15 Years' Application of NASA MODIS Imagery to Detection and Impact Assessment of Dust Storms in the Southwest USA

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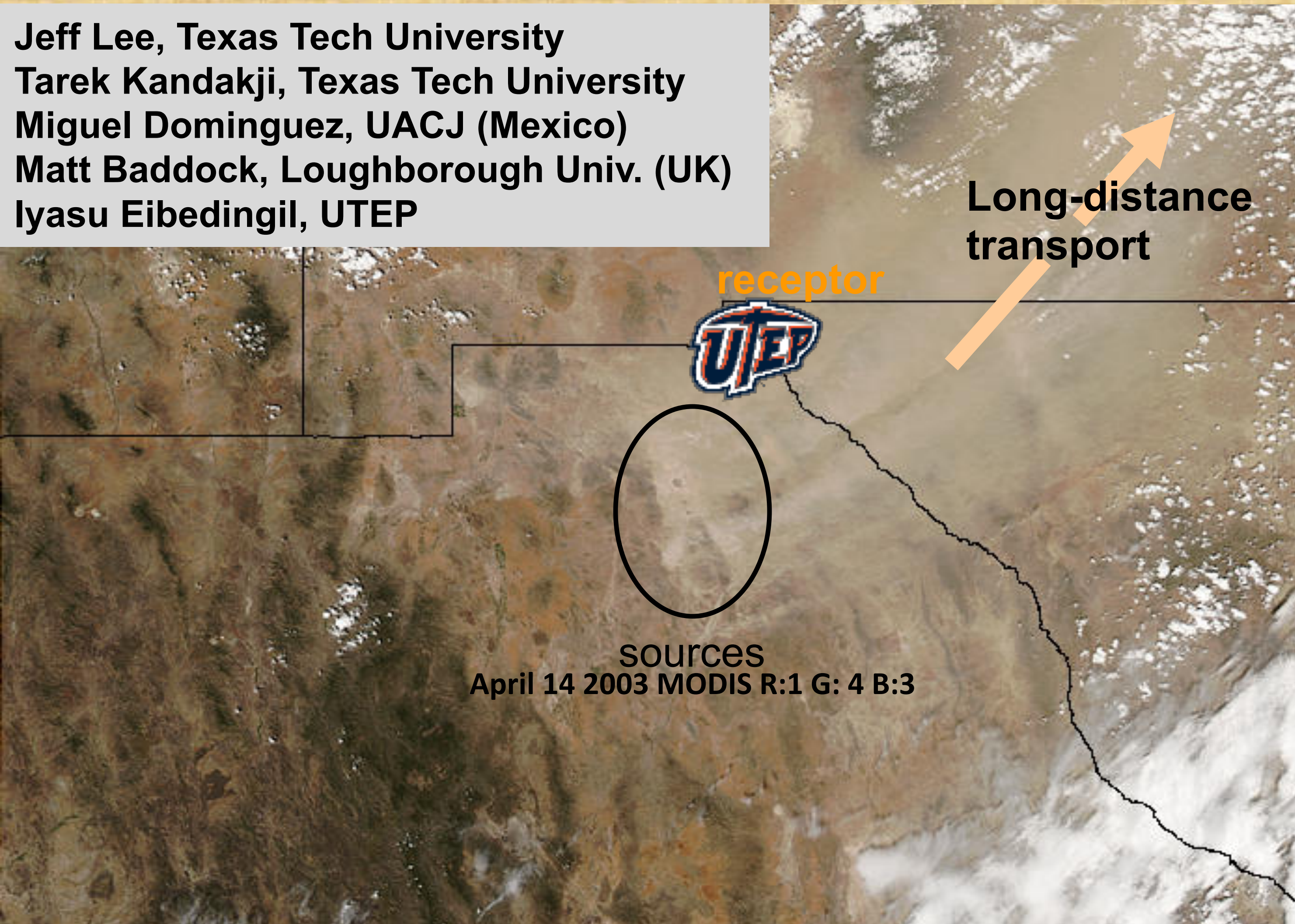


April 14 2003 MODIS R:1 G: 4 B:3

Phoenix, AZ 1/4/2019

HAQAST

MODIS- the MODerate-resolution Imaging Spectroradiometer

A key remote sensing instrument on board NASA's Terra and Aqua satellites which has revolutionized our understanding of many Earth system processes, including dust storms, since 2001.

Downloadable NRT data related to Dust Storms

MODIS / Aqua

Product (HTTPS Download)	Description	Volume (GB/day)		Comments
MYD04_L2	10.5067/MODIS/MYD04_L2.NRT.061 L2 Aerosol, 5-min Swath 10km	0.16	L2 Aerosol Browse	N/A
MYD09GA	L2G Light Surface Reflectance – Daily 500m and 1km	17.37	L2G Surface Reflectance Browse	Bands 1-4-3 & 7-2-1
MYD09GQ	L2G Light Surface Reflectance – Daily 250m	18.82	L2G Surface Reflectance Browse	Bands 1-4-3 & 7-2-1
MYD09GHK	L2G Surface Reflectance – Daily 500m	18.27	N/A	Bands 1-4-3 & 7-2-1
MYD09GQK	L2G Surface Reflectance - Daily 250m	25.48	N/A	Bands 1-4-3 & 7-2-1
MYDAODHD	10.5067/MODIS/MYDAODHD.NRT.061 L3 Value-added Aerosol Optical Depth	0.001	N/A	N/A

