Combat Outpost Tangi in the Tangi Valley, Afghanistan, Aug. 31, 2009. (Staff Sgt. Teddy Wade/DoD)

Source-Differentiated Air Quality System to Safeguard the Respiratory Health of US Military Personnel Deployed in Southwest Asia, Djibouti, and Afghanistan

Meredith Franklin
University of Southern California

NASA HAQ Applications Program

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Team

University of Southern California

- Ken Chau
- Ryan Lue

Harvard School of Public Health

- Petros Koutrakis (co-I)
- Jing Li
- Joel Schwartz

Veterans Affairs

- Eric Garshick (co-I)

Jet Propulsion Laboratory

- Olga Kalashnikova (co-I)
- Dave Diner

Airborne Exposures During Deployment

- Desert dust and sand:
  - Afghanistan, Iraq, Kuwait include desert regions
  - Dust storms 50-100 days/year in Iraq, spring and summer
  - Sand carries fungal spores, plant/grass pollens
- Combustion sources:
  - Poorly controlled emissions from motor vehicles (old diesel), unregulated industrial sources
  - Burn Pits:
    - Open-air waste burning was the primary means of solid-waste management
    - At large bases ran continually - visible smoke

Camp Bastion, Afghanistan, 2014

Logistics Support Area, Balad, Iraq

Images: Army Times http://www.blogs.va.gov/VAntage/16192/ten-things-veterans-should-know-about-burn-pits
http://www.coasttocoastam.com/photo/view/sand_dust_storm_at_iraq_airbase/46040/

Burn Pits

- Trash includes batteries, equipment, plastics, medical and human waste. Jet fuel is typically used as an accelerant.
- The largest burn pits were located in Iraq and Afghanistan
- The practice started during post-9/11 invasion of Iraq
- Action was not taken until 2011 to provide guidance to move pits away from areas where troops are located.
- Many burn pits replaced with proper incinerators after 2011.

http://www.blogs.va.gov/VAntage/16192/ten-things-veterans-should-know-about-burn-pits

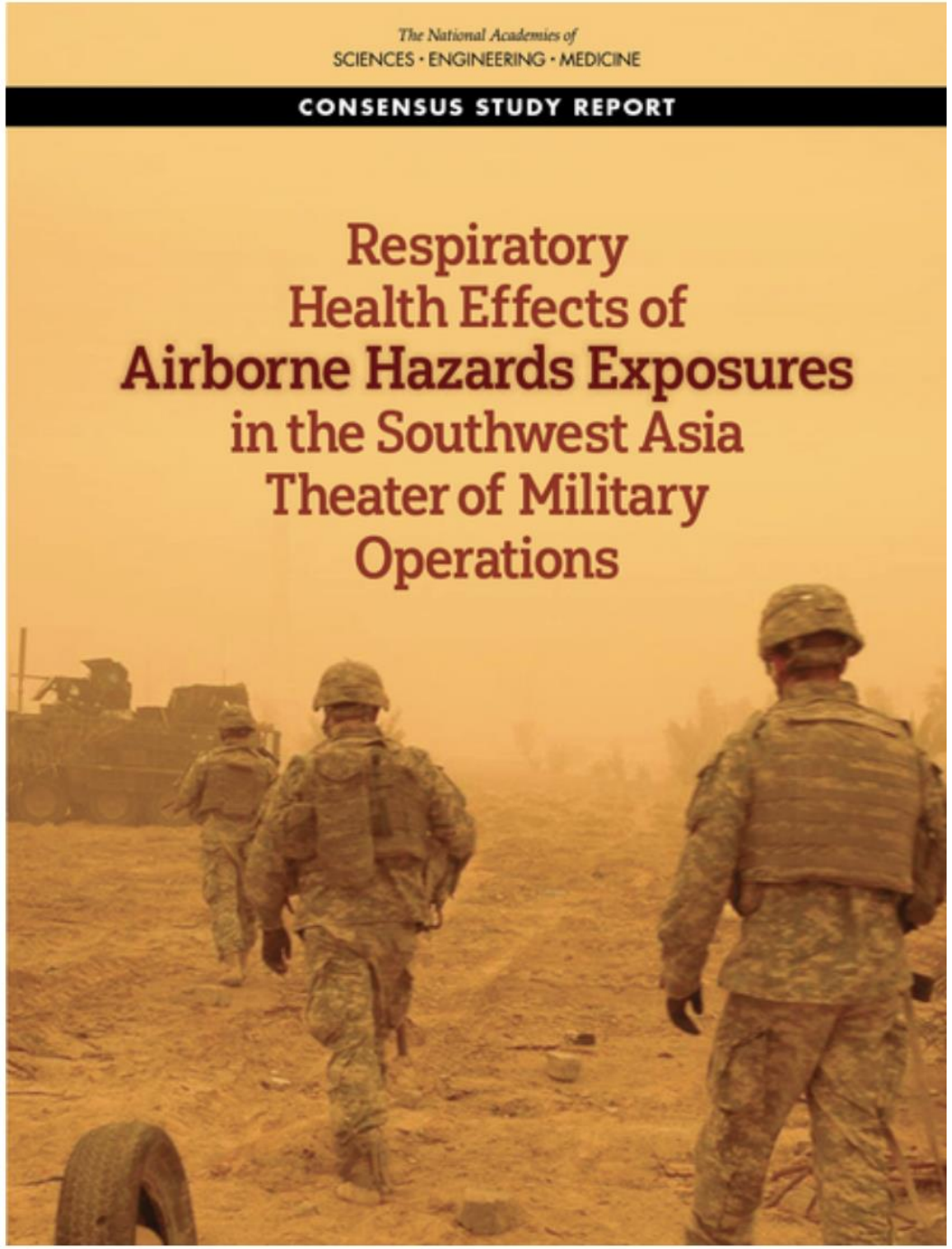
At Balad Air Base ~150 tons of waste burned per day 2003-2008, continued to 2011 Afghanistan's bases were burning up to 400 tons per day at their peak

Burn Pits: Air Quality

- Chemicals and byproducts emitted from burn pits include volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and PM with varying compositions including heavy metals.
- Very few ground-level sampling campaigns conducted during burn pit activity
  - Report by US Army, Screening Health Risk Assessment, Burn Pit Exposure, Balad Air Base, Iraq – Taylor, Rush, & Deck, 2008
  - Report by DOD, Enhanced Particulate Matter Surveillance Program – Engelbrecht et al., 2008

Health Effects

- Military personnel show higher rates of common respiratory illnesses like asthma and emphysema, as well as rare lung disorders.
  - Occupational and base-related exposures in addition to regional and off-base industrial source exposures
- Dust storms are an issue for respiratory illnesses, affecting both military and local residents.
- Through our VA partnership we are supporting the exposure assessment that is going into clinical- and research–based health assessments of veterans who were deployed in the region.



A recently released NASEM report indicated there are vast knowledge gaps in airborne exposure characterization in the southwest Asia region.

Recommend partnerships with other federal organizations to bridge these gaps.

https://www.nap.edu/catalog/25837/respiratory-health-effects-of-airborne-hazards-exposures-in-the-southwest-asia-theater-of-military-operations

