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

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NASA HAQ Applications Program
September 10-11, 2019
HAQ-ROSES 80NSSC19K0225

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 [allergens]

- 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

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 (also in Kuwait)

- The practice started during post-9/11 invasion of Iraq and continues in combat zones today.

- 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 those 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.

Study Objectives

- Primary objectives
  - 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 coupled with meteorology (including visibility), MERRA2, land use, and available $PM_{2.5}$ mass concentrations in region
  - To develop source-specific exposures of $PM_{2.5}$ speciation (sulfate, nitrate, EC, OC, dust)
    - MISR 4.4x4.4 km coupled with meteorology, MERRA2, land use and available $PM_{2.5}$ speciation concentrations in Kuwait (Qatar being sited)
  - 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 secondary target area)
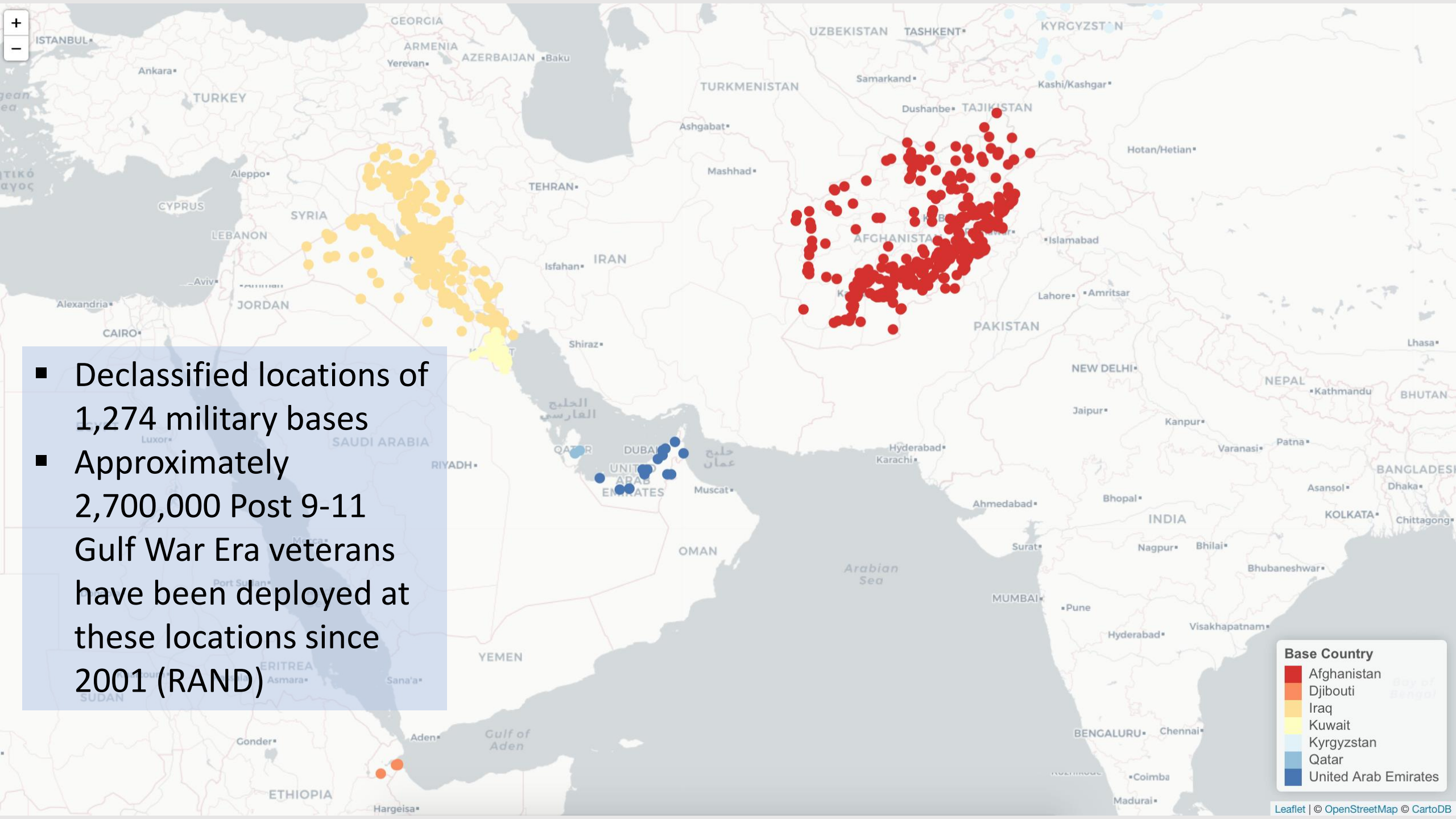
- Declassified locations of 1,274 military bases
- Approximately 2,700,000 Post 9-11 Gulf War Era veterans have been deployed at these locations since 2001 (RAND)

Base Country
- Afghanistan
- Djibouti
- Iraq
- Kuwait
- Kyrgyzstan
- Qatar
- United Arab Emirates

