Sandstorms in the Southwest US: An Exploratory Study to Implement a Predictive Model

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Introduction

(Goudie and Middleton, 2006)

Sand and Dust Storms

- Meteorological phenomena that occur in arid or semi-arid regions of the world
- Defined by the particle size
    - **Sand storm**: Particles >= 60 μm
    - **Dust storm**: Particles < 60 μm
- Dust storms are very prominent in the Southwest U.S.
    - **Dust storms**: Result of turbulent winds raising large quantities of dust into the air and reducing visibility below 1000m
    - **Blowing dust**: Raised by winds to moderate heights above the ground and reducing visibility at eye level but not to less than 1000m
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(Goudie and Middleton, 2006)

What Causes Dust Storms?

- There are several meteorological, topographic, and hydrological factors known to have impacts on dust storms in the Southwest

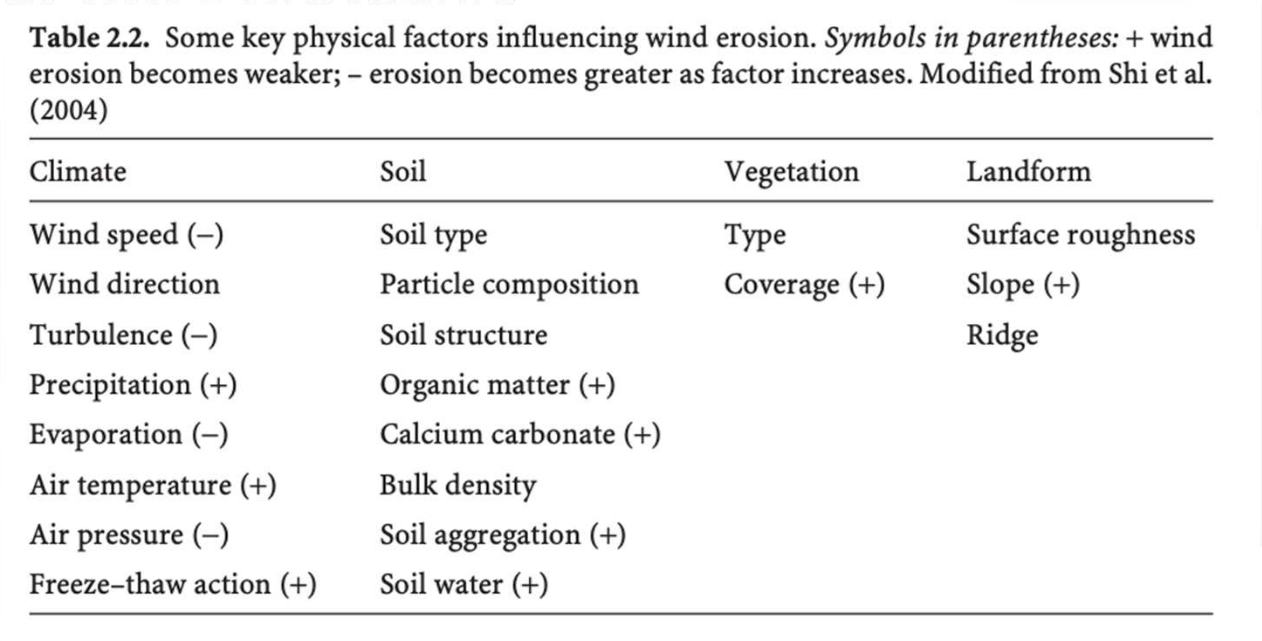


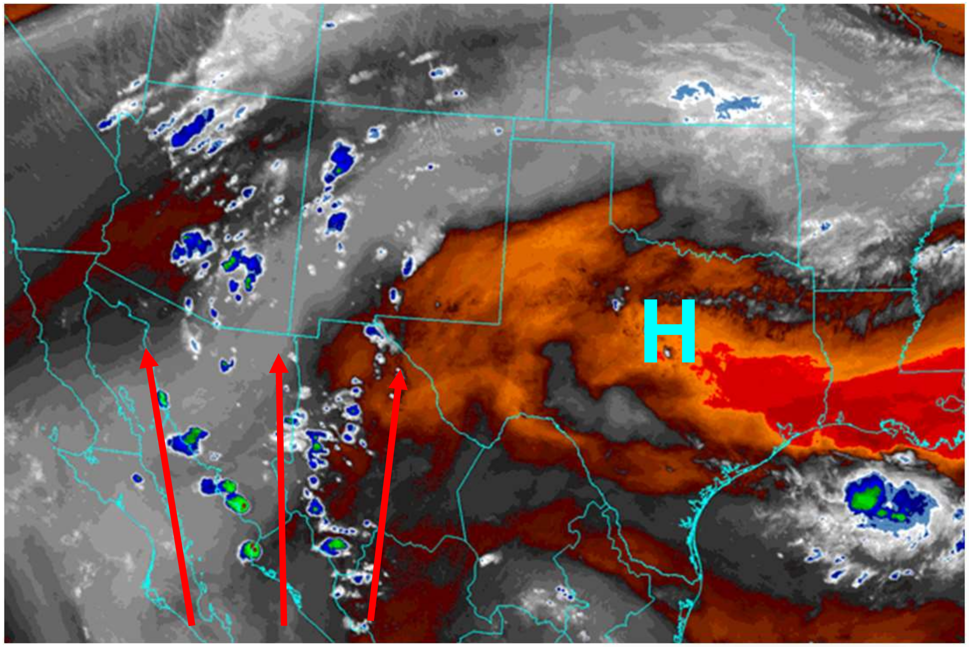
Table 2.2. Some key physical factors influencing wind erosion. *Symbols in parentheses:* + wind erosion becomes weaker; – erosion becomes greater as factor increases. Modified from Shi et al. (2004)

Climate	Soil	Vegetation	Landform
Wind speed (–)	Soil type	Type	Surface roughness
Wind direction	Particle composition	Coverage (+)	Slope (+)
Turbulence (–)	Soil structure		Ridge
Precipitation (+)	Organic matter (+)		
Evaporation (–)	Calcium carbonate (+)		
Air temperature (+)	Bulk density		
Air pressure (–)	Soil aggregation (+)		
Freeze–thaw action (+)	Soil water (+)		

Table: factors influencing wind erosion in the Southwest. Eroded sediment is critical for lofting of dust particles.

(National Weather Service, 2018)

Monsoonaly Generated Dust Storms



Gulf of California moisture

- North American Summer Monsoon
  - Forms from uneven heating of the land vs. the surrounding ocean
  - Develops in Mexico in June, then impacts the southwestern United States in July through September
  - High pressure over the Southwest paired with southerly winds bring moisture from the Gulf of California and the Pacific Ocean into the region
  - This moisture increase and surface heating generate strong monsoonal thunderstorms

Monsoonaly Generated Dust Storms

- When these monsoonal thunderstorms develop in the summer months, they generate intense downward outflows
- When these outflows reach the ground, they travel horizontally outward as a gust front, which can pick up dust and other loose sediment, forming dust storms
- Monsoonal dust storms (also called haboobs) account for the majority of the events in the Southwest

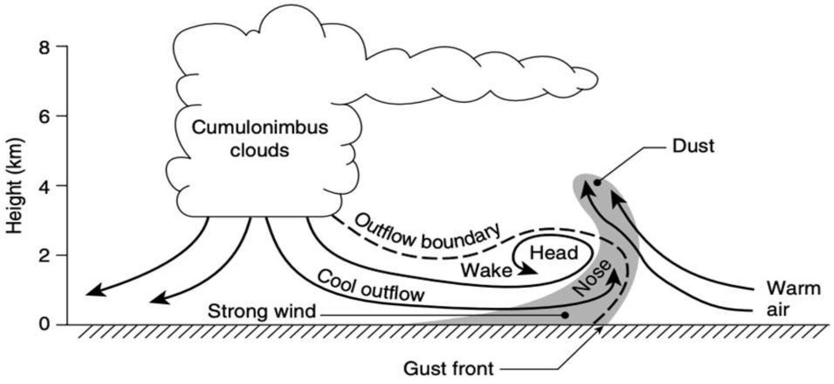


Figure: Diagram of monsoonal thunderstorm outflow causing a dust storm

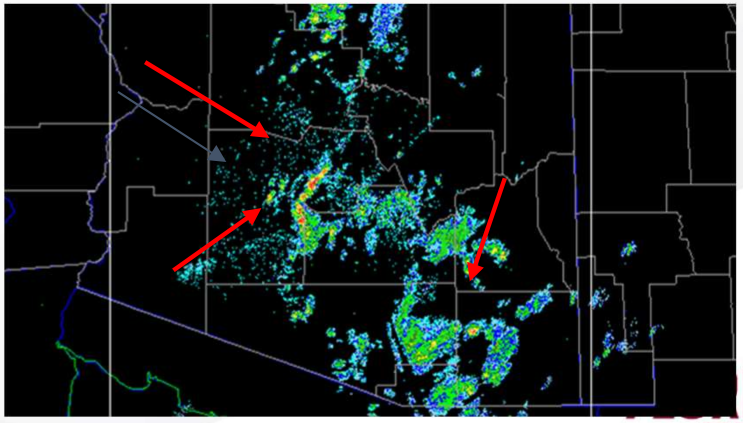


Figure: Radar image from a convectively active monsoon day with dust storm reports

(National Weather Service, 2016)

Synoptically Generated Dust Storms

- These storms are prevalent outside of the monsoon season, but occur less often
- These occur when surface fronts or strong low pressure systems move across the Southwest and loft dust upwards due to strong winds

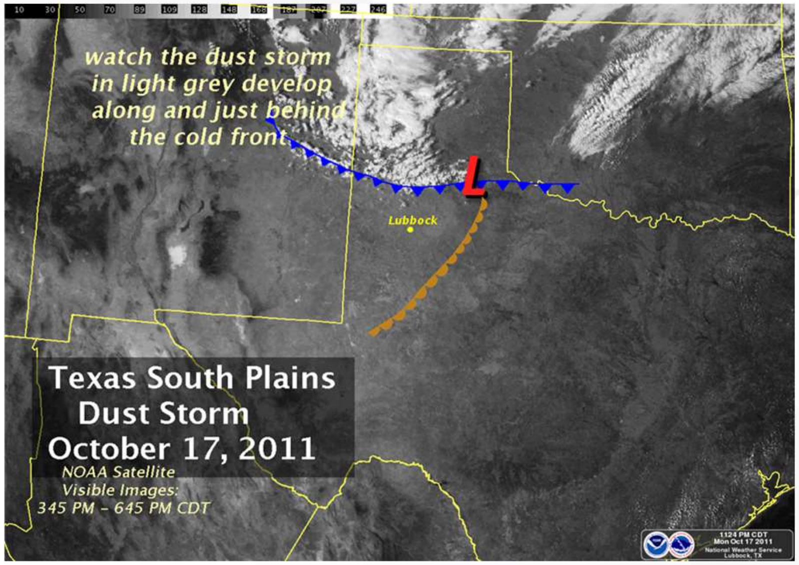


Figure: Satellite image of cold front and dust storm

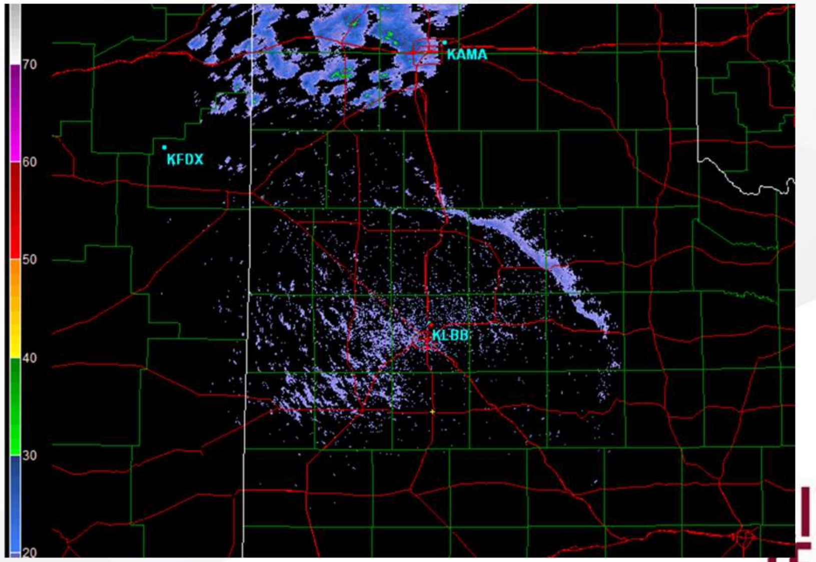


Figure: Radar image of cold front and dust storm

Purpose of Study

Dust storms have many damaging impacts:

- Human health: Decreased air quality from dust can irritate lung tissue, trigger allergic reactions, and cause asthma attacks
- Aviation: Limited visibility and engine clogging
- Weather and climate: Cloud condensation nuclei increase
- Environment: Crop yield reduction, reduced photosynthesis in plants, increased erosion
- Society: Decreased visibility while driving and diversion of solar radiation from solar panels

Future Issues

Research Setting

- This project focuses on three states: Arizona, New Mexico, and Nevada
  - Arid or semi-arid climate
  - Mountains and valleys for thunderstorm formation
- Focus on nine airport stations in the region
  - Many stations in each state have Automatic Surface Observing Systems (ASOS)
  - Special selection for this project based on presence of SYNOP (surface synoptic) reports
    - SYNOP reports are taken manually every 6 hours and provide a human observer's report of past and present weather conditions

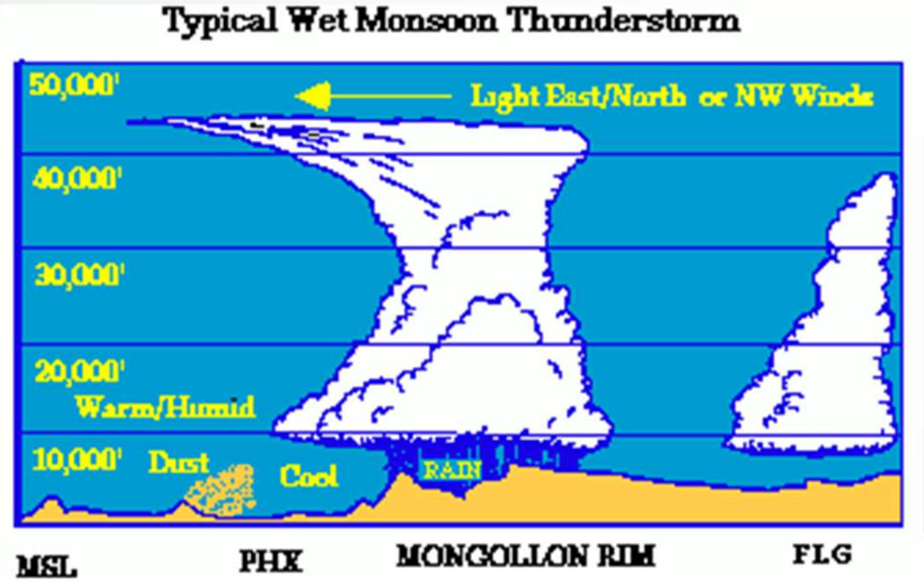
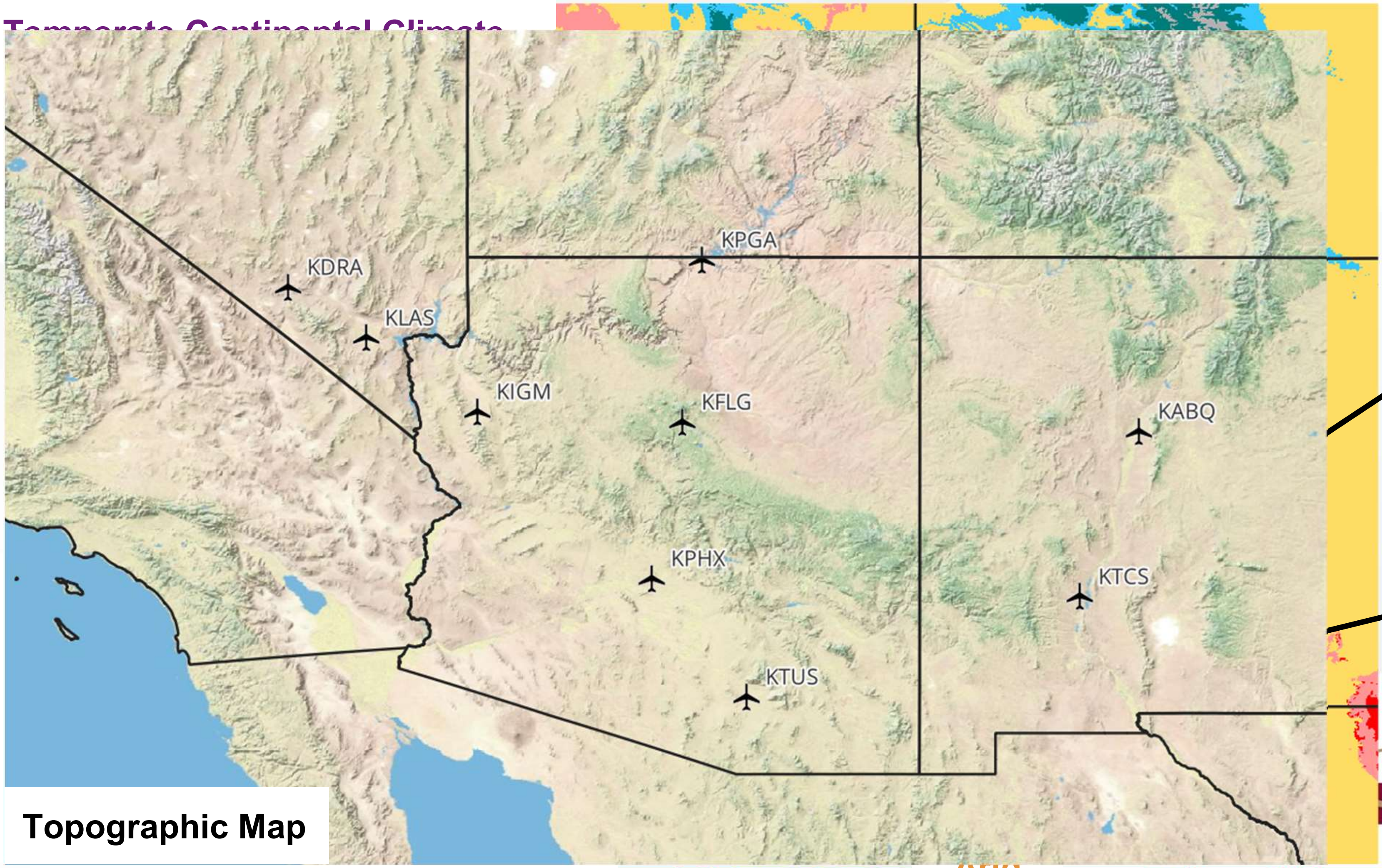


Figure: Diagram of thunderstorm formation over mountain and dust storm generation in valley

Temperate Continental Climate

Types



Topographic Map

Hot Desert Arid

Cool Semi-Arid

Cool Desert Arid

Arid

Dataset	**Variables**	**Time Span**	**Time Scale**	**Spatial Resolution**
Integrated Surface Dataset (ISD)	Sand or dust reports from manual and automated observations	1948-2022	Monthly averaged	Observation station dependent
ERA5	U wind, V wind, precipitation, evaporation, temperature, CAPE, Total Totals, water vapor	1948-2022	Monthly averaged	30 km
TerraClimate	Evapotranspiration, runoff, climate water deficit, soil moisture, palmer drought severity index, max and min temperature	1958-2022	Monthly averaged	4 km
North American Summer Monsoon Index	Index describing the North American Summer Monsoon	1948-2022	Monthly averaged only in JAS	Spans over 17.5 - 35° N to 100 - 120° W
SPEI Database	Drought Index	1901-2021	Monthly averaged	0.5 x 0.5°

Procedures

- Evaluate univariate relationships between variables and ISD dust data
- Utilize neg. Binom regression to

Results

Analysis

Limitations of the Model

Conclusions

Works Cited

National Weather Service, N. (2016, September 26). *NWS Lubbock, TX, October 17th haboob—Severe winds and blowing dust*. https://www.weather.gov/lub/events-2011-20111017-haboob

National Weather Service, N. (2018, September 14). *North American Monsoon highlights*. https://www.weather.gov/abq/northamericanmonsoon-intro

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Lit Review: Desert Dust in the Global System

- World Meteorological Organization definitions
    - Dust storms - Result of turbulent winds raising large quantities of dust into the air and reducing visibility below 1000m
    - Blowing dust - Raised by winds to moderate heights above the ground and reducing visibility at eye level but not to less than 1000m
    - Dust haze - Produced by dust particles in suspended transport which have been raised from the ground by a dust storm prior to the time of observation
- Sand storms vs. dust storms
    - Sand storms: low altitude phenomena of limited area composed of sand sized materials
    - Dust storms: higher altit onger distances and are primar

(Goudie and Middleton, 2006)

Lit Review: Desert Dust in the Global System

- Entrainment
  - In the U.S. southwest, the threshold velocities for dust entrainment range from 5.1 m/s to 16.0 m/s (~10 kt to 31 kt) depending on the surface type
  - Increased surface roughness can increase the threshold velocity needed to loft sand or dust, but also leads to higher wind friction and therefore increased emissions
  - Degree of cover by non-erodible elements (rock or vegetation)
  - Moisture content (P-E)

(Goudie and Middleton, 2006)

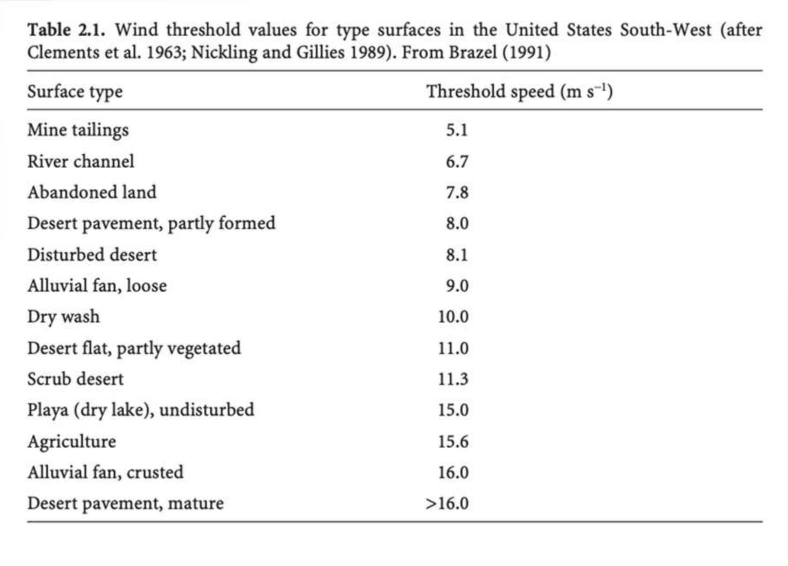
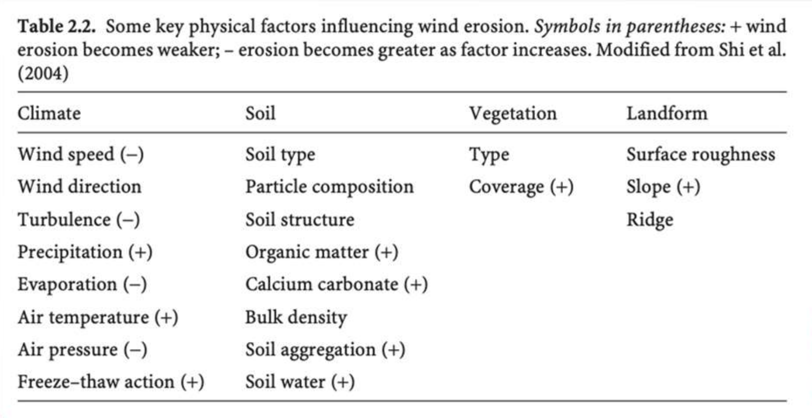


Table 2.1. Wind threshold values for type surfaces in the United States South-West (after Clements et al. 1963; Nickling and Gillies 1989). From Brazel (1991)

Surface type	Threshold speed (m s^{-1})
Mine tailings	5.1
River channel	6.7
Abandoned land	7.8
Desert pavement, partly formed	8.0
Disturbed desert	8.1
Alluvial fan, loose	9.0
Dry wash	10.0
Desert flat, partly vegetated	11.0
Scrub desert	11.3
Playa (dry lake), undisturbed	15.0
Agriculture	15.6
Alluvial fan, crusted	16.0
Desert pavement, mature	>16.0



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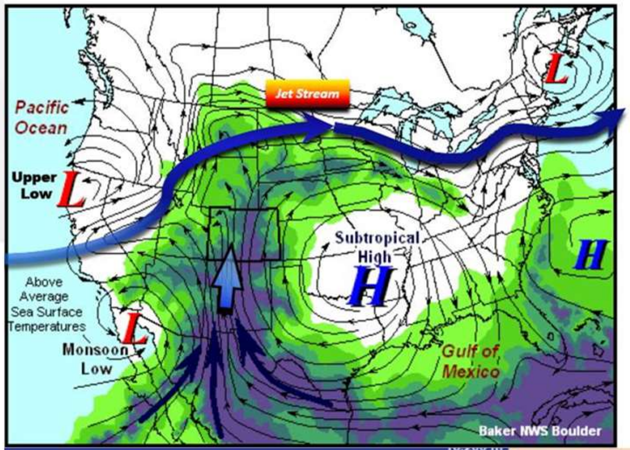
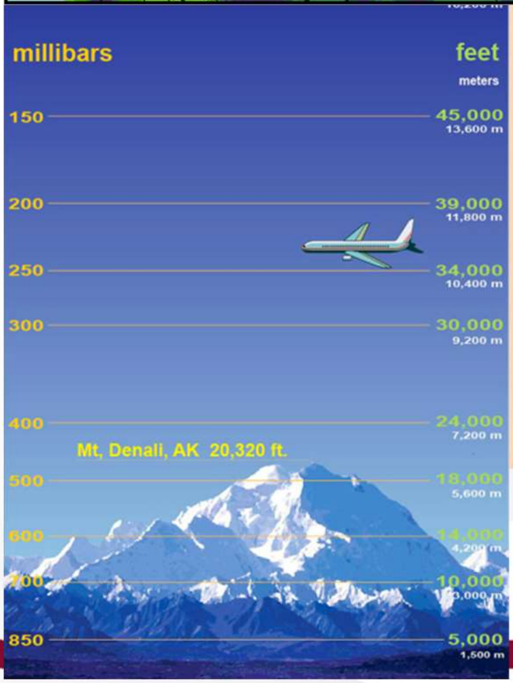
Freeze–thaw action (+)	Soil water (+)		

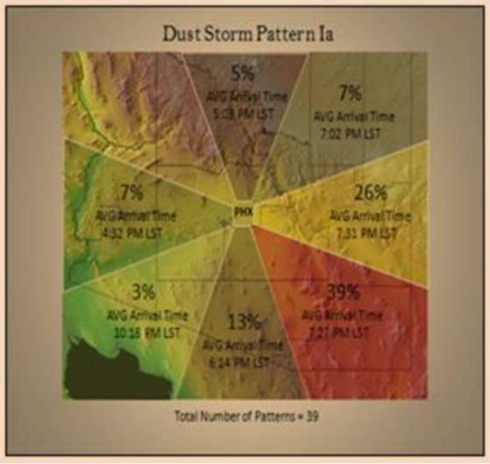
Key Takeaways From Synoptic Setups

- Can we find links between winds from the east or from the south and dust storm events in the Southwest?
    - Based on the synoptic maps, we expect an easterly flow to initiate haboobs
    - Based on the North American Monsoon, we expect a southerly flow to bring moisture into the region
- At what levels in the atmosphere do these flows influence dust storm frequency?



North American Monsoonal flow

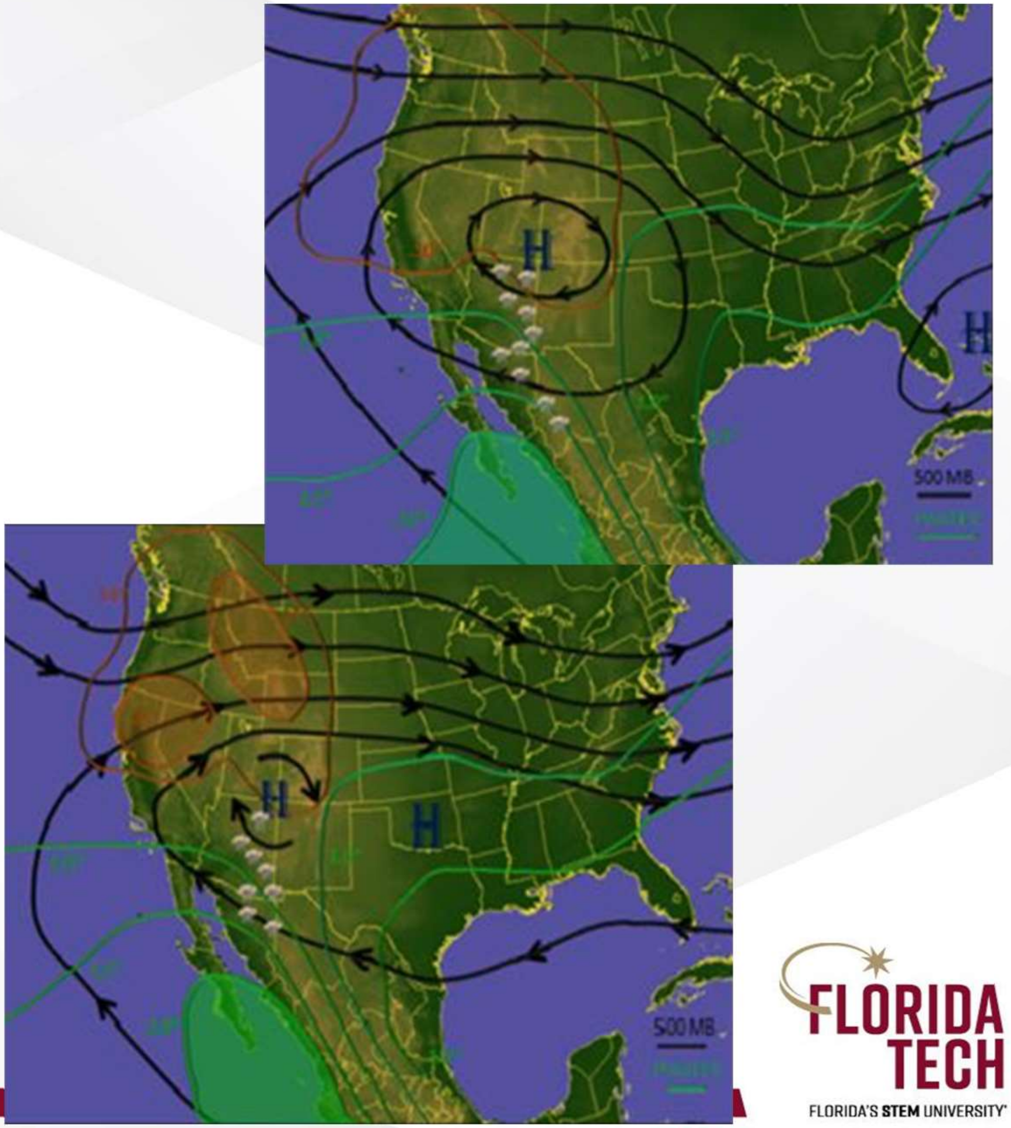




Where dust storms approach PHX from (Type 1)

Synoptic Scale Patterns for Sandstorms

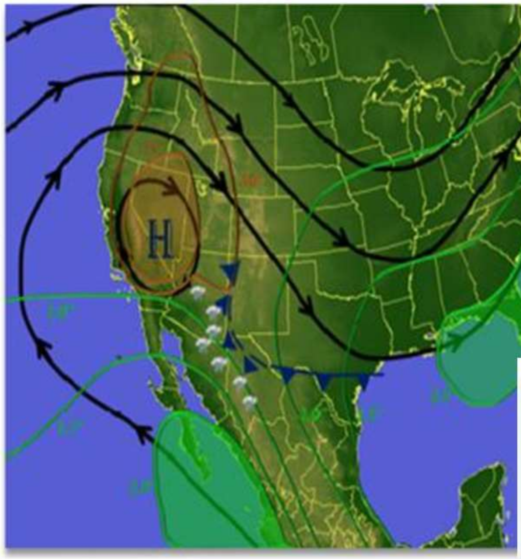
- Type 1: characterized by a large area of 500 mb high pressure over the southern and central United States
- “Four corners high” due to the location of the high pressure over the AZ-NM-UT-CO border
- Accounts for the formation about 50% of dust storms in Phoenix, AZ
- Results in dust storms that often approach from the Southeast (~35%)



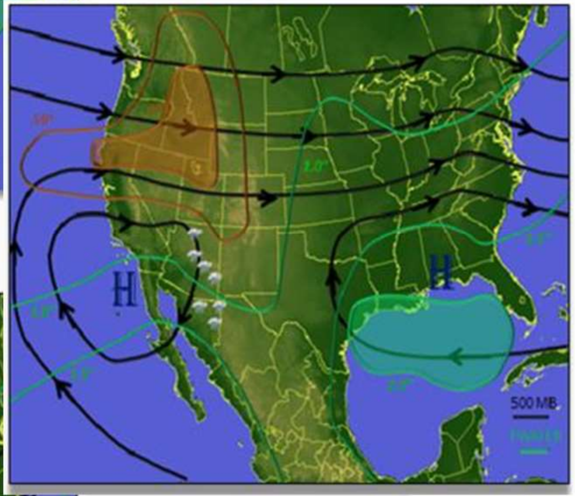
(NOAA, 2016)

Synoptic Scale Sandstorm Patterns

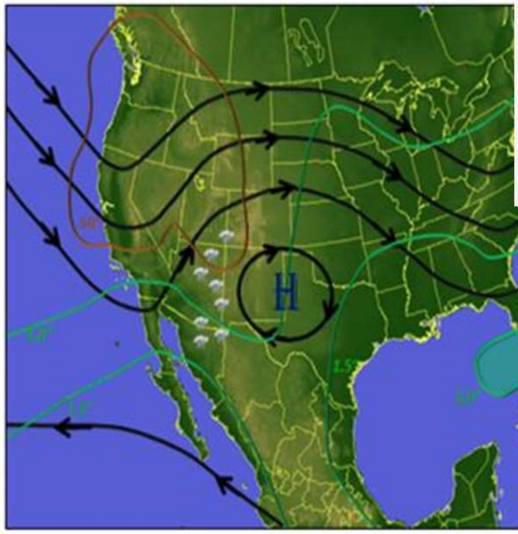
- These additional three patterns account for about 45% of sandstorms in the Southwest
- Type 2: high pressure over the Great Basin and trough over the Eastern U.S.
- Type 3: two distinct cells of high pressure in the south, sometimes accompanies by a low between highs
- Type 4: high pressure over the southern plains and a sharp trough axis over the west coast



Type 2



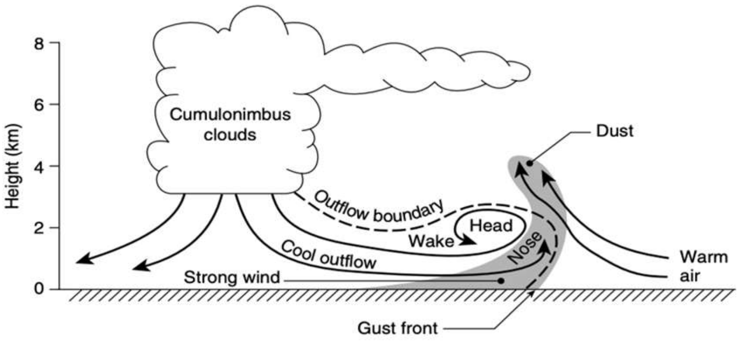
Type 3



Type 4

(NOAA, 2016)

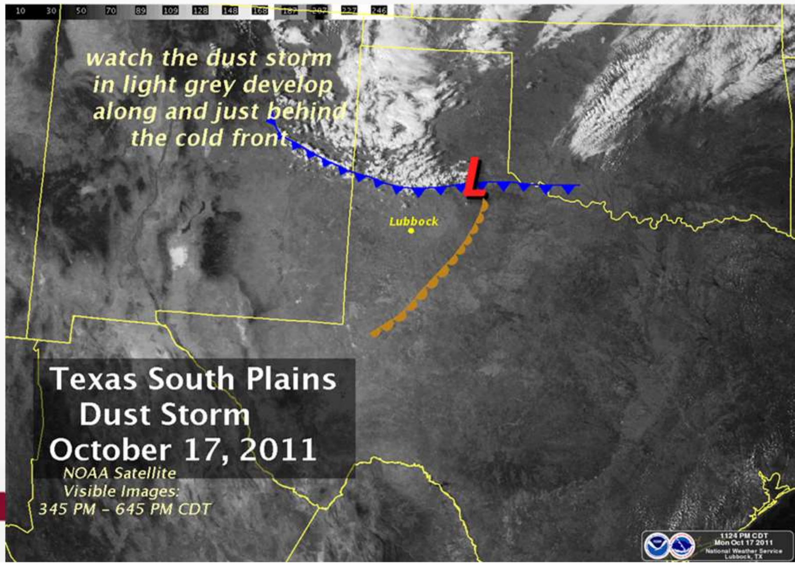
Lit Review: Desert Dust in the Global System



(Goudie and Middleton, 2006)

- Transport
  - Passage of low pressure fronts (strong baroclinic gradients)
  - Surface cyclones if intense circulation
  - Outflow propagation and gust front generation
- Deposition
  - Gravitational settling (dry deposition)
  - Precipitation (wet deposition)

** In Texas, Saharan events with moderate to high fine particulate contents occur on three to six days in the year, last for one to three days and travel from their source in 10-14 days. Not a huge concern in AZ, NM, and CA due to the terrain of the Southwest.



Yuma, AZ - Synoptic Dust Storm

	2009-12-22T19:28:00Z			34740	Southwest Deserts [AZ], Northwest and North Central Pinal County [AZ], Yuma/Martinez Lake and Vicinity [AZ], Southwest Maricopa County [AZ], Lower Colorado River Valley AZ [AZ],

KNYL - Yuma, AZ - Synoptic Event

	12/22/09	**12/22/09**	**12/22/09**	**12/22/09**	**12/23/09**	
	20 UTC	**21 UTC**	**22 UTC**	**23 UTC**	**00 UTC**	
	13 MST	**14 MST**	**15 MST**	**16 MST**	**17 MST**	**AVERAGE**
Wind Direction	290	280	280	280	290	284
Wind Speed (kts)	19	22	15	9	16	16.2
Pk Wind Gust (kts)	27	28	26	18	20	23.8

KNYL 222051Z 29019G27KT 6SM **BLDU** HZ SCT050 BKN120 18/00 A2968 RMK AO2 PK WND 28035/2003 SLP051 T01780000 58019

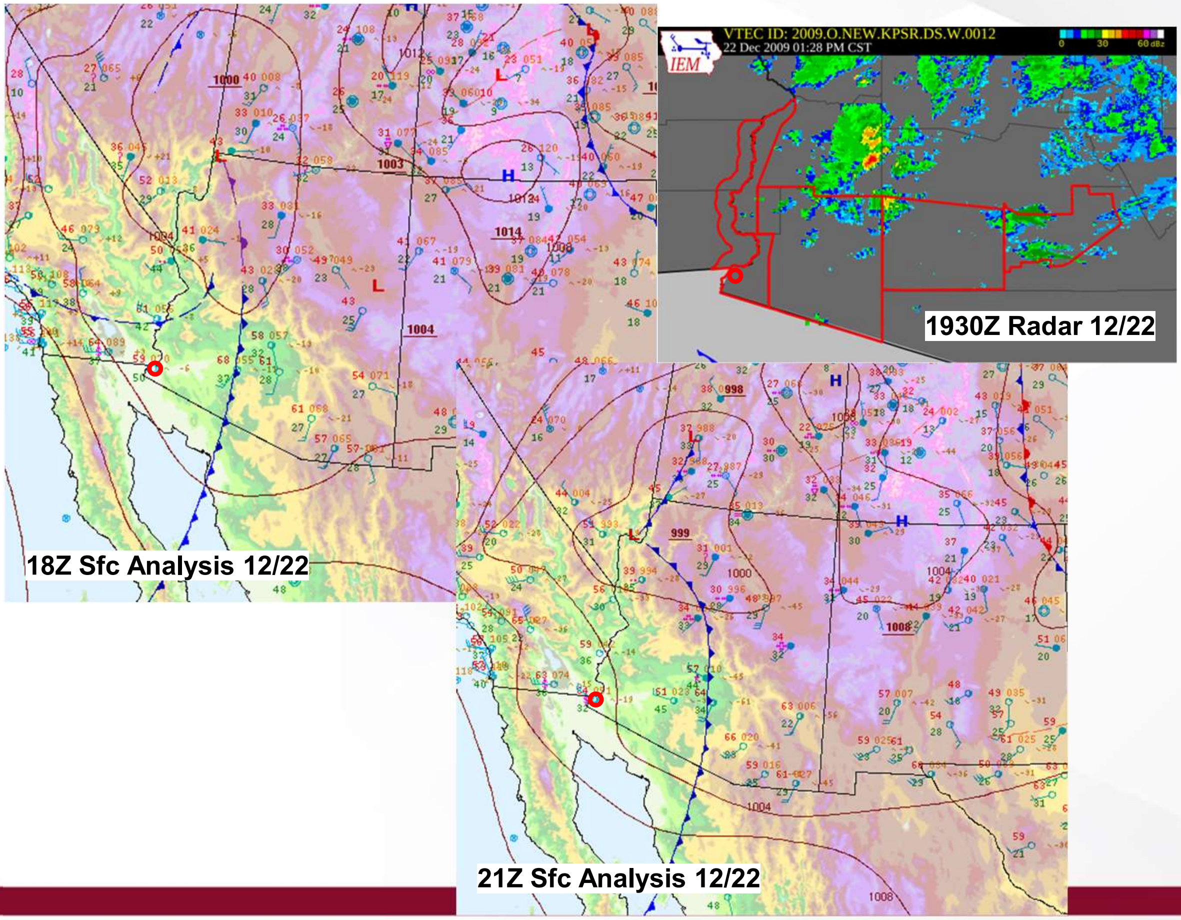
KNYL 222151Z 28022G28KT 8SM **DU** HZ SCT050 BKN120 17/M02 A2968 RMK AO2 PK WND 27029/2126 SLP051 T01721017

KNYL 222251Z 28015G26KT 10SM **DU** HZ CLR 17/M01 A2968 RMK AO2 PK WND 28030/2156 SLP050 T01721011

KNYL 222351Z 28009G18KT 10SM CLR 16/01 A2969 RMK AO2 PK WND 29027/2325 SLP054 T01610011 10183 20150 53003

KNYL 230051Z 29016G20KT 10SM CLR 14/01 A2970 RMK AO2 SLP056 T01440006

Yuma, AZ - Synoptic Dust Storm



18Z Sfc Analysis 12/22

1930Z Radar 12/22

21Z Sfc Analysis 12/22

AREA FORECAST DISCUSSION
NATIONAL WEATHER SERVICE PHOENIX AZ
302 PM MST TUE DEC 22 2009

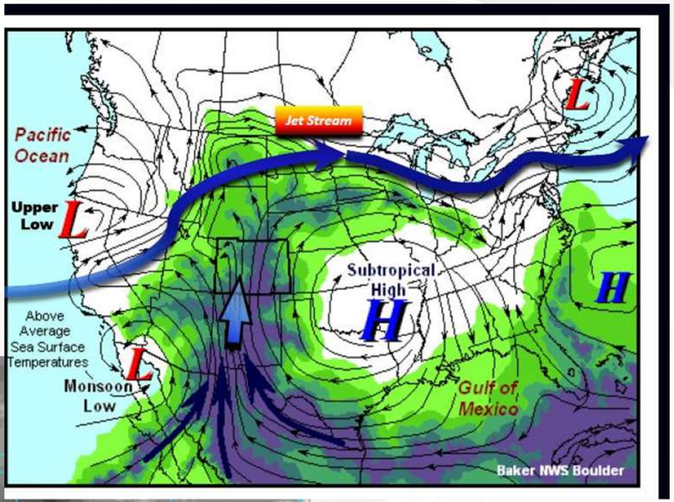
.SYNOPSIS...
A STRONG **LOW PRESSURE SYSTEM** AND ASSOCIATED **COLD FRONT** WILL BRING COLDER AND BREEZY TO WINDY WEATHER INTO THE REGION THIS EVENING...WITH THE STRONGEST WINDS EXPECTED IN SOUTHEAST CALIFORNIA AND SOUTHWEST ARIZONA PRODUCING AREAS OF BLOWING DUST.

…

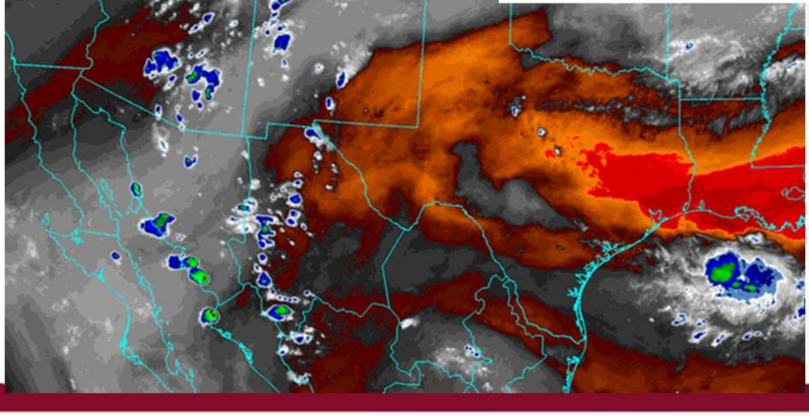
THE STRONG GUSTY WINDS HAVE RESULTED IN AREAS OF BLOWING DUST ACROSS OUR SOUTHERN ZONES. A **WIND ADVISORY** AND DUST STORM WARNING ARE IN EFFECT FOR PORTIONS OF THE PHOENIX FORECAST AREA THROUGH THIS EVENING.

