical gradients in heat and vapor to quantify energy fluxes from one state to another by sensible heat and latent heating respectively. This can then be used to estimate the amount of moisture a surface retains
  - Most often, AET estimated from the Bowen Ratio is lower than PET during times of low soil moisture

- Standardized precipitation evapotranspiration index (SPEI)
  - An extension of the widely used Standardized Precipitation Index (SPI)
  - Designed to take into account both precipitation and potential evapotranspiration (PET) in determining drought
  - Captures the main impact of increased intensities and durations of temperatures on water demand



Background

- Landsat 8 Operational Land Imager (OLI)
  - Landsat 8 OLI & Thermal Infrared Sensor (TIRS) consists of nine spectral bands with a spatial resolution of 30 meters for bands 1 to 7 and 9, 15 meters for panchromatic band 8 and 100 meters for thermal bands 10 and 11
  - Replaced Landsat 7 in 2013
- MSI
  - Moisture Stress Index is used for canopy stress analysis, productivity prediction and biophysical modeling
  - MSI is inverted relative to other water vegetation indices, therefore, high MSI values indicate greater plant water stress and in prediction, less soil moisture content (Welikhe et al., 2017)

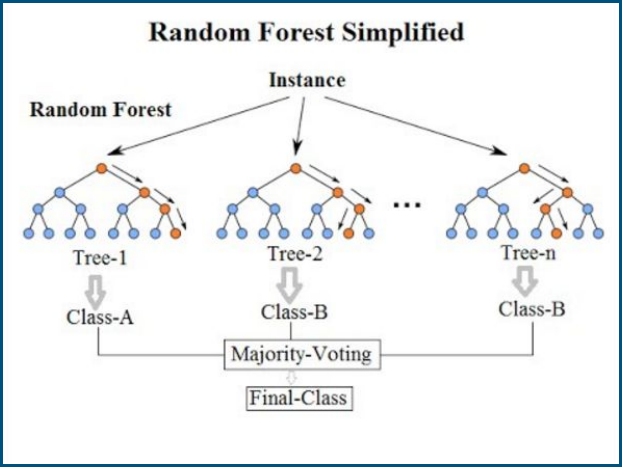
Index	Acronym	Formula	Reference
Middle Infrared Wavelengths	MID	Band 6 + Band 7	[28]
Moisture Stress Index	MSI	$\frac{\text{Band 6}}{\text{Band 5}}$	[29]
Normalized Difference Moisture Index	NDMI	$\frac{\text{Band 5} - \text{Band 6}}{\text{Band 5} + \text{Band 6}}$	[30]
Normalized Difference Vegetation Index	NDVI	$\frac{\text{Band 5} - \text{Band 4}}{\text{Band 5} + \text{Band 4}}$	[31]
Normalized Burn Ratio	NBR	$\frac{\text{Band 5} - \text{Band 7}}{\text{Band 5} + \text{Band 7}}$	[32]

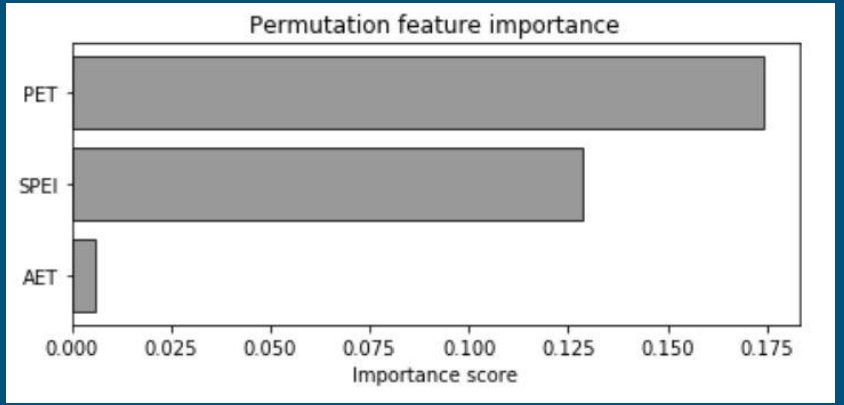
Experiment 1 Design

- Location: COPR
- Years: 2017-2019
  - Dependent on field data days
- Datasets:
  - COPR Soil Moisture (SMwfv_1) *only 2018-2019*
  - Landsat ClimateEngine SPEI (Standardized Precipitation Evapotranspiration Index)
  - Field Data (Height&Photos)
    - Avg NPV, SHADE, GV
  - Calculations
    - PET & AET
- Multivariate linear regression
- PCA (principal component analysis)
  - SPEI, PET, AET, and Soil Moisture relation to GV from field measurements
- RandomForest Permutation Feature Importance
- GOAL: Uncover and analyse the relationships between SPEI, PET, AET, Soil Moisture, and Plant Growth

