Improving Use of Drought Indices by Using Soil Moisture Modeling

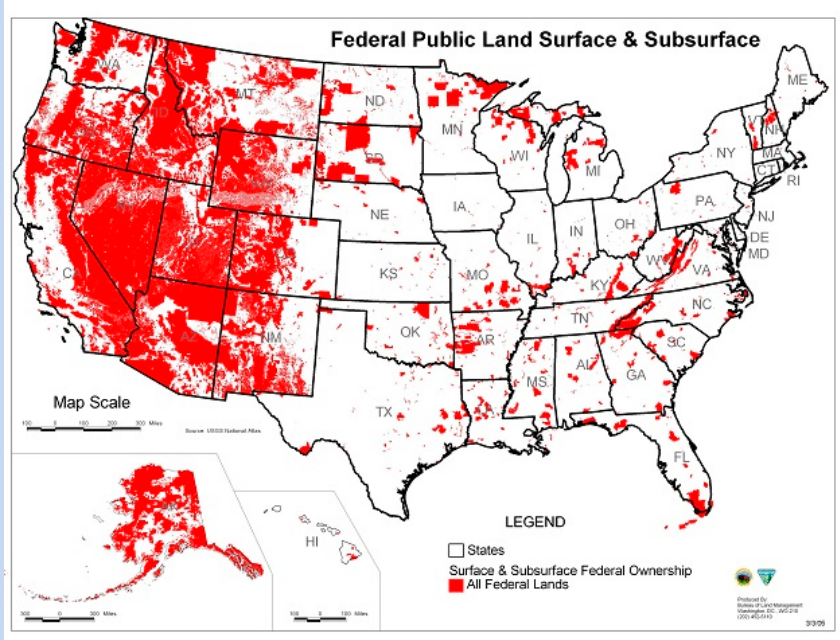
Trevor McKellar, Mike Crimmins

Outline

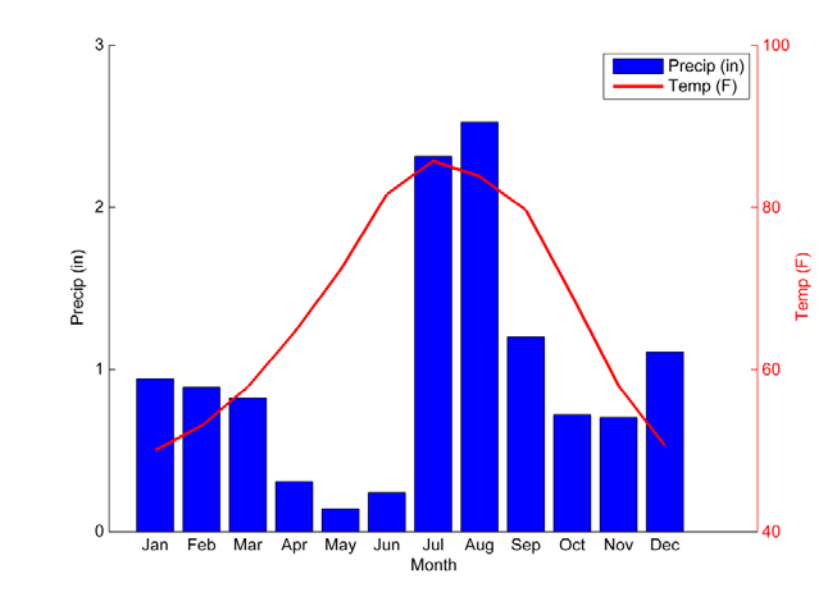
- Context
- Drought Index Background
  - Calculation and Time Windows
- Soil Moisture Modeling
  - Relationship between soil moisture memory and index time windows
- Communicating Information via Web Application

Five C's in Arizona: Copper, *Cattle*, Citrus, Cotton, and *Climate*

- 73% of AZ land area is grazing land
- Grazing systems vulnerable to precipitation variability – rainfed agriculture
- AZ has seasonal-transitional climate
  - Timing, frequency, magnitude
- Monitoring drought critical for planning and management decision making



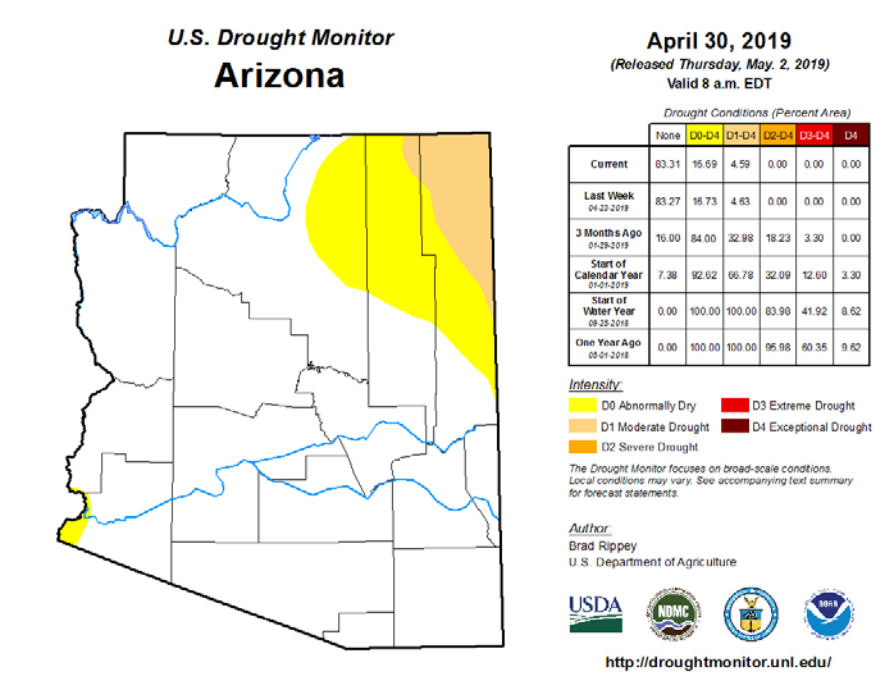
Bureau of Land Managment



Cochise County Avg Precip/Temp

Drought Monitoring Strategies

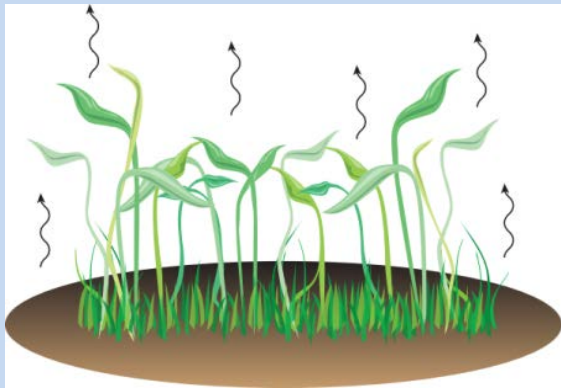
- Ideally, Use Soil Moisture
  - Good indicator of potential drought stress on vegetation, ecosystem health
  - Data limited, problematic, expensive
- Vegetation Monitoring
- Track Climate Variables (Drought Indices)
- Modeling



	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	83.31	16.69	4.59	0.00	0.00	0.00
Last Week 04-23-2019	83.27	16.73	4.63	0.00	0.00	0.00
3 Months Ago 01-29-2019	16.00	84.00	32.98	18.23	3.30	0.00
Start of Calendar Year 01-01-2019	7.38	92.62	66.78	32.09	12.60	3.30
Start of Water Year 09-25-2018	0.00	100.00	100.00	83.98	41.92	8.62
One Year Ago 05-01-2018	0.00	100.00	100.00	95.98	60.35	9.62

What Are Drought Indices?

- *Drought Indices* – Statistical representations of **indicators of drought severity**
  - **Precipitation, Temperature, Transpiration**
- Proxy for overall ecosystem health
- Many different types of indices
  - Meteorological, Modeling, Statistical, etc.



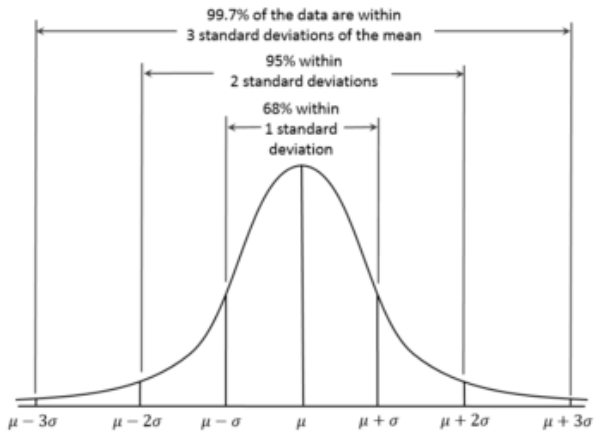
What Are **Standardized** Drought Indices?

- Statistically transform data to standard normal distribution
  - Ranks data by standard deviations around mean
- Gives idea of event frequency
- Allows for comparisons between locations

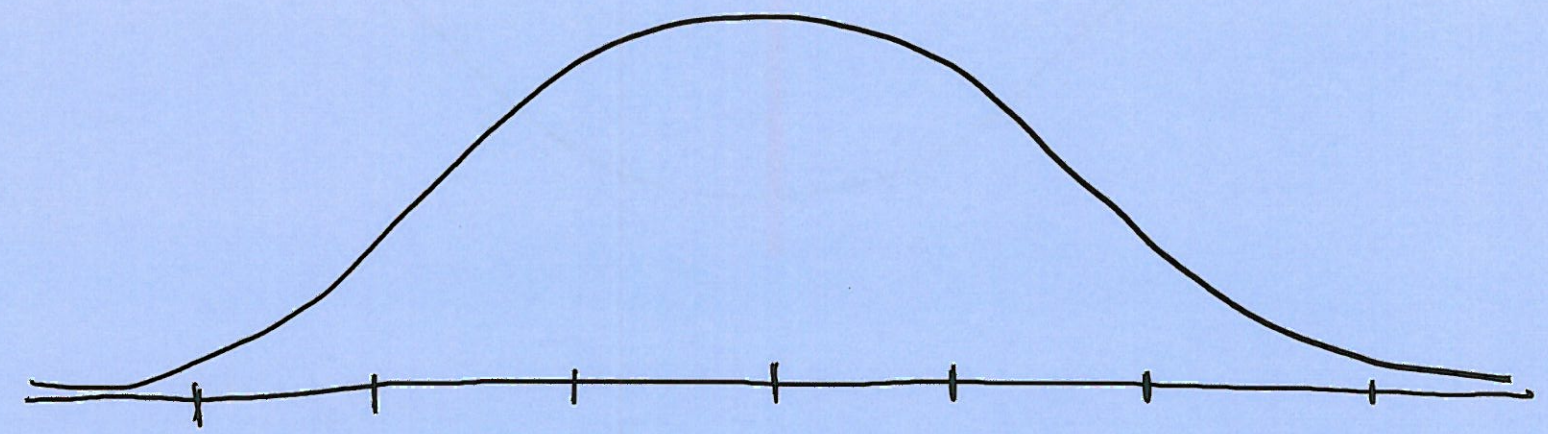
Yearly Total Precip

year	total precip
1990	15.86
1991	10.85
1992	16
1993	15.39
1994	13.22
1995	9.64
1996	9.64
1997	10.93
1998	13.54
1999	9.65
2000	13.04
2001	9.56
2002	7.62
2003	9.78
2004	9.05
2005	10.77
2006	11.99
2007	11.04
2008	10.34
2009	6.71
2010	12.3
2011	10.35
2012	8.86
2013	7.58
2014	10.98

Where does this year rank?



