Monitoring and Modeling of Long-term Dust Storm Trend: Guarding against future "Dust Bowl"

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The "Dust Bowl"

- Dust Bowl: A period of severe dust storms during the 1930s;
- Causes: Extended droughts and poor land management;
- Impacts:
  - ✓ Stripped 75% of top soils over thousands of farms;
  - ✓ Destroyed agriculture and ecosystem (~1950s);
  - ✓ 400,000 – 2.5 millions lost homes and communities;


Hundreds of thousands fled the 1930s US Dust Bowl; more drought-spurred migrations are expected.

(Source: USDA; Romm, 2011)

"And then the dispossessed were drawn west--from Kansas, Oklahoma, Texas, New Mexico; from Nevada and Arkansas, families, tribes, dusted out, tractored out... They streamed over the mountains, hungry and restless--restless as ants, scurrying to find work … anything, any burden to bear, for food. The kids are hungry. We got no place to live…"

-- John Steinbeck in the Grapes of Wrath

Another "Dust Bowl"?

YES!

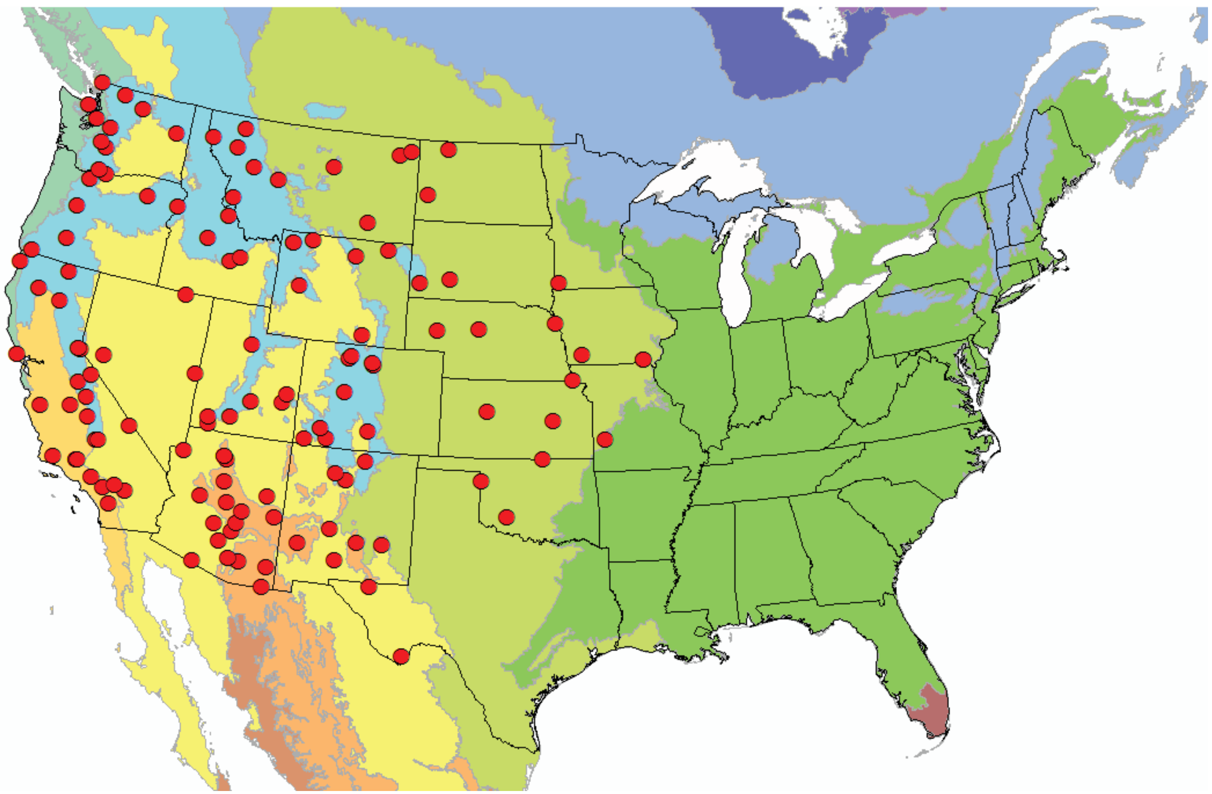
- Central U.S. plains saw severe droughts about once or twice a century over the past 400 years (Woodhouse & Overpeck, 1998).
- This recurring trend may be enhanced global climate change (Schubert et al., 2004).
- Global warming → Precipitation shift from subtropics, greater evaporation, less snow/ice, and earlier spring → amplify the effects of natural climatic variations → intensified droughts and "dust-bowlification" (Romm, 2011).

NO!

- The Dust Bowl of the 1930s was as much a human caused disaster as a natural one (drought) (Lee and Gill, 2015);
  -- misguided land cultivation practices;
  -- economic shock (Great Depression);
- Soil conservation measures implemented by USDA Natural Resources Conservation Service.

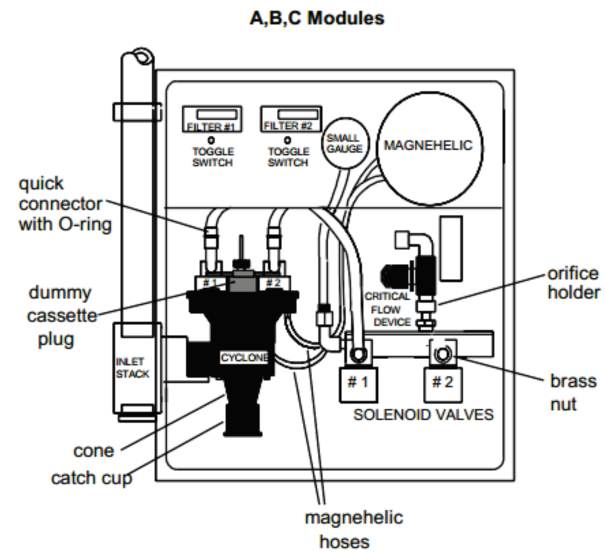
The Problem: No long-term dust climatology in the United States.