North American Summer Monsoon

(Colorado Climate Center)

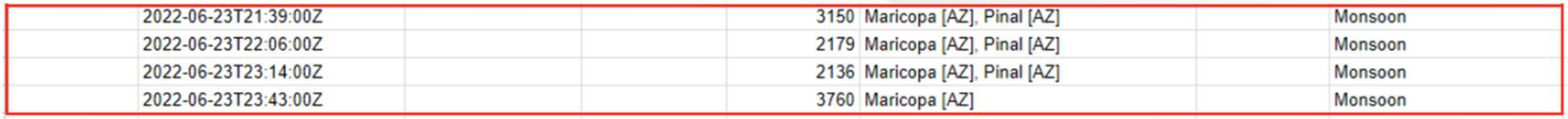


(Climate.gov)



- Forms due to uneven heating of the land vs. the surrounding ocean
- Begins to develop in Mexico in June, then impacts the southwestern United States in July through September
- High pressure over the Southwest paired with southerly winds bring moisture from the Gulf of California and the Pacific Ocean into the region
- This moisture increase paired with heat from the surface generates monsoonal thunderstorms that bring isolated heavy rain

Phoenix, AZ - Monsoonal Dust Storm

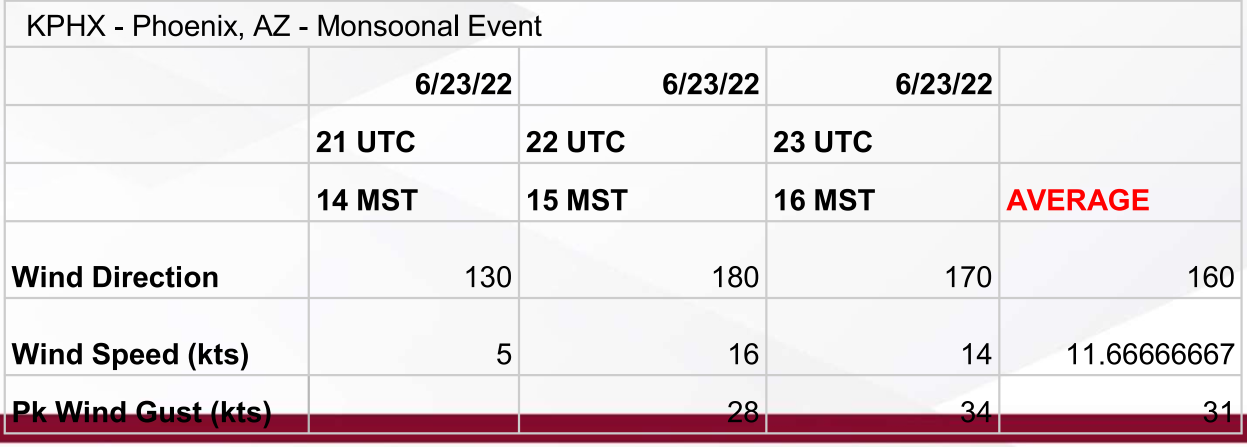


2022-06-23T21:39:00Z			3150	Maricopa [AZ], Pinal [AZ]		Monsoon
2022-06-23T22:06:00Z			2179	Maricopa [AZ], Pinal [AZ]		Monsoon
2022-06-23T23:14:00Z			2136	Maricopa [AZ], Pinal [AZ]		Monsoon
2022-06-23T23:43:00Z			3760	Maricopa [AZ]		Monsoon

KPHX 232151Z 13005KT 10SM FEW040 FEW060 SCT120 SCT220 SCT270 41/12 A2970 RMK AO2 LTG DSNT S SLP033 CB DSNT E-S-SW SHRA DSNT SE-SW T04110117

KPHX 232251Z 18016G28KT 5SM **VCTS BLDU** FEW040 SCT060CB SCT120 BKN160 BKN190 BKN250 39/09 A2968 RMK AO2 PK WND 19028/2248 LTG DSNT SE-SW SLP029 CB VC W MOV NE CB DSNT E-S-SW SHRA SE-E BLDU VC E-SW T03890094

,KPHX 232358Z 17012G23KT 120V200 2SM -TSRA **BLDU** SCT019 BKN090CB BKN110 BKN190 29/17 A2977 RMK AO2 OCNL LTGIC ALQDS TS ALQGS MOV NE P0000 T02940172



KPHX - Phoenix, AZ - Monsoonal Event

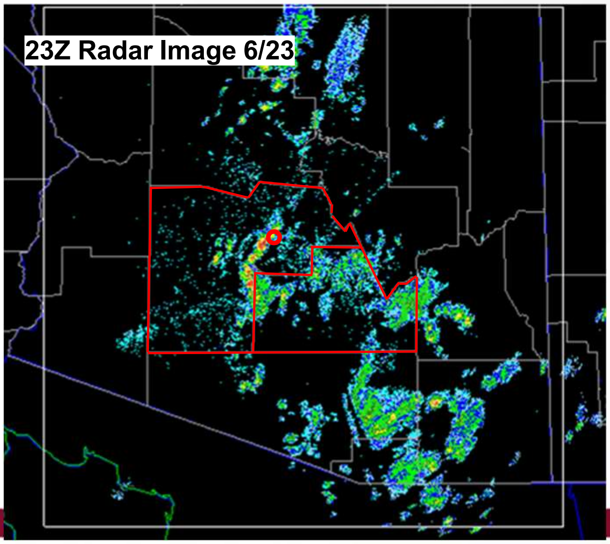
	6/23/22	**6/23/22**	**6/23/22**	
	21 UTC	**22 UTC**	**23 UTC**	
	14 MST	**15 MST**	**16 MST**	**AVERAGE**
Wind Direction	130	180	170	160
Wind Speed (kts)	5	16	14	11.66666667
Pk Wind Gust (kts)		28	34	31

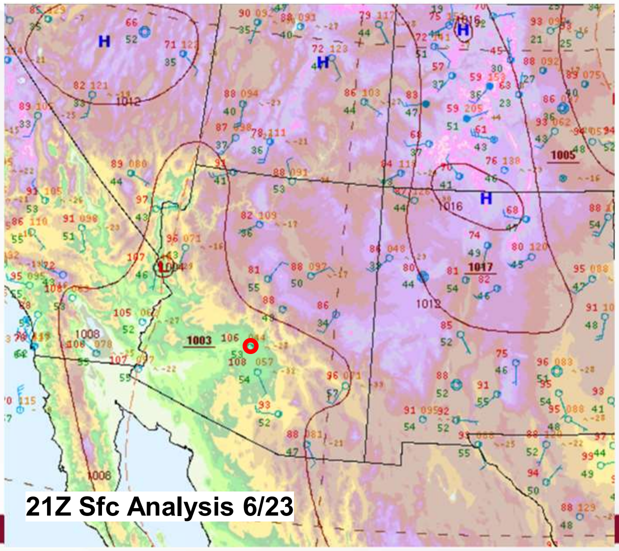
Phoenix, AZ - Monsoonal Dust Storm

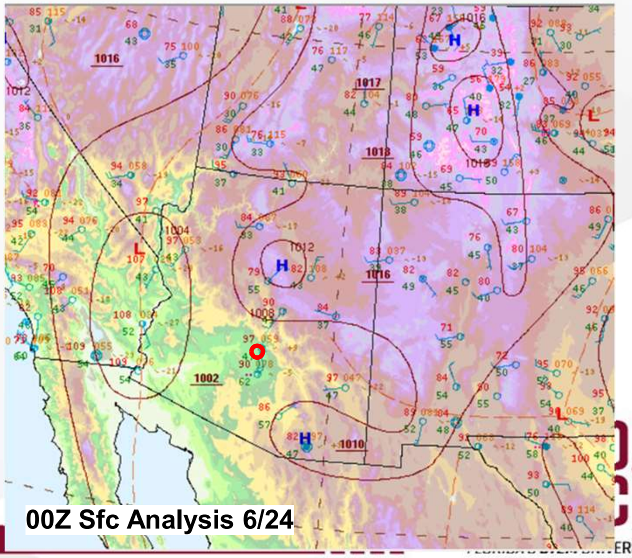
Monsoonal moisture will continue to promote daily opportunities for shower and thunderstorm activity during the next several days. Today, the highest coverage of storms will be across the northern and eastern half of Arizona, including portions of the Phoenix metro. **Strong to severe thunderstorm wind gusts, blowing dust, heavy rain, and lightning** will be the main weather risks in these areas.

…

HREF has greater than a 70% chance of seeing winds of 35 mph or greater across much of these areas, including the Phoenix area and the dust corridor on 1-10 between Tucson and Phoenix. Therefore, blowing dust/dust storms will also be a concern today across Maricopa and Pinal counties. In addition, the HREF max 4 hr wind speed is showing the potential for some downbursts to produce 50-60 kts winds.


23Z Radar Image 6/23


21Z Sfc Analysis 6/23


00Z Sfc Analysis 6/24

The North American Monsoon

- Regional variability
  - Great variability of precipitation in the Southwestern U.S.
  - Mountainous regions in central Arizona experience greater amounts of rainfall during the monsoon season than the desert southwest.
- Localized variability
  - In Arizona, only small to moderate interstation correlations exist between rainfall events due to the isolated nature of the monsoonal thunderstorms
  - Maximum in convective activity:
    - Colorado Plateau - early afternoon
    - Highlands of southern AZ and northern Sonora - early evening
    - Lower desert regions of southern and central AZ - late evening and early morning

(Adams and Comrie, 1997)

The North American Monsoon and Global Warming

- Global monsoon rainfall is projected to increase due to global warming and an increase in water vapor capacity
  - The Asian and North African monsoon rainfall totals are projected to increase
  - The North American Monsoon rainfall total is projected to be uncertain or even decrease
- Sea surface temperatures over the equatorial Pacific are increasing, resulting in a smaller sea-land temperature gradient, thus weakening the NAM
- These findings apply mainly to the Central-American region of the NAM, but could ultimately influence the strength of the NAM over time in the Southwestern U.S.

(He et al., 2020)

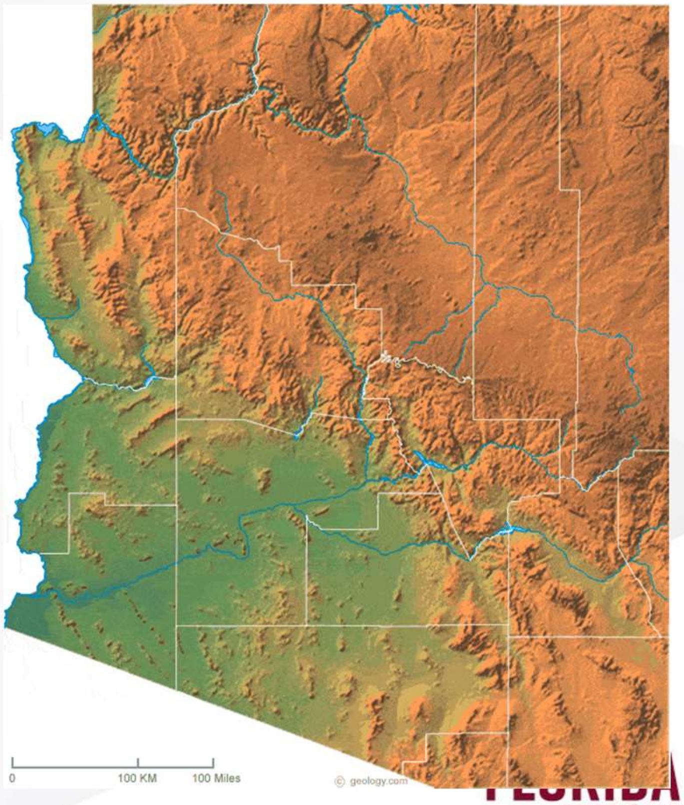
Factors to Consider

There are many known factors that contribute to dust storm formation in the southwestern United States

- Land use/land cover
- Soil moisture
- Wind
- Precipitation

** Wind and precipitation vary on an annual scale due to the summer monsoon that impacts the Southwest.

** We must carefully move forward by separating monsoonal events from synoptic events



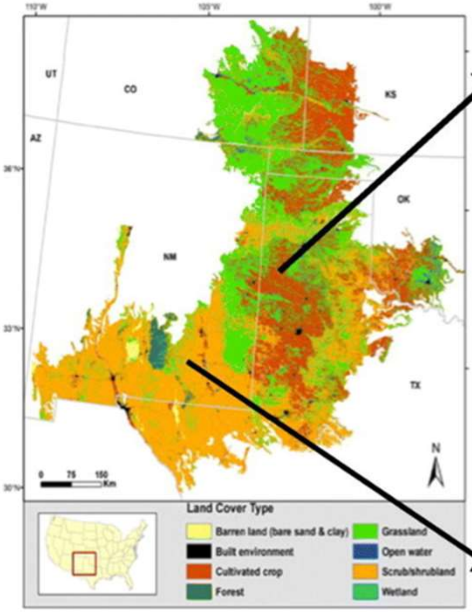
Lit review: land use/land cover

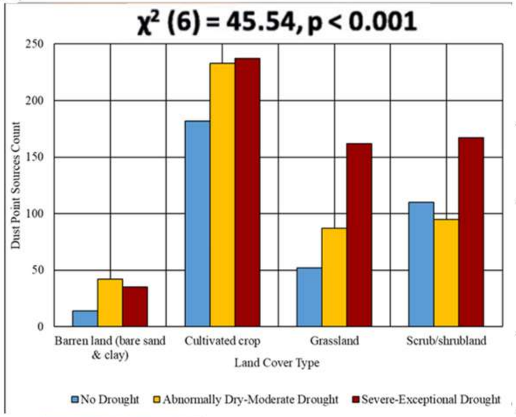
Land cover

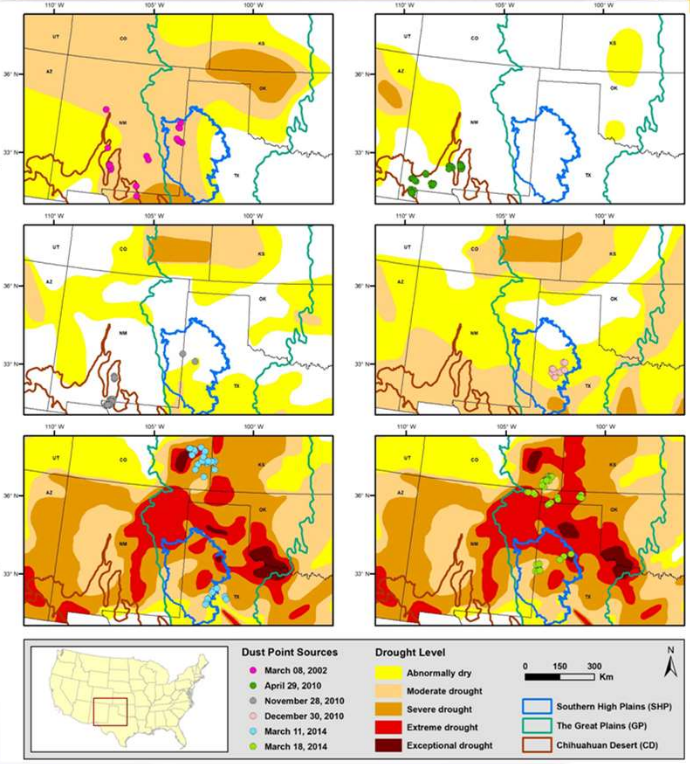
Significantly associated with

Drought

in the contribution to the number of dust point sources in southwestern U.S.







Anthropogenic impact → "Human activities in dust-prone regions have clear potential to worsen the negative impacts of drought by changing LULC and increasing erodibility in multiple ways."

(Yin et al., 2006)

Lit review:

Impacts of **wind, precipitation, vegetation, and soil moisture** on dust storm frequency in Northern China

(Kandakji et al., 2005)

- Spring dust storm frequency (DSF):
  - Positively correlated with upwind wind speed
  - Negatively correlated with
    - Amount of rainfall and moisture in the soil (during previous summer and the whole year)
    - Spring vegetation condition
- Primary factor influencing spring DSF = amount of rainfall during previous summer near China-Mongolia border
  - as this rain impacts soil moisture during the summer, influencing vegetation health in the following spring

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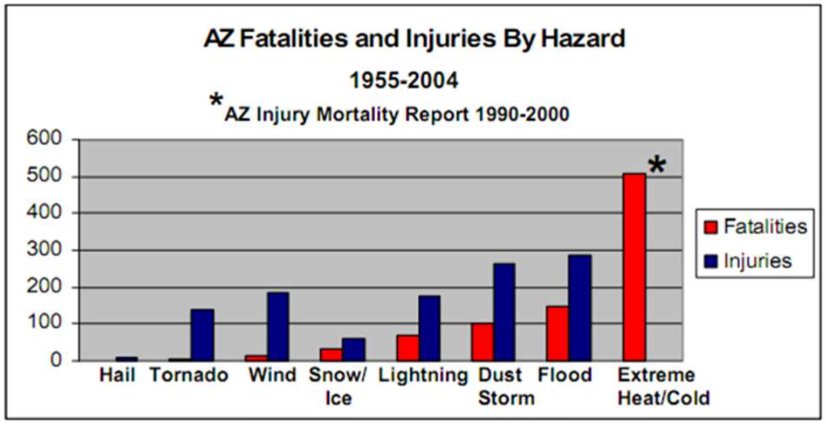
Research Problem

Dust storms loft large amounts of sand an
dust into the atmosphere in the Southwest
United States.

- Human health: Decreased air quality from dust can irritate lung tissue, trigger allergic reactions, and cause asthma attacks
- Aviation: Limited visibility and engine clogging
- Weather and climate: Cloud condensation nuclei increase
- Environment: Crop yield reduction, reduced photosynthesis in plants, increased erosion
- Society: Decreased visibility while driving and diversion of solar radiation from solar panels

Why Do We Care?

Arizona Deaths and Injuries
by Hazardous Weather Type



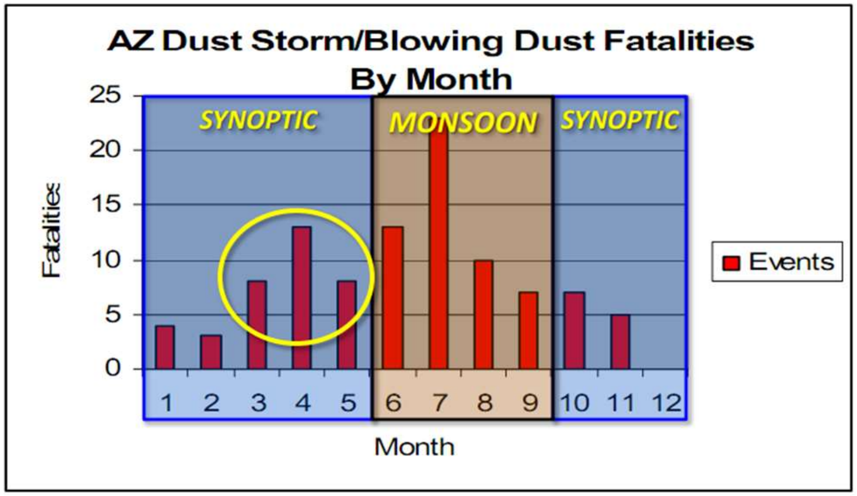
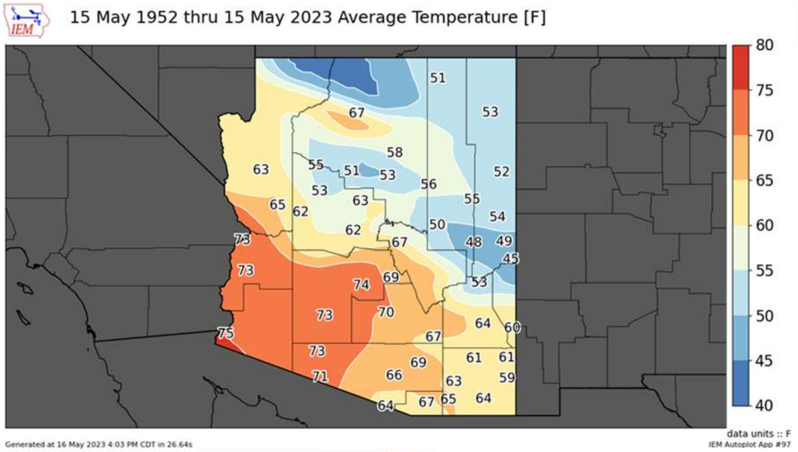


Figure 25. Frequency of dust storm fatalities by month from 1955 to 2004

Climate Zones in the Southwestern U.S.

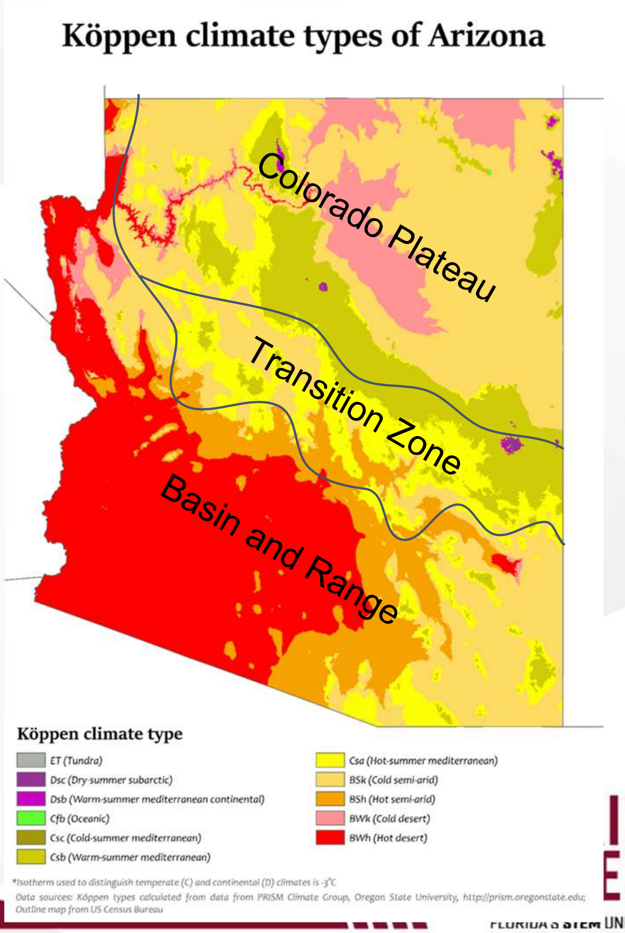
(Peterson, 2016)



15 May 1952 thru 15 May 2023 Average Temperature [F]

Generally, Arizona's climate is considered arid or semi-arid

- Plateau: Elevation upwards of 8,000 ft
- Transition Zone: Rugged mountains
- Basin and Range: Lowland deserts



Köppen climate types of Arizona

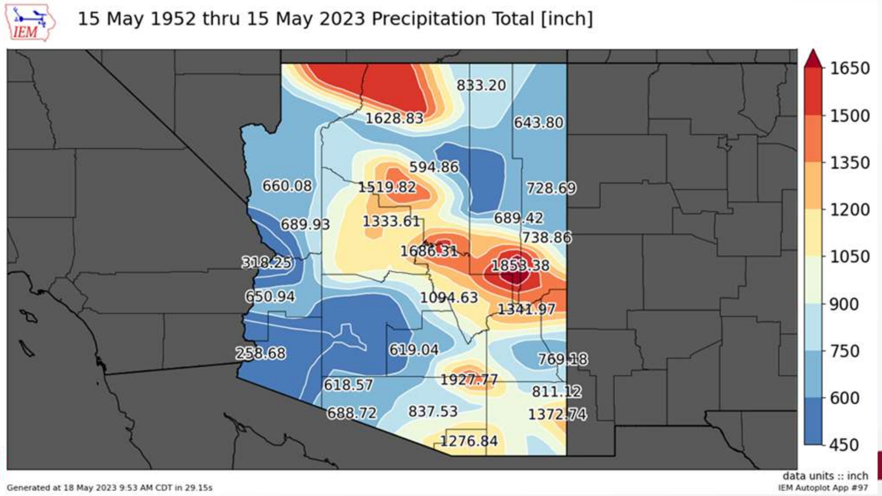
Köppen climate type

ET (Tundra)	Csa (Hot-summer mediterranean)
Dsc (Dry-summer subarctic)	BSk (Cold semi-arid)
Dsb (Warm-summer mediterranean continental)	BSh (Hot semi-arid)
Cfb (Oceanic)	BWk (Cold desert)
Csc (Cold-summer mediterranean)	BWh (Hot desert)
Csb (Warm-summer mediterranean)	

*Isotherm used to distinguish temperate (C) and continental (D) climates is -3°C

Data sources: Köppen types calculated from data from PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu; Outline map from US Census Bureau

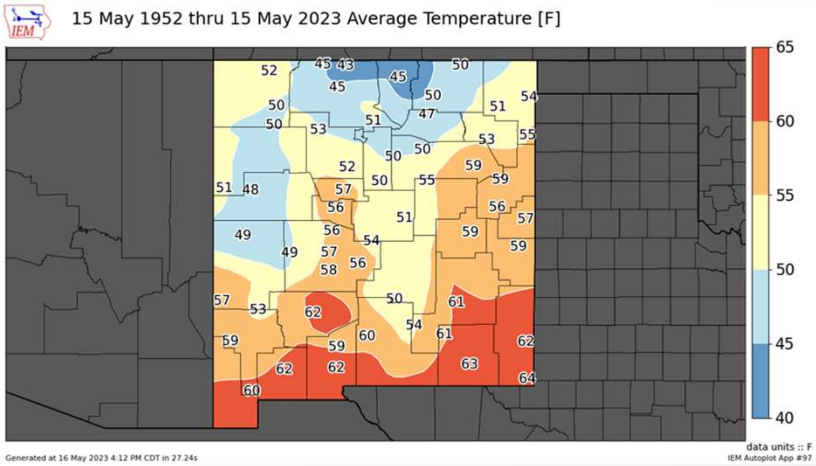
(Iowa Environmental Mesonet of Iowa State University)



15 May 1952 thru 15 May 2023 Precipitation Total [inch]

Climate Zones in the Southwestern U.S.

(Peterson, 2016)


15 May 1952 thru 15 May 2023 Average Temperature [F]

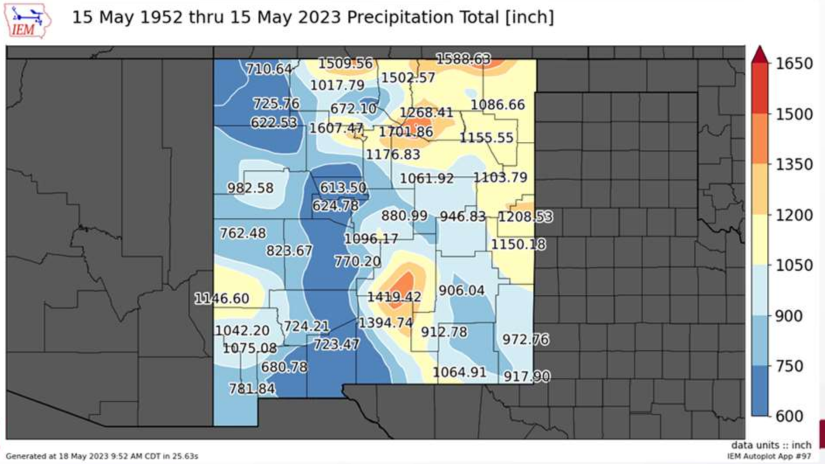
Generated at 16 May 2023 4:12 PM CDT in 27.24s

-Mountains in the northwestern part of the state

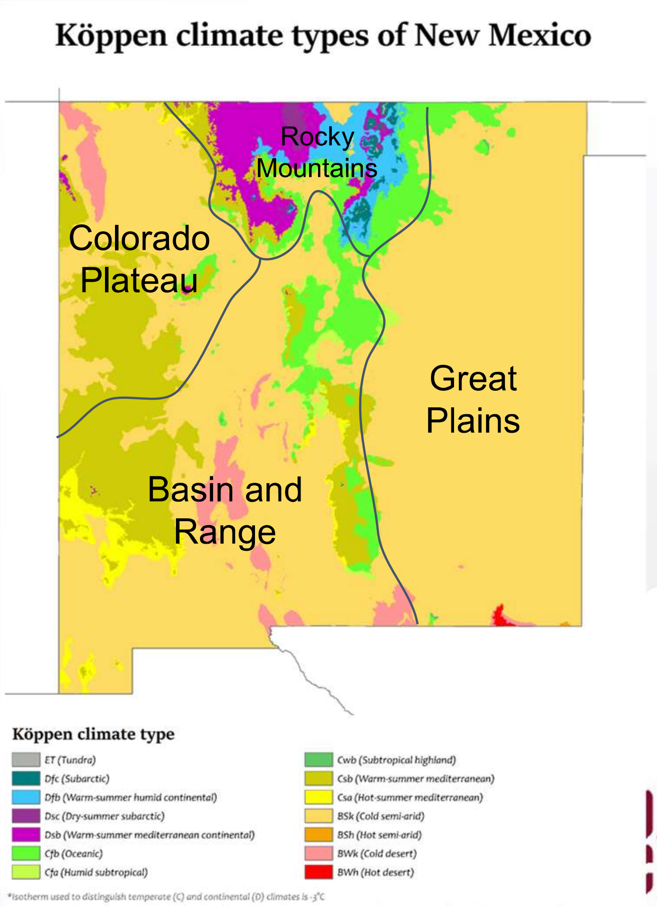
- Lowlands in the southeastern part of the state

-Basin and Range continues into southern AZ

(Iowa Environmental Mesonet of Iowa State University)


15 May 1952 thru 15 May 2023 Precipitation Total [inch]

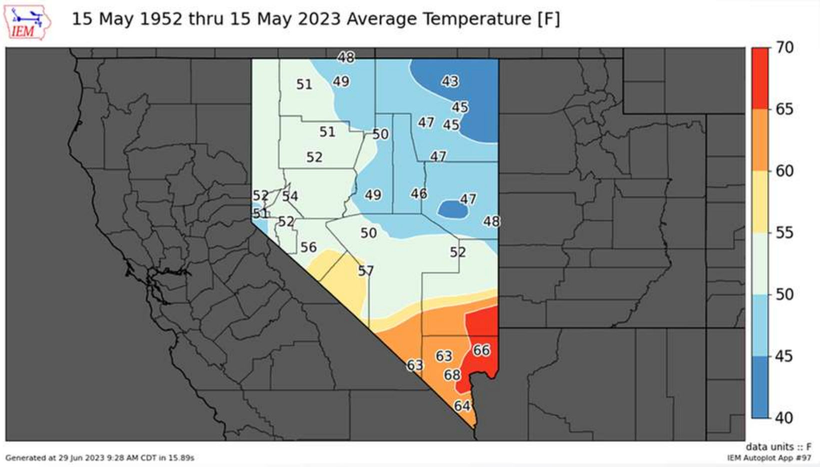
Generated at 18 May 2023 9:52 AM CDT in 25.63s


Köppen climate types of New Mexico

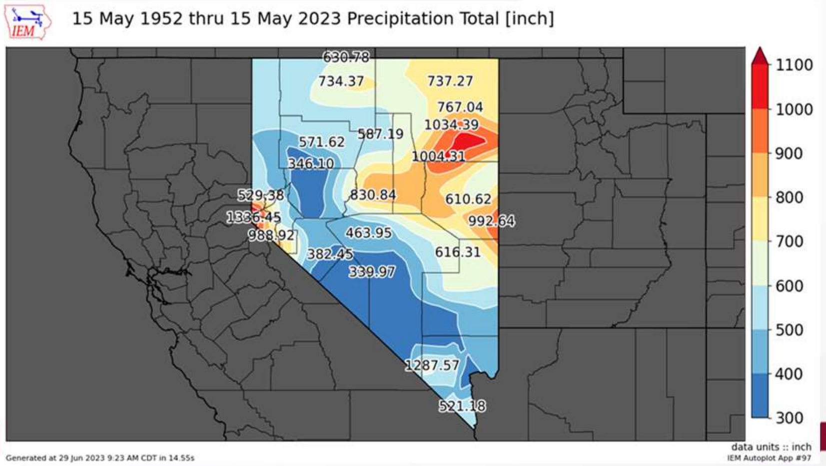
*Isotherm used to distinguish temperate (C) and continental (D) climates is -3°C

Data sources: Köppen types calculated from data from PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu; Outline map from US Census Bureau

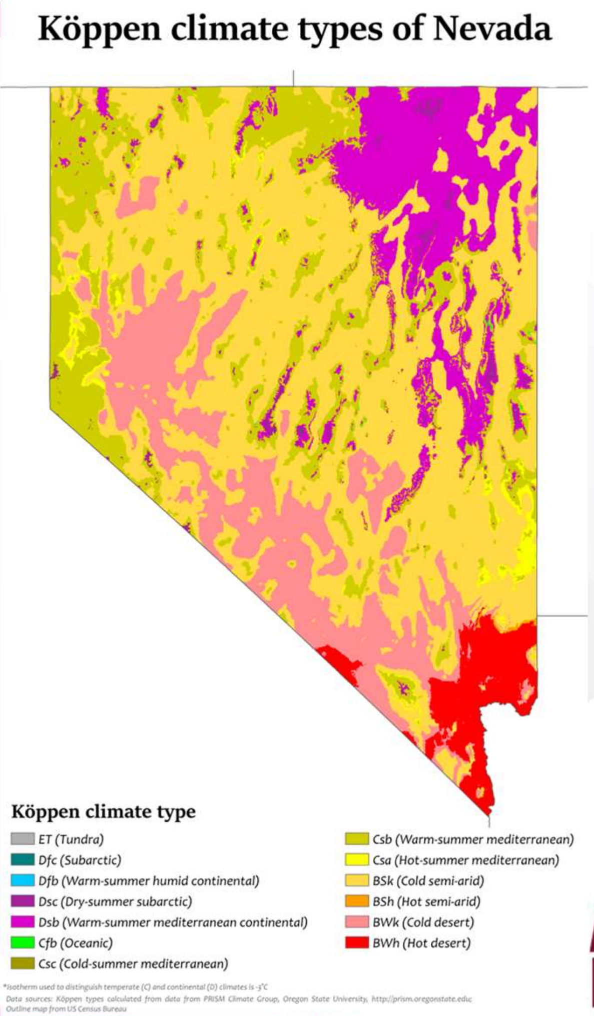
Climate Zones in the Southwestern U.S


15 May 1952 thru 15 May 2023 Average Temperature [F]

(Iowa Environmental Mesonet of Iowa State University)


15 May 1952 thru 15 May 2023 Precipitation Total [inch]

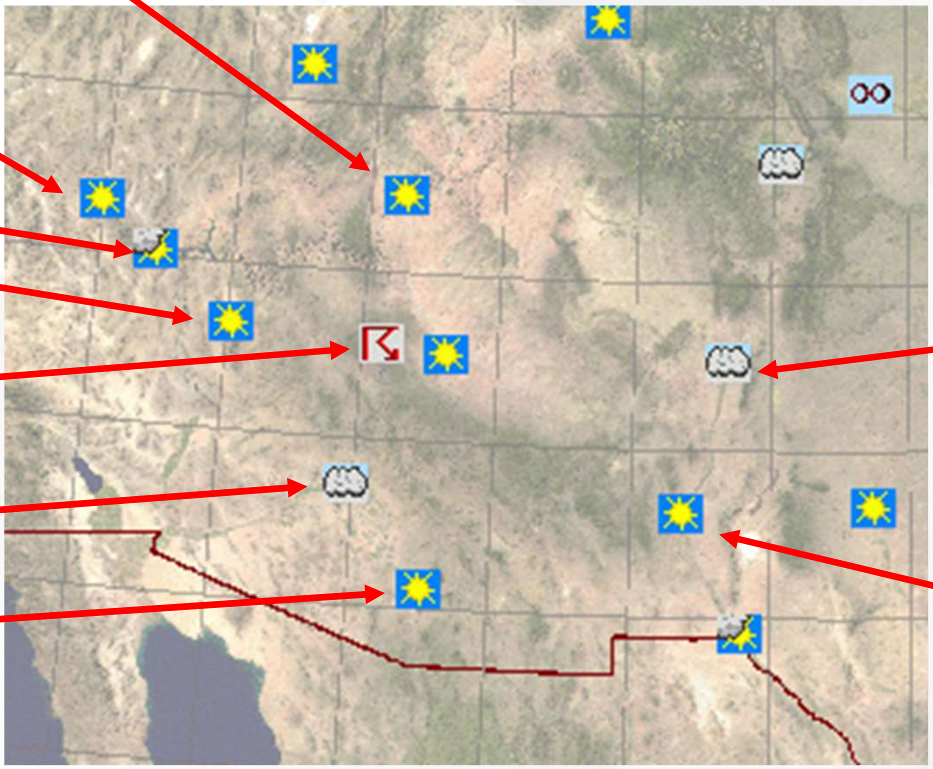
(Peterson, 2016)


Köppen climate types of Nevada

*Isotherm used to distinguish temperate (C) and continental (D) climates is -3°C
Data sources: Köppen types calculated from data from PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu
Outline map from US Census Bureau

OGIMET Synoptic Report: Locations in the Southwest US

(OGIMET: graphic synop report)



Page, AZ

Desert Rock Airport, NV

Las Vegas, NV

Kingman, AZ

Flagstaff, AZ

Phoenix, AZ

Tucson, AZ

Albuquerque, NM

Truth or Consequence, NM

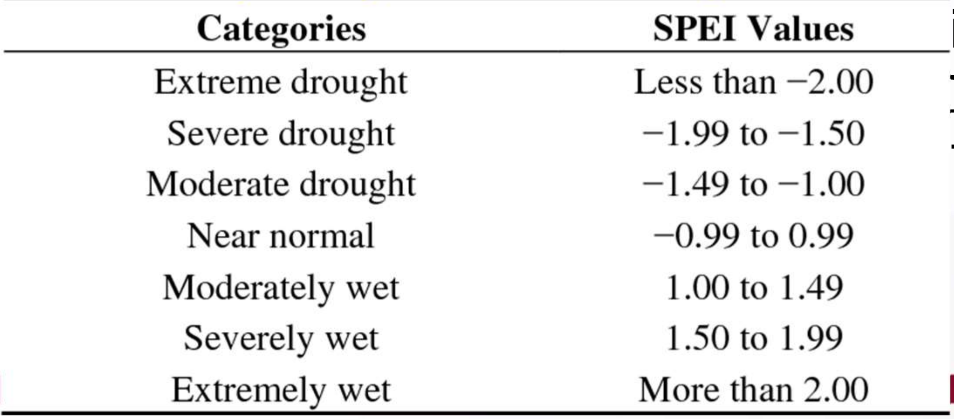
Current Datasets:

- Standardized Precipitation Evapotranspiration Index (SPEI)
- Iowa Environmental Mesonet - Dust Storm Warning Data
- Web-based Reanalysis Intercomparison Tools (WRIT)
- Integrated Surface Dataset (ISD)
  - METARS
  - SYNOPS

SPEI

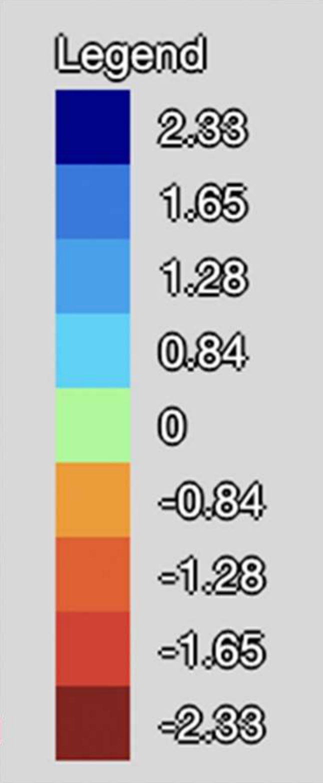
Standardized Precipitation Evapotranspiration Index (SPEI)

- Multiscalar index used to quantify drought
- Based on a climate water balance
  - Calculated using the monthly difference between precipitation and potential evapotranspiration (PET).



Categories	SPEI Values
Extreme drought	Less than −2.00
Severe drought	−1.99 to −1.50
Moderate drought	−1.49 to −1.00
Near normal	−0.99 to 0.99
Moderately wet	1.00 to 1.49
Severely wet	1.50 to 1.99
Extremely wet	More than 2.00

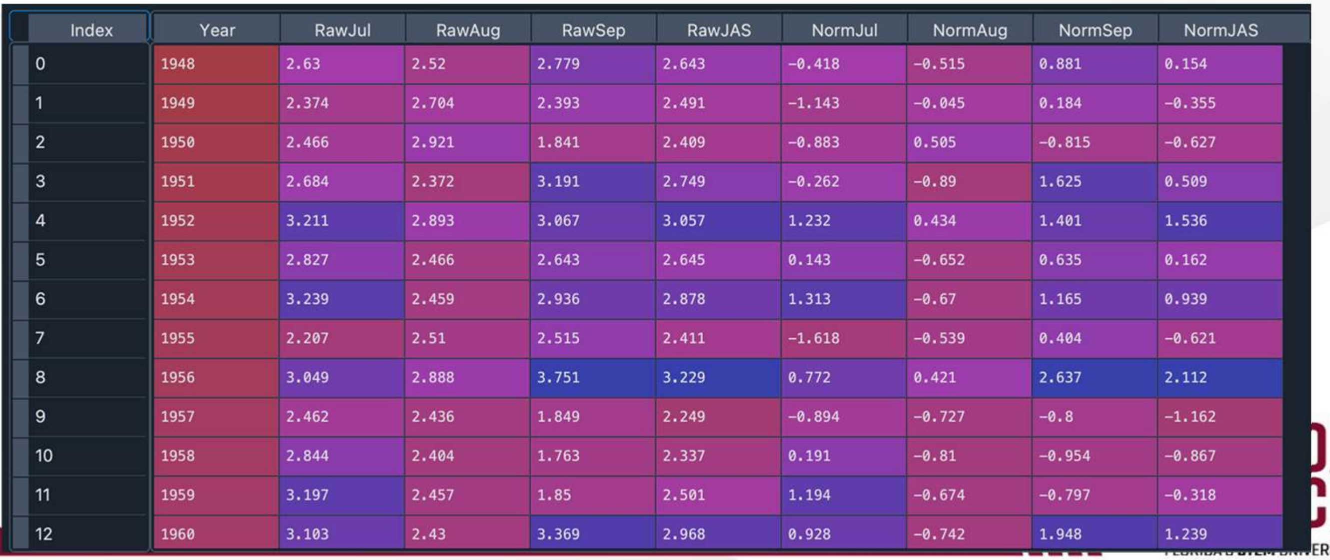
imatic water balance which
ne scales to obtain the SPEI
ths



North American Summer Monsoon Index (NASMI)

- Data spans from 1948 through 2022
- Quantifies the strength of the summer monsoon and provides both raw and normalized values for July, August, and September
- Averaged values

This is the dataset currently being worked with. Future plans are presented in later slides.



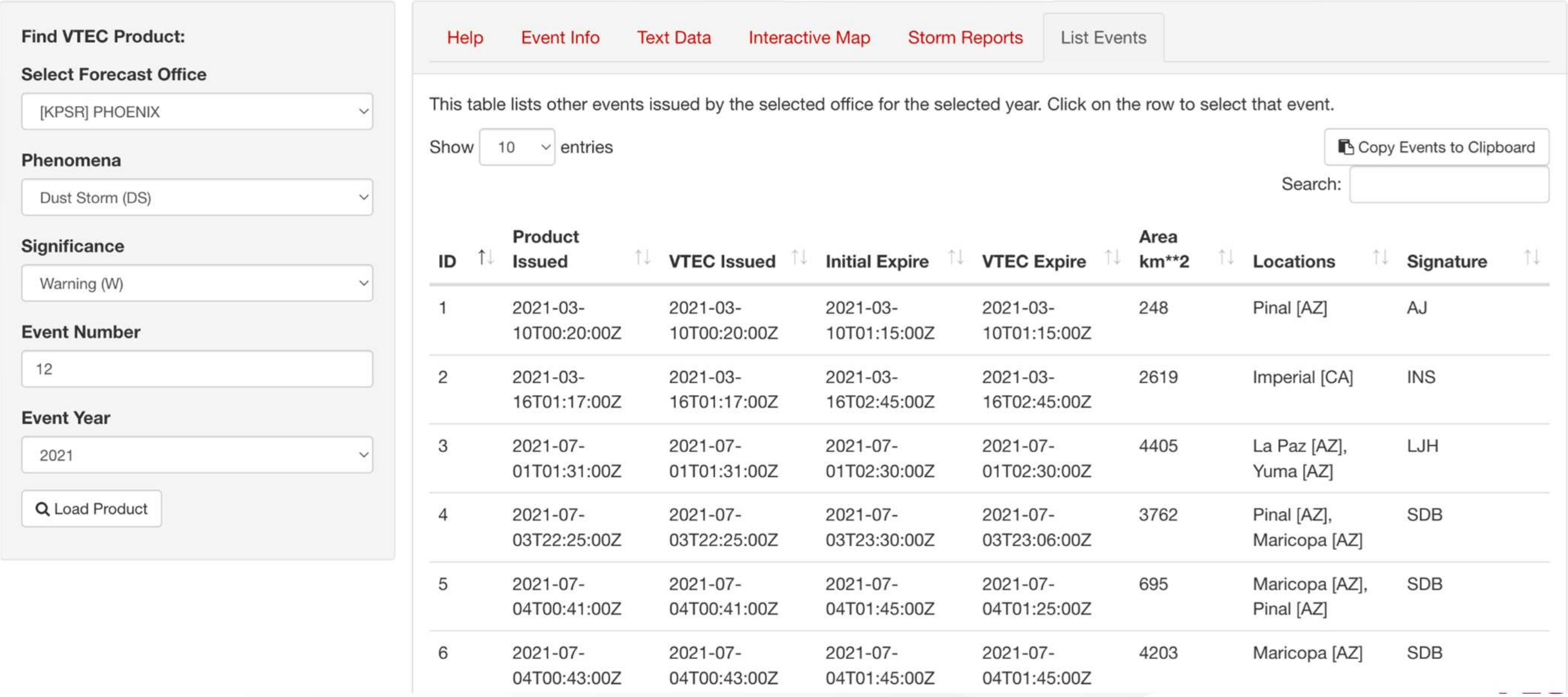
Index	Year	RawJul	RawAug	RawSep	RawJAS	NormJul	NormAug	NormSep	NormJAS
0	1948	2.63	2.52	2.779	2.643	−0.418	−0.515	0.881	0.154
1	1949	2.374	2.704	2.393	2.491	−1.143	−0.045	0.184	−0.355
2	1950	2.466	2.921	1.841	2.409	−0.883	0.505	−0.815	−0.627
3	1951	2.684	2.372	3.191	2.749	−0.262	−0.89	1.625	0.509
4	1952	3.211	2.893	3.067	3.057	1.232	0.434	1.401	1.536
5	1953	2.827	2.466	2.643	2.645	0.143	−0.652	0.635	0.162
6	1954	3.239	2.459	2.936	2.878	1.313	−0.67	1.165	0.939
7	1955	2.207	2.51	2.515	2.411	−1.618	−0.539	0.404	−0.621
8	1956	3.049	2.888	3.751	3.229	0.772	0.421	2.637	2.112
9	1957	2.462	2.436	1.849	2.249	−0.894	−0.727	−0.8	−1.162
10	1958	2.844	2.404	1.763	2.337	0.191	−0.81	−0.954	−0.867
11	1959	3.197	2.457	1.85	2.501	1.194	−0.674	−0.797	−0.318
12	1960	3.103	2.43	3.369	2.968	0.928	−0.742	1.948	1.239

SPEI cont.