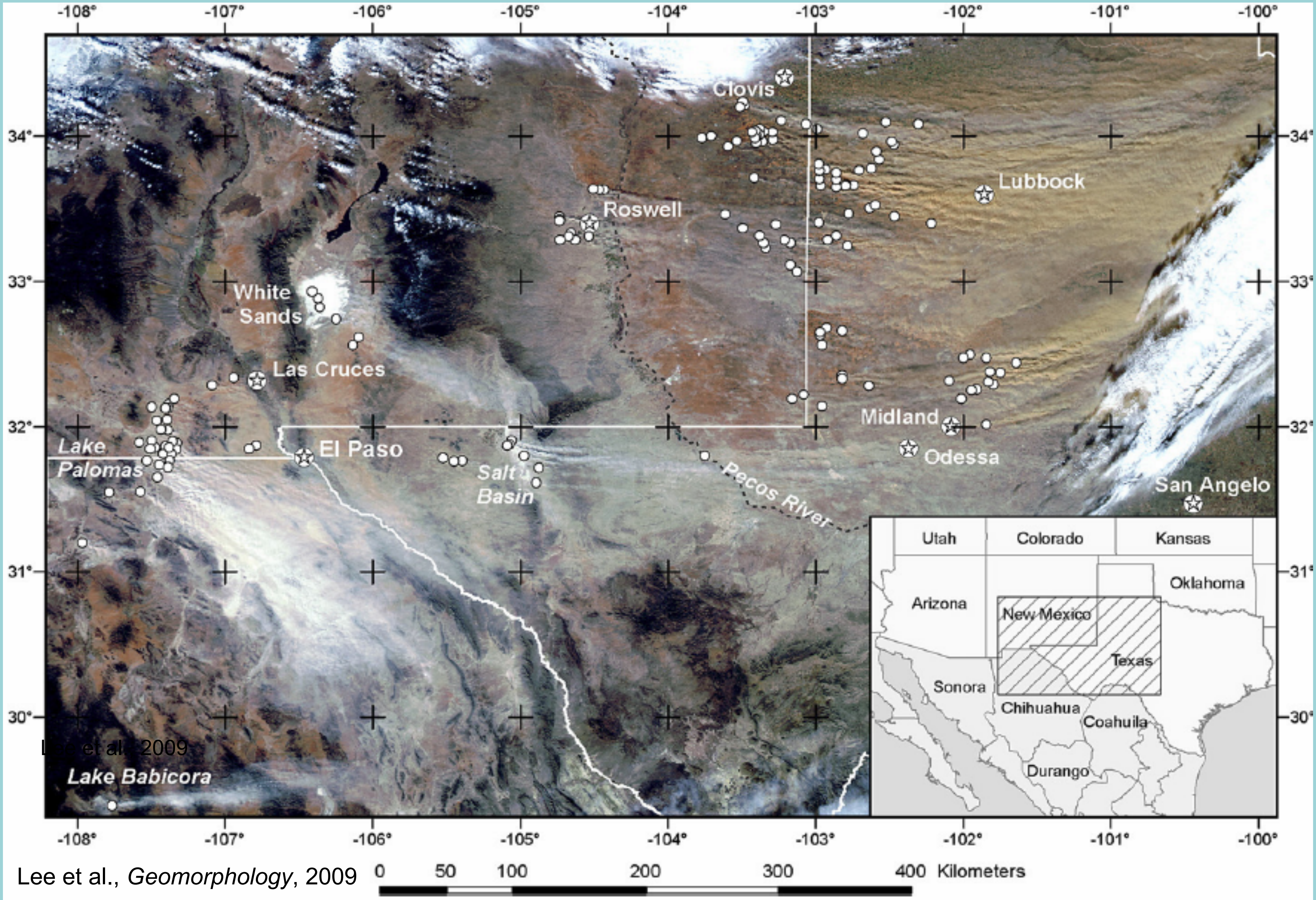
December 15, 2003: Dust storm turned the sky brown (or white or grey) over much of west Texas.

Texas Tech University, Lubbock

Typical day

December 15, 2003

First major case study: event of 15 Dec. 2003, ~150 discrete point sources of dust were identified on a single true-color NASA MODIS satellite image. Many of these individual point source locations were then visited in the field.