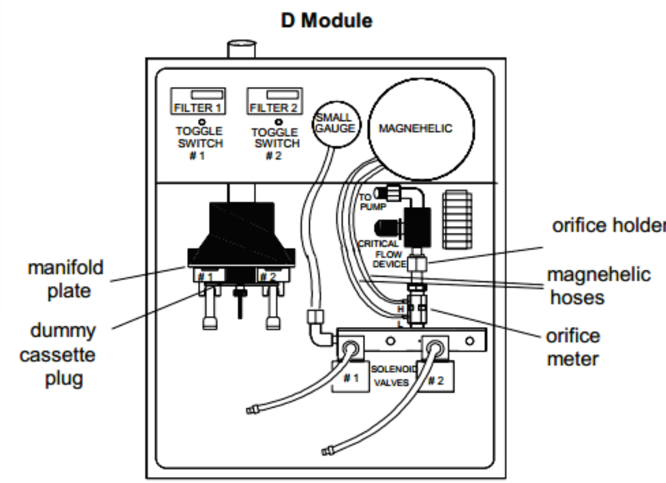
How to Monitor Dust Storms



The IMPROVE Network in the Western US

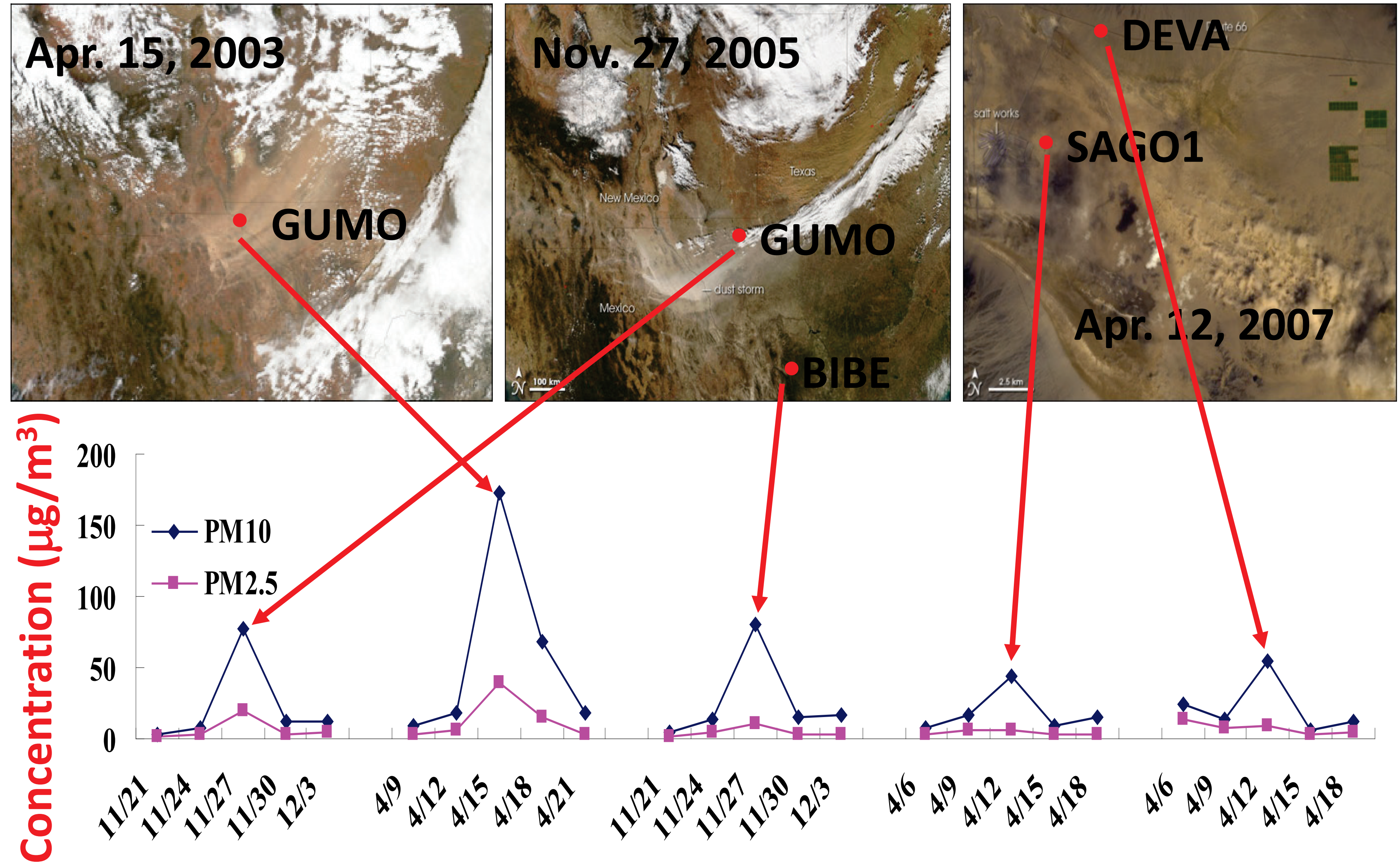
(IMPROVE: Interagency Monitoring of Protected Visual Environment)





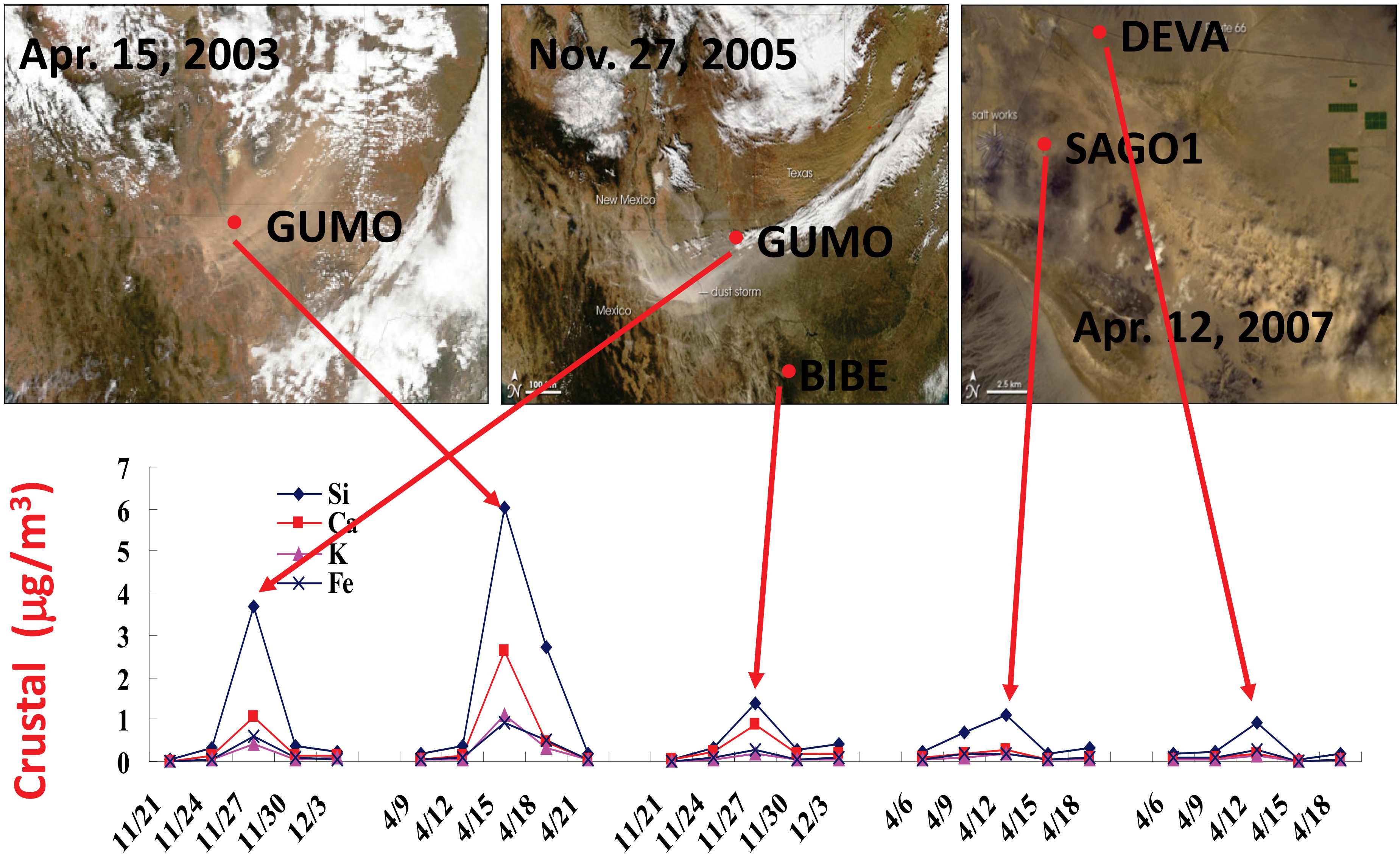
IMPROVE Samplers
Samples Analyzed at UC-Davis