Standard Distribution ("Bell Curve")



The higher number random samples in a dataset, the data will approach shape of a "bell curve"

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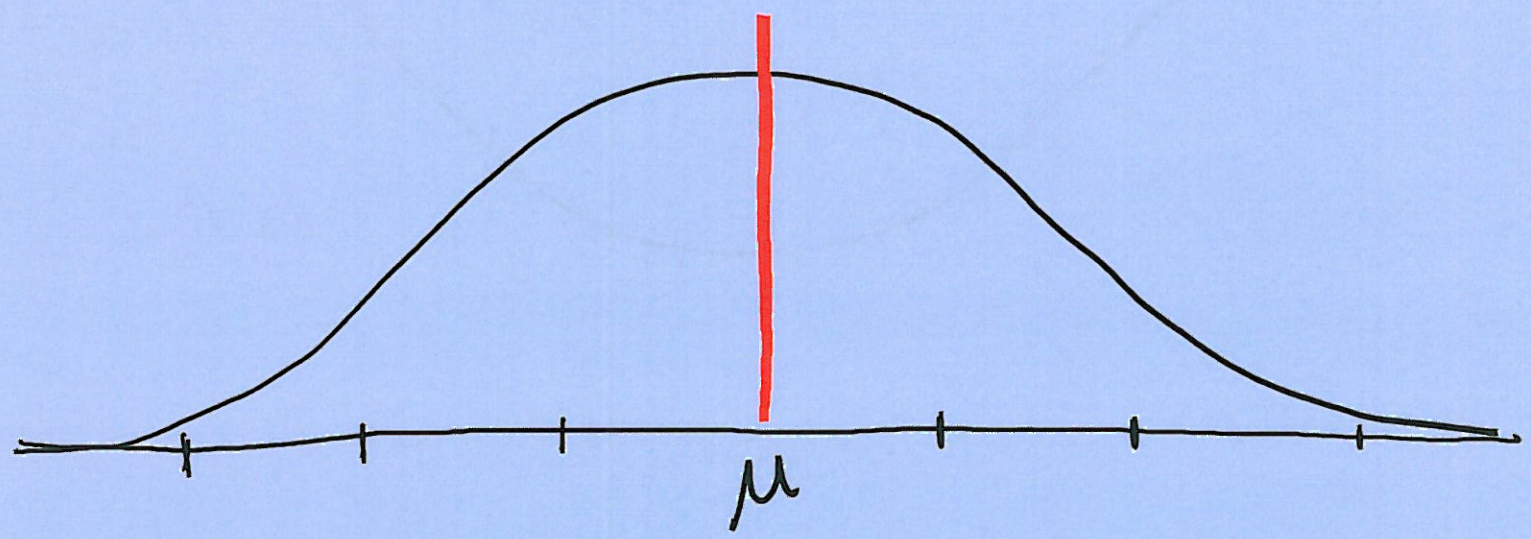

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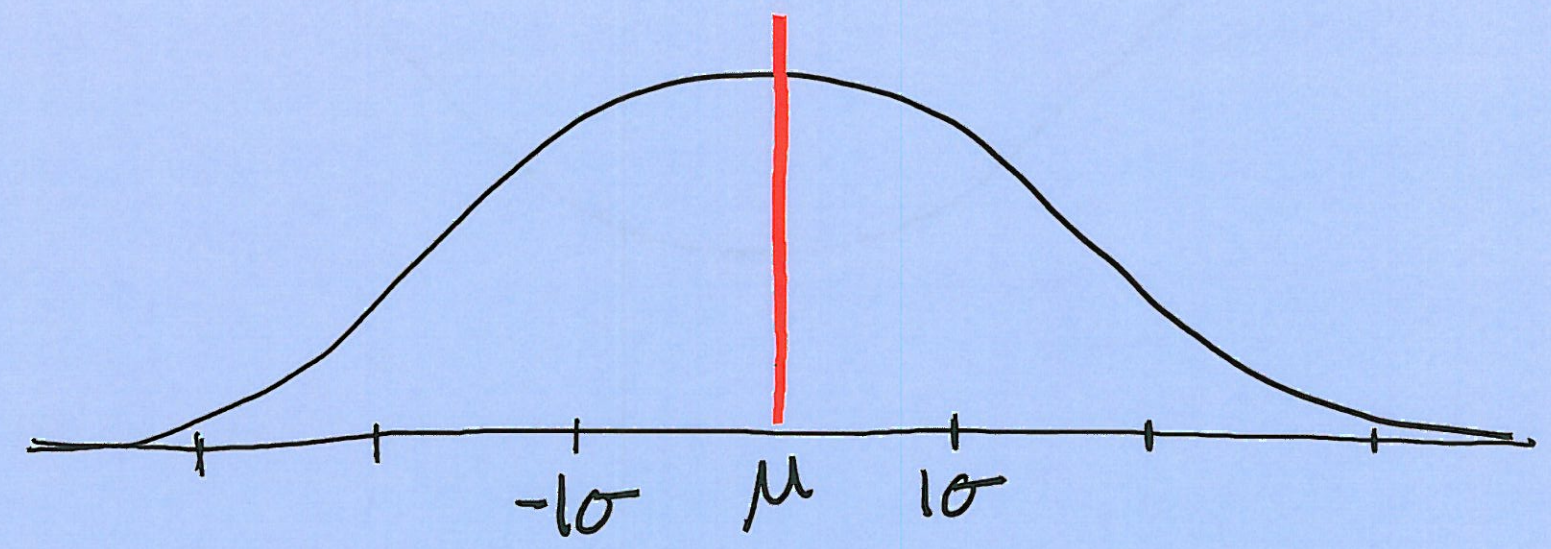

Standard Deviation – number used to tell how measurements for a dataset are spread out from the mean

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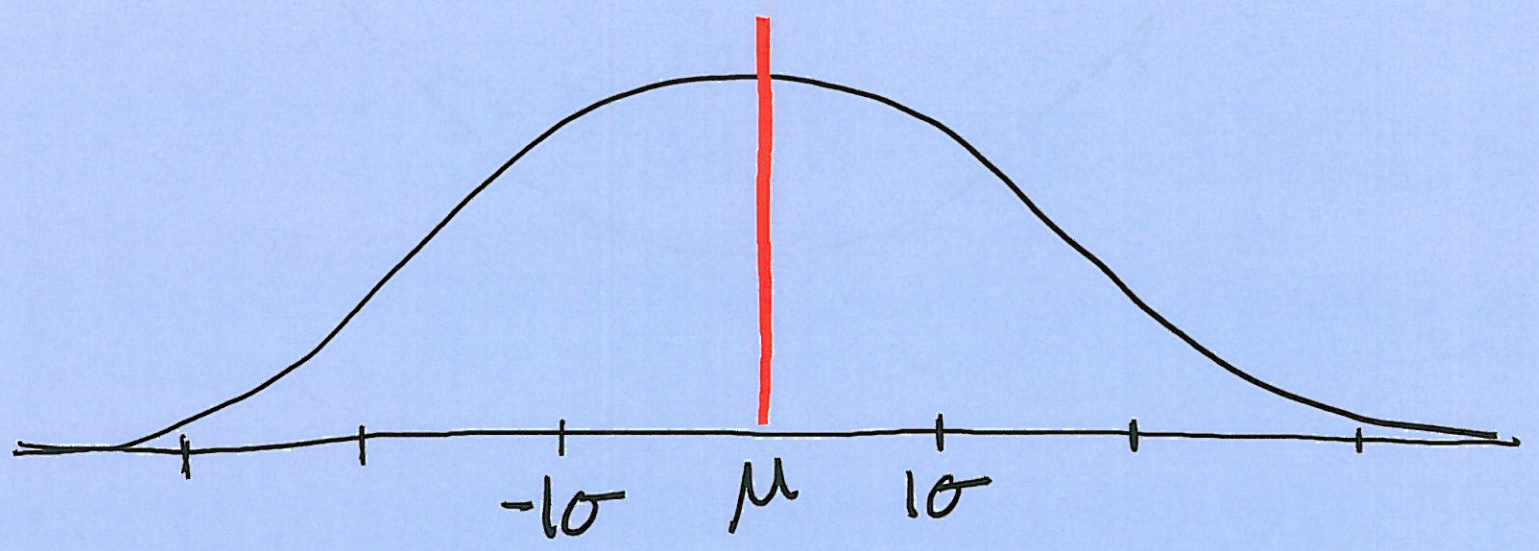

Standard Deviation – number used to tell how measurements for a dataset are spread out from the mean

68-95-99.7 Rule – shorthand rule used to remember percentage of values that lie within a band of 1, 2 and 3 standard deviations of the mean

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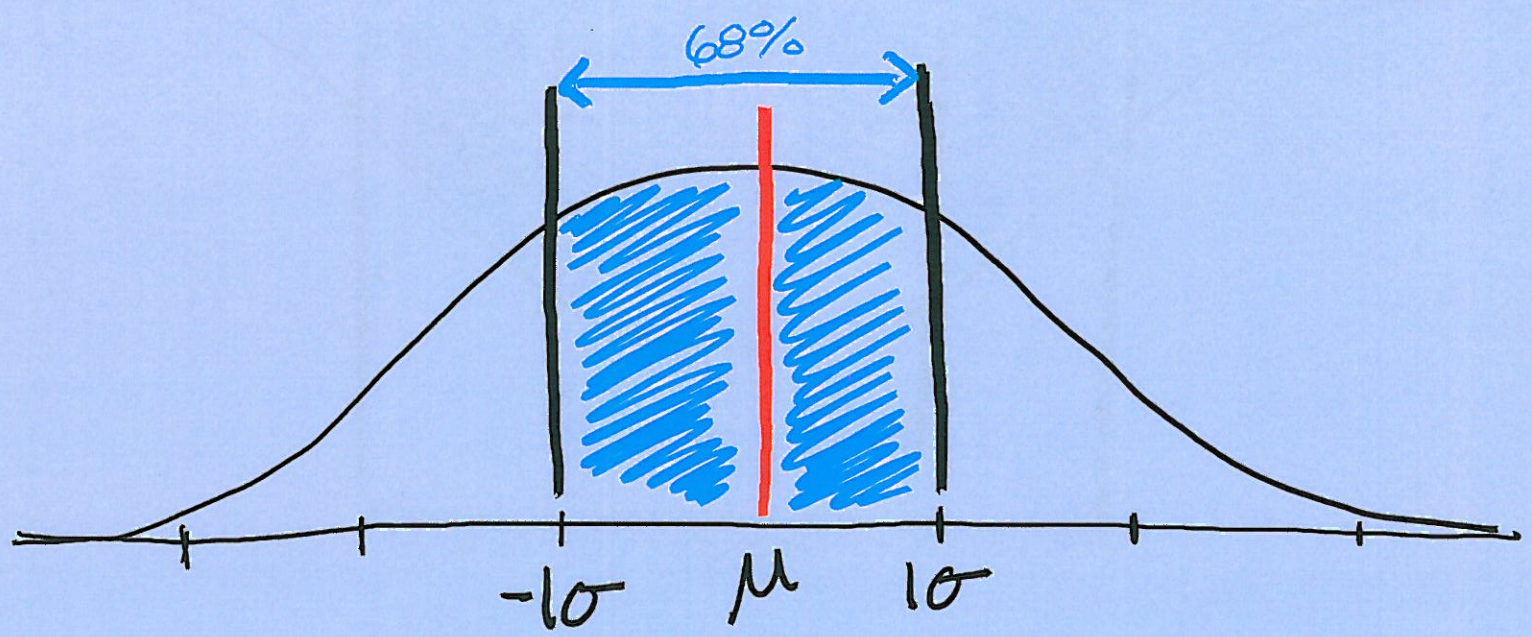

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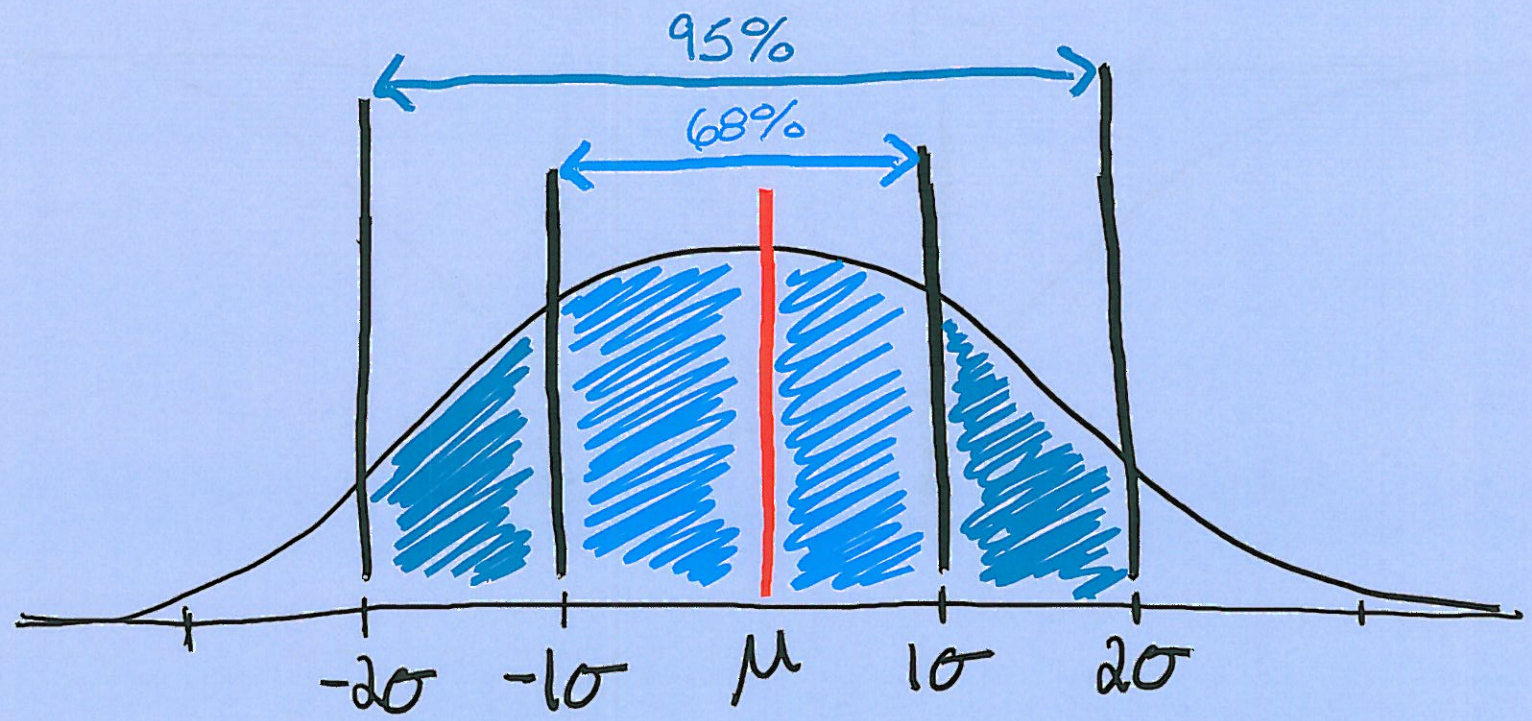