Random Forest Feature Importance

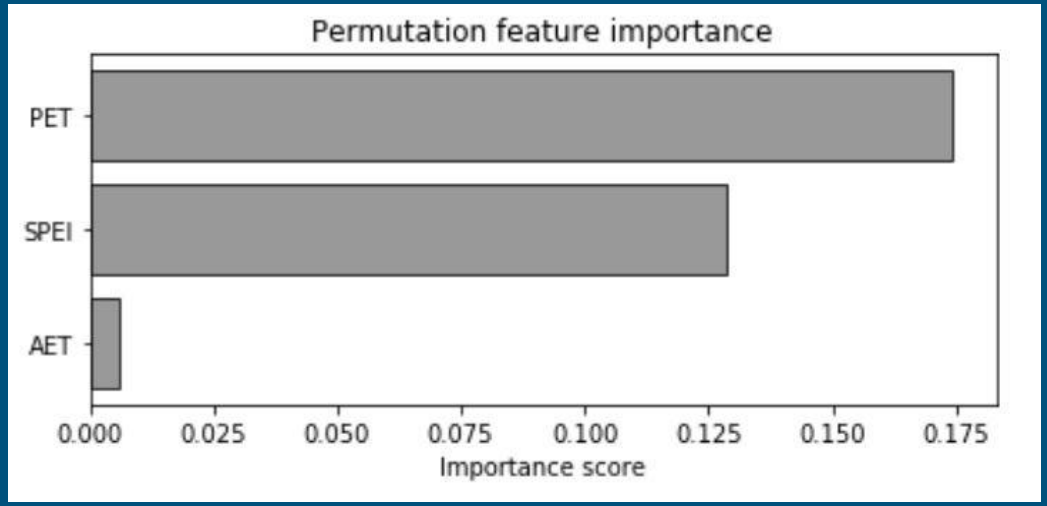
- Random Forest- aggregation of decision trees to improve accuracy, however loss of interpretability
- By averaging the total reduction in node impurity provided by each variable in each tree across all trees, we get measure of variable/feature importance





Random Forest Feature Importance

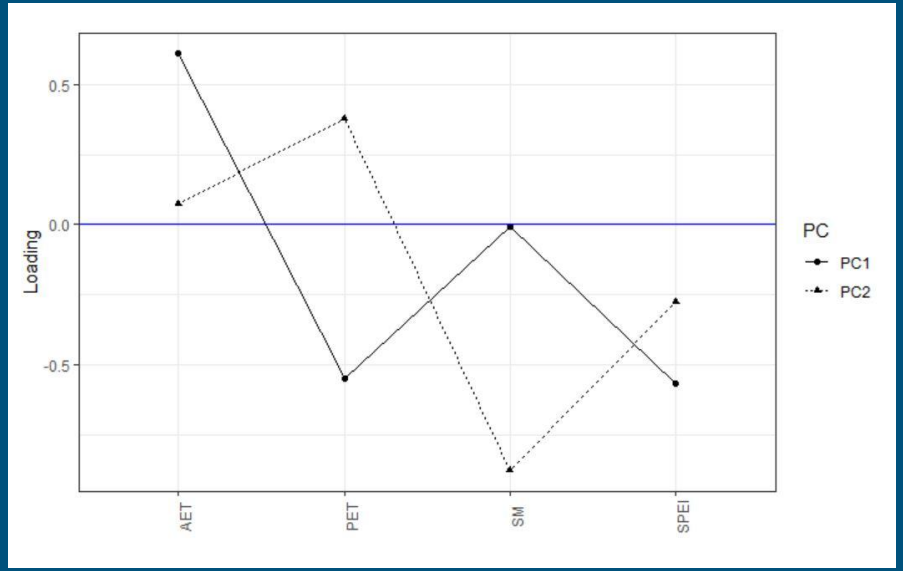
- Created a forest of 1000 decision trees
- Soil moisture was left out because sensor was not working for 2017
  - Would’ve had too small sample size