Satellite-aided Algorithm Training



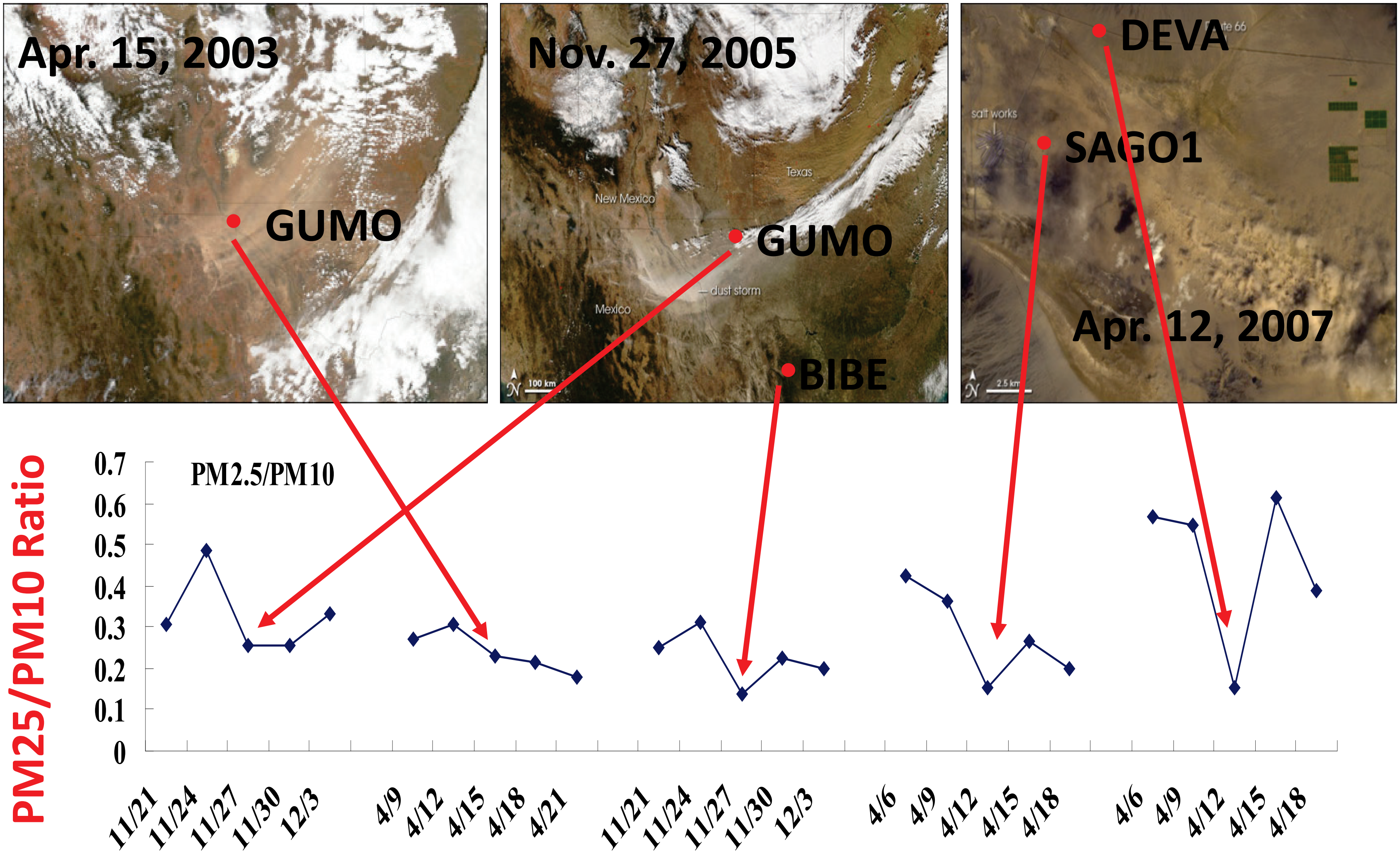
PM10: Particulate Matter < 10 μm   PM2.5: Particulate Matter < 2.5 μm

Satellite-aided Algorithm Training



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

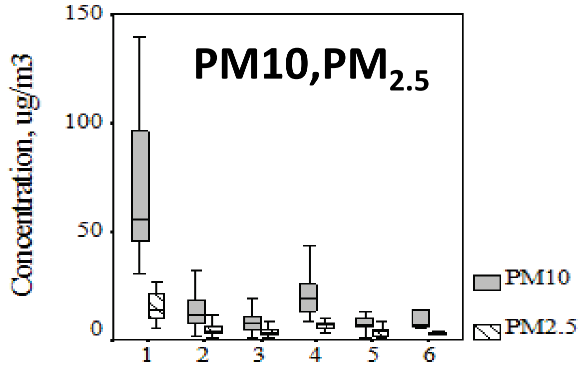
Satellite-aided Algorithm Training

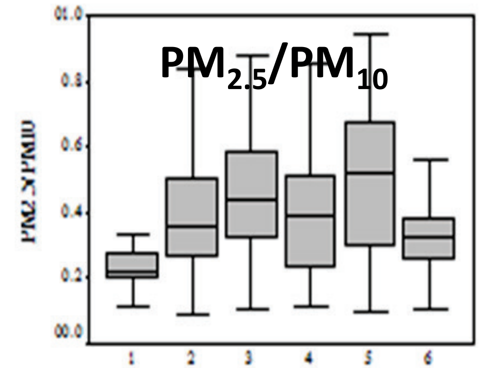


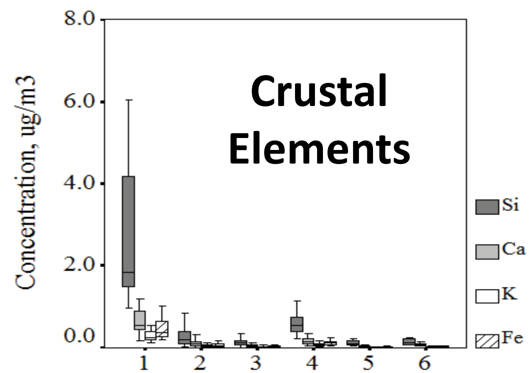
Dust Identification through Cluster Analysis

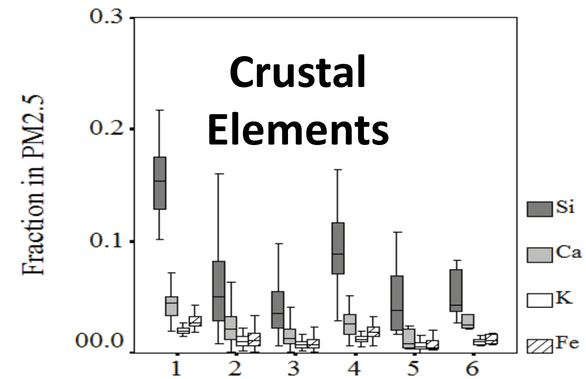
Five Dust Indicators:

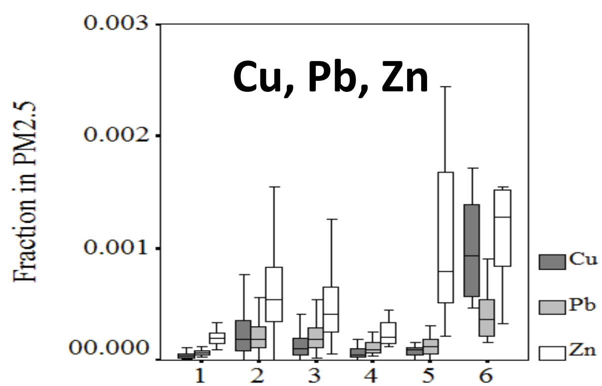
- ❖ High PM_{10}, $PM_{2.5}$;
- ❖ Low $PM_{2.5}/PM_{10}$ ratio
- ❖ High Crustal Fraction
- ❖ Low anthropogenic Fraction;
- ❖ Low Enrichment Factor;

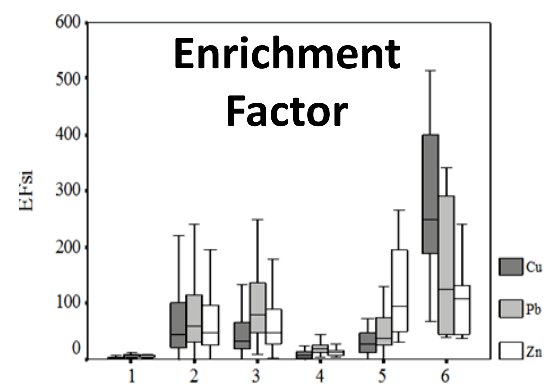