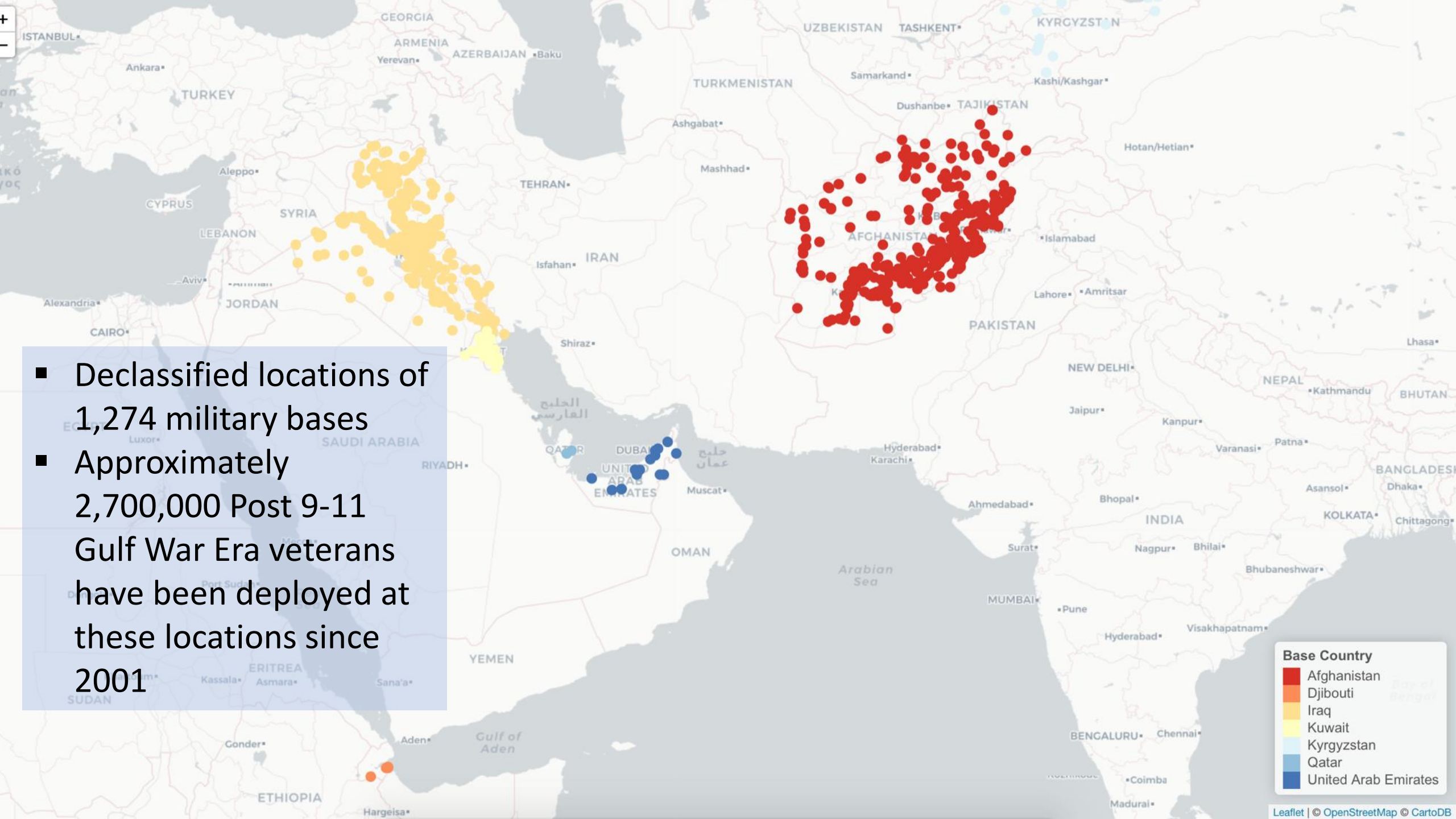
Study Objectives

- Primary objectives

1. To develop exposures to fine particulate matter ($PM_{2.5}$) during deployments to the U.S. bases and other locations in Central Asia (Afghanistan and Kyrgyzstan), Southwest Asia (Iraq, Kuwait, Qatar, and United Arab Emirates) and Africa (Djibouti)
    - MAIAC 1x1 km AOD coupled with meteorology (including visibility), MERRA2, land use, and available $PM_{2.5}$ mass concentrations in region
2. To develop source-specific exposures of $PM_{2.5}$ speciation (sulfate, nitrate, EC, OC, dust)
    - MISR 4.4x4.4 km AOD types coupled with meteorology, MERRA2, land use and available $PM_{2.5}$ speciation concentrations in Kuwait and Qatar
3. To develop and implement a software tool for deployment-related exposure assessment
    - To be used in clinical and research settings by the VA and DoD

Study Objectives

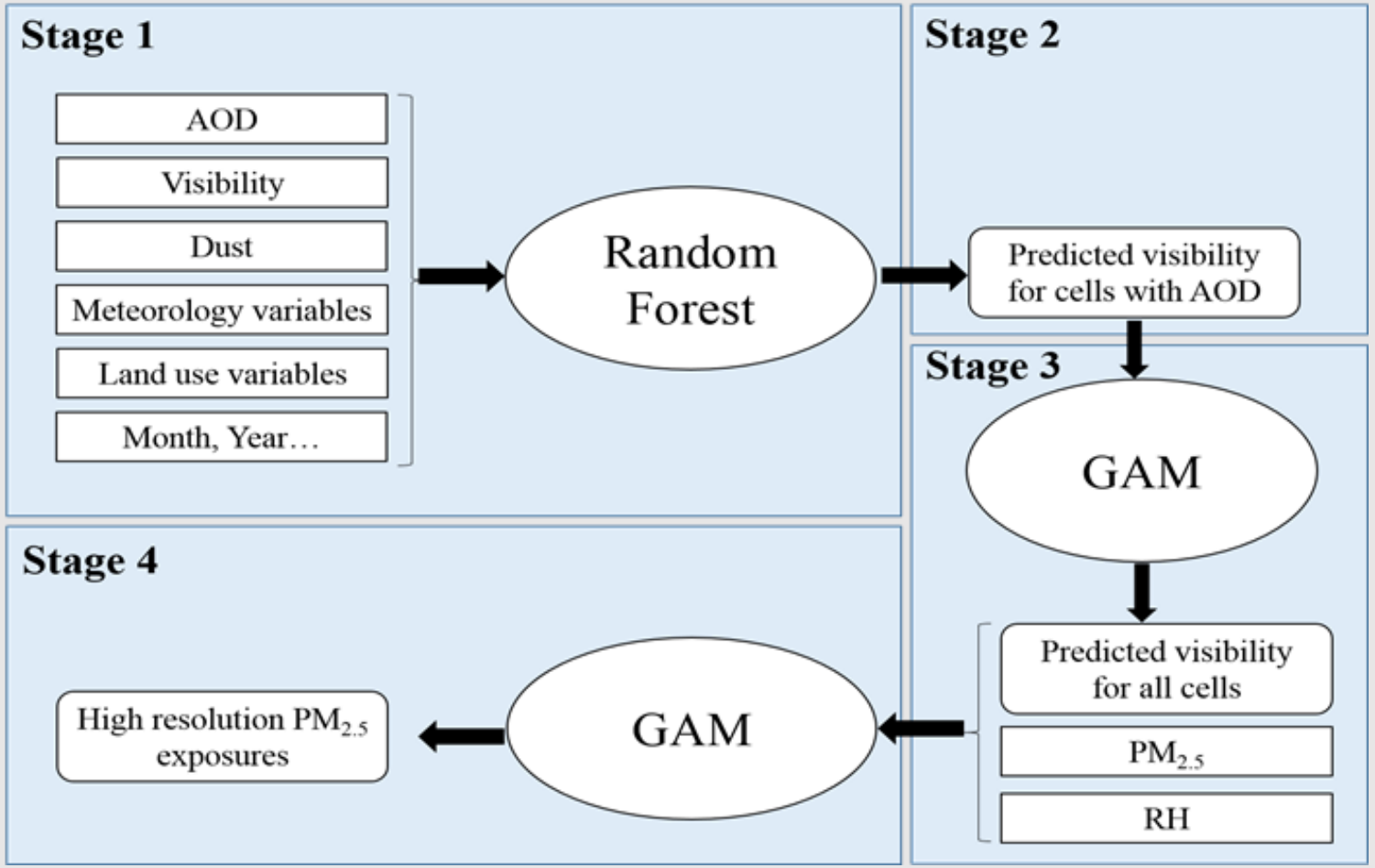
- Secondary/exploratory objectives
  - To identify locations of and assess duration of burn pit exposures
    - Examine MODIS fire and VIIRS active fire in proximity to base locations with burn pits
    - Apply density based clustering to identify persistent sources of burning, minimizing distance between base and identified fires (Franklin et al ES&T 2019)
  - To conduct epidemiological assessment with VA partners (CSP#595) and Kuwait hospital admissions and mortality records
  - To forge partnership with State Dept and provide exposures for embassies in SADA region
  - To provide use-case for MAIA mission (Kuwait a proposed MAIA secondary target area)



- Declassified locations of 1,274 military bases
- Approximately 2,700,000 Post 9-11 Gulf War Era veterans have been deployed at these locations since 2001