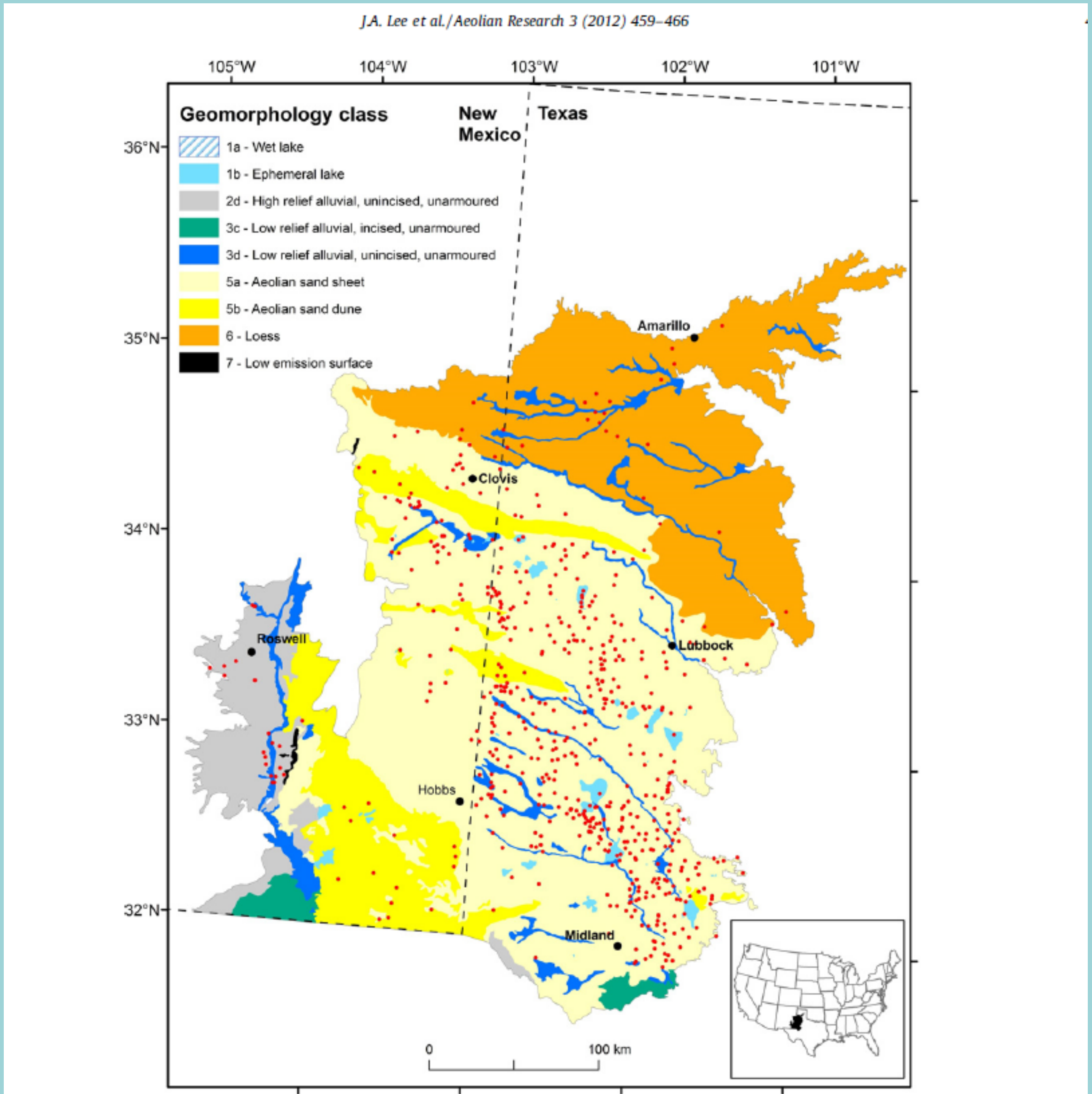


Lee et al., *Geomorphology*, 2009

By visiting satellite-detected dust point sources in the field, we can

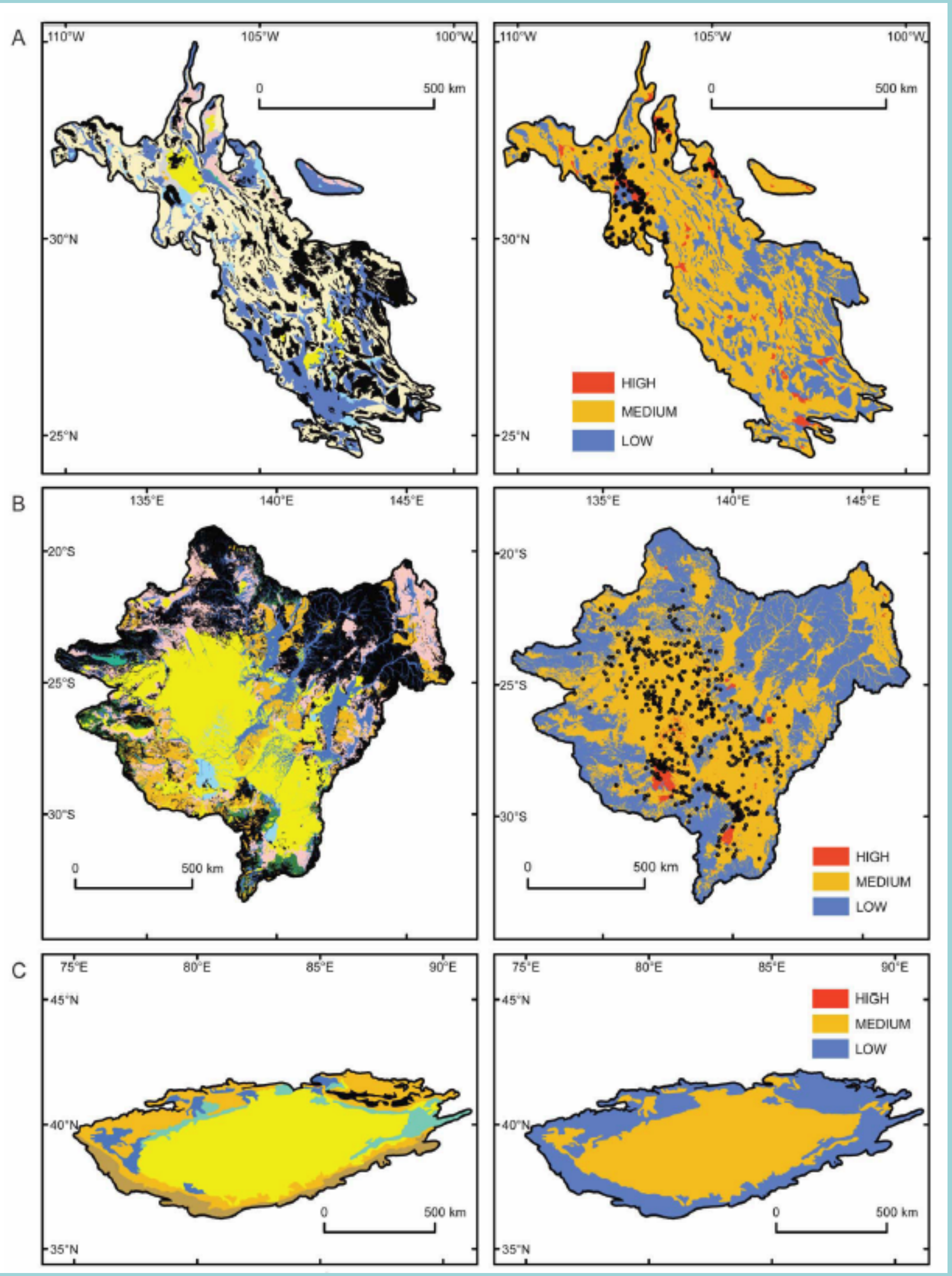
- **Determine what the land use and geomorphology is of actual dust source spots**
- **Learn how these characteristics may differ from other areas where dust didn't blow as much or wasn't evident on satellite**
- **Obtain soil samples to understand the physical and chemical characteristics of dust source materials for source apportionment and health effects studies**
- ***And, of course, get the vehicle stuck, so it qualifies as a traditional field geology project ☺***

By overlaying the MODIS- identified point sources with soil and land use data in a GIS, we can systematize these observations.



This was done not only in North America but throughout the world, ***creating <u>a global classification system of the land surface, based on dust emissions</u>***.

Bullard et al., *JGR- Earth Surface*, 2011

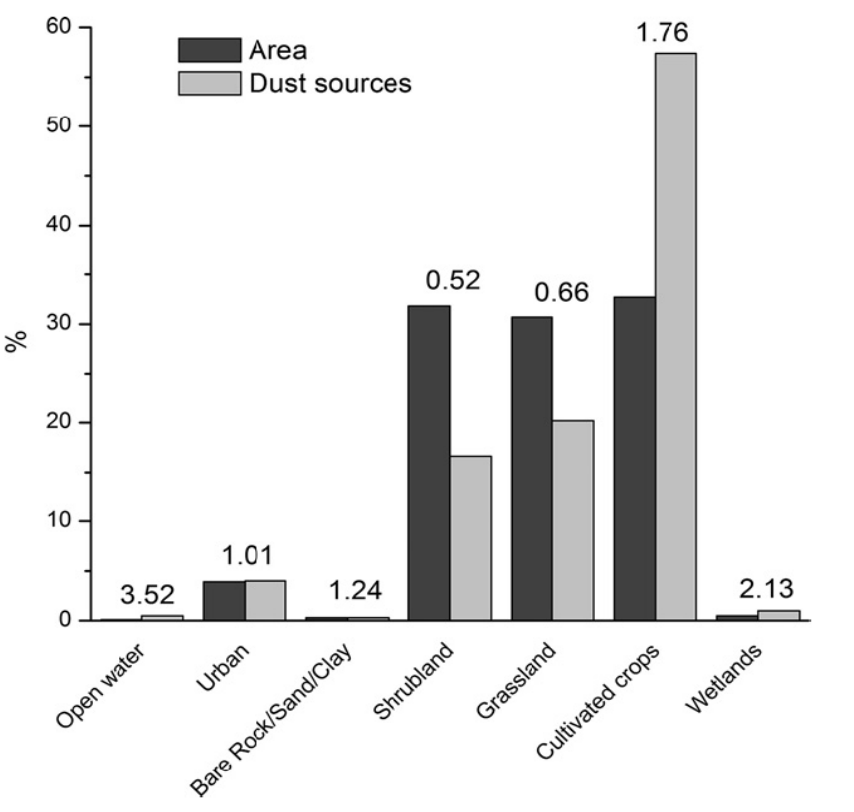


Chihuahuan Desert, N. America

Lake Eyre Basin, Australia

Takla Makan Desert, China

We can quantify the relative "dust plume intensity" of different land use and soil types.



