Climate Change, Dust Storms and Societal Vulnerabilities in North America

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Barcelona Dust Regional Center Webinar
November 15, 2023, Barcelona, Spain

The "Dust Bowl" during the Great Depression (1930s)

- Dust Bowl: A period of severe dust storms during the 1930s;
- Causes: Extended droughts and poor land management;
  - ✓ Homestead Acts: settlement over the Plains for agriculture ;
  - ✓ New agricultural machinery: Deep plowing, eliminating native grass;
  - ✓ Favorable dust storm conditions during 1930s drought;
- Farms/houses Buried; Millions forced out; Black sky in DC

(Source: Library of Congress)

Another "Dust Bowl"?

Yes!

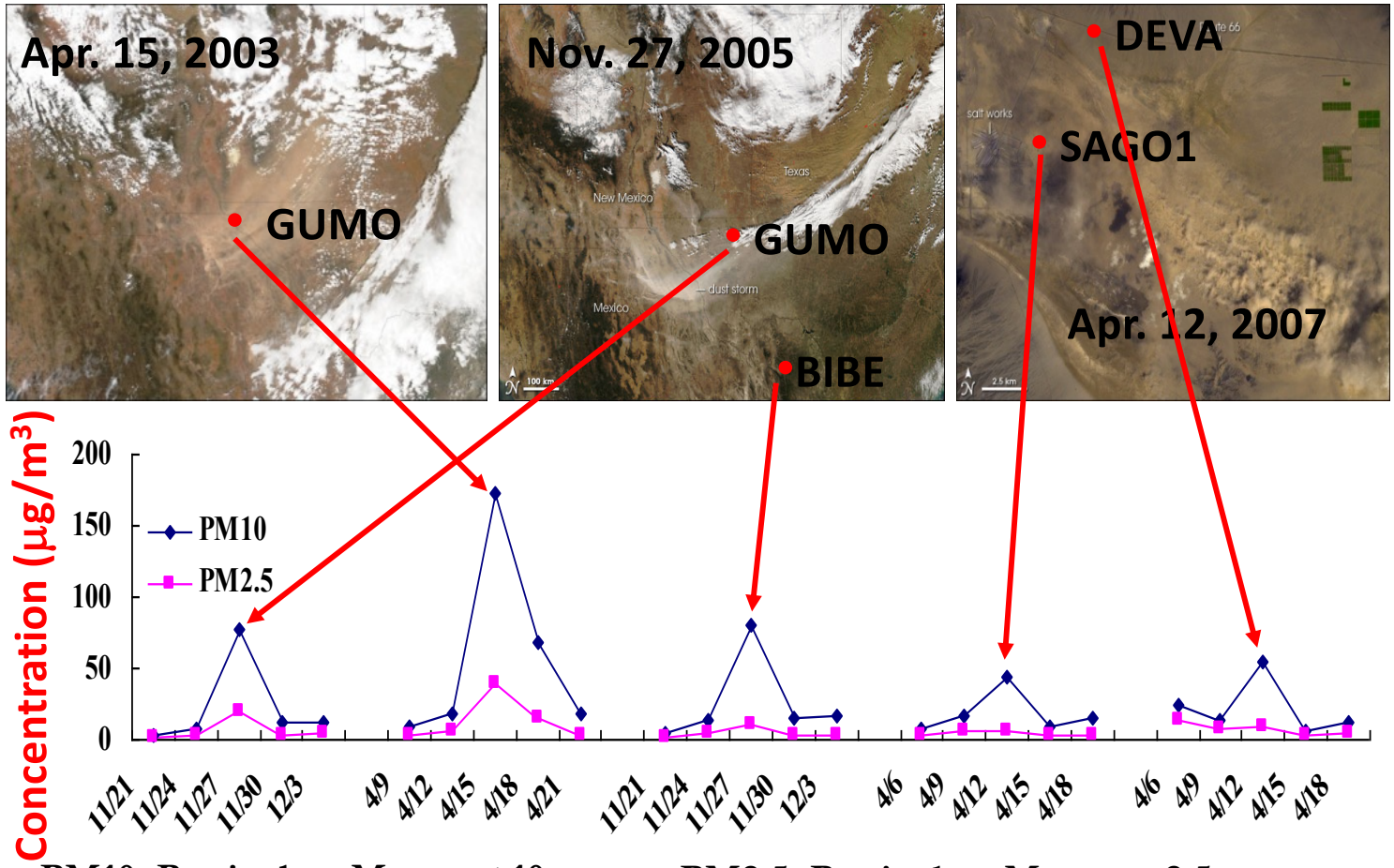
- Central U.S. plains saw severe droughts about once or twice a century over the past 400 years (Woodhouse & Overpeck, 1998).
- Global warming → Precipitation shift from subtropics, greater evaporation, less snow/ice, and earlier spring → amplify the effects of natural climatic variations → intensified droughts and "dust-bowlification" (Romm, 2011).

Probably Not?

- Partially man-made → Lessons learned (Lee and Gill, 2015).
- Under economic stress in 1930s;
- Many soil conservation measures in places.

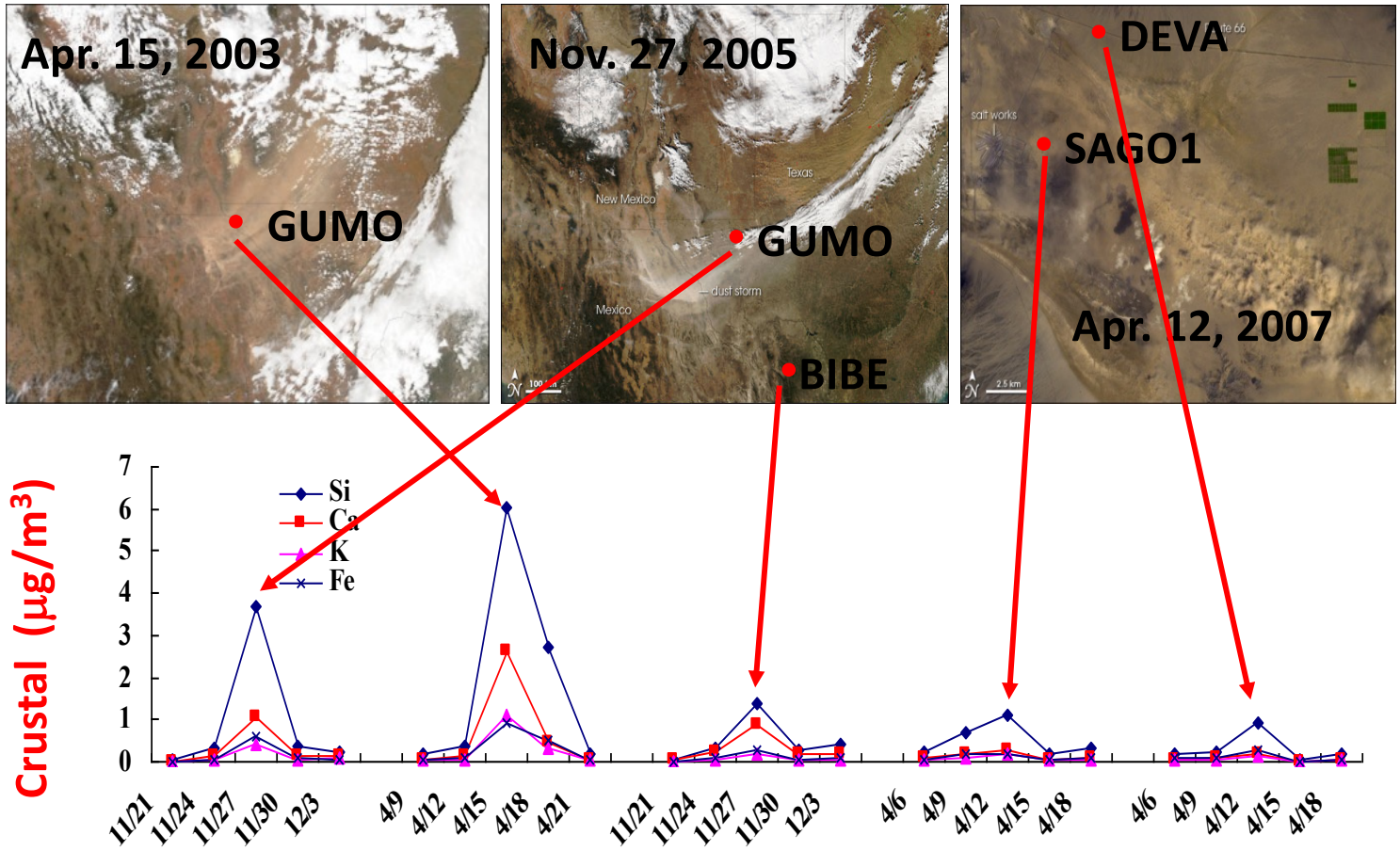
Question: *Who is right?*

Satellite-aided Dust Detection



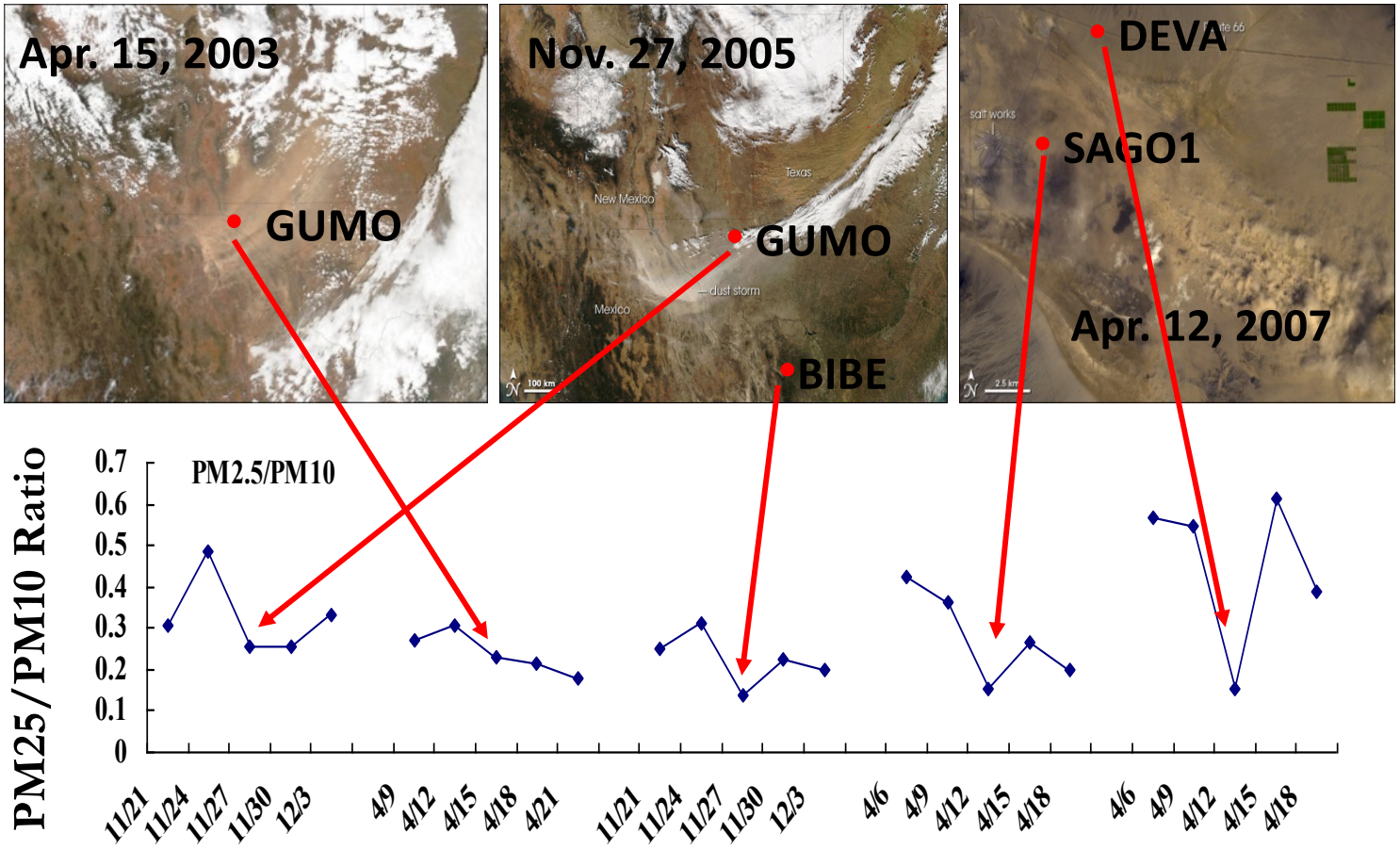
PM10: Particulate Matter < 10 mm **PM2.5: Particulate Matter < 2.5 mm**

Satellite-aided Algorithm Training



Si – Silicon; Ca – Calcium; K – Potassium; Fe – Iron

Satellite-aided Algorithm Training

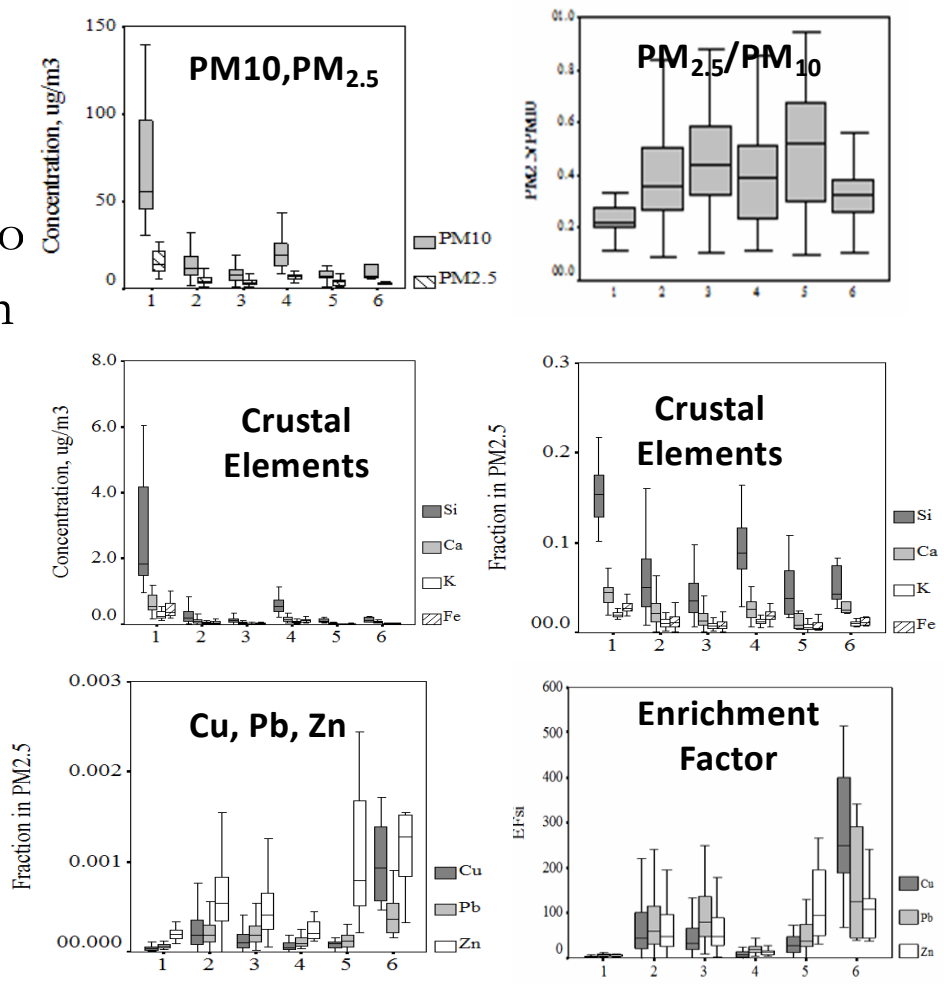


Dust Identification through Cluster Analysis

Five Dust Indicators:

- ❖High PM_{10}, $PM_{2.5}$;
- ❖Low $PM_{2.5}/PM_{10}$ ratio
- ❖High Crustal Fraction
- ❖Low anthropogenic Fraction;
- ❖Low Enrichment Factor;

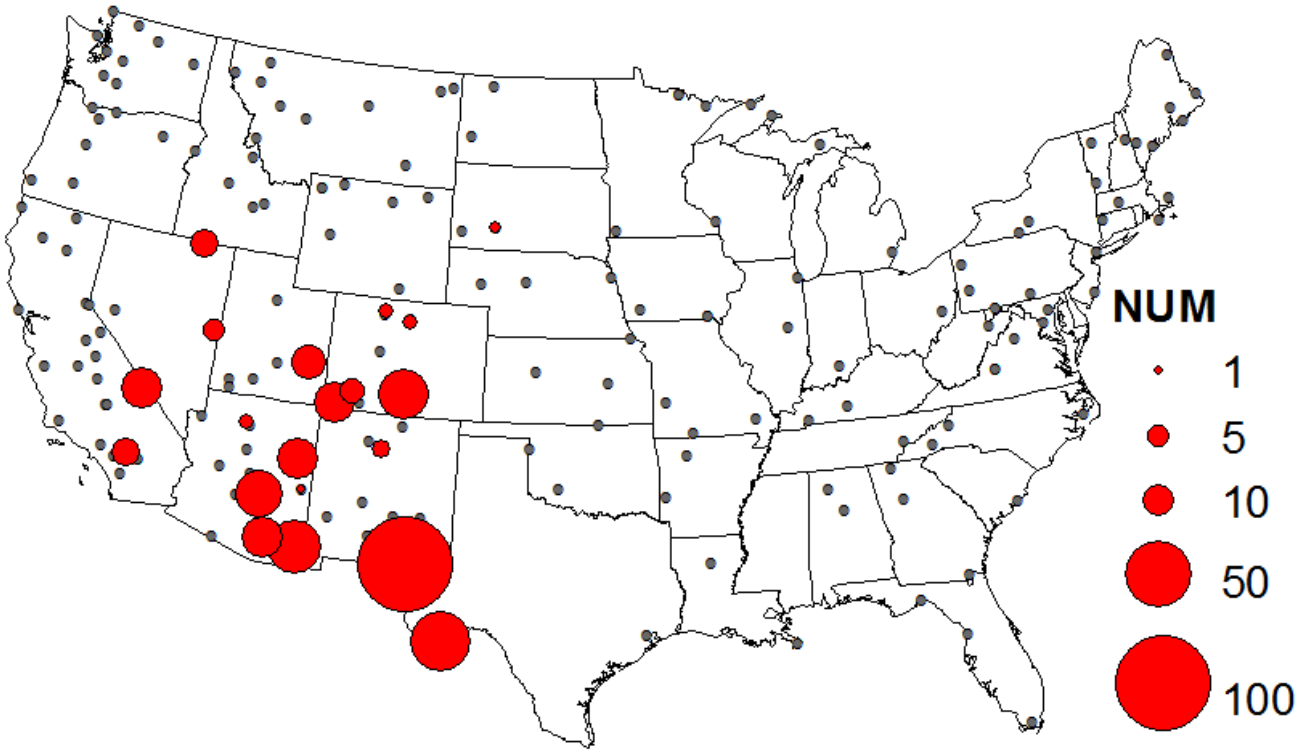
Cu– Copper
Pb – Lead
Zn – Zinc



(Tong et al., 2012)

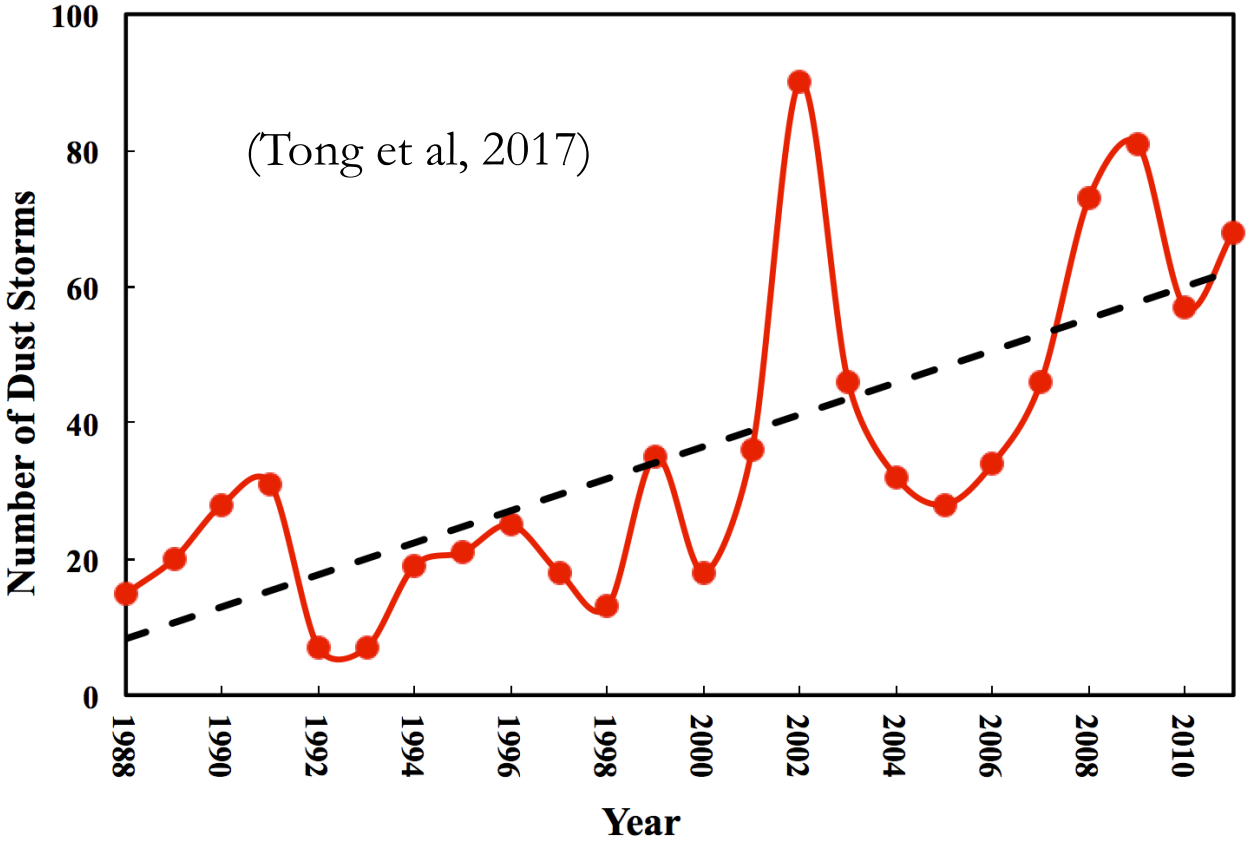
Locations of Dust Storms

(Tong et al., 2017)



Dust storms detected at 29 sites with continuous data records.

Long-term Dust Trend



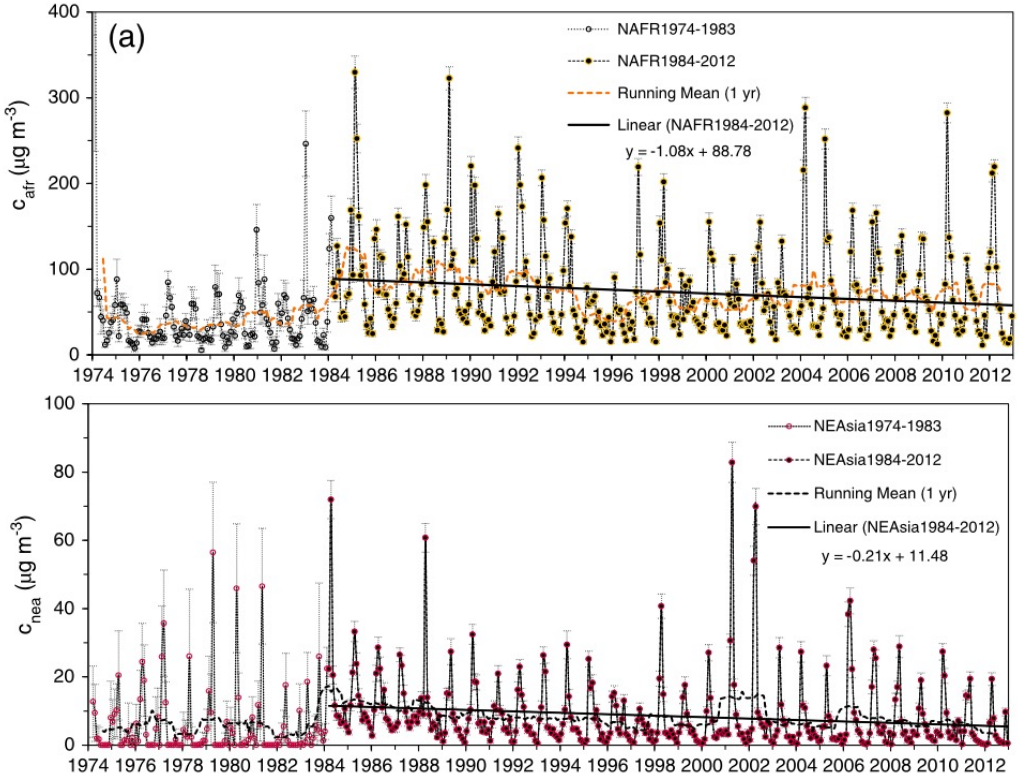
US dust trend: +12%/yr;

Multiple lines of evidence:

- Increase in rainwater calcium (Ca^{2+}) (Brahney et al., 2013);
- Dust deposition on snow (Clow et al. 2016);
- Fine soil air concentration (Hand et al., 2017);
- Dust from agricultural expansion (Lambert et al. 2020)

Decreasing Dust Trends in Asia and Africa

(Shao et al., 2013)



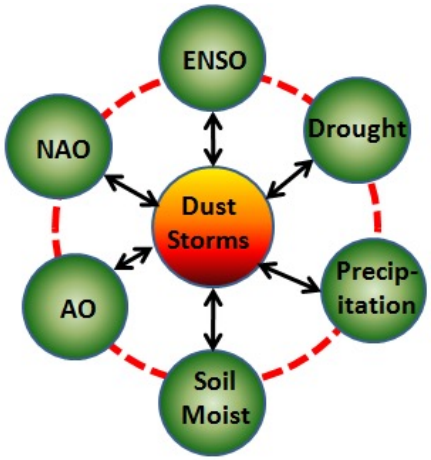
Northern Africa

Northern Asia

Global dust concentration decreased at 1.2%/yr from 1984 –2012

What Drives the Dust Trend?

(Tong et al., 2017)

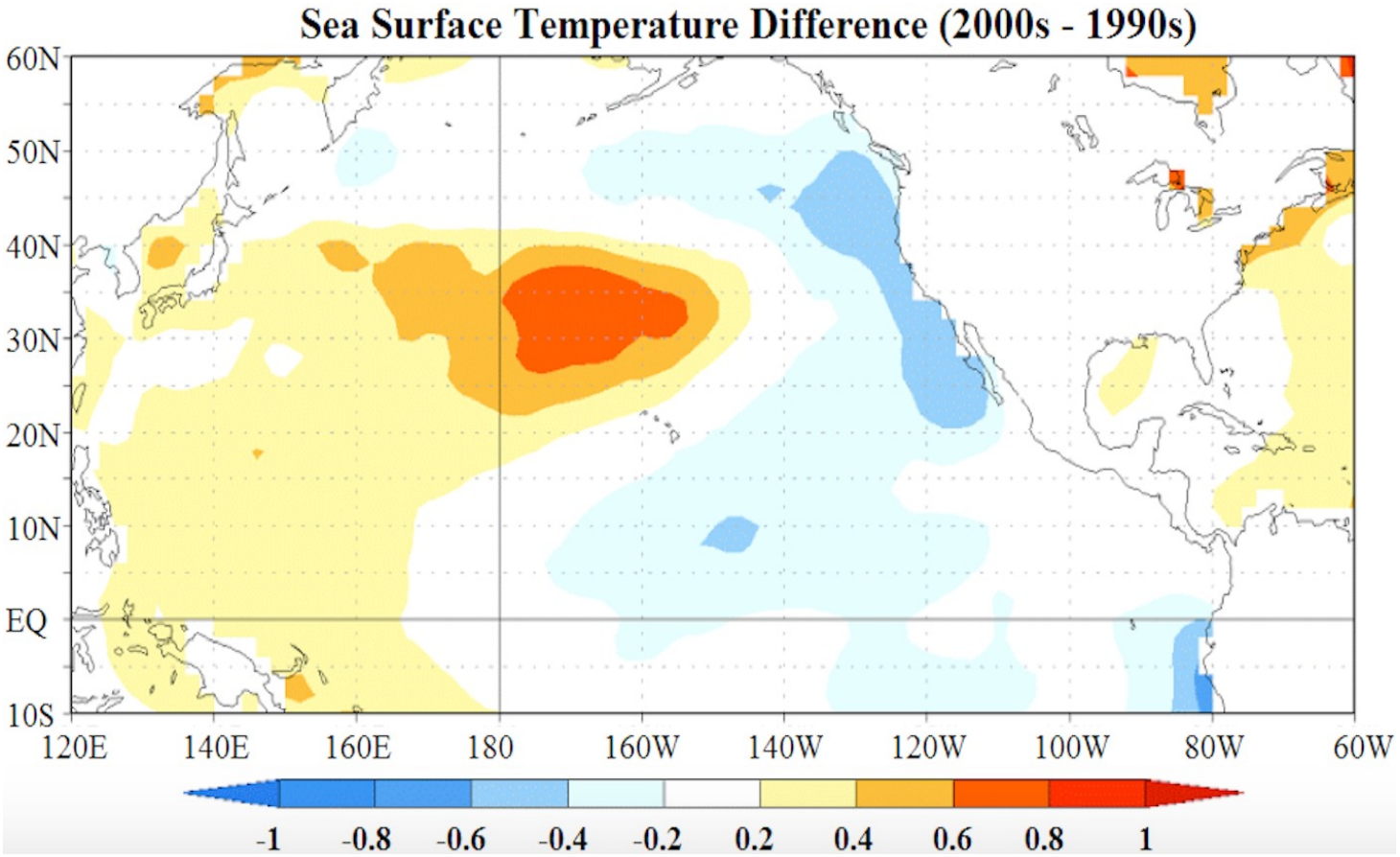


ENSO - El-Nino Southern Oscillation
PDO - Pacific Decadal Oscillation
NAO - North Atlantic Oscillation
PNA - Pacific/North American Oscillation
AO - Arctic Oscillation