Progress on Primary Objective 1

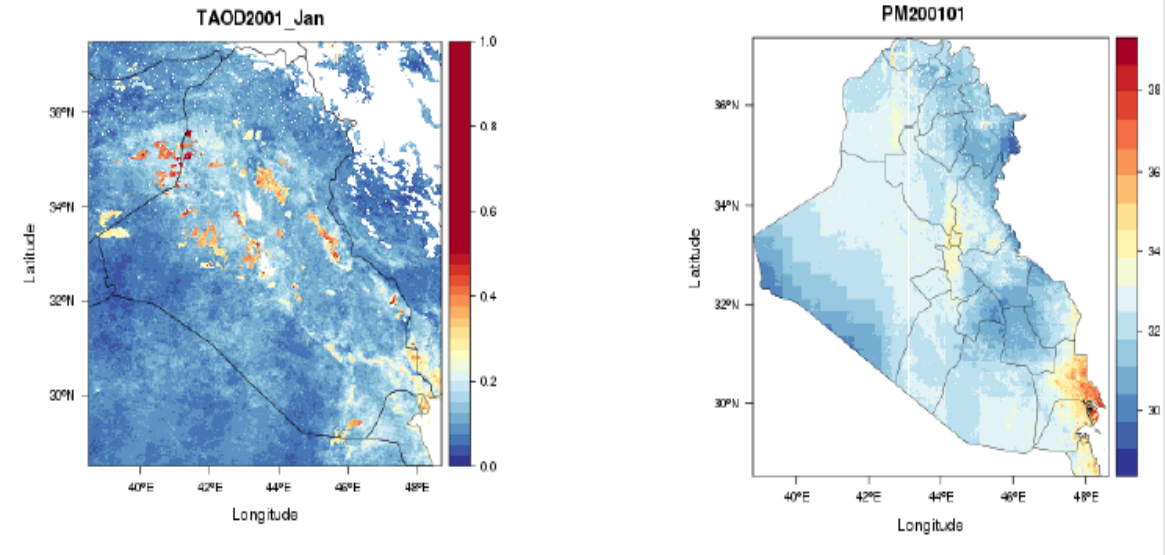
Modeling $PM_{2.5}$ from MAIAC AOD



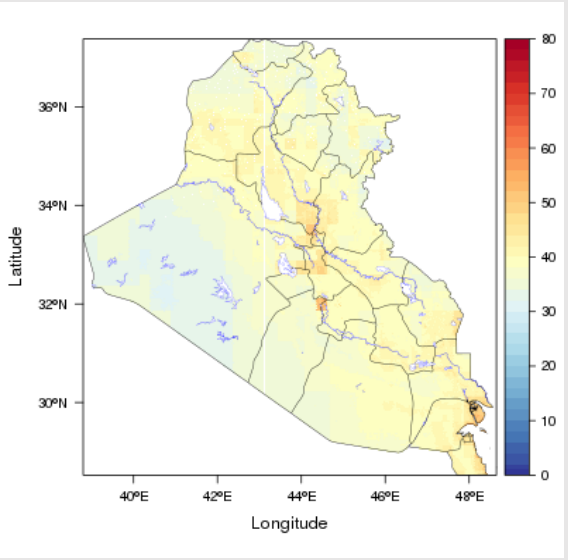
- Using MAIAC AOD, visibility stations and surface $PM_{2.5}$ sites generated 1x1 km $PM_{2.5}$ averaged over the entire study period.
- Updating with additional $PM_{2.5}$ data from Iran and openAQ

$PM_{2.5}$ estimates

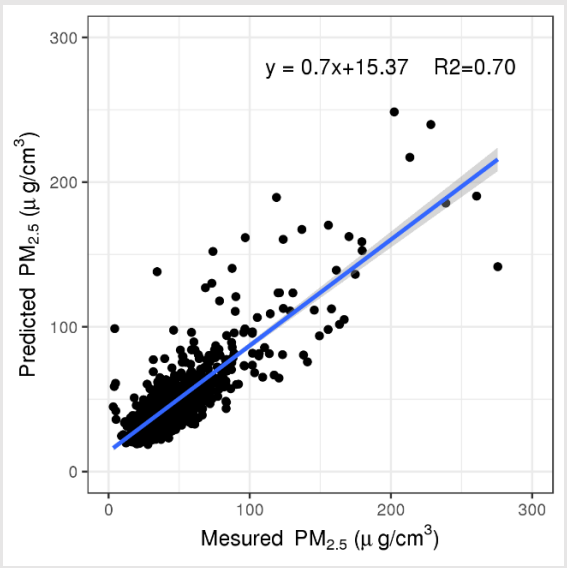
- Weekly $PM_{2.5}$ concentrations for Iraq and Kuwait at 1 km^2 resolution during 2001-2018 have been predicted and the database sent to VA.



MAIAC AOD and mean $PM_{2.5}$ concentrations ($\mu g/m^3$) in each $1km^2$ grid for January 2001 over Kuwait and Iraq



$PM_{2.5}$ concentrations ($\mu g/m^3$) in each $1km^2$ grid averaged 2001-2018 over Kuwait and Iraq

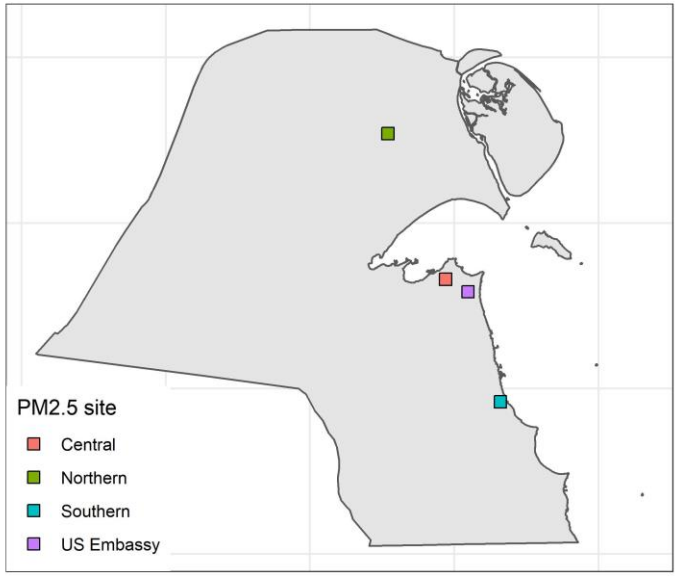


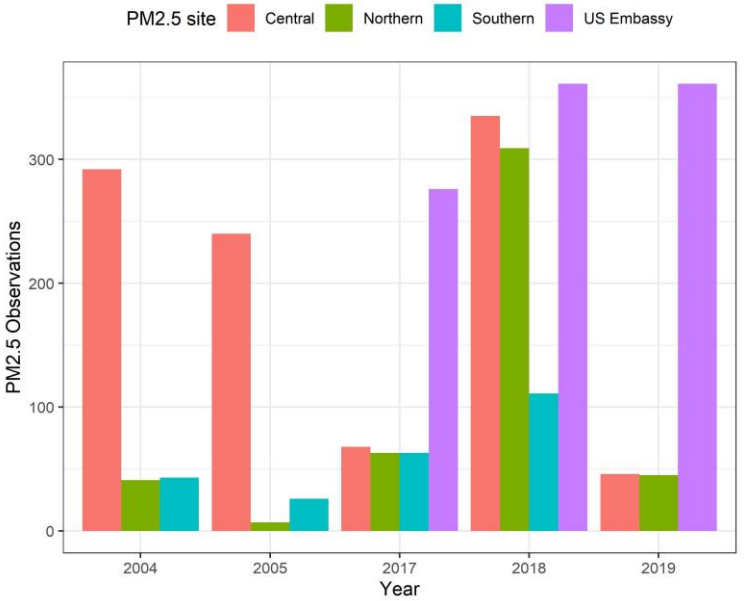
Observed vs Predicted PM2.5 concentrations over Kuwait and Iraq

Li, J et al (2020) A novel approach to estimate $PM_{2.5}$ exposures with high spatial resolution for countries without air quality monitoring networks, In revision with ES&T

Air Quality Monitoring in Kuwait

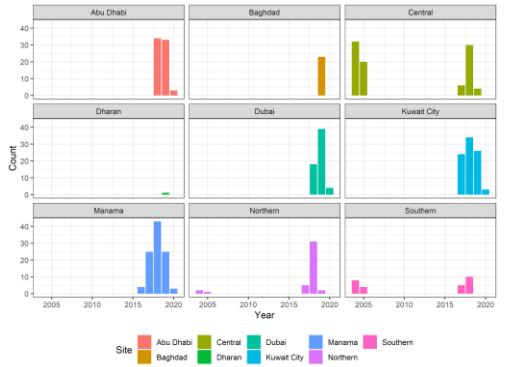
- Characterization of Particulate Matter (PM_{10} and $PM_{2.5}$ 2004-2006) for three Sites in Kuwait
  - PM_{10} ranged from 65.8 to 92.8 µg/m^3, $PM_{2.5}$ ranging from 30.8 µg/m^3 to 37.6 µg/m^3
- Since 2018 $PM_{2.5}$ and PM_{10} at two sites by co-I Petros Koutrakis' group (daily mass and XRF, ions, ICPMS).
  - One co-located at AERONET site (Kuwait U), other south of Kuwait city.

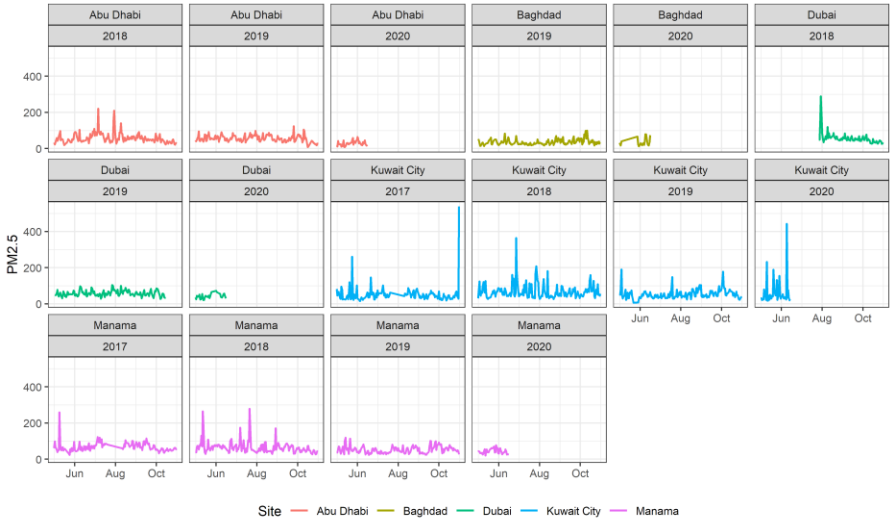




Other Air Quality Monitoring in Region

- We have acquired data from ~75 sites in Iran (1996-2016) for $PM_{2.5}$ and some gases
- OpenAQ data from US Embassies in the region provide $PM_{2.5}$ data from 2017-present
  - Bahrain: Manama
  - Iraq: Baghdad
  - Kuwait: Kuwait City + 3
  - Saudi Arabia: Dhahran
  - UAE: Abu Dhabi & Dubai