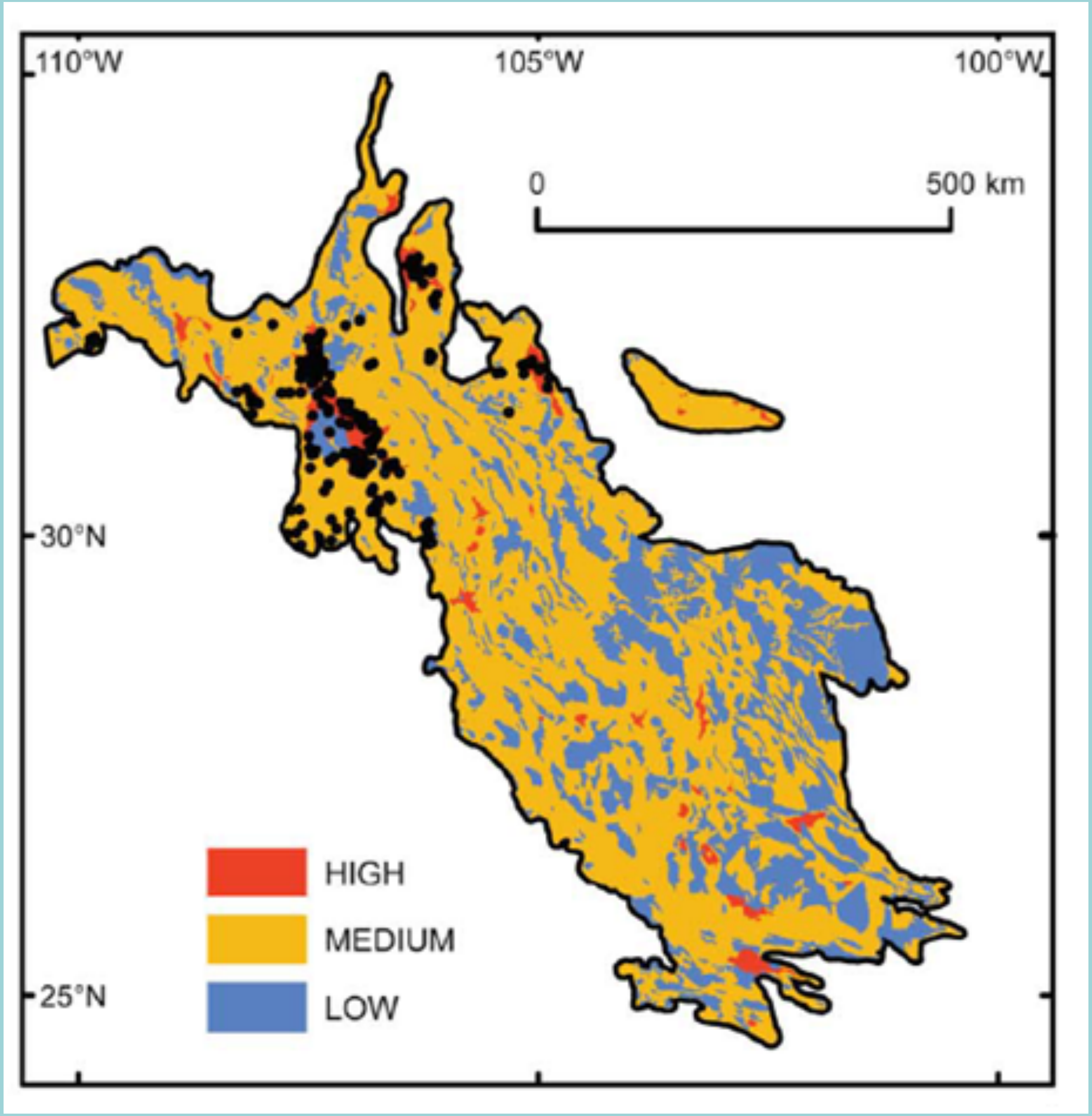
Relative emission of dust by land cover category. Number above bars is the Dust Emission Ratio, percent of dust sources divided by percent area.

Lee et al., *Aeolian Research*, 2012

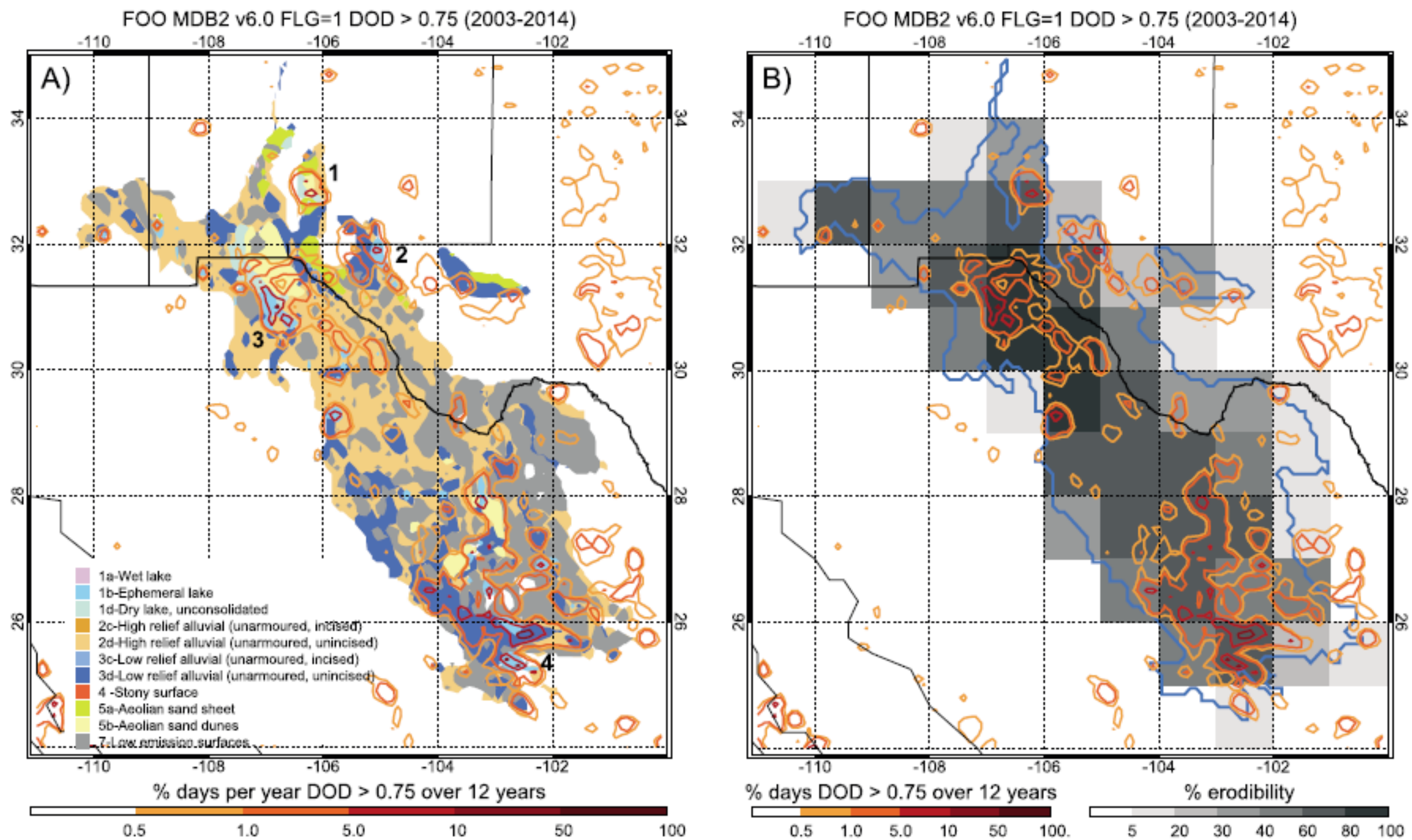
Main geomorphology class	Geomorphology sub-division	Code	Importance for dust emission	Area (km²)	Area (%)	% of dust plumes
Lakes	Wet	1a	Low	243	<0.1	0
	Ephemeral	1b	High-Med	8905	2.8	29.5
	Dry – consolidated	1c	Low	-	-	-
	Dry – non consolidated	1d	High-Med	3564	1.1	18.4
High Relief alluvial systems	Armoured, incised	2a	Low	-	-	-
	Armoured, unincised	2b	Low	-	-	-
	Unarmoured, incised	2c	Medium	32	<0.1	0
	Unarmoured, unincised	2d	Med-High	138728	43.0	20.7
Low Relief alluvial systems	Armoured – incised	3a	Low	-	-	-
	Armoured - unincised	3b	Medium	-	-	-
	Unarmoured – incised	3c	Low	436	0.1	0
	Unarmoured– unincised	3d	Medium	64683	20.1	12.0
	Stony surfaces	4	Low	141	<0.1	0.5
Aeolian systems	Sand Sheet	5a	Low-Med	7178	2.2	1.8
	Aeolian sand dunes	5b	Low-High	9450	2.9	13.8
	Loess	6	Low-Med	-	-	-
	Low emission surfaces	7	Low	89090	27.6	3.2