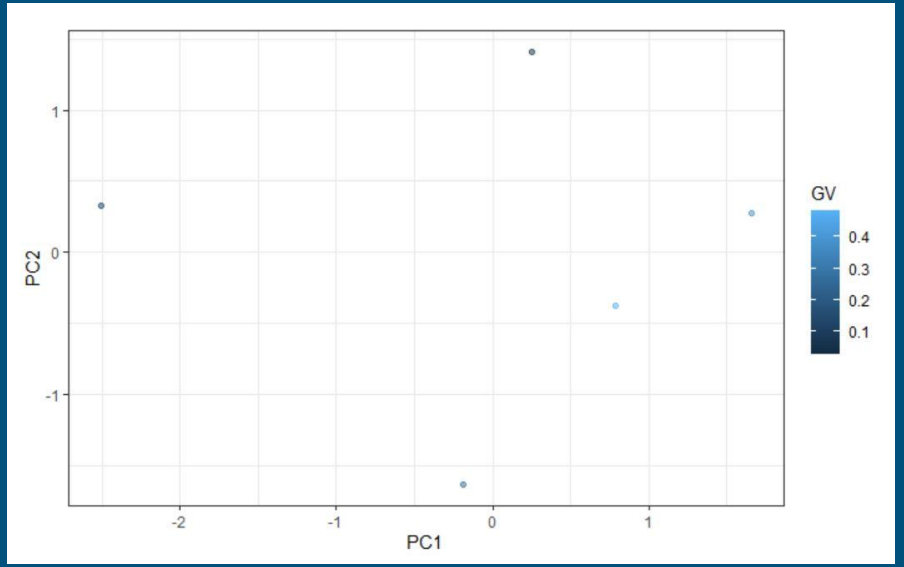


Principal Component Analysis (PCA)

- What is it?
  - Unsupervised Learning Technique
  - A dimension reduction technique that finds a lower dimension linear approximation of explanatory variables
    - Produces principal components!

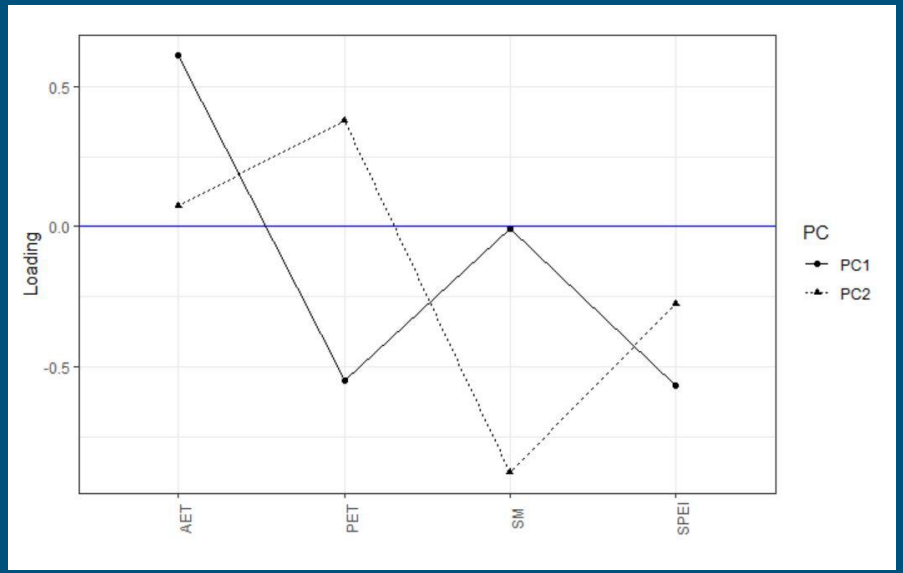
Principal Component Analysis

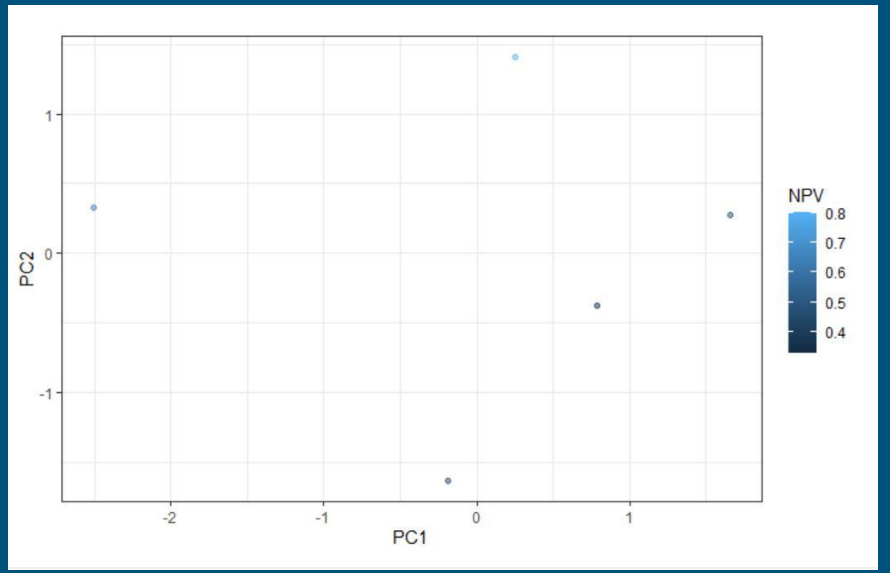




- Including Soil Moisture, seems like a higher PC1 leads to higher GV (small sample)
  - AET seems most prominent in high GV