- Calculation:
  - Comparing the cumulative distribution function of monthly precipitation minus monthly potential evapotranspiration against a fitted probability distribution
- Data that goes back to 1901? → calculated using historical climate data
  - Index can be estimated for earlier periods by using global gridded climate datasets and statistical modeling techniques
  - Reanalysis datasets; combining observations from various sources
- Limitations:
  - The availability and quality of climate data may vary across regions and time periods
  - Data limitations in sparsely monitored regions introduce uncertainty in calculations
  - Certain factors which can influence drought impacts are not directly accounted for

IEM: Dust Storm Warnings

(Iowa Environmental Mesonet of Iowa State University)



Find VTEC Product:

Select Forecast Office: [KPSR] PHOENIX

Phenomena: Dust Storm (DS)

Significance: Warning (W)

Event Number: 12

Event Year: 2021

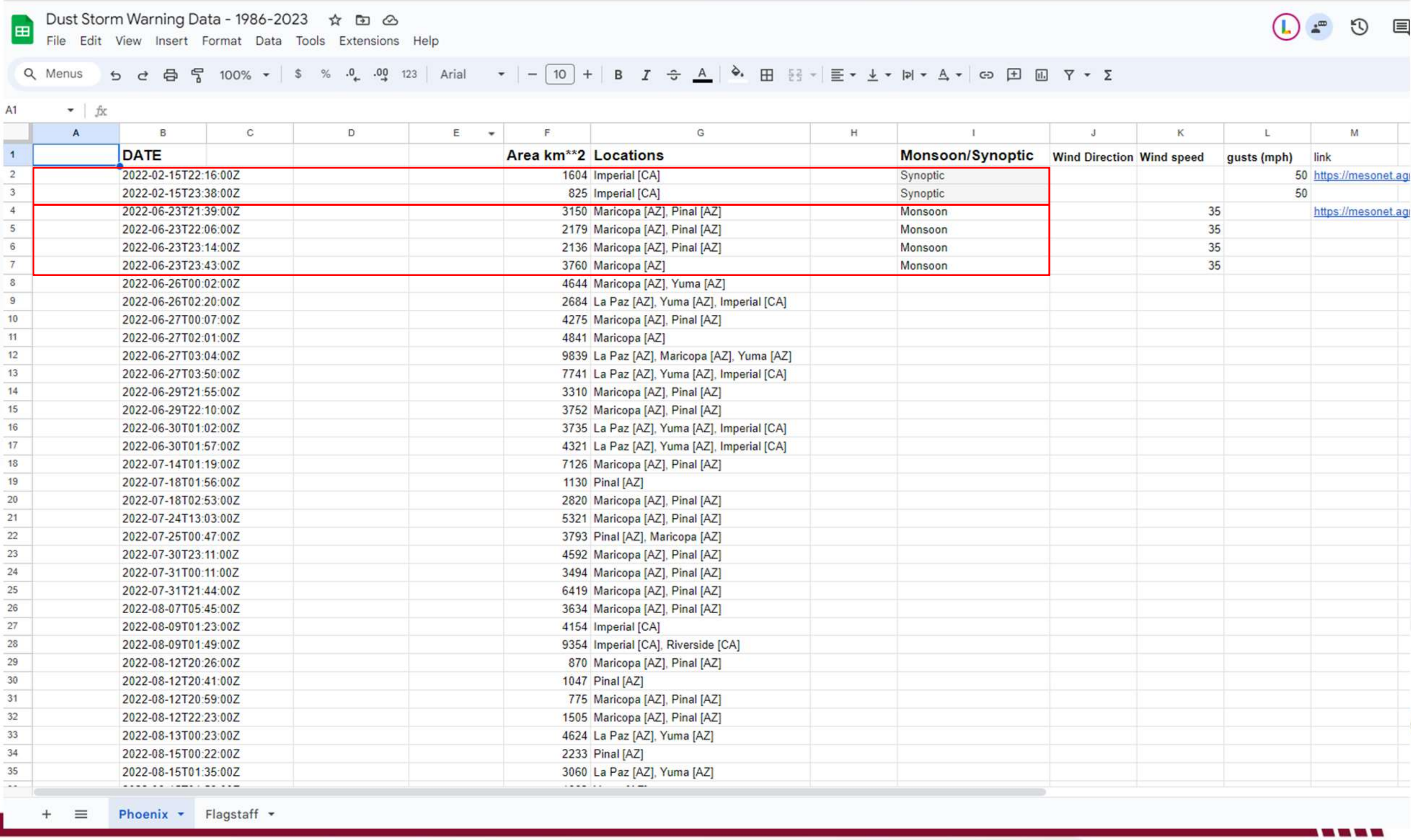
This table lists other events issued by the selected office for the selected year. Click on the row to select that event.

Show 10 entries

ID	Product Issued	VTEC Issued	Initial Expire	VTEC Expire	Area km**2	Locations	Signature
1	2021-03-10T00:20:00Z	2021-03-10T00:20:00Z	2021-03-10T01:15:00Z	2021-03-10T01:15:00Z	248	Pinal [AZ]	AJ
2	2021-03-16T01:17:00Z	2021-03-16T01:17:00Z	2021-03-16T02:45:00Z	2021-03-16T02:45:00Z	2619	Imperial [CA]	INS
3	2021-07-01T01:31:00Z	2021-07-01T01:31:00Z	2021-07-01T02:30:00Z	2021-07-01T02:30:00Z	4405	La Paz [AZ], Yuma [AZ]	LJH
4	2021-07-03T22:25:00Z	2021-07-03T22:25:00Z	2021-07-03T23:30:00Z	2021-07-03T23:06:00Z	3762	Pinal [AZ], Maricopa [AZ]	SDB
5	2021-07-04T00:41:00Z	2021-07-04T00:41:00Z	2021-07-04T01:45:00Z	2021-07-04T01:25:00Z	695	Maricopa [AZ], Pinal [AZ]	SDB
6	2021-07-04T00:43:00Z	2021-07-04T00:43:00Z	2021-07-04T01:45:00Z	2021-07-04T01:45:00Z	4203	Maricopa [AZ]	SDB

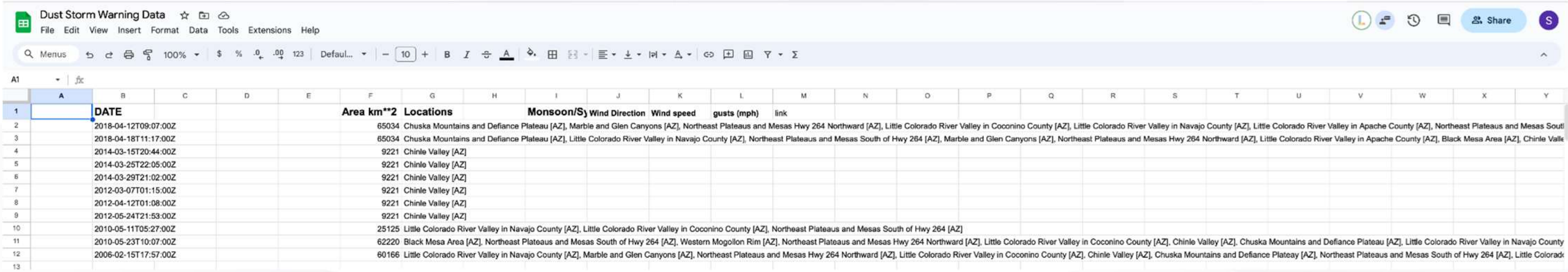
Note: this dataset only has warnings that go back to 2006, but provides specific instances in which dust storms were imminent as provided by various forecast offices.

Phoenix, AZ



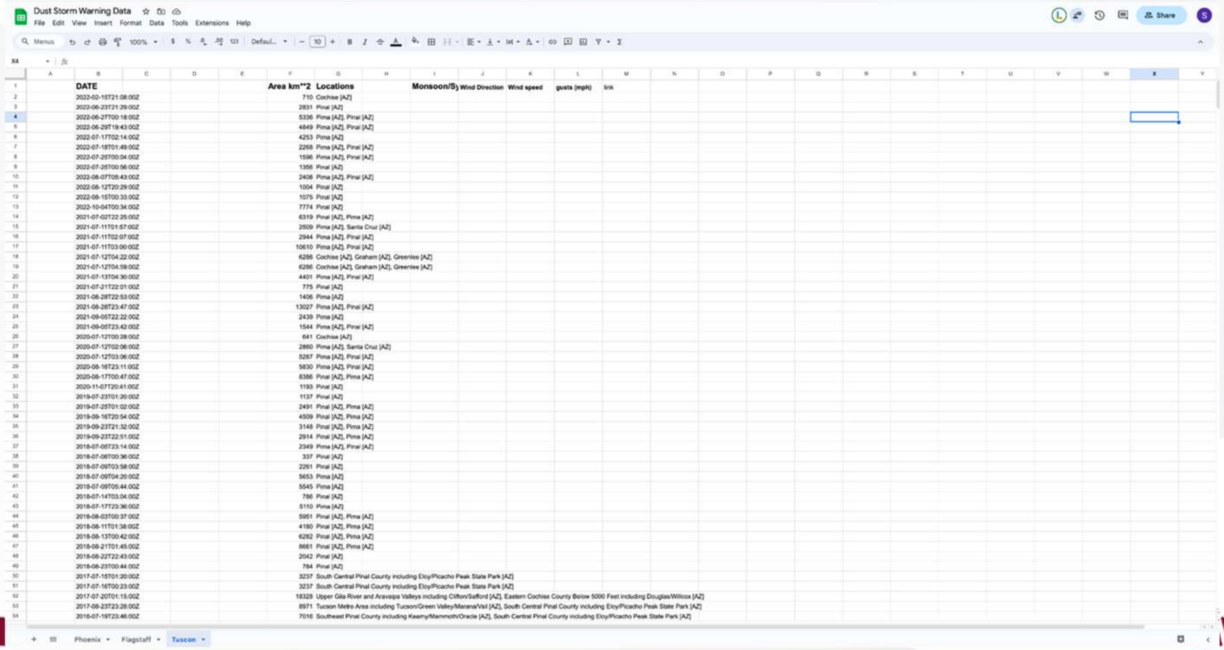
	DATE	Area km**2	Locations	Monsoon/Synoptic	Wind Direction	Wind speed	gusts (mph)	link
2	2022-02-15T22:16:00Z	1604	Imperial [CA]	Synoptic			50	https://mesonet.ag
3	2022-02-15T23:38:00Z	825	Imperial [CA]	Synoptic			50	
4	2022-06-23T21:39:00Z	3150	Maricopa [AZ], Pinal [AZ]	Monsoon		35		https://mesonet.ag
5	2022-06-23T22:06:00Z	2179	Maricopa [AZ], Pinal [AZ]	Monsoon		35		
6	2022-06-23T23:14:00Z	2136	Maricopa [AZ], Pinal [AZ]	Monsoon		35		
7	2022-06-23T23:43:00Z	3760	Maricopa [AZ]	Monsoon		35		
8	2022-06-26T00:02:00Z	4644	Maricopa [AZ], Yuma [AZ]					
9	2022-06-26T02:20:00Z	2684	La Paz [AZ], Yuma [AZ], Imperial [CA]					
10	2022-06-27T00:07:00Z	4275	Maricopa [AZ], Pinal [AZ]					
11	2022-06-27T02:01:00Z	4841	Maricopa [AZ]					
12	2022-06-27T03:04:00Z	9839	La Paz [AZ], Maricopa [AZ], Yuma [AZ]					
13	2022-06-27T03:50:00Z	7741	La Paz [AZ], Yuma [AZ], Imperial [CA]					
14	2022-06-29T21:55:00Z	3310	Maricopa [AZ], Pinal [AZ]					
15	2022-06-29T22:10:00Z	3752	Maricopa [AZ], Pinal [AZ]					
16	2022-06-30T01:02:00Z	3735	La Paz [AZ], Yuma [AZ], Imperial [CA]					
17	2022-06-30T01:57:00Z	4321	La Paz [AZ], Yuma [AZ], Imperial [CA]					
18	2022-07-14T01:19:00Z	7126	Maricopa [AZ], Pinal [AZ]					
19	2022-07-18T01:56:00Z	1130	Pinal [AZ]					
20	2022-07-18T02:53:00Z	2820	Maricopa [AZ], Pinal [AZ]					
21	2022-07-24T13:03:00Z	5321	Maricopa [AZ], Pinal [AZ]					
22	2022-07-25T00:47:00Z	3793	Pinal [AZ], Maricopa [AZ]					
23	2022-07-30T23:11:00Z	4592	Maricopa [AZ], Pinal [AZ]					
24	2022-07-31T00:11:00Z	3494	Maricopa [AZ], Pinal [AZ]					
25	2022-07-31T21:44:00Z	6419	Maricopa [AZ], Pinal [AZ]					
26	2022-08-07T05:45:00Z	3634	Maricopa [AZ], Pinal [AZ]					
27	2022-08-09T01:23:00Z	4154	Imperial [CA]					
28	2022-08-09T01:49:00Z	9354	Imperial [CA], Riverside [CA]					
29	2022-08-12T20:26:00Z	870	Maricopa [AZ], Pinal [AZ]					
30	2022-08-12T20:41:00Z	1047	Pinal [AZ]					
31	2022-08-12T20:59:00Z	775	Maricopa [AZ], Pinal [AZ]					
32	2022-08-12T22:23:00Z	1505	Maricopa [AZ], Pinal [AZ]					
33	2022-08-13T00:23:00Z	4624	La Paz [AZ], Yuma [AZ]					
34	2022-08-15T00:22:00Z	2233	Pinal [AZ]					
35	2022-08-15T01:35:00Z	3060	La Paz [AZ], Yuma [AZ]					

Flagstaff, AZ



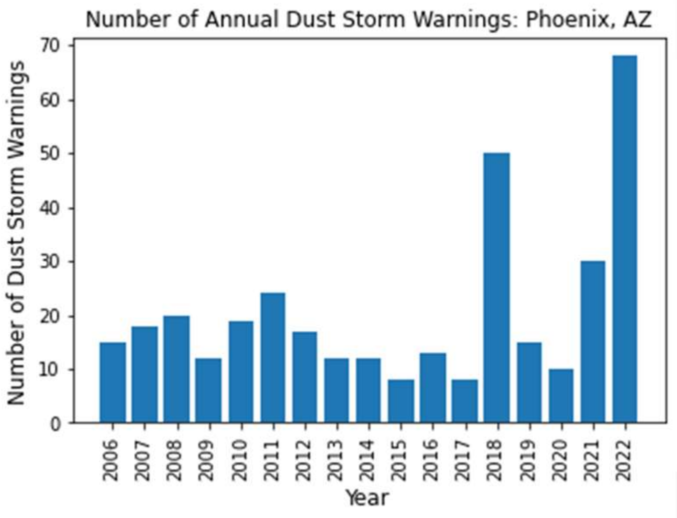
	DATE	Area km**2	Locations	Monsoon/S	Wind Direction	Wind speed	gusts (mph)	link
2	2018-04-12T09:07:00Z	65034	Chuska Mountains and Defiance Plateau [AZ], Marble and Glen Canyons [AZ], Northeast Plateaus and Mesas Hwy 264 Northward [AZ], Little Colorado River Valley in Coconino County [AZ], Little Colorado River Valley in Navajo County [AZ], Little Colorado River Valley in Apache County [AZ], Northeast Plateaus and Mesas Sout					
3	2018-04-18T11:17:00Z	65034	Chuska Mountains and Defiance Plateau [AZ], Little Colorado River Valley in Navajo County [AZ], Northeast Plateaus and Mesas South of Hwy 264 [AZ], Marble and Glen Canyons [AZ], Northeast Plateaus and Mesas Hwy 264 Northward [AZ], Little Colorado River Valley in Apache County [AZ], Black Mesa Area [AZ], Chinle Valle					
4	2014-03-15T20:44:00Z	9221	Chinle Valley [AZ]					
5	2014-03-25T22:05:00Z	9221	Chinle Valley [AZ]					
6	2014-03-29T21:02:00Z	9221	Chinle Valley [AZ]					
7	2012-03-07T01:15:00Z	9221	Chinle Valley [AZ]					
8	2012-04-12T01:08:00Z	9221	Chinle Valley [AZ]					
9	2012-05-24T21:53:00Z	9221	Chinle Valley [AZ]					
10	2010-05-11T05:27:00Z	25125	Little Colorado River Valley in Navajo County [AZ], Little Colorado River Valley in Coconino County [AZ], Northeast Plateaus and Mesas South of Hwy 264 [AZ]					
11	2010-05-23T10:07:00Z	62220	Black Mesa Area [AZ], Northeast Plateaus and Mesas South of Hwy 264 [AZ], Western Mogollon Rim [AZ], Northeast Plateaus and Mesas Hwy 264 Northward [AZ], Little Colorado River Valley in Coconino County [AZ], Chinle Valley [AZ], Chuska Mountains and Defiance Plateau [AZ], Little Colorado River Valley in Navajo County					
12	2006-02-15T17:57:00Z	60166	Little Colorado River Valley in Navajo County [AZ], Marble and Glen Canyons [AZ], Northeast Plateaus and Mesas Hwy 264 Northward [AZ], Little Colorado River Valley in Coconino County [AZ], Chinle Valley [AZ], Chuska Mountains and Defiance Plateay [AZ], Northeast Plateaus and Mesas South of Hwy 264 [AZ], Little Colorad					

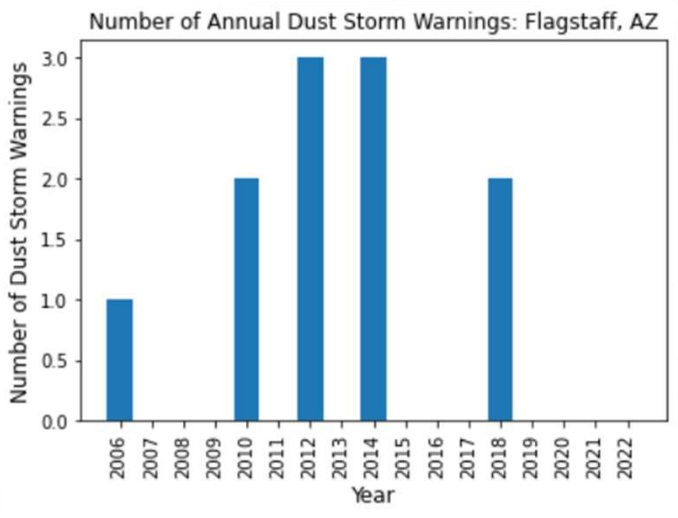
Tucson, AZ

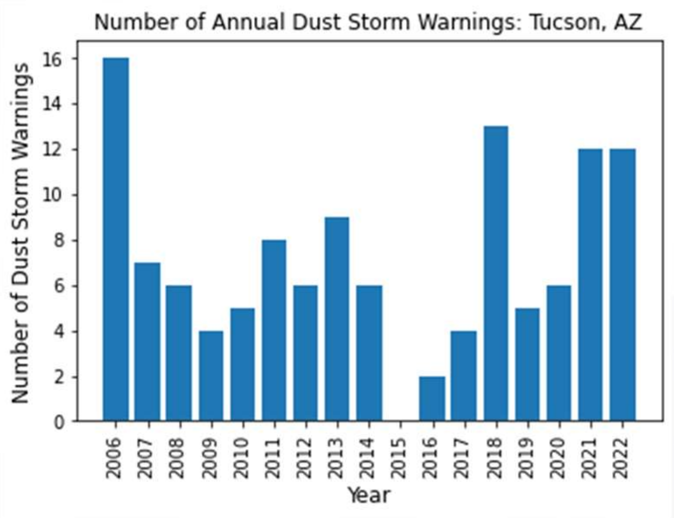


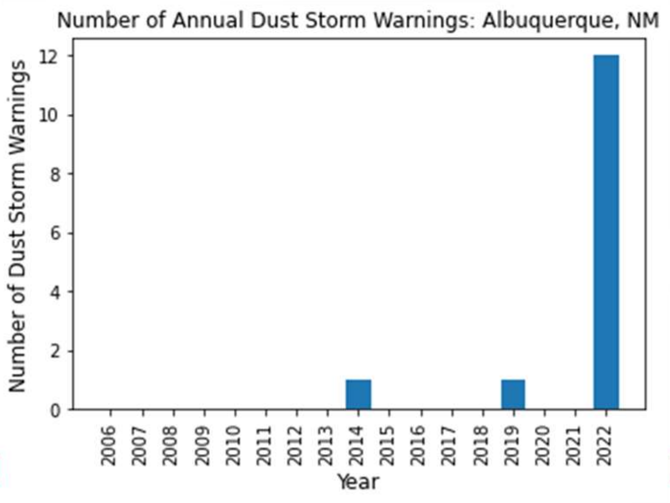
	DATE	Area km**2	Locations	Monsoon/S	Wind Direction	Wind speed	gusts (mph)	link
2	2022-02-15T21:08:00Z	710	Cochise [AZ]					
3	2022-06-23T21:29:00Z	2831	Pinal [AZ]					
4	2022-06-27T00:18:00Z	5336	Pima [AZ], Pinal [AZ]					
5	2022-06-29T19:43:00Z	4849	Pima [AZ], Pinal [AZ]					
6	2022-07-17T02:14:00Z	4253	Pima [AZ]					
7	2022-07-18T01:49:00Z	2268	Pima [AZ], Pinal [AZ]					
8	2022-07-26T00:04:00Z	1596	Pima [AZ], Pinal [AZ]					
9	2022-07-26T00:56:00Z	1356	Pinal [AZ]					
10	2022-08-07T05:43:00Z	2408	Pima [AZ], Pinal [AZ]					
11	2022-08-12T20:29:00Z	1004	Pinal [AZ]					
12	2022-08-15T00:33:00Z	1075	Pinal [AZ]					
13	2022-10-04T00:34:00Z	7774	Pinal [AZ]					
14	2021-07-02T22:25:00Z	6319	Pinal [AZ], Pima [AZ]					
15	2021-07-11T01:57:00Z	2509	Pima [AZ], Santa Cruz [AZ]					
16	2021-07-11T02:07:00Z	2944	Pima [AZ], Pinal [AZ]					
17	2021-07-11T03:00:00Z	10610	Pima [AZ], Pinal [AZ]					
18	2021-07-12T04:22:00Z	6286	Cochise [AZ], Graham [AZ], Greenlee [AZ]					
19	2021-07-12T04:59:00Z	6286	Cochise [AZ], Graham [AZ], Greenlee [AZ]					
20	2021-07-13T04:30:00Z	4401	Pima [AZ], Pinal [AZ]					
21	2021-07-21T22:01:00Z	775	Pinal [AZ]					
22	2021-08-28T22:53:00Z	1406	Pima [AZ]					
23	2021-08-28T23:47:00Z	13027	Pima [AZ], Pinal [AZ]					
24	2021-09-05T22:22:00Z	2439	Pima [AZ]					
25	2021-09-05T23:42:00Z	1544	Pima [AZ], Pinal [AZ]					
26	2020-07-12T00:28:00Z	641	Cochise [AZ]					
27	2020-07-12T02:06:00Z	2860	Pima [AZ], Santa Cruz [AZ]					
28	2020-07-12T03:06:00Z	5267	Pima [AZ], Pinal [AZ]					
29	2020-08-16T23:11:00Z	5830	Pima [AZ], Pinal [AZ]					
30	2020-08-17T00:47:00Z	8386	Pinal [AZ], Pima [AZ]					
31	2020-11-07T20:41:00Z	1193	Pinal [AZ]					
32	2019-07-23T01:20:00Z	1137	Pinal [AZ]					
33	2019-07-25T01:02:00Z	2491	Pinal [AZ], Pima [AZ]					
34	2019-09-16T20:54:00Z	4509	Pinal [AZ], Pima [AZ]					
35	2019-09-23T21:32:00Z	3148	Pinal [AZ], Pima [AZ]					
36	2019-09-23T22:51:00Z	2914	Pinal [AZ], Pima [AZ]					
37	2018-07-05T23:14:00Z	2349	Pima [AZ], Pinal [AZ]					
38	2018-07-06T00:36:00Z	337	Pinal [AZ]					
39	2018-07-09T03:58:00Z	2261	Pinal [AZ]					
40	2018-07-09T04:20:00Z	5653	Pima [AZ]					
41	2018-07-09T05:44:00Z	5545	Pima [AZ]					
42	2018-07-14T03:04:00Z	786	Pinal [AZ]					
43	2018-07-17T23:36:00Z	5110	Pima [AZ]					
44	2018-08-03T00:37:00Z	5951	Pinal [AZ], Pima [AZ]					
45	2018-08-11T01:38:00Z	4180	Pinal [AZ], Pima [AZ]					
46	2018-08-13T00:42:00Z	6282	Pinal [AZ], Pima [AZ]					
47	2018-08-21T01:45:00Z	8661	Pinal [AZ], Pima [AZ]					
48	2018-08-22T22:43:00Z	2042	Pinal [AZ]					
49	2018-08-23T00:44:00Z	784	Pinal [AZ]					
50	2017-07-15T01:20:00Z	3237	South Central Pinal County including Eloy/Picacho Peak State Park [AZ]					
51	2017-07-16T00:23:00Z	3237	South Central Pinal County including Eloy/Picacho Peak State Park [AZ]					
52	2017-07-20T01:15:00Z	18328	Upper Gila River and Aravaipa Valleys including Clifton/Safford [AZ], Eastern Cochise County Below 5000 Feet including Douglas/Willcox [AZ]					
53	2017-08-23T23:28:00Z	8971	Tucson Metro Area including Tucson/Green Valley/Marana/Vail [AZ], South Central Pinal County including Eloy/Picacho Peak State Park [AZ]					
54	2016-07-19T23:46:00Z	7016	Southeast Pinal County including Kearny/Mammoth/Oracle [AZ], South Central Pinal County including Eloy/Picacho Peak State Park [AZ]					

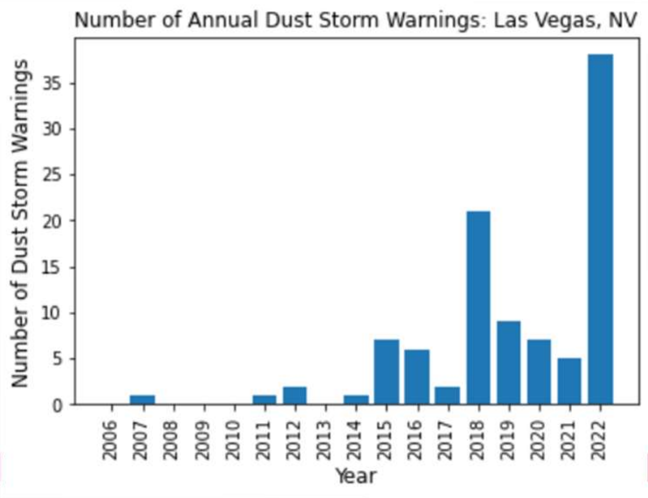
Number of Annual Dust Storm Warnings by Forecast Office











Web-Based Reanalysis Intercomparison Tools (WRIT)

- Allows examination of sea level pressure, 2m air temperature, 10m meridional winds, 10m zonal winds, and precipitation
- Also includes variables from different atmospheric pressure levels
  - Monthly mean, anomaly, and climatology data can be generated
- Allows for the display of data from various datasets isolated to chosen latitudes and longitudes
- **ERA5** - Dataset begins in 1948 - 5th generation of ECMWF atmospheric reanalyses
  - Uses satellites and in-situ observations
  - 31 km horizontal resolution

REANALYSES.ORG Advancing Reanalysis

Slide 49

---

1 CHANGE TO ERA5

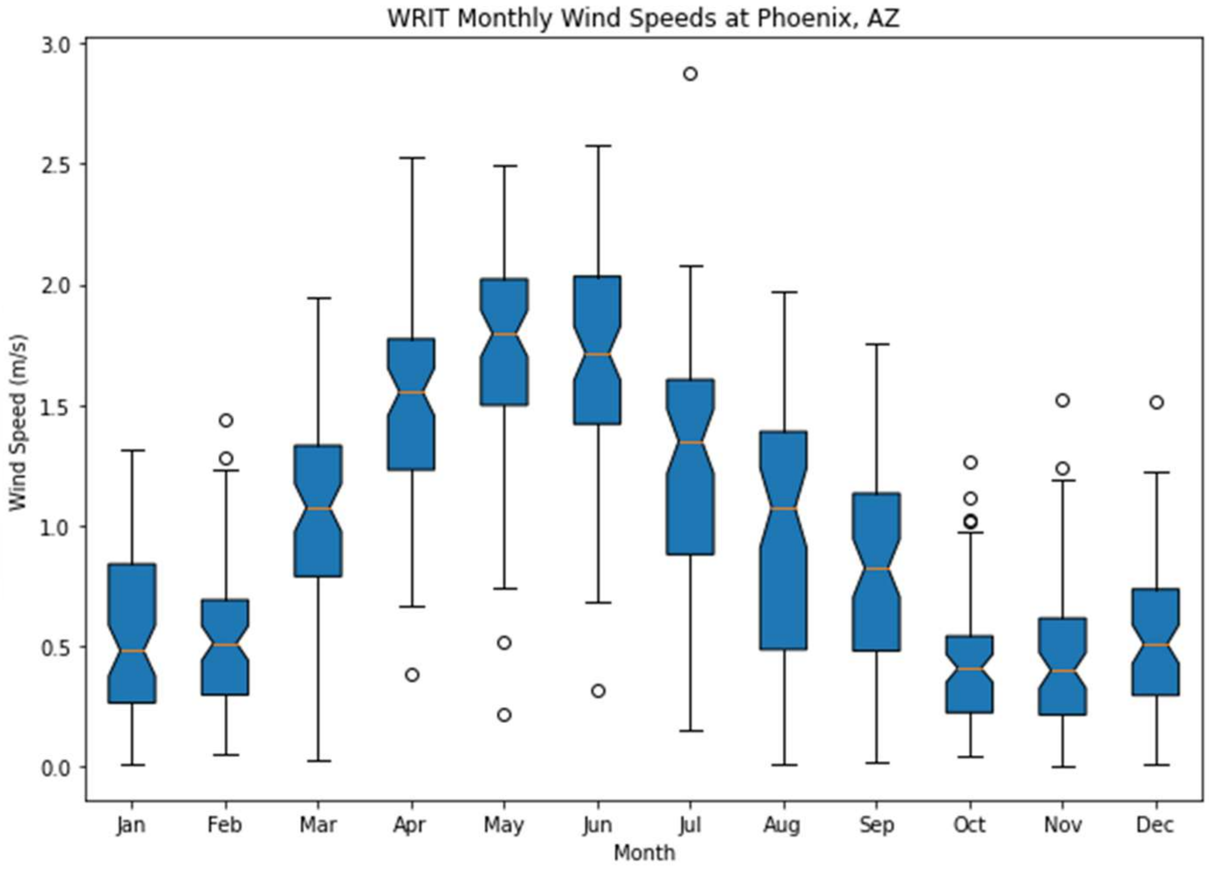
Alexis Cole, 6/29/2023

10m Wind Speeds Centered over Phoenix, AZ

Box corner coordinates:
(31N, 110W)
(35N, 110W)
(35N, 114W)
(31N, 114W)

PHX coordinates:
(33.45N, 112.07W)

Next goal: use precipitation data from WRIT and correlate with NASMI data



Slide 50

2 REDO AT SMALLER SCALE

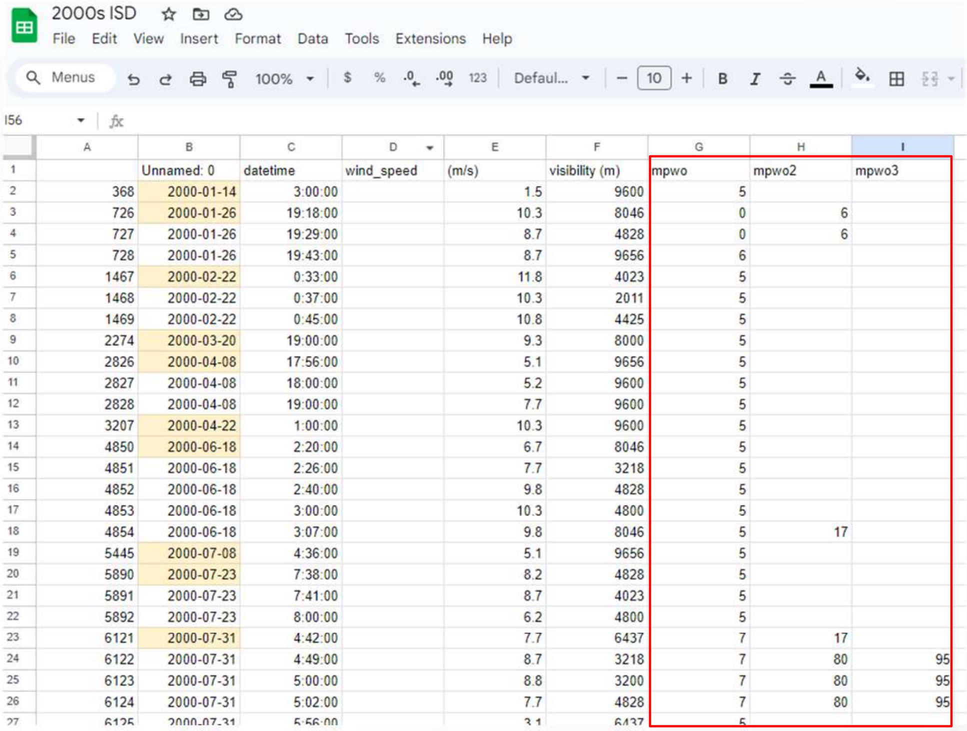
Alexis Cole, 6/29/2023

ISD - Integrated Surface Dataset

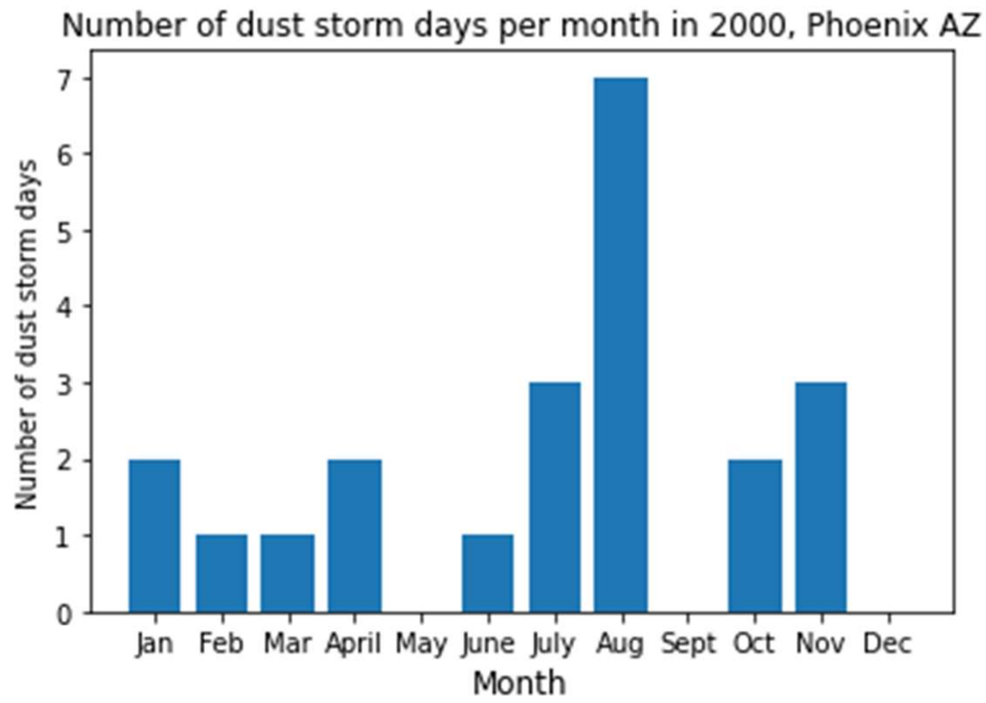
National Centers for Environmental Information

- Composed of worldwide surface weather obs from 35,000+ stations
- Global hourly and synoptic observations compiled from numerous sources
- Includes numerous parameters observed by each station
    - Wind speed & direction, wind gust, temp, cloud data, present weather, visibility, precipitation amounts for various time periods, etc.

ISD Present Weather Tracking



	A	B	C	D	E	F	G	H	I
1		Unnamed: 0	datetime	wind_speed	(m/s)	visibility (m)	mpwo	mpwo2	mpwo3
2	368	2000-01-14	3:00:00		1.5	9600	5		
3	726	2000-01-26	19:18:00		10.3	8046	0	6	
4	727	2000-01-26	19:29:00		8.7	4828	0	6	
5	728	2000-01-26	19:43:00		8.7	9656	6		
6	1467	2000-02-22	0:33:00		11.8	4023	5		
7	1468	2000-02-22	0:37:00		10.3	2011	5		
8	1469	2000-02-22	0:45:00		10.8	4425	5		
9	2274	2000-03-20	19:00:00		9.3	8000	5		
10	2826	2000-04-08	17:56:00		5.1	9656	5		
11	2827	2000-04-08	18:00:00		5.2	9600	5		
12	2828	2000-04-08	19:00:00		7.7	9600	5		
13	3207	2000-04-22	1:00:00		10.3	9600	5		
14	4850	2000-06-18	2:20:00		6.7	8046	5		
15	4851	2000-06-18	2:26:00		7.7	3218	5		
16	4852	2000-06-18	2:40:00		9.8	4828	5		
17	4853	2000-06-18	3:00:00		10.3	4800	5		
18	4854	2000-06-18	3:07:00		9.8	8046	5	17	
19	5445	2000-07-08	4:36:00		5.1	9656	5		
20	5890	2000-07-23	7:38:00		8.2	4828	5		
21	5891	2000-07-23	7:41:00		8.7	4023	5		
22	5892	2000-07-23	8:00:00		6.2	4800	5		
23	6121	2000-07-31	4:42:00		7.7	6437	7	17	
24	6122	2000-07-31	4:49:00		8.7	3218	7	80	95
25	6123	2000-07-31	5:00:00		8.8	3200	7	80	95
26	6124	2000-07-31	5:02:00		7.7	4828	7	80	95
27	6125	2000-07-31	5:56:00		3.1	6437	5		



Present weather codes 4-9 and 30-35 indicate a dust, sand, haze, or smoke event.

Current Dataset Issues

- Many of the datasets only go back to ~1950
- The datasets have different temporal resolutions: many need to be upscaled from daily to monthly time scales.
- Event tracking in complicated with such close proximity to the Rocky Mountains
  - Plans to use the North American Extratropical Cyclone Catalogue in this region were hindered by the inability to track low pressure centers near the Rockies
  - Cyclones in this region are often short-lived or have irregular tracks

Works Cited

Kandakji, T., Gill, T. E., & Lee, J. A. (2021). Drought and land use/land cover impact on dust sources in Southern Great Plains and Chihuahuan Desert of the U.S.: Inferring anthropogenic effect. *Science of The Total Environment*, *755*, 142461. https://doi.org/10.1016/j.scitotenv.2020.142461

Li, Y., Mickley, L. J., & Kaplan, J. O. (2021). Response of dust emissions in southwestern North America to 21st century trends in climate, CO_2 fertilization, and land use: Implications for air quality. *Atmospheric Chemistry and Physics*, *21*(1), 57–68. https://doi.org/10.5194/acp-21-57-2021

Yin, D., Nickovic, S., & Sprigg, W. A. (2007). The impact of using different land cover data on wind-blown desert dust modeling results in the southwestern United States. Atmospheric Environment, 41(10), 2214–2224. https://doi.org/10.1016/j.atmosenv.2006.10.061

Database links:

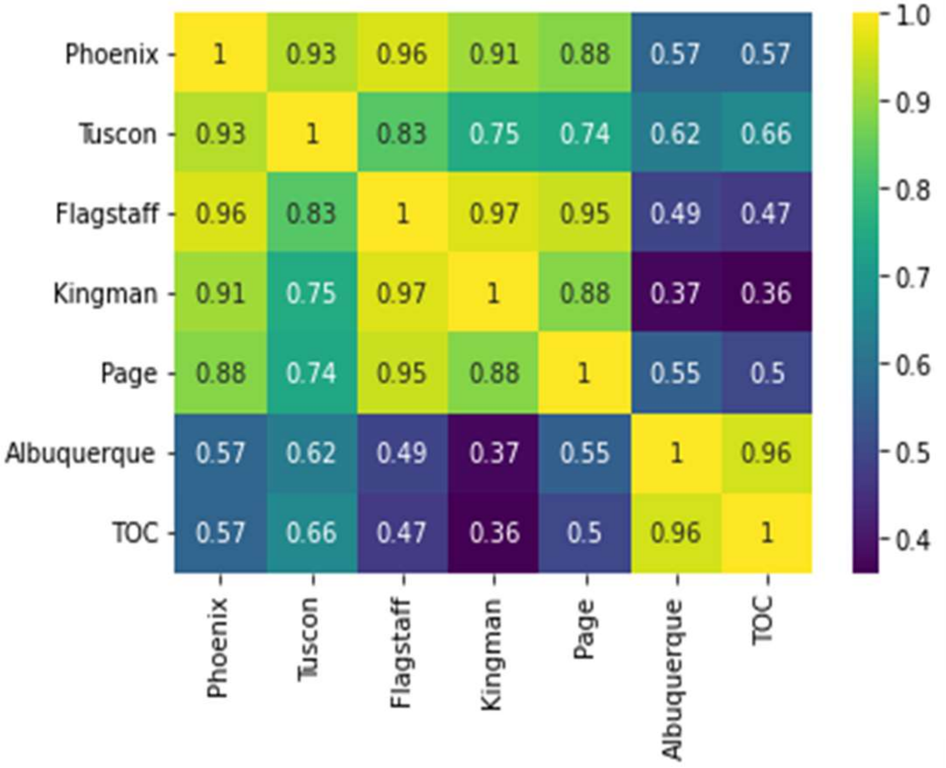
SPEI: https://lcsc.csic.es/

IEM: https://mesonet.agron.iastate.edu/

WRIT: https://psl.noaa.gov/data/atmoswrit/timeseries/

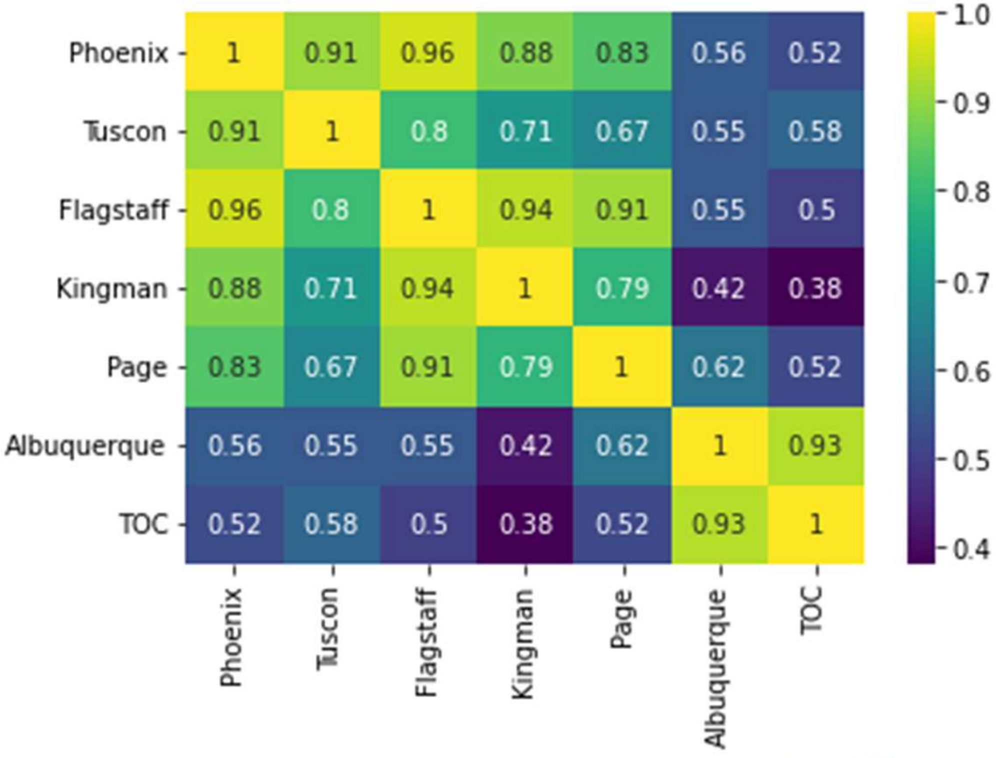
ISD: https://www.ncei.noaa.gov/products/land-based-station/integrated-surface-database

Correlation Heat Map of Precipitation in all months



	Phoenix	Tuscon	Flagstaff	Kingman	Page	Albuquerque	TOC
Phoenix	1	0.93	0.96	0.91	0.88	0.57	0.57
Tuscon	0.93	1	0.83	0.75	0.74	0.62	0.66
Flagstaff	0.96	0.83	1	0.97	0.95	0.49	0.47
Kingman	0.91	0.75	0.97	1	0.88	0.37	0.36
Page	0.88	0.74	0.95	0.88	1	0.55	0.5
Albuquerque	0.57	0.62	0.49	0.37	0.55	1	0.96
TOC	0.57	0.66	0.47	0.36	0.5	0.96	1