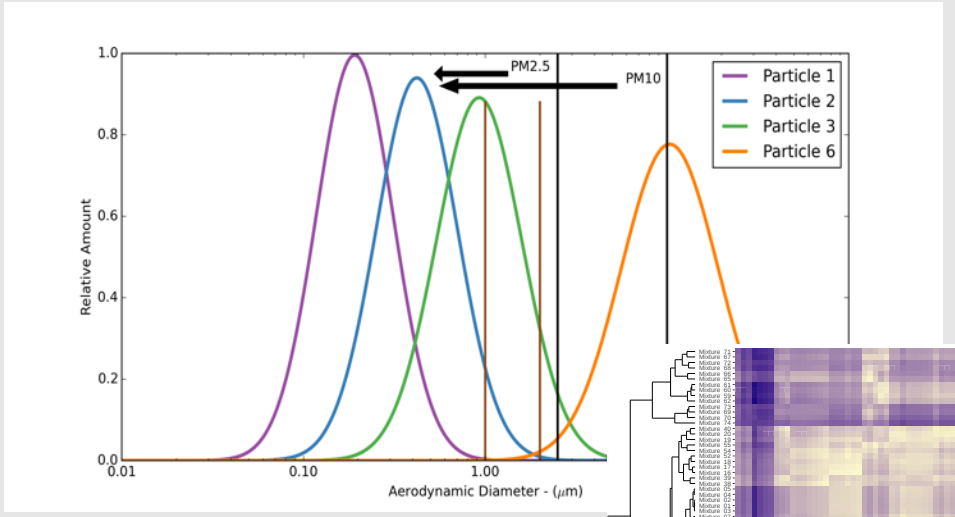


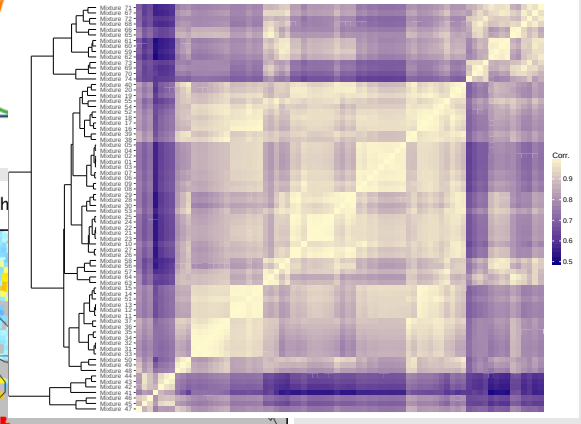


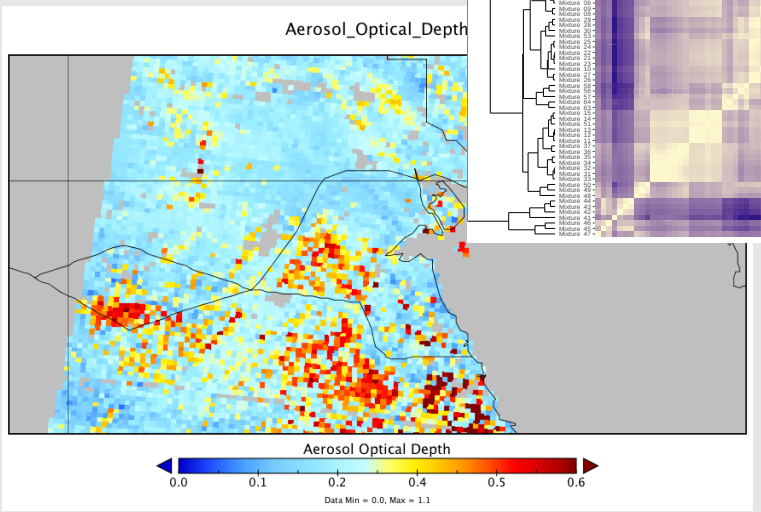
Progress on Primary Objective 2

Source-differentiated $PM_{2.5}$ from MISR AOD

- The 4.4 km MISR product *(Garay et al ACP, 2017)* provides
  - MISR total AOD and AOD particle types provide:
  - Fractions to distinguish size (small, medium large) *(Franklin et al. RSE, 2017)*
  - Mixtures to distinguish size and type (spherical, non-spherical, absorbing, non-absorbing, dust) *(Kahn and Gaitley JGR, 2015)*
  - MISR AOD raw and additional data provide observations under bright surfaces (not available from MODIS/MAIAC) *(Franklin et al RS, 2018)*