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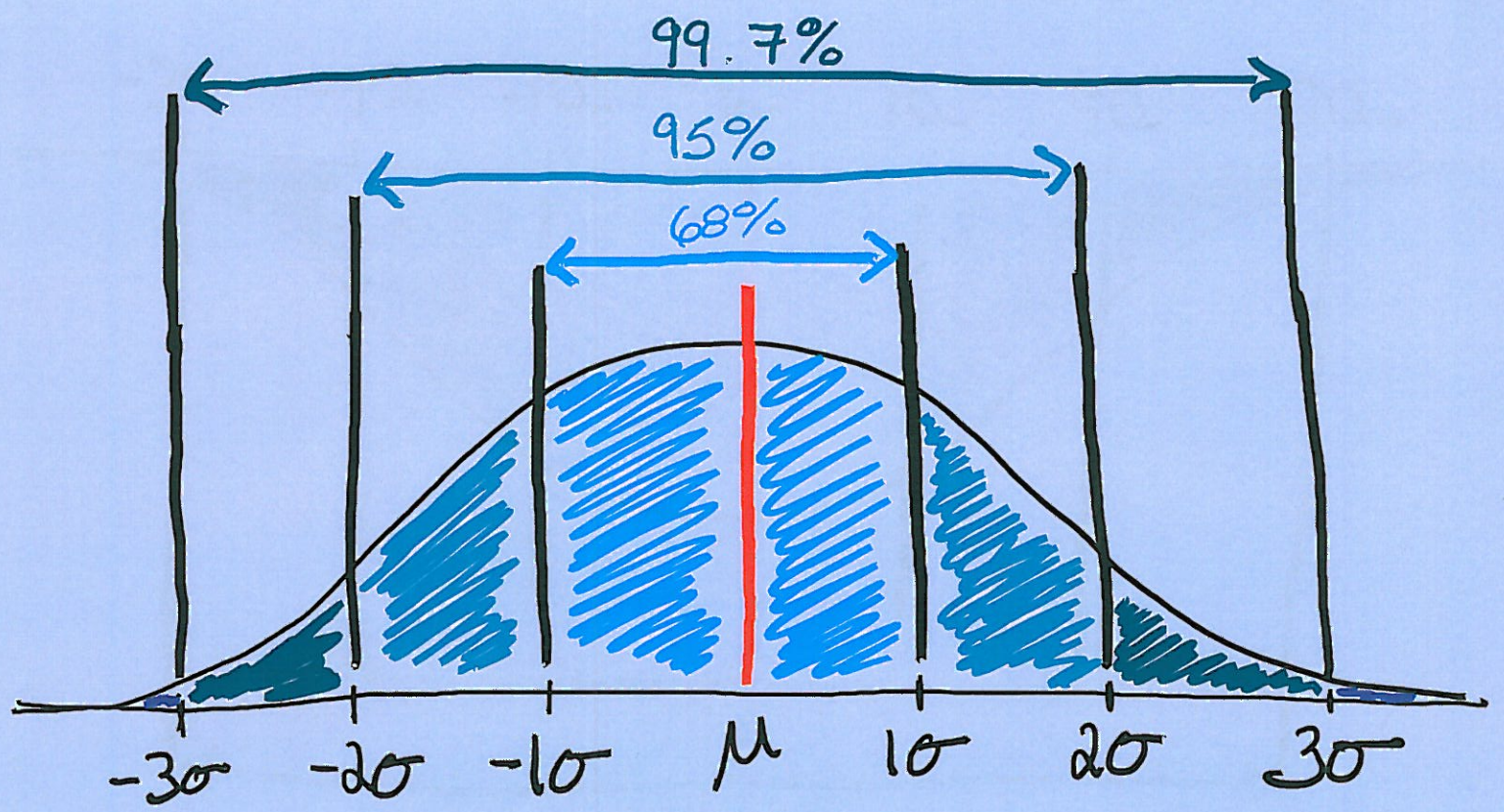

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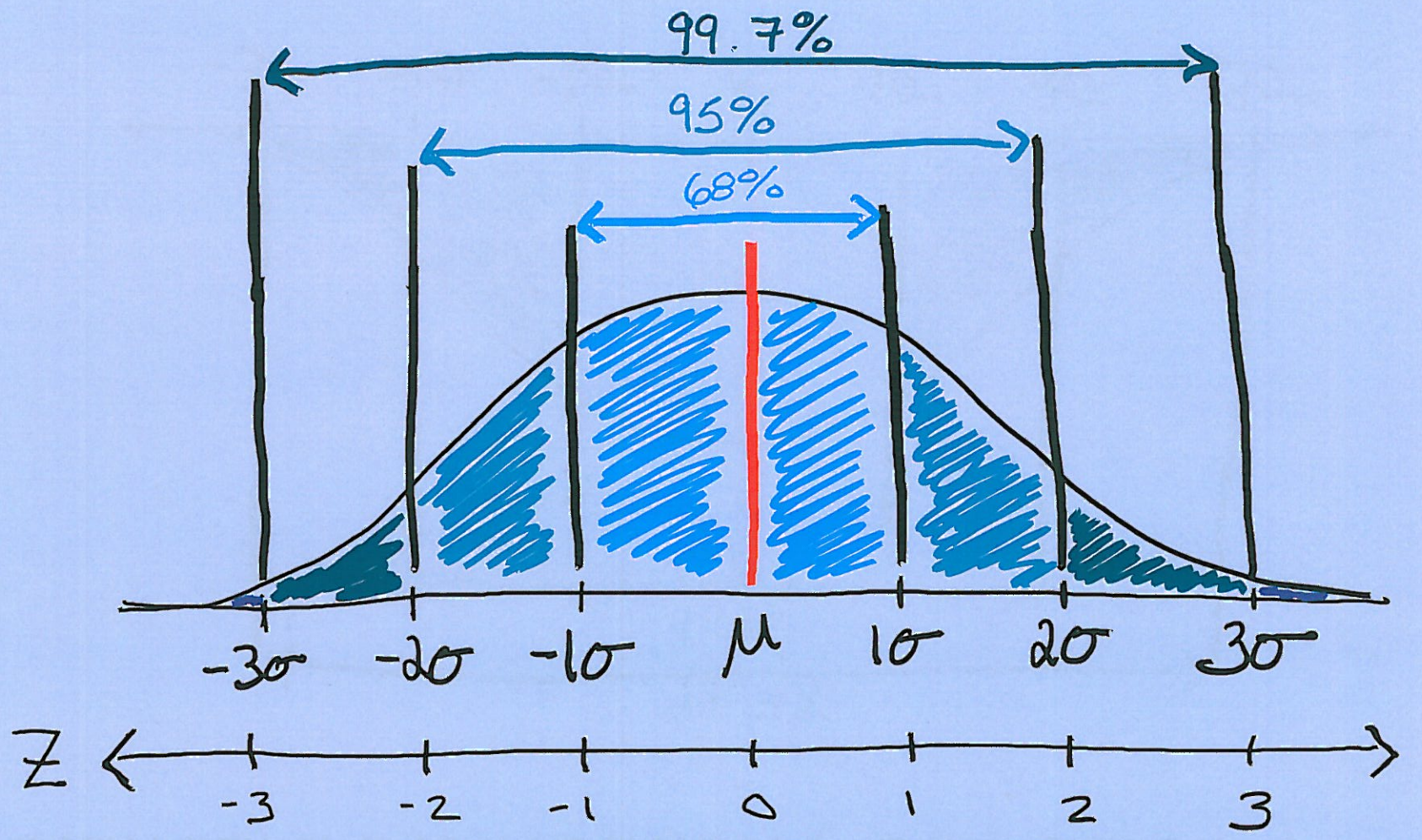

Z Score – number used to describe amount of standard deviations an observation is above or below the mean

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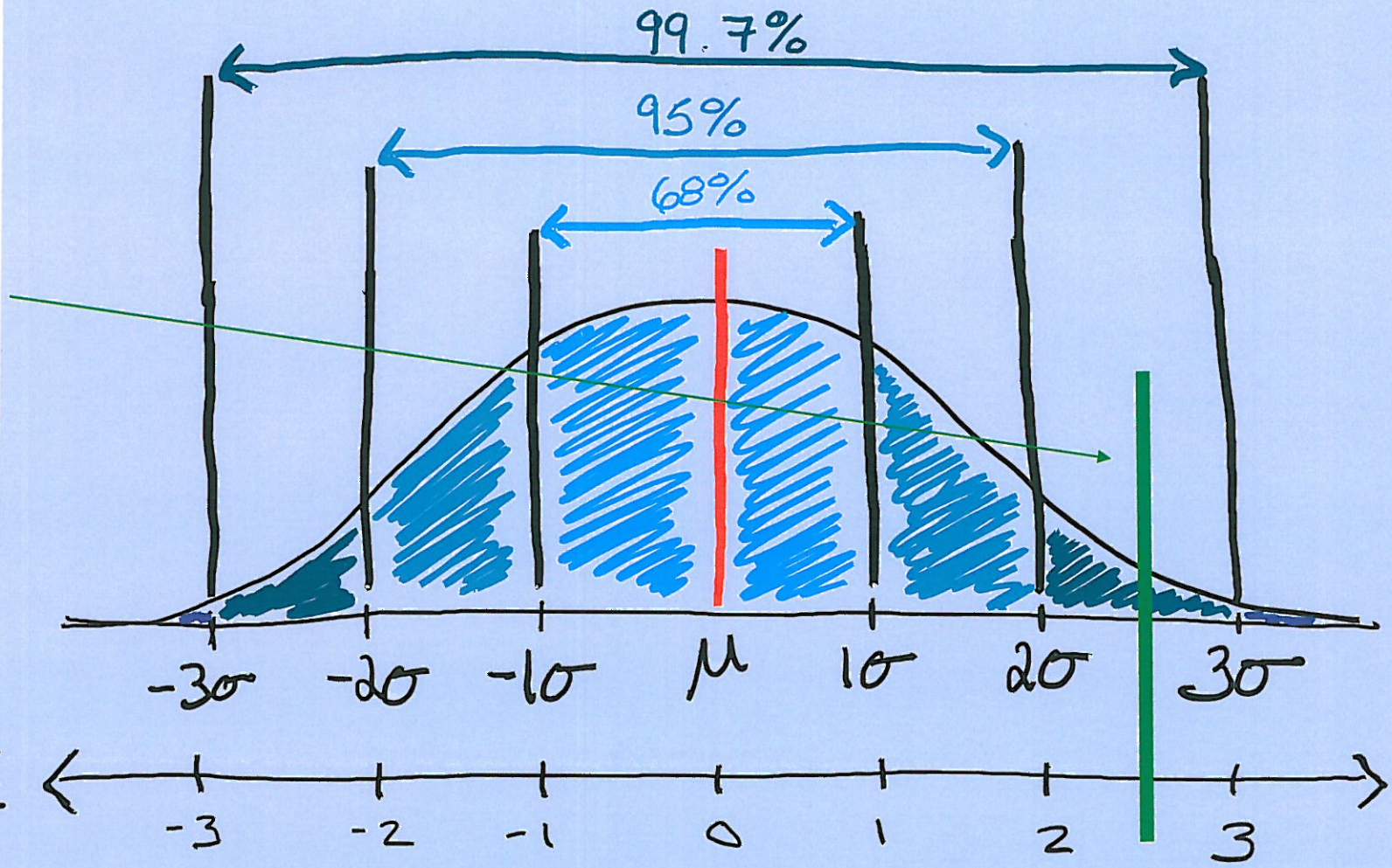