Burn pits were used at 1,101 of the bases. Mostly in Iraq and Afghanistan
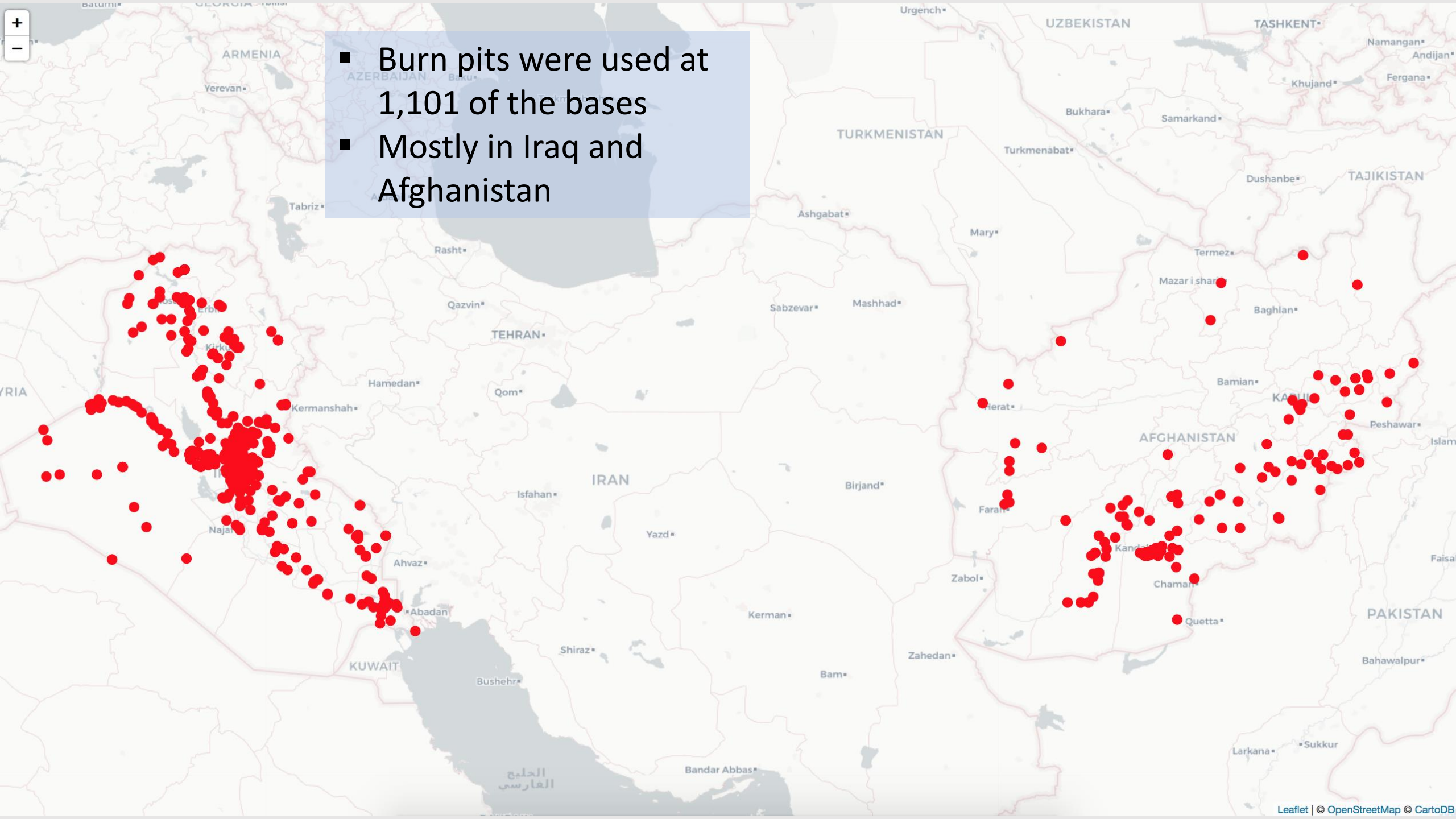
MODIS FIRE/VIIRS

- MODIS 1km available for study period
- Terra and Aqua provide two snapshots per day
- Only provides fire radiative power
- VIIRS 375m only available 2012-present

Iraq 2008

MODIS FRP
| 0 − 3 |
| 3 − 5 |
| 5 − 10 |
| 10 − 20 |
| 20 − 50 |
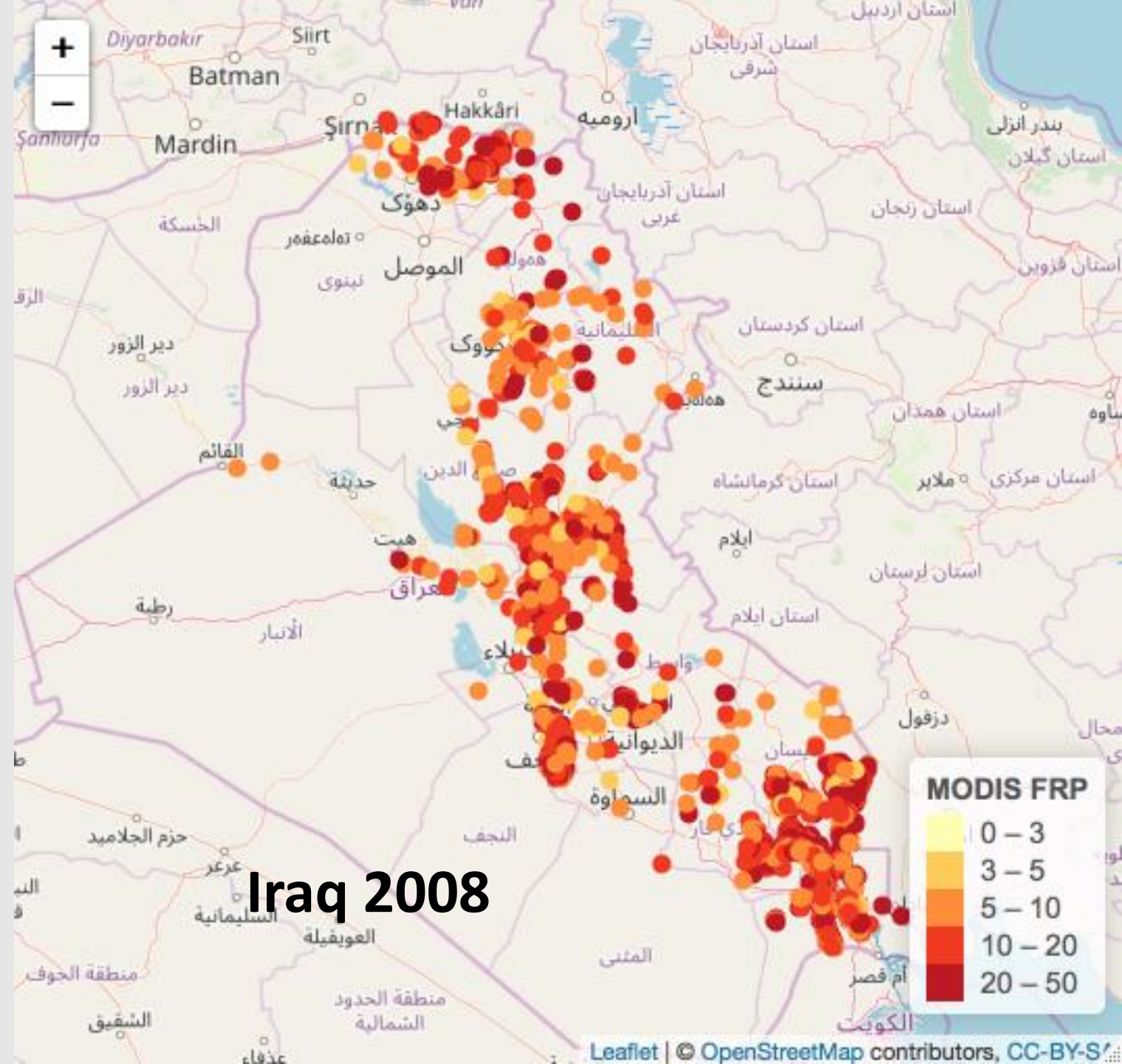
Historical Military Air Quality Monitoring