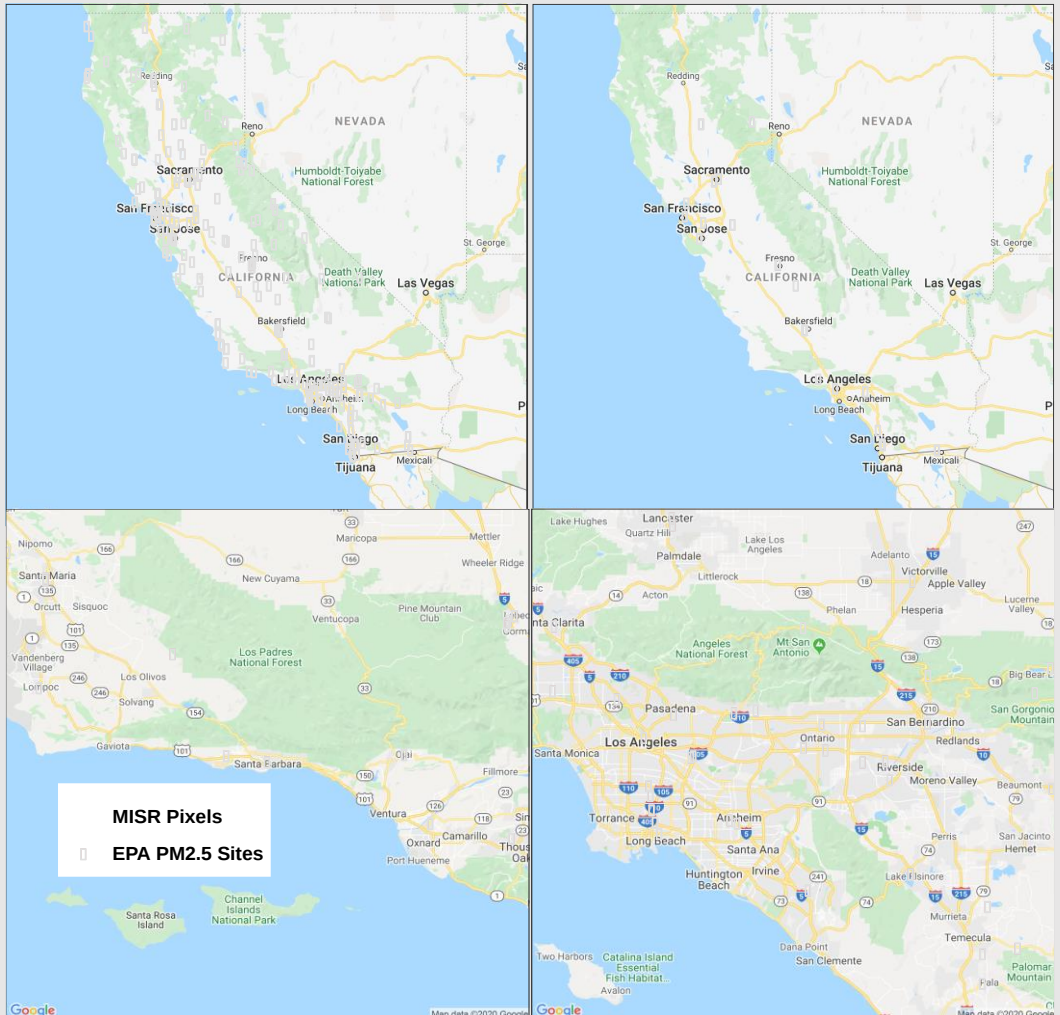


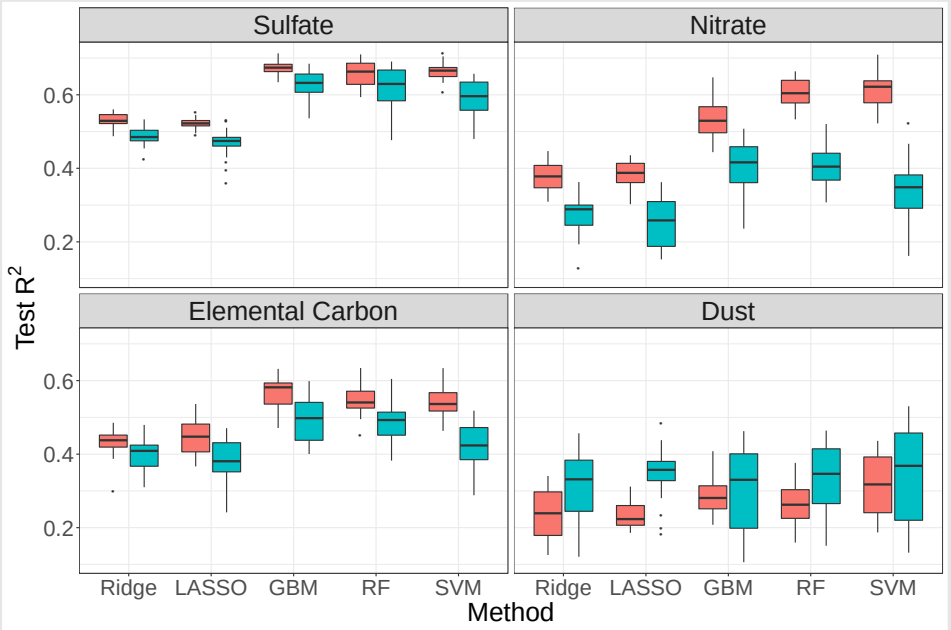




Speciated $PM_{2.5}$ from MISR

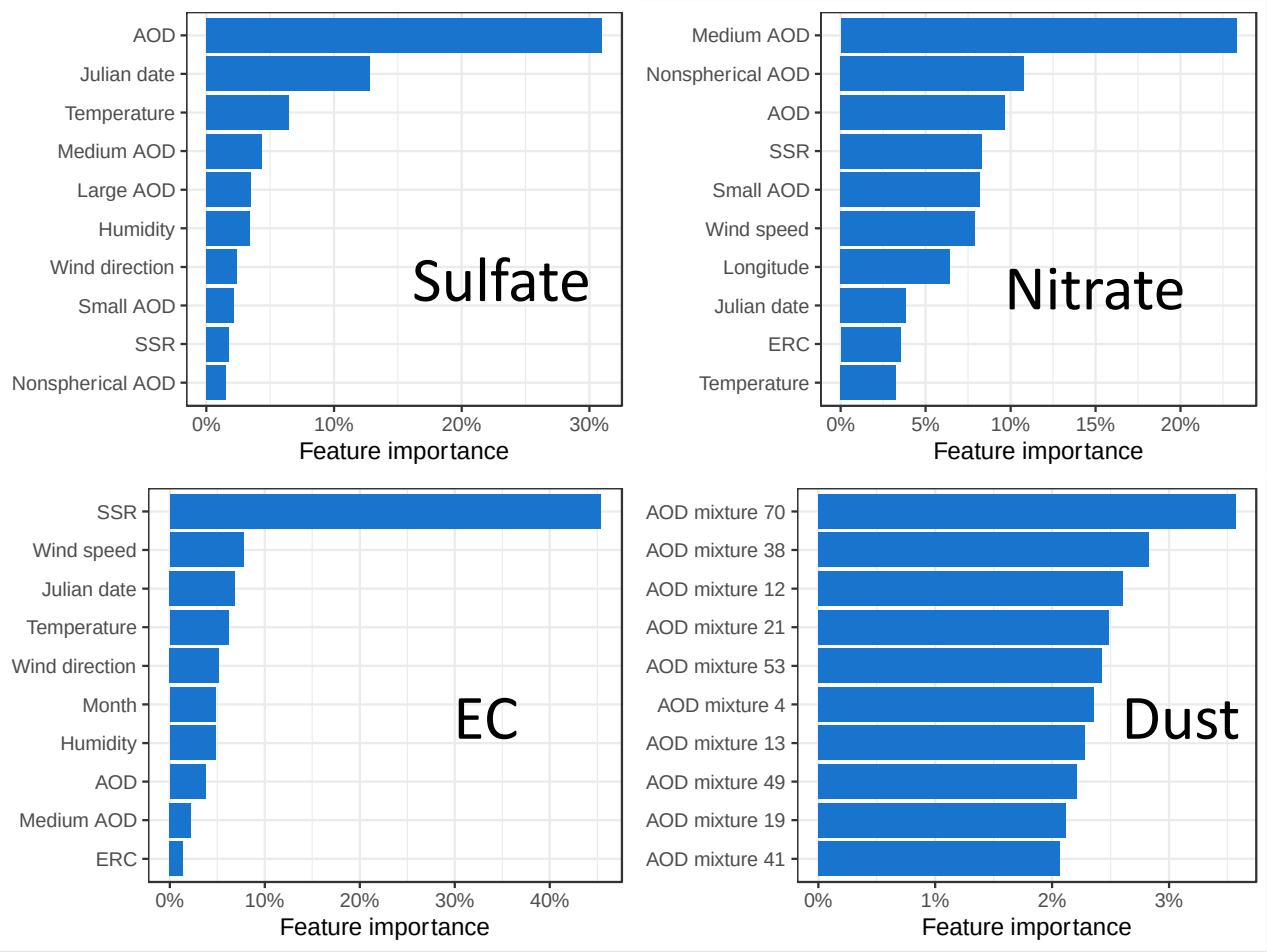
- Created a model testbed in California where we use the MISR AOD properties to estimate $PM_{2.5}$ and $PM_{2.5}$ chemical speciation

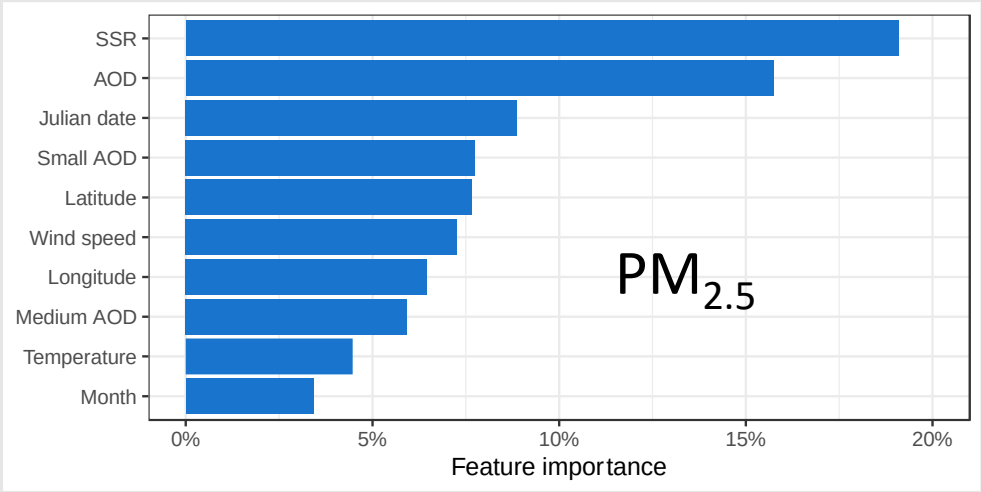




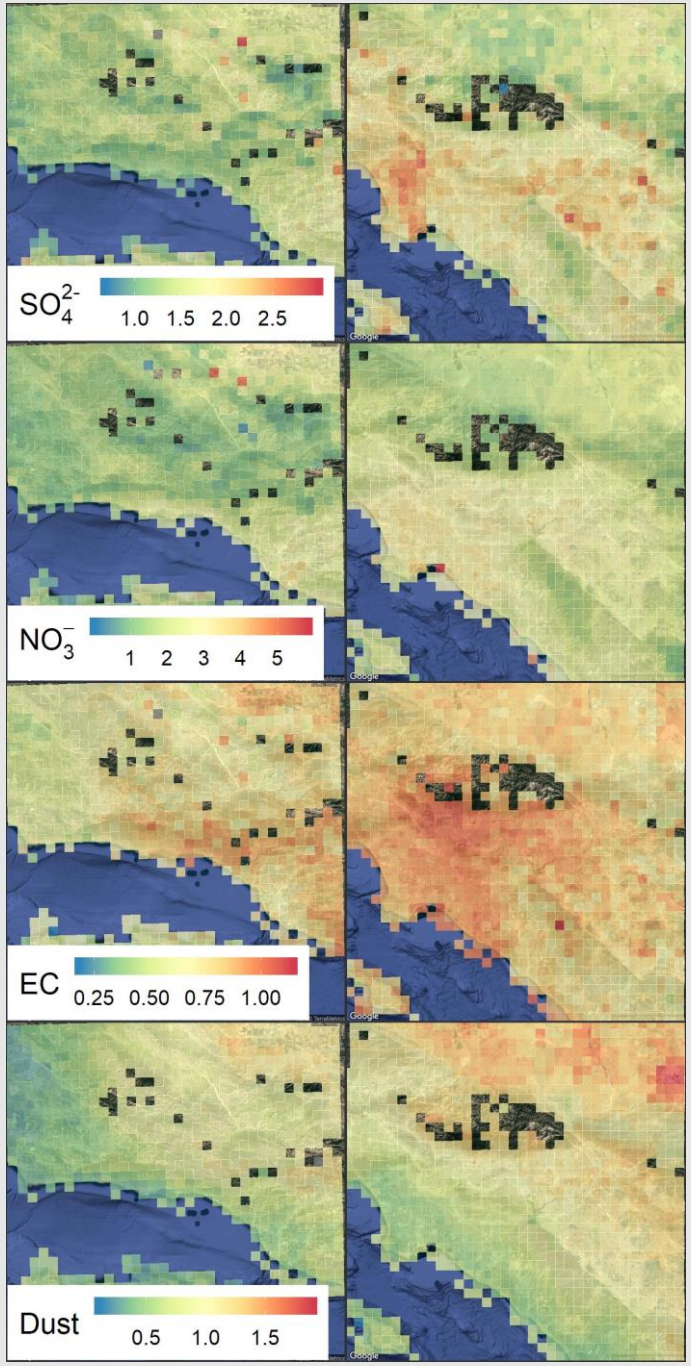
Exposure	ML Method	MISR Predictors	Best test R^2
$PM_{2.5}$	GBM	AOD Products	0.68
SO_4^{2-}	GBM	AOD Products	0.71
NO_3^-	SVM	AOD Products	0.71
EC	GBM	AOD Products	0.63
Dust	SVM	AOD Mixtures	0.53