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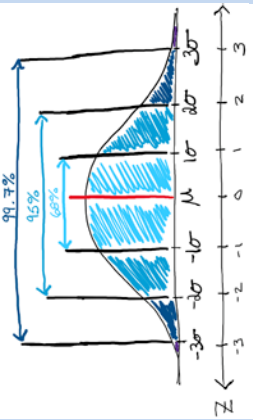
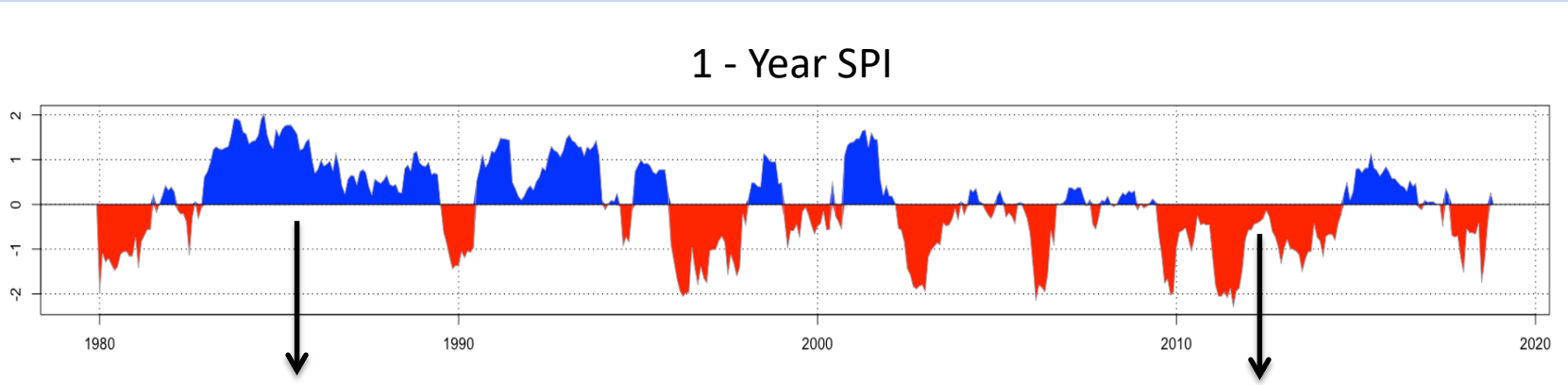
Standardized Precipitation Index (SPI)

- Used to analyze precipitation data
- Below: 12-month SPI comparing yearly total precipitation with all other years on record





Blue indicates above average precip (surplus)

Red indicates below average precip (drought)

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WestWideDroughtTracker

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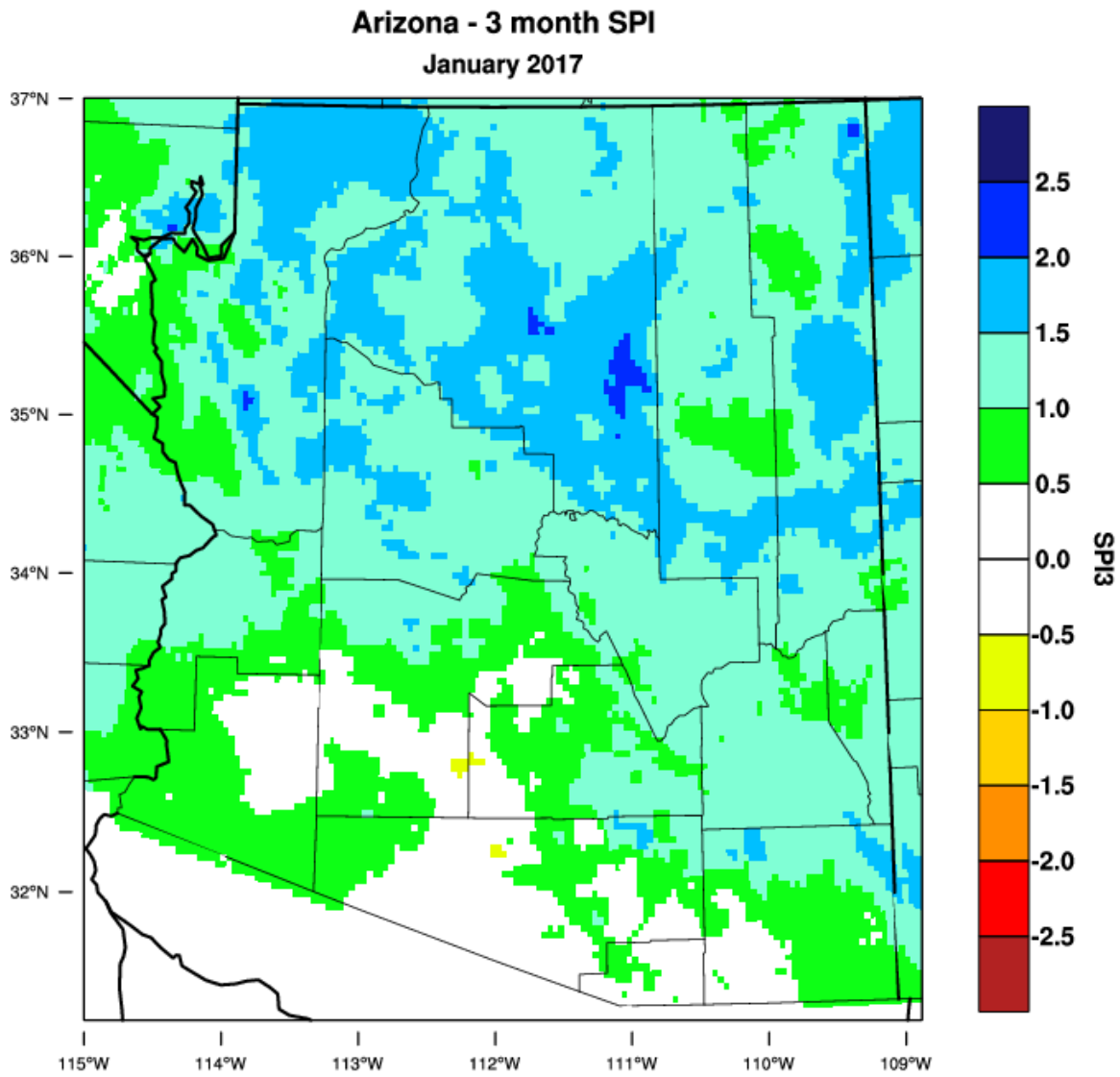
Climate Product Options

Expand All | Contract All

- Variable
  - Drought Index
    - Palmer Index
      - PDSI
      - Palmer Z-Index
      - Self-Calibrated PDSI
    - SPI
      - 1 Month
      - 2 Months
      - 3 Months
      - 4 Months
      - 5 Months
      - 6 Months
      - 7 Months
      - 8 Months
      - 9 Months
      - 10 Months
      - 11 Months
      - 12 Months
      - 15 Months
      - 18 Months
      - 24 Months
      - 30 Months
      - 36 Months
      - 48 Months
      - 60 Months
      - 72 Months
    - SPEI
      - 1 Month
      - 2 Months
      - 3 Months
      - 4 Months
      - 5 Months

Time Windows

Current Product:
PRISM > SPI 3 Month > Arizona

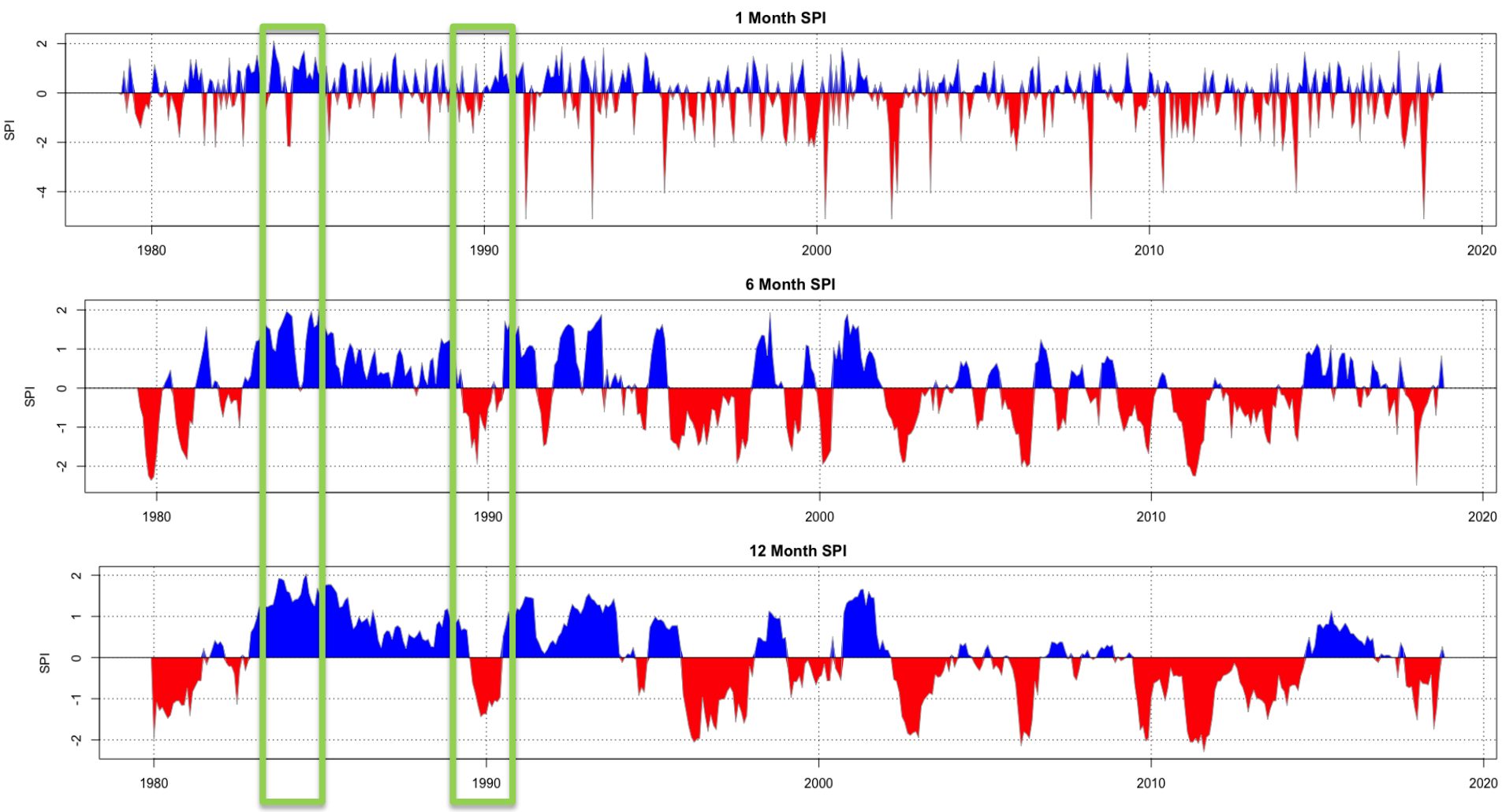


Index Time Windows

- Time windows aggregate data over multiple months
  - Short vs long-term drought
- Compare with same occurrence on record

<table>
<tr><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td></td><td></td><td></td><td></td><td>1 Mo.</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="2">2 Month</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="3">3 Month Window</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="4">4 Month Window</td><td></td><td></td><td></td></tr>
<tr><td colspan="12">12 Month Window</td></tr>
</table>