Baddock et al., *Journal of Maps*, 2011

That allows us to map out regions of high, medium, and low dust emission propensity over large areas of the landscape.



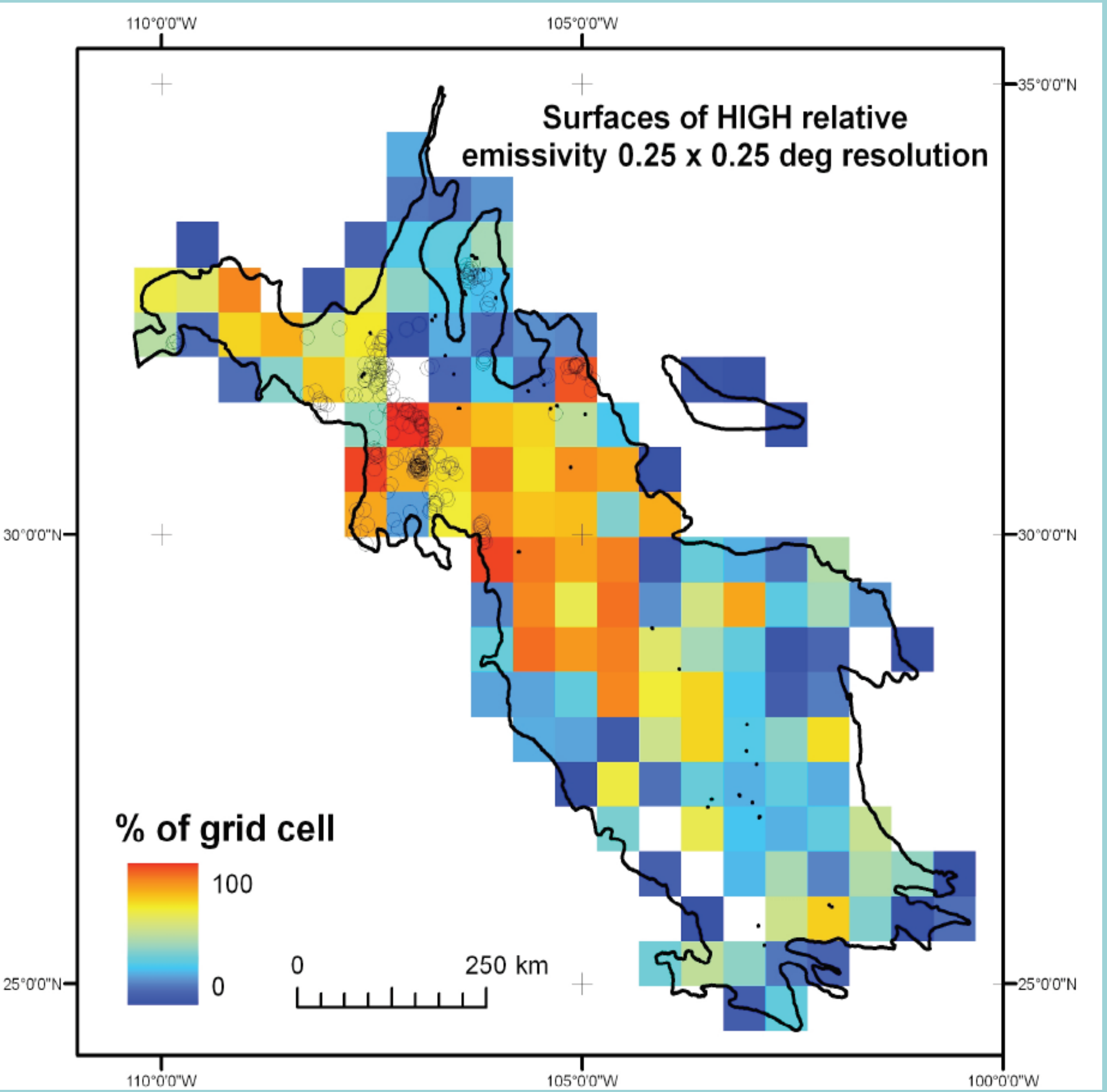
These maps of ground-based dust emissivity can be geospatially cross-checked against other MODIS products such as optical depth.



(a) Distribution of FoO (% days 2003–2014) for DOD > 0.75 over PDS classes for Chihuahuan Desert. (b) Same FoO distribution over 1 × 1° cells showing percentage of cell with geomorphology classed as medium- or high-emission potential by *Bullard et al.* [2011]. Numbers 1–4 indicate dust hot spots in text.

Baddock et al., *GRL*, 2016

This creates the ability for these products to *serve as input and initialization parameters to earth system models*, such as meteorological models used for forecasting of wind storms, and thus improve prediction of dust events.



Much more; geospatial relationships of the locations of dust plumes to drought intensity (also see Kandakji et al. poster)

Exploring the Relationship between Temporal and Spatial Dynamics of Drought Intensity and Dust Storm Point Sources in New Mexico, Texas, and Oklahoma

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1. Abstract

Drought is a deficiency in precipitation over an extended period, usually a season or more, resulting in a water shortage causing adverse impacts on vegetation, animals, and/or people [1]. Excessive drought can also lead to an increase in sand and dust storms [2]. The Southern Great Plains and Chihuahuan Desert regions, the former primarily cropland and the latter primarily rangeland, are some of the most dust-storm-prone areas of the United States. Dust events in these regions are assumed to be magnified by drought. Our project relates the temporal and spatial effects of drought (utilizing United States Drought Monitor data) to comprehensive dataset of dust storm initiation points since 2001 in New Mexico, Texas, and Oklahoma.
Results indicate that dust points in the Chihuahuan Desert are mostly highly concentrated in areas of severe to extreme drought, while those in the Southern Great Plains span a wider range of drought conditions. There were an increased number of dust events in those areas which were experiencing or recovering from severe to exceptional drought conditions, especially in the southwestern Southern High Plains west and south of Lubbock, a region dominated by non-irrigated cropland. The effects of drought intensity on dust sources were seen more at large time scales (2 -5 years), especially in the Plains: at the shortest time scale (0 -1 years), drought has a weaker association with the locations of dust storm initiation points. Increasing the spatial size of buffer distance around the dust points skews toward stronger drought conditions in the desert, but weaker drought conditions in the plains.