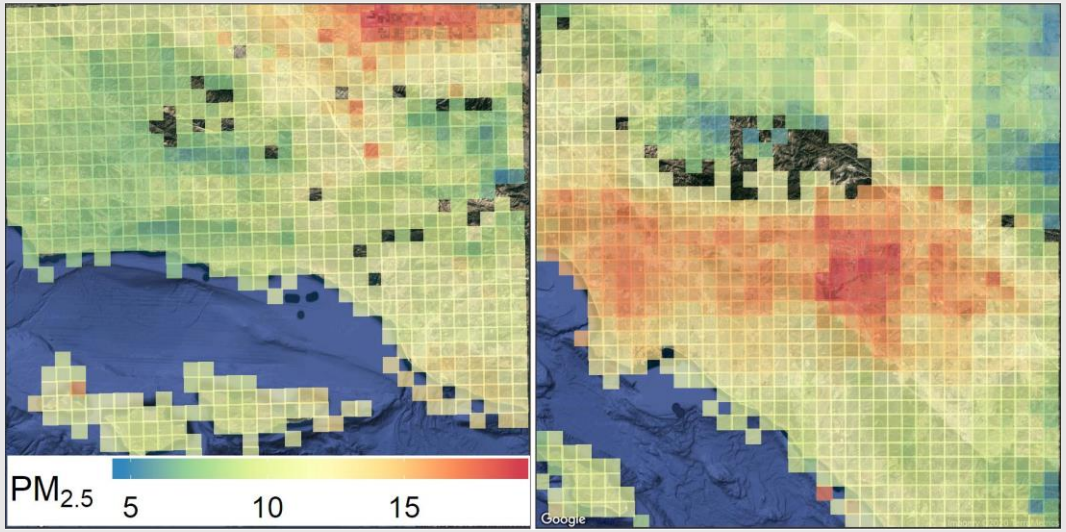
MISR Products and Mixtures: Variable Importance

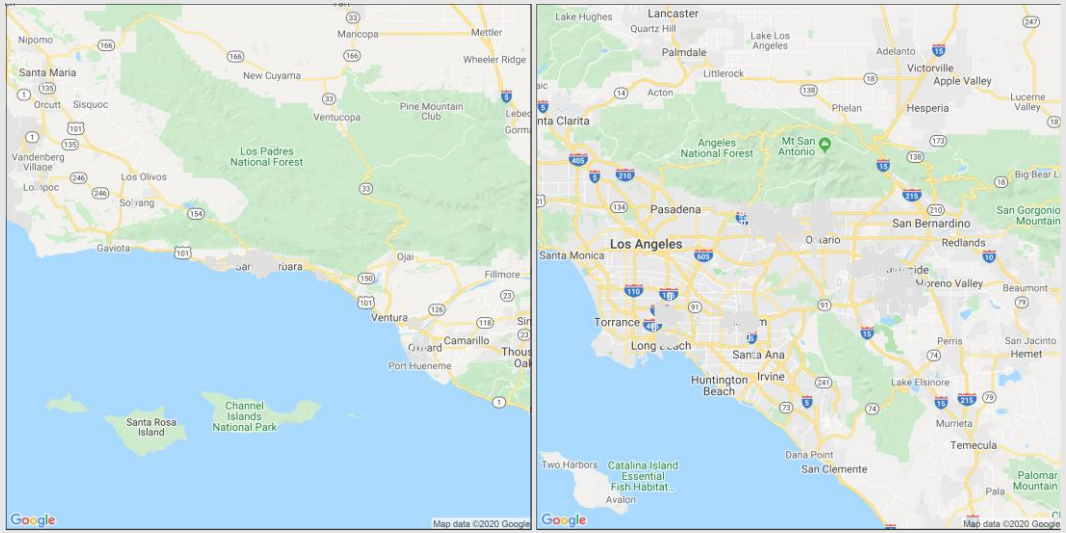




Prediction Surfaces







Santa Barbara | Anaheim | Glendora | Long Beach | Mira Loma | Riverside | San Dimas | Upland

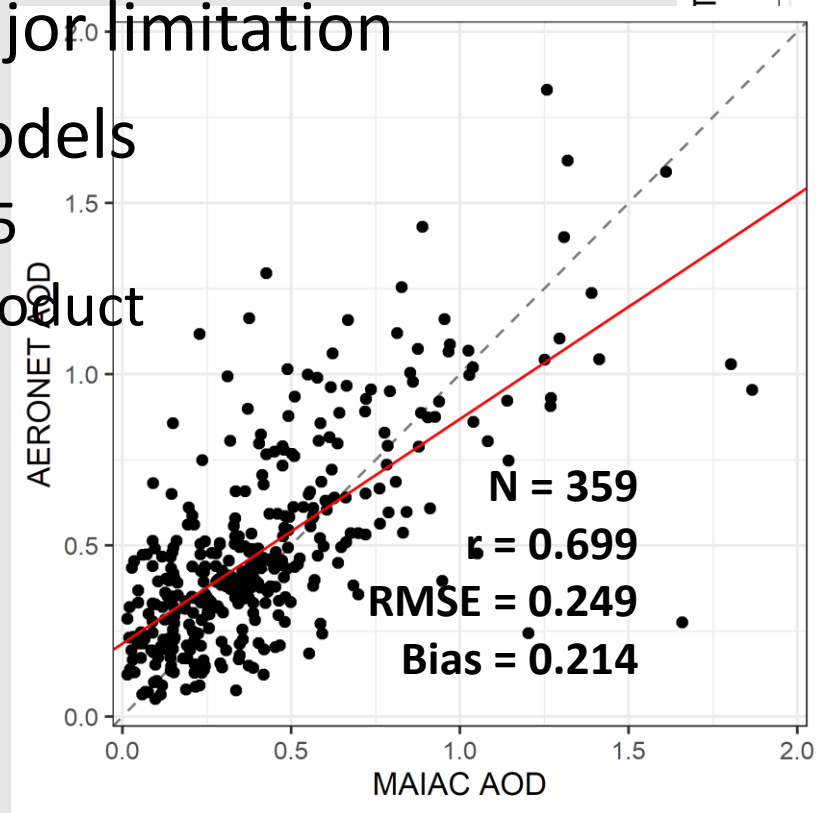
- Locations of >1,200 kids part of the USC Children's Health Study
- Conducted an epidemiological assessment of lung function
- Found differential associations with certain chemical species of PM and lung function

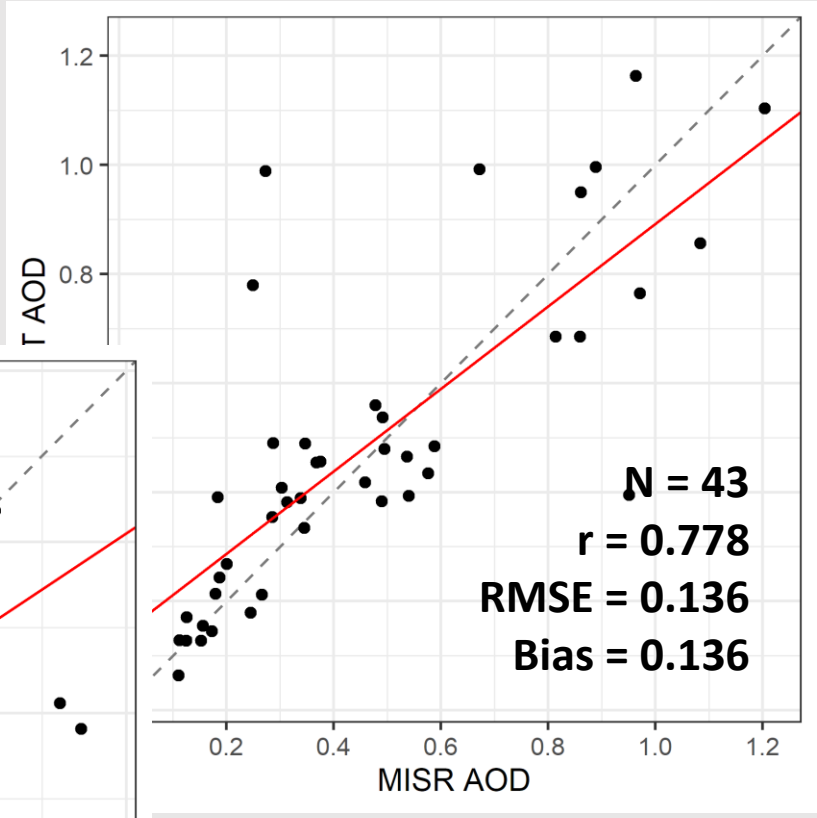
Chau, K., Franklin, M., & Gauderman, W. J. (2020). Satellite-Derived PM2.5 Composition and Its Differential Effect on Children's Lung Function. *Remote Sensing*, *12*(1028).