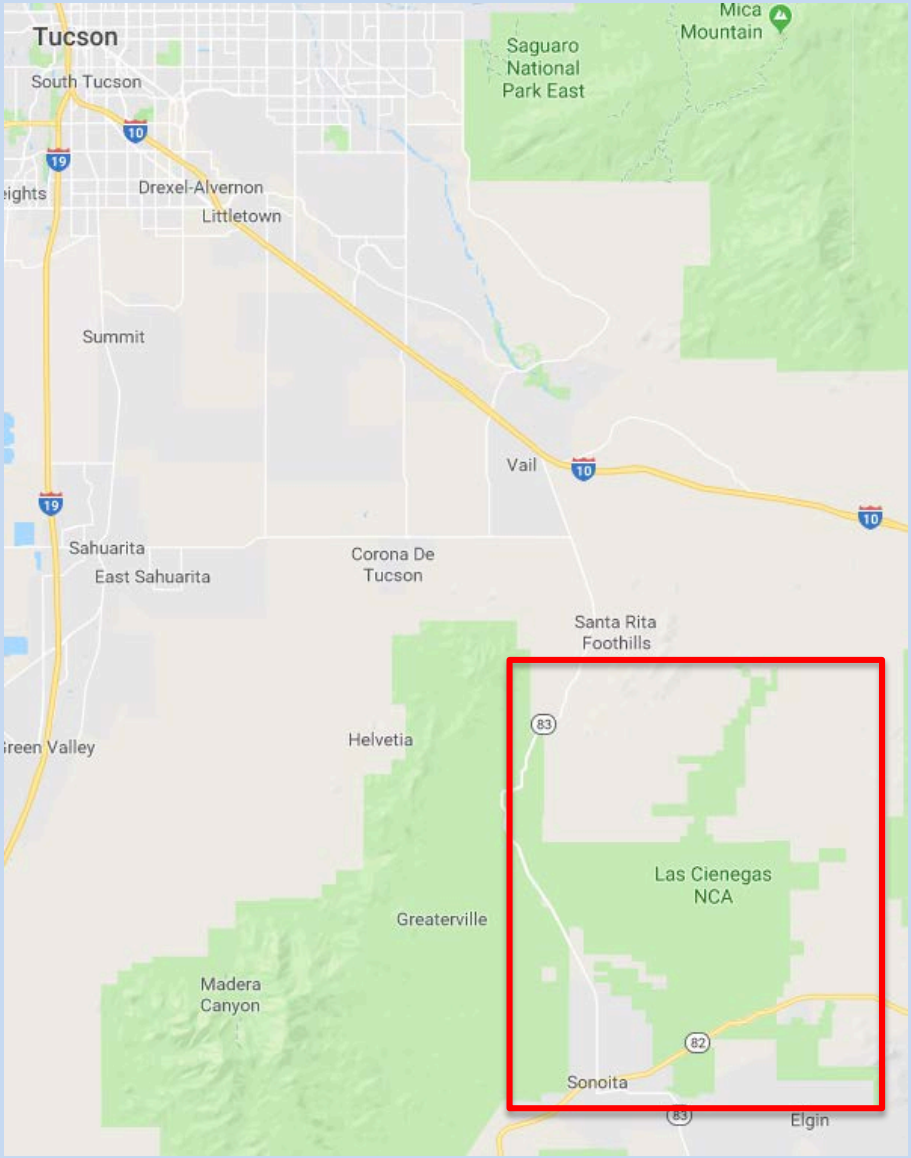
Differences Between Windows

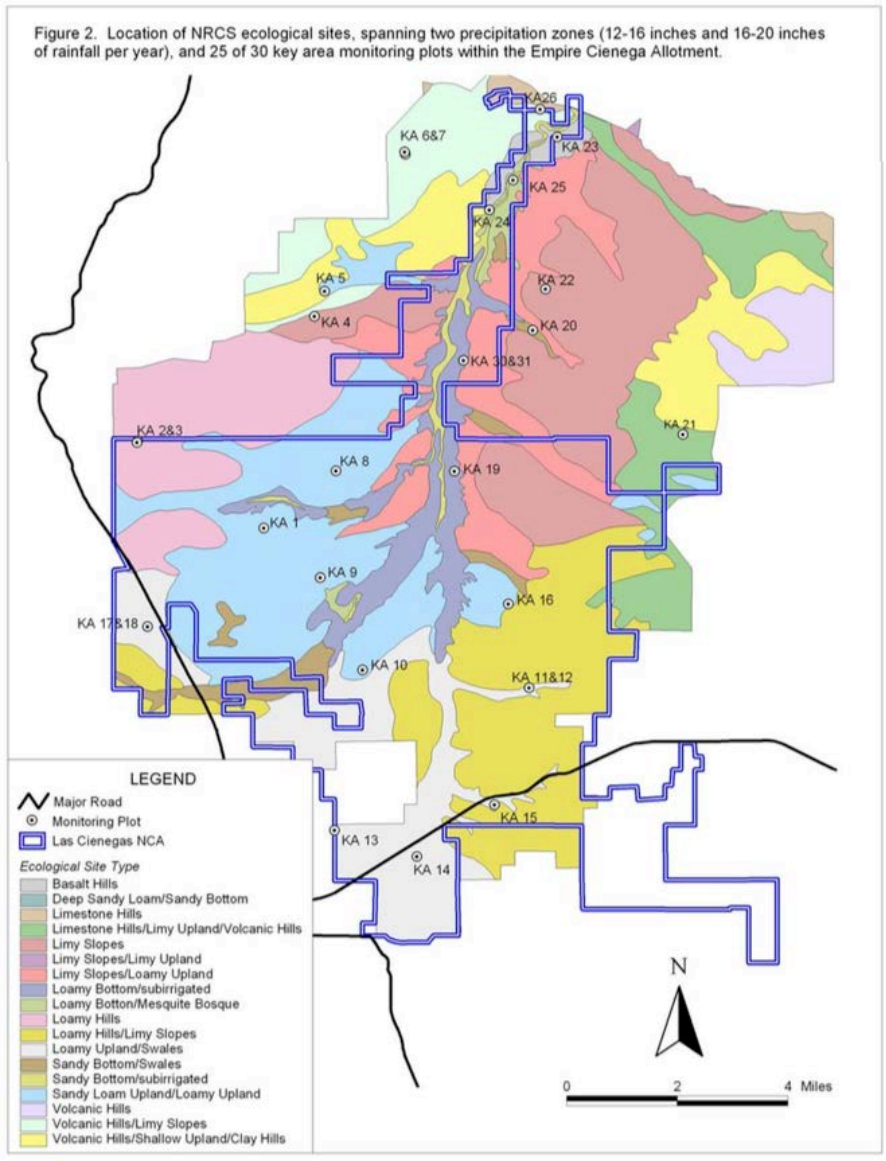


What Do Index Values Tell Us About Drought?

- If the 12-Month SPI signals drought, but the 1-Month SPI signals surplus, which is correct?
- Model soil moisture and use as an objective measure against which to evaluate simple, readily available indices.
  - **How well does modeled soil moisture represent standardized drought indices?**

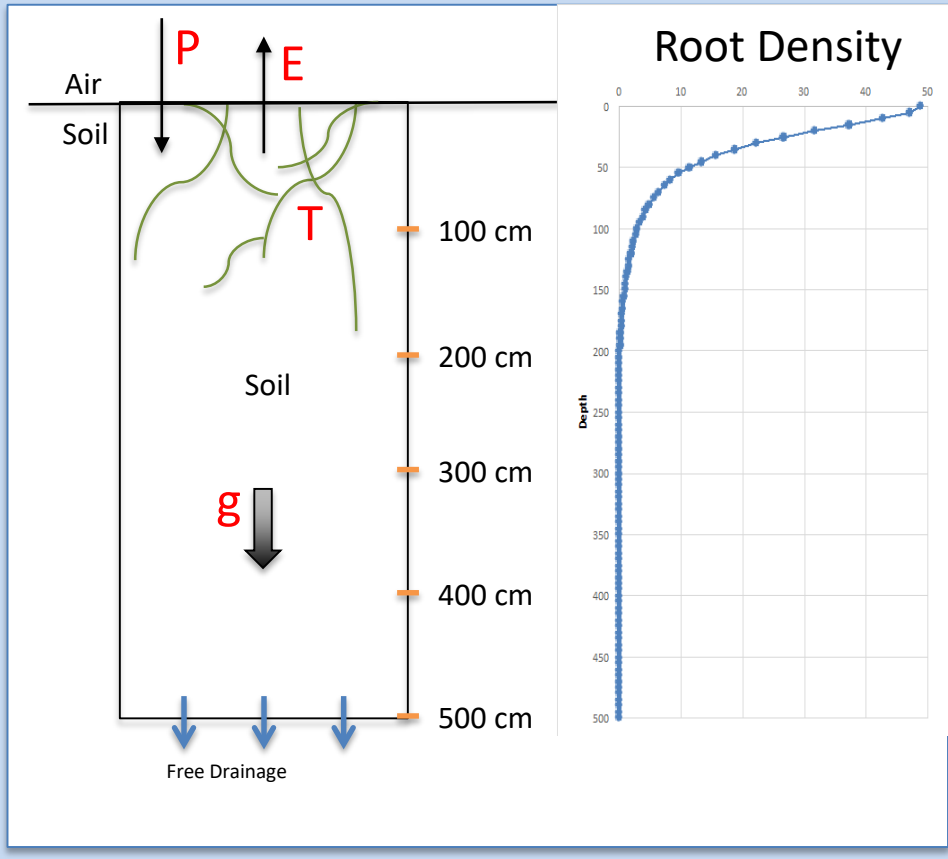
Study Area - Las Cienegas





HYDRUS Model Design

- Deterministic soil moisture model that solves the Richards equation for water transport
- Daily data 1979-2018
- Only evaporation, transpiration (Penman estimation) and gravity impact water movement



Project Concept

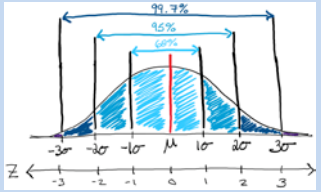
Inputs

- Location
- Climate Data
  - -Precipitation
  - -Min & Max Temp
- Soil Type
- Vegetation

Soil Model

Output

Soil Moisture Time Series

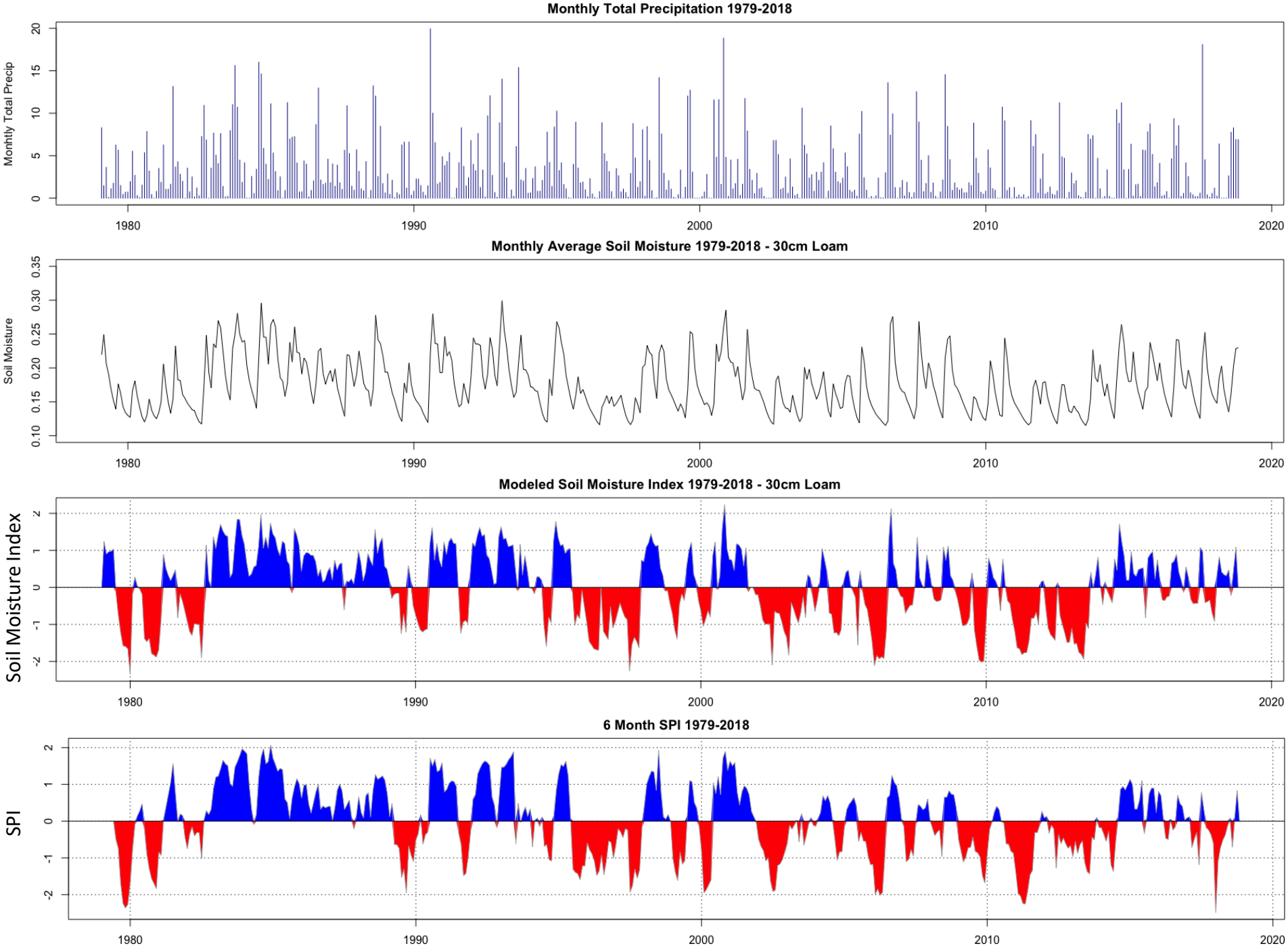


Simple, readily available indices like SPI, SPEI, PDSI

?