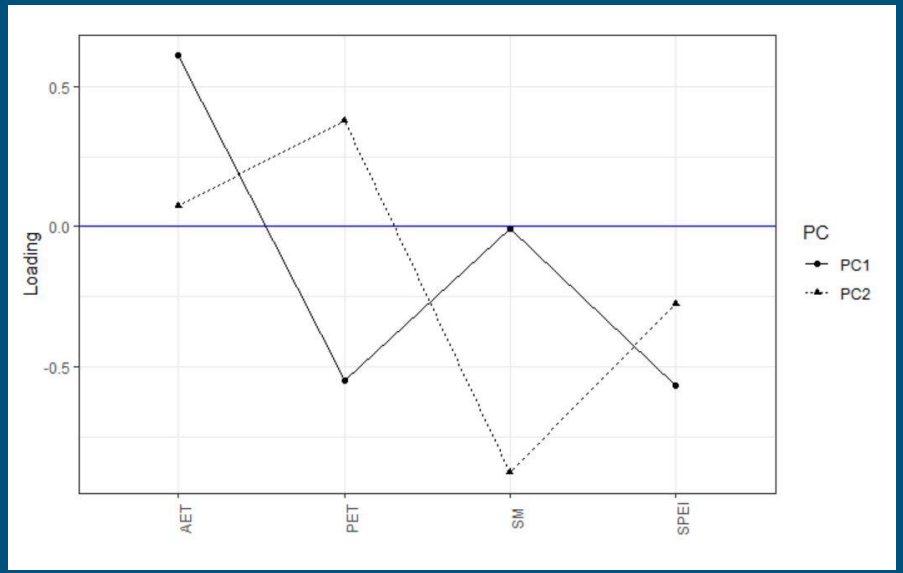
PCA

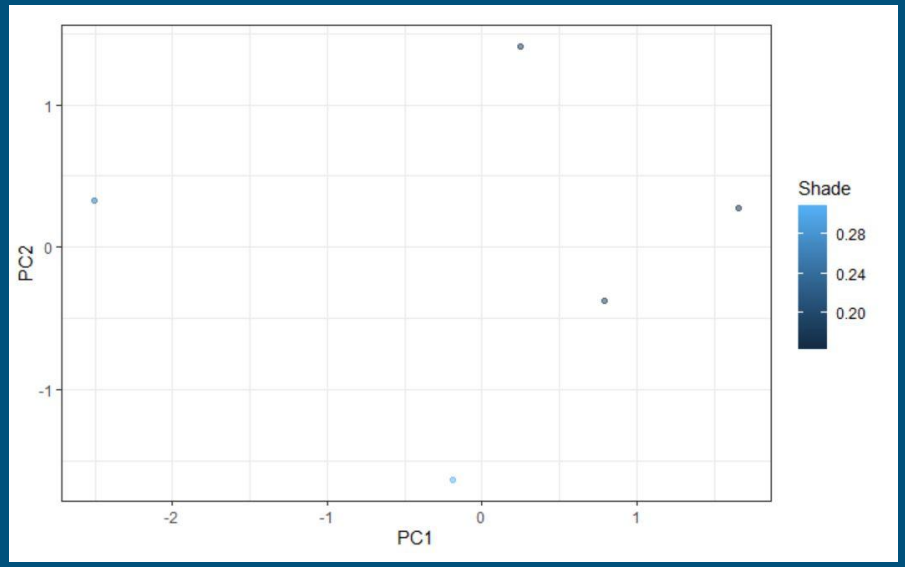




- For NPV, PC2 seems to be more relevant
  - PET seems prominent when relating to NPV