Correlation Heat Map of Precipitation in Jul, Aug, and Sep

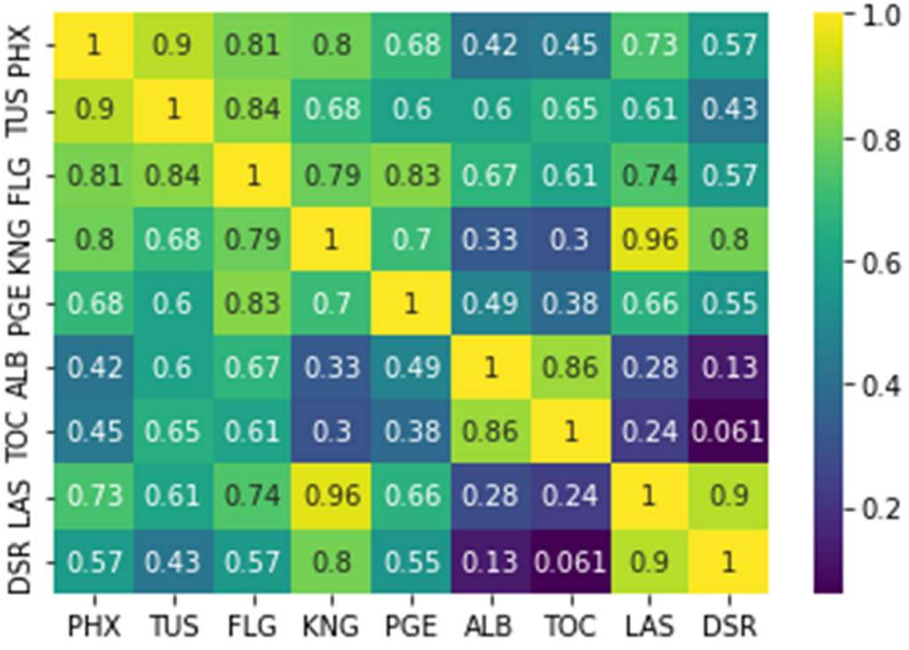


	Phoenix	Tuscon	Flagstaff	Kingman	Page	Albuquerque	TOC
Phoenix	1	0.91	0.96	0.88	0.83	0.56	0.52
Tuscon	0.91	1	0.8	0.71	0.67	0.55	0.58
Flagstaff	0.96	0.8	1	0.94	0.91	0.55	0.5
Kingman	0.88	0.71	0.94	1	0.79	0.42	0.38
Page	0.83	0.67	0.91	0.79	1	0.62	0.52
Albuquerque	0.56	0.55	0.55	0.42	0.62	1	0.93
TOC	0.52	0.58	0.5	0.38	0.52	0.93	1

- Similar results in summer compared to all 12 months
- Less extreme correlation values

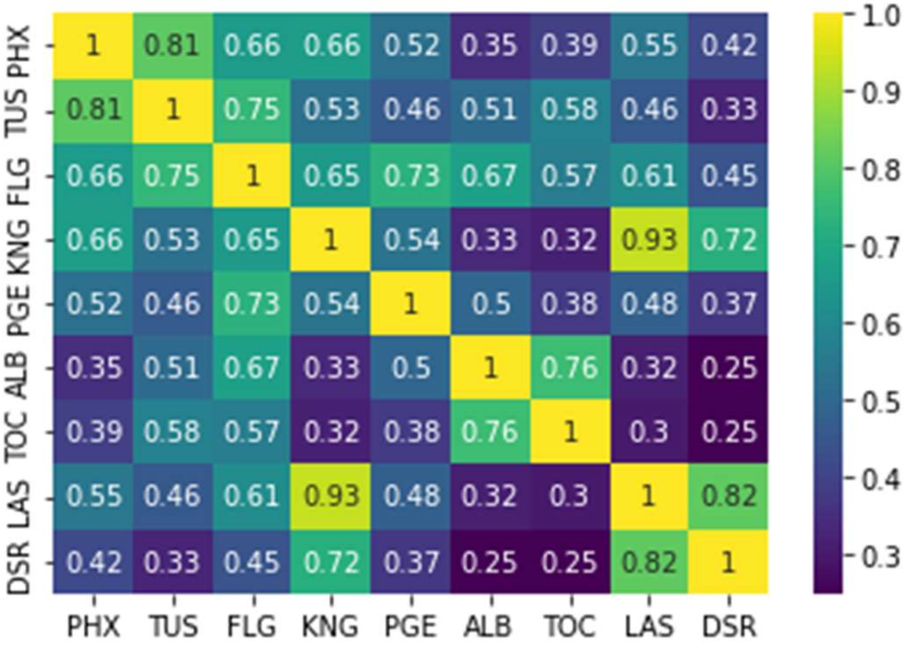
4° Lat/Lon ERA5 Data

ERA5 Precipitation Rate 2° Lat/Lon Station Correlations



	PHX	TUS	FLG	KNG	PGE	ALB	TOC	LAS	DSR
PHX	1	0.9	0.81	0.8	0.68	0.42	0.45	0.73	0.57
TUS	0.9	1	0.84	0.68	0.6	0.6	0.65	0.61	0.43
FLG	0.81	0.84	1	0.79	0.83	0.67	0.61	0.74	0.57
KNG	0.8	0.68	0.79	1	0.7	0.33	0.3	0.96	0.8
PGE	0.68	0.6	0.83	0.7	1	0.49	0.38	0.66	0.55
ALB	0.42	0.6	0.67	0.33	0.49	1	0.86	0.28	0.13
TOC	0.45	0.65	0.61	0.3	0.38	0.86	1	0.24	0.061
LAS	0.73	0.61	0.74	0.96	0.66	0.28	0.24	1	0.9
DSR	0.57	0.43	0.57	0.8	0.55	0.13	0.061	0.9	1

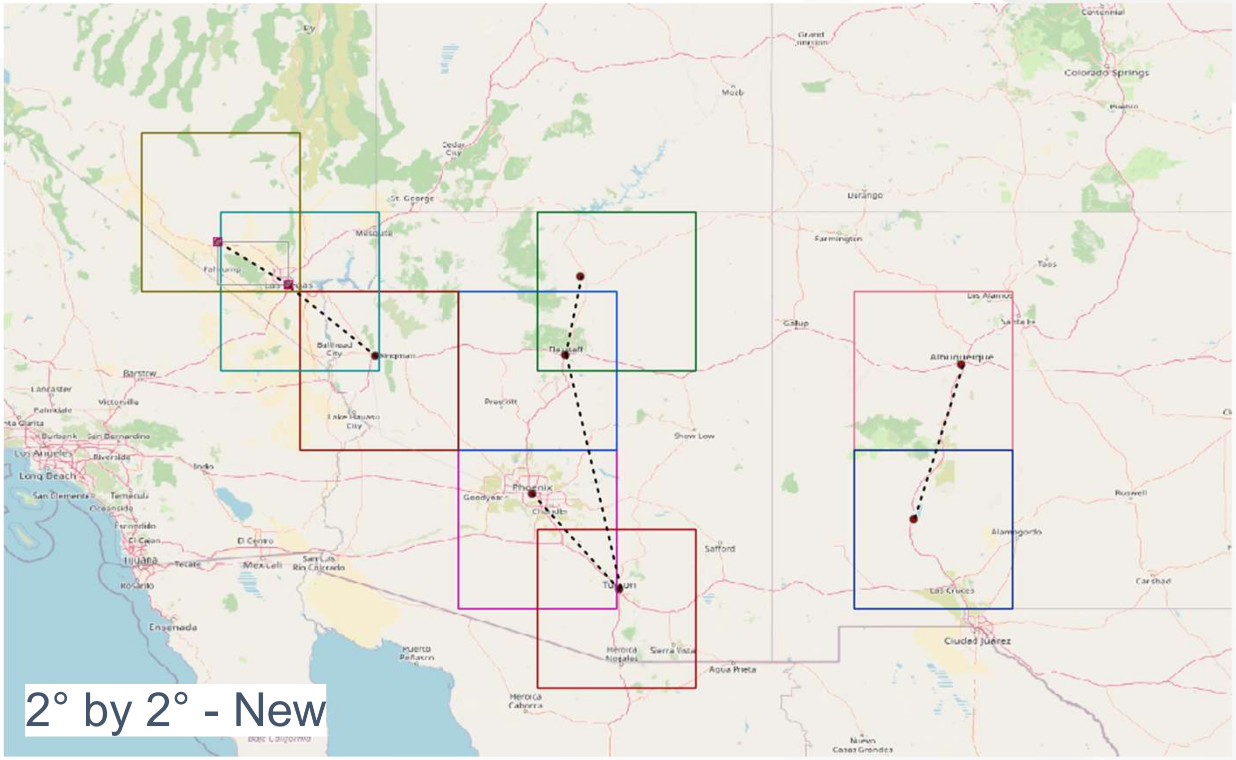
Precipitation rate - 12 months since 1948

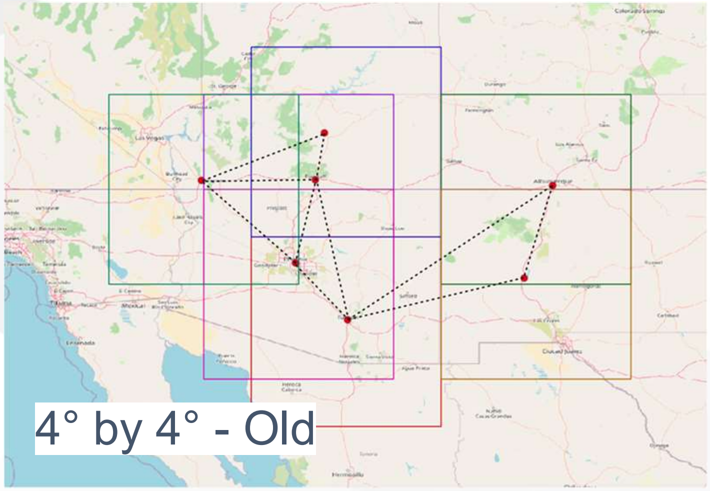


	PHX	TUS	FLG	KNG	PGE	ALB	TOC	LAS	DSR
PHX	1	0.81	0.66	0.66	0.52	0.35	0.39	0.55	0.42
TUS	0.81	1	0.75	0.53	0.46	0.51	0.58	0.46	0.33
FLG	0.66	0.75	1	0.65	0.73	0.67	0.57	0.61	0.45
KNG	0.66	0.53	0.65	1	0.54	0.33	0.32	0.93	0.72
PGE	0.52	0.46	0.73	0.54	1	0.5	0.38	0.48	0.37
ALB	0.35	0.51	0.67	0.33	0.5	1	0.76	0.32	0.25
TOC	0.39	0.58	0.57	0.32	0.38	0.76	1	0.3	0.25
LAS	0.55	0.46	0.61	0.93	0.48	0.32	0.3	1	0.82
DSR	0.42	0.33	0.45	0.72	0.37	0.25	0.25	0.82	1

Precipitation rate - JAS since 1948

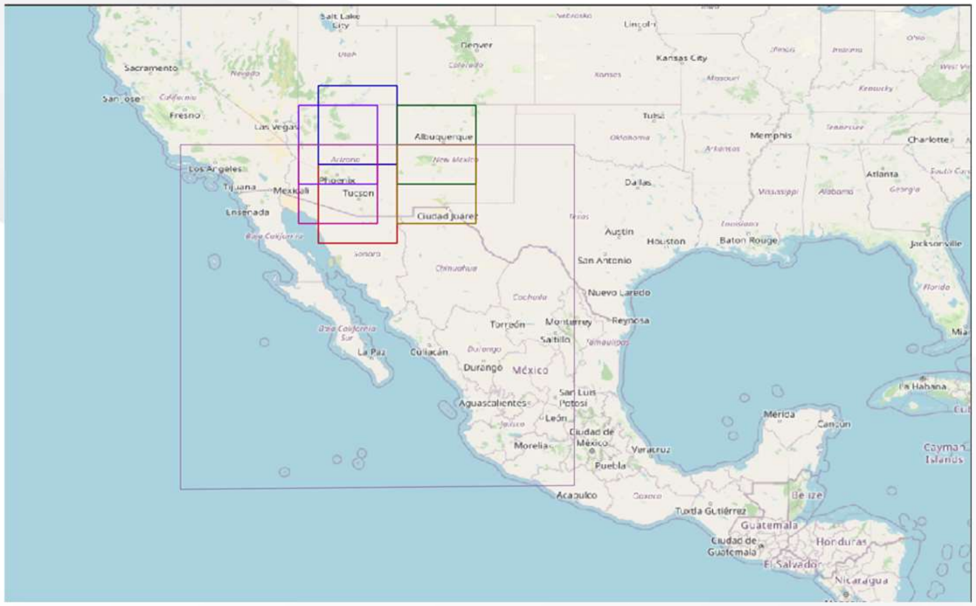
ERA5 Weather Data



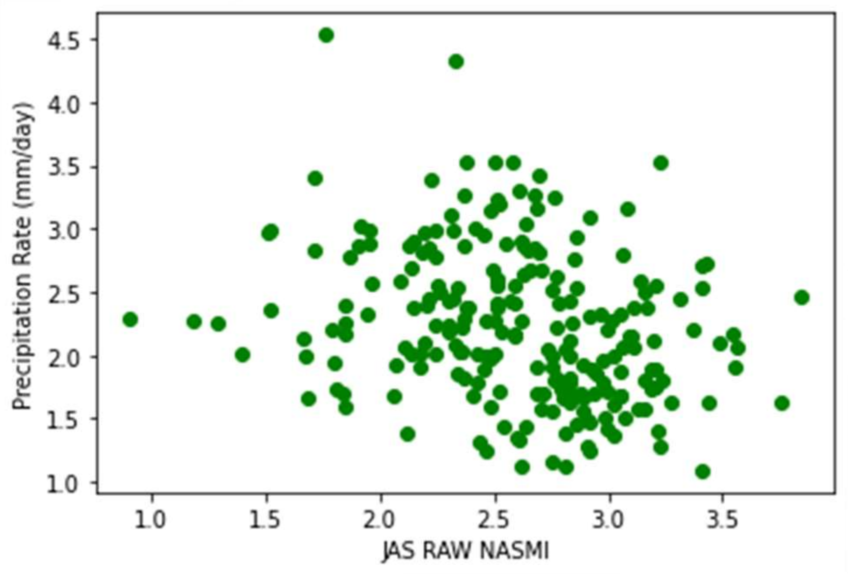


- Cut down each observation box into 2° by 2° lat/lon boxes instead of 4° by 4°
- Linked locations with highest correlation between precipitation rates
- Note 3 distinctive clusters of cities

NASMI and Precipitation in the SW U.S.



RANGE: 17.5 - 35 N, 100 - 120 W



Date	Prate
1/1/48	0.61
2/1/48	0.695
3/1/48	0.368
4/1/48	0.26
5/1/48	0.475
6/1/48	0.982
7/1/48	2.87
8/1/48	1.717
9/1/48	2.414
10/1/48	1.085
11/1/48	0.254

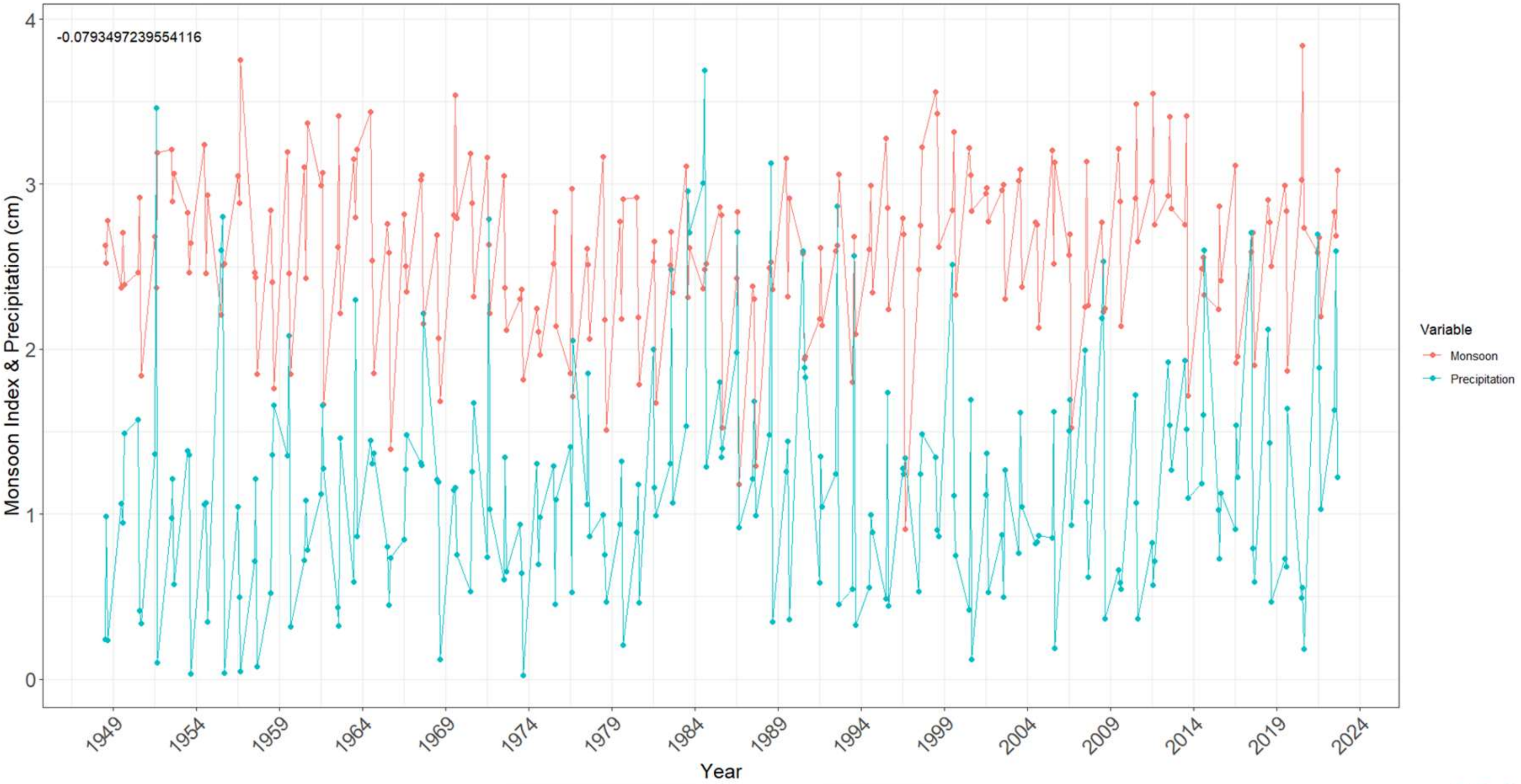
Year	RawJul	RawAug	RawSep
1948	2.63	2.52	2.779
1949	2.374	2.704	2.393
1950	2.466	2.921	1.841
1951	2.684	2.372	3.191
1952	3.211	2.893	3.067
1953	2.827	2.466	2.643
1954	3.239	2.459	2.936
1955	2.207	2.51	2.515
1956	3.049	2.888	3.751
1957	2.462	2.436	1.849
1958	2.844	2.404	1.763

Pearson Correlation: -0.264

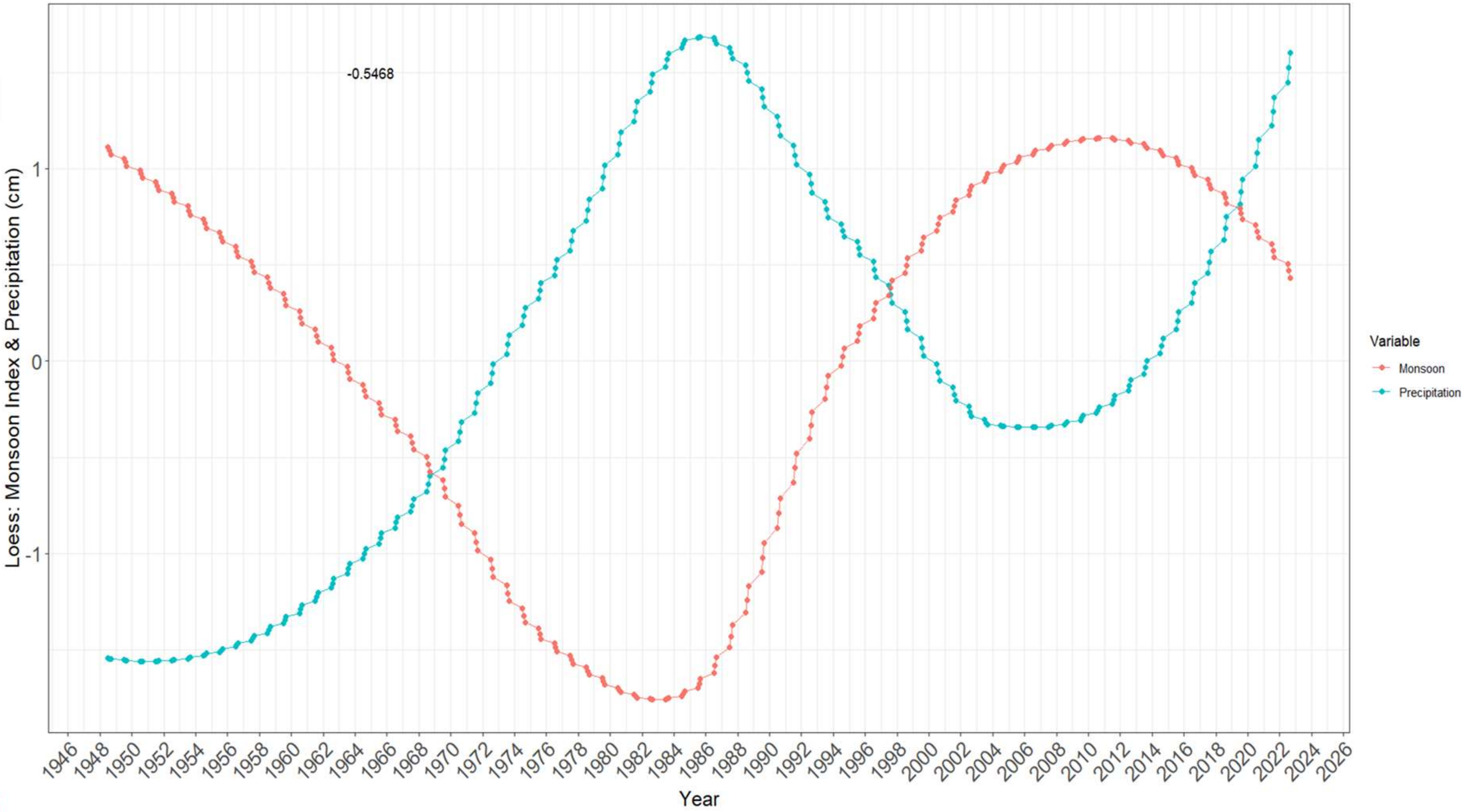
NASMI and Precipitation in PHX

Unsmoothed time series of both NASMI and precipitation

Limited relationships can be derived by the naked eye



Smoothed PHX Precipitation and NASMI



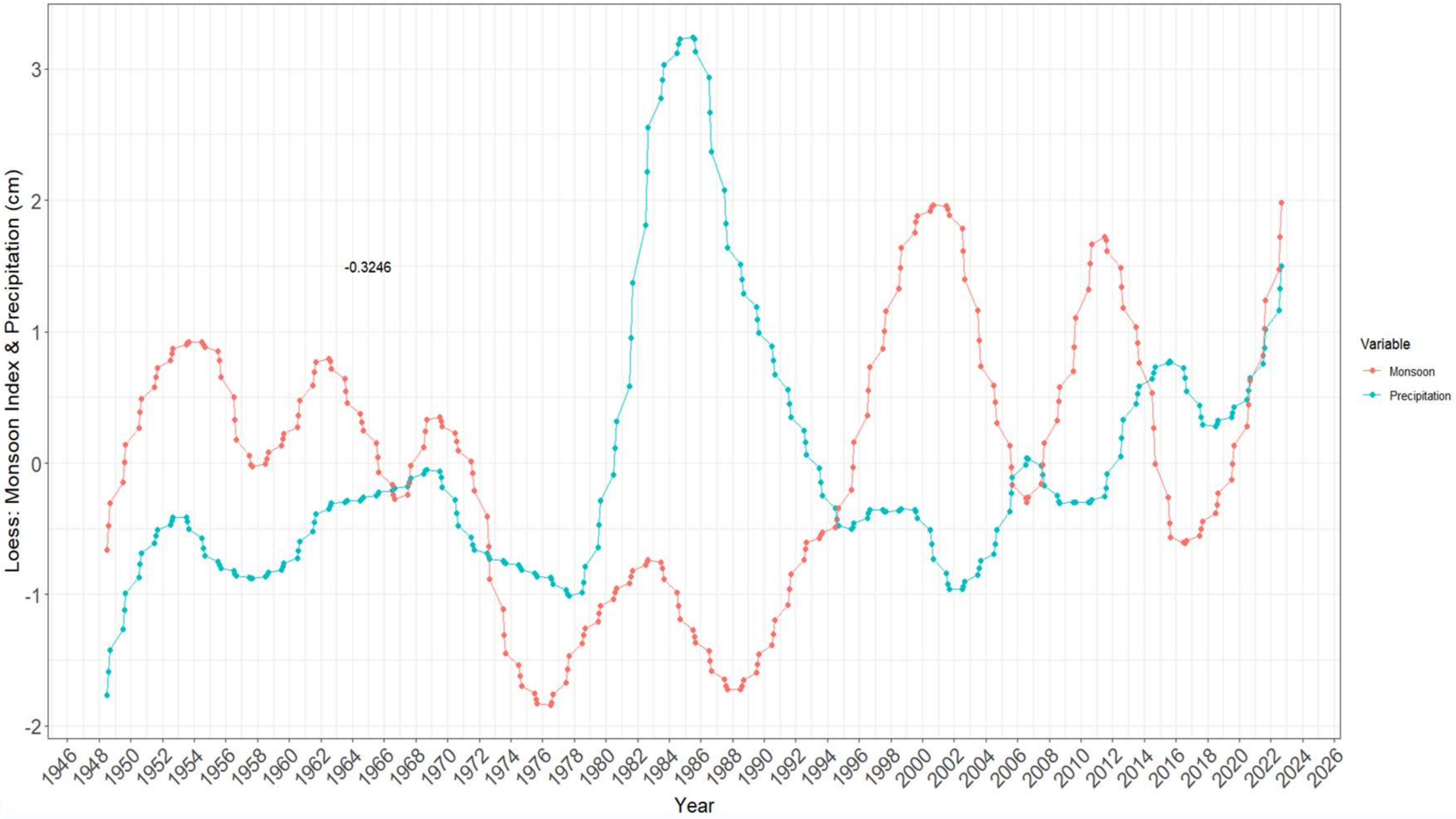
Smoothing parameter: 0.75

Trends are very easy to decipher

Provides a decadal view of how both NASMI and precipitation change over time

Too smooth?

Smoothed PHX Precipitation and NASMI

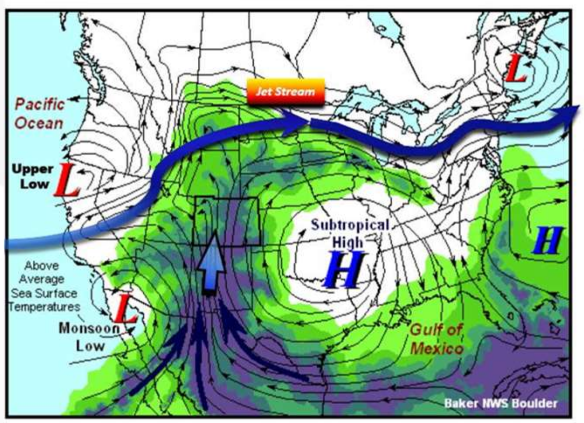


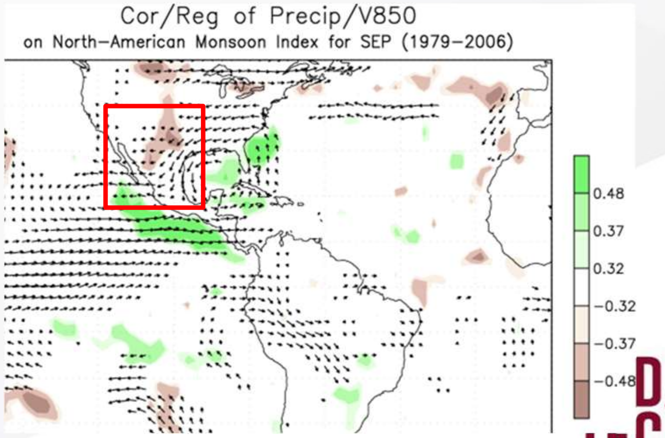
Smoothing parameter: 0.2

Still provides a decadal view of NASMI and monthly precipitation, but maintains more detail

North American Summer Monsoon Index and Precipitation

- NASMI: "area-averaged seasonally (JAS) dynamical normalized seasonality (DNS) within the North American monsoon domain (17.5°-35°N,100°-120°W).
- Caveat: The NASMI has a negative correlation with precipitation (possibly due to wind-direction conventions used in calculation)
  - We initially expected a positive correlation (i.e. stronger monsoon index → more precipitation)
  - In reality, weaker (more negative) monsoon index → more precipitation

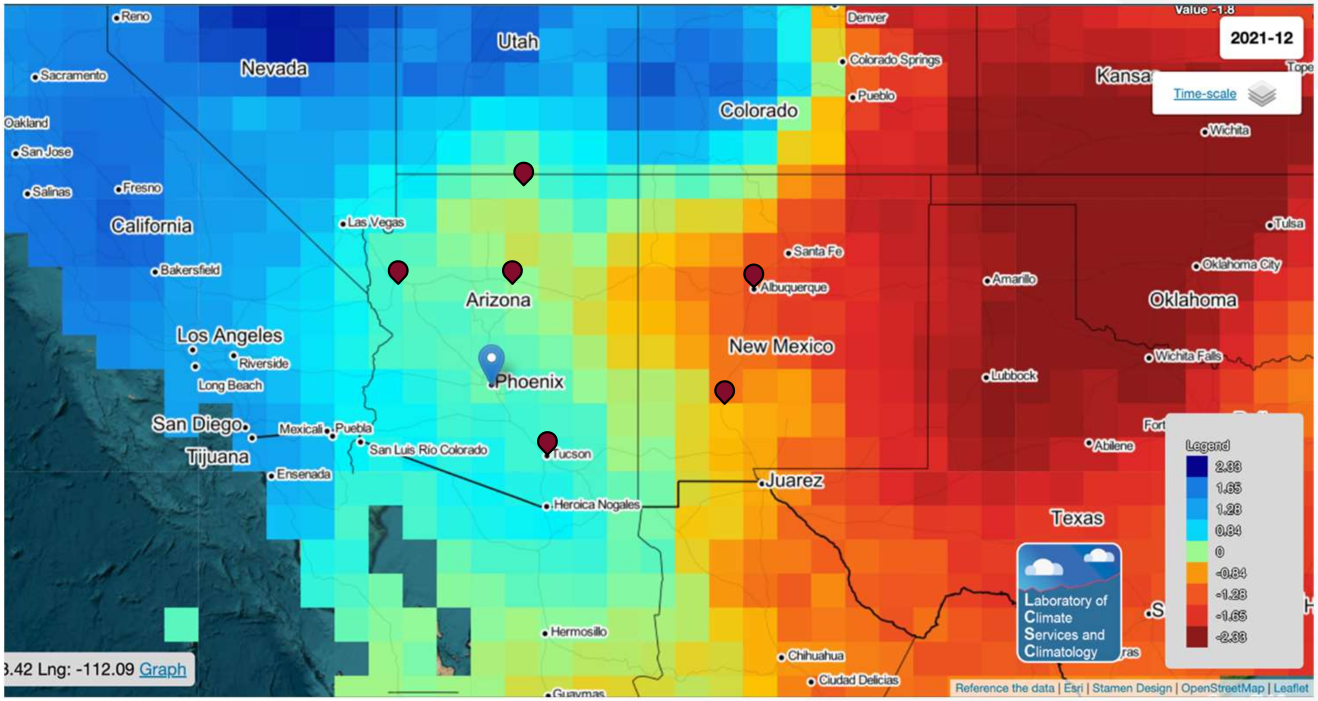



Cor/Reg of Precip/V850 on North–American Monsoon Index for SEP (1979–2006)

Colorbar: correlation of precip on NASMI

(Li and Zeng, 2002)

Return to SPEI Data (Drought Index)



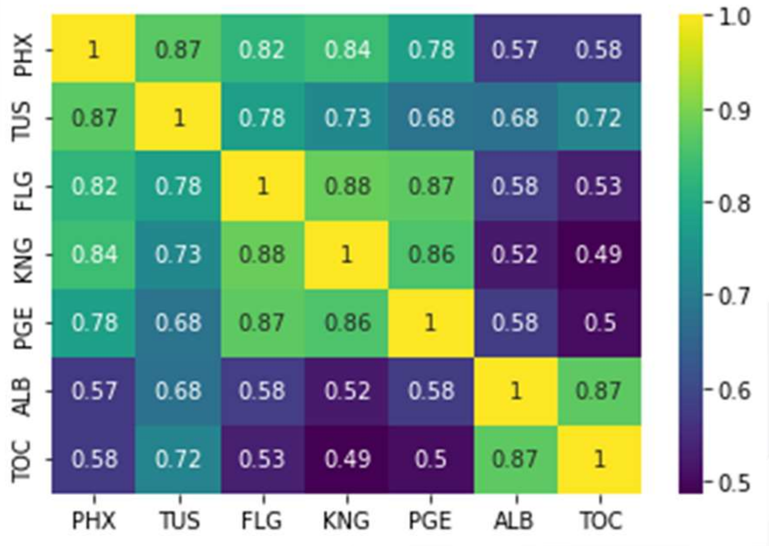
Dataset is at a smaller resolution than the WRIT dataset

Can we still form linkages between different variables in select cities without any boundary overlaps?

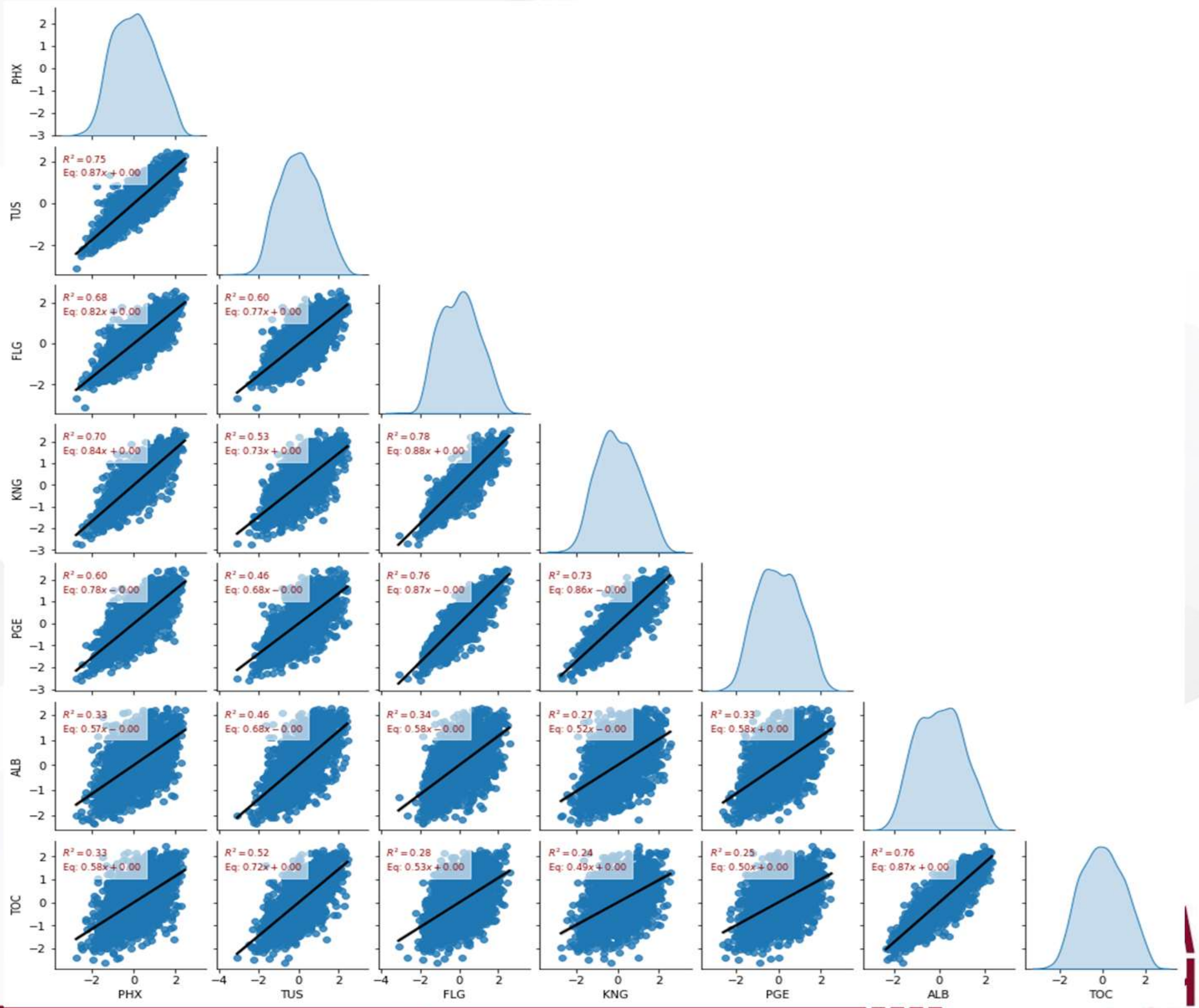
Provides a gateway into considering evaporation rate as a factor in the modelling process

**Using 1 month averaged values (SPEI 1)

Return to SPEI Data (Drought Index)



	PHX	TUS	FLG	KNG	PGE	ALB	TOC
PHX	1	0.87	0.82	0.84	0.78	0.57	0.58
TUS	0.87	1	0.78	0.73	0.68	0.68	0.72
FLG	0.82	0.78	1	0.88	0.87	0.58	0.53
KNG	0.84	0.73	0.88	1	0.86	0.52	0.49
PGE	0.78	0.68	0.87	0.86	1	0.58	0.5
ALB	0.57	0.68	0.58	0.52	0.58	1	0.87
TOC	0.58	0.72	0.53	0.49	0.5	0.87	1



Maintaining similar relationships between cities as monitored with WRIT precipitation data

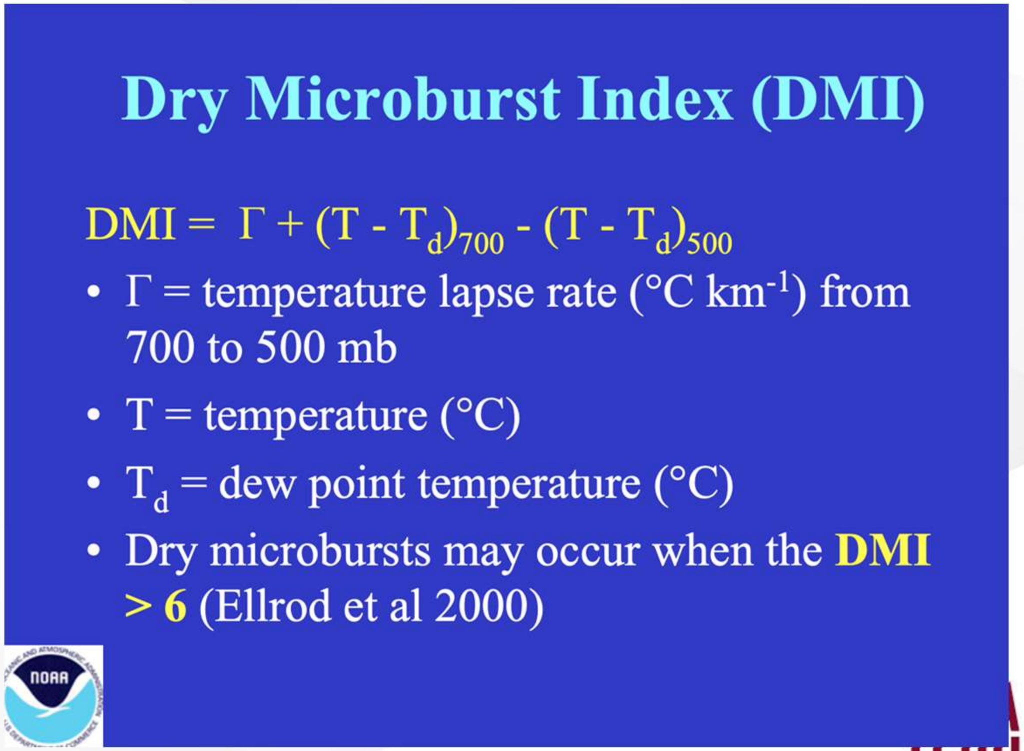
Questions Moving Forward

- What is the ideal spatial resolution for our forecast model?
  - Ideally, we want a city-wide or regional model to provide useful input for constituents…
  - But, we are limited by both the spatial and temporal resolution of our input variables?
- Should we continue to use the 4° x 4° box when working with WRIT data?
  - It seems as though there's enough correlation between some cities to link them…
  - But is there too much correlation between Phoenix, Tucson, and Flagstaff that we lose the signal from each individual location?
- How can we align our input data to provide a model output on a short-enough time scale that could be helpful?
  - NASMI varies at a much longer time scale than other factors like wind or precipitation…
  - How can we combine the influence of climatic variables with short term weather variables to produce an effective model?

Next Steps...

- Analyze the Dry Microburst Index using information from the WRIT ERA5 database
- Evaluate evaporation rate (also available on WRIT ERA5 database) and connect to precipitation, drought, and dust storm frequency
- Dive into the Integrated Surface Dataset

Needed variables: Specific humidity (500 and 700 mb), temperature (500 and 700 mb), and heights (500 and 700 mb)



Dry Microburst Index (DMI)

$DMI = \Gamma + (T - T_d)_{700} - (T - T_d)_{500}$

- Γ = temperature lapse rate (°C km^{-1}) from 700 to 500 mb
- T = temperature (°C)
- T_d = dew point temperature (°C)
- Dry microbursts may occur when the **DMI > 6** (Ellrod et al 2000)

Works Cited

NASMI data and information: http://lijianping.cn/dct/page/65580

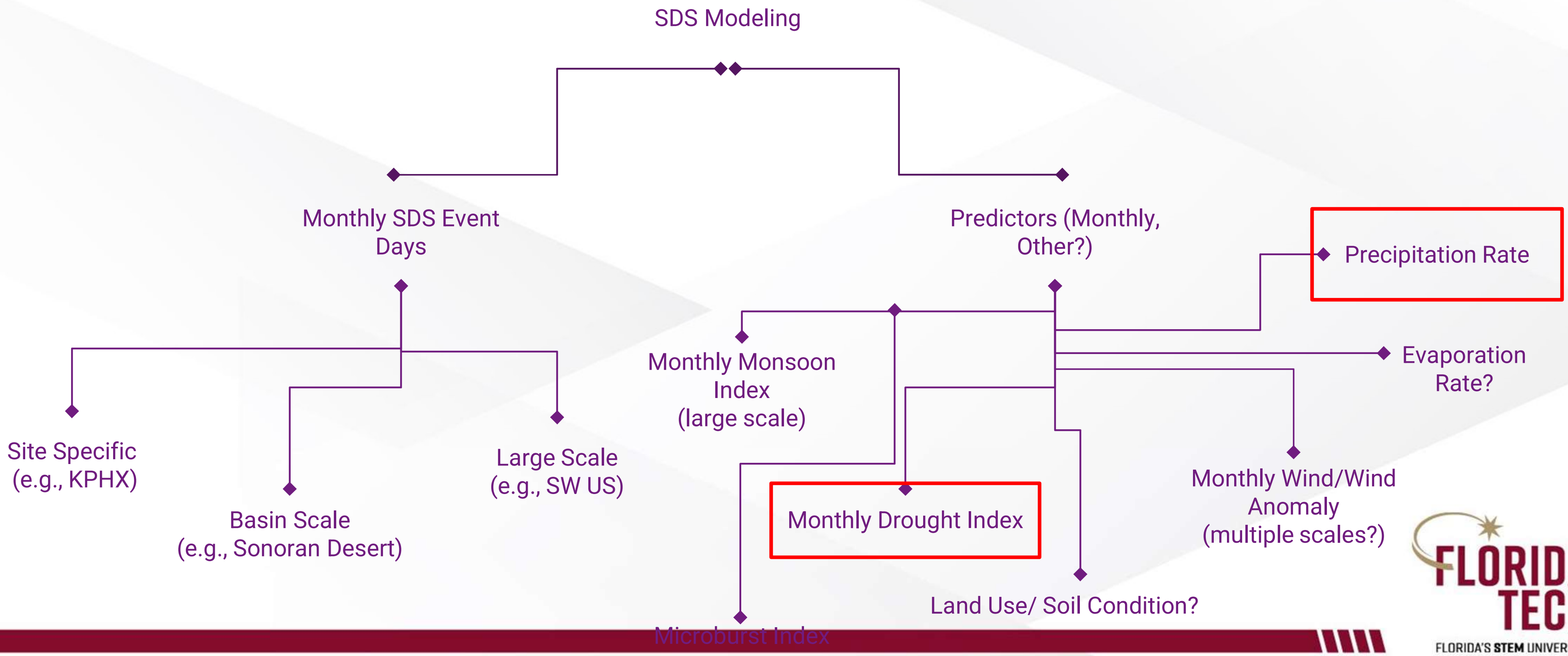
North American Monsoon: https://journals-ametsoc-org.ezaccess.libraries.psu.edu/view/journals/bams/78/10/1520-0477_1997_078_2197_tnam_2_0_co_2.xml?tab_body=pdf

NAM and global warming: https://journals-ametsoc-org.ezaccess.libraries.psu.edu/view/journals/clim/33/22/jcliD200189.xml

DMI: https://www.star.nesdis.noaa.gov/star/documents/bios/Pryor_K/spcpres.pdf

Current Research Course

Can we model sand/dust storm (SDS) monthly frequency?



SDS Modeling

Monthly SDS Event Days

Site Specific (e.g., KPHX)

Basin Scale (e.g., Sonoran Desert)

Large Scale (e.g., SW US)

Predictors (Monthly, Other?)

Precipitation Rate

Evaporation Rate?

Monthly Monsoon Index (large scale)

Monthly Drought Index

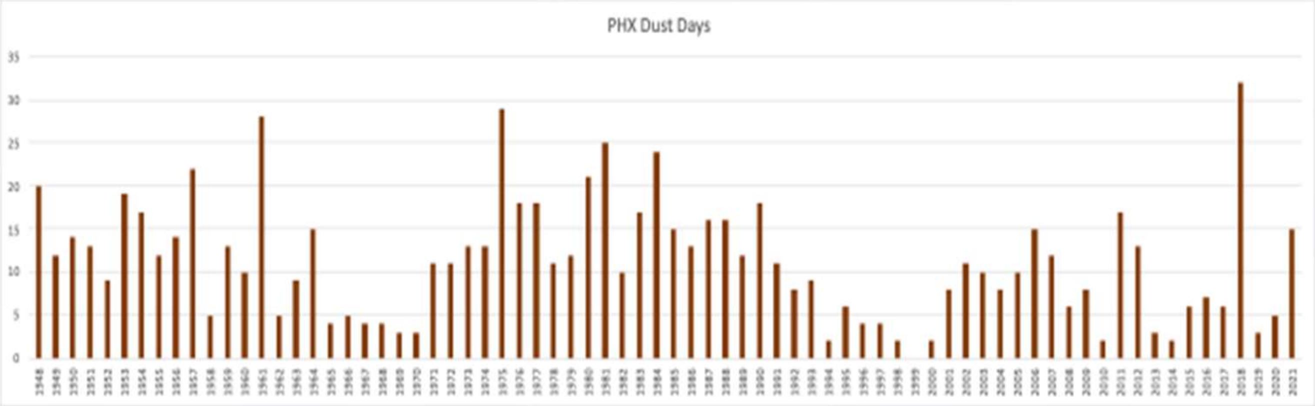
Monthly Wind/Wind Anomaly (multiple scales?)