New Soil Moisture Index

Modeled Soil Moisture Index - MSMI

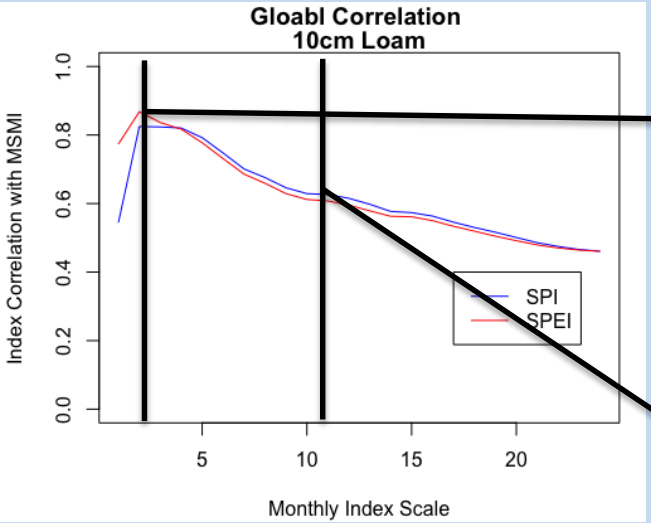

Monthly Total Precipitation 1979-2018
Monhtly Total Precip
0
5
10
15
20
1980
1990
2000
2010
2020
Monthly Average Soil Moisture 1979-2018 - 30cm Loam
Soil Moisture
0.10
0.15
0.20
0.25
0.30
0.35
1980
1990
2000
2010
2020
Modeled Soil Moisture Index 1979-2018 - 30cm Loam
Soil Moisture Index
-2
-1
0
1
2
1980
1990
2000
2010
2020
6 Month SPI 1979-2018
SPI
-2
-1
0
1
2
1980
1990
2000
2010
2020

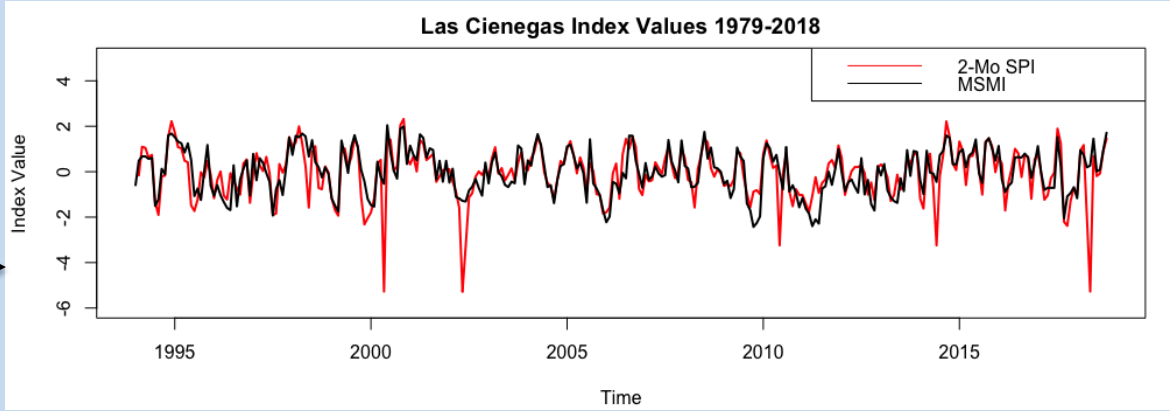
Model Correlation With Different Time Windows

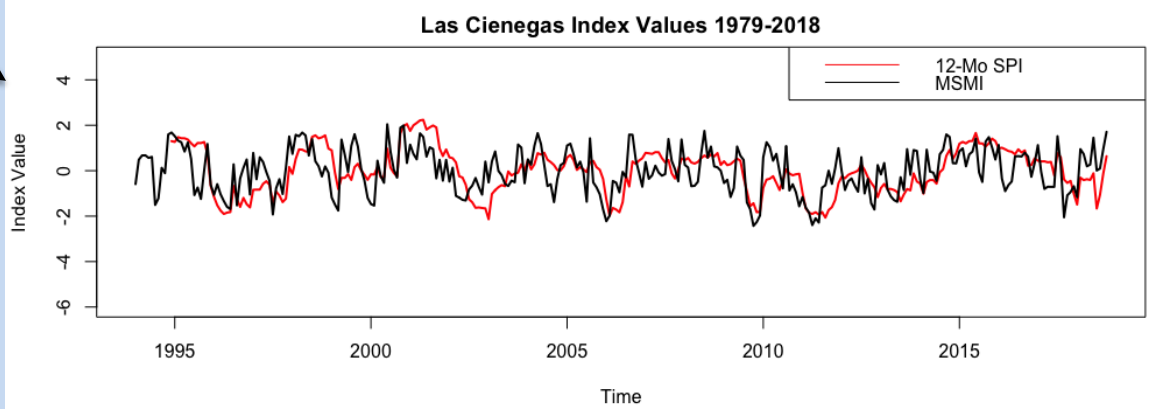
Depth	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
10cm					1 Mo.							
					MSMI							
				2 Month								
					MSMI							
			3 Month Window									
					MSMI							
		4 Month Window										
					MSMI							

Always 1 month

Index Correlations With Modeled Soil Moisture

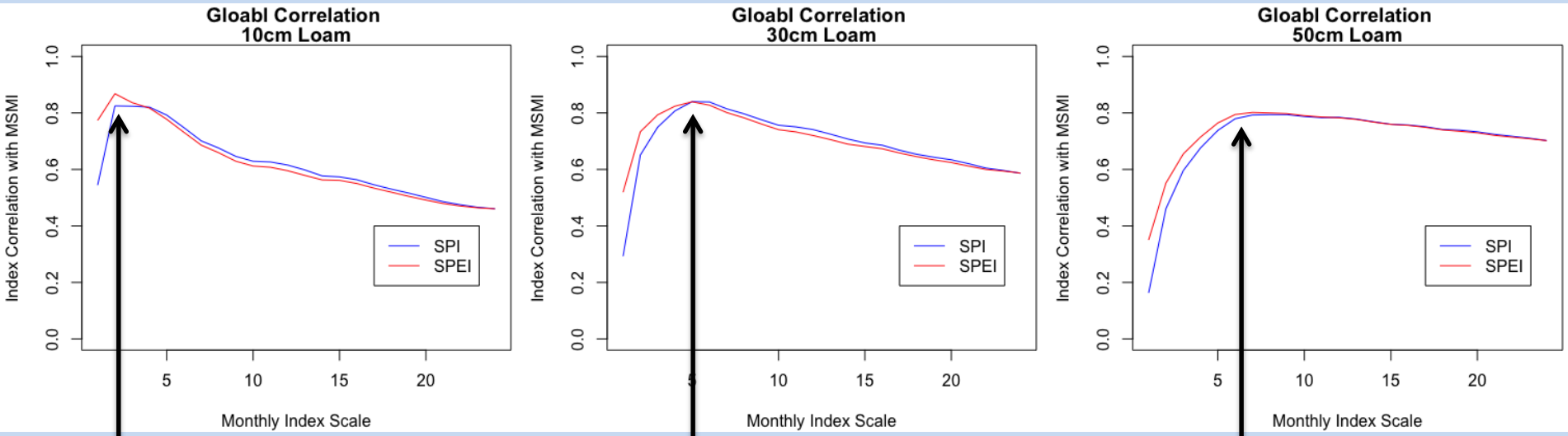






Index Correlations With Modeled Soil Moisture

Depth



Scale

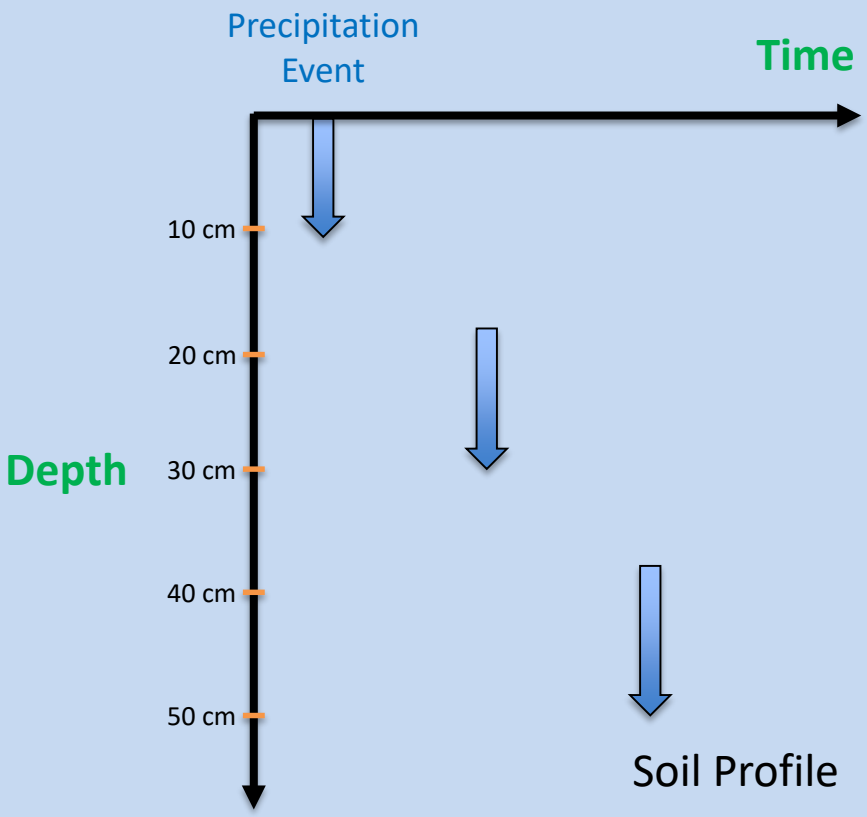
SPI best correlates at a 2 month index scale

SPI best correlates at 5 month index scale

SPI best correlates at 7 month index scale

Soils Have Memory

- Precipitation takes time to travel to different depths through a soil profile
- Time lag between precipitation occurrence and wetting front at depth



Standardized Indices Also Have Memory

- Memory varies by time window
  - Short windows = less, recent precip events
  - Longer windows = more, past precip events
- Can use relationship between index window and soil moisture memory as proxy for depth

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Heavy Precipitation Event

Depth	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
10cm												
30cm												
50cm												

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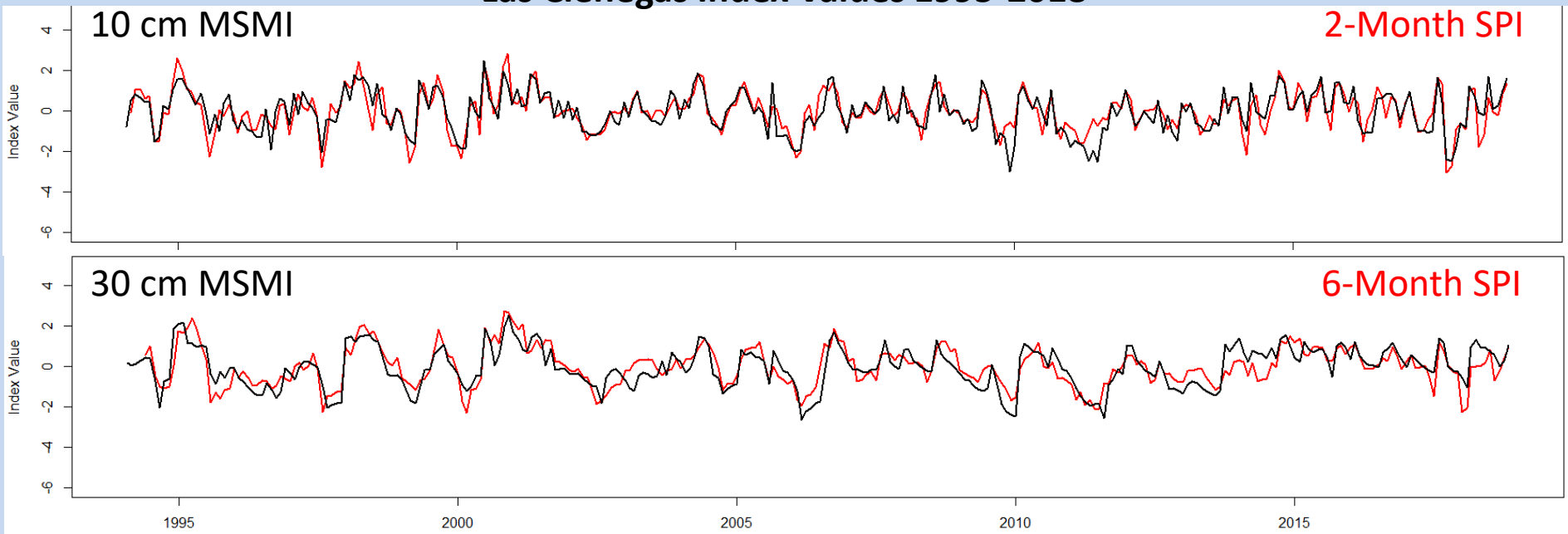
10cm	2 Mo											
30cm	5 Month Window											
50cm	7 Month Window											