	ENSO	PDO	NAO	PNA	AO
LL-dust	-0.44	-0.62	-0.41	-0.33	0.38
HL-dust	-0.32	-0.73	-0.40	-0.56	0.33

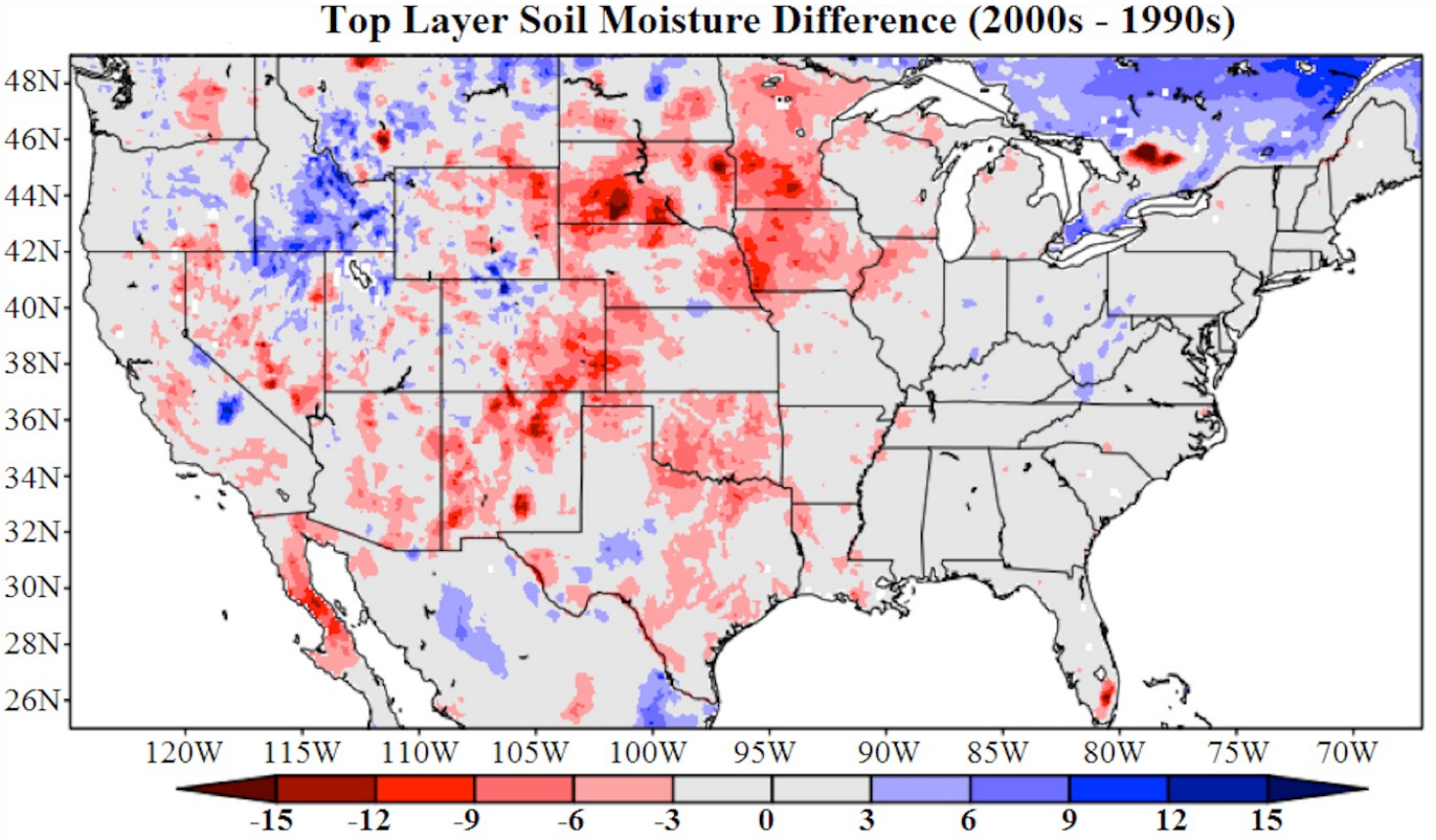
LL – Low Latitude North American deserts (Chihuahua, Mojave, and Sonoran);
HL – High Latitude Deserts (Great Basin and Colorado Plateau)

Changes in Sea Surface Temperature



(Contributed by Julian Wang)

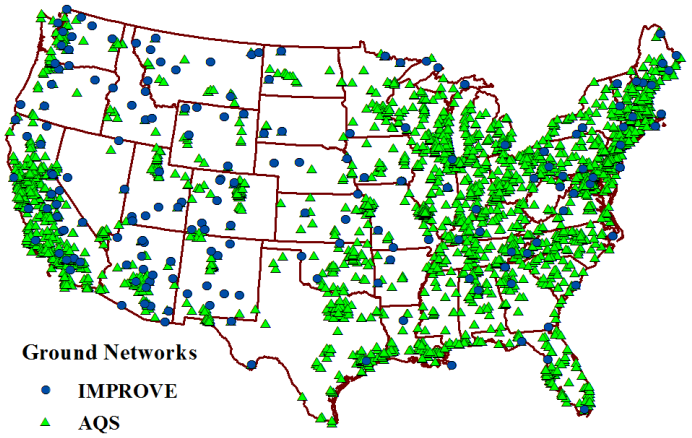
Changes in Soil Moisture



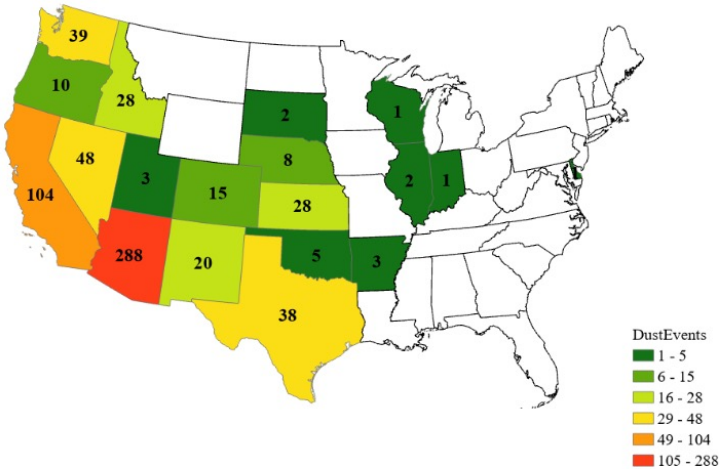
(Contributed by Julian Wang)

Updating Dust Trends from Multiple Sources

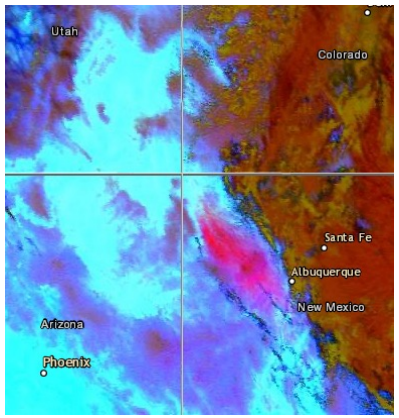
- Dust loading over Great Plains increased over the last two decades due to agricultural expansion (Lambert et al., 2020).
- Global dust event frequency has increased at 0.02%/yr from 1986 to 2019 (Xi 2021).
- Spring high-concentration dust events are becoming less frequent, while the number of low-concentration dust events is increasing (Aryal and Evans, 2022).



IMPROVE & AQS



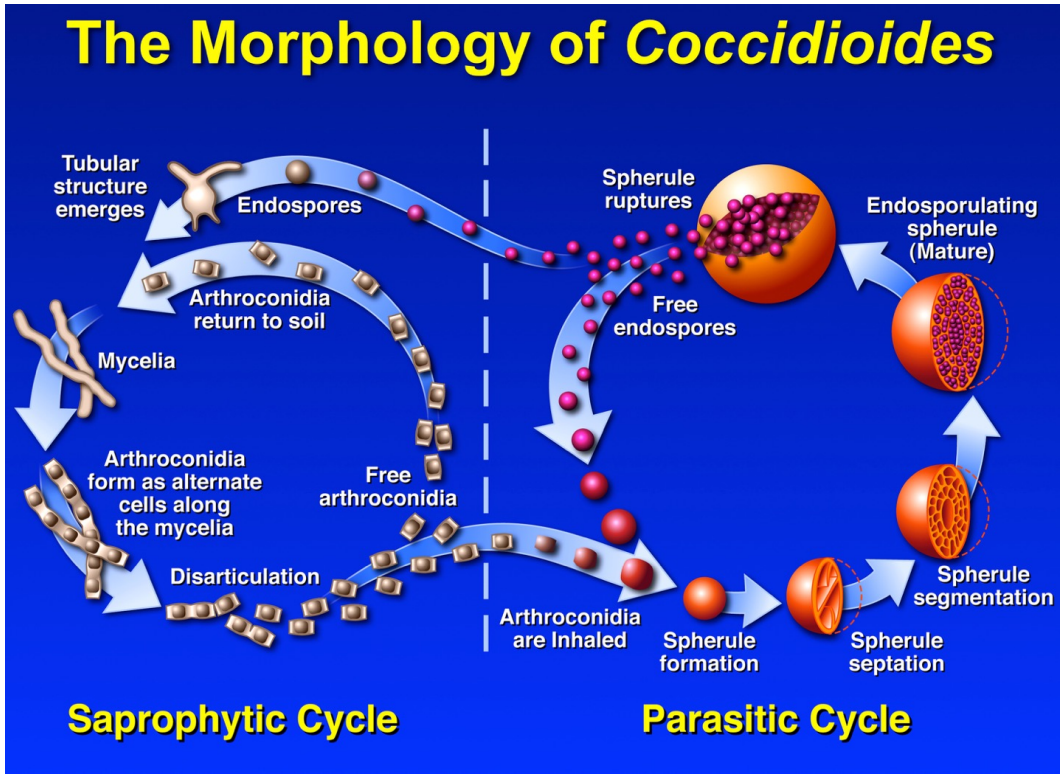
Storm Data 2000-2020 (Ardon-Dryer et al., 2022)



Satellite Dust Mask (pink)

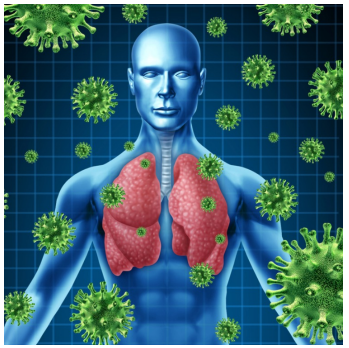
Valley Fever (Coccidioidomycosis)

Infection caused by inhaling the soil-dwelling fungus Coccidioides



(Source: thinklink.com)

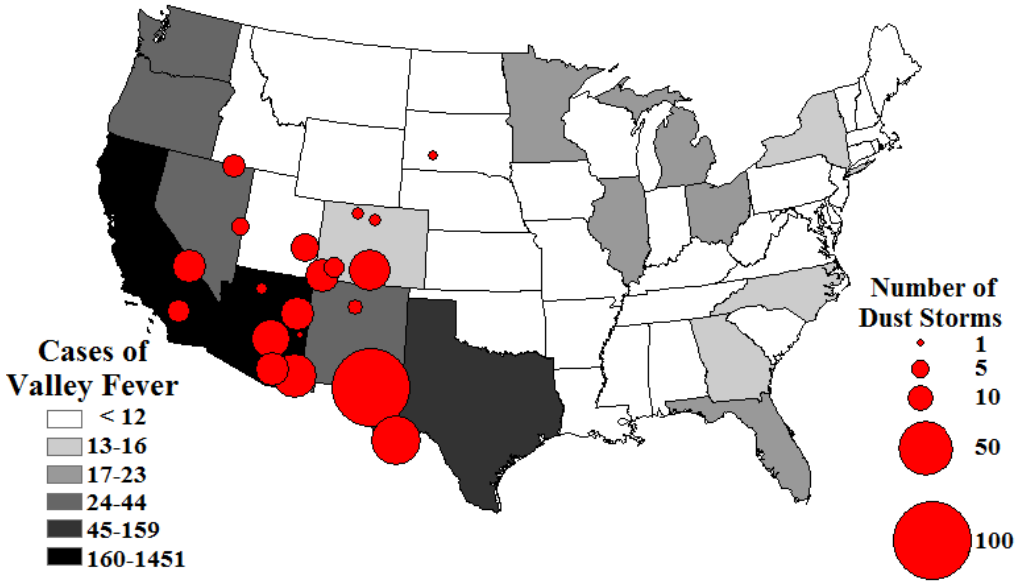
Coccidioidomycosis: Lung infection;