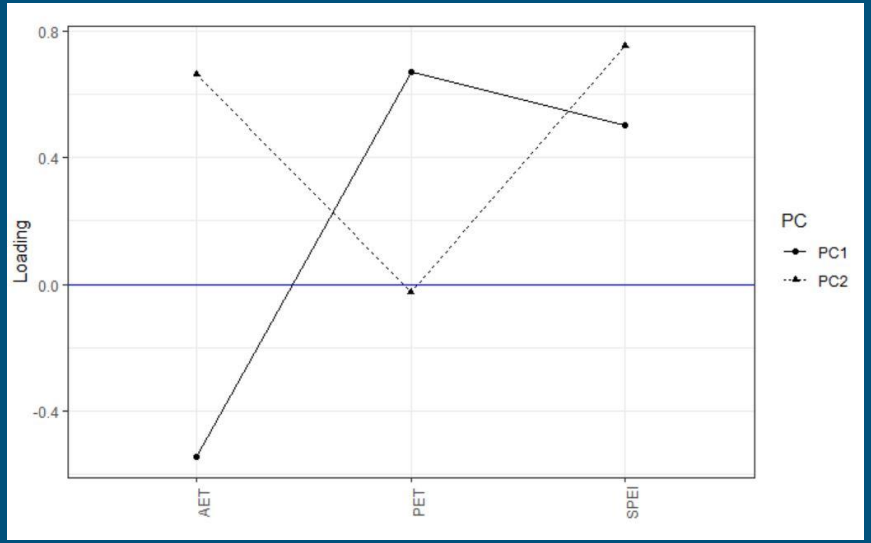
PCA

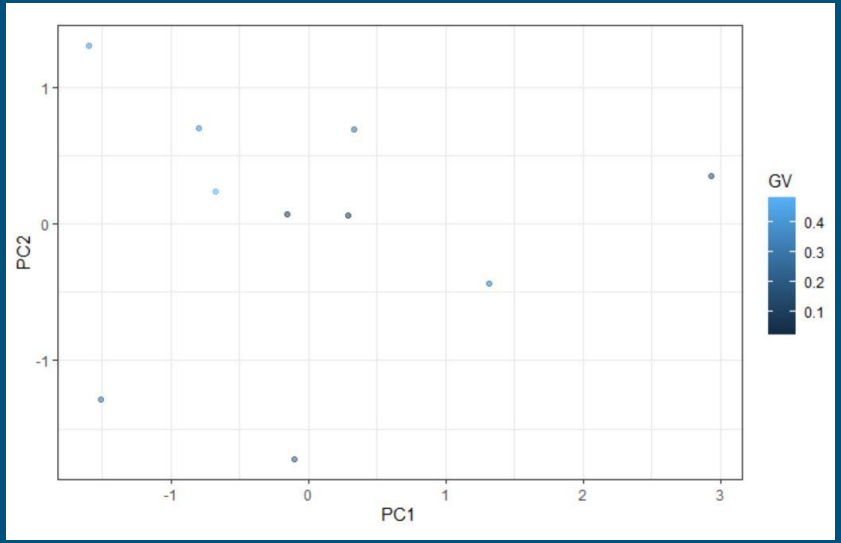




- High Shade levels go with lower PC1
  - Soil Moisture has biggest effect
    - (does the matlab pick up wet dark soil as shade?)