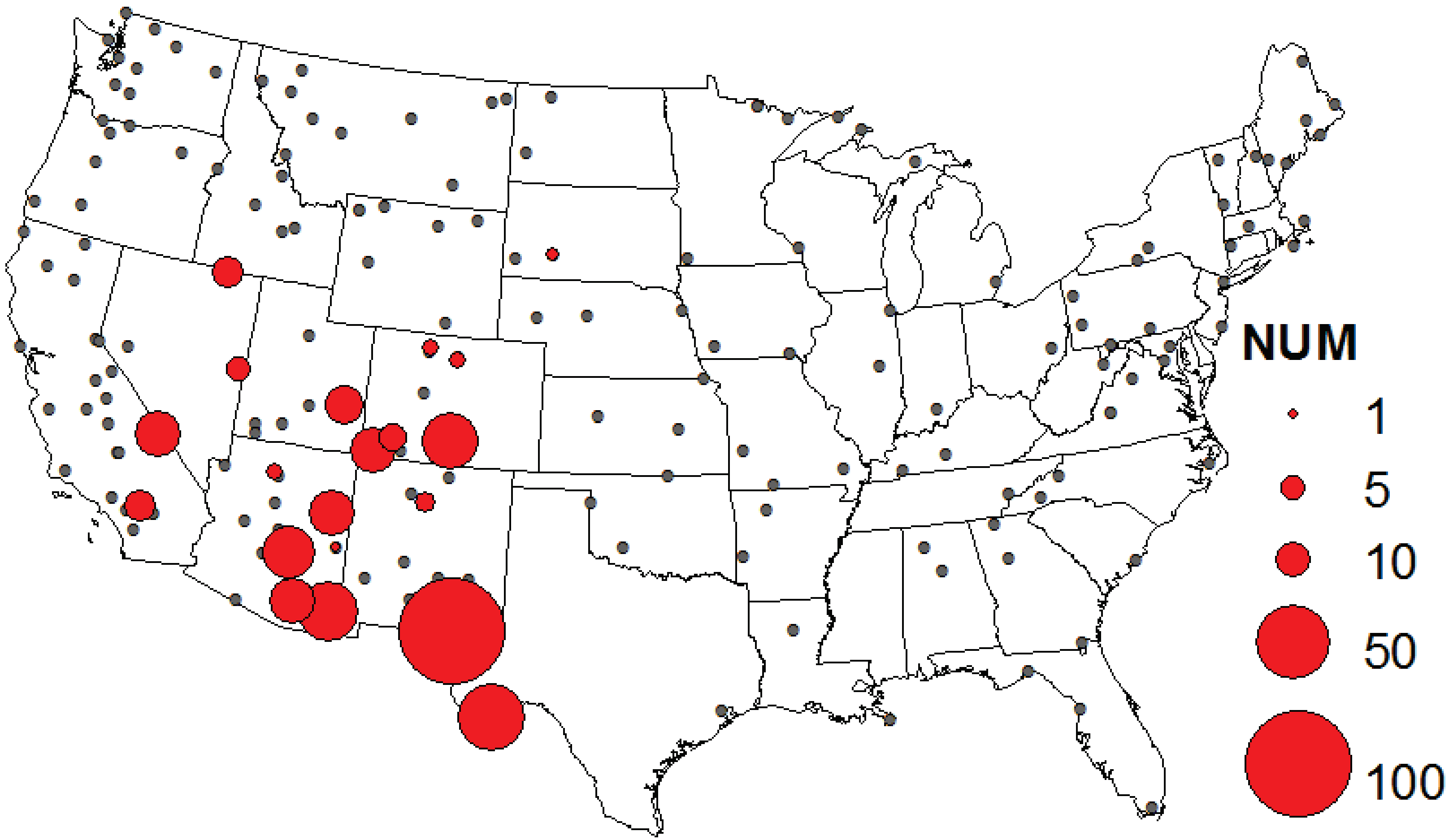






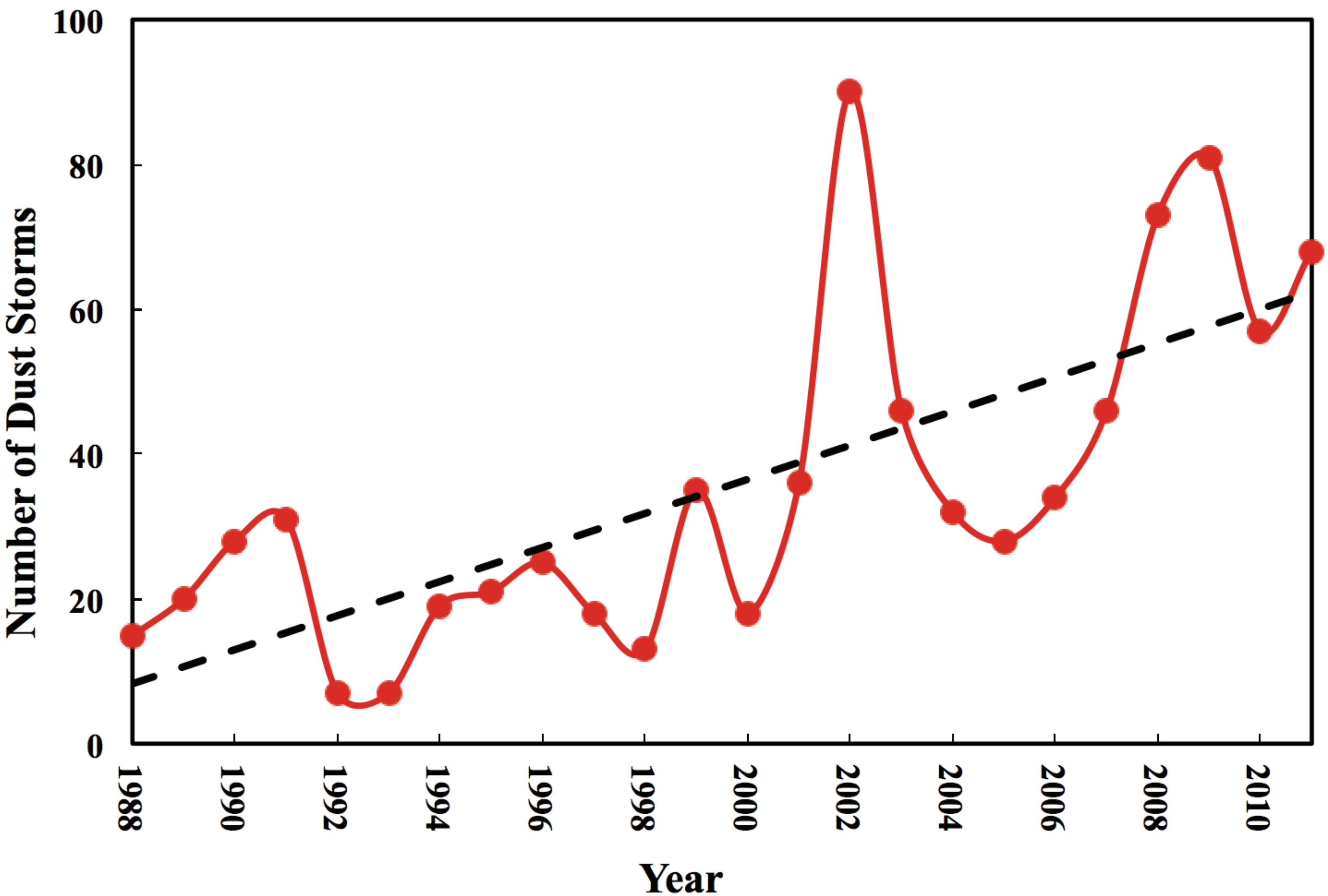
Cu– Copper
Pb – Lead
Zn – Zinc

Locations of Dust Storms



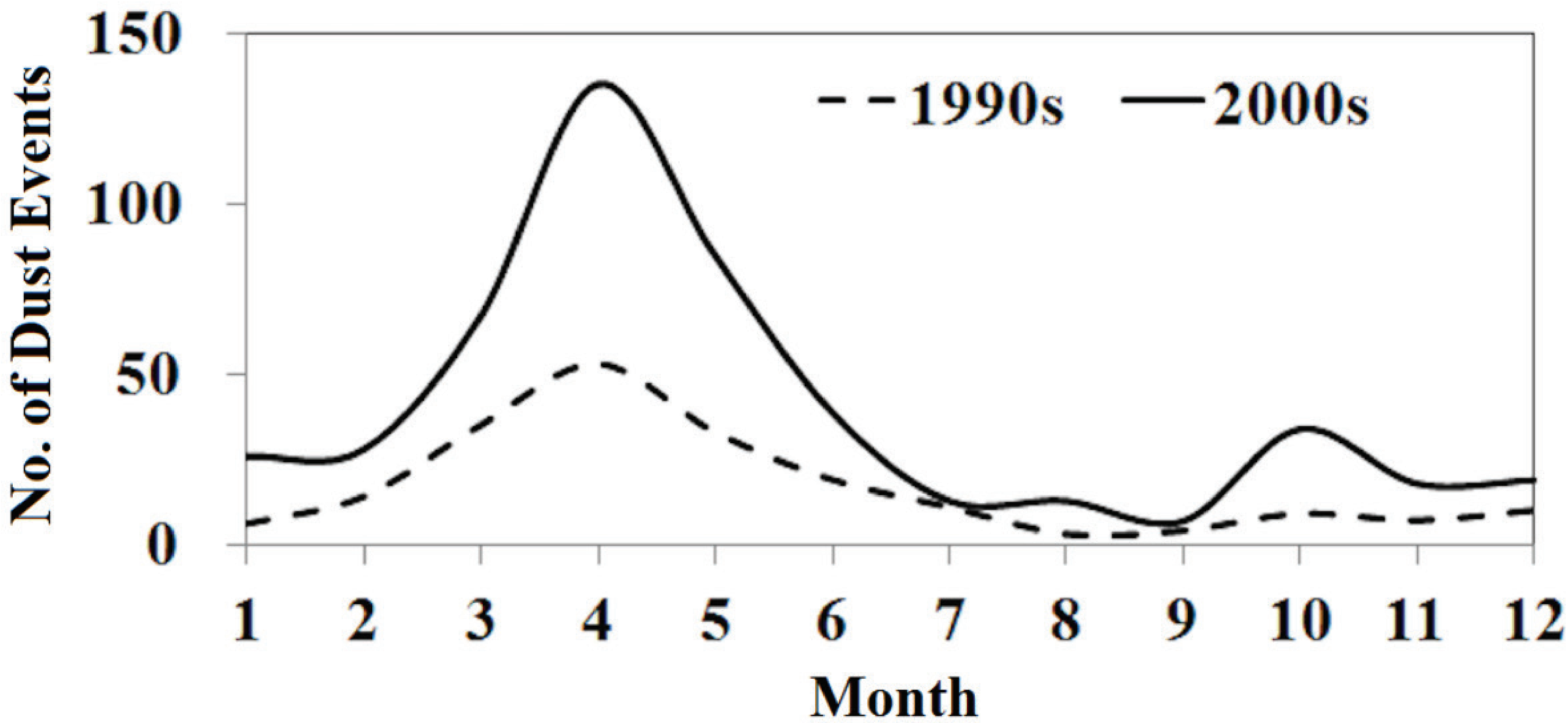
Dust storms detected at 29 sites with continuous data records.