Speciated $PM_{2.5}$ from MISR in SADA

- Validation of MISR with AERONET in Kuwait shows better performance of MISR AOD compared to MAIAC AOD
- Data availability of MISR is a major limitation
- Model building similar to CA models
  - Included meteorology from ERA-5
  - MERRA-2, a NASA assimilation product
  - NDVI for land use

MERRA-2 provides AOD, speciated AOD, column PM2.5 for total mass, black carbon, organic carbon, sulfate and dust





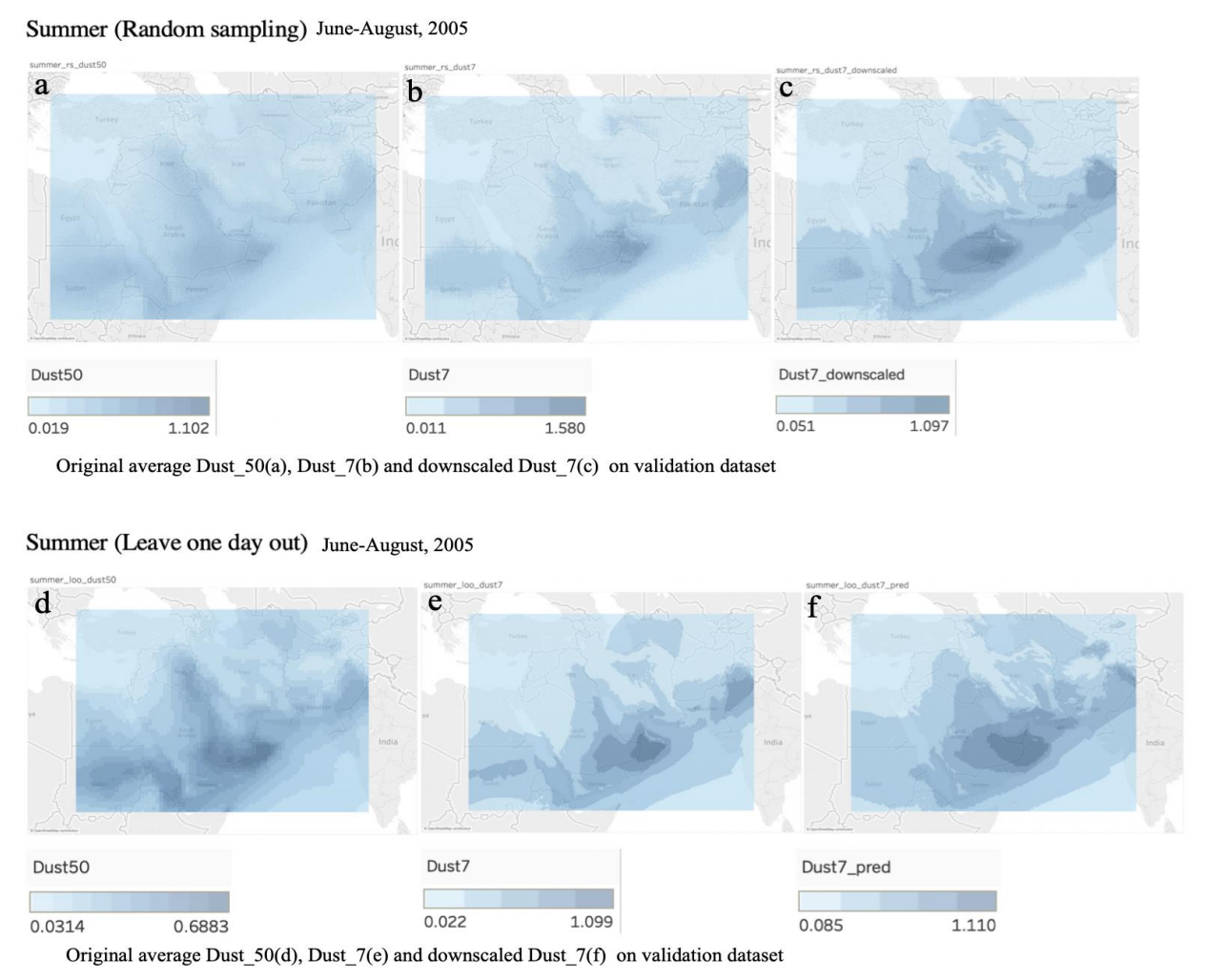
Speciated $PM_{2.5}$ from MISR in SADA

	MISR		
Subsets	**All M-2**	**Dust**	**Dust & SO_4**
N	490	490	490
GBM	0.343	0.369	0.400
RF	0.377	0.437	0.435
SVM	0.388	0.413	0.401

Variable	Mean rank
Dust extinction	1.12
AOD	1.92
BLH	3.64
Small AOD	3.88
Medium AOD	5.88
Wind speed	6.44
Julian date	7.68
Temperature	8.24
Large AOD	8.48
Relative humidity	11.6

Downscaling MERRA-2

- The MERRA-2 product is 50 km resolution but a special run of the assimilation model, G5NR (nature run), was conducted at 7 km resolution for 2 year (2005-2007)
- Used a neural network to train a model with 50 km MERRA-2 as input (with elevation) and 7 km G5NR as output.