- US Army monitoring PM_{10}, VOCs, PM metals. Only 60 samples, results not conclusive (max concentrations PM_{10} 225 ug/m^3)

- DOD study measured PM_{25} and PM_{10} at 15 sites in 2006-2007
  - Concentrations consistently exceeded standards (150ug/m^3 PM_{10}, 35 ug/m^3 $PM_{2.5}$)
 - High levels of lead, arsenic, cadmium, zinc
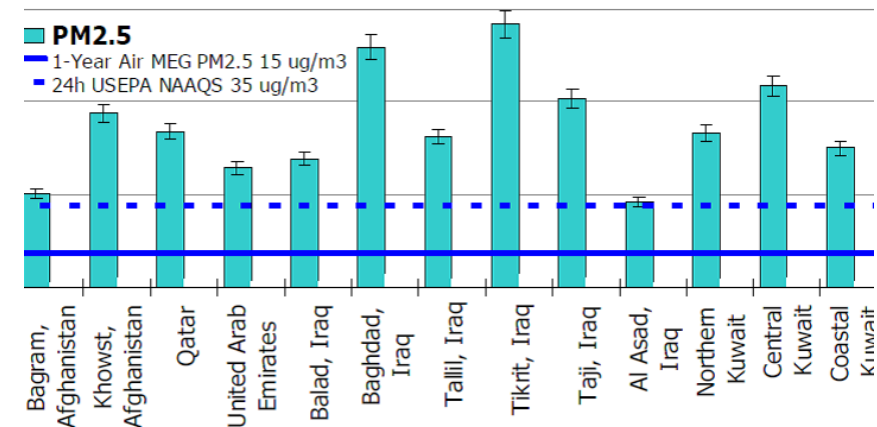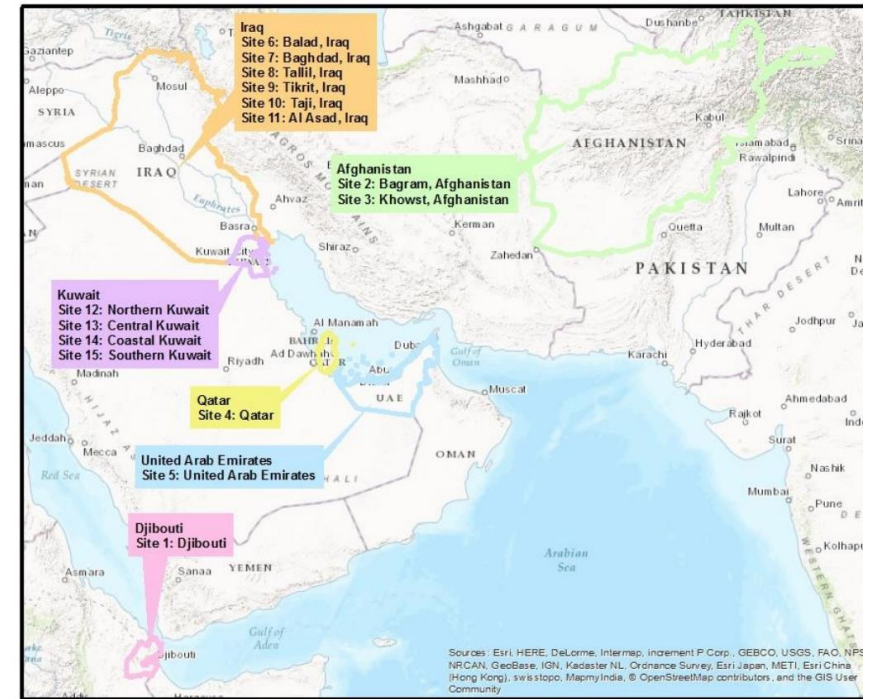
Air Quality Monitoring in Kuwait

- 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/m³, $PM_{2.5}$ ranging from 30.8 μg/m³ to 37.6 μg/m³
- Kuwait EPA conducted a study with 10 monitoring sites in 2011-2012
- 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.
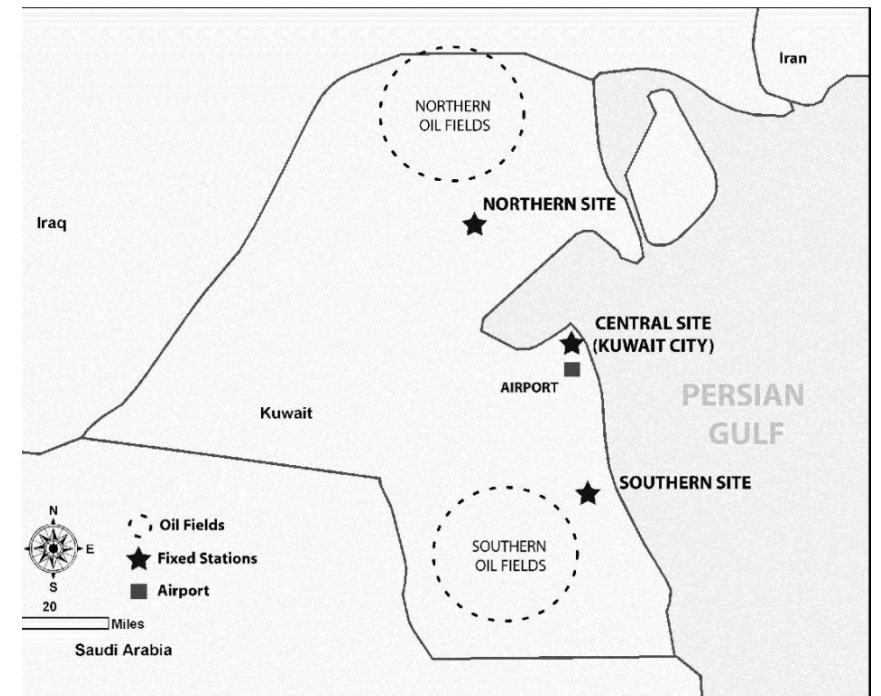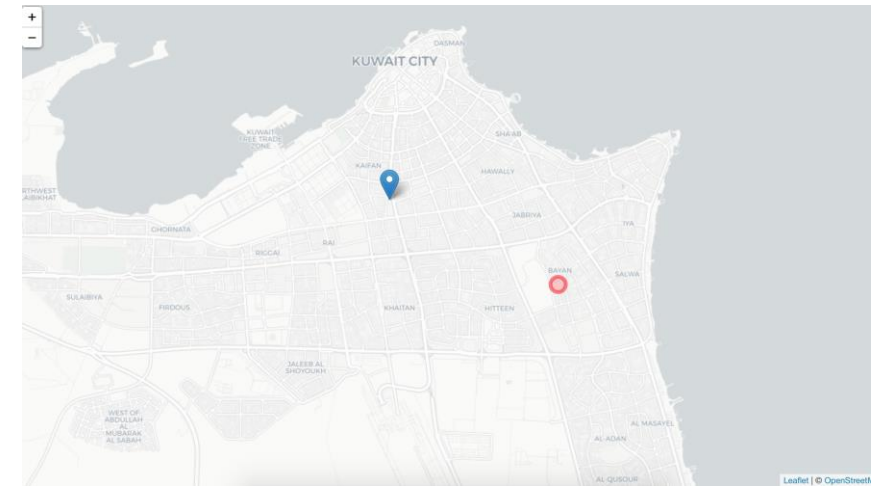
Other Air Quality Monitoring in Region