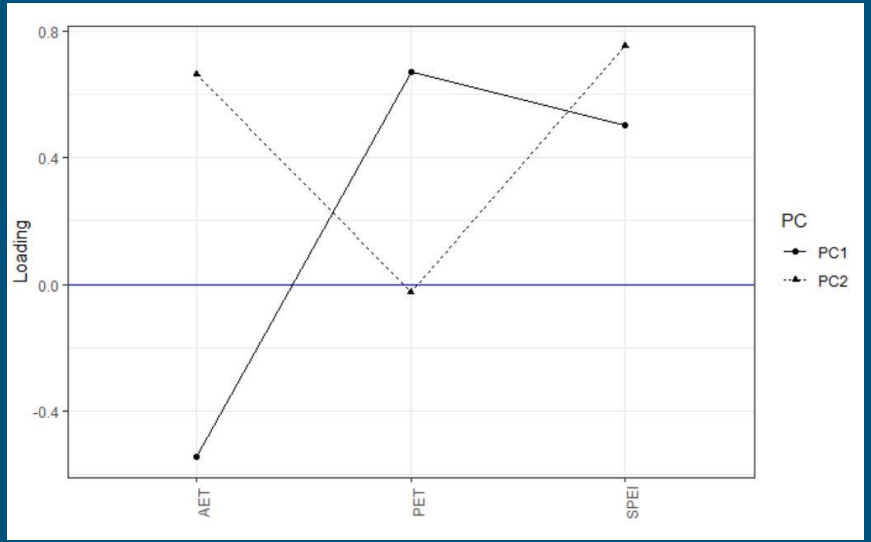
PCA Without Soil Moisture

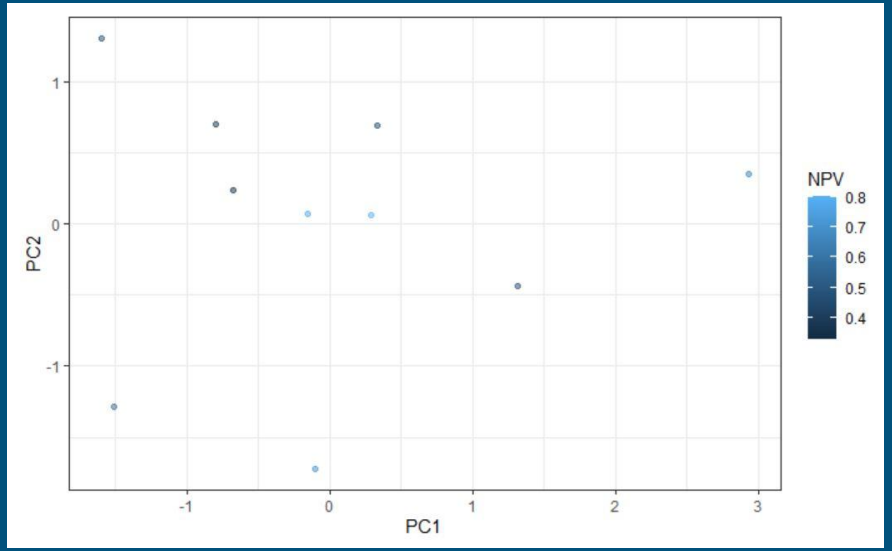




- Higher GV relates to lower PC1 and higher PC2
  - PET!

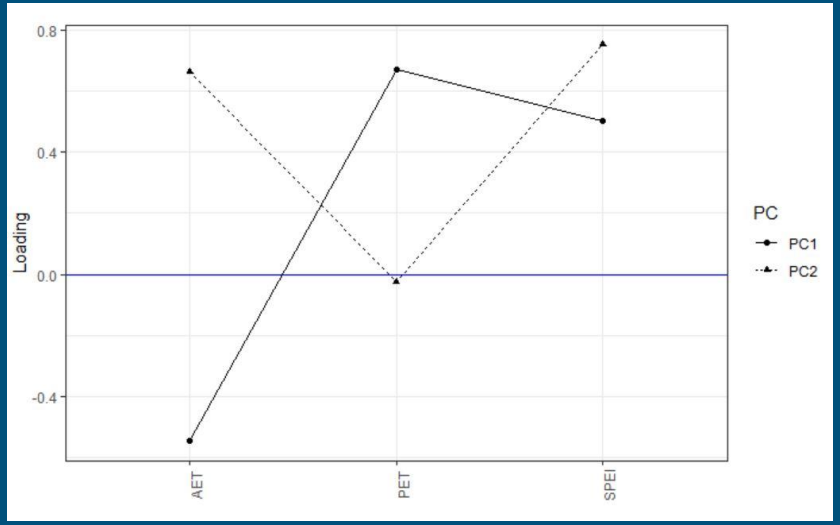
PCA Without Soil Moisture

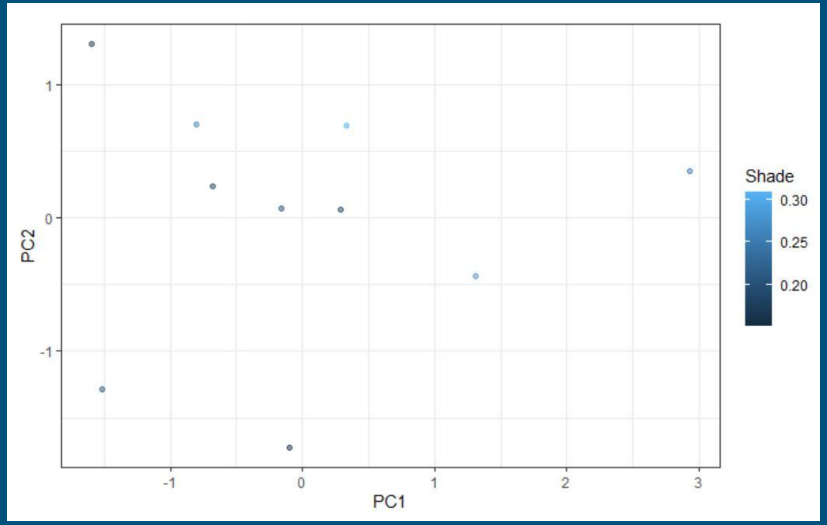




- Not much clustering and not clear
  - Maybe around PC2=0 thus PET is important again but ?