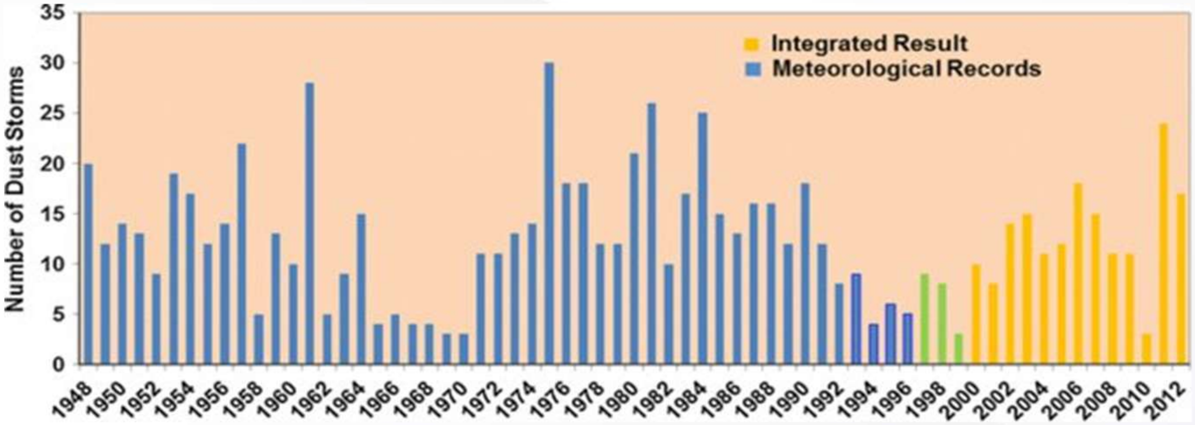
Land Use/ Soil Condition?

Microburst Index

PHX Dust Days

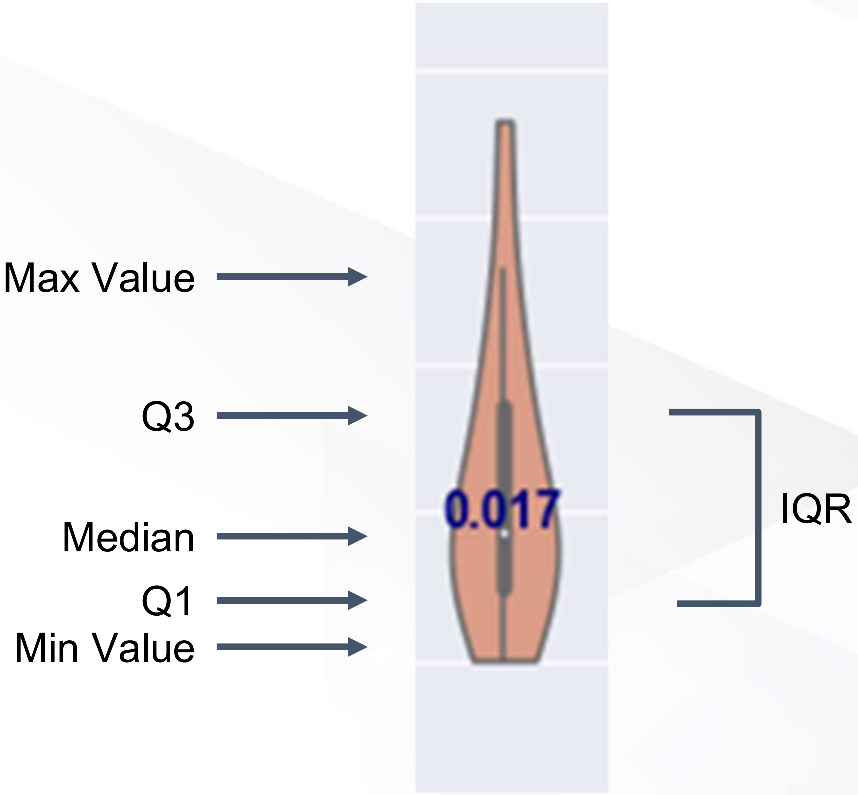
Dust Days from Dr. L's processing compared to results from Lei et al. (2016)





Lei, H., Wang, J. X., Tong, D. Q., & Lee, P. (2016). Merged dust climatology in Phoenix, Arizona based on satellite and station data. *Climate Dynamics*, *47*, 2785-2799.

Understanding a Violinplot



Max Value

Q3

Median

Q1

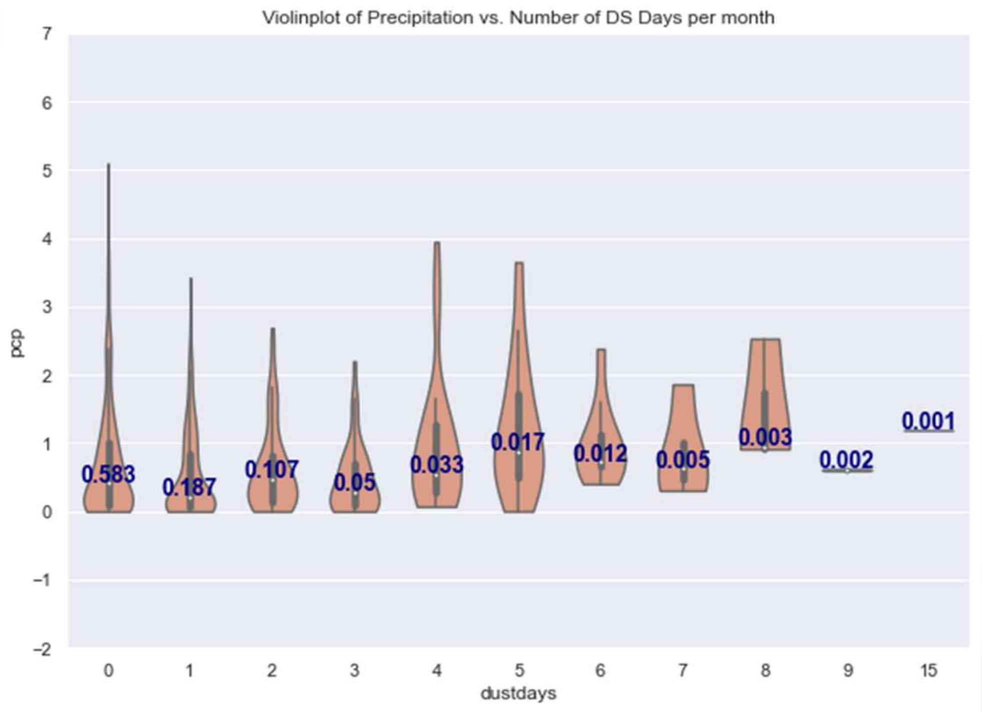
Min Value

IQR

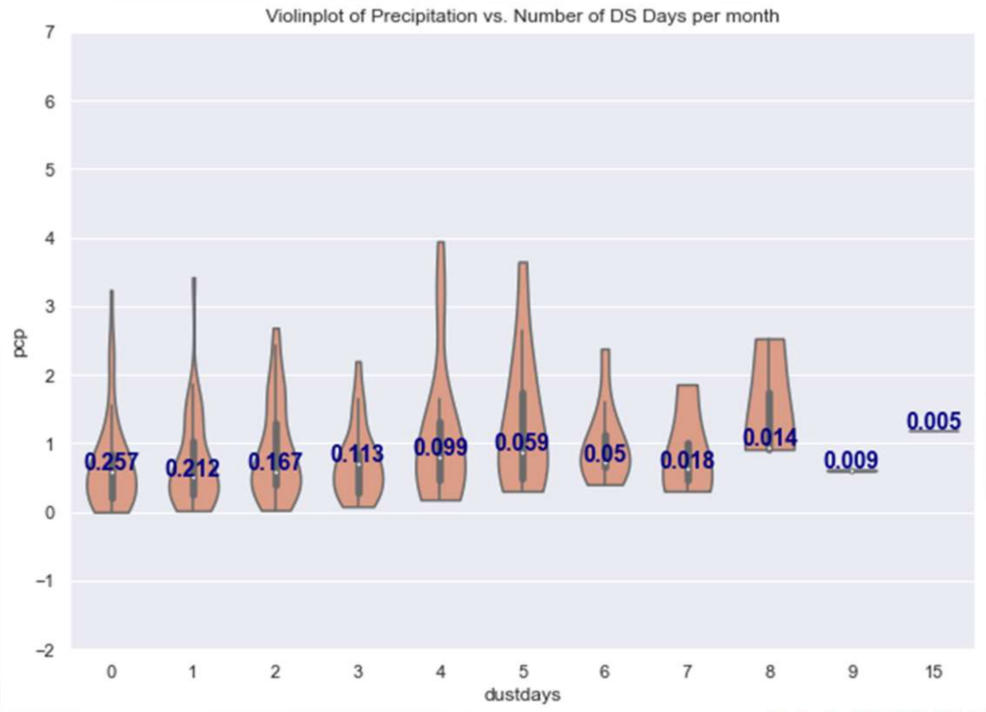
Orange shape represents the frequency, which is proportional to the density plot width.

Blue value represents the percentage of x-axis category values out of the total sample size

Days With Dust Reports and Respective Precipitation PHX

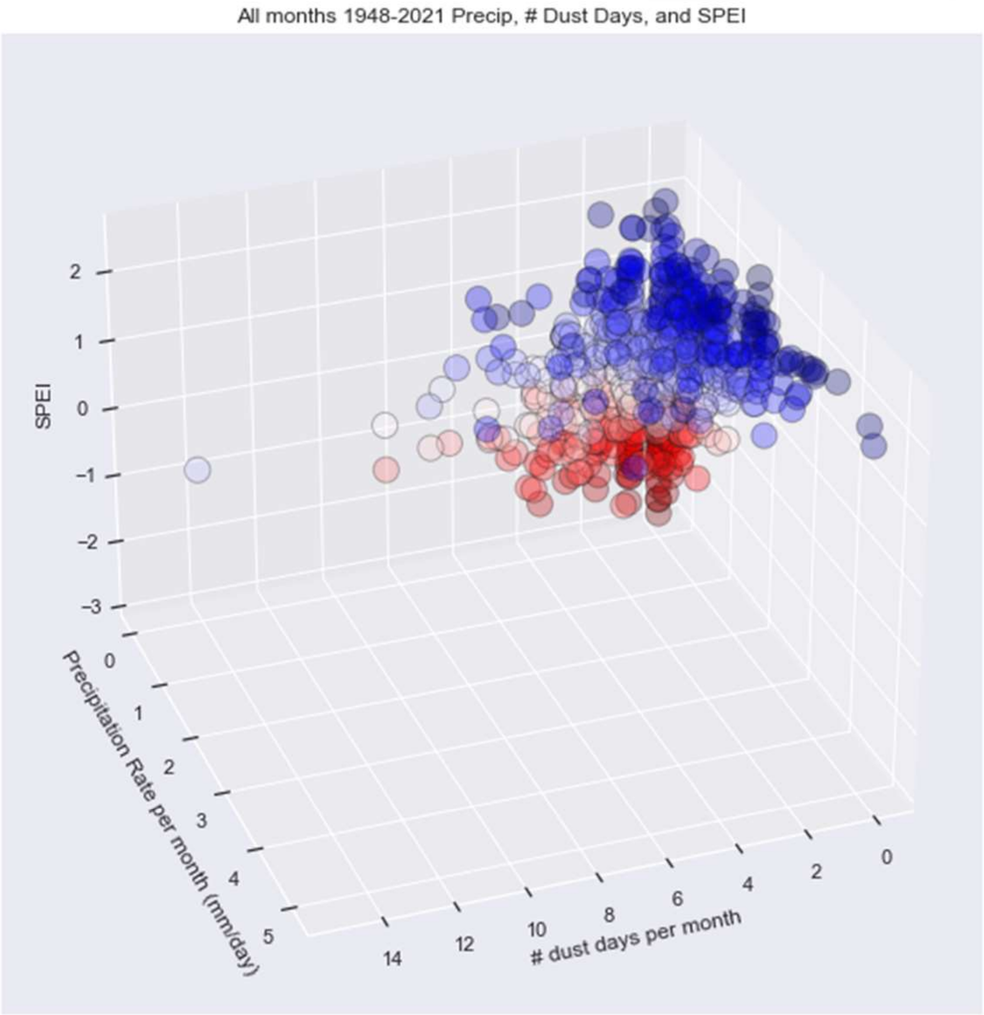


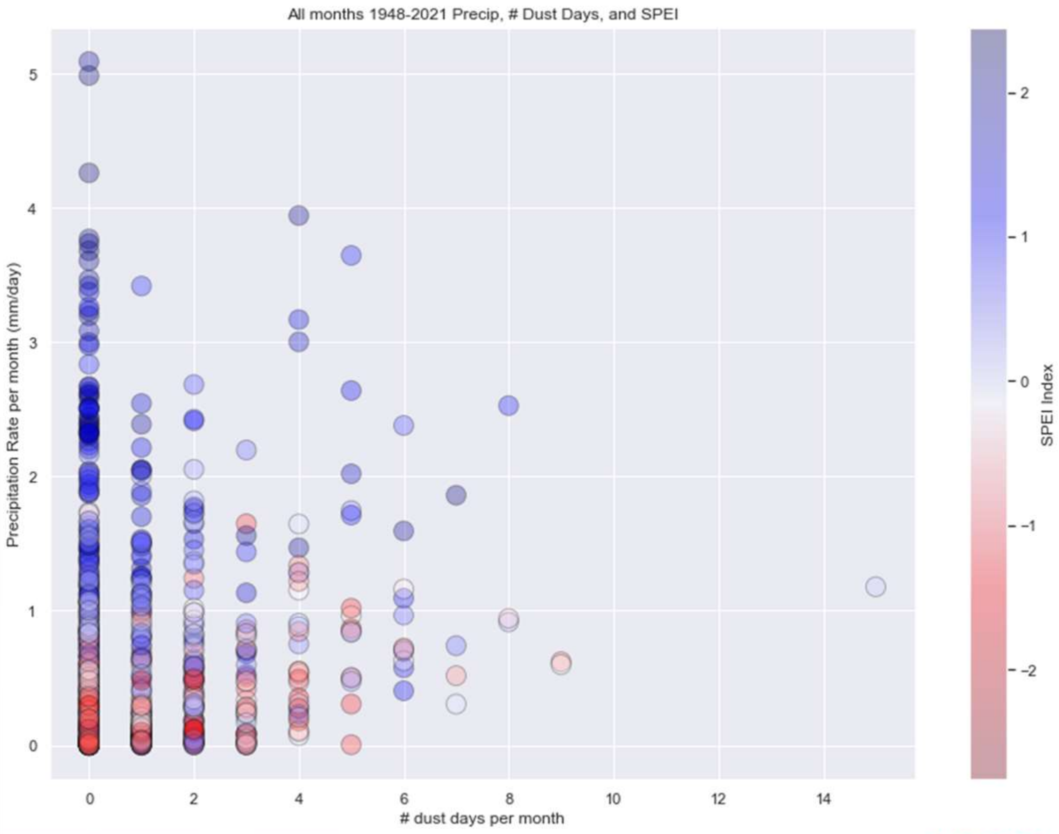
All 12 months since 1948



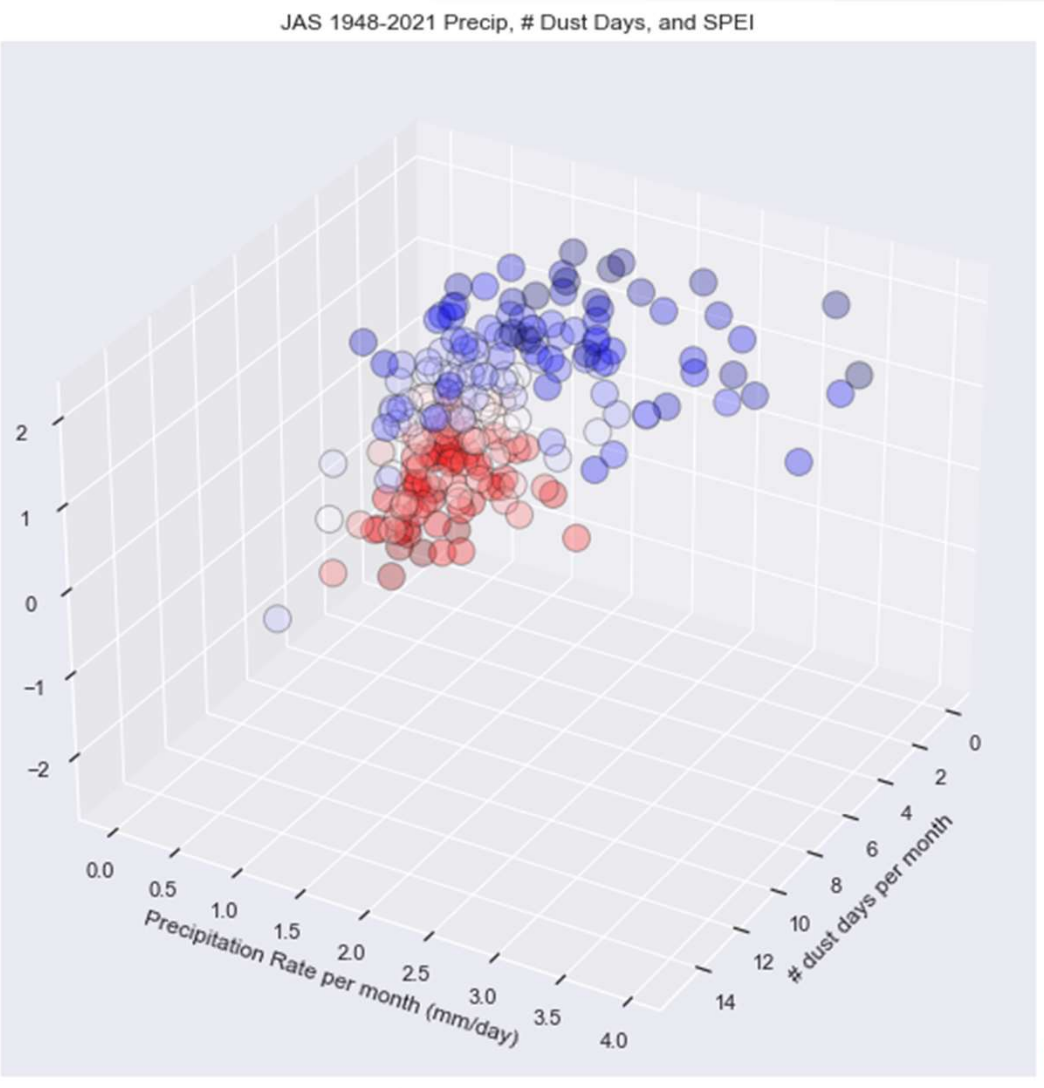
JAS since 1948

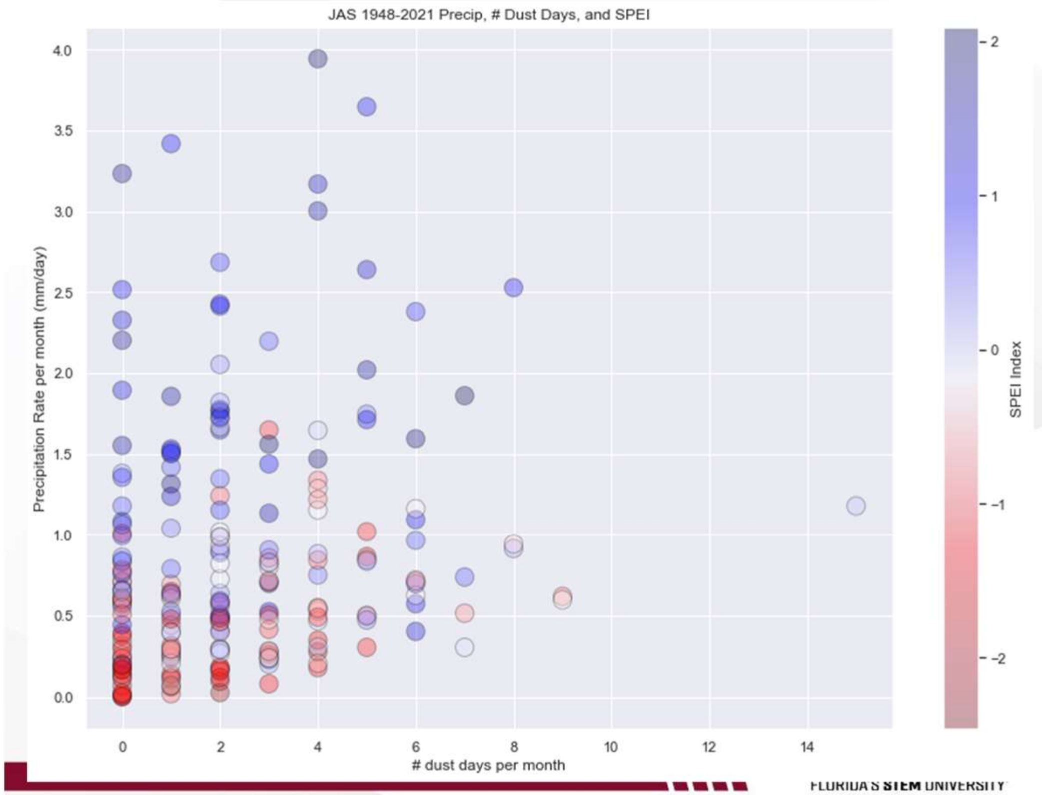
All Months Precipitation, Dust Days per Month, and SPEI (1948-2021) - Phoenix



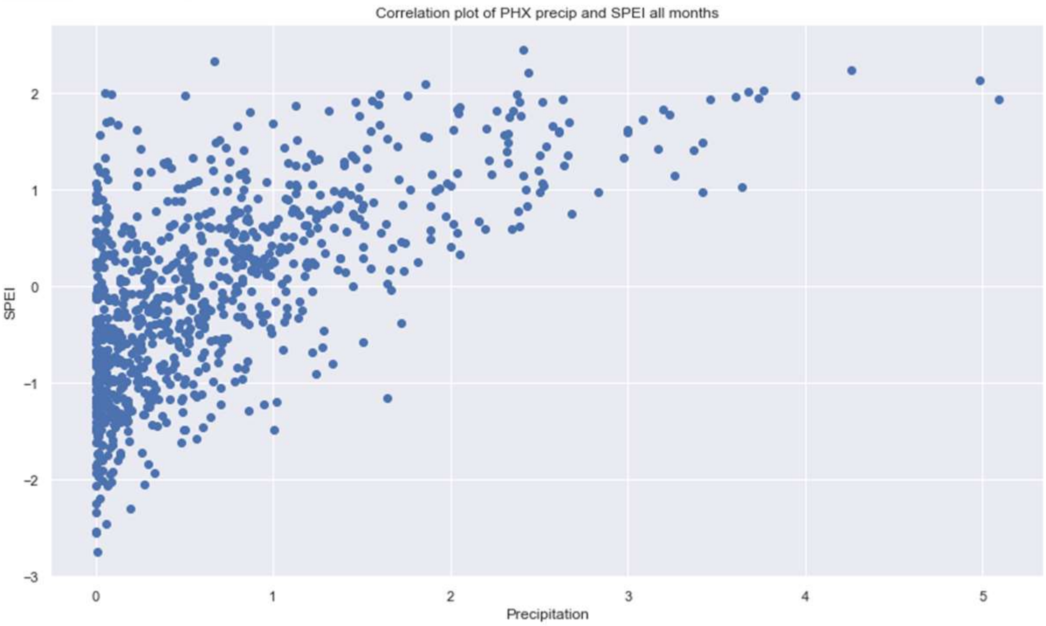


JAS Precipitation, Dust Days per Month, and SPEI (1948-2021) - Phoenix

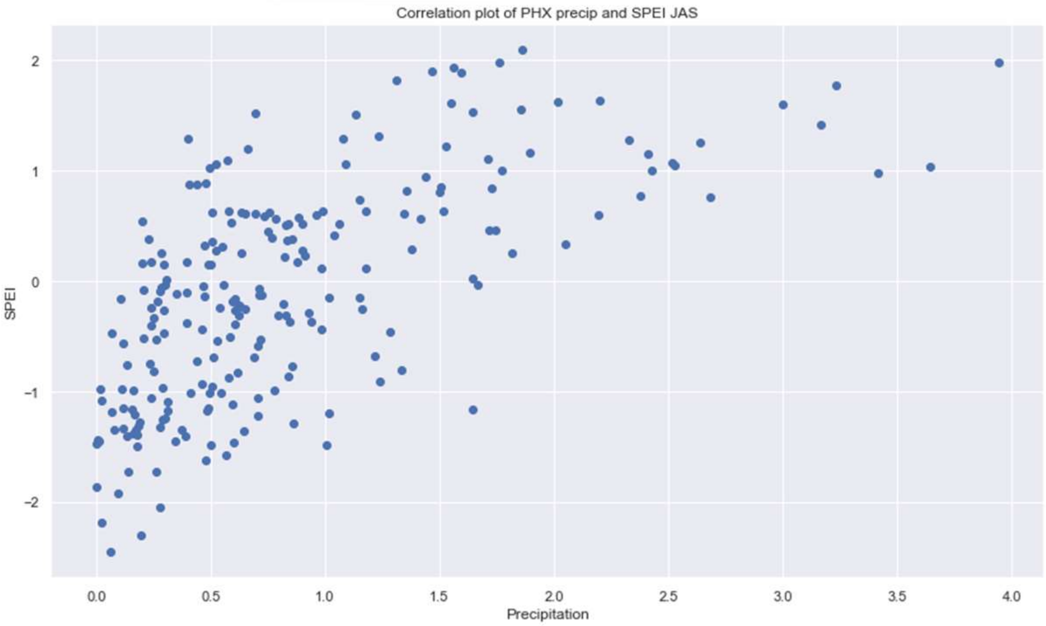




SPEI vs. Precipitation - A Simplified Look at PHX

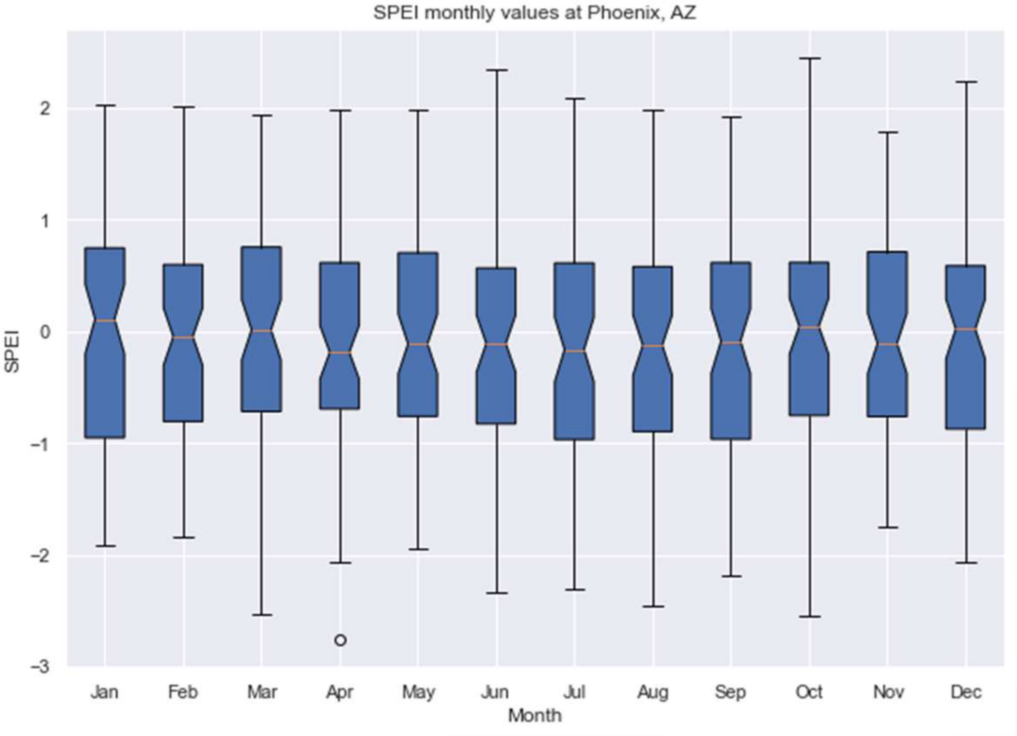

Correlation plot of PHX precip and SPEI all months

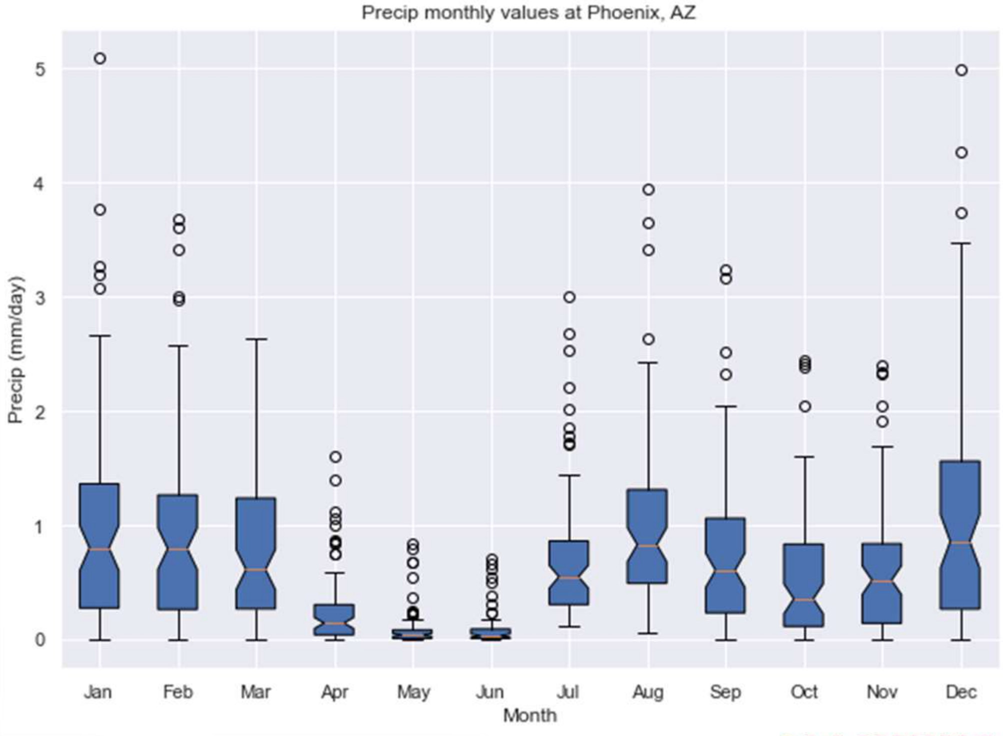
All months


Correlation plot of PHX precip and SPEI JAS

JAS

Single Variable Analyses at PHX

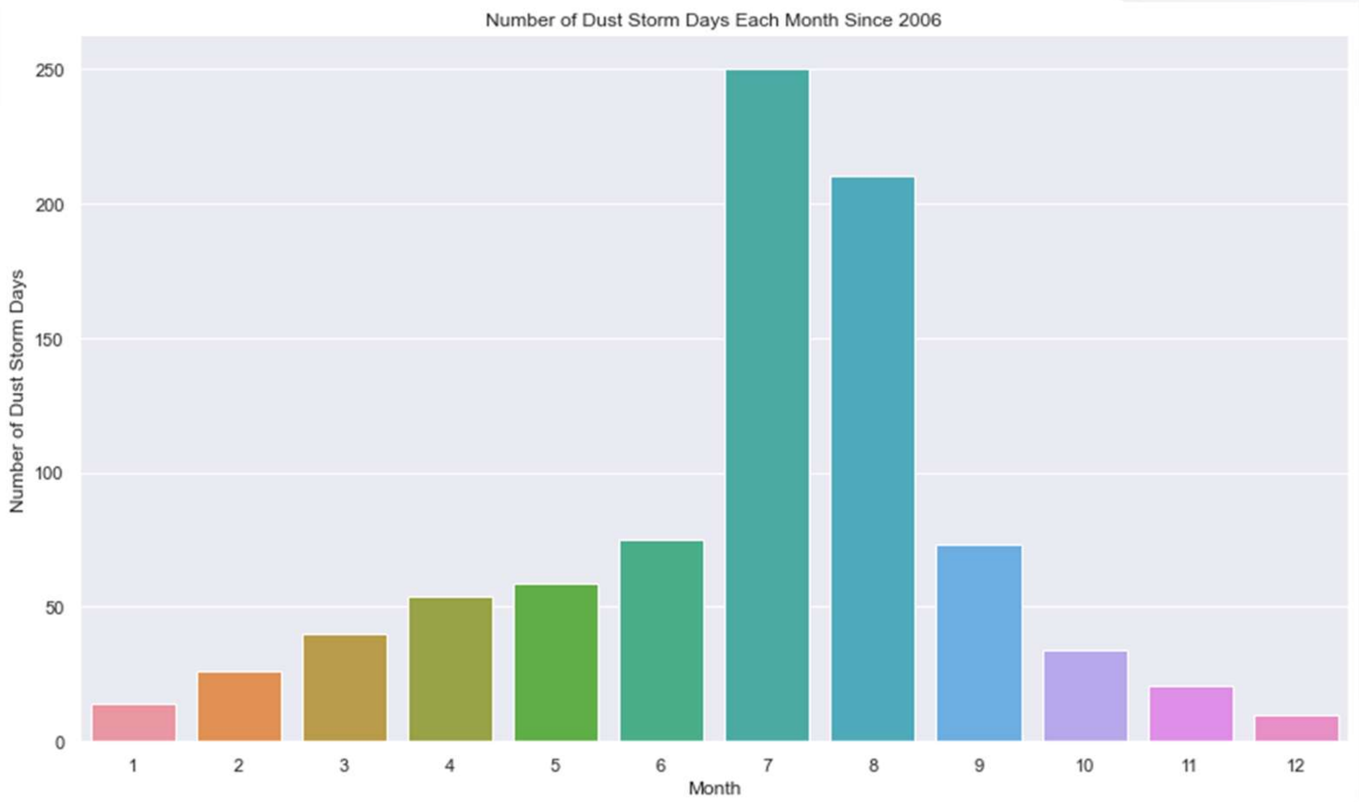


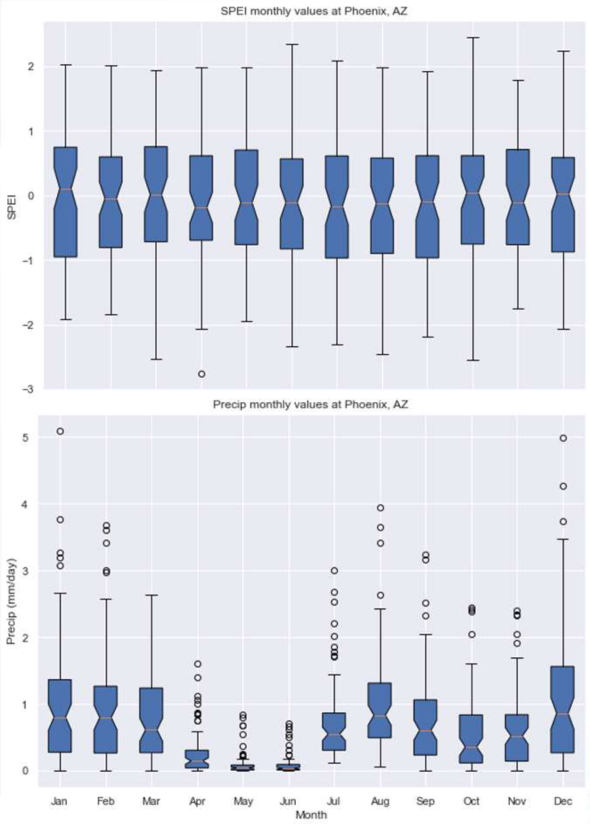


Very limited monthly signal

Note the extreme general lack of precipitation in April, May, and June, right before the NAM

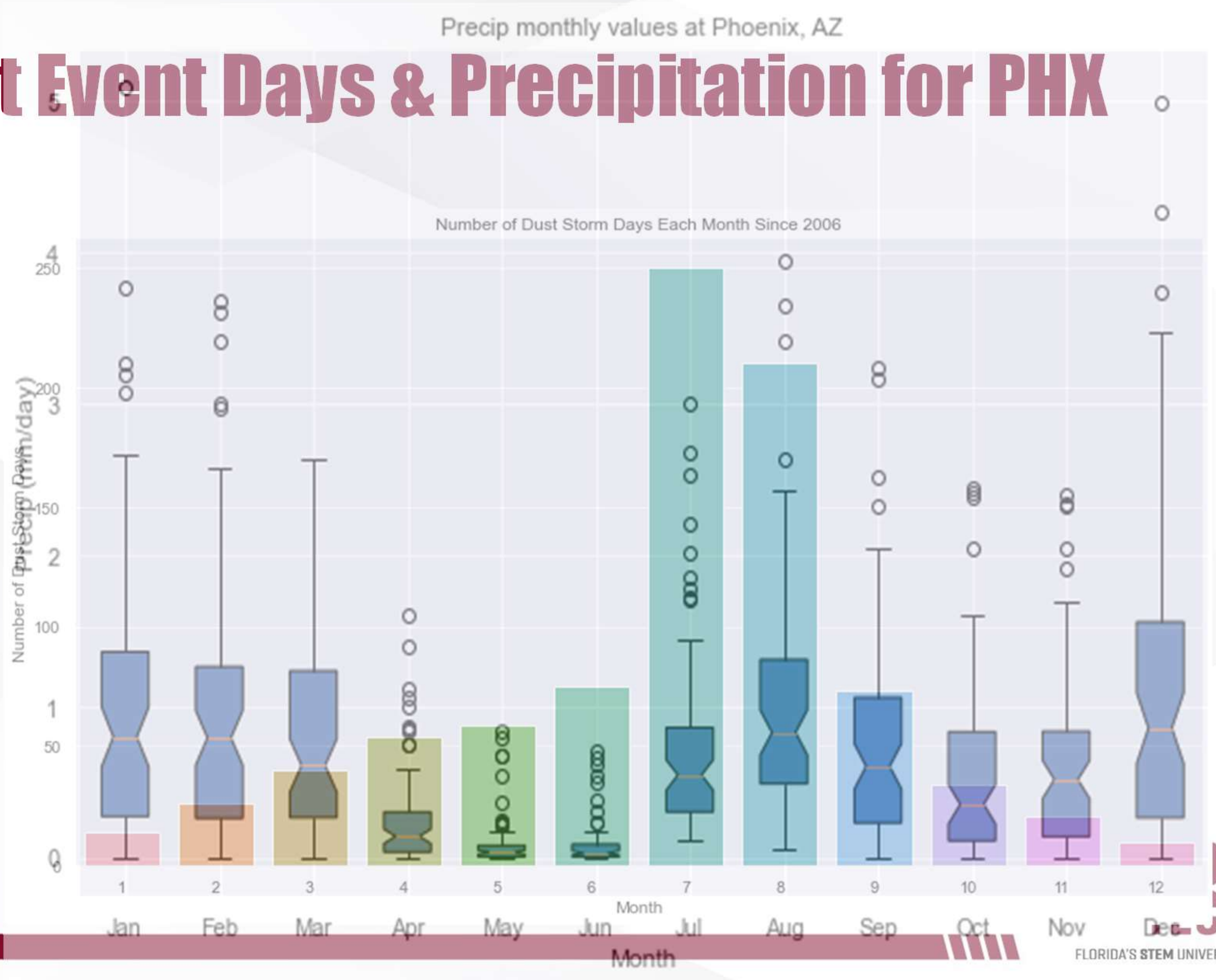
ISD Total Dust Event Days for PHX



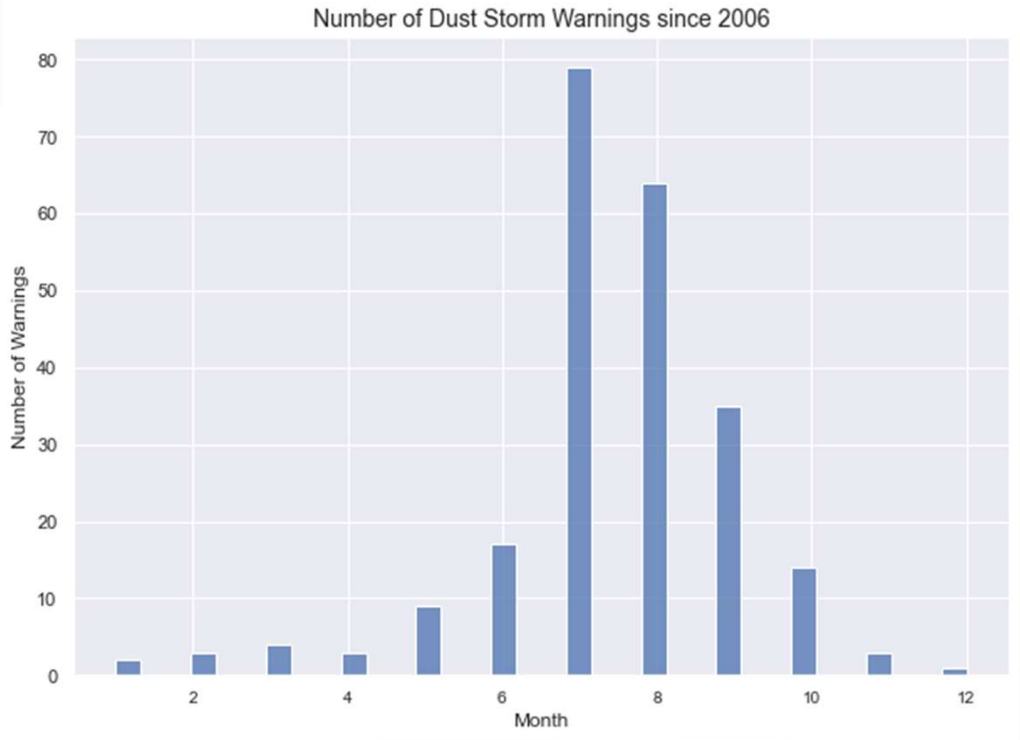


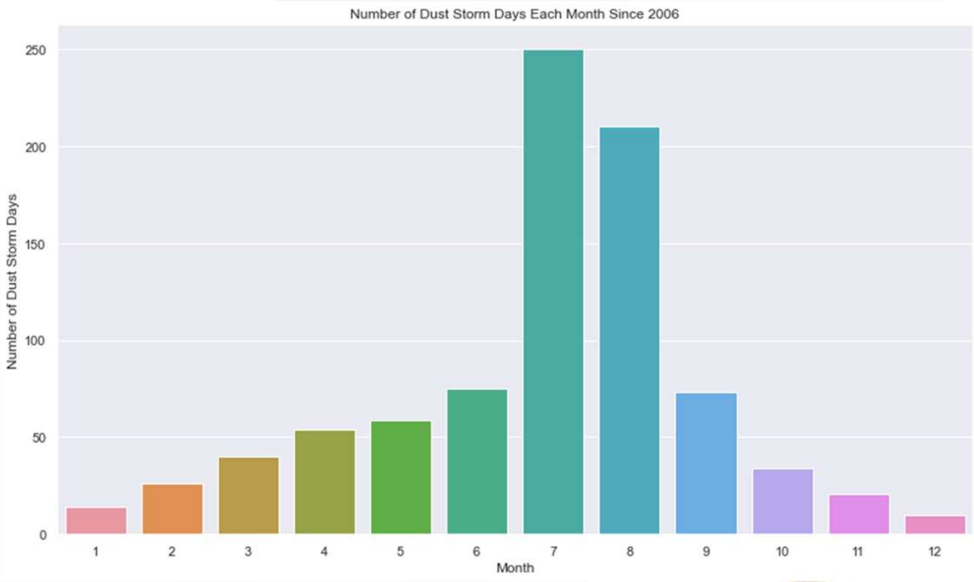
ISD Monthly Dust Event Days & Precipitation for PHX

- Association not a simple function of precipitation.
- Monsoon season peak in precipitation associated with dust peak, but dust events peak in July, not August.
- Winter precipitation peak not well associated with dust event frequency.



Do Dust Storm Warnings Align with Dust Reports in PHX?


Number of Dust Storm Warnings since 2006


Number of Dust Storm Days Each Month Since 2006

Where Do We Go From Here?

- Process and evaluate monthly dust events for remaining sites in SW US
  - Evaluate site to site variability
- Continue evaluation of potential predictors for number of monthly dust storms for the period of 1948-2022
  - Microburst index, wind speed, etc.
  - Evaluate site to site variability
  - Usage of raw values or anomalies?
- Set up a modeling framework for predicting dust event counts

References

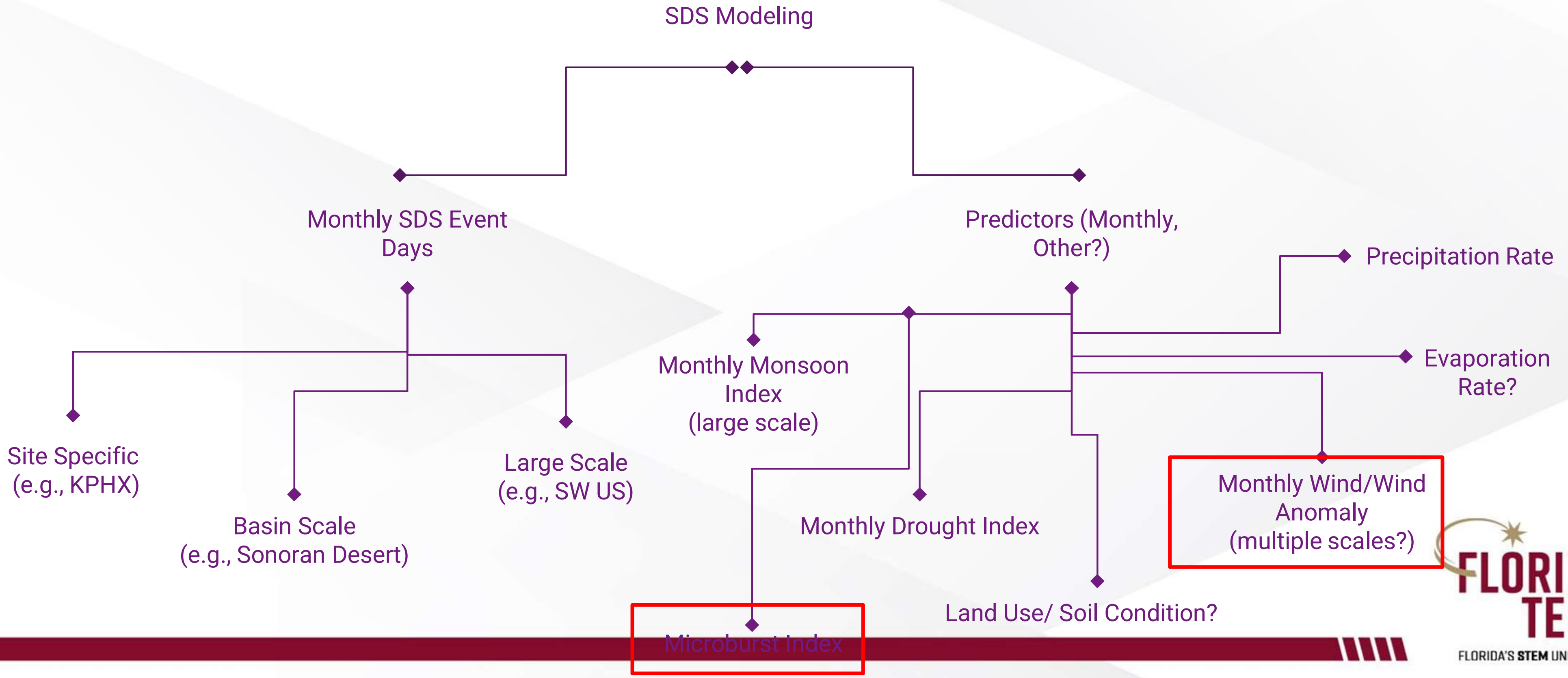
Desert Dust in the Global System: https://link.springer.com/content/pdf/10.1007/3-540-32355-4.pdf

ERA5 Precipitation Data: https://reanalyses.org/atmosphere/web-based-reanalysis-intercomparison-tools-writ

SPEI Data: https://lcsc.csic.es/

Current Research Course

Can we model sand/dust storm (SDS) monthly frequency?