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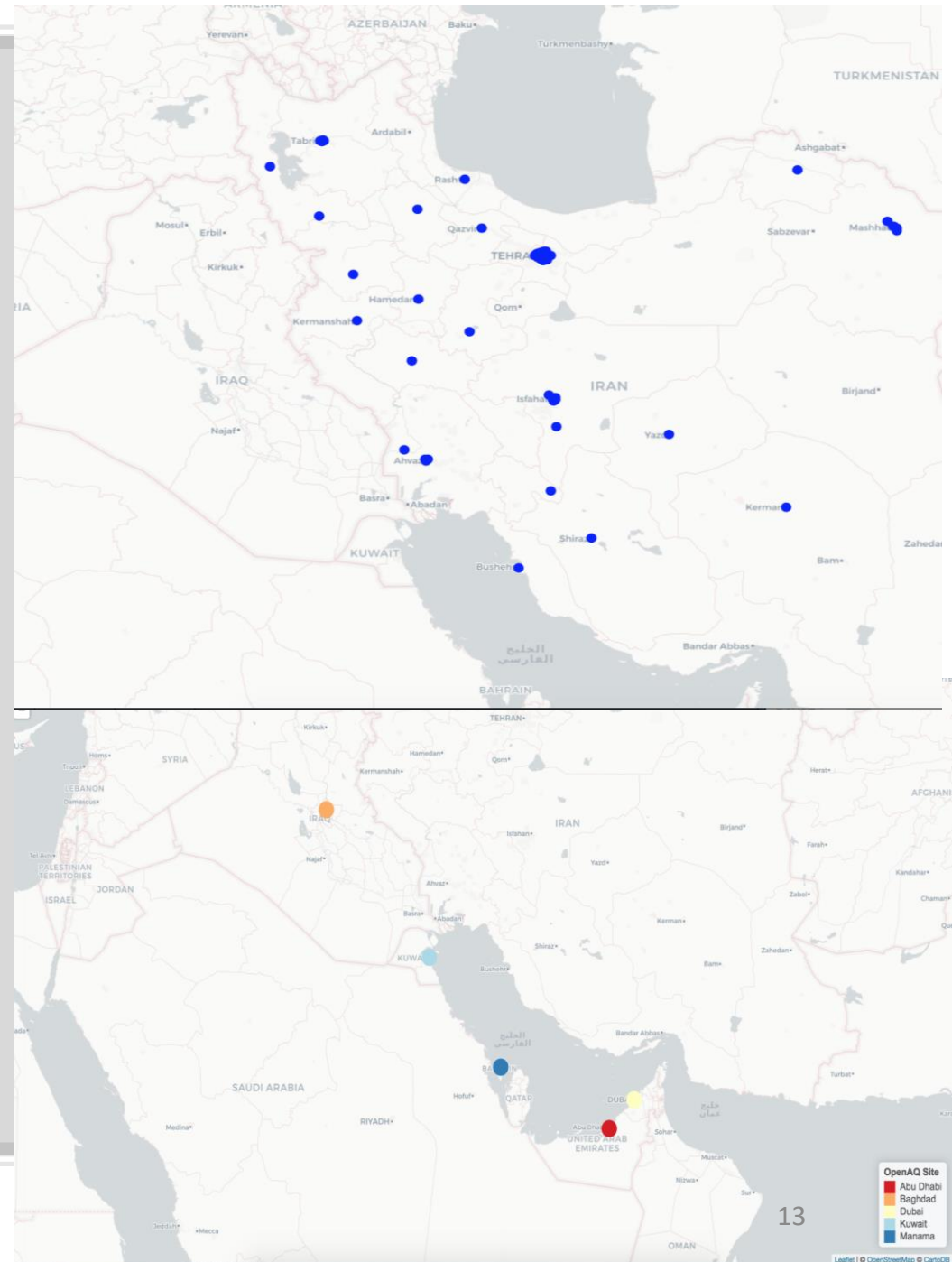
Satellite-Derived PM$_{2.5}$ from MAIAC
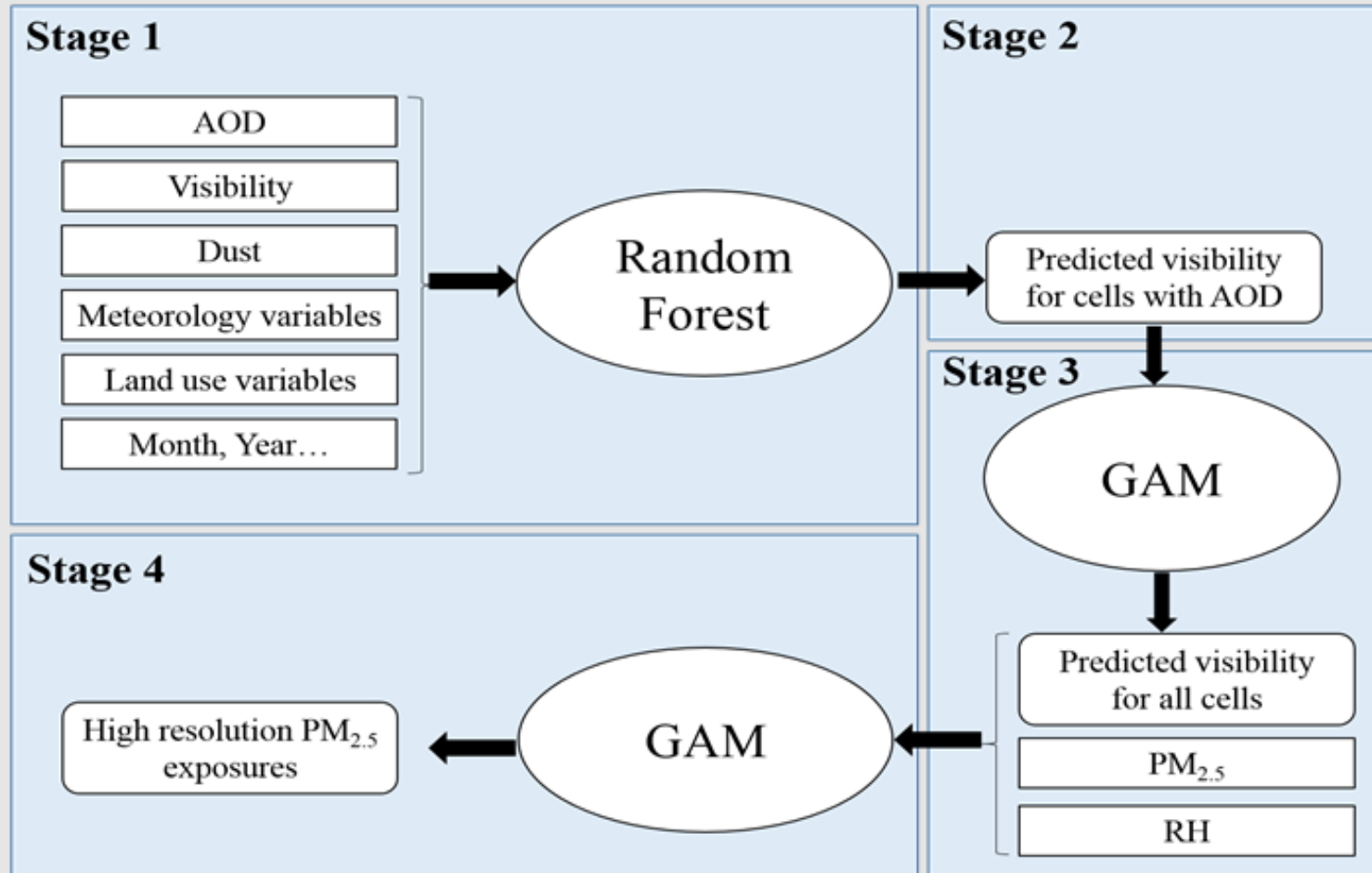
- Using MAIAC AOD, visibility stations and surface PM$_{2.5}$ sites generated 1x1 km PM$_{2.5}$ averaged over the entire study period.
- Updating with additional PM$_{2.5}$ data from Iran and openAQ