PCA without Soil Moisture





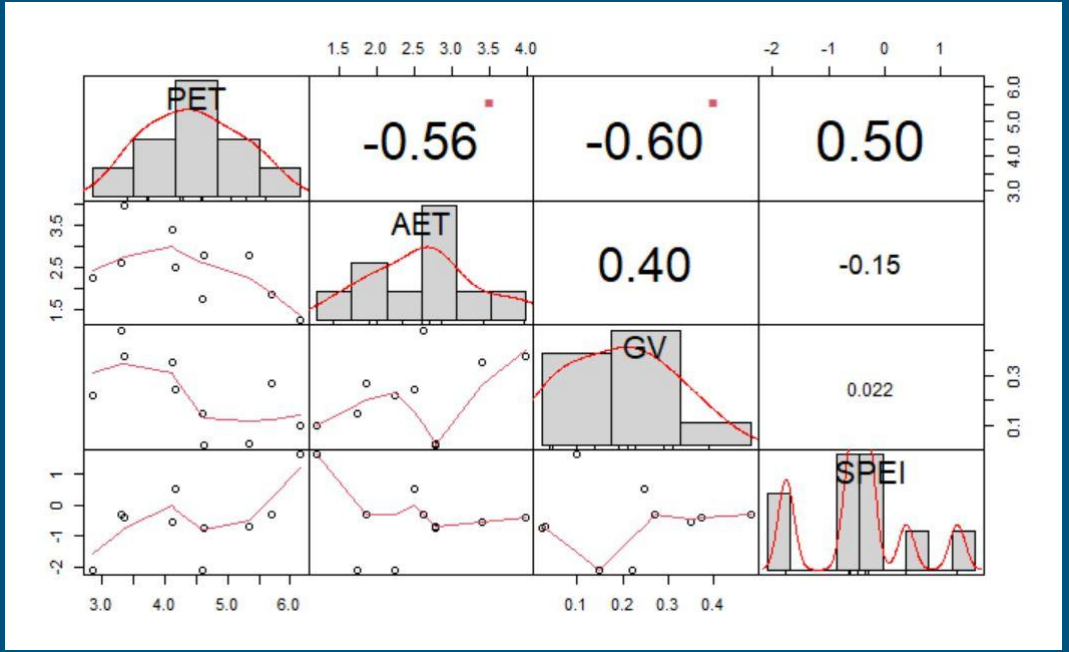
- Again not clear

Multivariate Linear Regression

- Without soil moisture
- X's : PET, AET, SPEI
- Y: GV

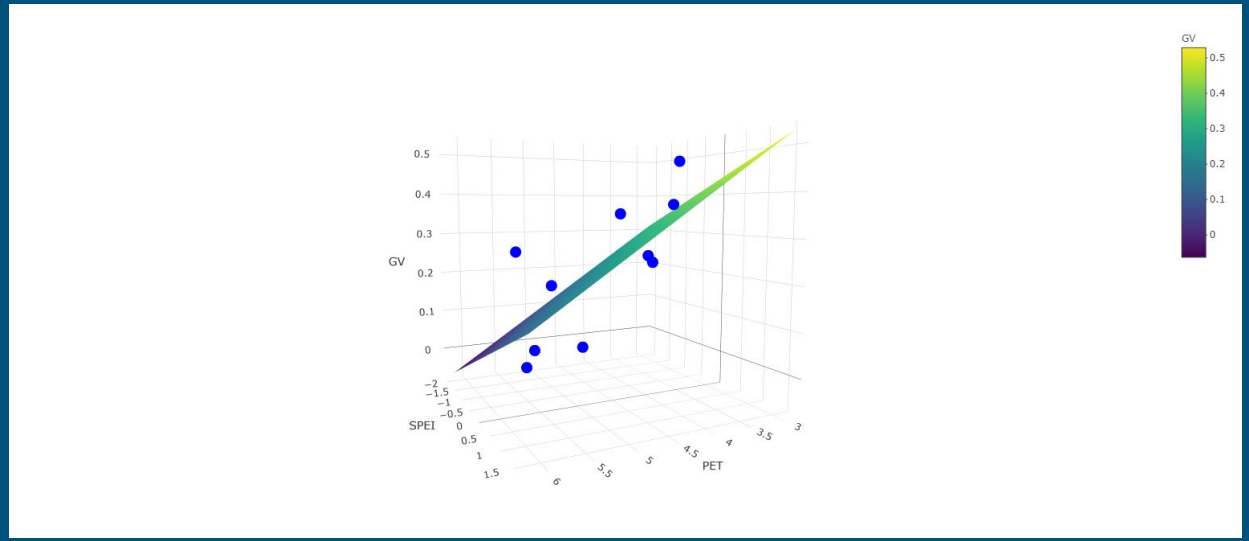
- Red dots- significance test

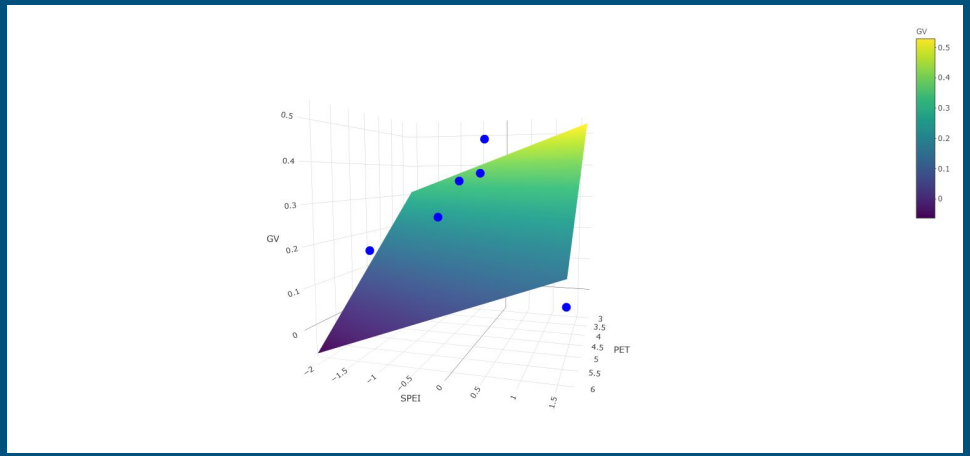
  Alpha = 0.05



Multivariate Linear Regression

- Y = 0.75 - 0.11277(X1) + 0.05932(X2) + e
- Where
  - Y = predicted GV
  - X1 = PET
  - X2 = SPEI
- This was the model with the lowest AIC of -39.49 and thus, we will not use AET in regression modeling
- Negative relationship between GV and PET
- R^2 = .49
  - Makes sense for small sample size
- LINK TO 3d INTERACTIVE REGRESSION PLOT ←---
  - Still pictures on next slide


GV
SPEI
PET


GV
SPEI
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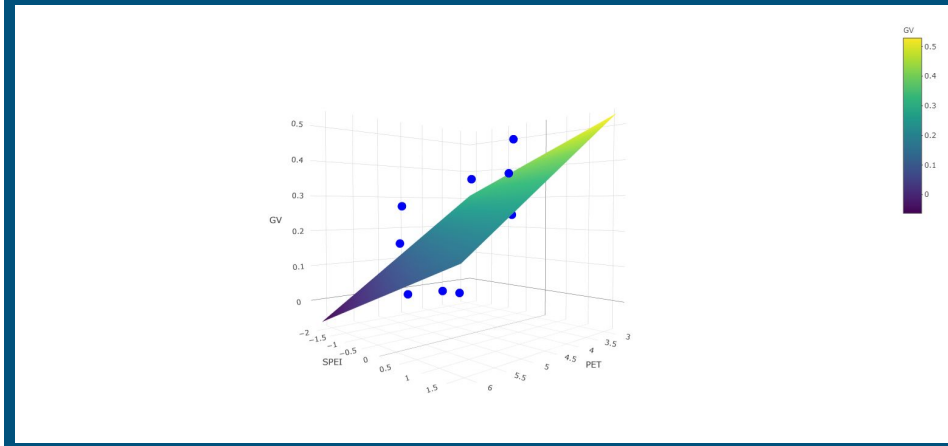
GV
SPEI
PET

Experiment 1 Results

- Between all three statistical techniques of RandomForest Feature Importance, PCA, Multivariate Linear Regression
  - PET and SPEI were chosen as most correlated and important variables associated with plant growth measured by GV
  - AET was almost considered noise in the regression model because of its limited calculated correlation for the COPR station.

Experiment 1 Discussion

- If more time we would collect more data
  - Sample size was small if included soil moisture
- Would we get the same results if we chose a different location?
  - Being by the coast could affect PET and SPEI at COPR
  - Different Vegetation
  - Different Soil
- PCA with soil moisture data was too small a sample size
  - n=5

Experiment 2

- 2019 Landsat imagery attained
  - March 18th & May 5th → closest non-cloudy landsat scenes available to field expeditions