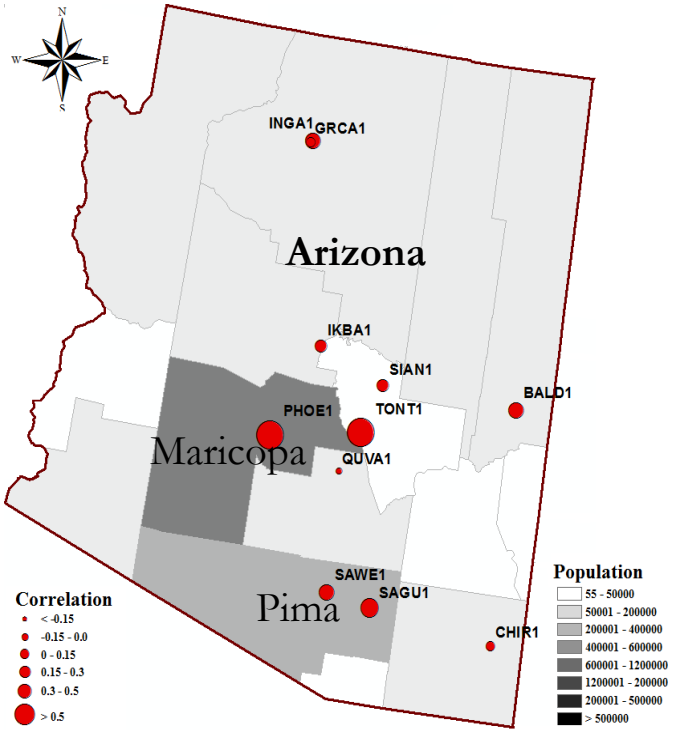


Disseminated Coccidioidomycosis: Bloodstream transport to Skin, Brain, Nerve etc

Collocation of Dust Storms and Valley Fever

(Tong et al., 2017)



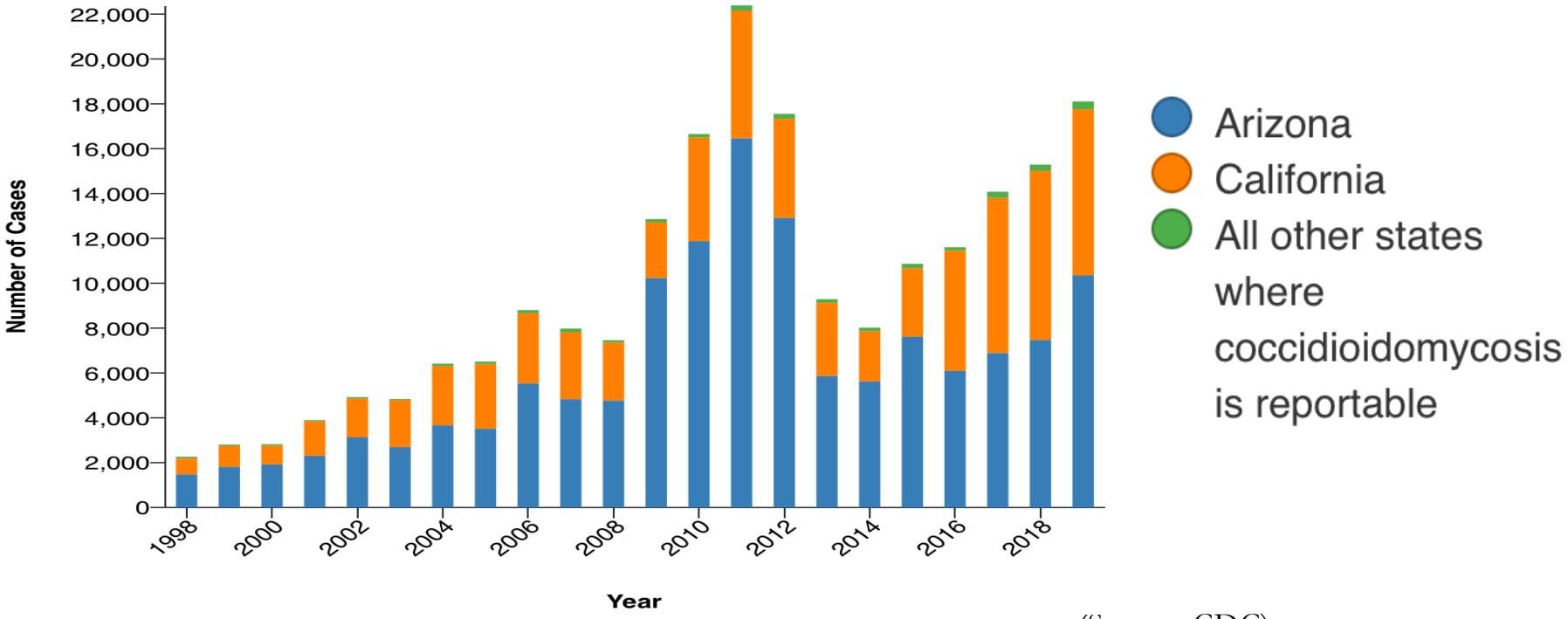


High infection rate of Valley fever in states frequented by dust storms.

Only near-city dust storms are strongly correlated to Valley Fever;

Health Burden of Valley Fever

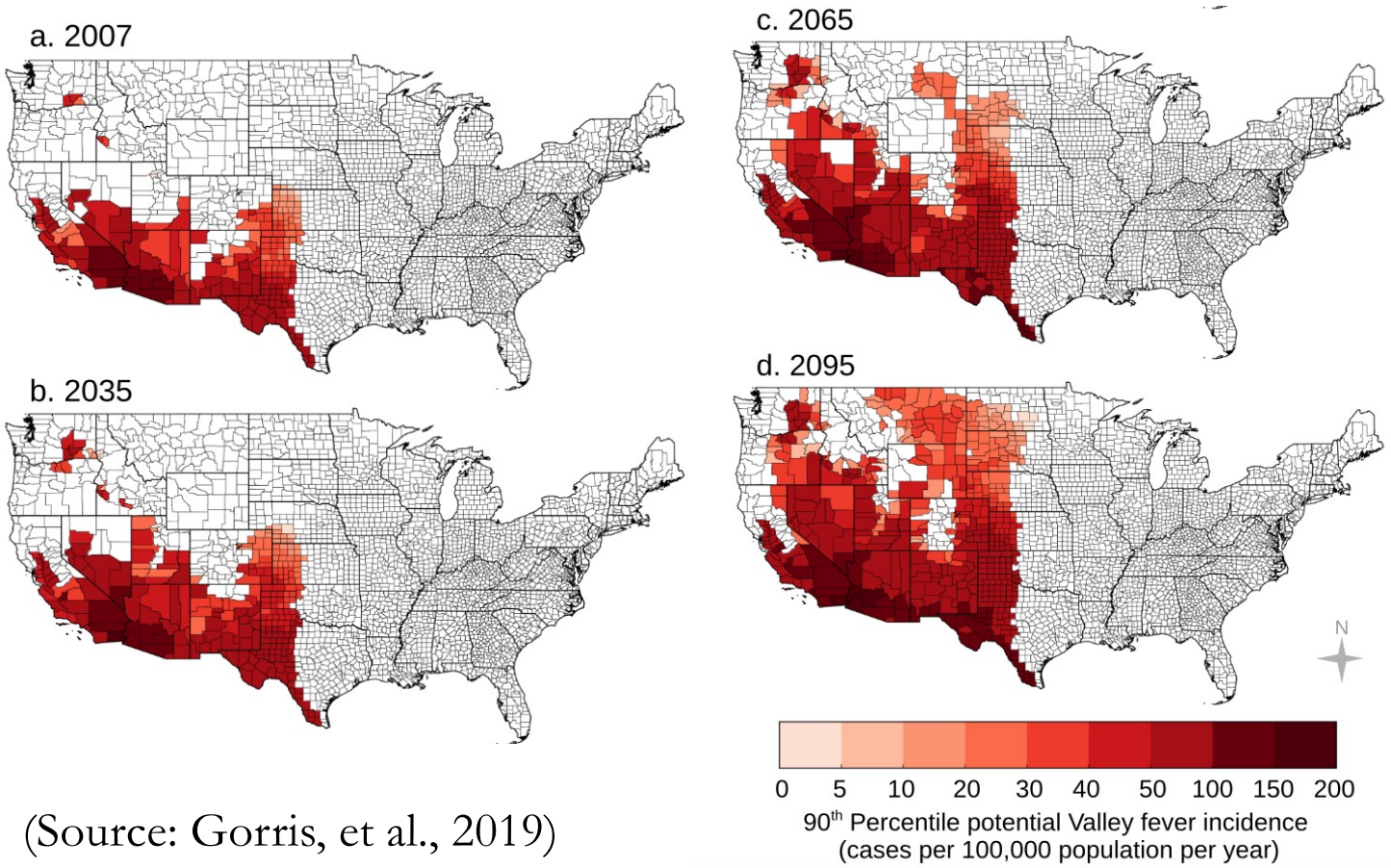
- ~10,000-20,000 cases reported to public health annually
- 200 deaths each year (mostly in Arizona and California)



(Source: CDC)

>4,000 deaths in the United States

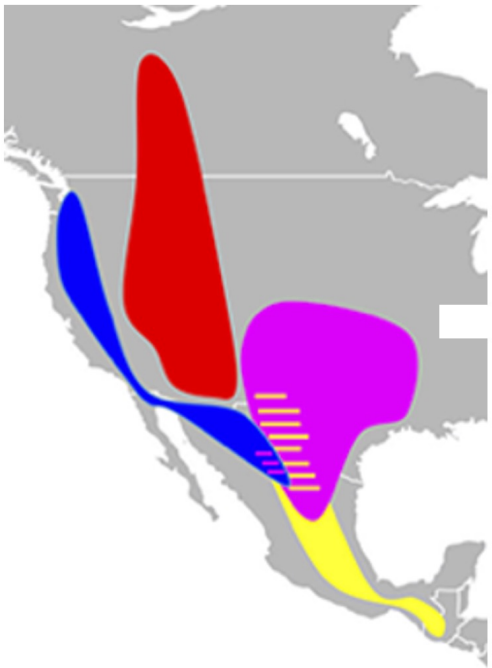
Expansion of Valley Fever Endemic Zone in Response to Climate Change



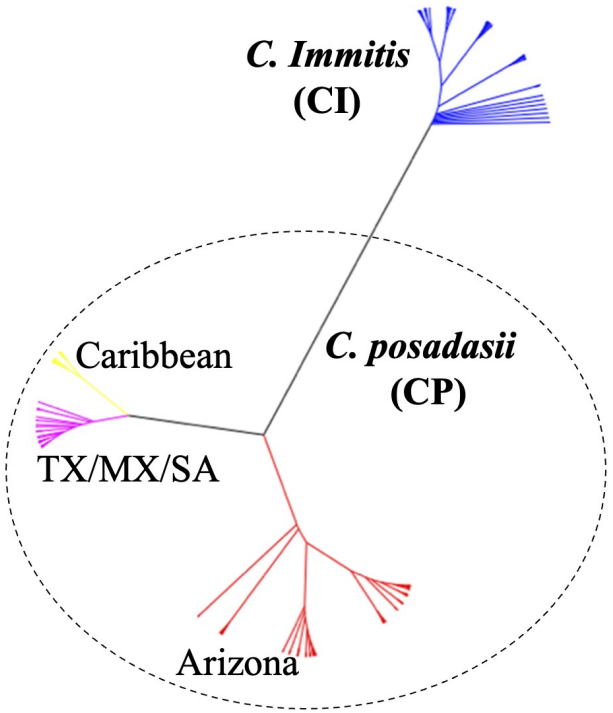
(Source: Gorris, et al., 2019)

Distribution of Coccidioidomycosis Outside the US

Geographic regions of different phylogenetic lineages



Collapsed phylogenetic tree



(Source: Tong et al., 2023; reproduced from Barker, et al., 2019)

Detecting Valley fever Fungi in Dust Storms

Ling Ren, Zack Chester, Siqi Ma, Pat Gillevet, Thomas Gill (UTEP), Scott Van Pelt (USDA)

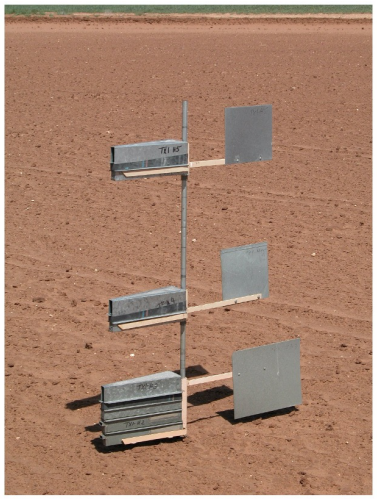
Funded by NASA and GMU Institute of a Sustainable Earth

Detecting Valley fever Fungi in Dust Storms

Marble Dust Collector (MDCO)

(Zack Chester)

Big Spring Number Eight



Aspirated Air Sampler

PurpleAir Air Quality Sensor

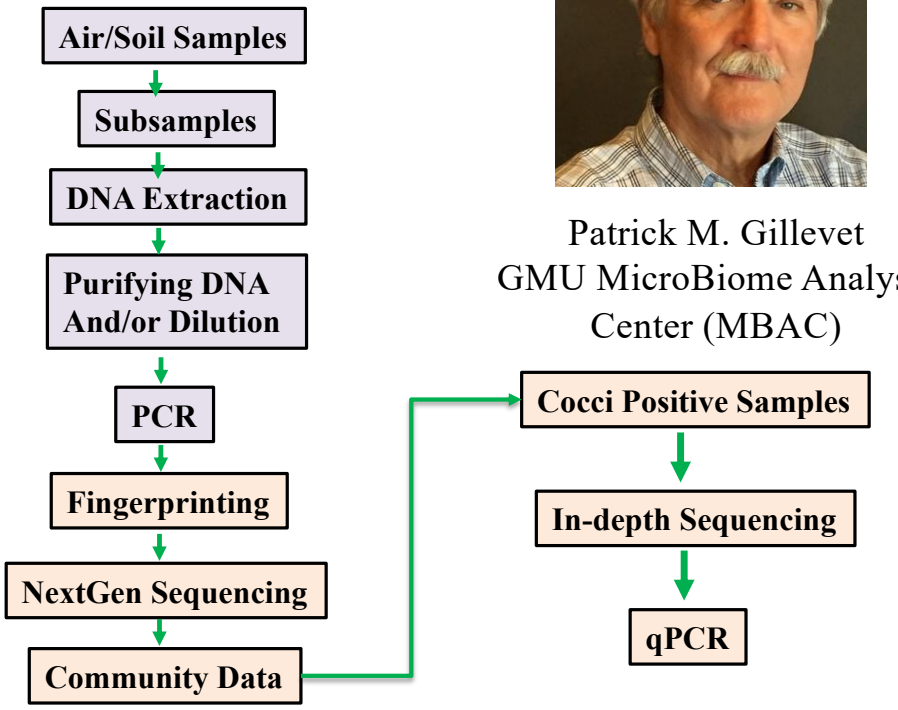
Laboratory Analysis

(Contributed by Ling Ren)

- In Collaboration with CDC
- Multitag sequencing of bacterial and fungal communities
- Detection and real-time PCR on *Coccidioides*

DNA extraction

NextGen Sequencing

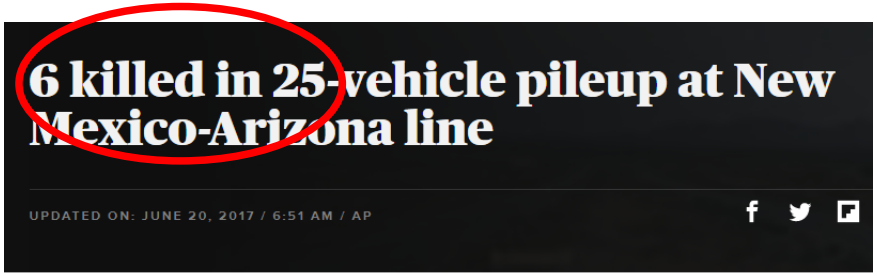


Patrick M. Gillevet
GMU MicroBiome Analysis Center (MBAC)

DNA: Deoxyribonucleic Acid (DNA)
PCR: polymerase chain reaction

Dust Storms and Highway Safety

How Many People Were Killed by Windblown Dust Events? A Myth of Two Tales



6 killed in 25-vehicle pileup at New Mexico-Arizona line

UPDATED ON: JUNE 20, 2017 / 6:51 AM / AP

LORDSBURG, N.M. -- Authorities in New Mexico say six people are dead after a 25-vehicle pileup on I-10 was caused by sudden blowing dust in New Mexico near the Arizona state line.