Long-term Dust Trend



20 Giant Storms in 1990s → 48 Storms in 2000s;

Seasonal Variation

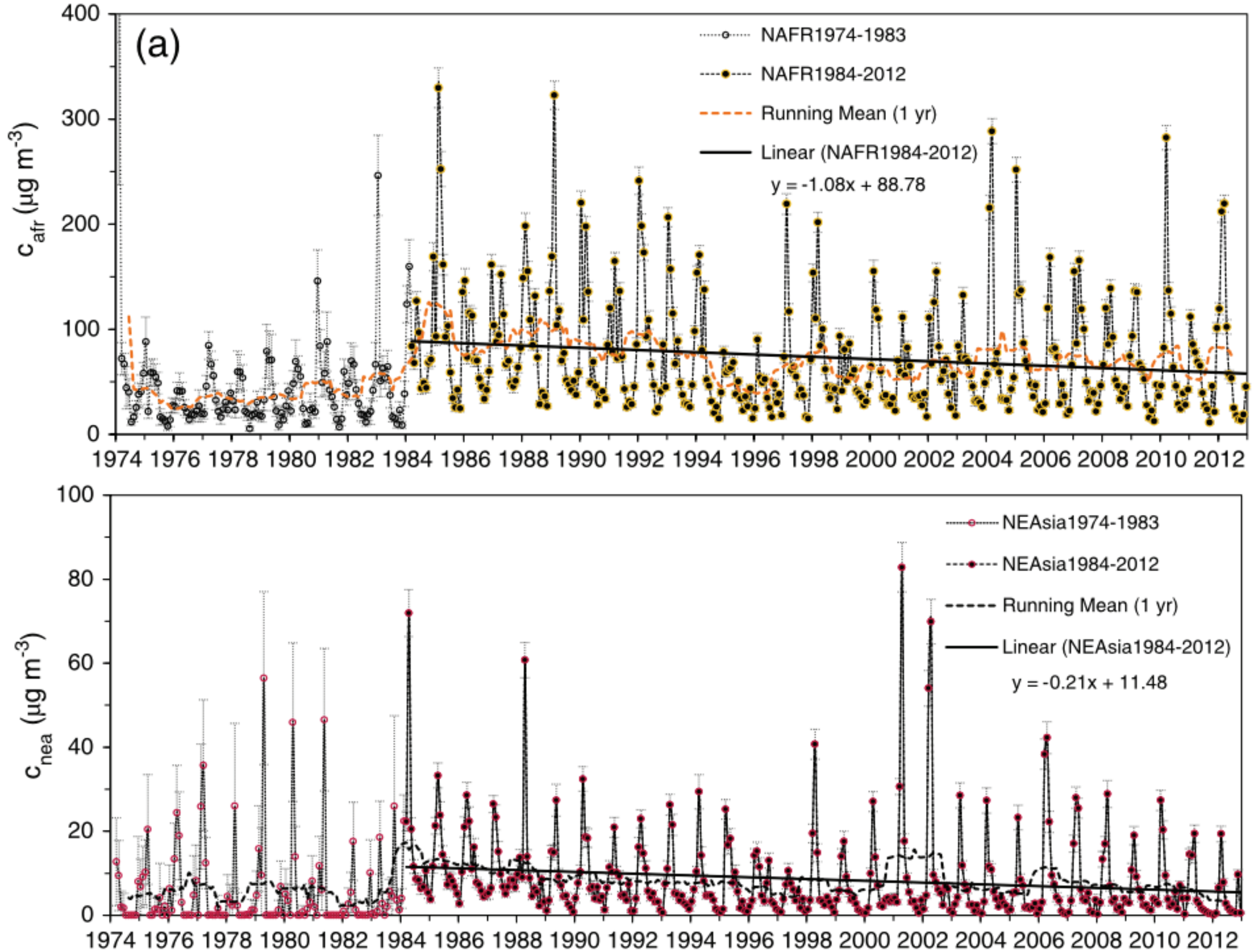


Increase in Spring (mostly) and Fall;

Almost no change in Summer/Wet Season;

Decreasing Dust Trends in Asia and Africa

(Shao et al., 2013)



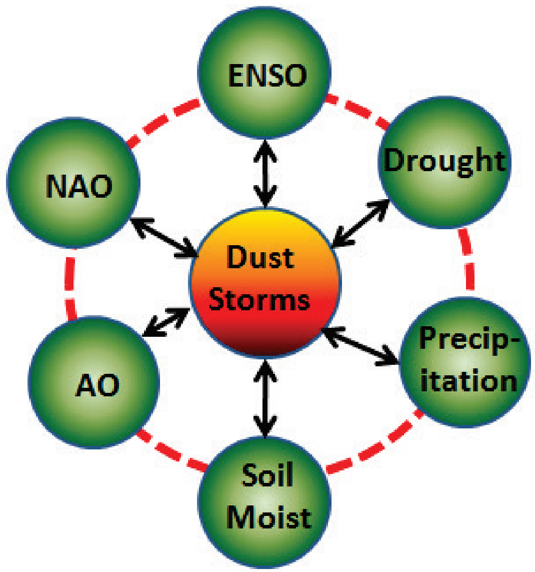
Northern Africa

Northern Asia

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

What Drives the Dust Trend?

(Contributed by Hang Lei)