    - Limited in dates because of file size and preprocessing computation time
  - COPR and AIRS shapefiles attained by referencing google maps and manually drawing station polygons in QGIS
- R Studio
  - Preprocessing, cropping and masking to shapefiles, & MSI calculations
    - FIles sizes proved to large to compute on laptop so MSI average values could not be attained even after masking to shapefiles
    - Research attempt was aimed towards qualifying a correlation between MSI values, field measured green values and station recorded soil moisture values
    - When researching many papers pointed at a connection between MSI and soil moisture values but addition surface temperature data was required for analysis as well

Takeaways and Future research

- Needed more data
  - With more data can continue to apply advanced techniques
    - Neural Network & Deep Learning?
- PET was identified as the most important feature was comparing to an predicting of plant growth measured by GV
- Would be useful to incorporate more study sites to compare varying climate anomalies such as persistence of fog, RH, average temperature, average wind direction and wind intensity.
- As for using landsat data, computing space and time is much larger than expected
  - Interesting because landsat scenes were cropped and masked to COPR and AIRS polygon shapefiles early in preprocessing steps.

Citations and Acknowledgments

- Arkley, R., & Ulrich, R. (1962). The use of calculated actual and potential evapotranspiration for estimating potential plant growth. Hilgardia. *Journal of Agricultural Science* 32(10): 443-469.
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