Satellite-Derived PM$_{2.5}$ from MAIAC

- Model performance:
  - 10-fold CV R^2 of stage 1 predictions = 0.81.
  - 10-fold CV R^2 of stage 4 model for weekly PM$_{2.5}$ predictions = 0.75.
- Weekly PM$_{2.5}$ concentrations for Iraq and Kuwait at 1 km^2 resolution during 2001-2018 have been predicted and preliminary database sent to VA.
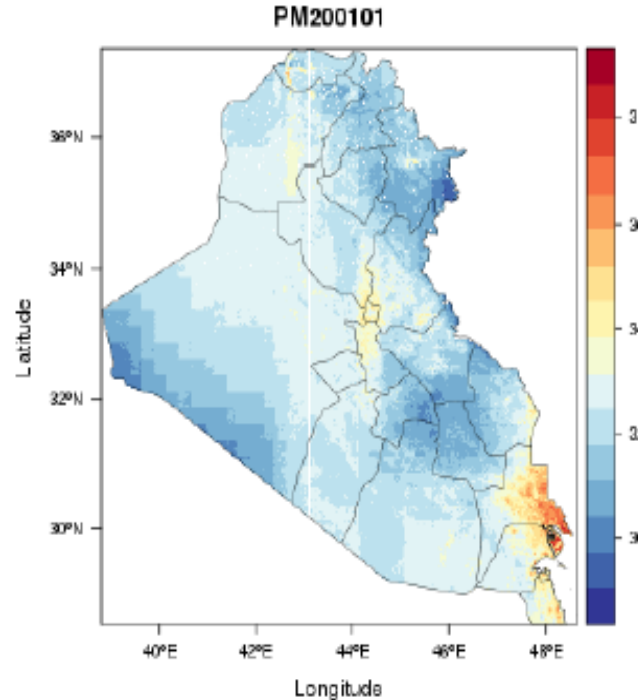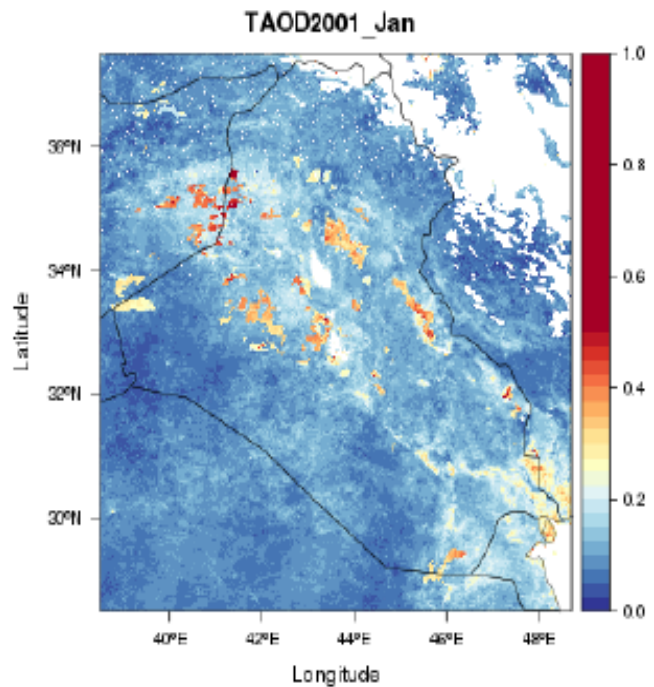
Shown: MAIAC AOD and mean PM$_{2.5}$ concentrations ($\mu g/m^3$) in each 1km^2 grid for January 2001 over Kuwait