SDS Modeling

Monthly SDS Event Days

Predictors (Monthly, Other?)

Site Specific (e.g., KPHX)

Basin Scale (e.g., Sonoran Desert)

Large Scale (e.g., SW US)

Monthly Monsoon Index (large scale)

Microburst Index

Monthly Drought Index

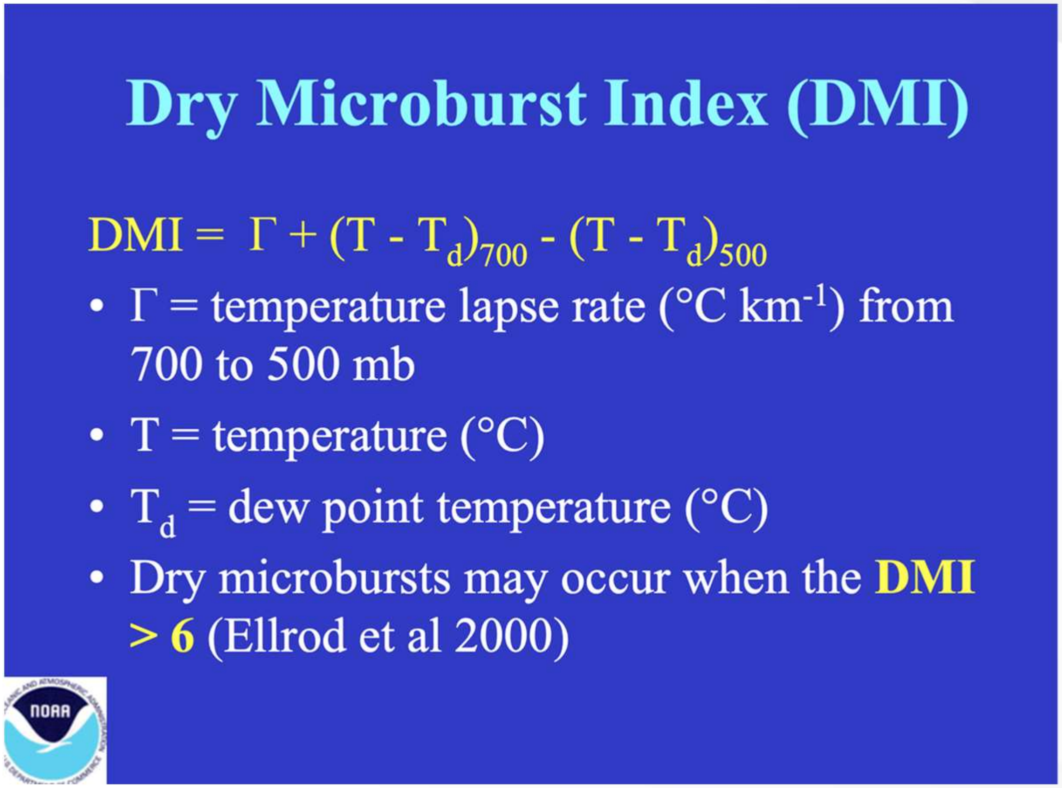
Land Use/ Soil Condition?

Monthly Wind/Wind Anomaly (multiple scales?)

Evaporation Rate?

Precipitation Rate

Microburst Index



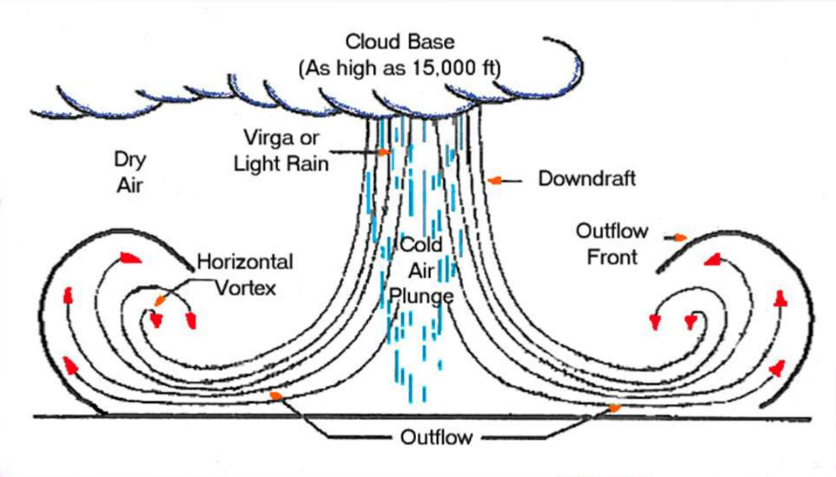
Dry Microburst Index (DMI)

$DMI = \Gamma + (T - T_d)_{700} - (T - T_d)_{500}$

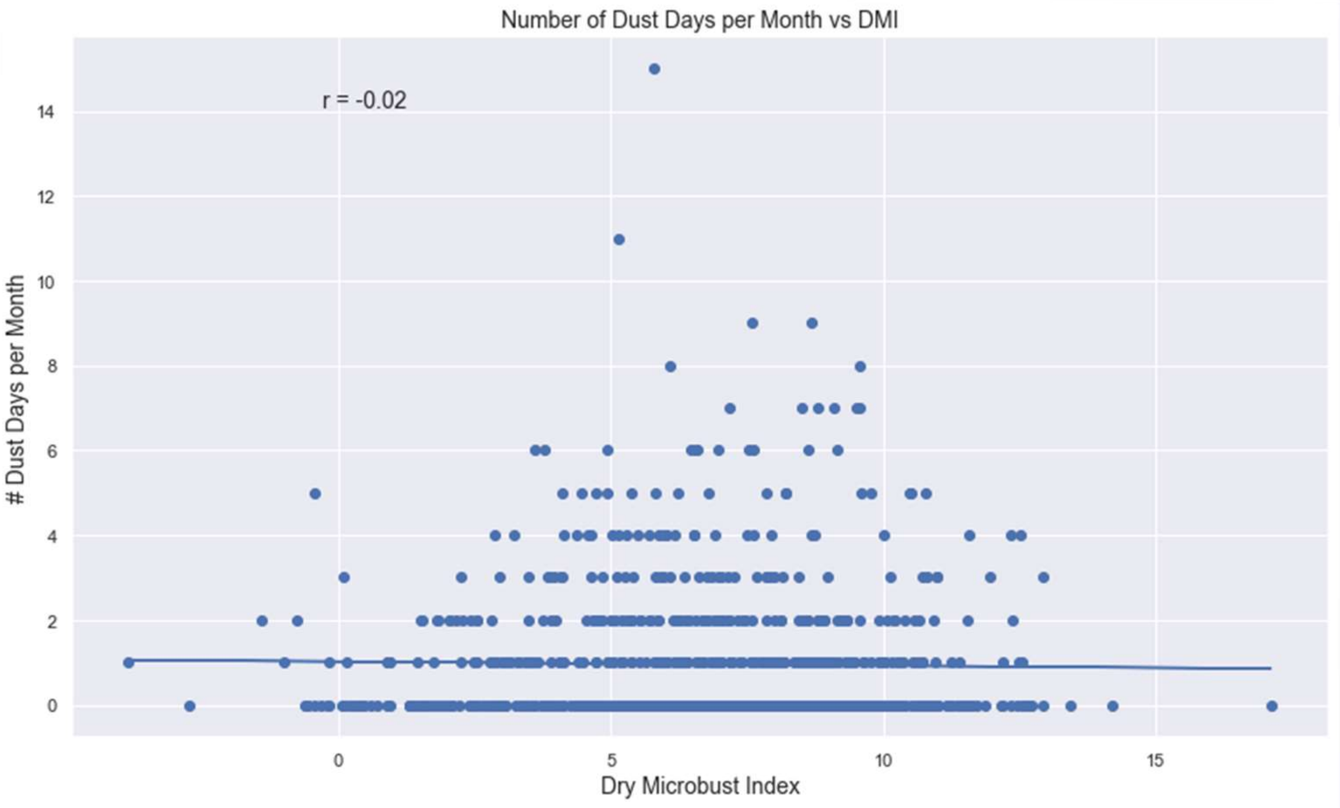
- Γ = temperature lapse rate (°C km^{-1}) from 700 to 500 mb
- T = temperature (°C)
- T_d = dew point temperature (°C)
- Dry microbursts may occur when the **DMI > 6** (Ellrod et al 2000)

(Rose, 2016)

- Microbursts are strong downdrafts that cause an outflow of strong winds at or near the surface
- Dry microbursts are common in the American Southwest and exhibit little to no precipitation during the outflow period
- Often associated with virga
- Occur in a convectively unstable environment with a deep dry boundary layer, where precipitation evaporates and cools the air, thus causing negative buoyancy.



Dust Frequency and Dry Microburst Index

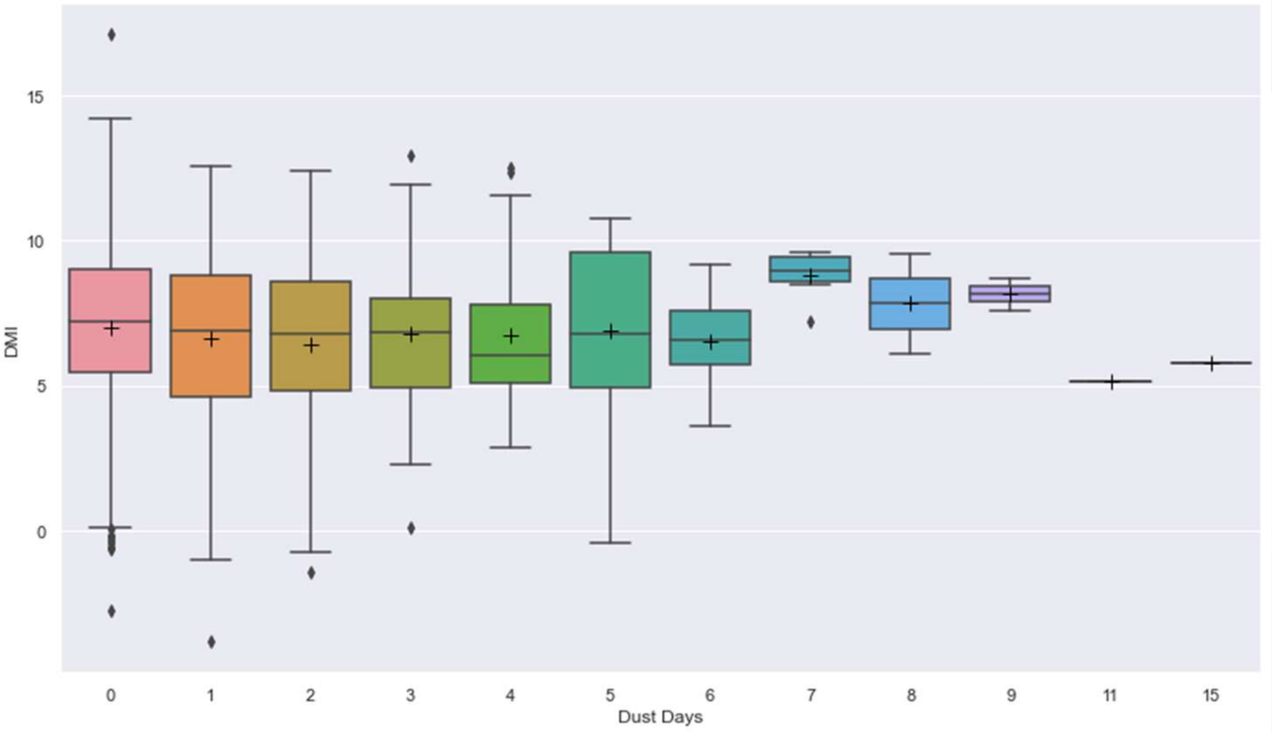


Not a strong correlation visible by the naked eye

“Pyramid” shape appears, making it tricky to draw conclusions

Make a boxplot

Dust Frequency and Dry Microburst Index



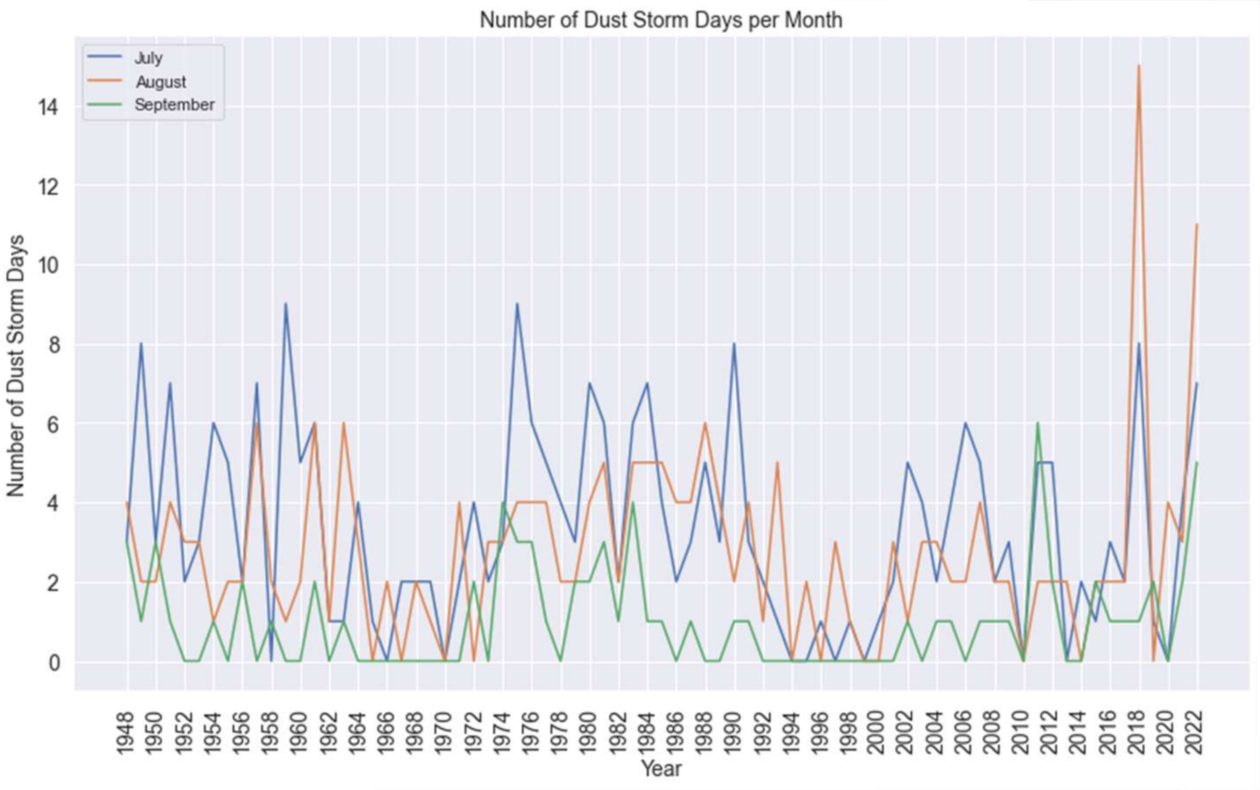
Categories of 2 and 7 events per month have lowest probability of false rejection

Even when showing mean and spread values, we cannot derive any clear relationships between the DMI and dust storm frequency beyond a slight increase.

ANOVA p-value between DMI categorized by dust day frequency: 0.5377

Notably: DMI is valuable on a day-to-day basis, so the signal may be averaged out at a monthly timescale. Still could be a useful parameter

Dust Storm Frequency During Monsoon Season



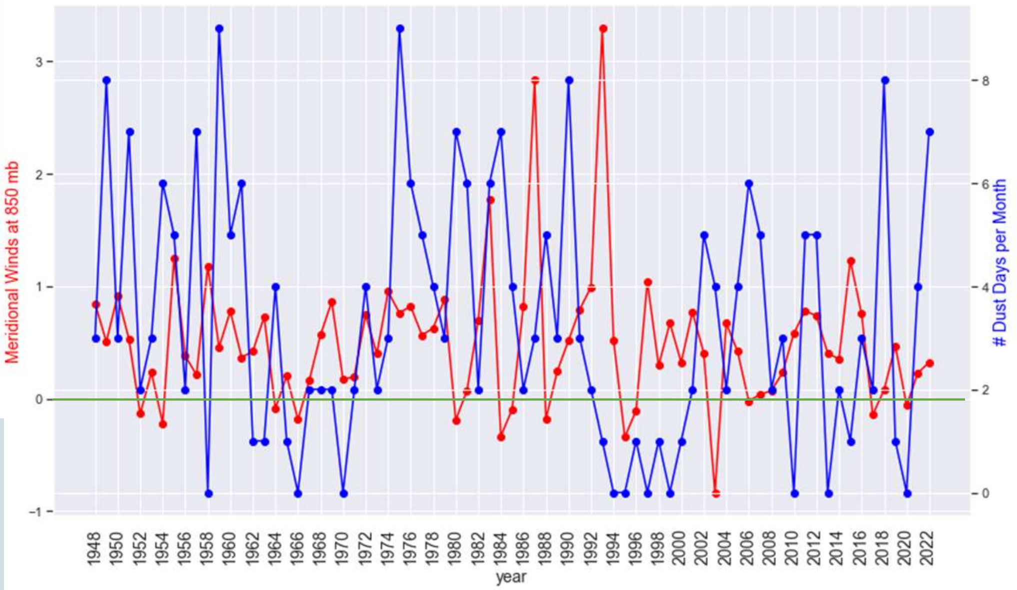
Breakdown of dust and sandstorm frequency in the Southwest by summer monsoon month

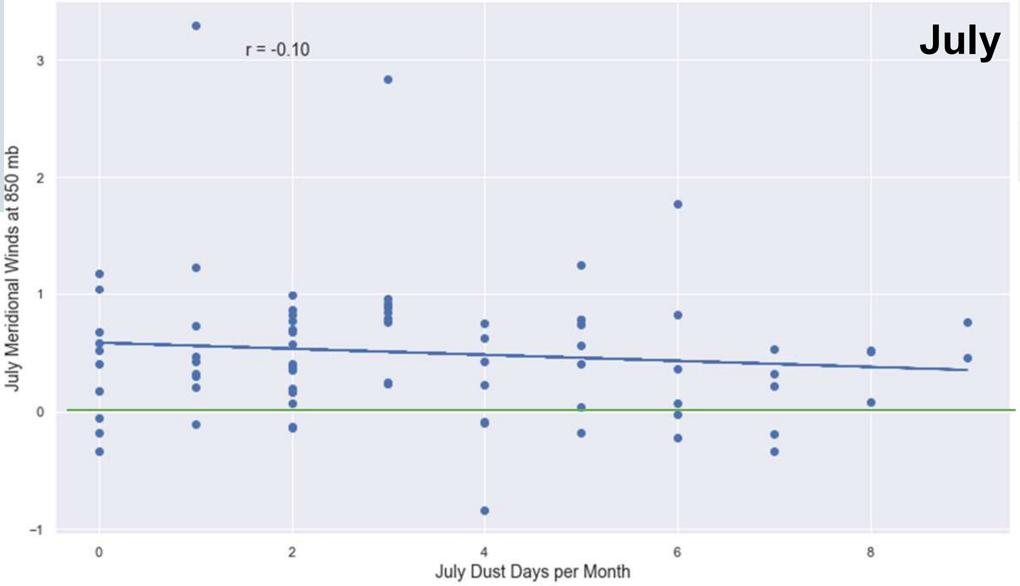
Note the spike from 1970-1990 and the jump once again in recent years

Phoenix <u>850mb meridional</u> winds and dust storm frequency at a monthly time scale:

- Plotted separately for July, August, and September
- Time series and correlation plots are both included
- Examines the “v” component of the wind, or the North-South flow at 850 mb over Phoenix.

PHOENIX





July

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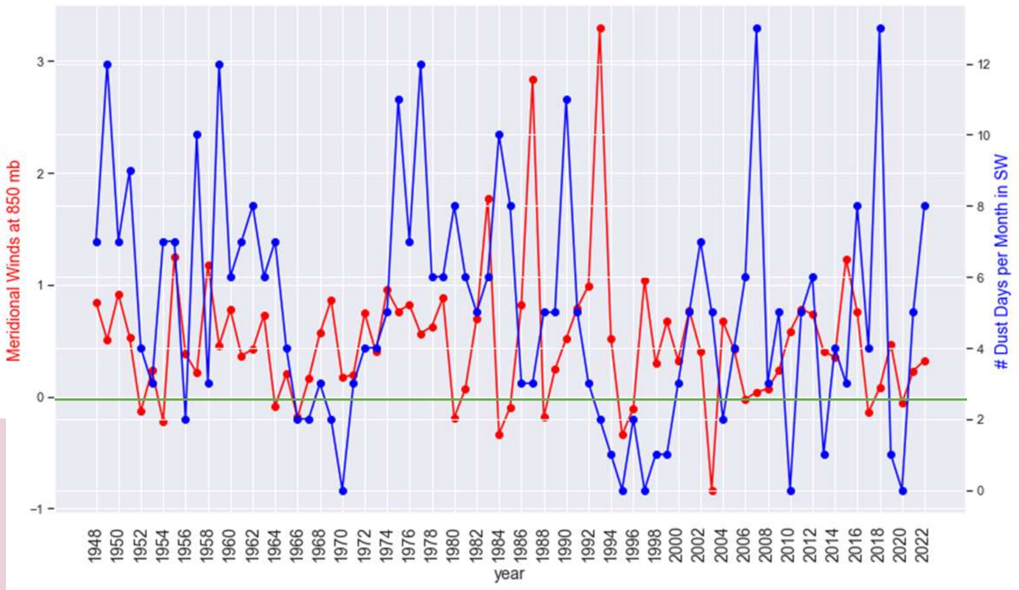
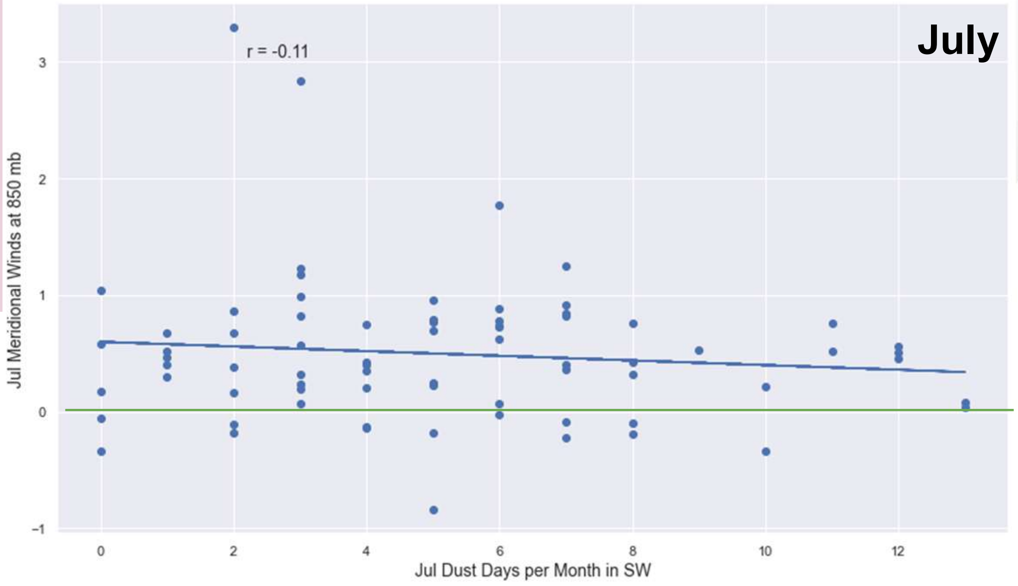
SOUTHWEST





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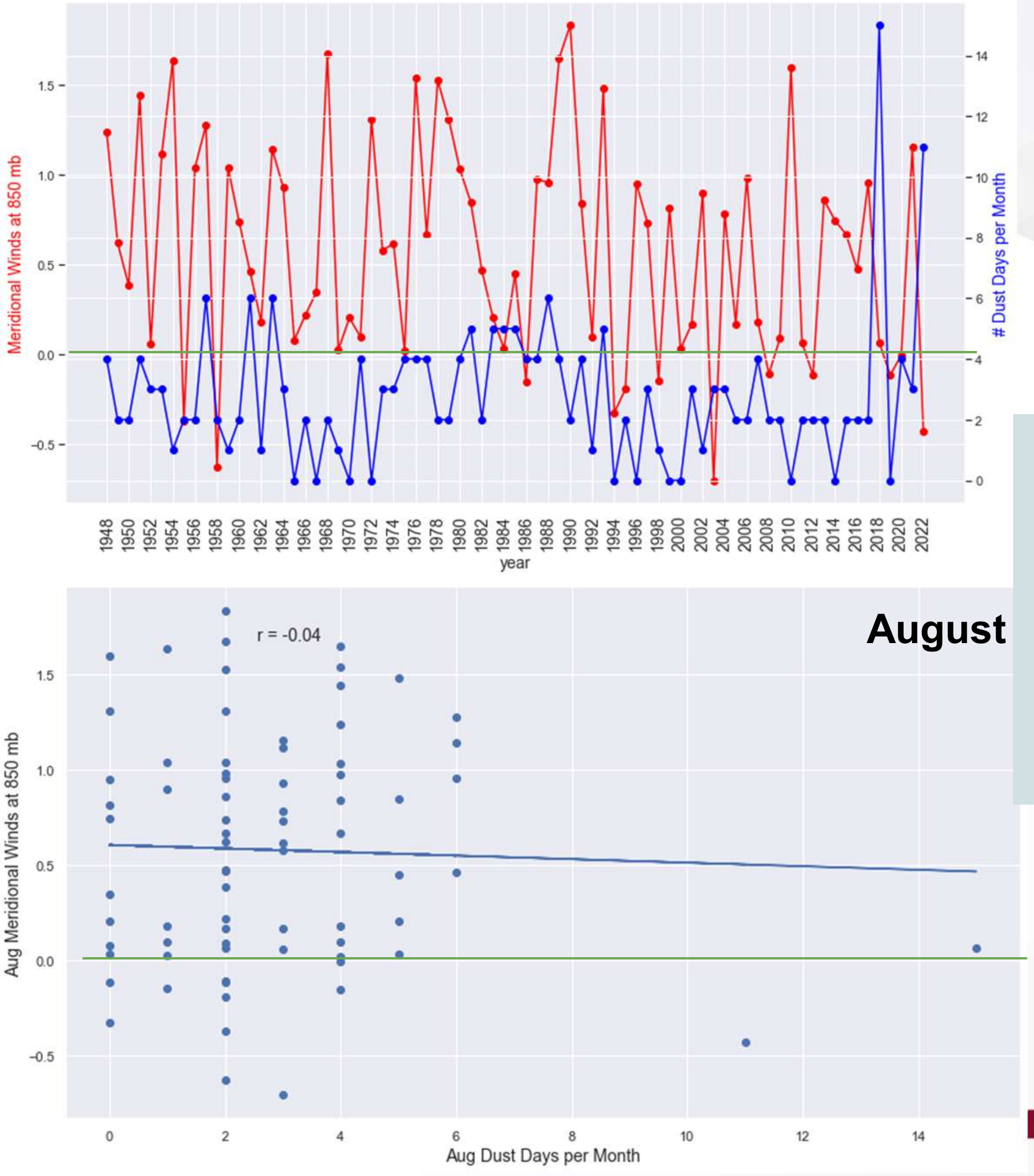
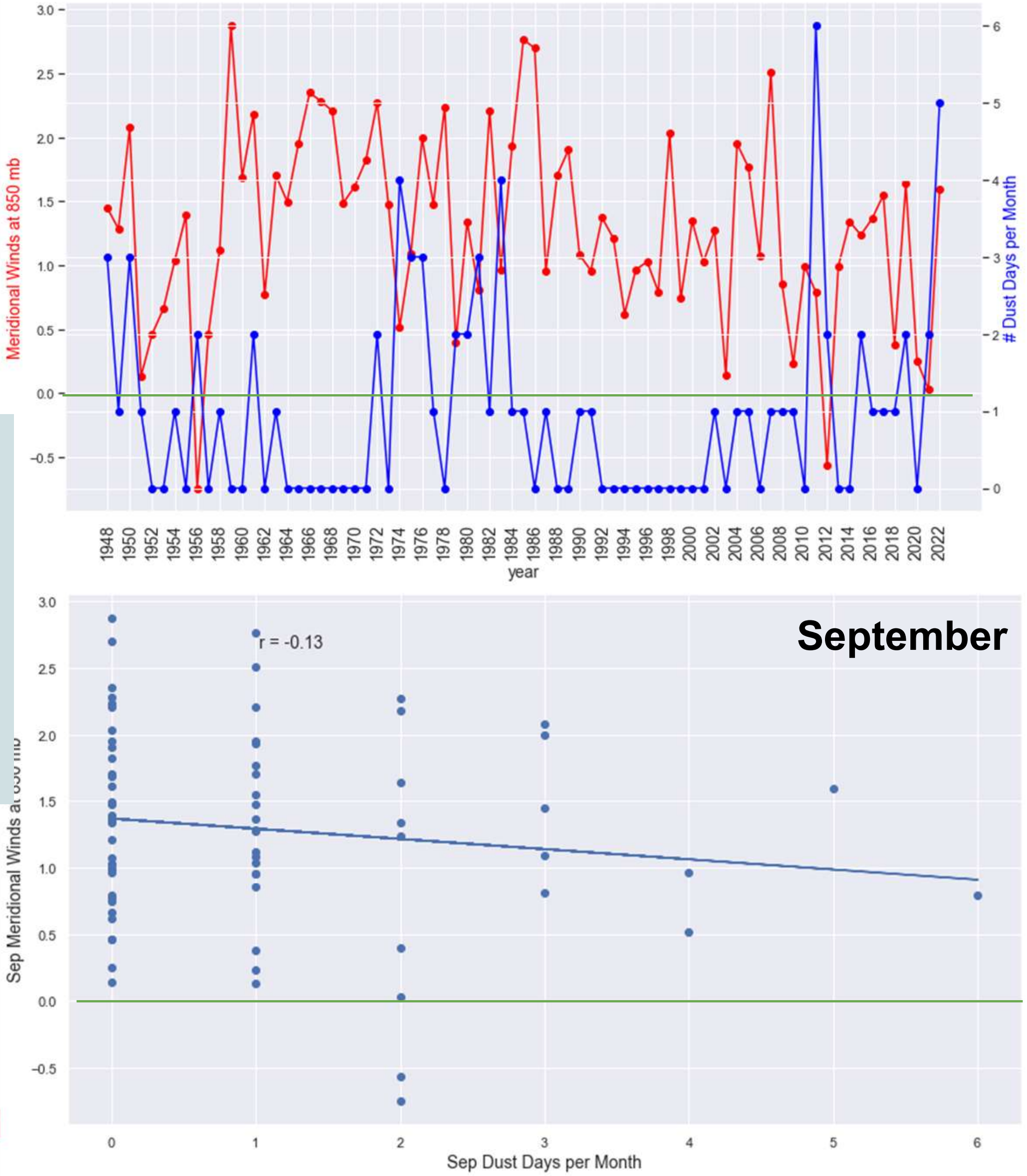


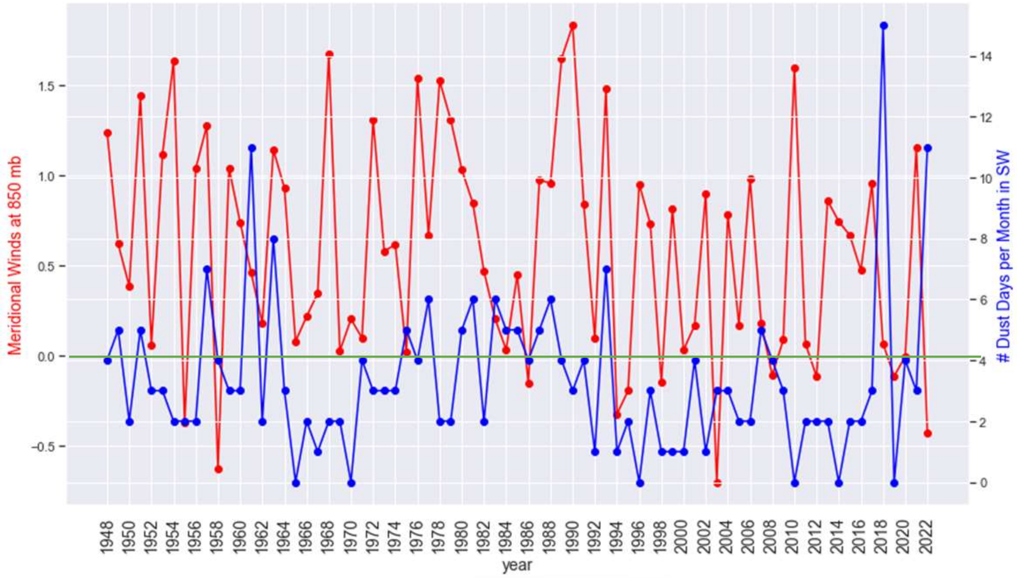
August

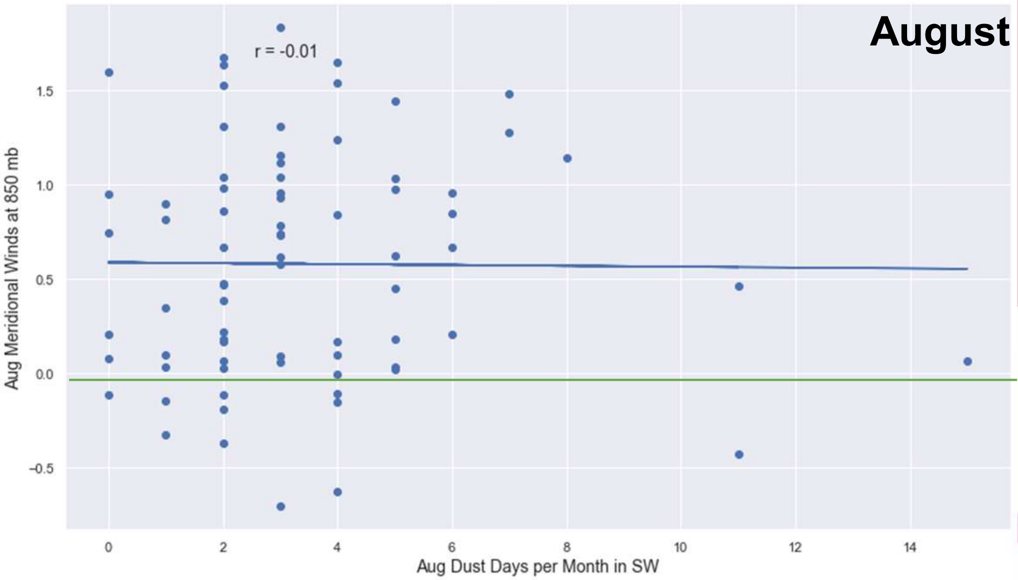


September

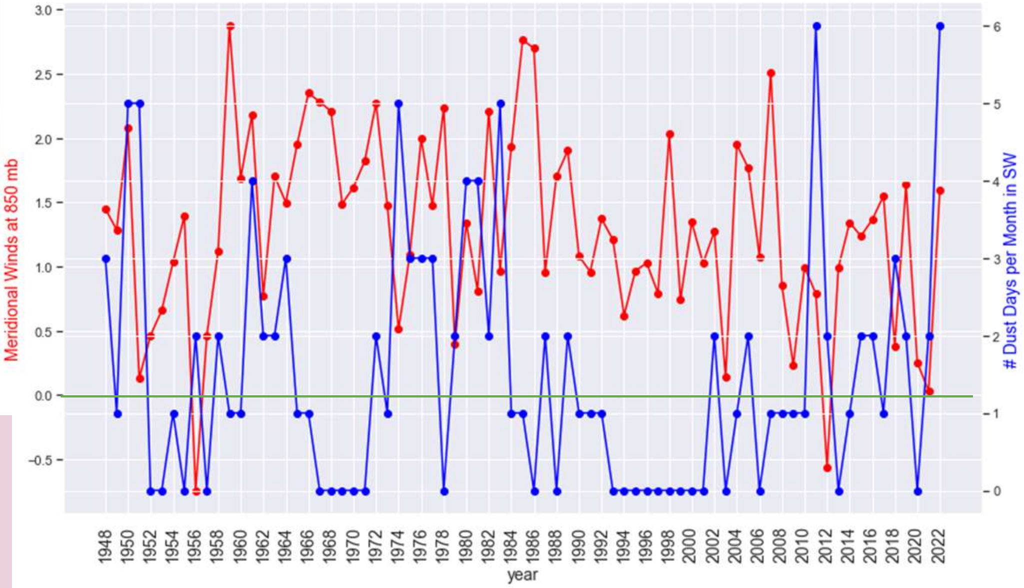
S O U T H W E S T

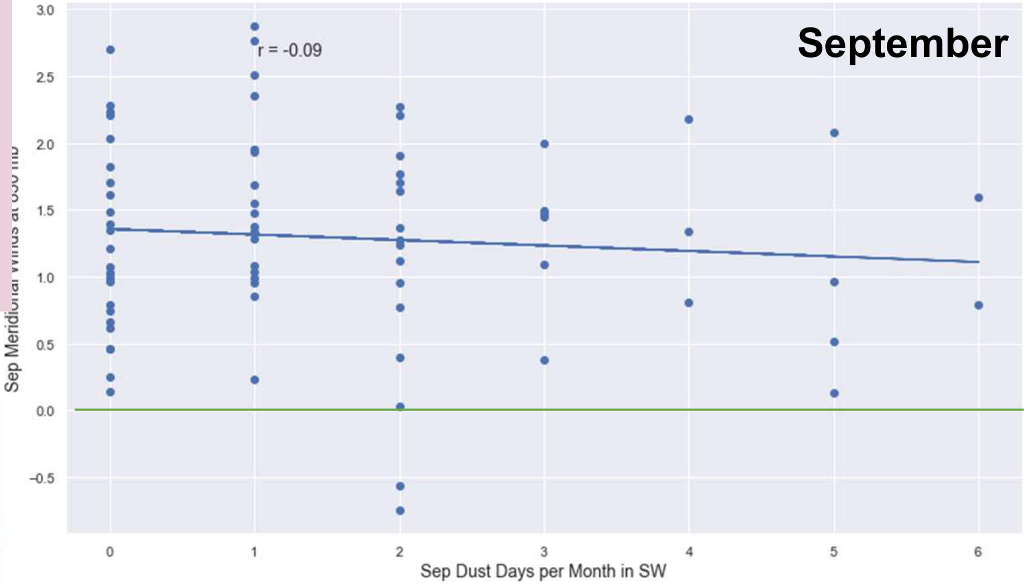
August





September





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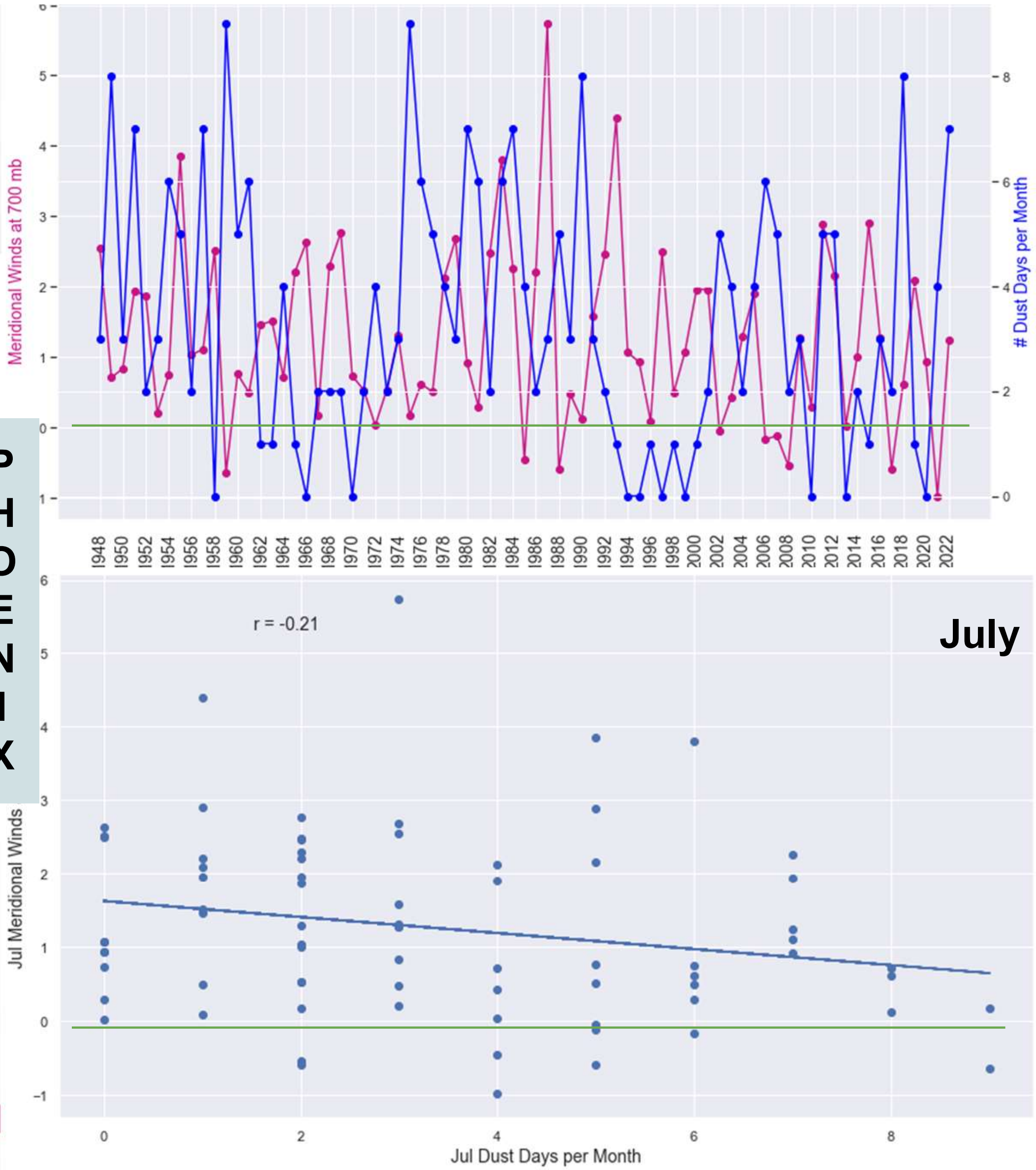