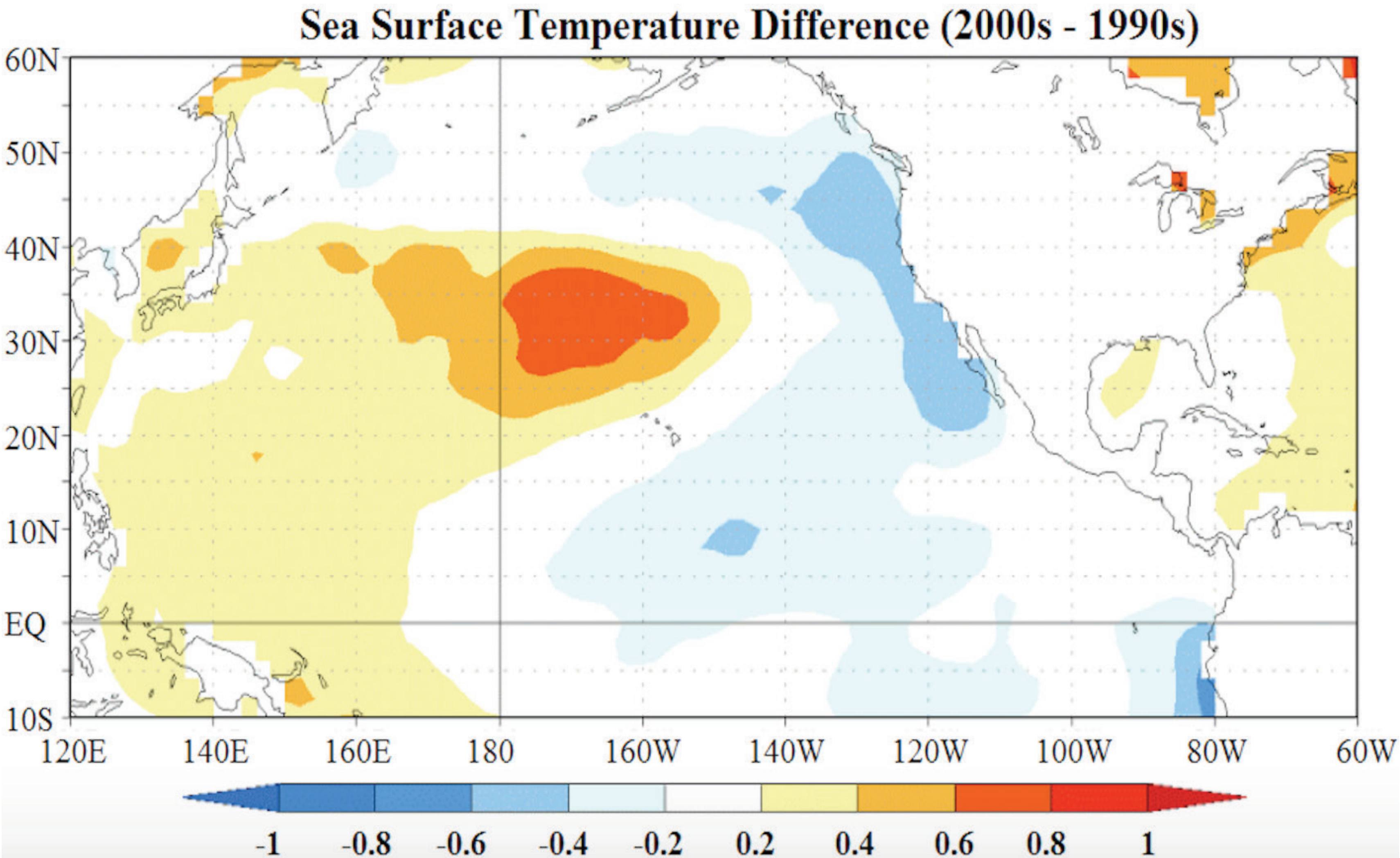


ENSO - El-Nino Southern Oscillation
PDO - Pacific Decadal Oscillation
NAO - North Atlantic Oscillation
PNA - Pacific/North American Oscillation
AO - Arctic Oscillation

	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

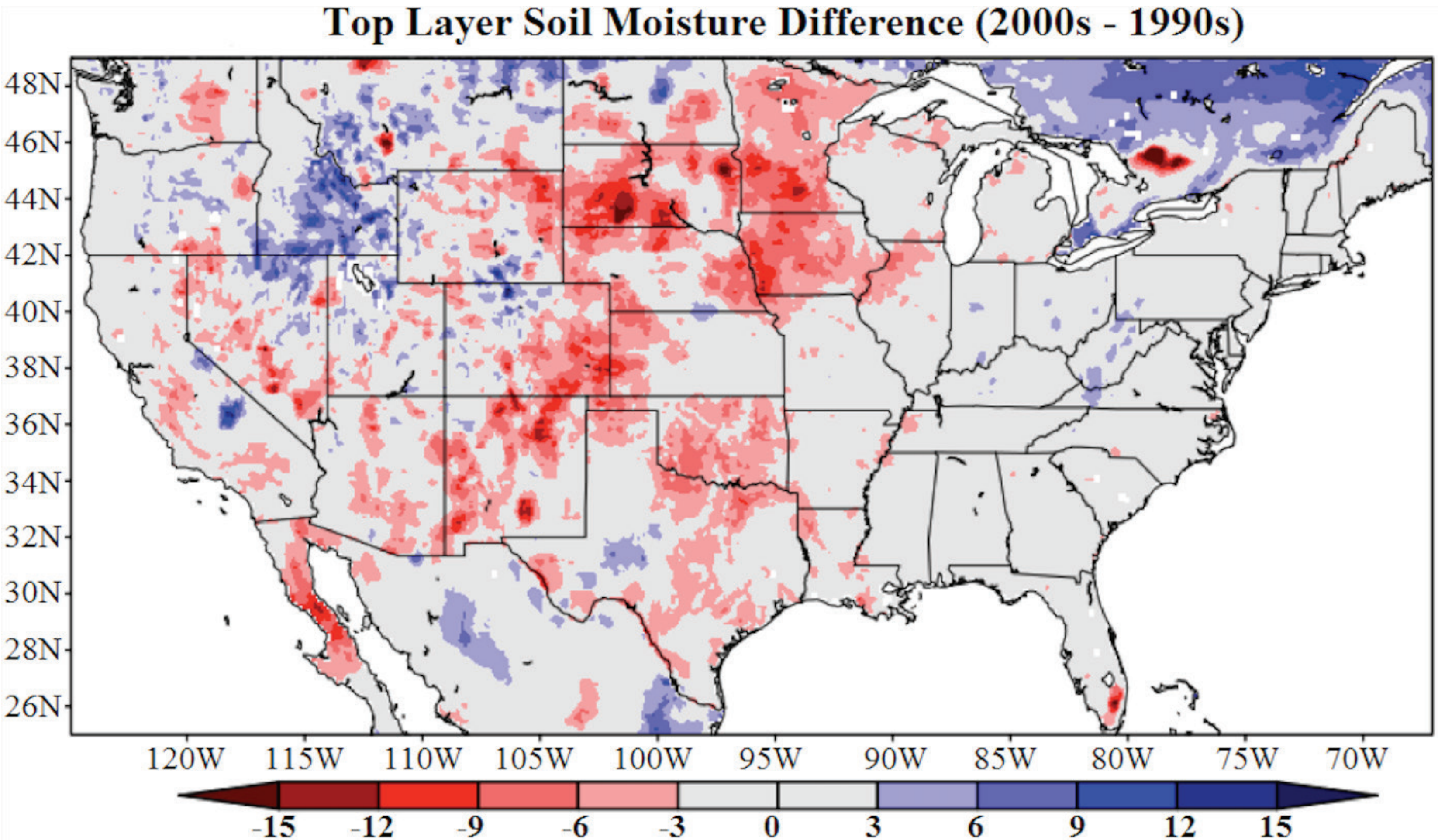
LL – Low Latitude North American deserts (Chihuahua, Mojave, and Sonoran);
HL – High Latitude Deserts (Great Basin and Colorado Plateau)