2. Data & Methods

2.1. Data

2.1.1. United States Drought Monitor (USDM): National Drought Mitigation Center – University of Nebraska-Lincoln .
Spatial resolution: 0.1° x 0.1° (after processing), Temporal resolution: weekly, Spatial Coverage: -110° to -93° longitude and +25° to +38° latitude (after processing), and Temporal Coverage: Jan. 04, 2000 to Apr. 11, 2017 (Figure 1).

2.1.2. Dust storm source points: these points were previously identified by Prof. Jeff Lee's and Prof. Thomas Gill's research groups using MOD09 and MOD021km products of MODIS sensor. Spatial Coverage: New Mexico, Texas, and Oklahoma (after processing) , and Temporal Coverage: from 2001 to 2014 (Figure 2).

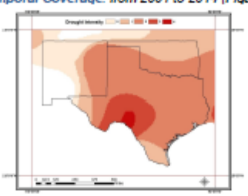


Figure 1

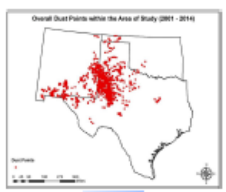


Figure 2

2.2. Methods

2.2.1. Comparison of Areal Graph of Drought Intensity to Frequency Distribution of Dust Points: *comparison of the areal graph monthly drought intensities and the monthly and yearly frequency distribution of dust points by classifying the dust points into their respective states.*

2.2.2. Buffer Zone Analysis of Drought Intensity around the Dust Points: *to obtain drought history for each of the dust source points, we identified the nearest drought data pixel to the dust points using the Euclidean distance method, and obtained drought intensity at the time of the dust event as well as averages for 1-, 2-, and 5- years prior at the dust points and in regions of 30, 60, and 60 km radius around the dust points.*

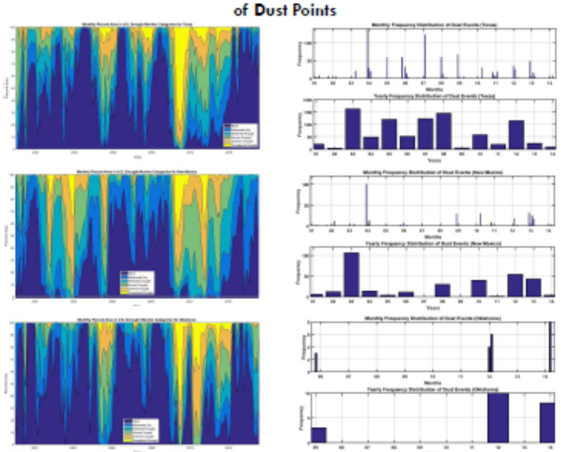
$$\text{Distance} = \sqrt{(\text{Long}_{DP} - \text{Long}_{USDM})^2 + (\text{Lat}_{DP} - \text{Lat}_{USDM})^2}$$

2.2.3. Application of Scatter Diagram and Frequency Distributions: *the scatter diagram and frequency distributions are prepared between different combinations of spatial and temporal dust point drought intensities in order to explore the relationship between both of the data.*

2.2.4. Two-Sample Kolmogorov-Smirnov Hypothesis Test: *this statistical hypothesis test approach from Matlab package is applied to compare the distributions of different combinations of spatial and temporal scenarios within Chihuahuan Desert, Southern High Plains, and between Chihuahuan Desert and Southern High Plains.*

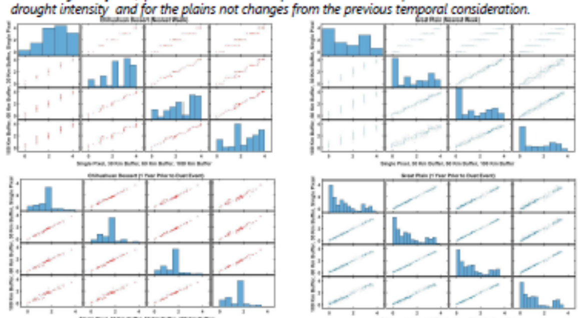
3. Discussion & Results

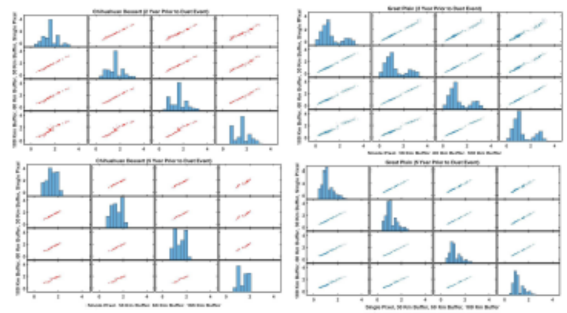
3.1. Comparison of Areal Graph of Drought Intensity to Frequency Distribution of Dust Points



3.2. Buffer Zone Analysis of Drought Intensity around the Dust Points

- *For the **nearest week**, the desert exhibited the drought intensity of 3 and 4 for the buffer distance from 0 to 60 km. For plains, going from 0 to 100 km leads to the skewness of the frequency distribution to further to the left.*
- *In the **1 year prior** to the dust events, the desert experienced a drought intensity of around 1.9 irrespective of different spatial scenarios. The plains, similar to the previous temporal extent consideration, the distribution is totally skewed to the left.*
- *For the **2 years prior**, in the desert most of the dust points are associated with the drought intensity of 1.9 irrespective of different spatial coverages. For the plains, the high density of dust points is shifted from around 0.1 to around 1.6.*
- *In the **5 years prior**, for the desert the dust points are extended from around 0.6 to around 2.2 drought intensity and for the plains not changes from the previous temporal consideration.*





3.4. Two-Sample Kolmogorov-Smirnov Hypothesis Test

H Value (Between different combinations of distributions at different spatial scenarios)					
Dust Point Classification	Combination	Single Pixel	30 Km Buffer	60 Km Buffer	100 Km Buffer
Chihuahuan Desert	Nearest Week – 1 Year Prior	1	1	1	1
	Nearest Week – 2 Year Prior	1	1	1	1
	Nearest Week – 5 Year Prior	1	1	1	1
	1 Year Prior – 2 Year Prior	1	1	1	1
	1 Year Prior – 5 Year Prior	1	1	1	1
	2 Year Prior – 5 Year Prior	1	1	1	1
Southern High Plains	Nearest Week – 1 Year Prior	1	1	1	1
	Nearest Week – 2 Year Prior	1	1	1	1
	Nearest Week – 5 Year Prior	1	1	1	1
	1 Year Prior – 2 Year Prior	1	1	1	1
	1 Year Prior – 5 Year Prior	1	1	1	1
	2 Year Prior – 5 Year Prior	1	1	1	1