Speciated PM$_{2.5}$ from MISR

▪ The new(ish) 4.4 km MISR product *(Garay et al ACP, 2017)* provides total AOD, particle types and mixtures:

- 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)*
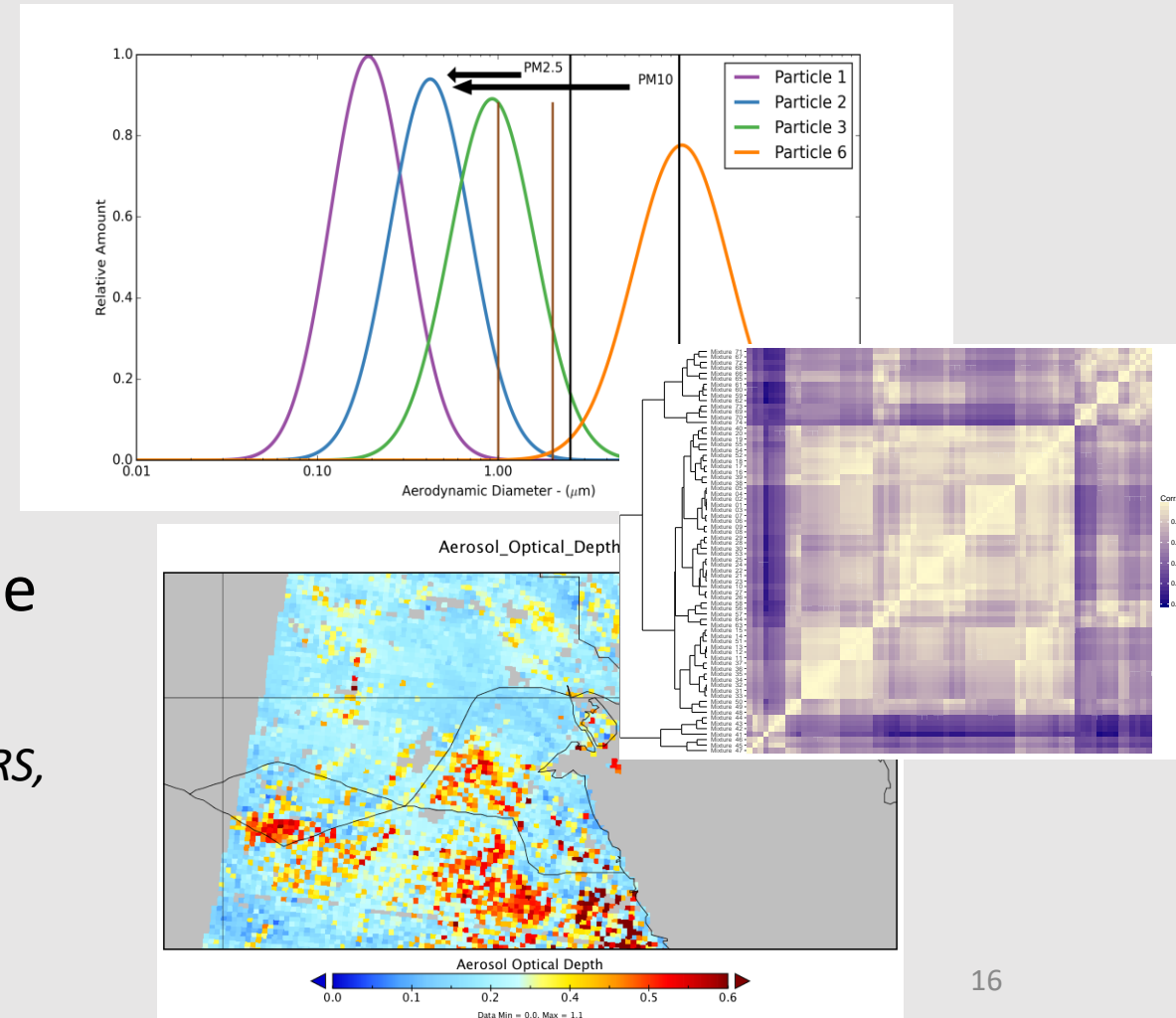
Speciated PM$_{2.5}$ from MISR

- Trained machine learning models in California using CSN data linked with coincident MISR mixtures and products

Model performance:
- CV R^2 nitrate and sulfate (regional sources) ~0.7
- CV R^2 EC (vehicle exhaust) 0.59
- CV R^2 dust 0.37

Note: not enough data for OC prediction (biomass burning/burnpits)