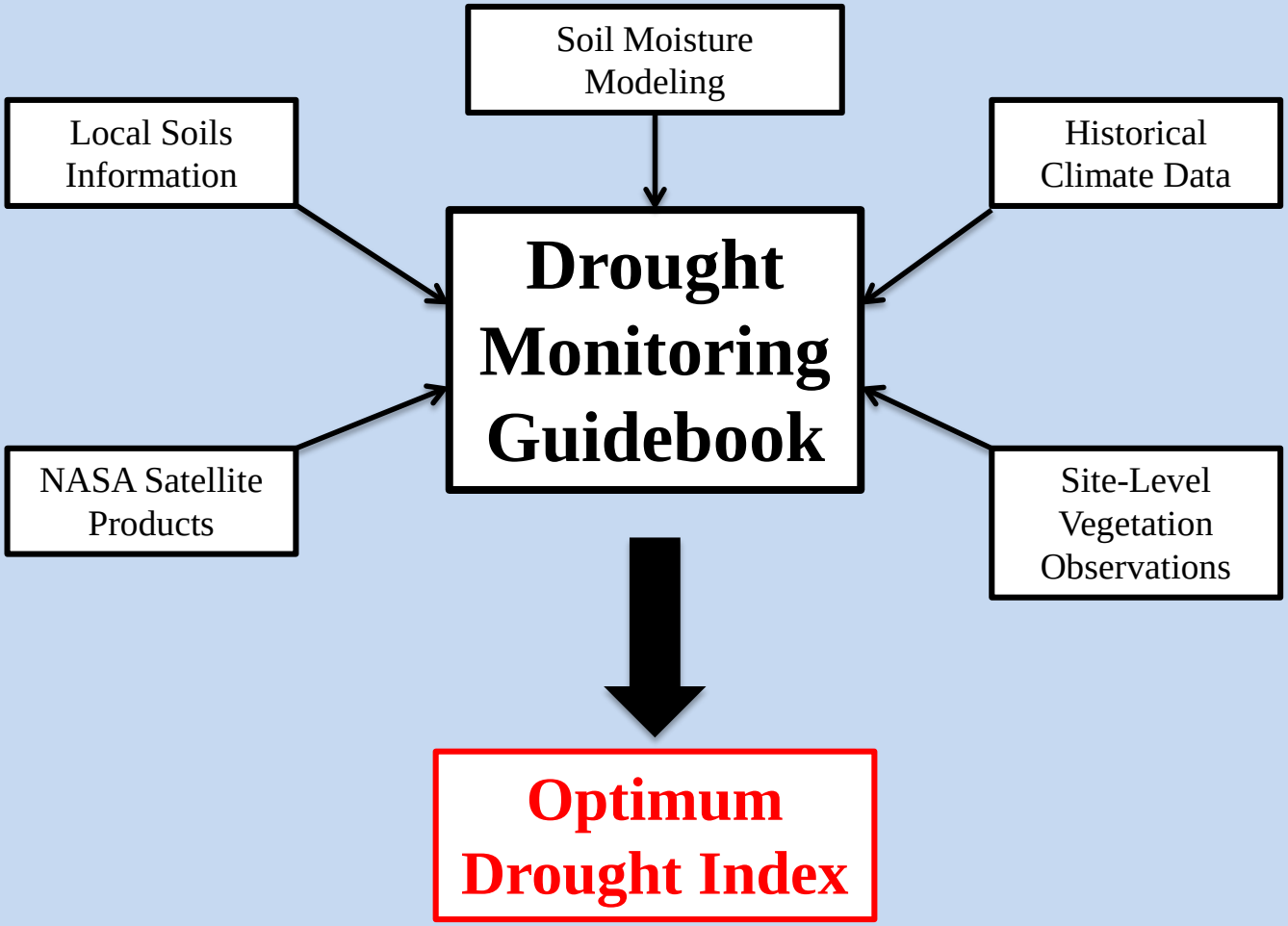
What Do Index Values Tell Us About Drought?

- If the 12-Month SPI signals drought, but the 1-Month SPI signals surplus, which is correct?
  - Both! Because the index time scale represents different portions of the soil profile

Las Cienegas Index Values 1995-2018



Distributing This Information



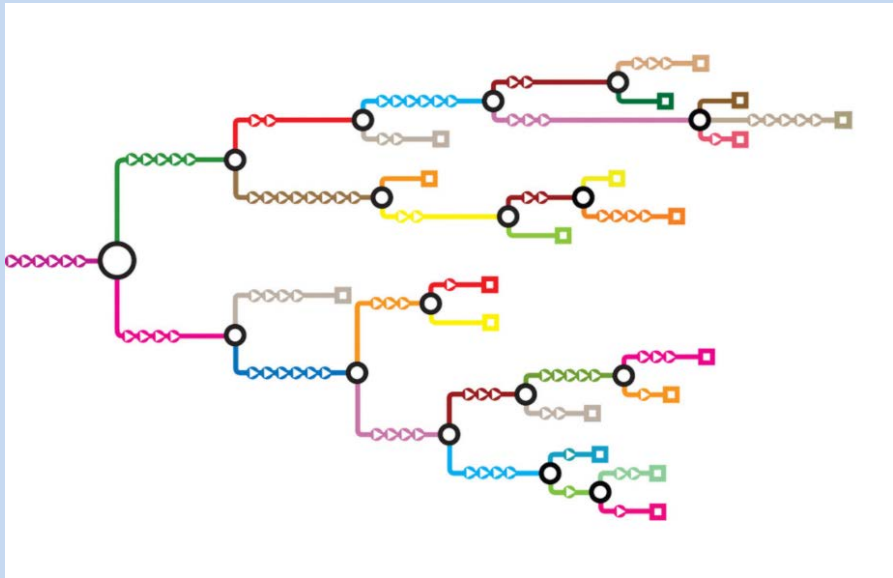
Webapp Development

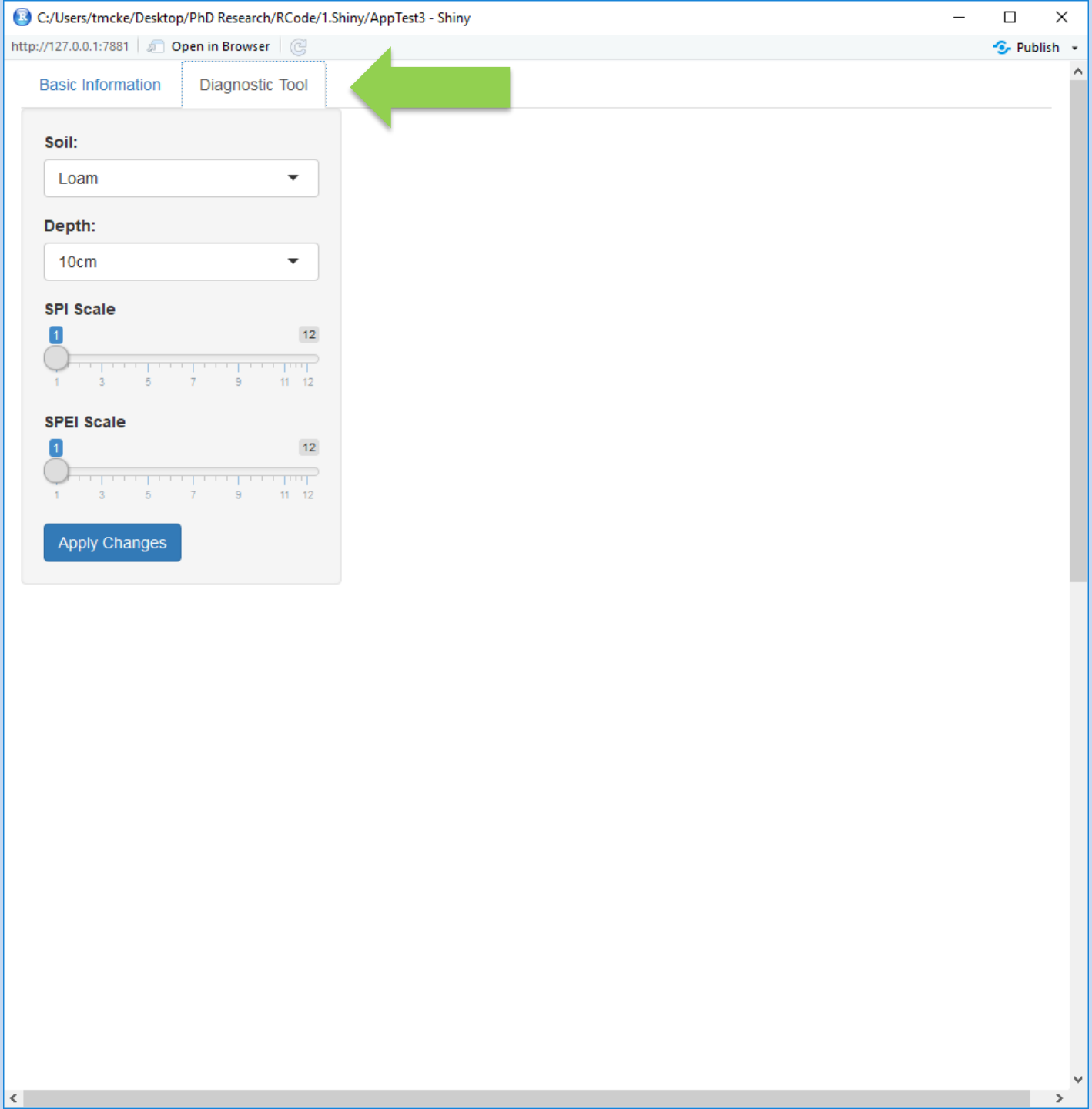
- Input: Soil and Depth
- Output:

1) Basic Information

Optimum Drought Index + Time Window

2) Choose Your Own Adventure




C:/Users/tmcke/Desktop/PhD Research/RCode/1.Shiny/AppTest3 - Shiny
http://127.0.0.1:7881
Open in Browser
Publish
Basic Information
Diagnostic Tool
Soil:
Loam
Depth:
10cm
SPI Scale
1
12
1 3 5 7 9 11 12
SPEI Scale
1
12
1 3 5 7 9 11 12
Apply Changes

C:/Users/tmcke/Desktop/PhD Research/RCode/1.Shiny/AppTest3 - Shiny

http://127.0.0.1:7881 Open in Browser Publish

Basic Information Diagnostic Tool

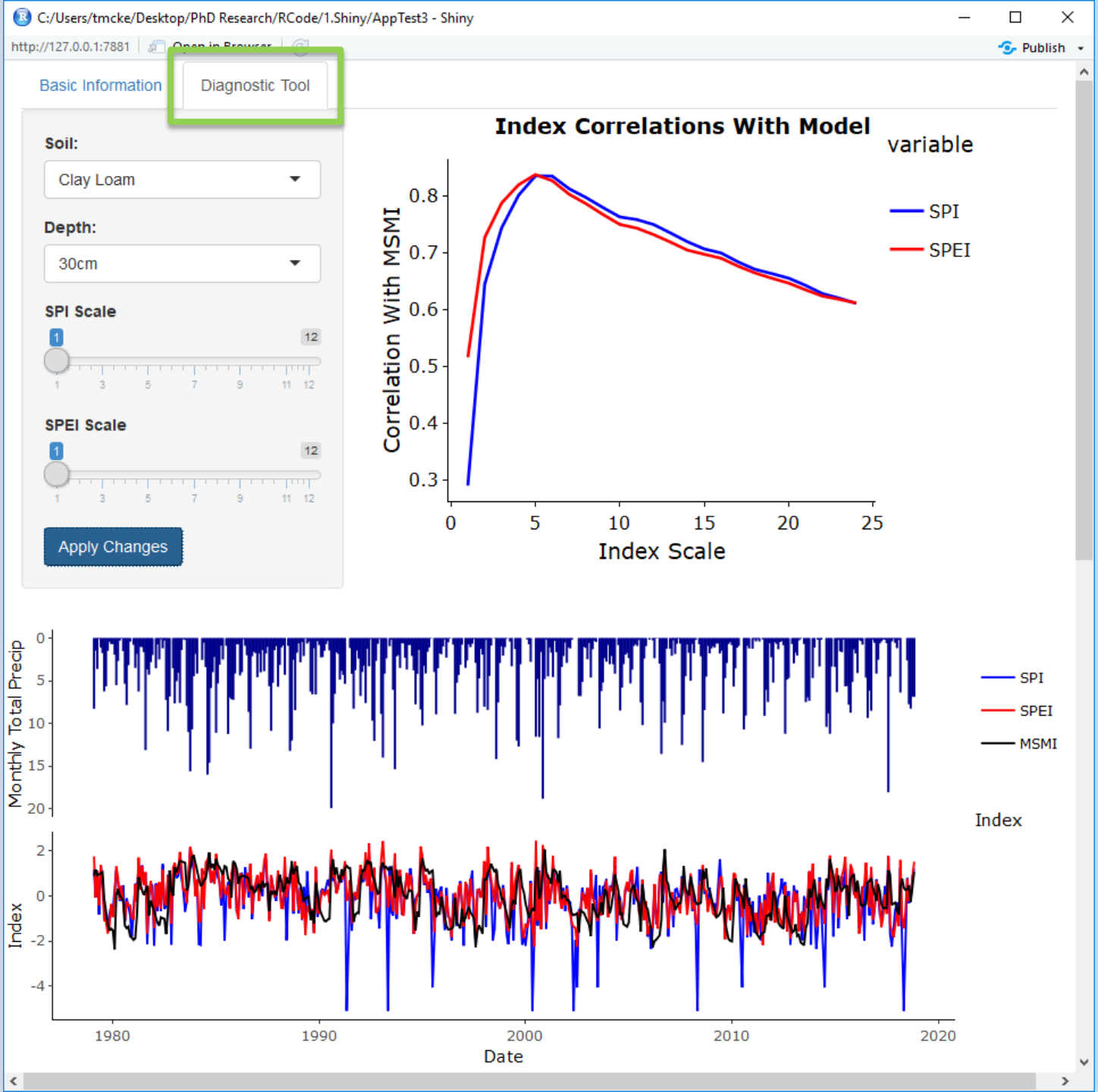
Soil:

Loam

Depth:

10cm

Depth(cm)	Month	Optimum Index	Best Scale
10	January	SPEI	1
10	February	SPI	2
10	March	SPI	2
10	April	SPEI	2
10	May	SPEI	3
10	June	SPEI	3
10	July	SPI	2
10	August	SPI	2
10	September	SPI	2
10	October	SPEI	1
10	November	SPEI	1
10	December	SPI	2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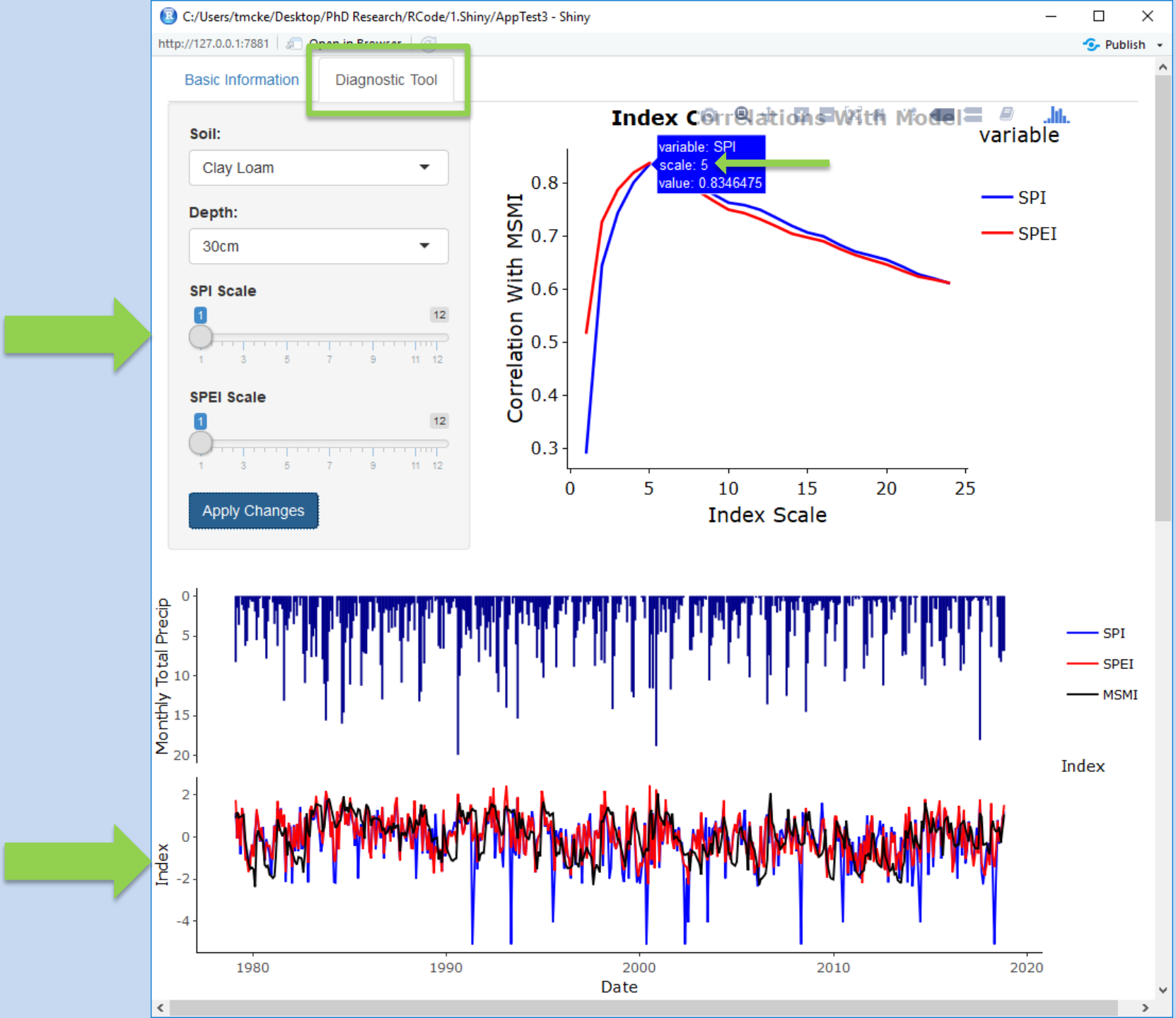
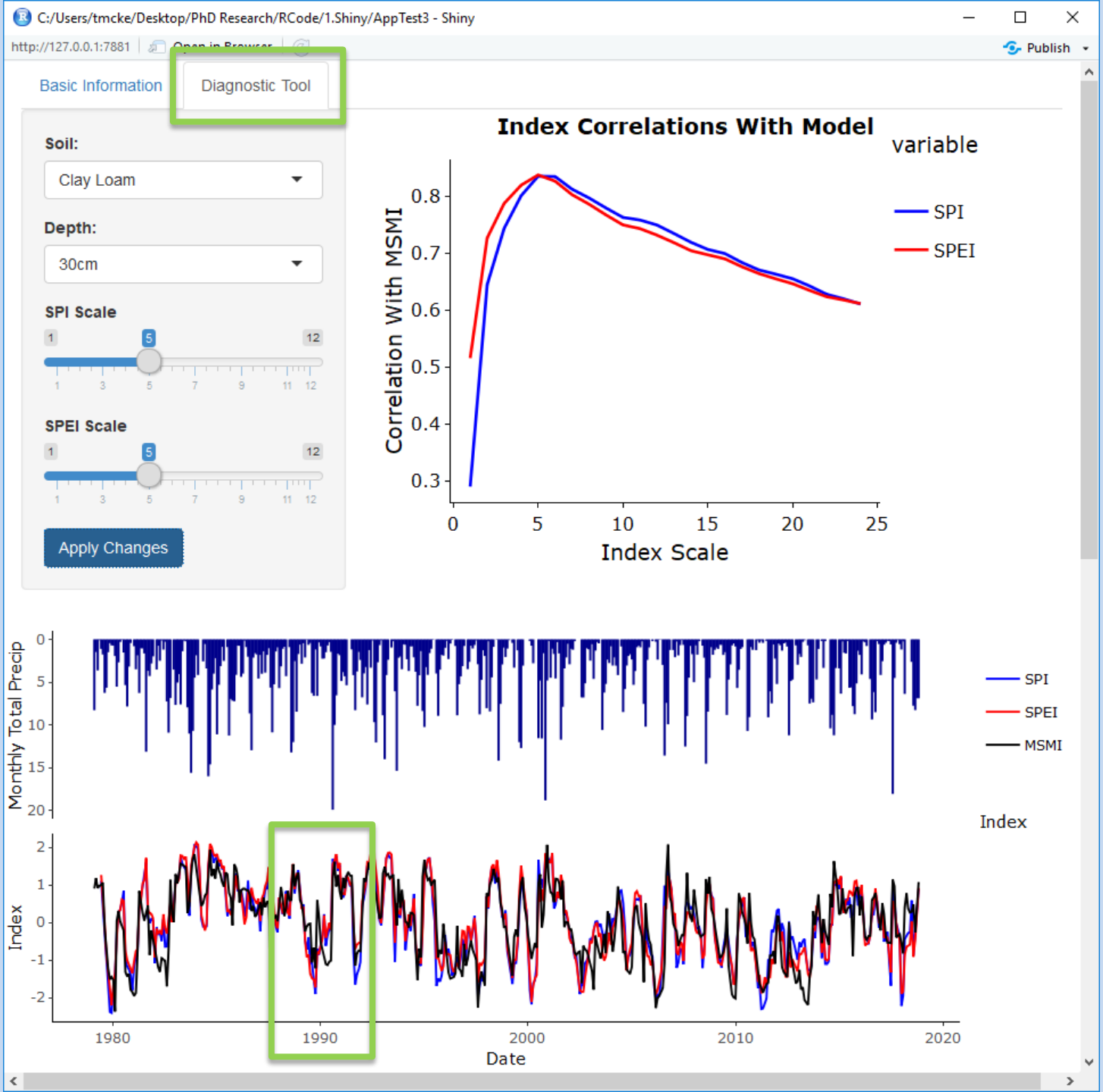
Publish
Basic Information
Diagnostic Tool
Soil:
Clay Loam
Depth:
30cm
SPI Scale
1
12
SPEI Scale
1
12
Apply Changes
Index Correlations With Model
variable
SPI
SPEI
Correlation With MSMI
Index Scale
Monthly Total Precip
Index
Date
SPI
SPEI
MSMI
Index


C:/Users/tmcke/Desktop/PhD Research/RCode/1.Shiny/AppTest3 - Shiny
http://127.0.0.1:7881
Publish
Basic Information
Diagnostic Tool
Soil:
Clay Loam
Depth:
30cm
SPI Scale
1
12
SPEI Scale
1
12
Apply Changes
Index Correlations With Model
variable: SPI
scale: 5
value: 0.8346475
Correlation With MSMI
Index Scale
variable
SPI
SPEI
Monthly Total Precip
Index
SPI
SPEI
MSMI
Date


C:/Users/tmcke/Desktop/PhD Research/RCode/1.Shiny/AppTest3 - Shiny
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Publish
Basic Information
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30cm
SPI Scale
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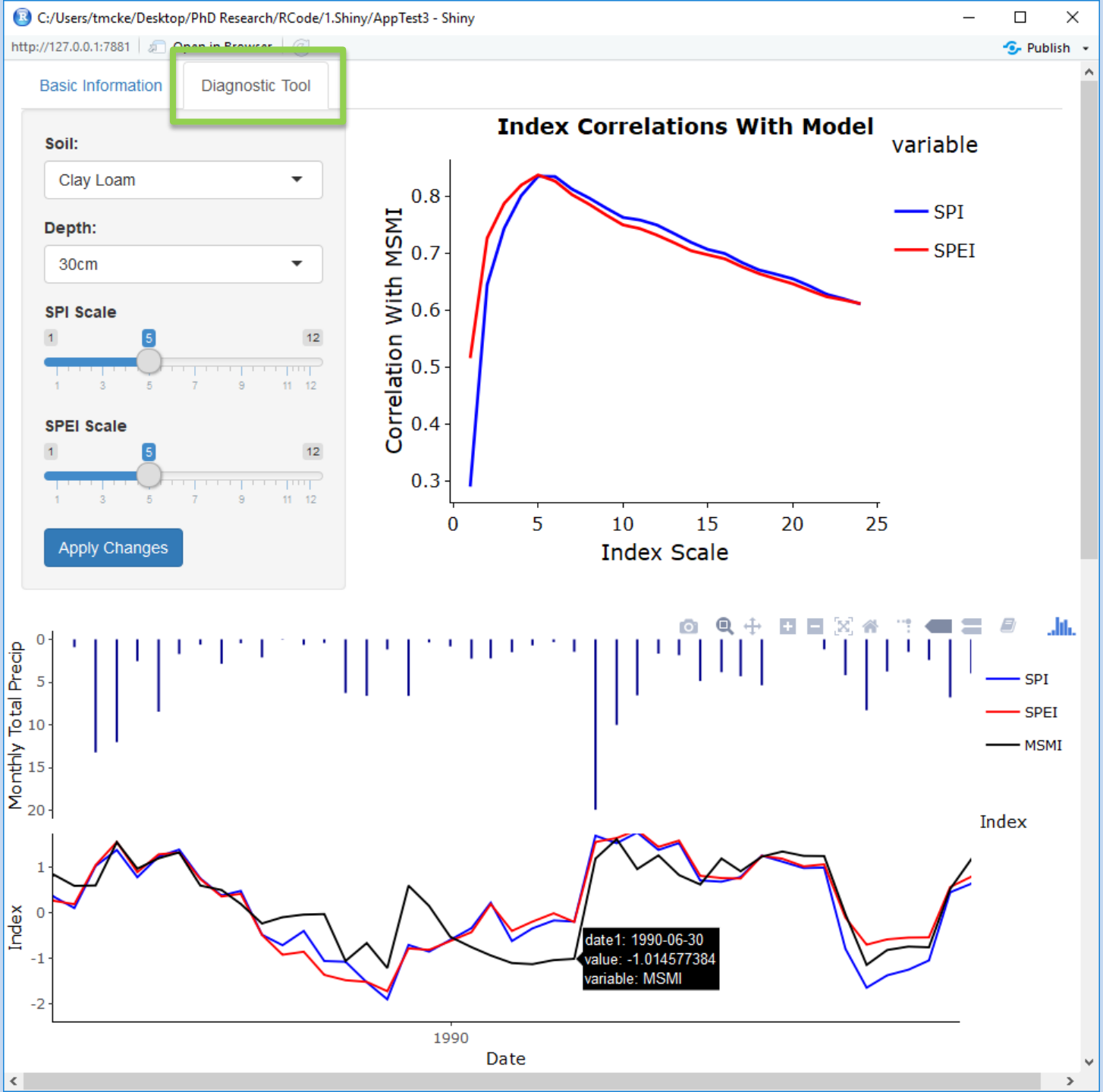
Apply Changes
Index Correlations With Model
variable
SPI
SPEI
Correlation With MSMI
Index Scale
Monthly Total Precip
Index
MSMI
Date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http://127.0.0.1:7881
Publish
Basic Information
Diagnostic Tool
Soil:
Clay Loam
Depth:
30cm
SPI Scale
SPEI Scale
Apply Changes
Index Correlations With Model
variable
SPI
SPEI
Correlation With MSMI
Index Scale
Monthly Total Precip
Index
date1: 1990-06-30
value: -1.014577384
variable: MSMI
1990
Date
MSMI

Summary

- Relationship exists between index time windows and soil moisture memory that can be used as a proxy for depth.
- Shallow depths use short index windows
  - Capturing more recent events
- Deeper depths use longer index windows
  - Capturing events further back
- Web application to improve drought index use

Thank You!

Questions?

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