"..six people dead after a 25-vehicle pileup"
(Source: CBS News June 2017)

Summary of Natural Hazard Statistics for 2017 in the United States

This National Weather Service (NWS) report summarizes fatalities, injuries and damages caused by severe weather in 2017. The NWS Office of Climate, Water and Weather Services and the National Climatic Data Center compiled this Summary of U.S. Natural Hazard Statistics from Storm Data, a report comprising statistics from NWS forecast offices in the 50 states, Puerto Rico, Guam, and the Virgin Islands.

Summary of 2017 Weather Events, Fatalities, Injuries, and Damage Costs

Weather Event	Fatalities	Injuries	Property Damage (million $)	Crop Damage (million $)	Total Damage (million $)
Other					
Drought	0	0	0.05	0.31	0.36
Dust Storm	0	0	0.35	0.00	0.35
Dust Devil	0	0	0.06	0.00	0.06

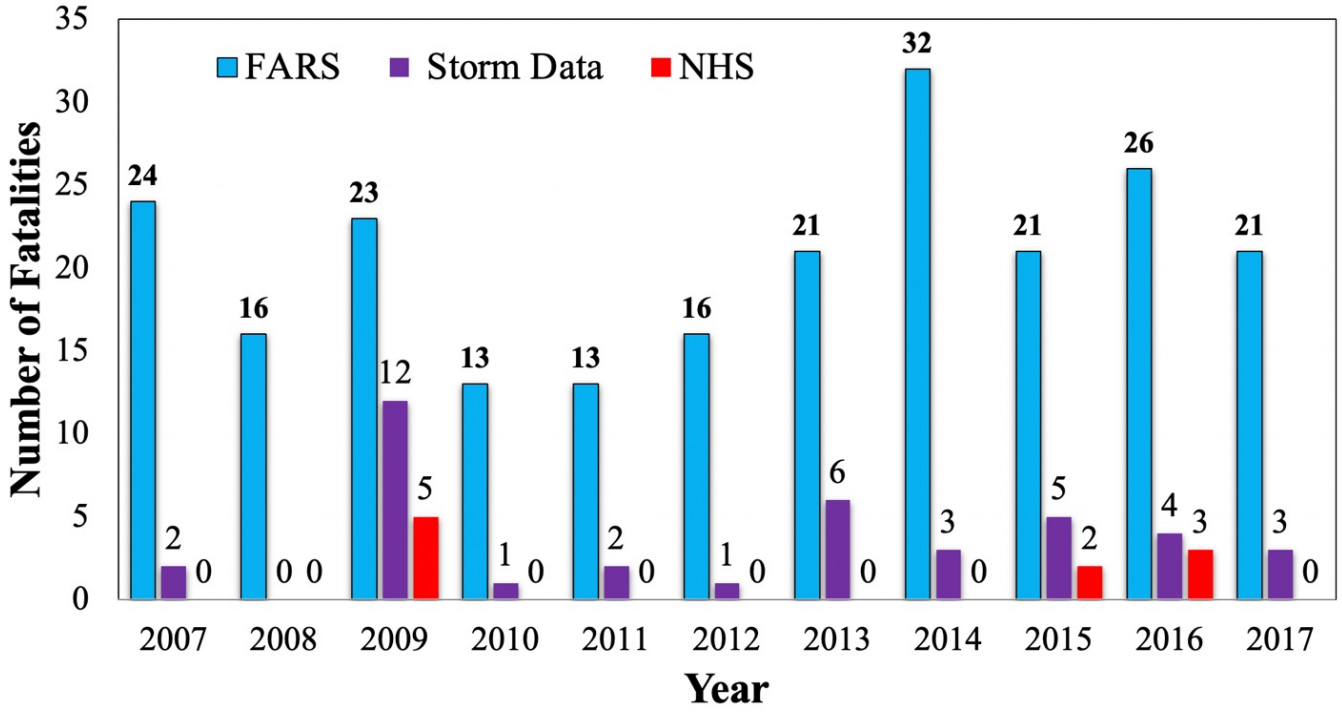
Source: https://www.nws.noaa.gov/om/hazstats/sum17.pdf

0-5 deaths, on average 1 death per year

Debunk the Myth

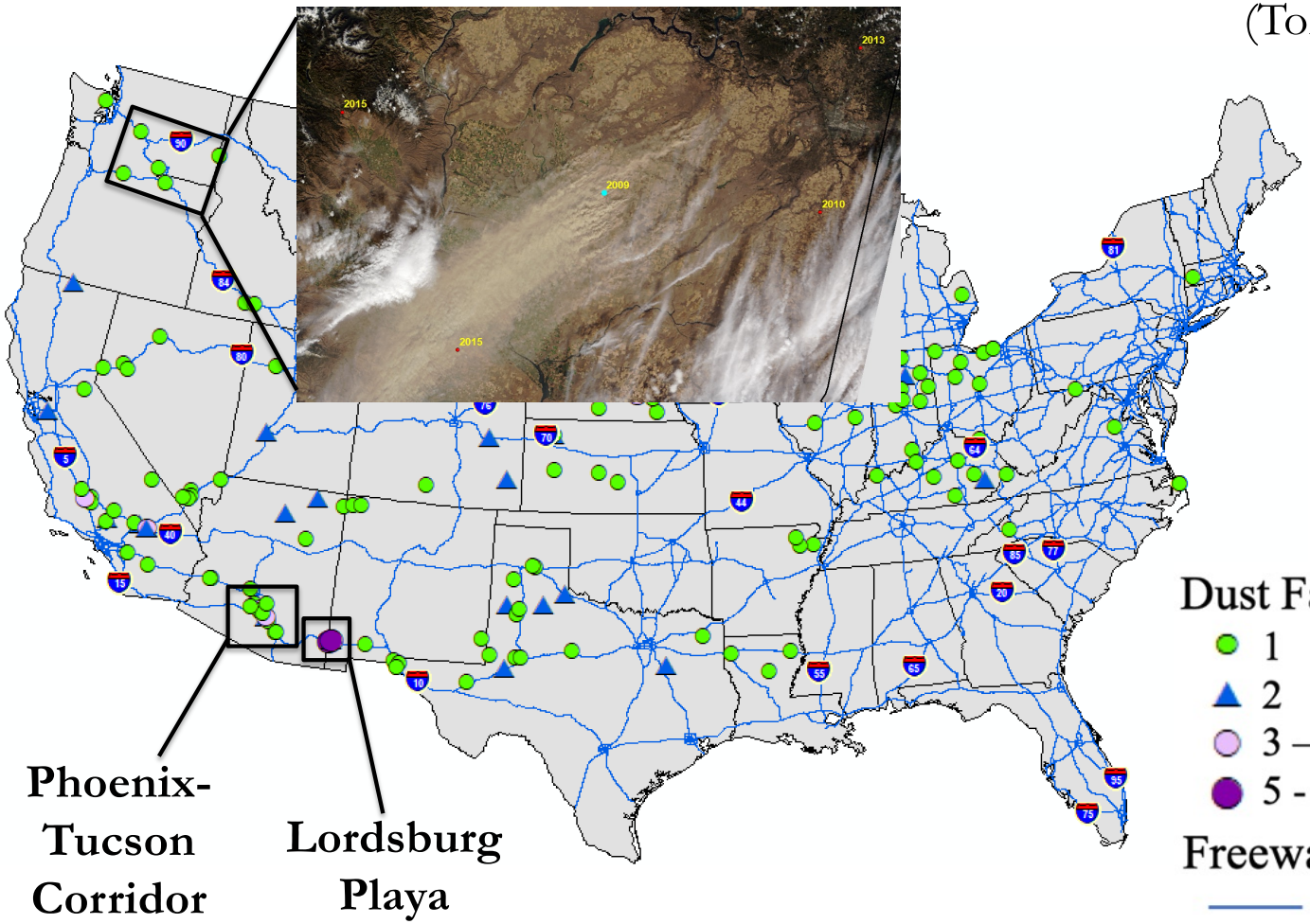
Comparison of three datasets: (Tong et al., BAMS, 2023)

- NOAA Natural Hazard Statistics (NHS)
- DOT Fatality Analysis Report System (FARS)
- NOAA Storm Events Dataset (Storm Data)



A Lot of People Killed by Dust Storms!

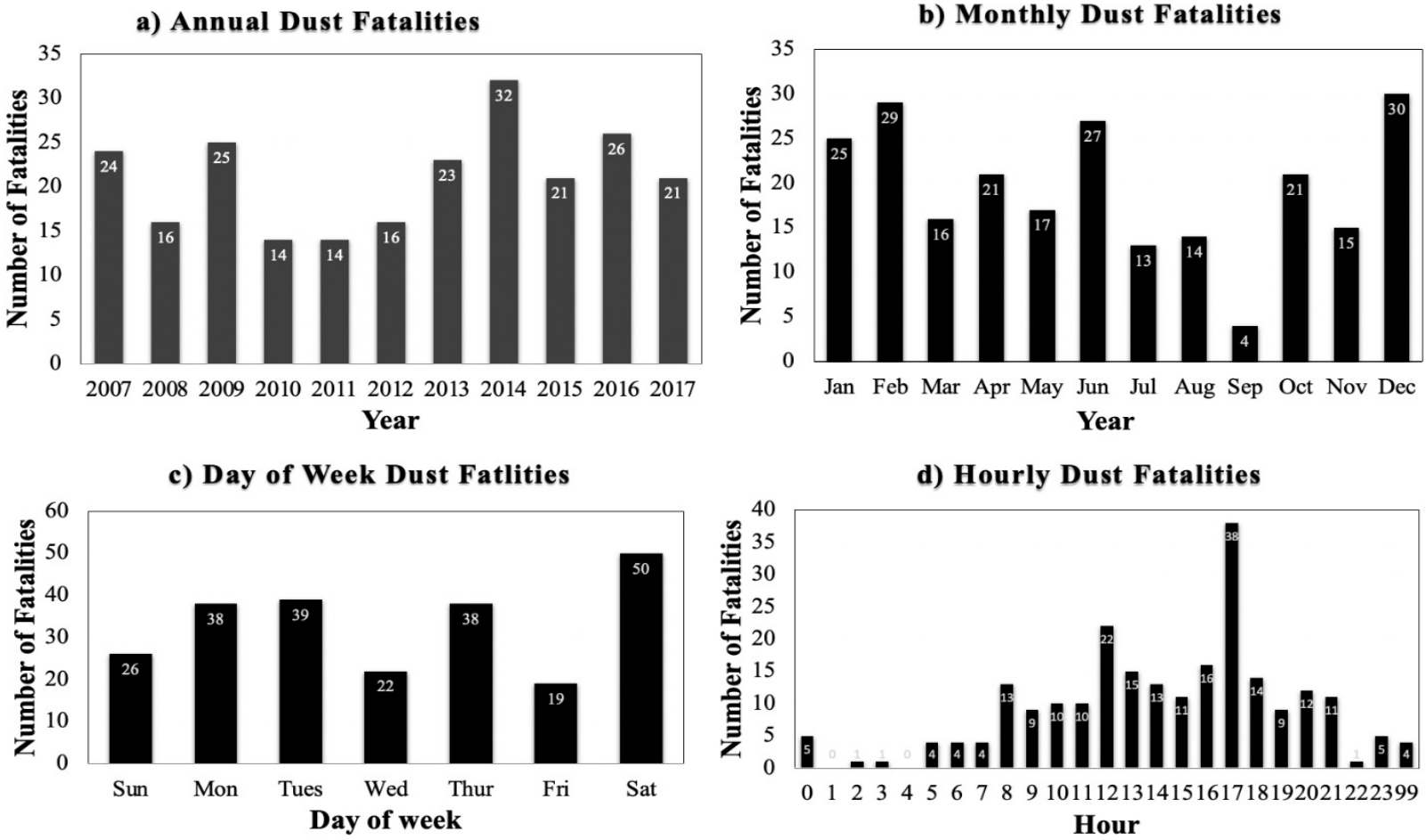
Where Did Fatal Accidents Occur?



(Tong et al., BAMS, 2023)

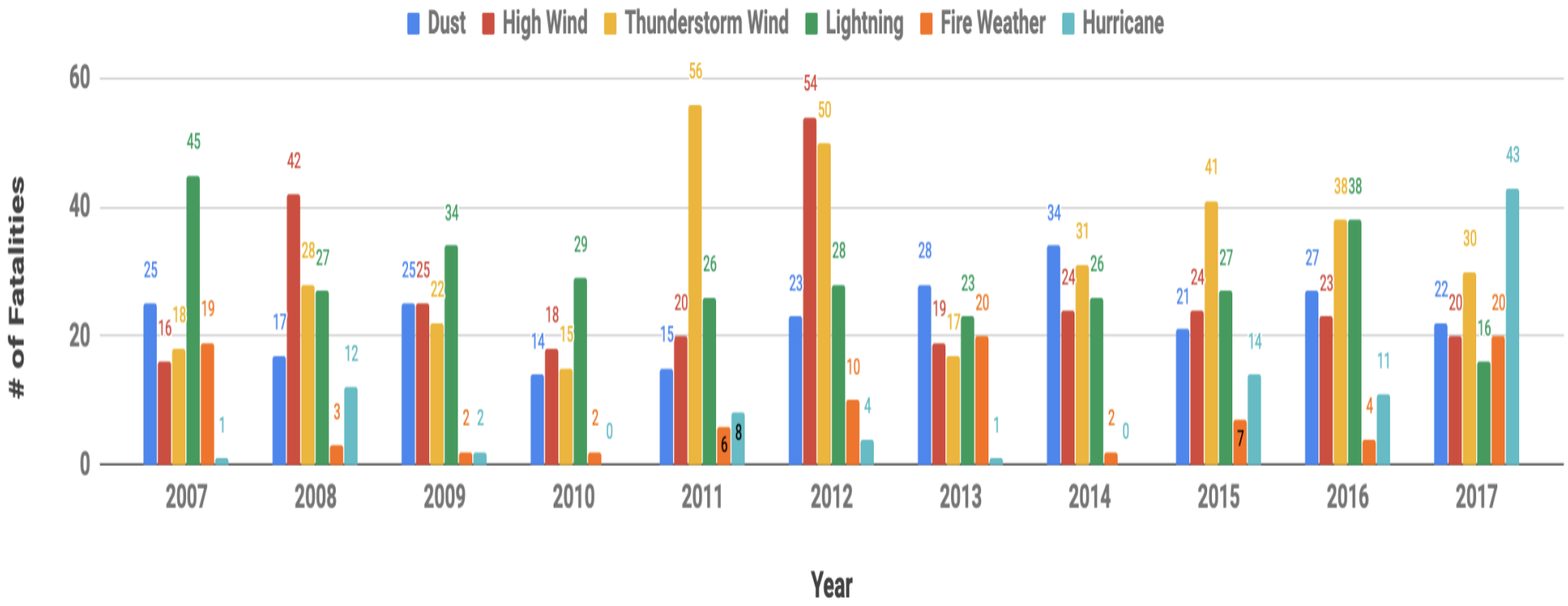
- 14-33 dust fatalities each year (2007-2017)
- Two hotspots: Deadliest Ten Miles and Lordsburg Playa
- 60% of deadliest accidents along I-10.