ARL

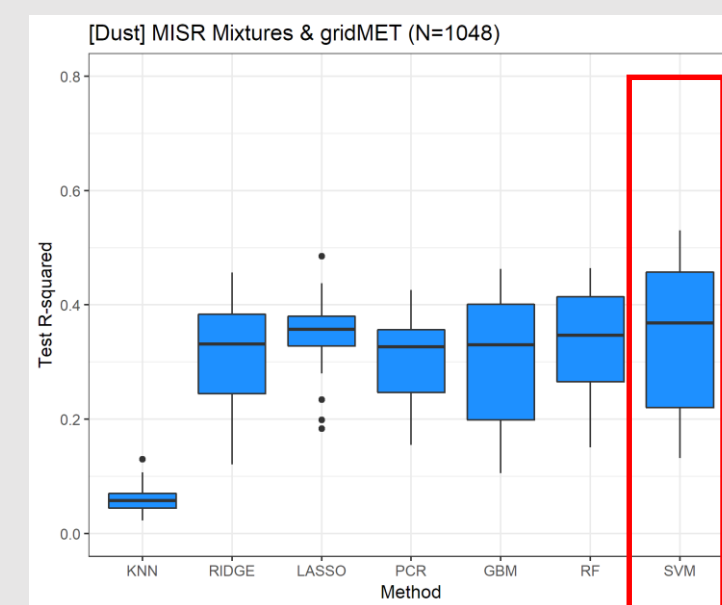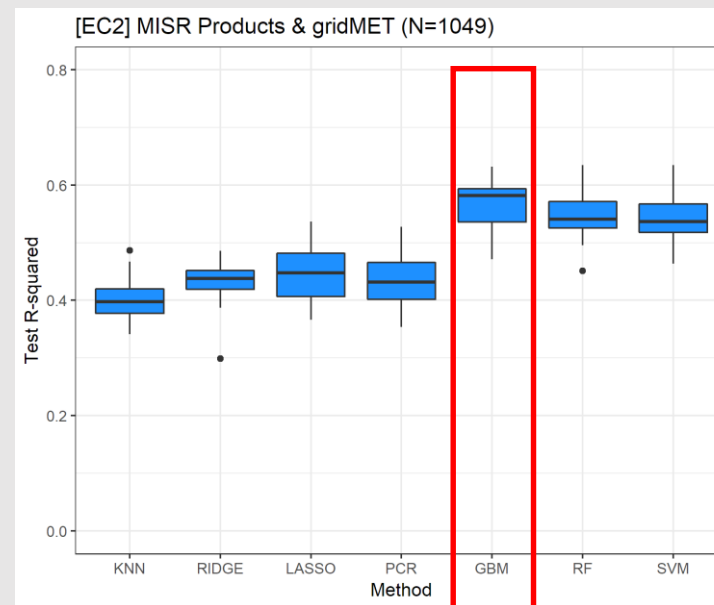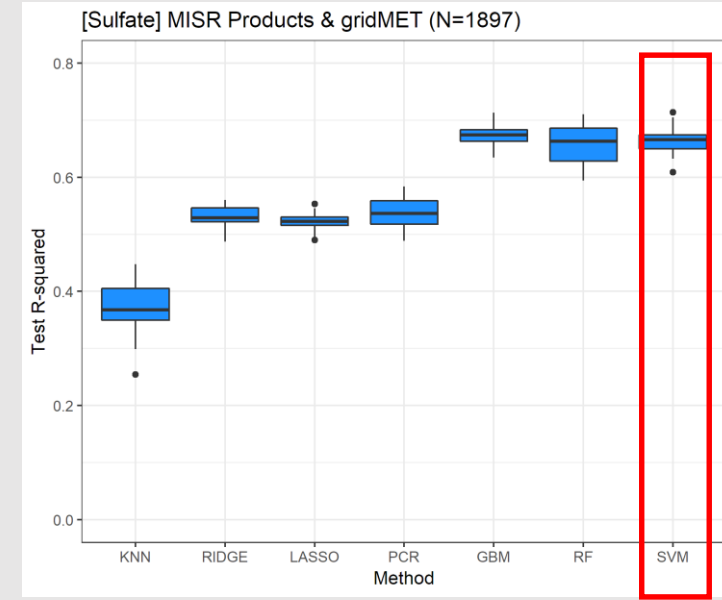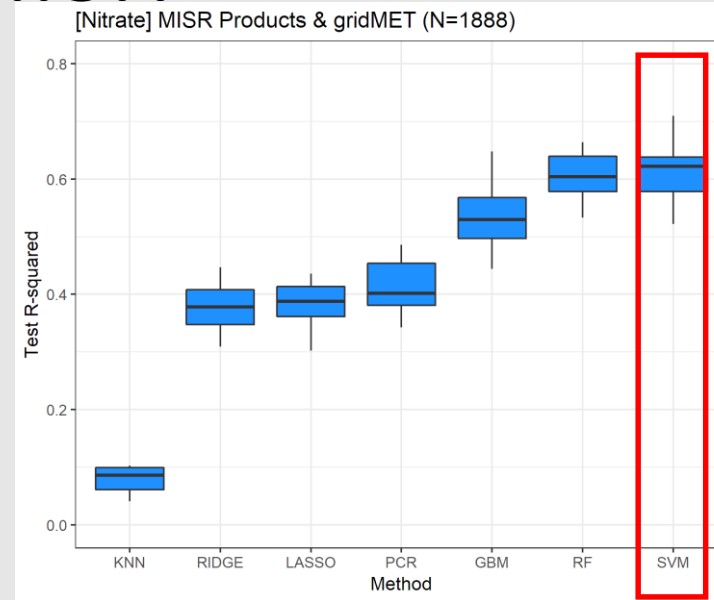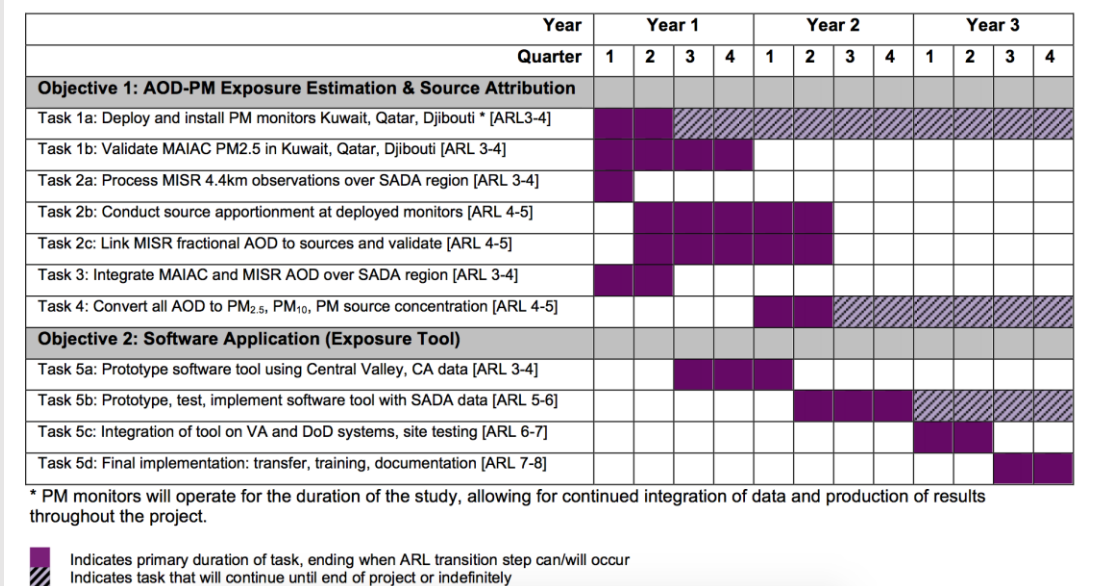- Started at 3, we are at 4+ (6 months in)
  - Meeting with VA end users (May 2019) and delivered prototype $PM_{2.5}$ data in July 2019
- Next step: implement MISR source-specific exposure methods in SADA region
  - Test on two $PM_{2.5}$ speciation sites in Kuwait, working on siting 1 more in Qatar
- Next step: prototype development of software tool using R Shiny integrated with leaflet for mapping
  - VA needs tool to be on their secure servers, connected to exposure database that is stored locally

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 PM2.5, PM10, 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