July

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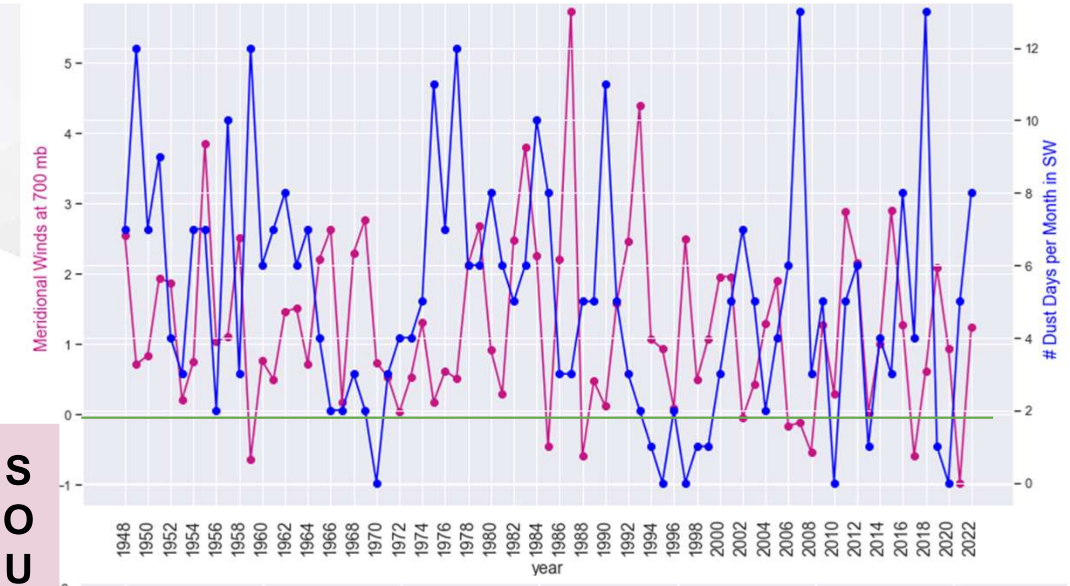
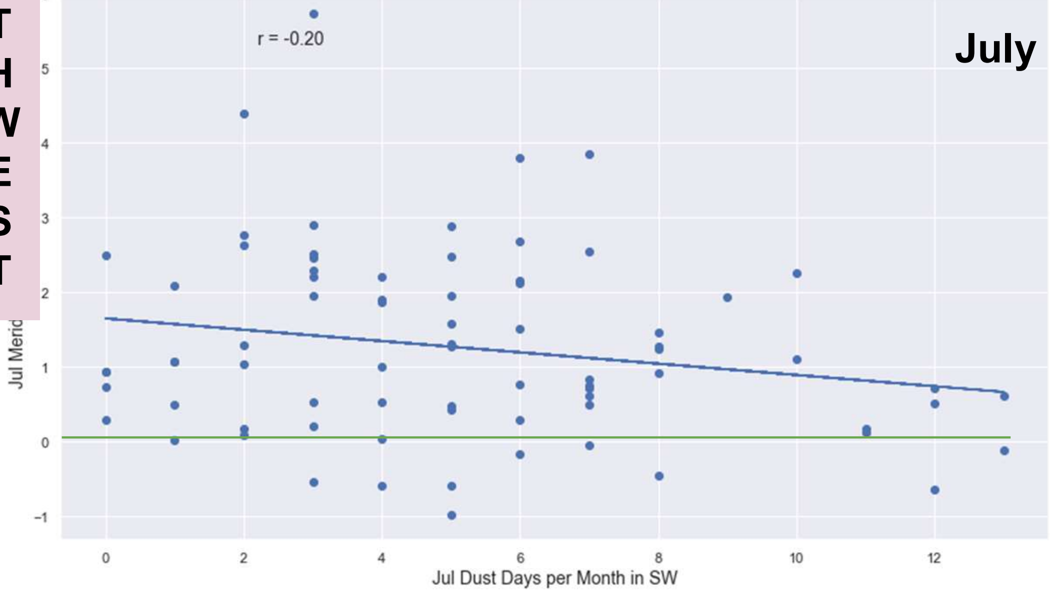
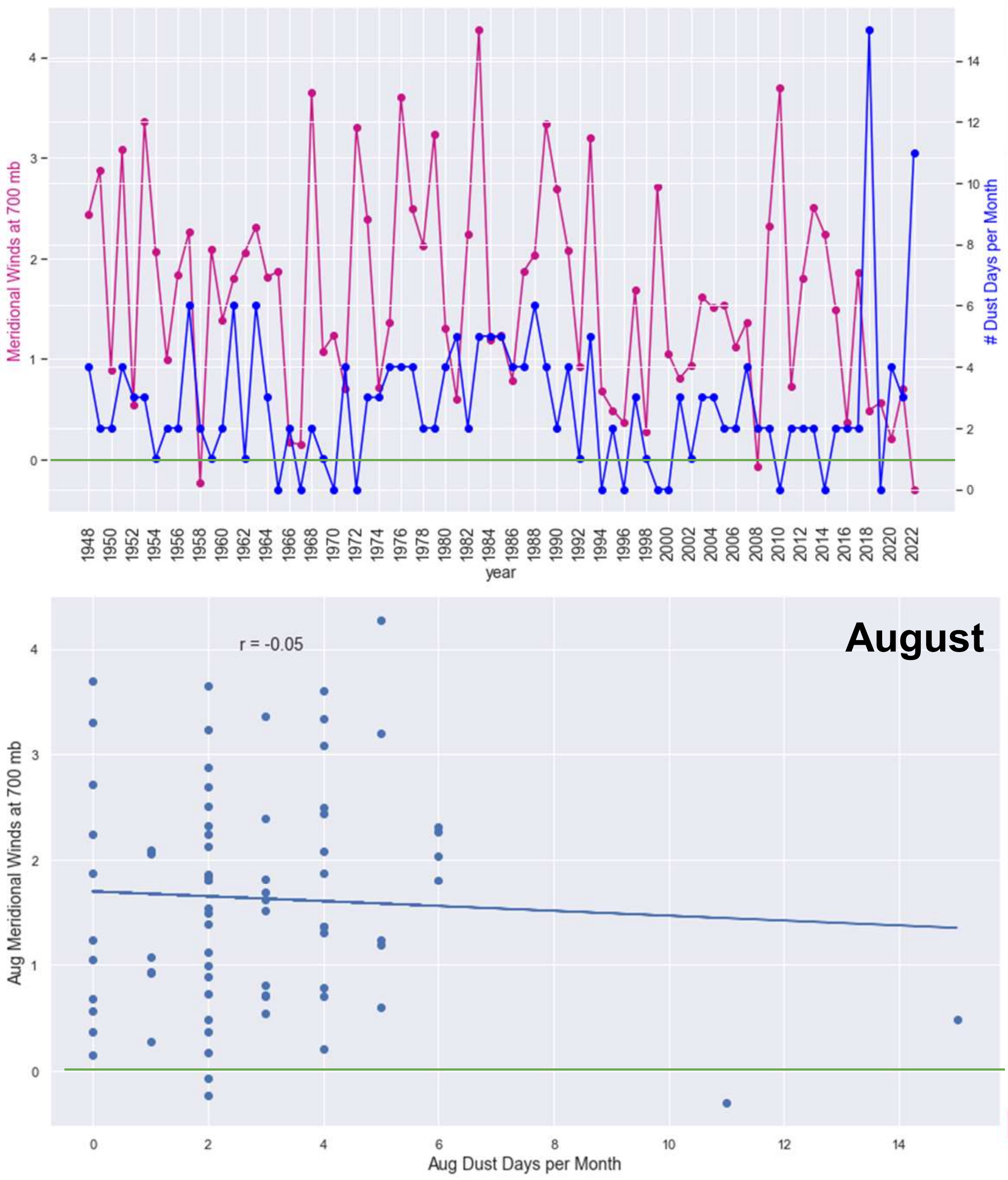
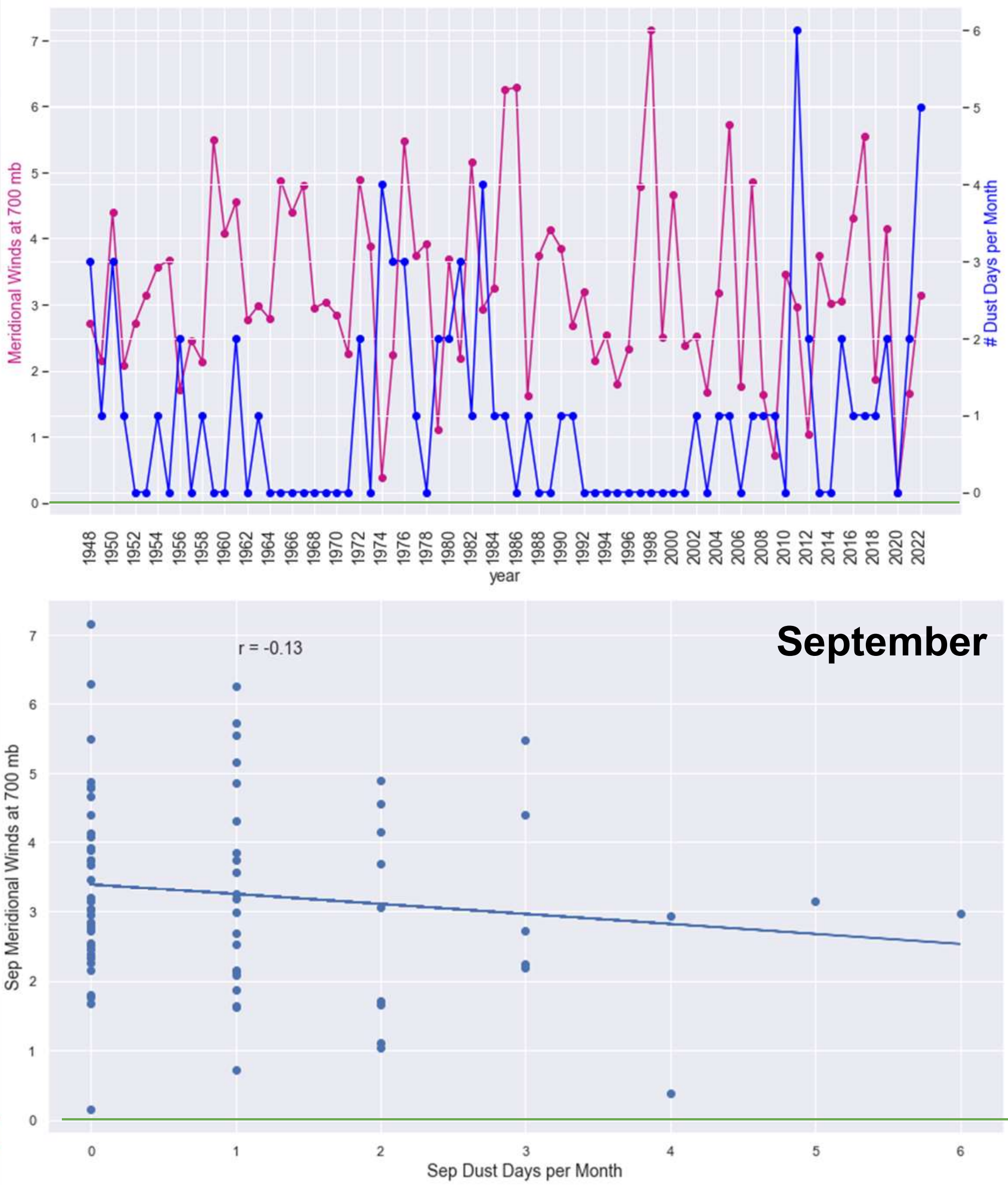




July


Meridional Winds at 700 mb
Dust Days per Month
year
r = -0.05
August
Aug Meridional Winds at 700 mb
Aug Dust Days per Month

PHOENIX


Meridional Winds at 700 mb
Dust Days per Month
year
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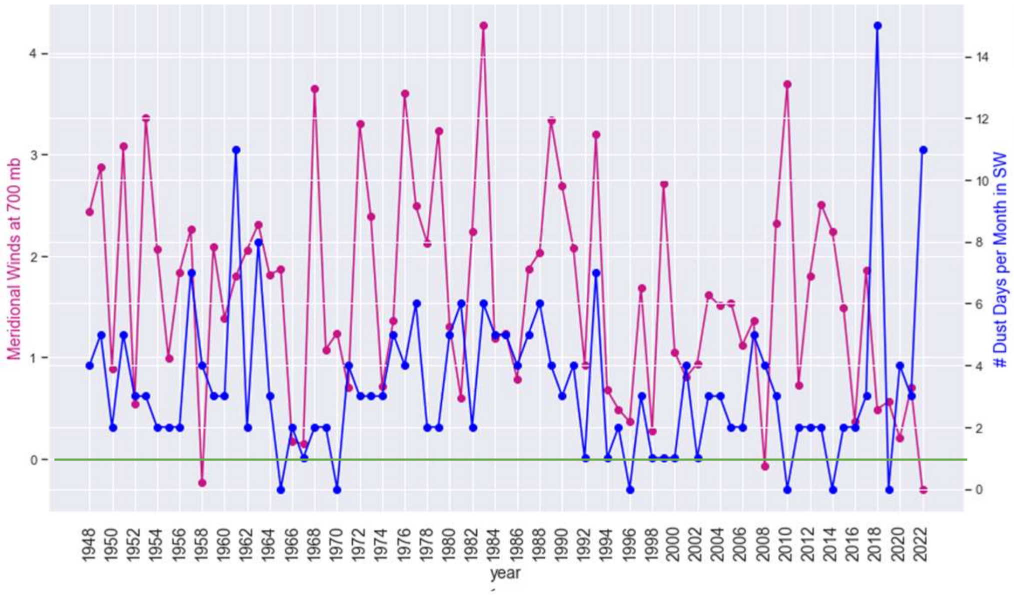
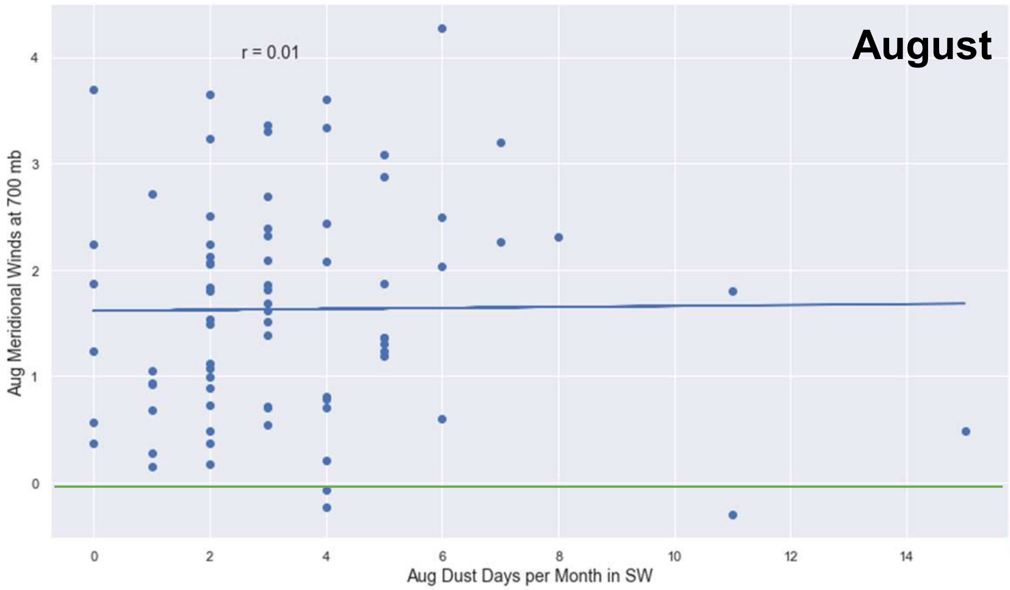
September
Sep Meridional Winds at 700 mb
Sep Dust Days per Month





August

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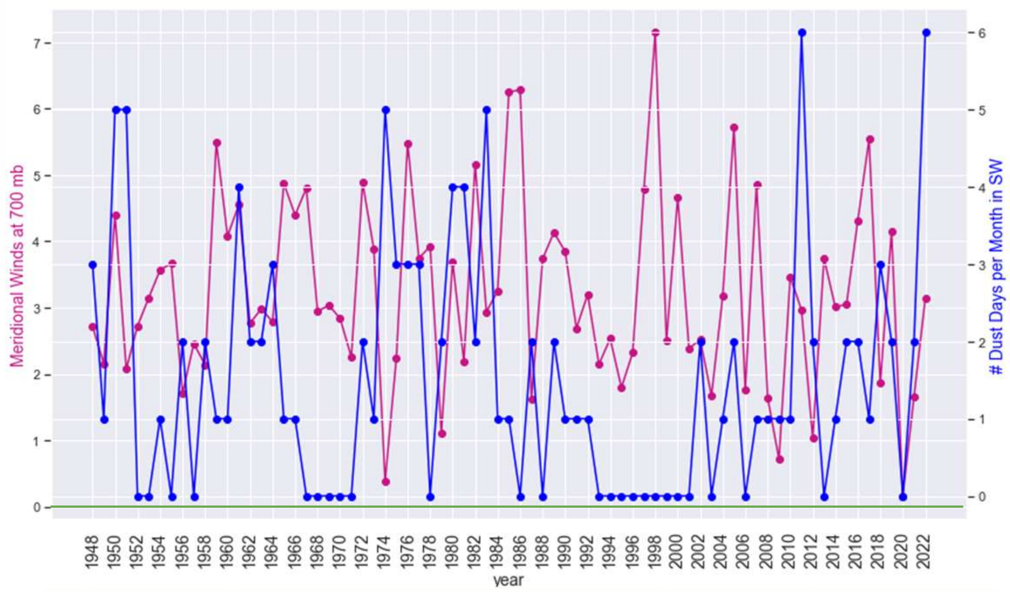

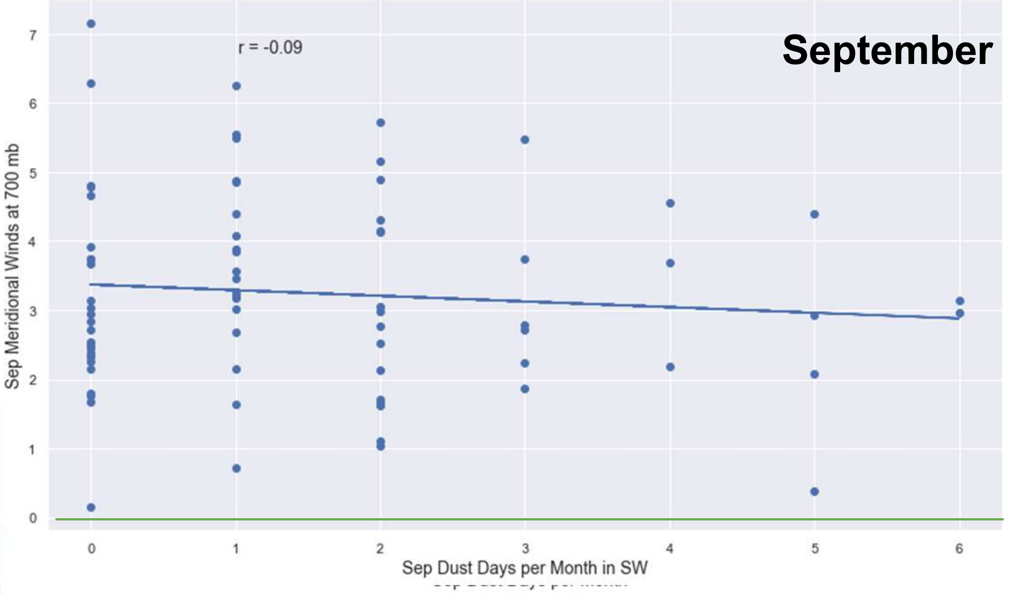

September

Phoenix <u>700mb zonal</u> winds and dust storm frequency at a monthly time scale:

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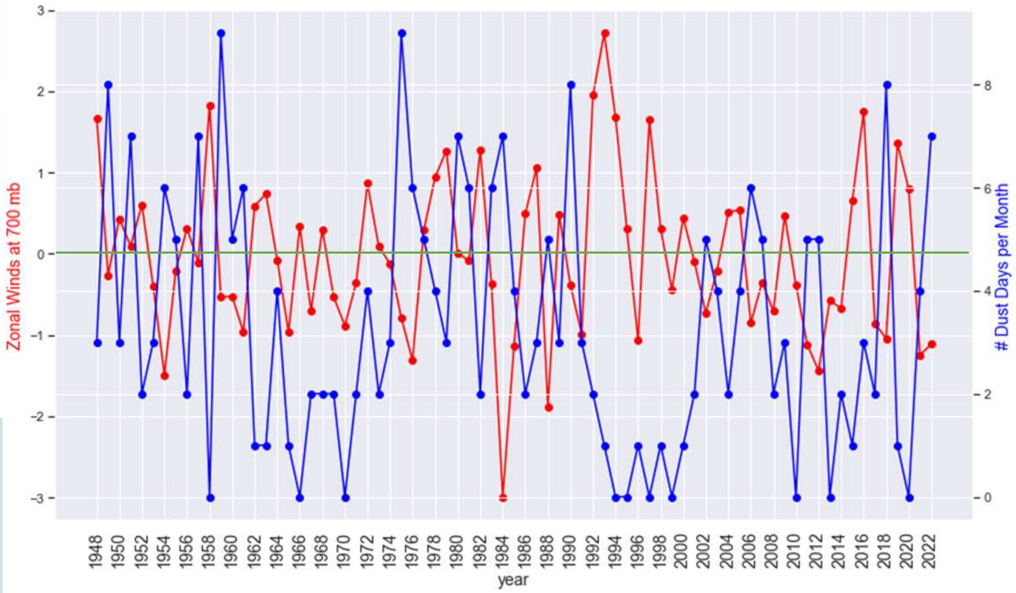
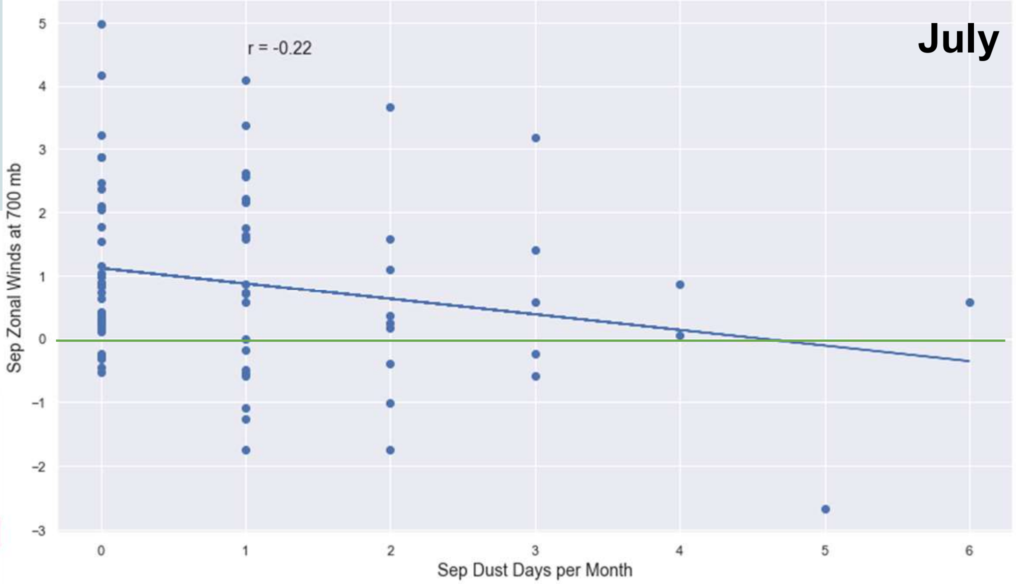
PHOENIX





July

SW US 700mb zonal winds and dust storm frequency at a monthly time scale:

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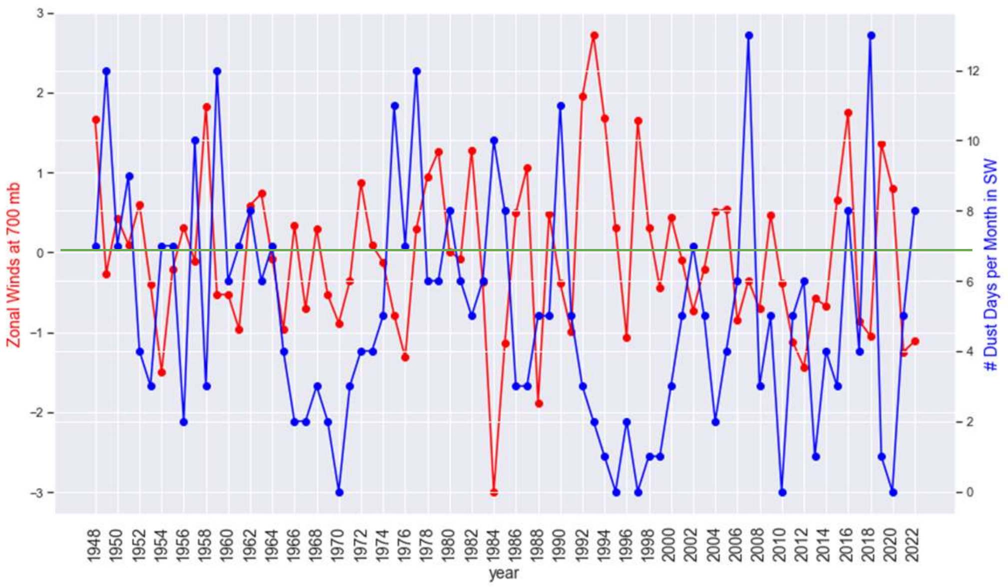
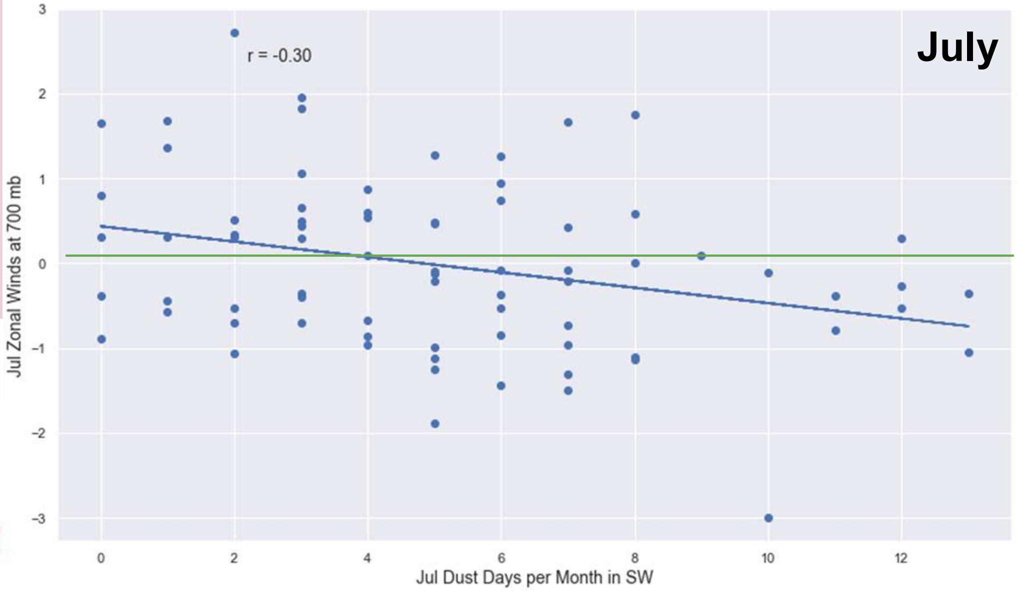
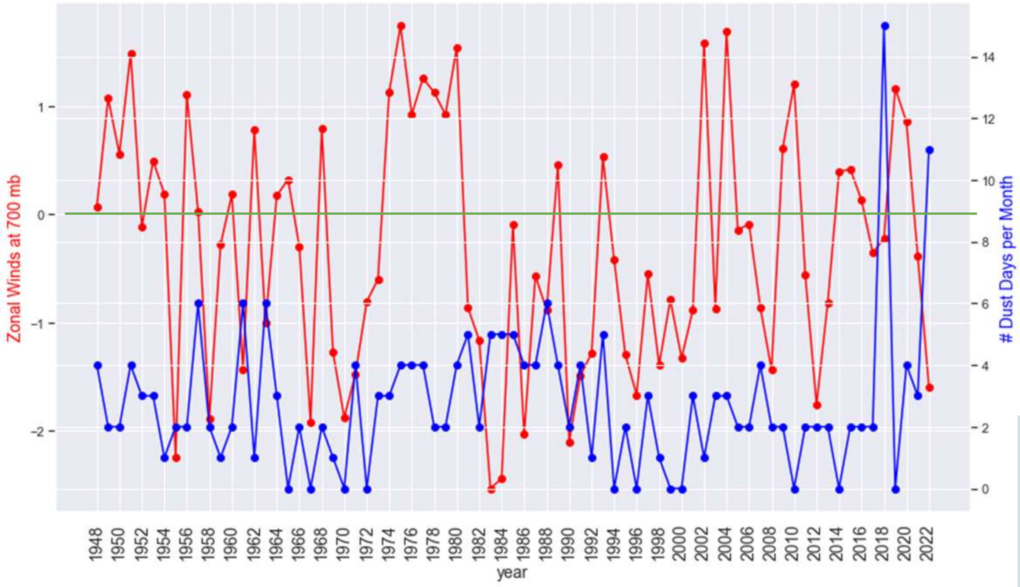
SOUTHWEST

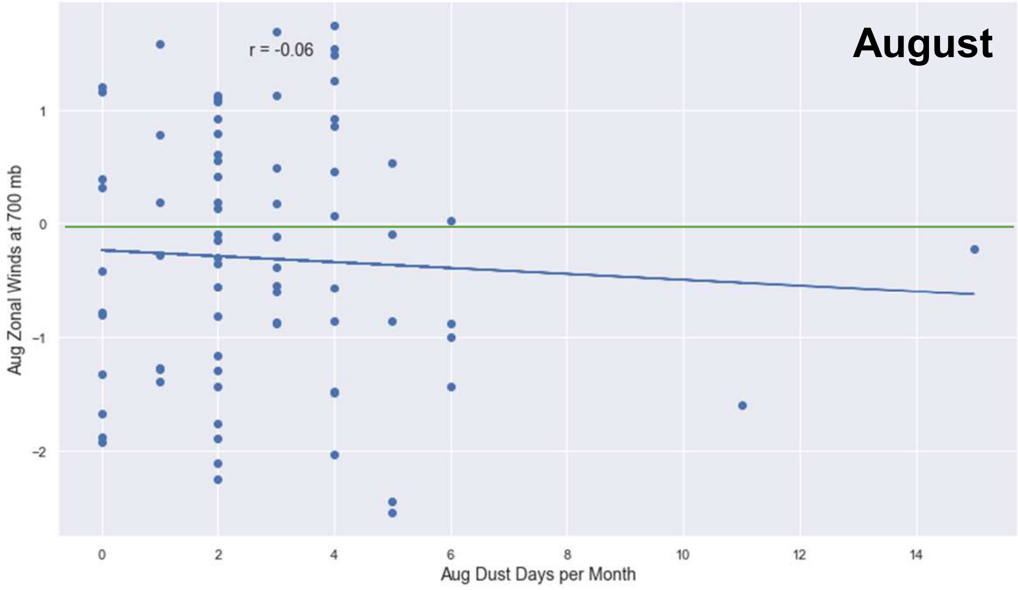


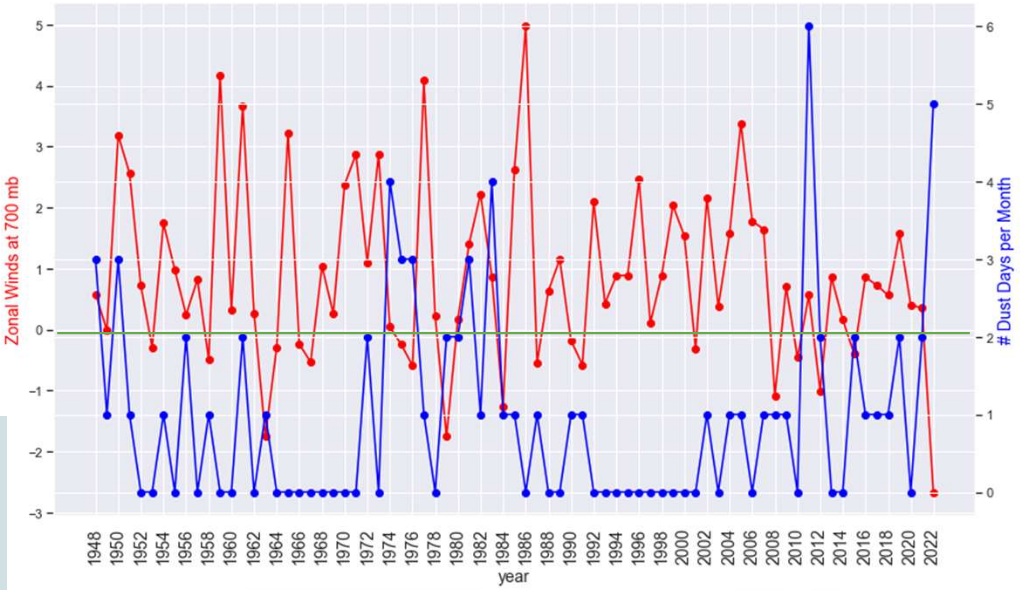


PHOENIX

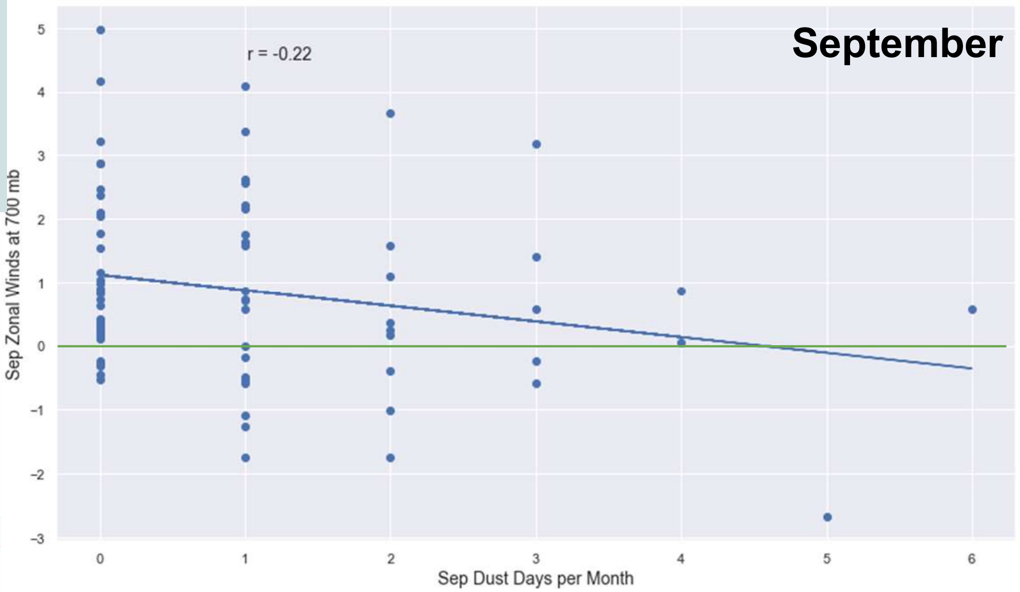


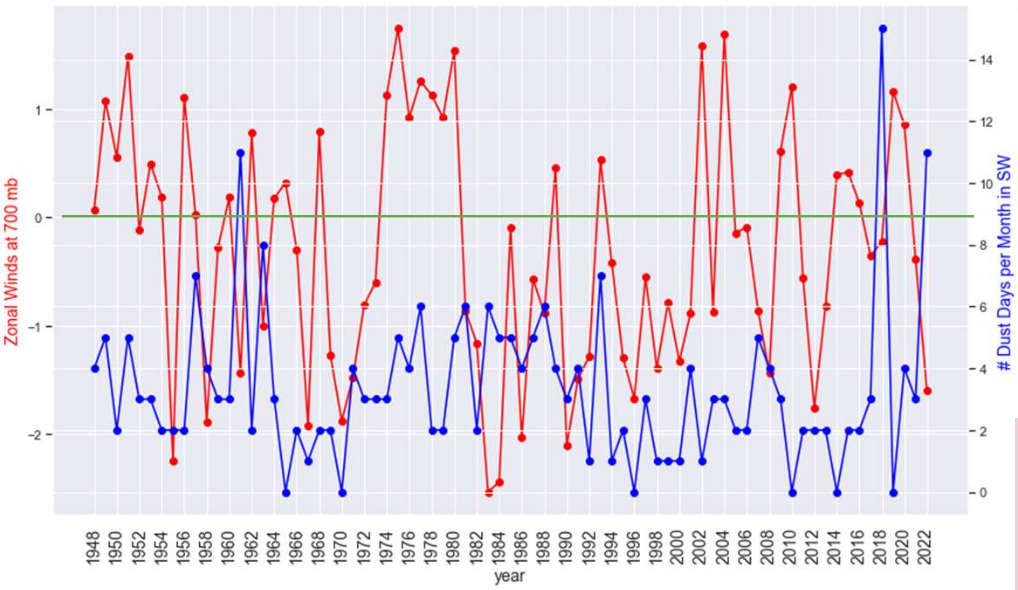
August

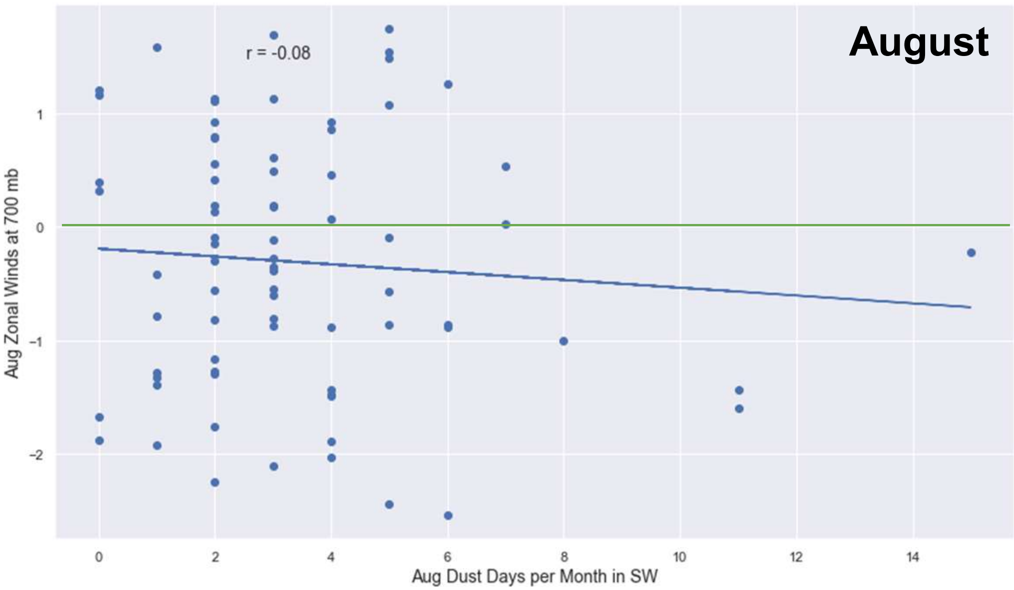




September







August

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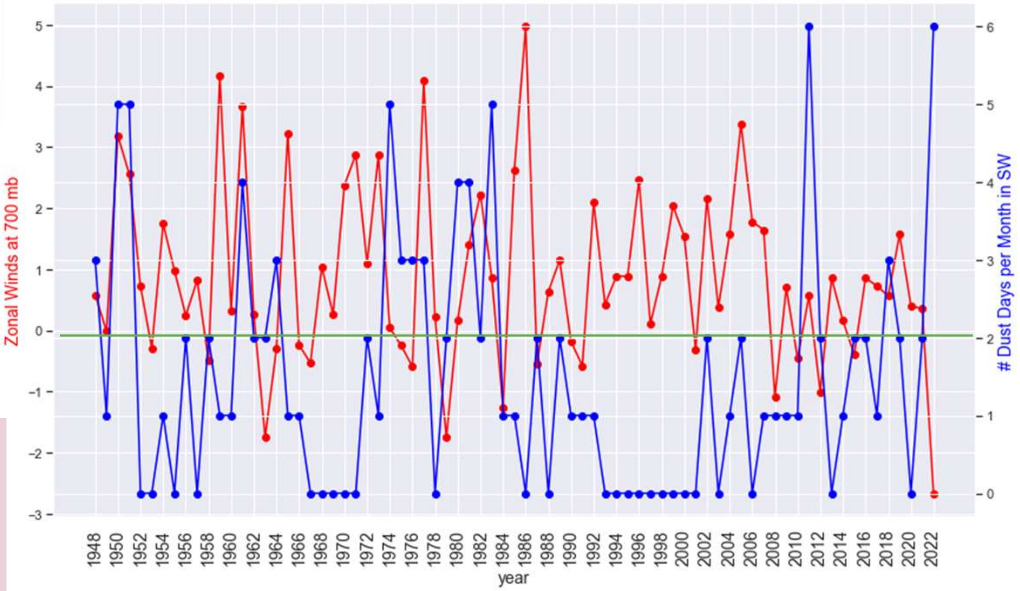

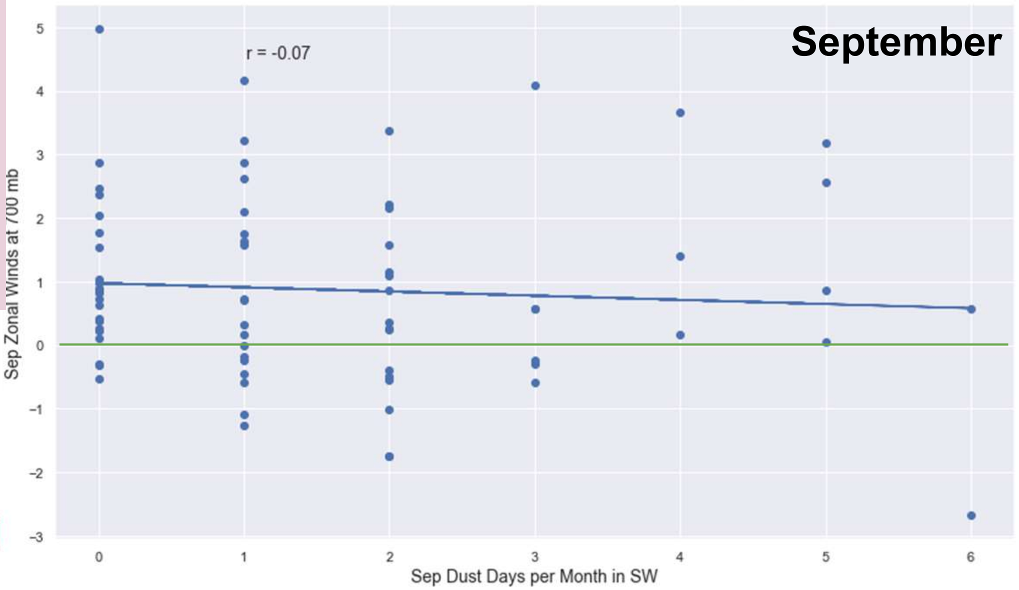

September

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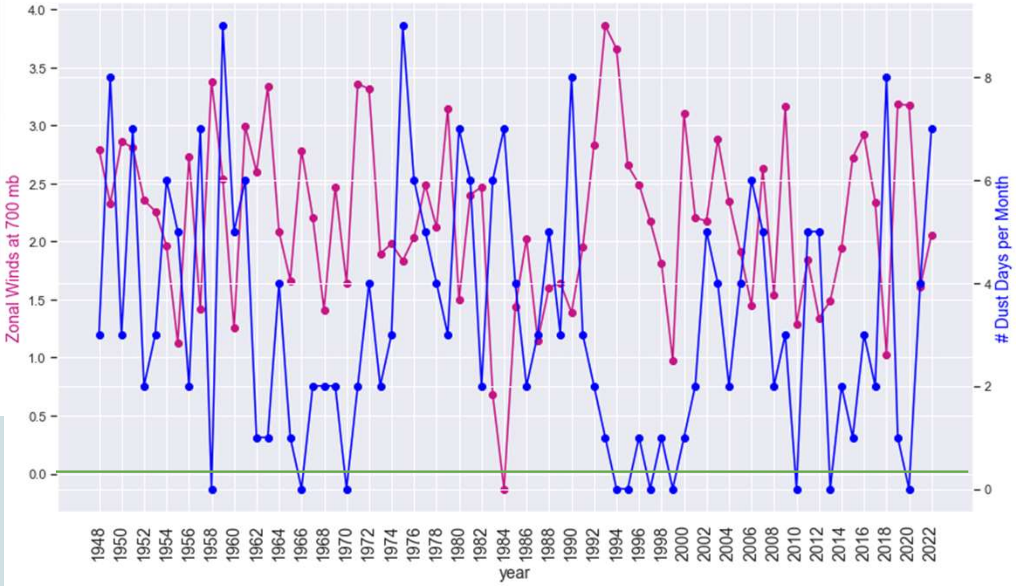
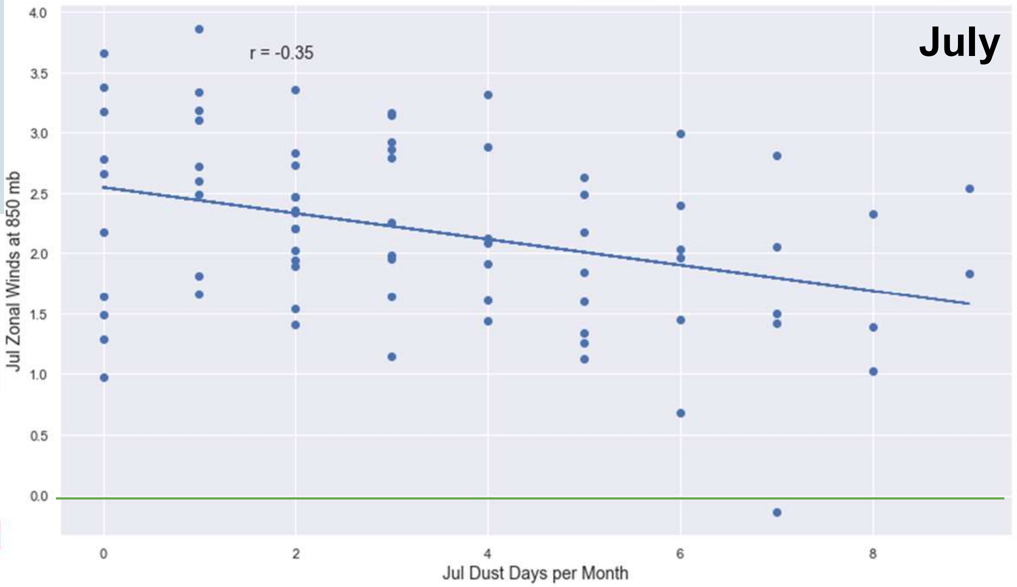
PHOENIX





SW US 850mb zonal winds and dust storm frequency at a monthly time scale:

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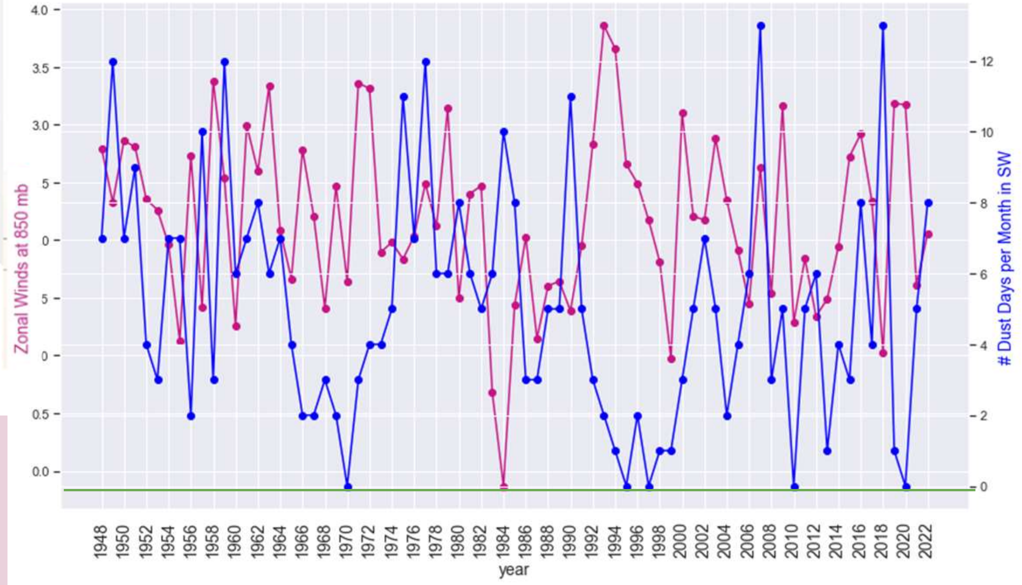
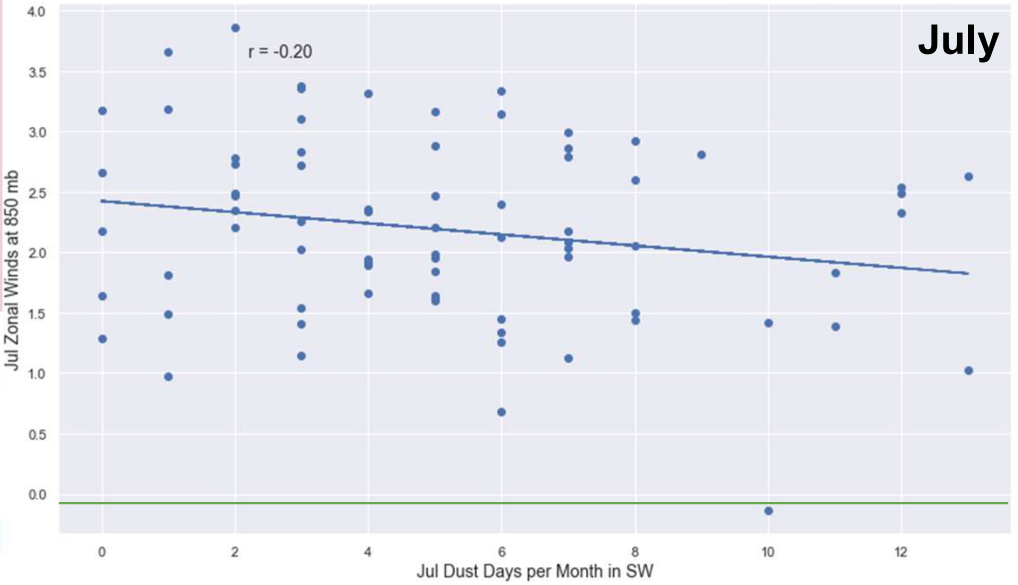
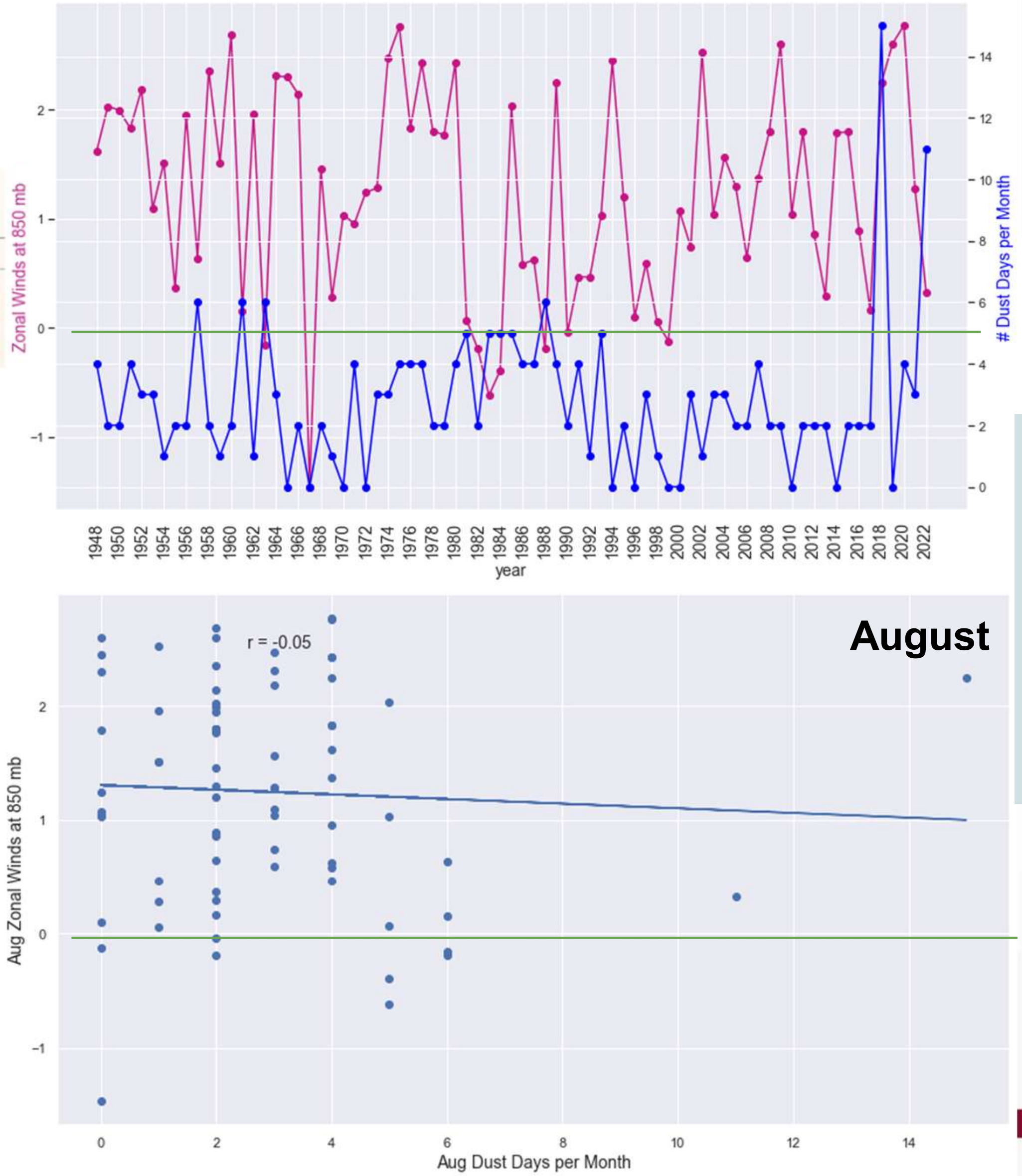
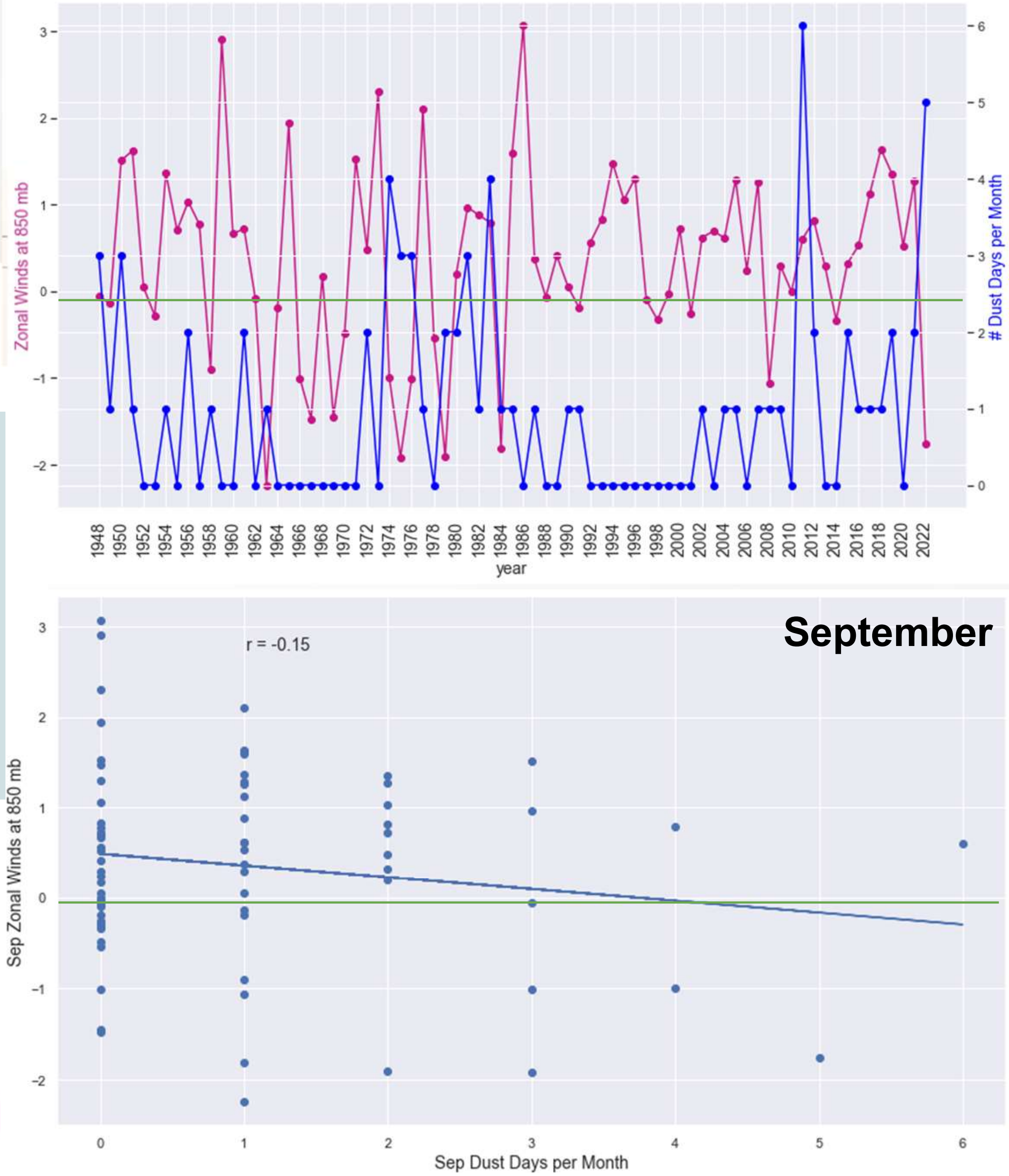




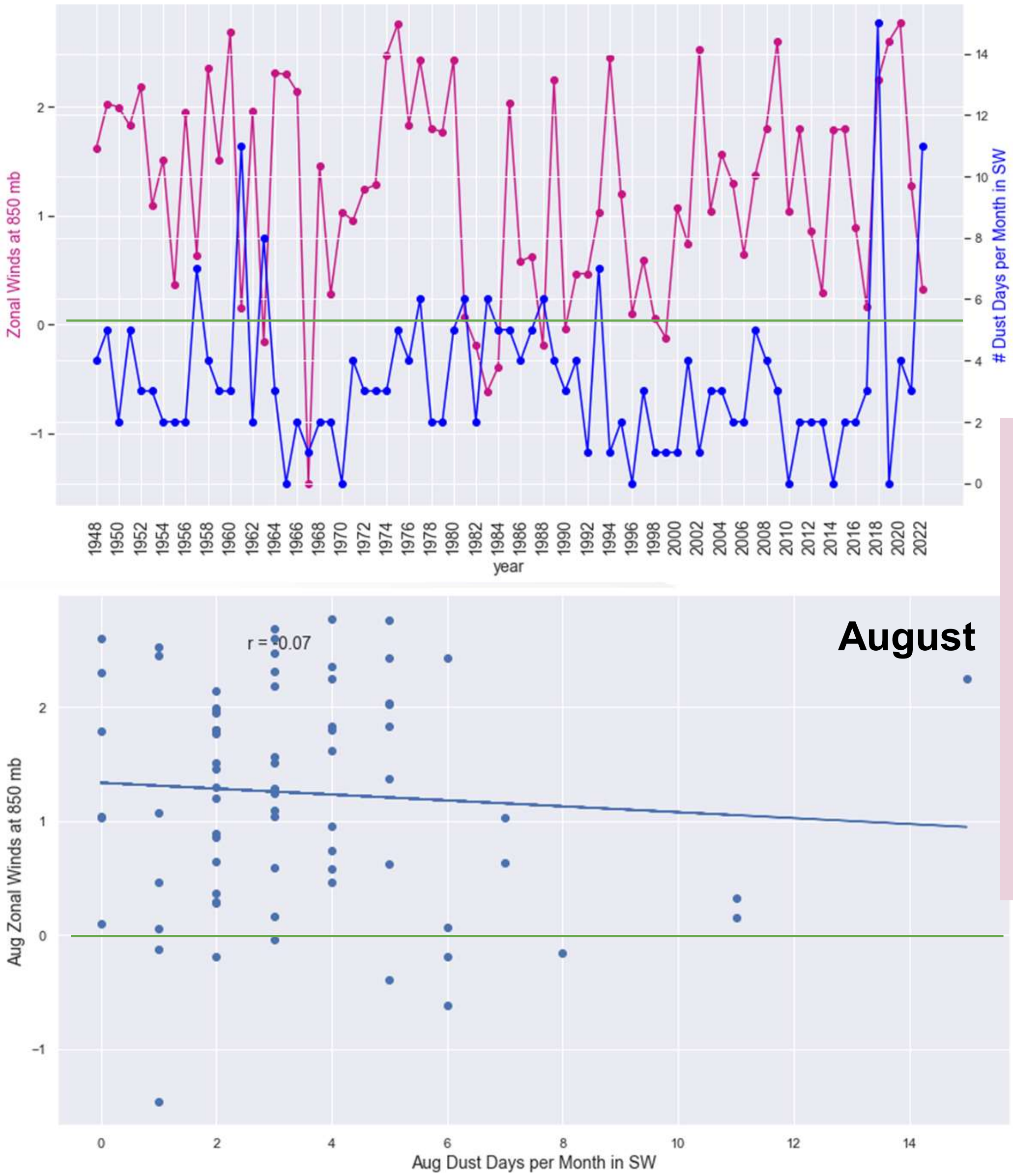
PHOENIX



August

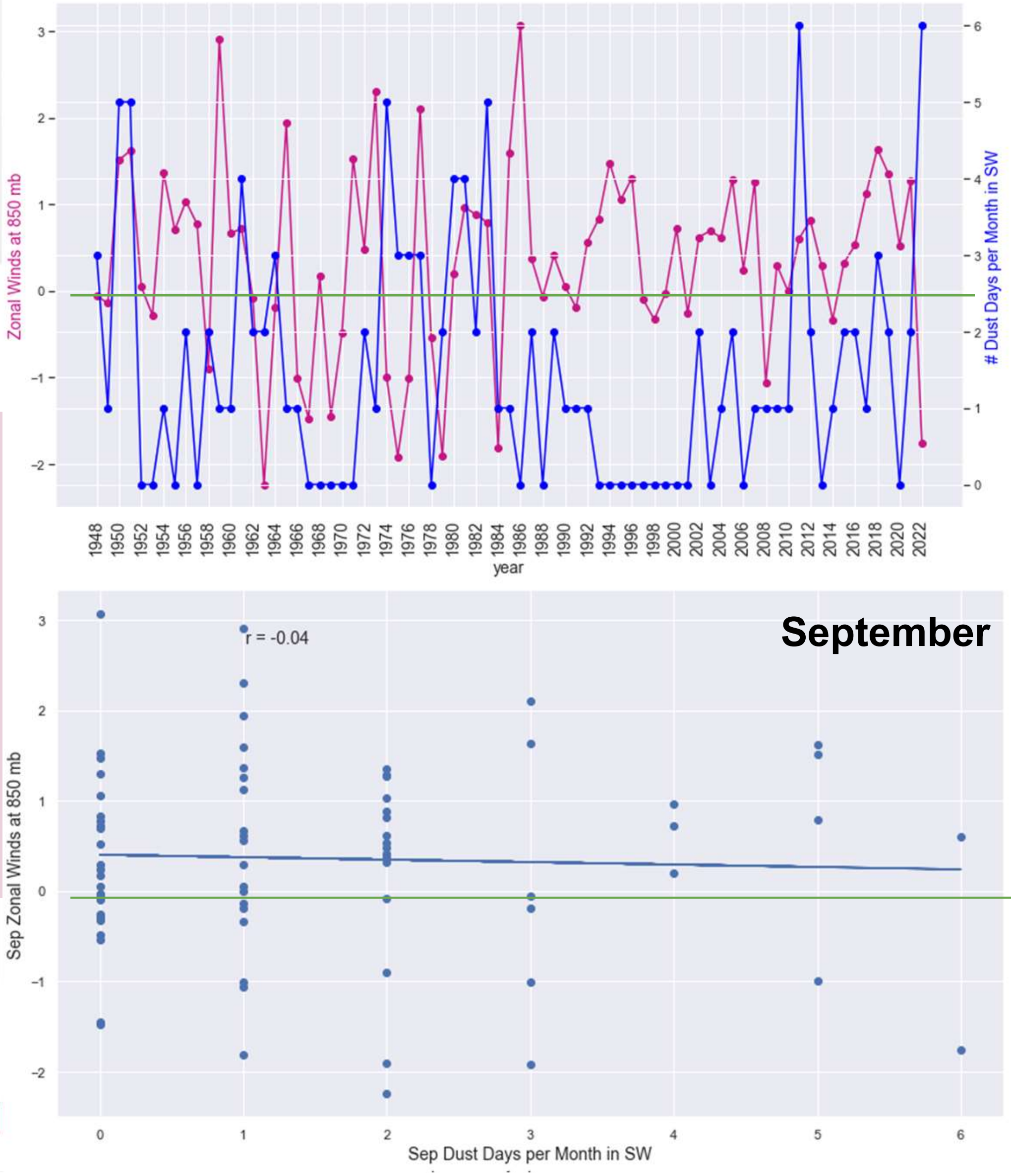


September



August

SOUTHWEST



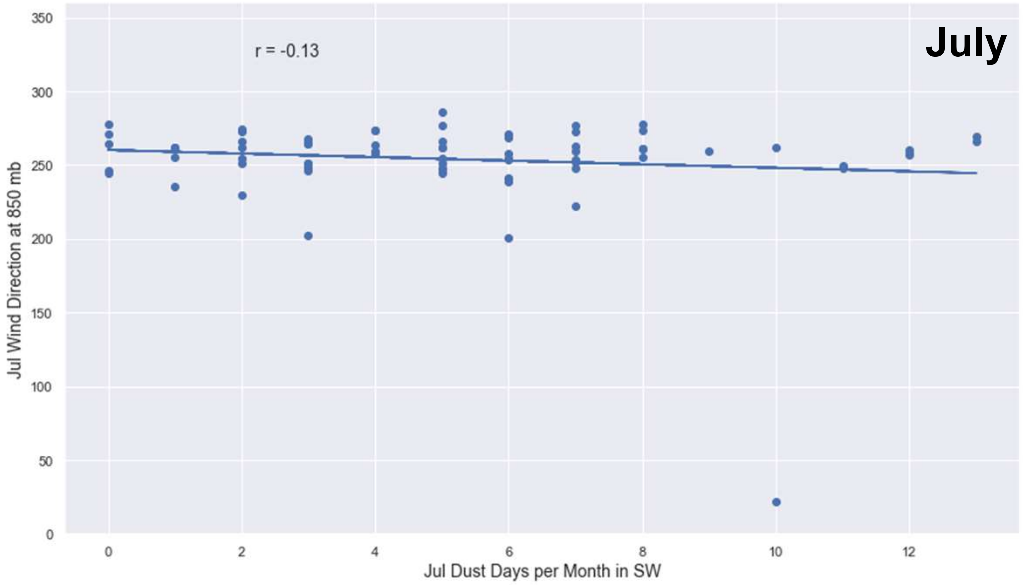
September

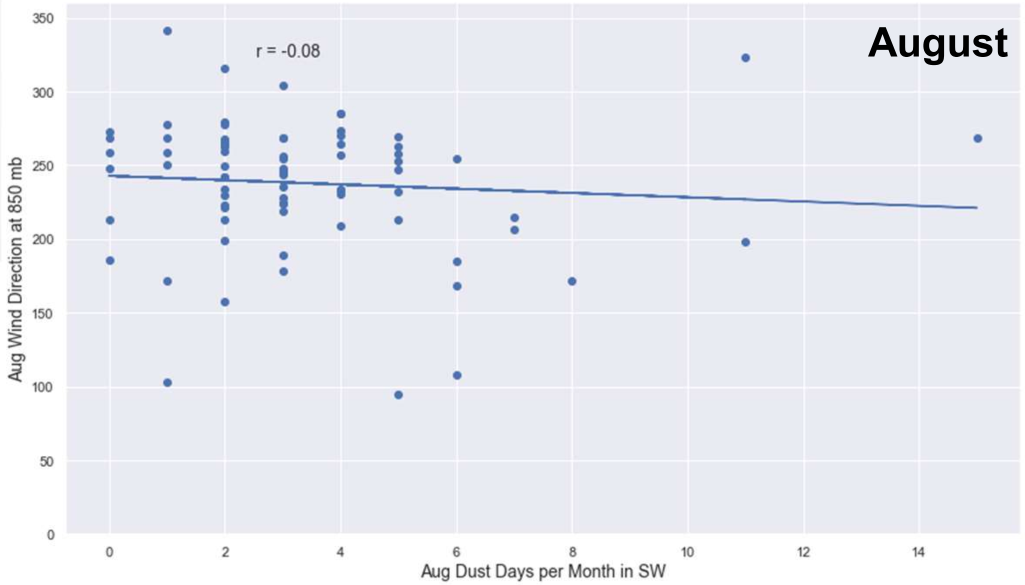
Issues With the Use of Wind Components

The “dust storm” patterns are defined by direction of the flow which is a combination of the the two wind components.

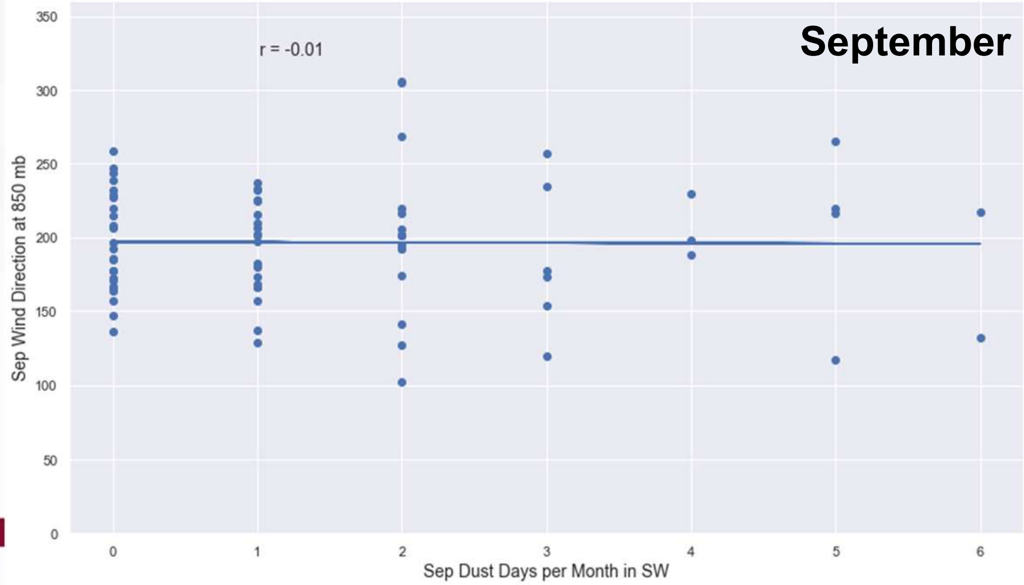
In order to examine the importance of flow direction, we can use the wind components to find the speed and direction of the wind for each month, then correlate this information with dust storm data

Goal: find which pressure level provides most insight, what speed is ideal, and what direction produces the highest frequency of events per month





Wind Direction and Dust Events at 850 mb



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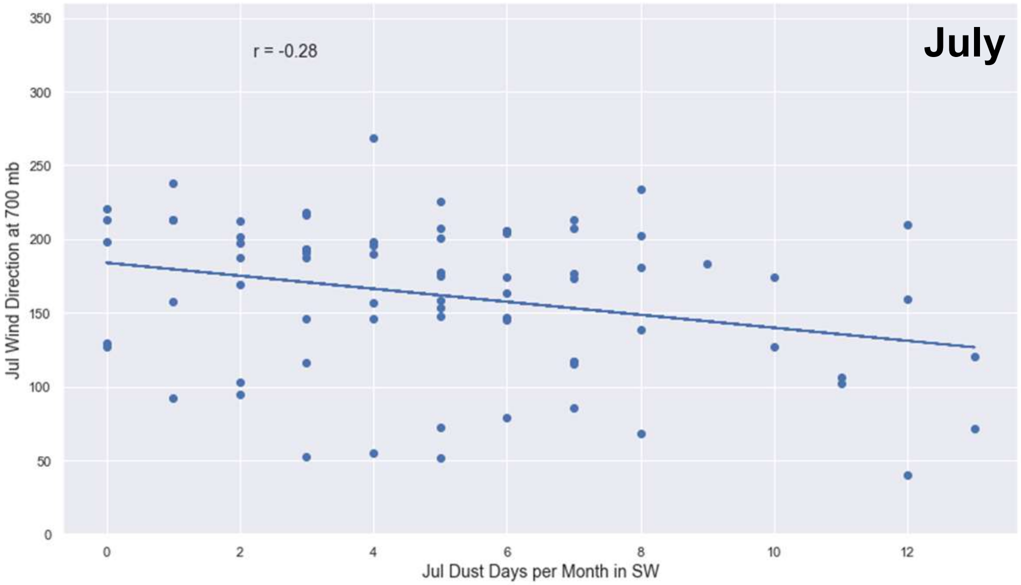
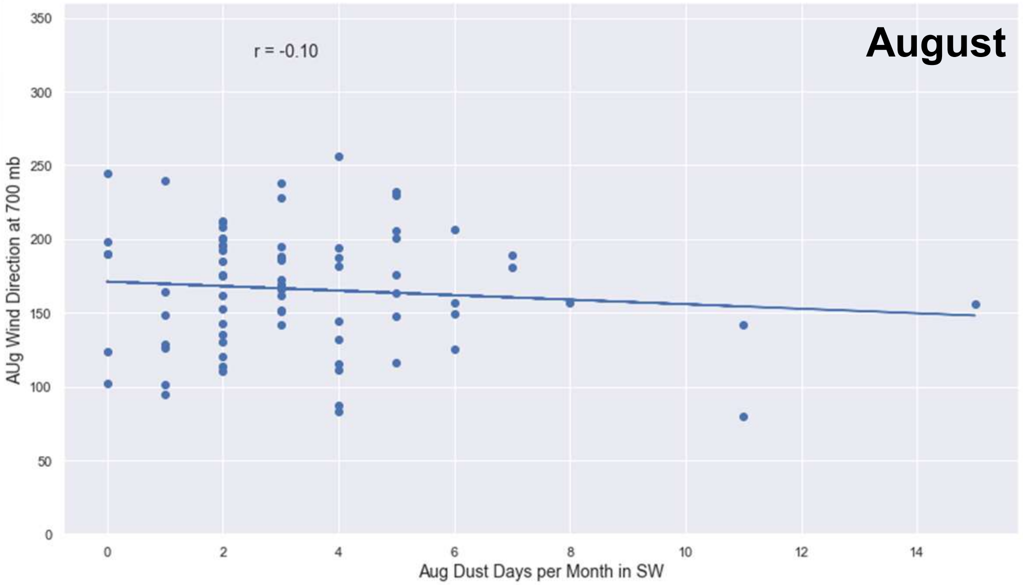
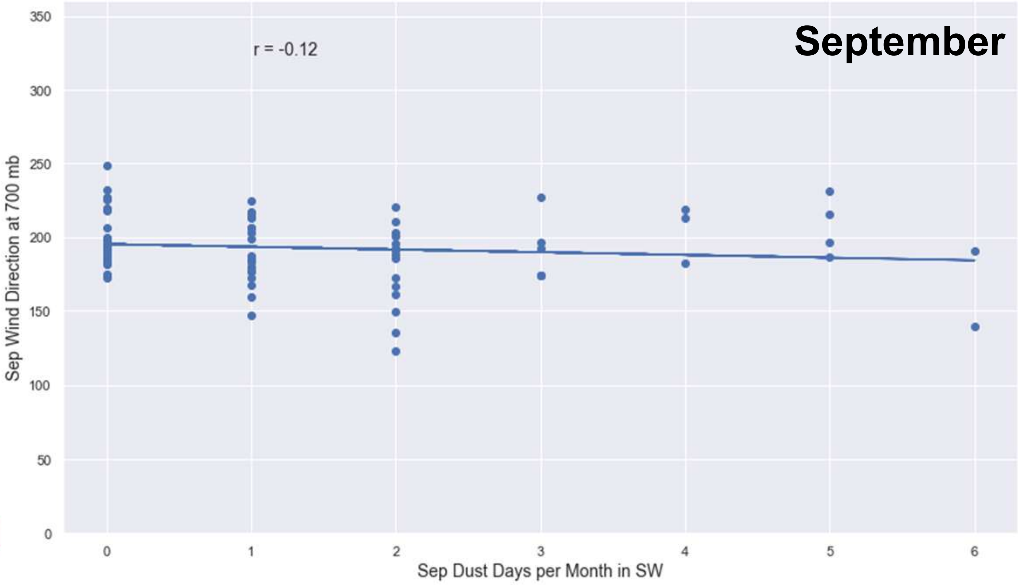




Wind Direction and Dust Events at 700 mb



Note stronger negative correlations than at 850 mb

Southeasterly flow across PHX correlated with greater frequency of SDS events across the Southwest

What Comes Next?

- Continue to explore 700mb, 850mb, and 10m surface winds to find links between wind speed and/or direction and SDS events
- Aggreg eloping simple ng

References

Blowing Dust and Dust Storms: One of Arizona’s Most Underrated Weather Hazards - NOAA (2016)

Downbursts - Mark A. Rose - https://www.weather.gov/ohx/downbursts

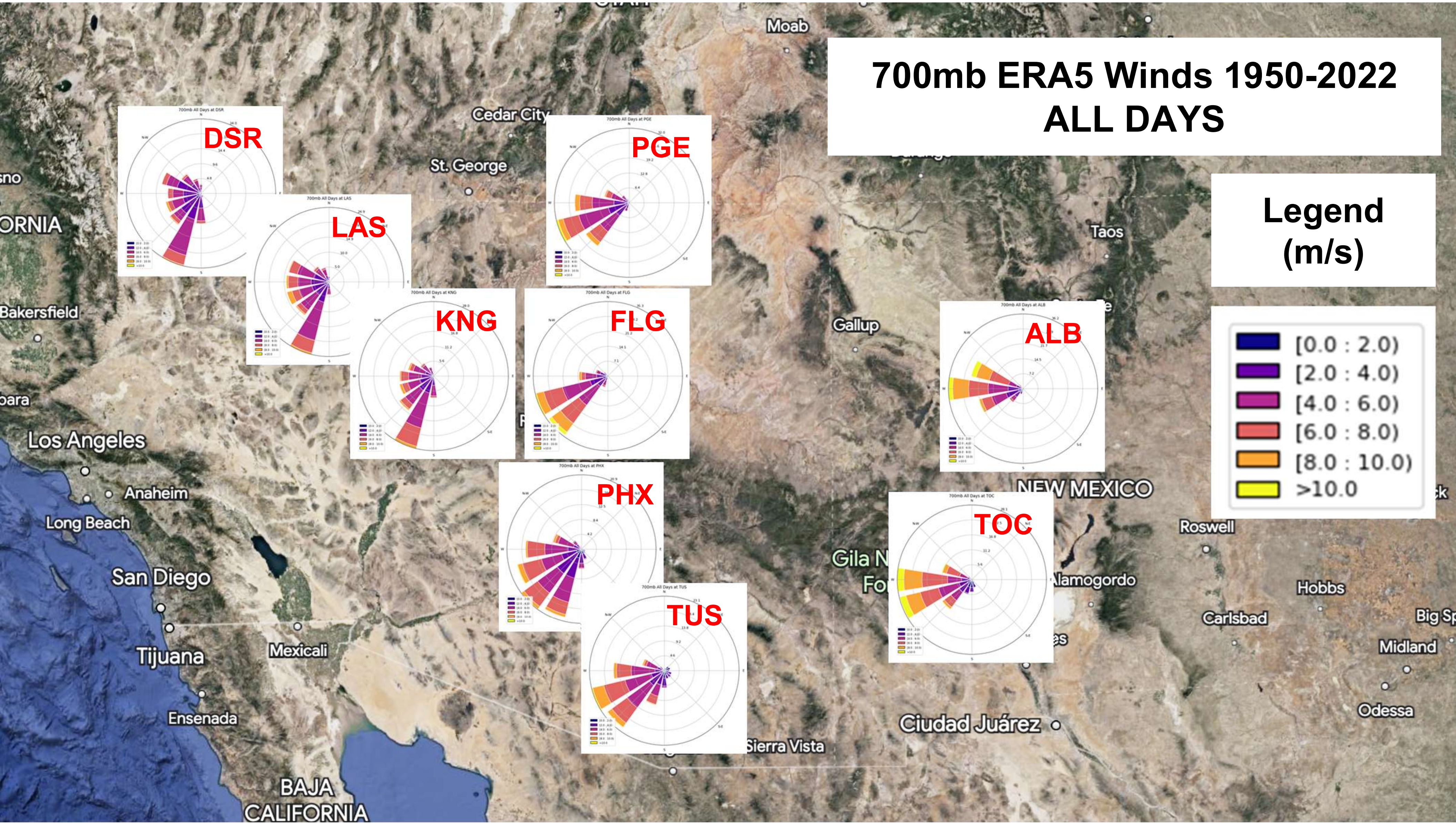
ERA5 Data - https://reanalyses.org/atmosphere/web-based-reanalysis-intercomparison-tools-writ

Sandstorms in the Southwestern U.S.

Lexi Cole

Week 7

700mb ERA5 Winds 1950-2022
ALL DAYS



Legend (m/s)

- 🟦 [0.0 : 2.0)
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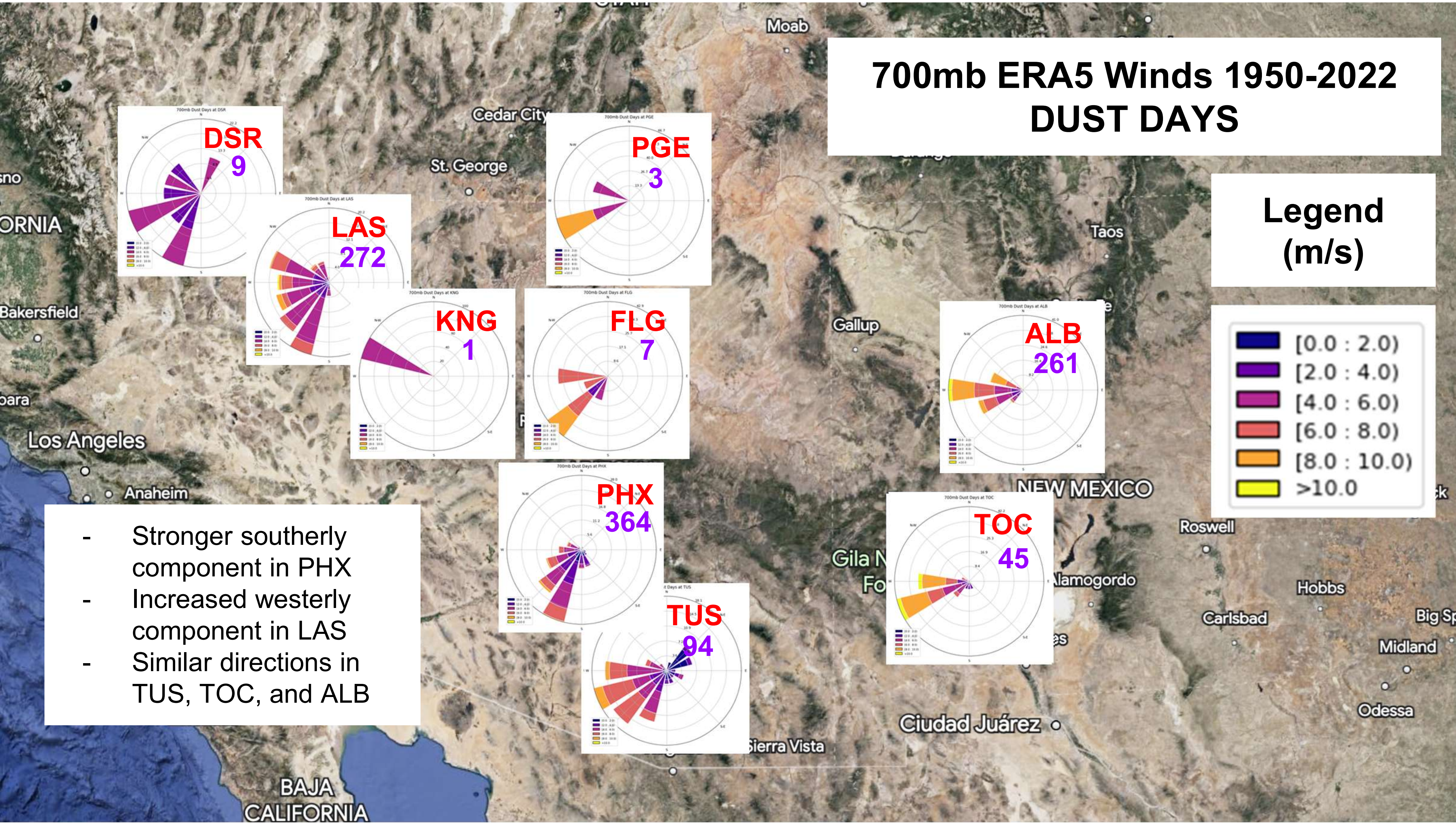
700mb ERA5 Winds 1950-2022
DUST DAYS



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(m/s)

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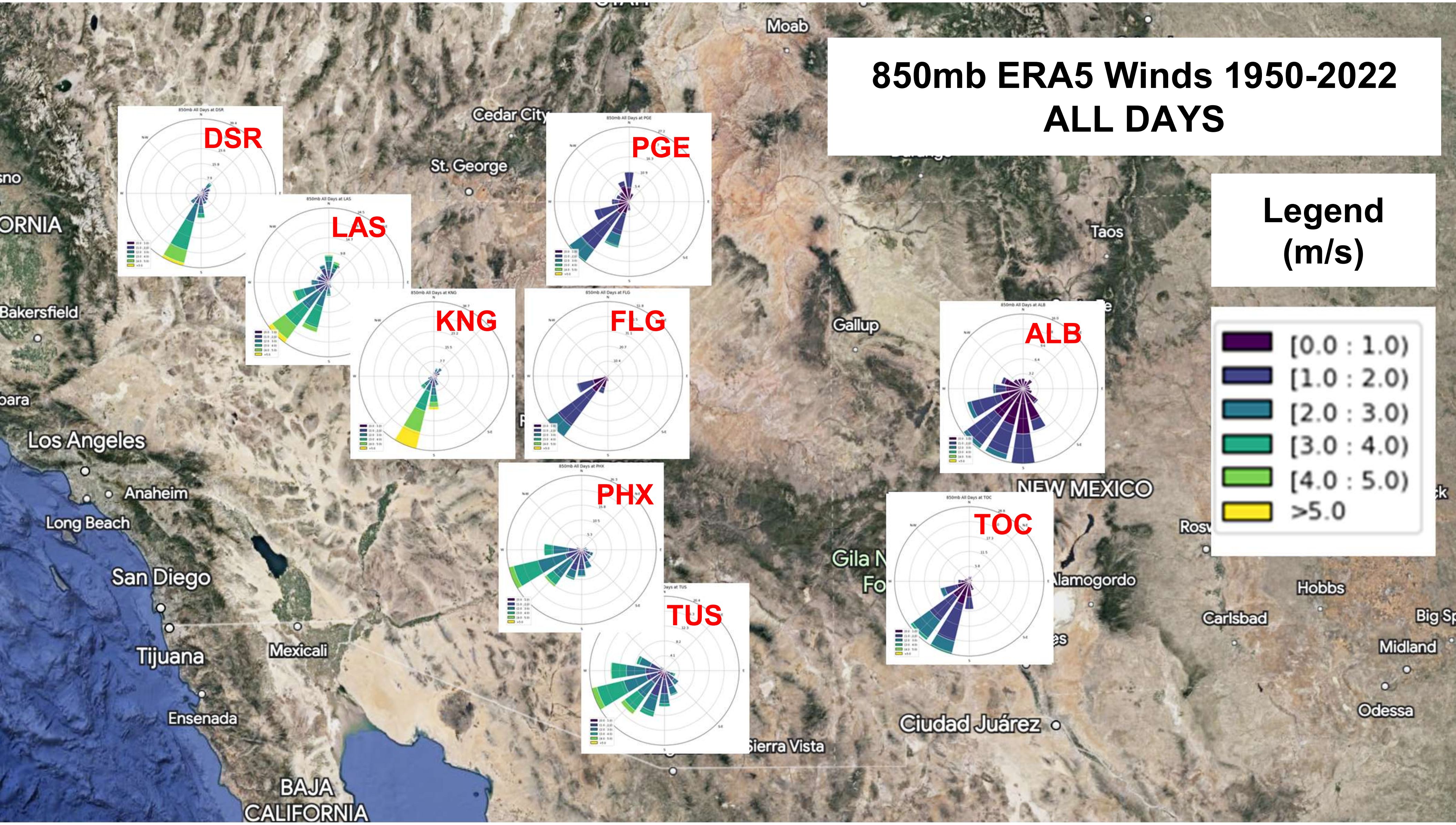
🟨 >10.0

- Stronger southerly component in PHX
- Increased westerly component in LAS
- Similar directions in TUS, TOC, and ALB

850mb ERA5 Winds 1950-2022
ALL DAYS



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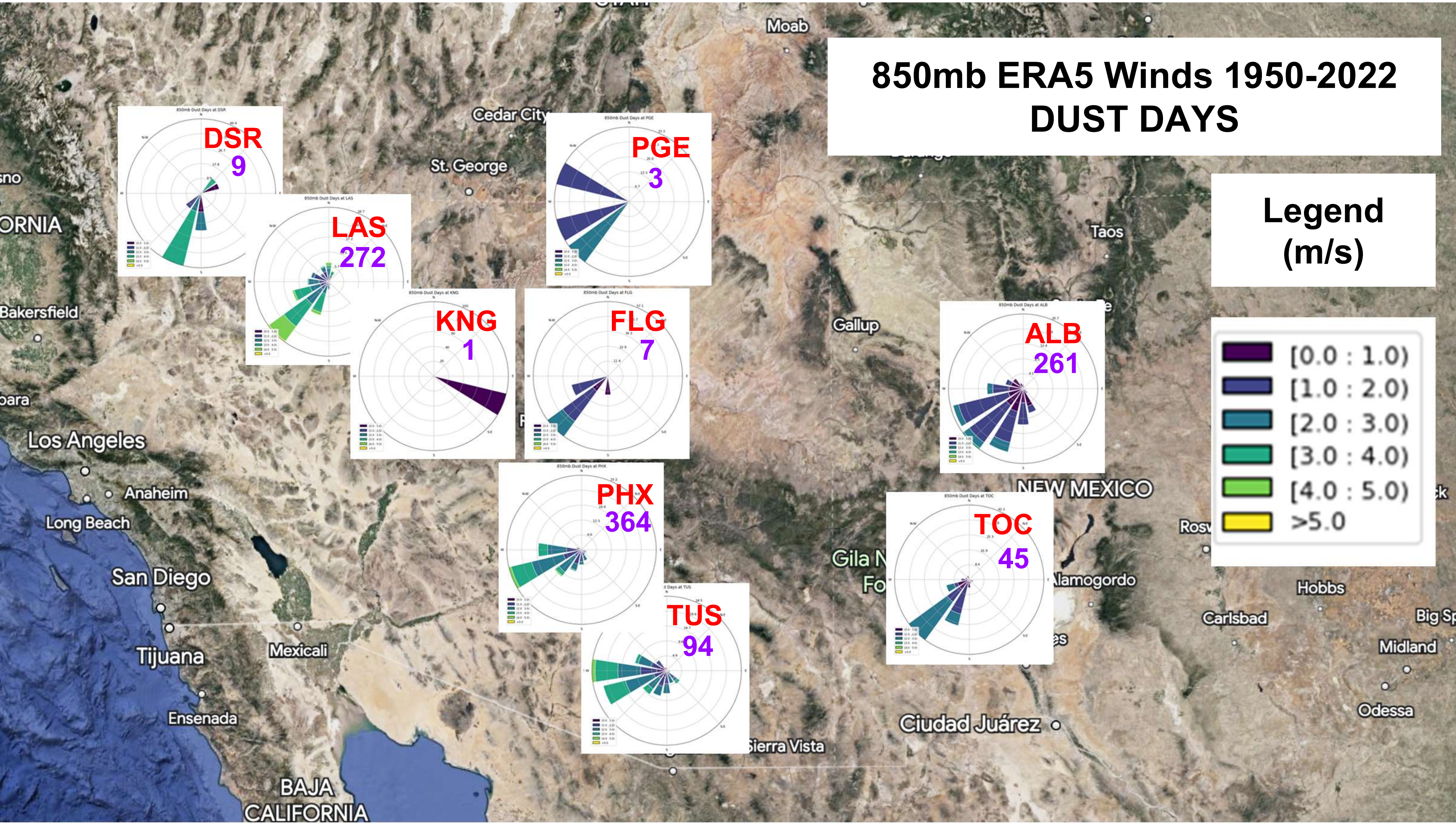
850mb ERA5 Winds 1950-2022
DUST DAYS



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- 🟨 >5.0

Modeling: Potential Inputs

ERA5: Precipitation, evaporation, 2m temperature, u and v wind components (10m, 850mb, and 700mb), CAPE, CIN, total column water vapor, total totals index

Derived ERA5: Microburst index, wind speed and direction (10m, 850mb, 700mb)

SPEI: Drought index

NASMI: North American Summer Monsoon Index

TerraClimate: Actual evaporation, climate water deficit, potential evapotranspiration, precipitation, runoff, soil moisture, downward surface shortwave radiation, average max temperature, average min temperature, vapor pressure, wind speed, vapor pressure deficit, Palmer Drought Severity Index

Modeling: Potential Input Database Information

ERA5: 1948-2022 - Monthly averaged data - 30 km spatial resolution - Point data, 2 x 2° spatially averaged data, and (31.5-37°N x 106-116°W) spatially averaged data

Derived ERA5: 1950-2022 - Monthly averaged data - 30 km spatial resolution - Point data, 2 x 2° spatially averaged data, and (31.5-37°N x 106-116°W) spatially averaged data

SPEI: 1901-2021 - Monthly averaged data - 0.5 x 0.5° resolution - “point” data

NASMI: 1948-2022 - Monthly data ONLY in JAS - (17.5-35°N x 100°-120°W) spatially averaged data

TerraClimate: 1958-2020 - Monthly averaged data - 4 km spatial resolution with both direct and derived variables - Point-based data

Issues Encountered with Modeling

What spatial resolution should we use use in this model?

Initially, we modeled using a combination of 2x2° variables and pointwise variables, but the pointwise variables proved to be more significant. This provided a good first look at the spatial issues we may encounter.

We ultimately decided to model for Phoenix using point data and to model for the entire Southwest using spatially averaged predictors and accumulated values of dust day frequency at Albuquerque, Tucson, Phoenix, and Las Vegas.