Temporal Variations of Dust Fatalities



(Tong et al., BAMS, 2023)

Dust vs Other Weather Hazards



In Most Years, Dust Costs Comparable Life Losses to Weather Hazards Such as Hurricanes, Thunderstorms, and Fire Weather

New Dust Crash: May 1, 2023 Dust Storm in Illinois

The New York Times

Seven Dead After Dust Storm Causes Crashes on Interstate 55 in Illinois

At least 72 vehicles were involved in pileup crashes after a dust storm swept through central Illinois, forcing the closure a key highway in the region.

NEWS POLITICS U.S. NEWS BUSINESS TECH WORLD HEALTH CULTURE & TRENDS NBC NEWS TIPLINE WATCH NOW

U.S. NEWS

7 dead, 37 hospitalized after blinding dust storm causes pileups on Illinois highway

The death toll in the pileups near Farmersville rose to seven Tuesday.

CNN US Crime + Justice Energy + Environment Extreme Weather Space + Science

Highway reopens after more than 70 vehicles crashed in a dust storm, leaving at least 7 dead

- 8 deaths
- 37 Injuries
- 72 Cars Piled Up

Deadliest Dust Storm in Eastern US

Deadliest Dust Storms in Past 30 Years

Deadliest Dust Storms	**Dust Sources**
- 17 deaths, 11/29/1991 CA	- Agricultural fields
- 8 deaths, 5/1/2023 Illinois	- Agricultural fields
- 8 deaths, 7/26/2021 Utah	- Exposed land (unknown land use)
- 7 deaths, 5/22/2014 NM	- Playa (dry lake)
- 6 deaths, 6/19/2017 NM	- Playa (dry lake)

Illinois Dust Storm

Utah Dust Storms

NM Lordsburg Playa

- Deadliest dust storms are from 1) cropland and 2) dry lakes (Playas);
- All from small-scale events → high-resolution dust forecasting?

What to Do if Driving into a Dust Storm?

(Source: Arizona DOT)

- Check traffic around your vehicle (front, back and side);
- Look for a safe place to pull off roadway.
- Turn off all vehicle lights.
- Take your foot off the brake.
- Stay in the vehicle, keep seat belt on,

and wait for the storm to pass.

"Pull Aside, Stay Alive"

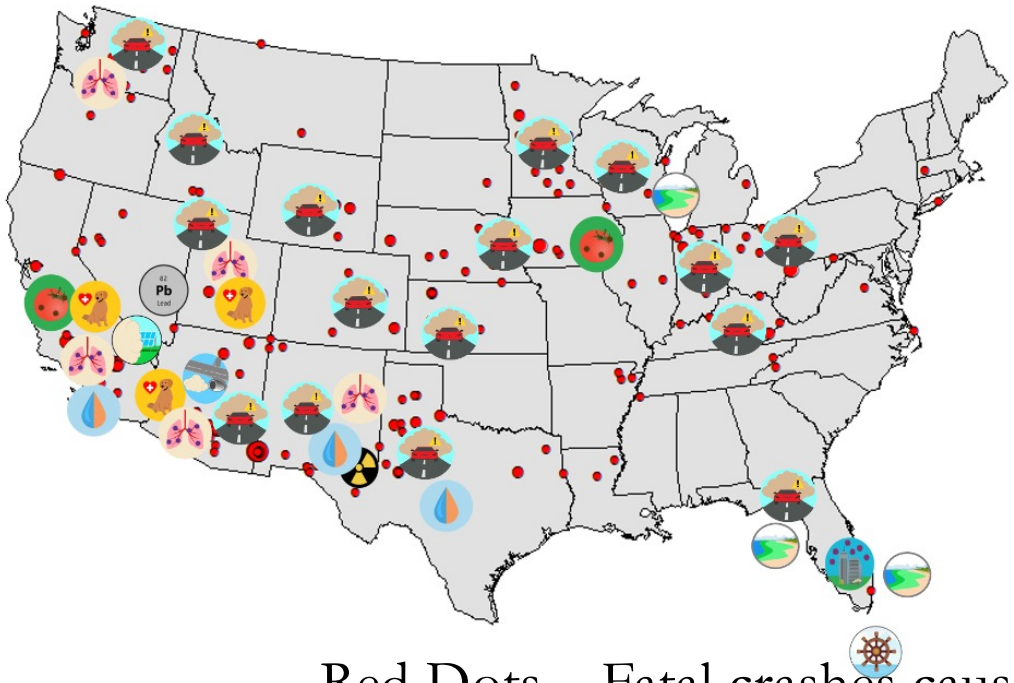
(Photo courtesy Arizona Department of Transportation)

More information:
https://azdot.gov/adot-blog/quiz-are-you-prepared-dust-storms

Dust Effects on Health and Safety

Daniel Q. Tong[1], Thomas E. Gill[2], William A. Sprigg[3], Robert Scott Van Pelt[4], Alexander A. Baklanov[5], Bridget Marie Barker[6], Jesse E. Bell[7], Juan Castillo[8], Santiago Gassó[9], Cassandra J. Gaston[10], Dale W. Griffin[11], Nicolas Huneeus[12], Ralph A. Kahn[13], Arunas P. Kuciauskas[14], Luis A. Ladino[15], Junran Li[16], Olga L. Mayol-Bracero[17], Orion Z. McCotter[18], Pablo A. Méndez-Lázaro[19], Pierpaolo Mudu[20], Slobodan Nickovic[21], Damian Oyarzun[22], Joseph Prospero[10], Graciela B. Raga[15], Amit U. Raysoni[23], Ling Ren[1], Nikias Sarafoglou[1], Andrea Sealy[24], Ziheng Sun[1], Ana Vukovic Vimic[25]

- Valley Fever Infection
- Animal Diseases
- Aviation Safety
- Roadway Safety
- Marine Navigation
- Reduced Solar Energy
- Harmful Algal Bloom
- Water Contamination
- Food Contamination
- Imported Urban Microorganisms
- Heavy Metal Contamination
- Radioactive Contamination



(Tong et al., Review of Geophysics, 2023)

Red Dots – Fatal crashes caused by dust storms

Windblown Dust Emission Model FENGSHA

(FENGSHA – "Windblown Dust" in Mandarin)

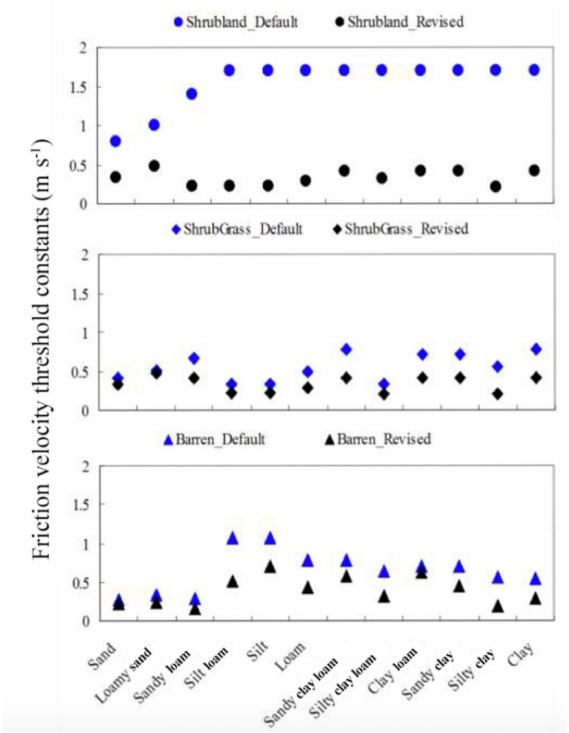
Land Use, Escape Fraction, Source Area, Soil Erosion Potential, Friction Velocity, Threshold Friction Velocity

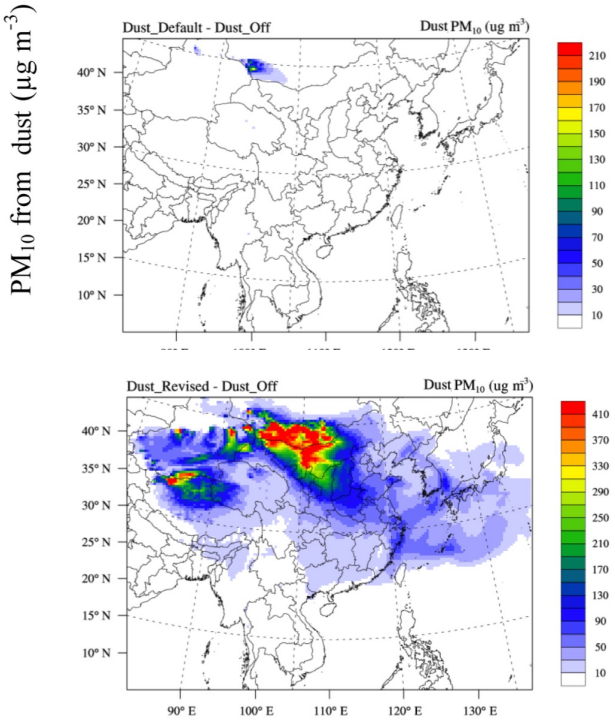
$$F = \sum_{i=1}^{M} \sum_{j=1}^{N} K \times A \times \frac{\rho}{g} \times S_i \times SEP \times u_* \times (u_*^2 - u_{*ti,j}^2)$$

- Escape fraction (K): Two options: Marticorena 1995; Lu and Shao, 1999.
- Dynamic map of source areas (S) based on three options: MODIS DOD (Ginoux et al., 2012); NDVI fraction (Kim et al., 2012); GOES-16/ABI dust sources (Kondragunta et al., 2018);
- Global soil texture map from USDA STATSGO;
- Reanalysis of threshold friction velocity (Gillette 1980, 1982);
- Albedo-based wind energy partition (Chappell and Webb, 2017);

Reanalysis of Gillette Field Data

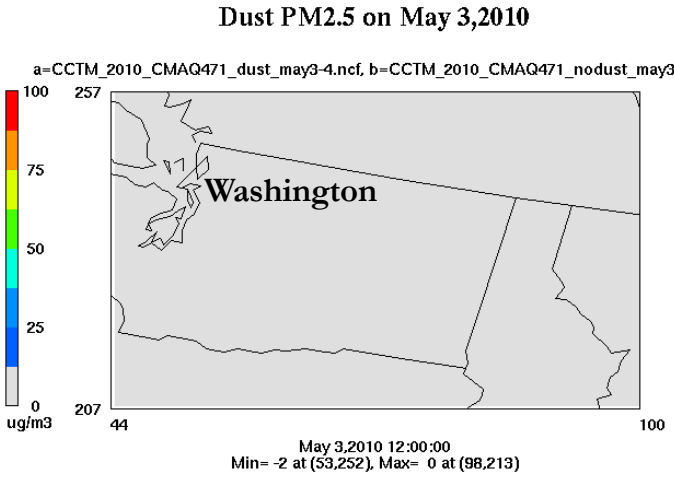
- Reanalysis of Gillette's observations (Gillette et al., 1980, 1982) to avoid double-counting of soil moisture effects;
- Field data were converted into dry condition using Fecan 1999;





(Dong et al., ACP, 2016)

NOAA Real-time Dust Forecasting (CMAQ-FENGSHA)



12:30 pm, May 3, 2010

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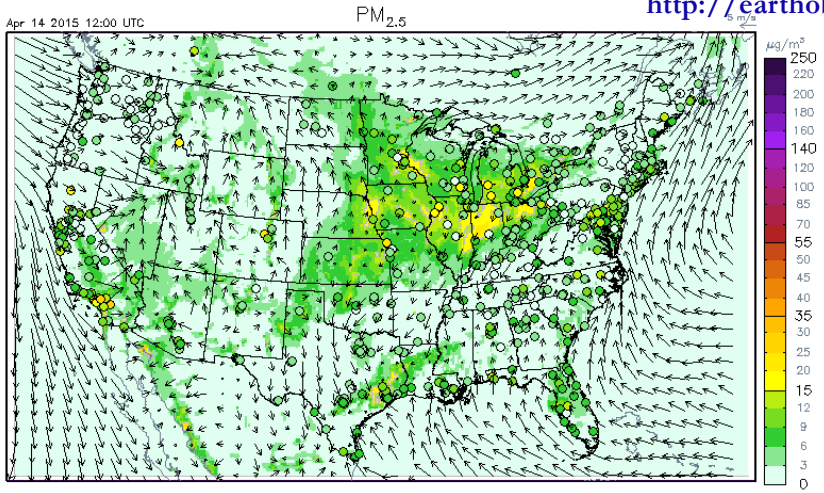
http://earthobservatory.nasa.gov/NaturalHazards