Acknowledgements

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Data Integration

Data		Data source	Spatial resolution	Temporal resolution
AOD		NASA MAIAC	1km	Daily
Visibility		United States air force airport	780 sites	Hourly
PM₂.₅	Kuwait: 2004-2005, 2017-now	Harvard	3 sites for 2004-2005;2 site for 2017-now	Around 2000 samples
	Kuwait: 2017-2018	EPA U.S. Embassy Kuwait	1 site	
	OpenAQ	US Embassies	4 sites	Hourly
	Iran	Iran cooperator	70-90 sites	Hourly
Dust	Dust Surface Mass Concentration	NASA MERRA-2	0.625°×0.5° And 7x7 km	Daily
	Dust Extinction AOD			
	Dust Scattering AOD			
	Dust Column Mass Density			
Land use	NDVI	NOAA AVHRR	5 km	Daily
	Road density	OpenStreetMap	1 km	--
	Distance to industrial area	U.S. Geospatial-Intelligence Agency	1 km	--
	Elevation	NOAA	1 arc-minute	--

Data Integration

Data		Data source	Spatial resolution	Temporal resolution
Meteorological data	Temperature at 2 m	ERA-5 Reanalysis produced by European Centre for Medium-Range Weather Forecasts	31 km	Daily
	U-wind speed at 10 m			
	V-wind speed at 10 m			
	Instantaneous 10m wind gust			
	Dew point temperature at 2m			
	Total precipitation			
	Surface pressure			
	Downward UV radiation			
	Planetary boundary layer height			
	Total cloud cover			
	Low cloud cover			
	Medium cloud cover			
	High cloud cover			
	High vegetation cover			
	Low vegetation cover			
	Forecast albedo			
	Evaporation			
	Relative humidity			

Military Health Studies – Current and Future

- VA Cooperative Study #595 Pulmonary Health and Deployment to Southwest Asia and Afghanistan
  - Estimated 1,400,450 Veterans from the Defense Manpower Data Center (DMDC) meet eligibility requirements
    - Served during the Post-9/11 Gulf War Era in a service branch that had land-based deployments (Air Force, Army, Marine Corps) (2.7M deployed)
    - Deployed to Afghanistan, Kyrgyzstan, Iraq, Kuwait, Qatar, United Arab Emirates, or Djibouti after October 1, 2001
    - Questionnaire, spirometry (lung function), asthma
    - Current recruitment plans up to 2022, expected enrollment ~5,000 participants (on target)
- Millennium cohort study (DoD, ongoing since 1991) N~200K

Exposure Assessment Tool
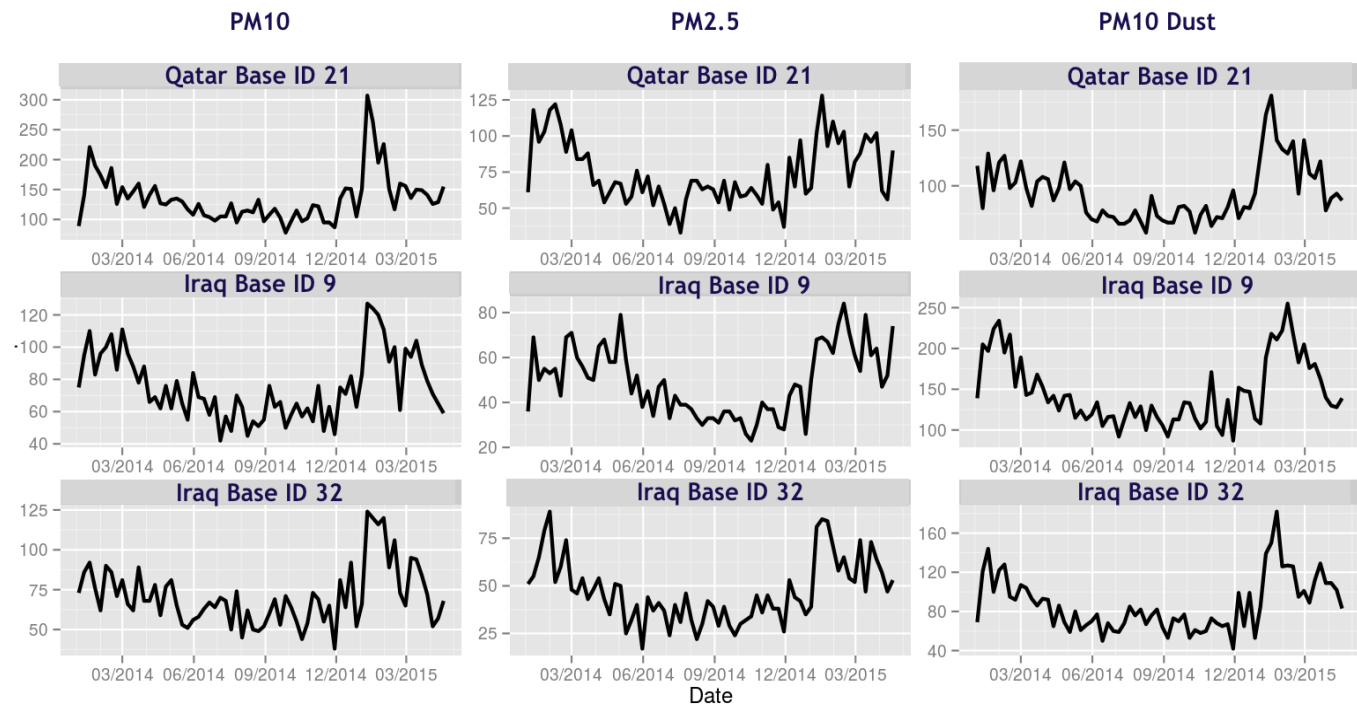
Kuwait Health Studies – Current and Future

- In collaboration with Kuwait Ministry of Health, examination of mortality records 2000-2016 (Achilleos et al, 2019) in an acute health study

- Found on low visibility days that the mortality rate higher than on low visibility days

- Dust storm days had even higher rates of death

- Future work planned to use these data with the estimated $PM_{2.5}$ and speciation concentrations

Health Studies – Current and Future

- VA Cooperative Study #595 Pulmonary Health and Deployment to Southwest Asia and Afghanistan
  - Estimated 1,400,450 Veterans from the Defense Manpower Data Center (DMDC) meet eligibility requirements
    - Served during the Post-9/11 Gulf War Era in a service branch that had land-based deployments (Air Force, Army, Marine Corps) (2.7M deployed)
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- Millennium cohort study (DoD, ongoing since 1991) N~200K
- Kuwait EPA studying health effects in collaboration with Kuwait Ministry of Health