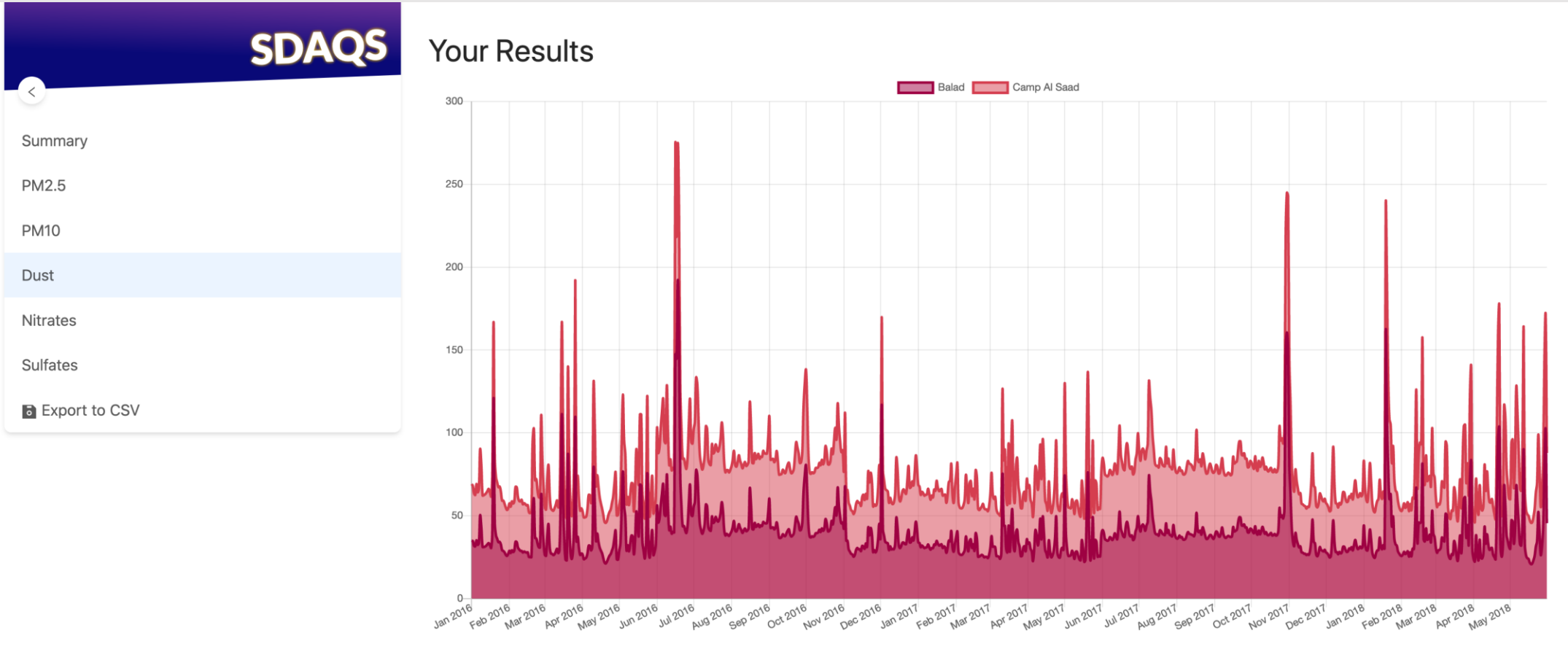


Progress on Primary Objective 3

Exposure Assessment Tool

https://airquality.ryanlue.com/

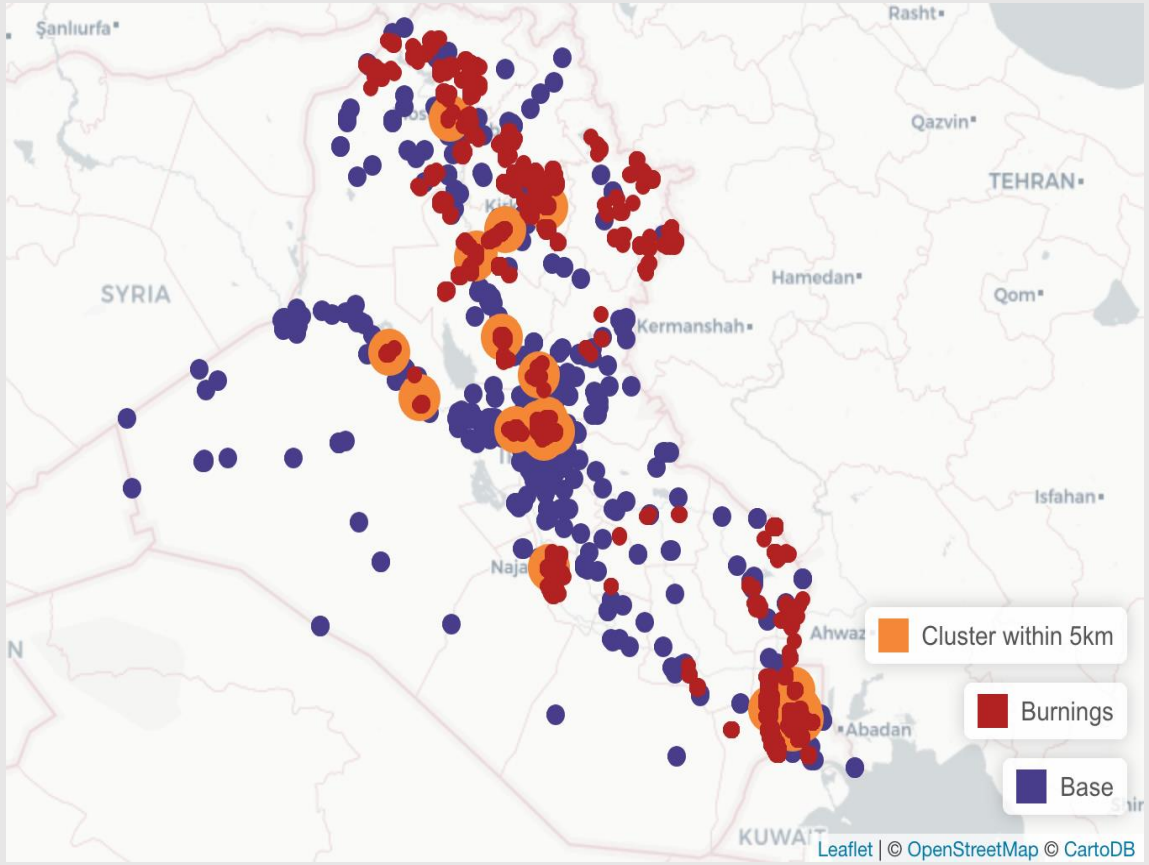
Exposure Assessment Tool



Progress on Secondary Objectives

Burn Pit Detection

- Records of the locations and durations of burn pits were not routinely taken.
- MODIS active fire with hierarchical density based clustering to detect persistent thermal sources annually
- Identified persistent sources within 5 km of known base locations



Burn Pit Detection

- Validated with imagery where possible (much of the imagery in the region is blurred)
- Identified bases with most thermal detections 2002-2012
  - Chindit, Steelback, Camp Hutch, Al Saad appear frequently

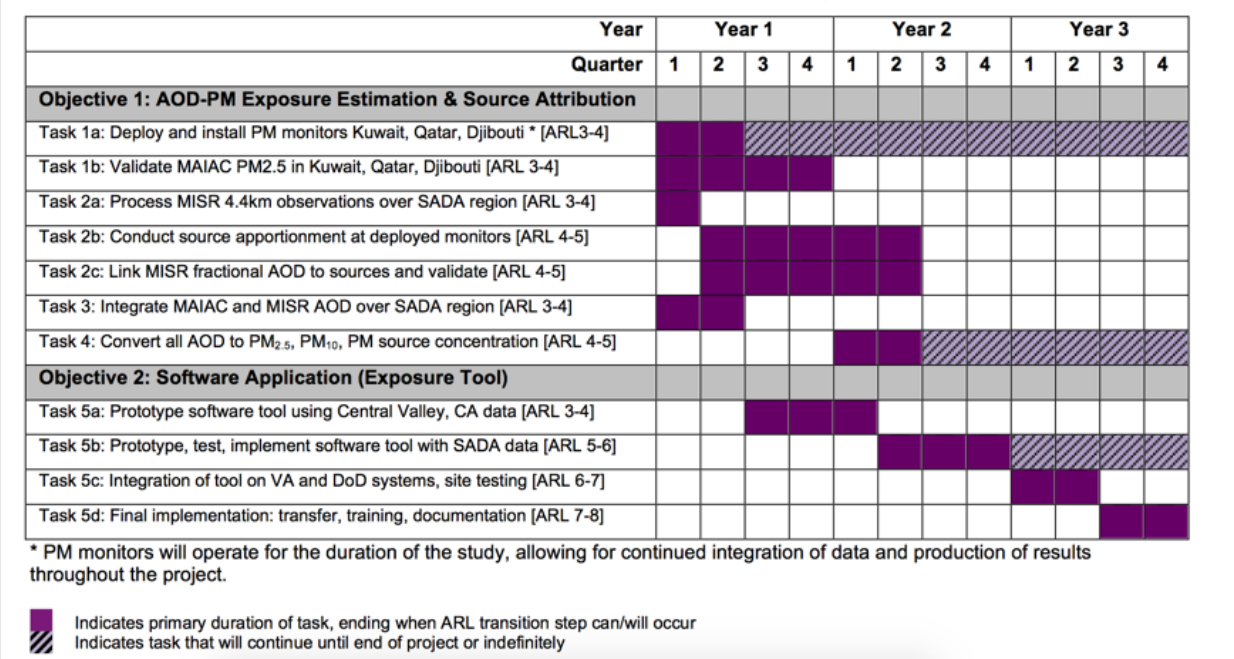
Camp Al Saad, Iraq

Challenges

- Due to COVID-19 lab work at Harvard has stalled
  - Kuwait samples backlogged
  - Qatar samples not yet analyzed
- Site visit to Kuwait and Qatar cancelled
- Issue getting to VA sites for software implementation

ARL

- Started at 3, we are at 6
  - Implemented software tool and tested with VA end users
- Next steps
  - Introduce downscaled MERRA-2 source-specific exposure methods into the software tool
  - Make enhancements to the software tool based on VA/DoD feedback.
  - Implement data download capability of the software tool



Year	Year 1				Year 2				Year 3			
Quarter	1	2	3	4	1	2	3	4	1	2	3	4
Objective 1: AOD-PM Exposure Estimation & Source Attribution												
Task 1a: Deploy and install PM monitors Kuwait, Qatar, Djibouti * [ARL3-4]	■	■	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Task 1b: Validate MAIAC PM2.5 in Kuwait, Qatar, Djibouti [ARL 3-4]	■	■	■	■								
Task 2a: Process MISR 4.4km observations over SADA region [ARL 3-4]	■											
Task 2b: Conduct source apportionment at deployed monitors [ARL 4-5]		■	■	■	■	■						
Task 2c: Link MISR fractional AOD to sources and validate [ARL 4-5]		■	■	■	■	■						
Task 3: Integrate MAIAC and MISR AOD over SADA region [ARL 3-4]	■	■										
Task 4: Convert all AOD to $PM_{2.5}$, PM_{10}, PM source concentration [ARL 4-5]					■	■	▨	▨	▨	▨	▨	▨
Objective 2: Software Application (Exposure Tool)												
Task 5a: Prototype software tool using Central Valley, CA data [ARL 3-4]			■	■	■							
Task 5b: Prototype, test, implement software tool with SADA data [ARL 5-6]						■	■	■	▨	▨	▨	▨
Task 5c: Integration of tool on VA and DoD systems, site testing [ARL 6-7]									■	■		
Task 5d: Final implementation: transfer, training, documentation [ARL 7-8]											■	■

* PM monitors will operate for the duration of the study, allowing for continued integration of data and production of results throughout the project.

■ Indicates primary duration of task, ending when ARL transition step can/will occur
▨ Indicates task that will continue until end of project or indefinitely