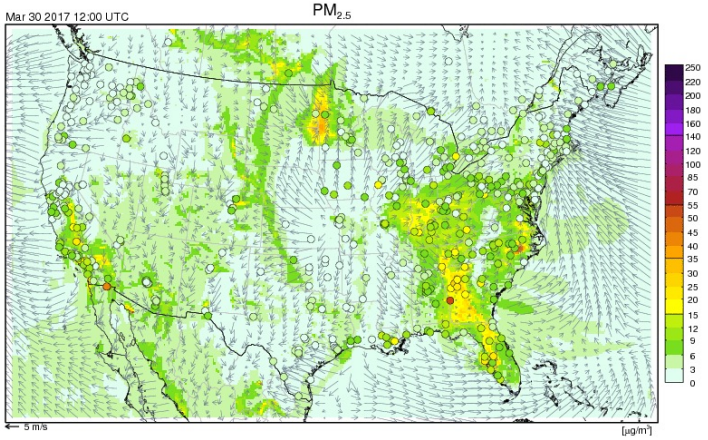


(Courtesy of Hyuncheol Kim)

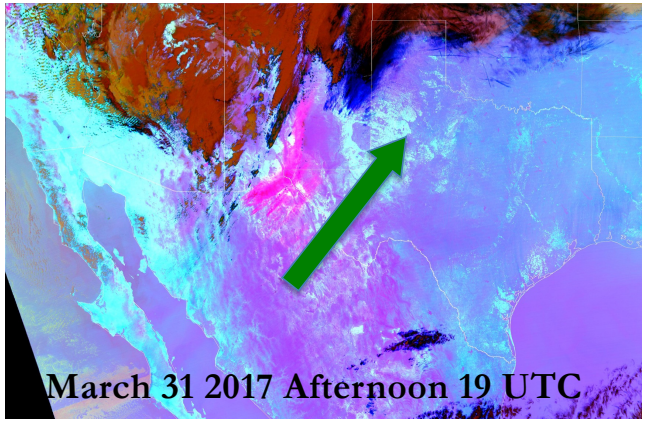
Dust emissions from cropland, rangeland, and deserts

Dust Forecast Diagnostics with Satellite Observations

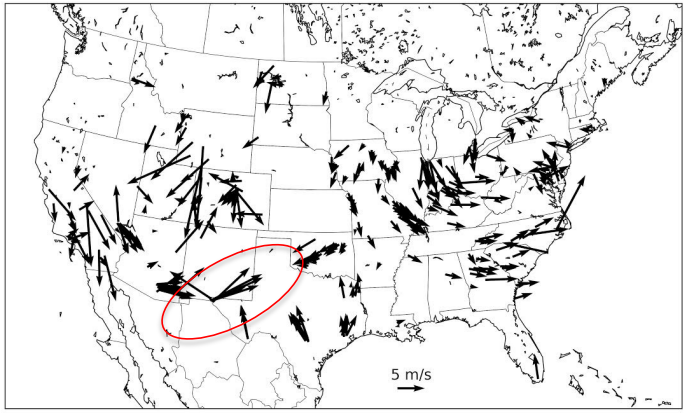
A Dual Dust Storm Event



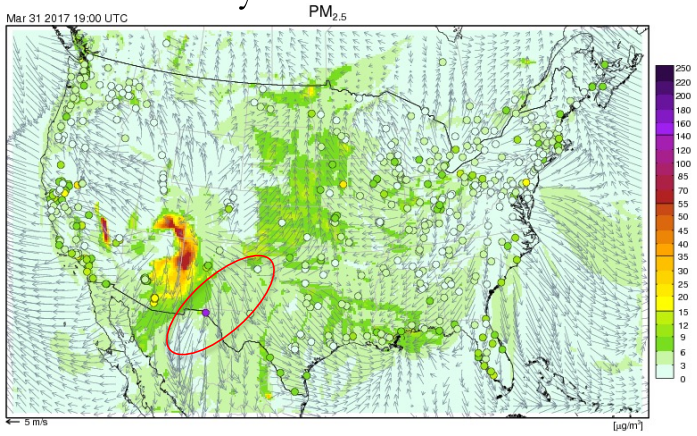
Southwesterly Wind from VIIRS



Ground wind observations



Northerly Wind from Model



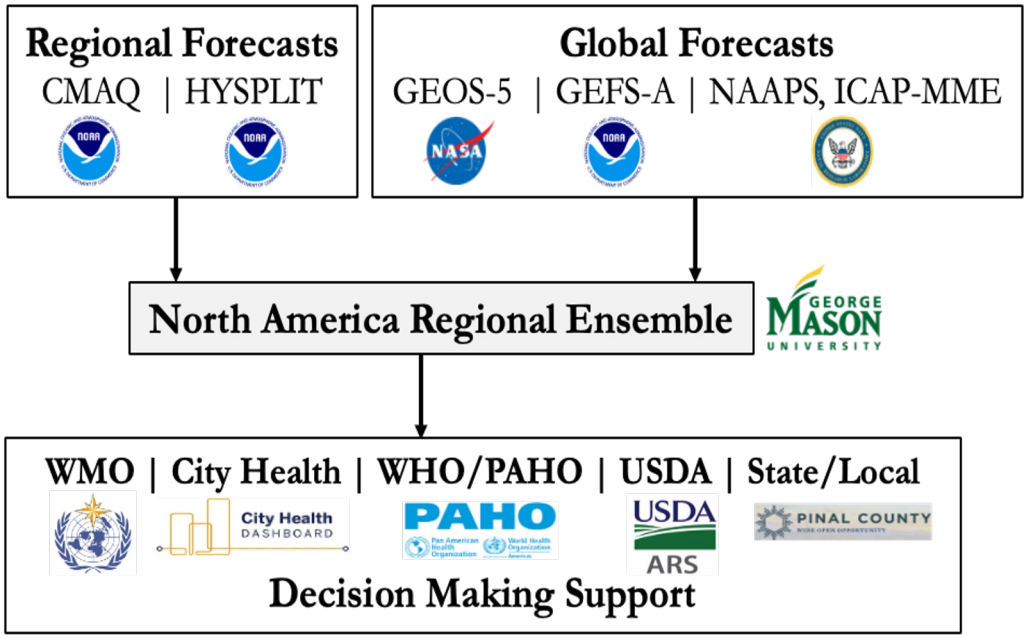
(Hyuncheol Kim, NOAA)

Beyond Single-Model: Ensemble Dust Forecasts

The Hazardous Air Quality Ensemble System (HAQES)

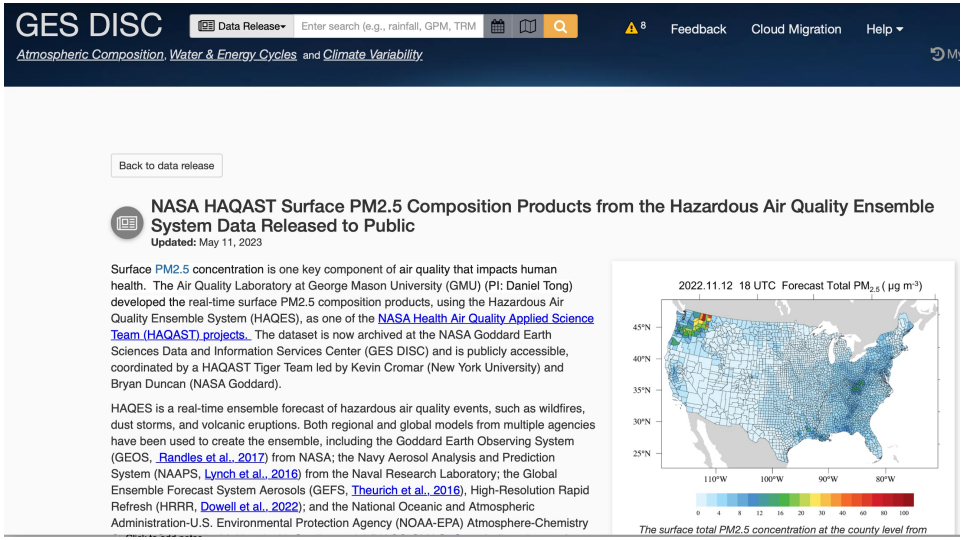
Consensus forecast using 5 products from US federal agencies (NOAA, NASA, NRL)

Multi-Model Ensemble



http://air.csiss.gmu.edu/haqes/

Release through NASA

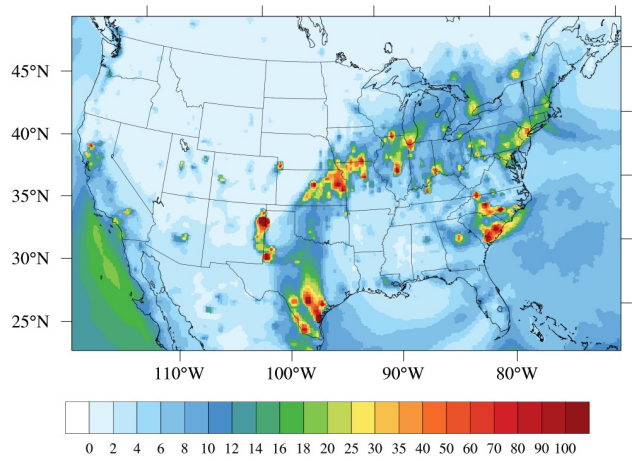


Real-time Forecast Data released to the public via NASA Goddard Data Center

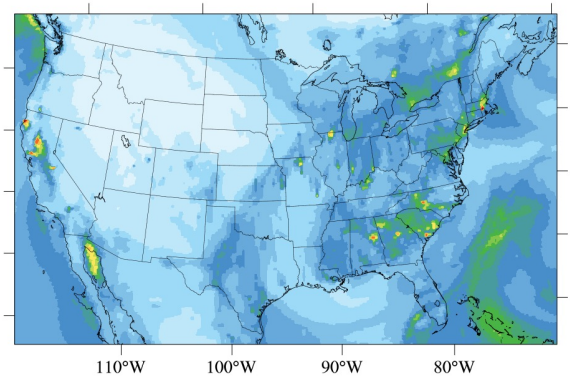
(Suhung Shen & Jen Wei, NASA)

Ensemble Dust $PM_{2.5}$ Forecasting on March 17th, 2022

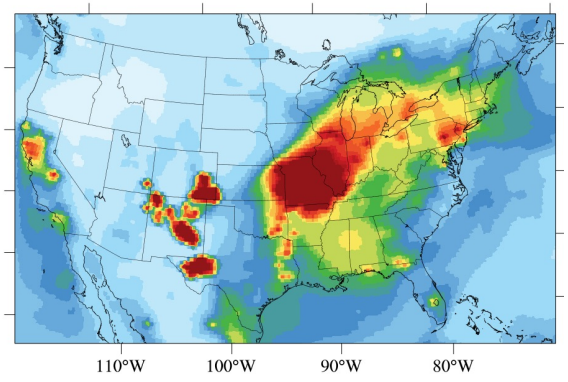
Model-1 20220317 Daily $PM_{2.5}$



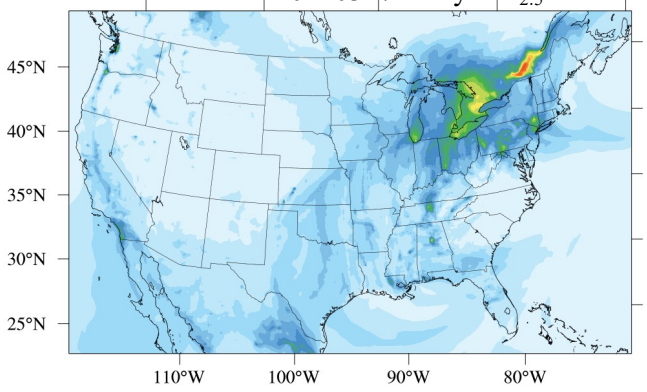
Model-2 20220317 Daily $PM_{2.5}$



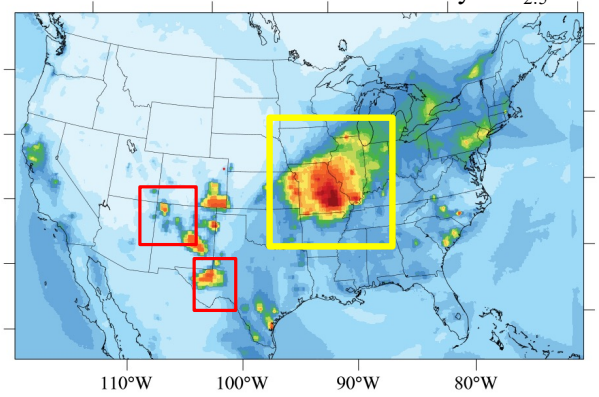
Model-3 20220317 Daily $PM_{2.5}$



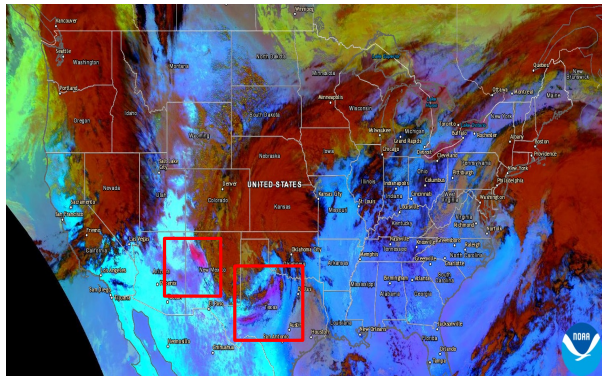
Model-4 20220317 Daily $PM_{2.5}$



Ensemble Mean 20220317 Daily $PM_{2.5}$



Dust RGB 20220317



(Peewara Makkaroon)