H Value (Between different combinations of distributions at different temporal scenarios)					
Dust Point Classification	Combination	Nearest Week	1 Year Prior	2 Year Prior	5 Year Prior
Chihuahuan Desert	Single Pixel – 30 Km Buffer	0	0	0	0
	Single Pixel – 60 Km Buffer	1	1	0	0
	Single Pixel – 100 Km Buffer	1	1	0	1
	30 Km Buffer – 60 Km Buffer	0	0	0	0
	30 Km Buffer – 100 Km Buffer	1	1	0	0
	60 Km Buffer – 100 Km Buffer	1	1	0	0
Southern High Plains	Single Pixel – 30 Km Buffer	1	0	0	0
	Single Pixel – 60 Km Buffer	1	0	0	0
	Single Pixel – 100 Km Buffer	1	1	1	1
	30 Km Buffer – 60 Km Buffer	0	0	0	0
	30 Km Buffer – 100 Km Buffer	1	1	0	1
	60 Km Buffer – 100 Km Buffer	0	0	0	0

Spatial Condition	Combination: Chihuahuan Desert	Combination: Southern High Plains	H Value	P Value
Single Pixel	Nearest Week	Nearest Week	1	[illegible]
	1 Year Prior	1 Year Prior	1	[illegible]
	2 Year Prior	2 Year Prior	1	[illegible]
	5 Year Prior	5 Year Prior	1	[illegible]
30 Km Buffer	Nearest Week	Nearest Week	1	[illegible]
	1 Year Prior	1 Year Prior	1	[illegible]
	2 Year Prior	2 Year Prior	1	[illegible]
	5 Year Prior	5 Year Prior	1	[illegible]
60 Km Buffer	Nearest Week	Nearest Week	1	[illegible]
	1 Year Prior	1 Year Prior	1	[illegible]
	2 Year Prior	2 Year Prior	1	[illegible]
	5 Year Prior	5 Year Prior	1	[illegible]
100 Km Buffer	Nearest Week	Nearest Week	1	[illegible]
	1 Year Prior	1 Year Prior	1	[illegible]
	2 Year Prior	2 Year Prior	1	[illegible]
	5 Year Prior	5 Year Prior	1	[illegible]

- *Effects of drought intensity seen more at large times scales (greater than 1 year, or 2 – 5 years)*
- *At the shortest time scale, drought has lesser effect on influencing position of dust storm source points.*
- *At every temporal and spatial scale, the drought intensities associated with Southern High Plains and Chihuahuan Desert dust points are significantly different.*

4. Conclusions & Future Developments

We investigated the temporal and spatial effects of drought using U.S. Drought Monitor data, to comprehensive dataset of dust storm initiation points since 2001 in New Mexico, Texas, and Oklahoma:

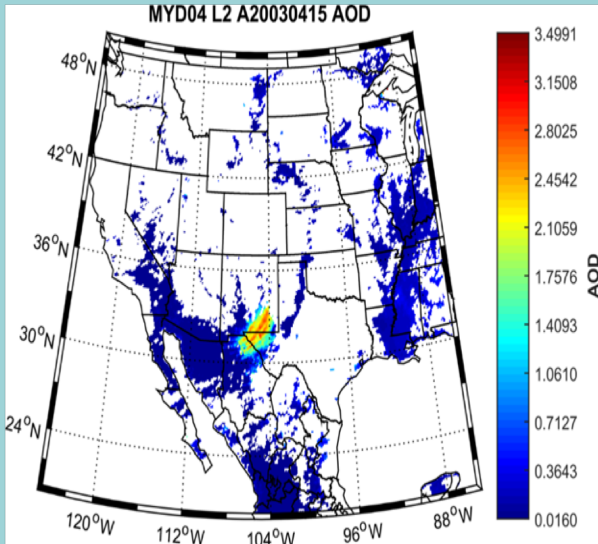
- *The dust points in Chihuahuan Desert are most highly concentrated in areas of severe to extreme drought, while those in the Southern Great Plains span a wider range of drought conditions.*
- *There were an increased number of dust events om those areas which were experiencing or recovering from severe to exceptional drought conditions, especially in the Southwestern Southern High Plains west and south of Lubbock, a region dominated by non-irrigated cropland.*
- *The effects of drought intensity on dust sources were seen more at large times scales (2 – 5 years), especially in the plains: at the shortest time scale (0 – 1 years), drought has a weaker association with the locations of dust storm initiation points.*
- *Increasing the spatial size of buffer distance around the dust points skews towards stronger drought conditions in the desert, but weaker drought conditions in the plans.*

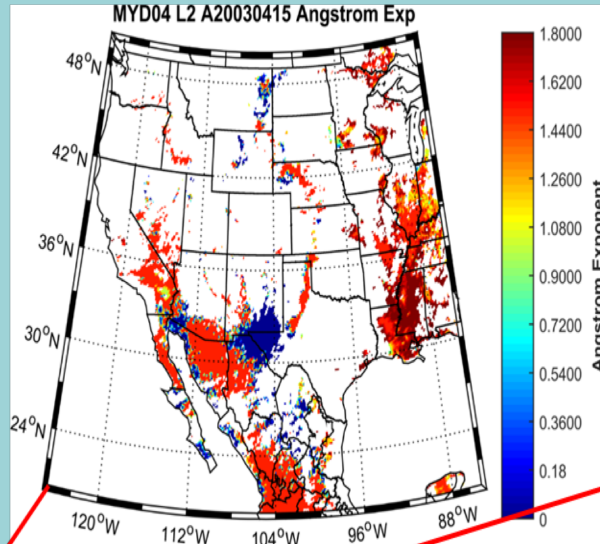
5. Bibliography

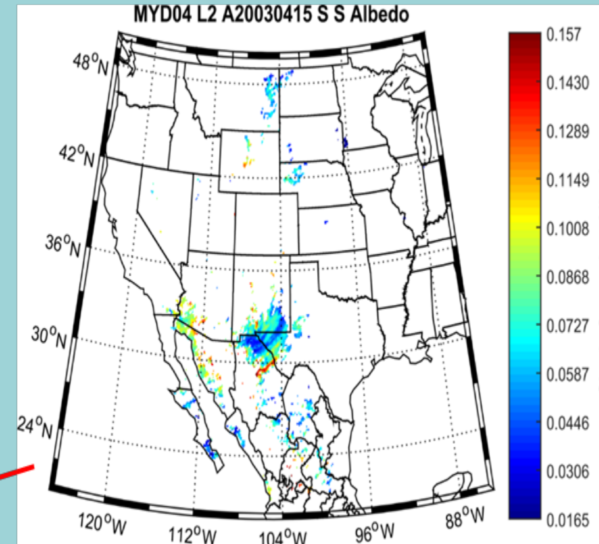
[1] National Drought Mitigation Center, "What is Drought?," 2017. [Online]. Available: http://drought.unl.edu/DroughtBasics/WhatisDrought.aspx. [Accessed: 07-Nov-2017].
[2] J. A. lee, M. C. Baddock, M. J. Mbuh, and T. E. Gill, "Geomorphic and land cover characteristics of aeolian dust sources in West Texas and eastern New Mexico, USA," Aeolian Res., vol. 3, no. 4, pp. 459-466, Jan. 2012.