Changes in Sea Surface Temperature



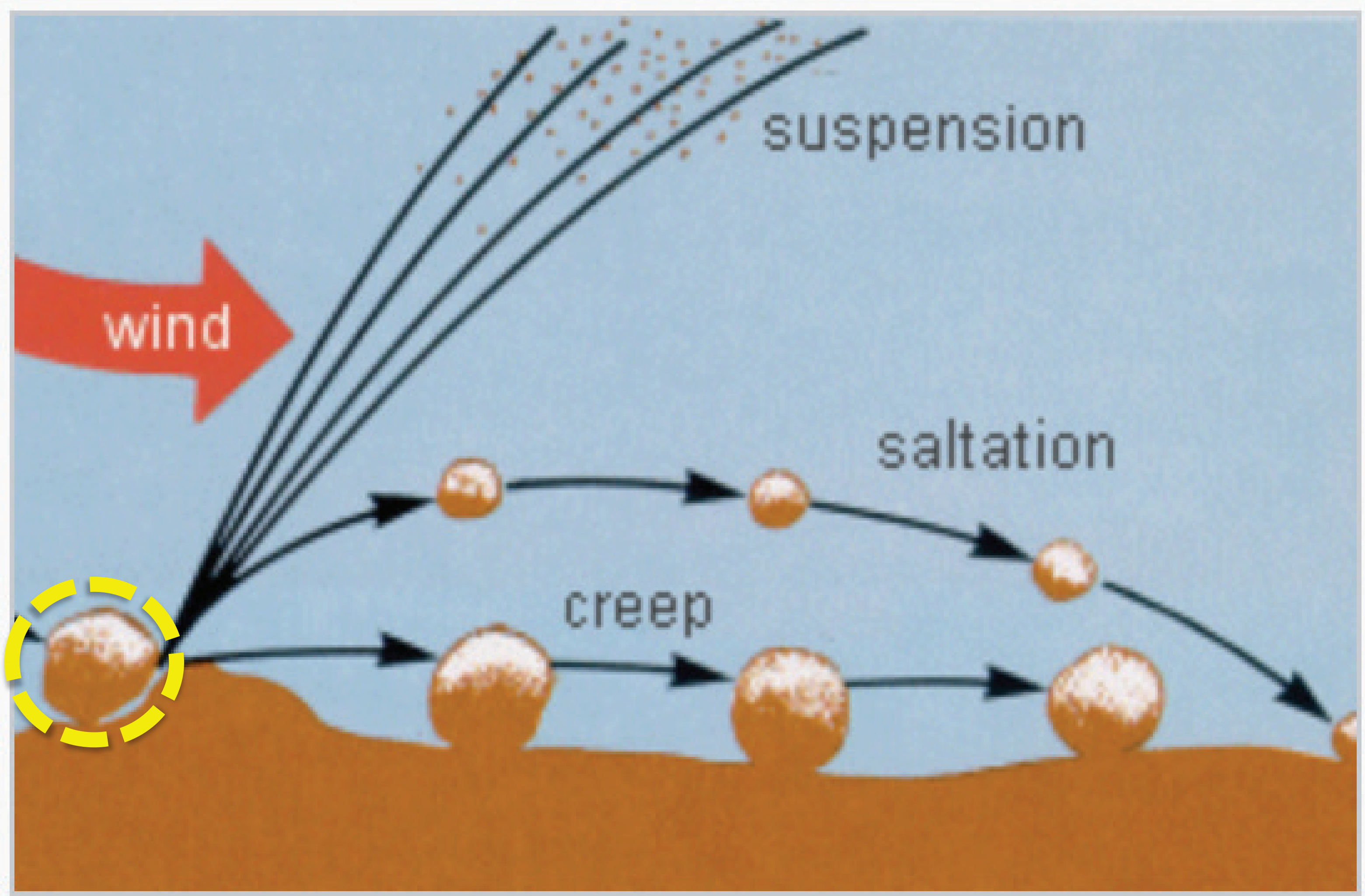
(Contributed by Julian Wang)

Changes in Soil Moisture



(Contributed by Julian Wang)

Physics of Dust Emission



Modeling Dust Emission

FENGSHA dust emission scheme: (*Tong et al. 2008*):

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

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

How does soil moisture affect dust emission?

Path 1: Vegetation cover partitions wind energy;

Path 2: Moist increases cohesive binding (Fecan et al., 1999);

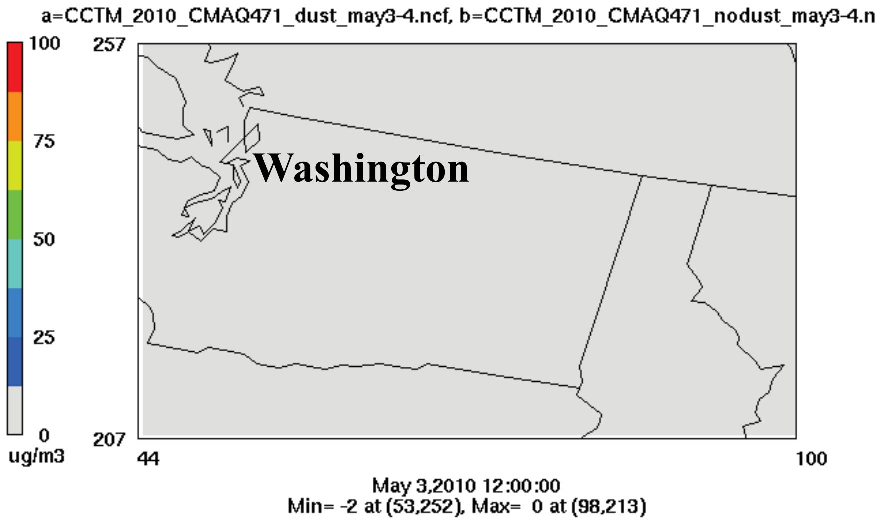
$$u_{*t} = u_{*t} \; x \; f_m$$

$$f_m = (1.0 + 1.21 * (s_m - w')^{0.68})^{0.5}$$

Soil Moisture | Saturation point

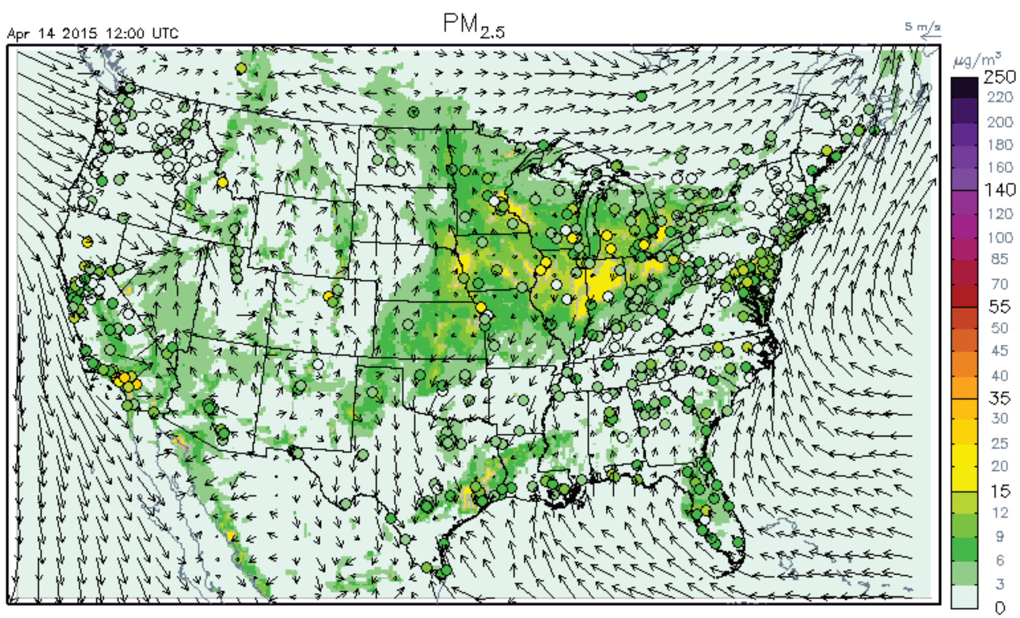
NOAA Dust Forecasting (CMAQ)

Dust PM2.5 on May 3,2010



12:30 p.m, May 3,2010

--http://earthobservatory.nasa.gov/NaturalHazards



Dust storm in UT/NV

(Courtesy of Hyuncheol Kim)

Summary

◆ **The frequency of dust storms more than doubled from 1990s to 2000s in the Southwest United States.**

◆ **The dust trend is likely driven by large-scale variations of sea surface temperature in the Pacific Ocean.**

- **Further information:**

Tong et al., Atmospheric Chemistry & Physics, 2012;

Tong et al., Geophysical Research Letter, 2017;

Acknowledgment & Data Access

- Funding Support: NASA ROSES and NOAA USWRP;
- Data: EPA, NOAA, NASA;
- Many colleagues for inspiring discussion.

- Data Access: Email qtong@gmu.edu
- Project Website: http://ws.laits.gmu.edu/nca