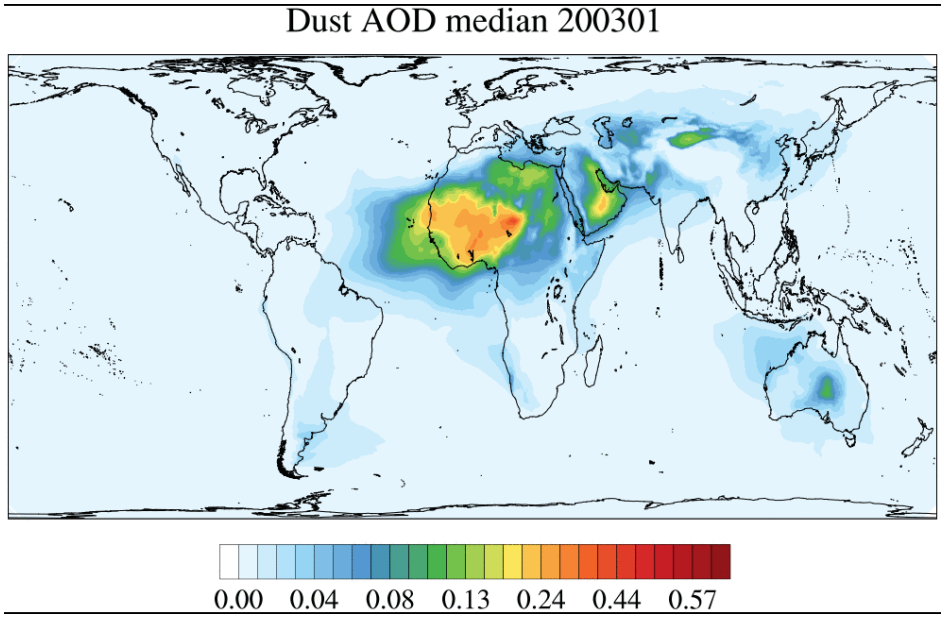
Global Dust Reanalysis Ensemble

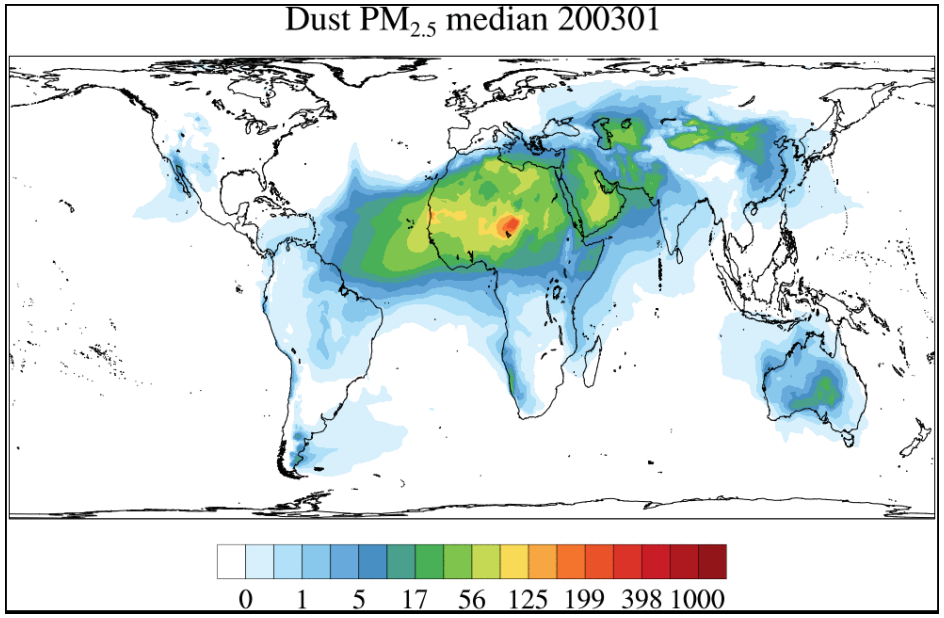
(WMO SDS-WAS Reanalysis Working Group)

Objectives:
- Building consensus of global dust budget
- Developing User-tailored SDS products/services

Phase I: Selected global reanalyses (NASA, ECMWF, NRL and FMI)

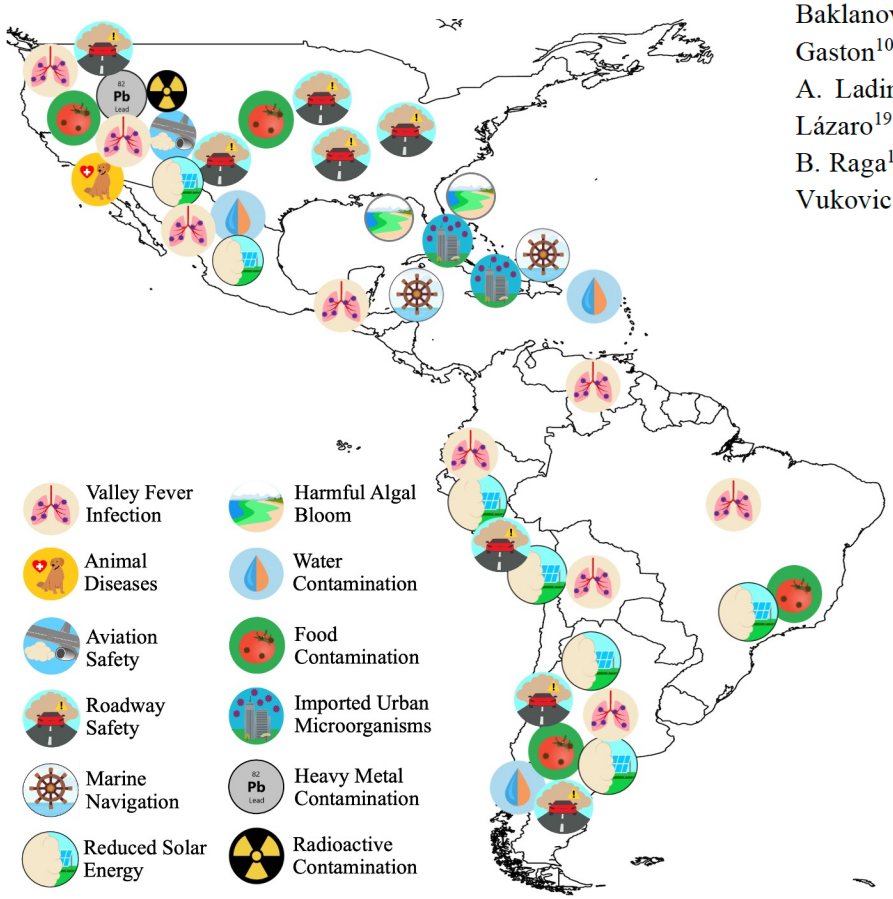
Phase II: More global datasets + regional reanalyses



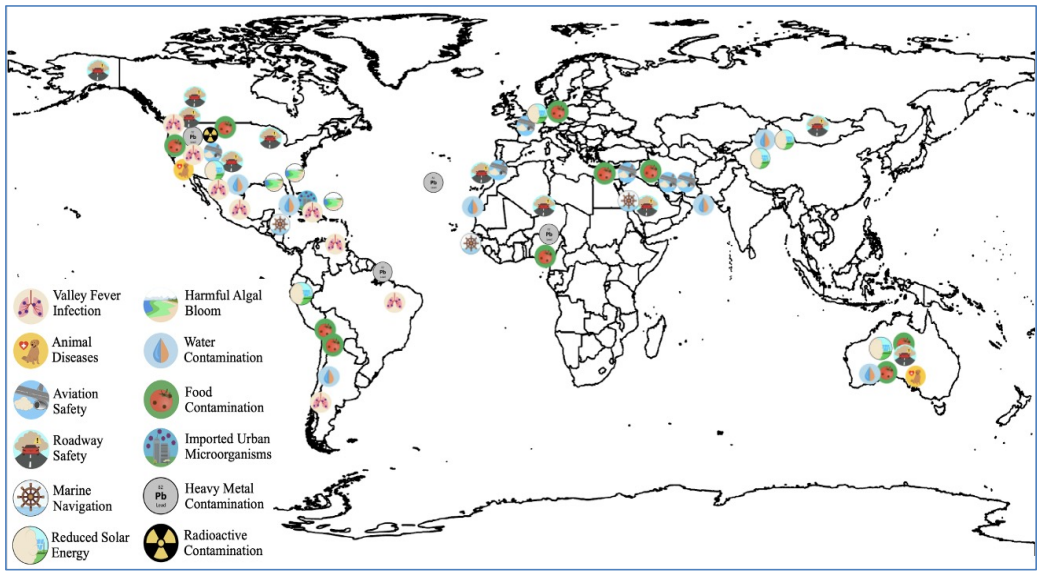


Mapping Global Dust Vulnerabilities

Daniel Q. Tong[1], Thomas E. Gill[2], William A. Sprigg[3], Robert Scott Van Pelt[4], Alexander A. Baklanov[5], Bridget Marie Barker[6], Jesse E. Bell[7], Juan Castillo[8], Santiago Gassó[9], Cassandra J. Gaston[10], Dale W. Griffin[11], Nicolas Huneeus[12], Ralph A. Kahn[13], Arunas P. Kuciauskas[14], Luis A. Ladino[15], Junran Li[16], Olga L. Mayol-Bracero[17], Orion Z. McCotter[18], Pablo A. Méndez-Lázaro[19], Pierpaolo Mudu[20], Slobodan Nickovic[21], Damian Oyarzun[22], Joseph Prospero[10], Graciela B. Raga[15], Amit U. Raysoni[23], Ling Ren[1], Nikias Sarafoglou[1], Andrea Sealy[24], Ziheng Sun[1], Ana Vukovic Vimic[25]



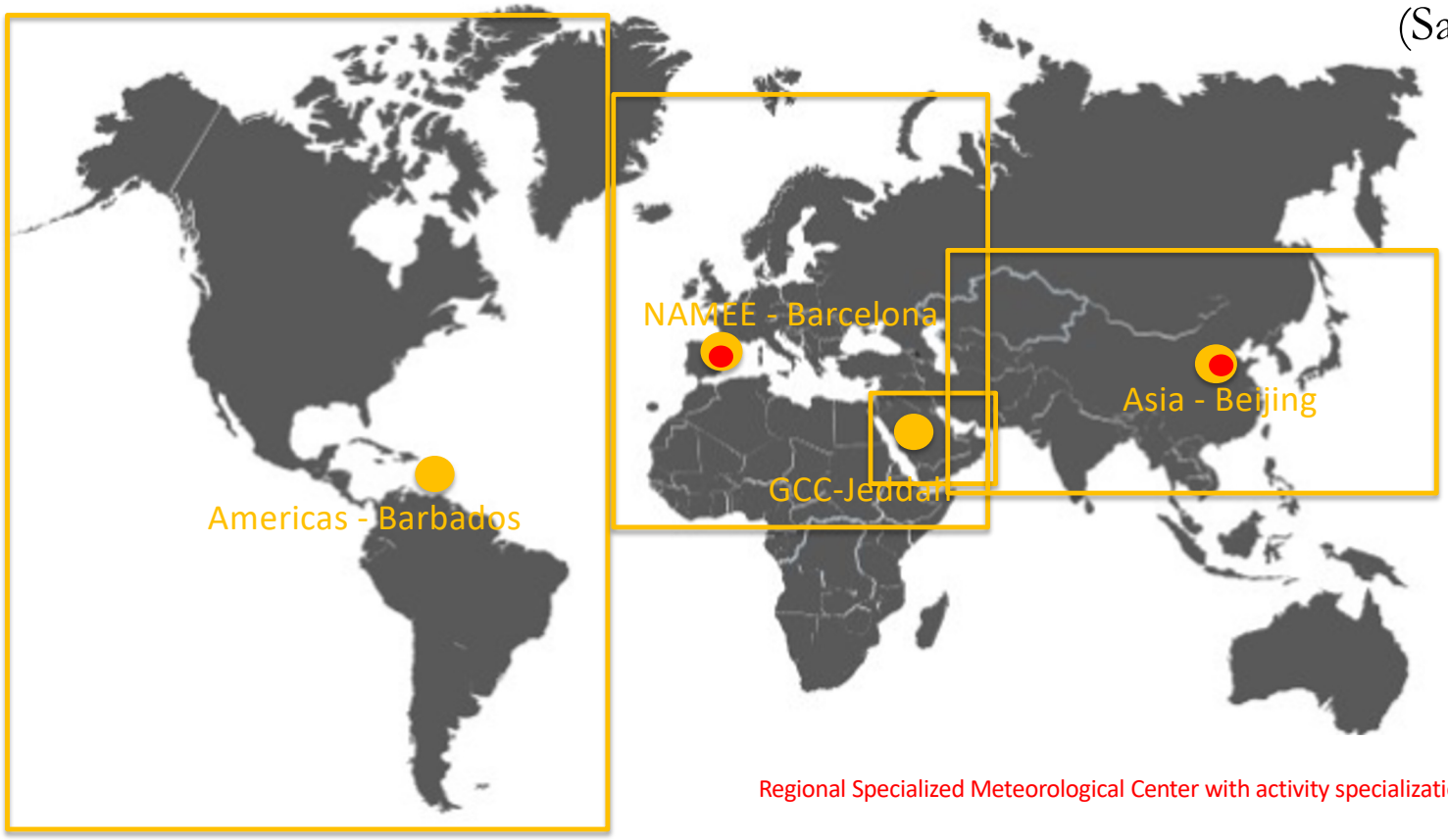
(Tong et al., Review of Geophysics, 2023)



(Nickovic et al., WMO Book, In Review)

WMO SDS-WAS Forecasting Capability

(Sara Basart, WMO)



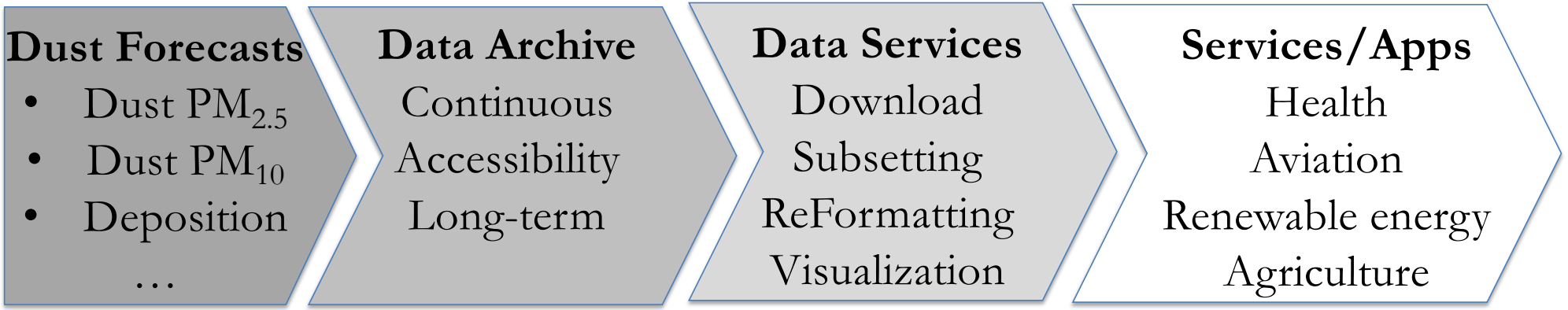
WMO INFRASTRUCTURE - GDPFS

Regional Specialized Meteorological Center with activity specialization on Atmospheric Sand and Dust Forecast (RSMC-ASDF)

Early Warning Needs:

1) Regions without operational centers;
2) Global Backbone Forecast(s)

From Dust Forecasts to Services



Dust Forecast Products: Single/Best or Ensemble

Global Operational Center???

WMO SDS-WAS & Partners

Join hands to deliver dust early wanting services to mitigate dust risks to the public.

Summary

- Another Dust Bowl? Jury is still out.
- Posing imminent risks to human health, safety, and the economy.
- Early warnings and outreach are important to mitigate dust impacts.
- Preparing the society for a dustier future in many parts of the world.

Acknowledgement

- Many collaborators in Pan-America, Europe and Asia;
- Financial support from NASA, NOAA, EPA, RWJ Foundation, GMU;
- Data and computing resources from NOAA, NASA, DOE, EPA and GMU.