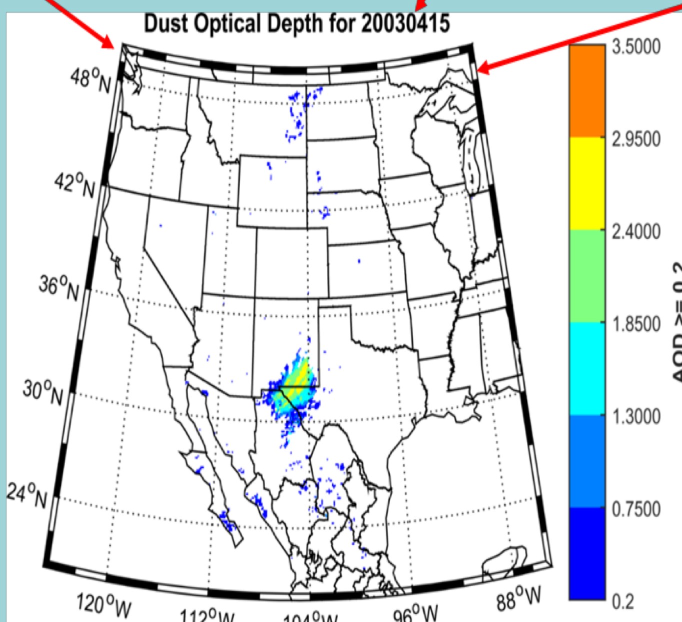
Acknowledgment: The authors acknowledge the project's funding from the U.S. Department of Transportation – Southern Plains Transportation Center.

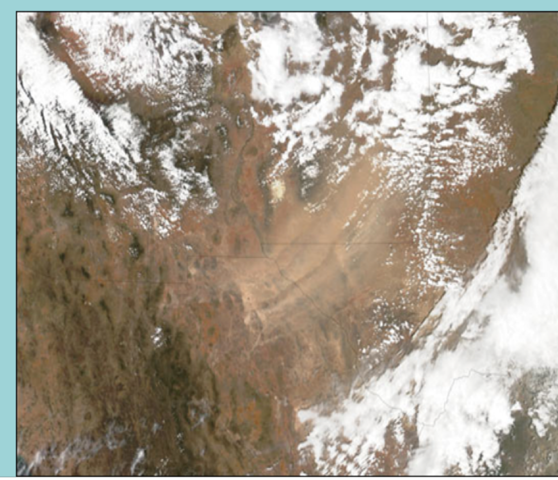
Relating MODIS- Based Dust Optical Depth to data from ground based air quality monitoring networks











Acquired April 15, 2003download large image (2 MB, JPEG, 4400x3400)

On Wednesday, April 15, 2003, strong winds blew dust from northern Mexico up into the United States, affecting Texas and New Mexico. In New Mexico at least two people were killed when blowing dust reduced visibility and caused a multiple car accident. This true-color Moderate Resolution Imaging Spectroradiometer (MODIS) of the storm was captured by the Aqua satellite, and it shows the blowing dust centered in the image.

AMS: Next Tuesday morning at 9:30

AMS American Meteorological Society 99th ANNUAL MEETING PHOENIX | 6-10 January 2019

Paper #4.5A

Estimation of Ground-Level Fine Particulate Matter using Remotely Sensed Data Augmenting Air Quality Monitoring Network Data in the Western United States

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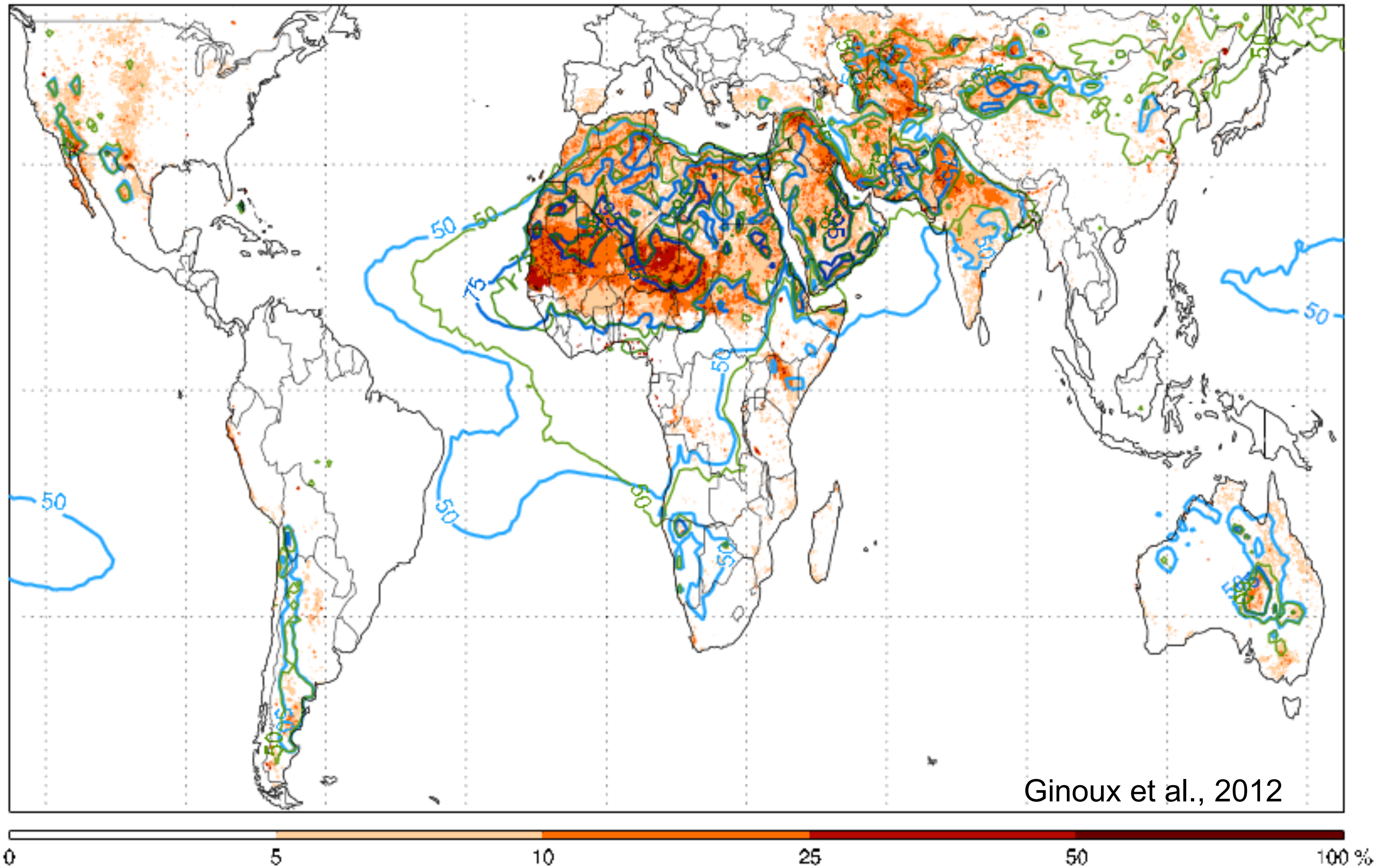
January 08, 2019

This is only scratching the surface of what has been done… thanks MODIS and NASA!

- Thanks to many other colleagues, collaborators and students.
- Support for this work has come from multiple NASA grants through ROSES, as well as grants from the US EPA, State of Texas, NOAA, and other agencies.



Global frequency of dust derived from MODIS Deep Blue product