M A I A

Associating particulate air pollution with human health

Multi-Angle Imager for Aerosols (MAIA)

IMPROVE Annual Meeting

Abbey Nastan
Kristal Verhulst

Jet Propulsion Laboratory
California Institute of Technology

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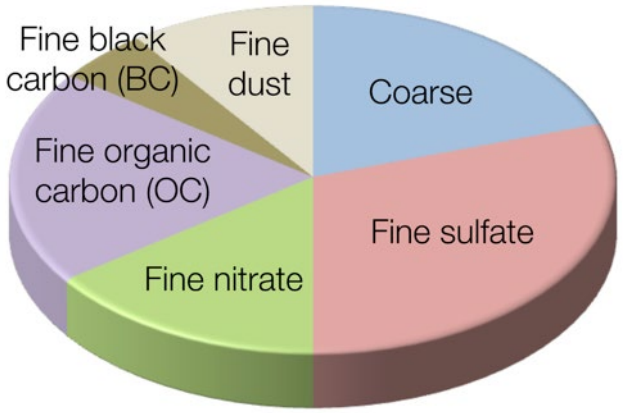
CL#19-

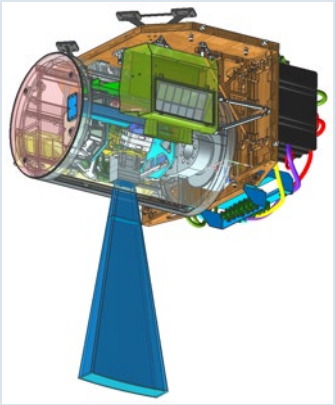
Motivation for MAIA

- Although PM is known to cause many health problems, the relative toxicity of specific PM types (fractional proportion of coarse particles, fine particles, and physical and chemical components) is not well understood.



- Surface monitors alone are too sparsely distributed to solve this problem.
- Many low- and middle income countries do not have resources or expertise to monitor air pollution.
- From space, we can map PM where people live and work and observe many different regions of the globe.

Elements of the MAIA investigation



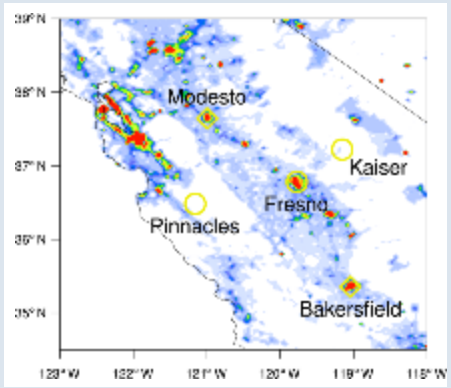
MAIA instrument

- Provides calibrated, georectified image data for retrieval of aerosol properties.

L. Tsutsui, KVPR

Surface PM monitors

- Used to calibrate the column aerosol-to-near surface PM relationships.



Chemical transport model (CTM)

- Assists spatial/temporal gap-filling.

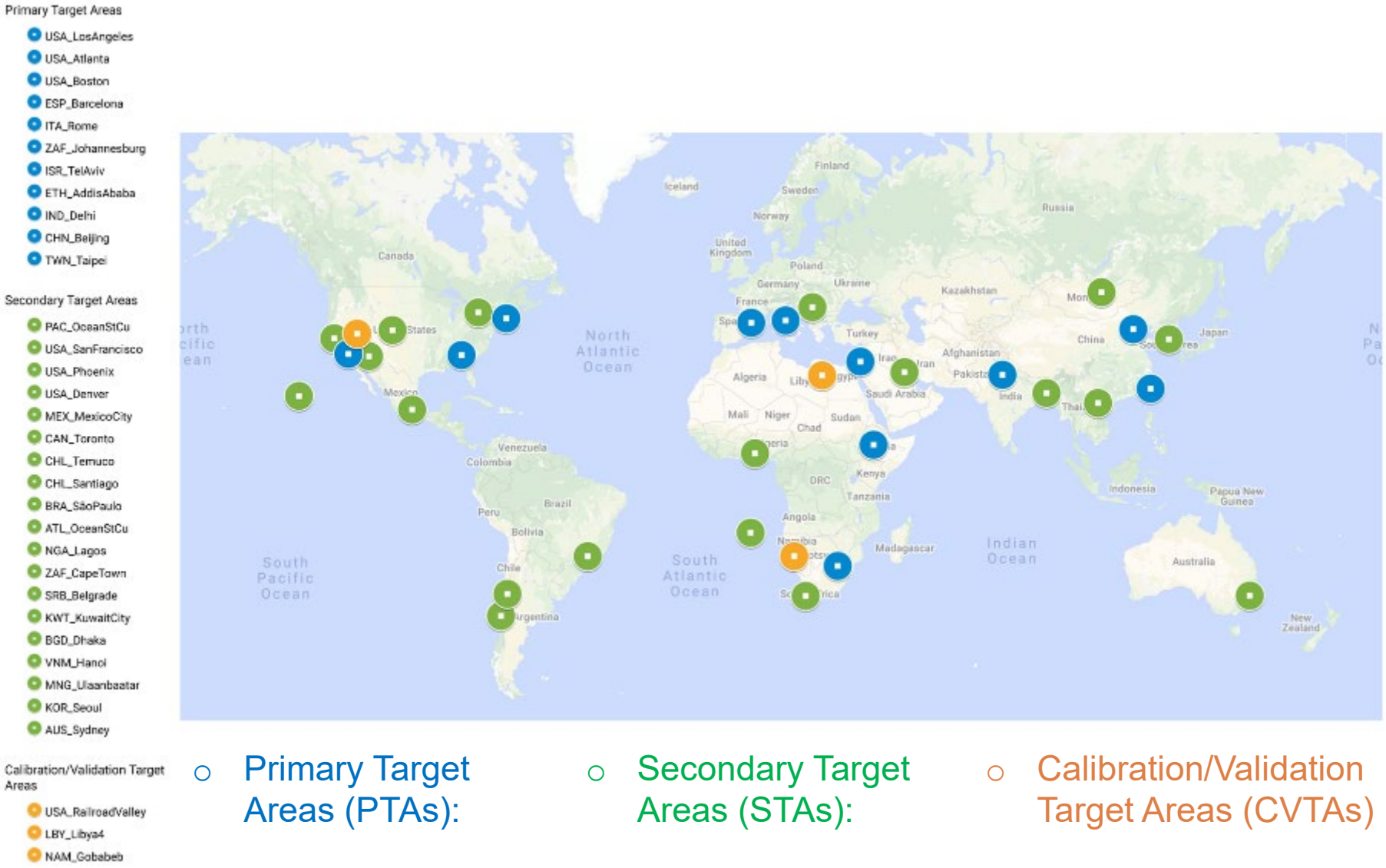
Health records

- Used to associate PM exposure with health effects.

Used to generate the archived and publicly distributed data products (free of charge) at the NASA Langley Atmospheric Science Data Center

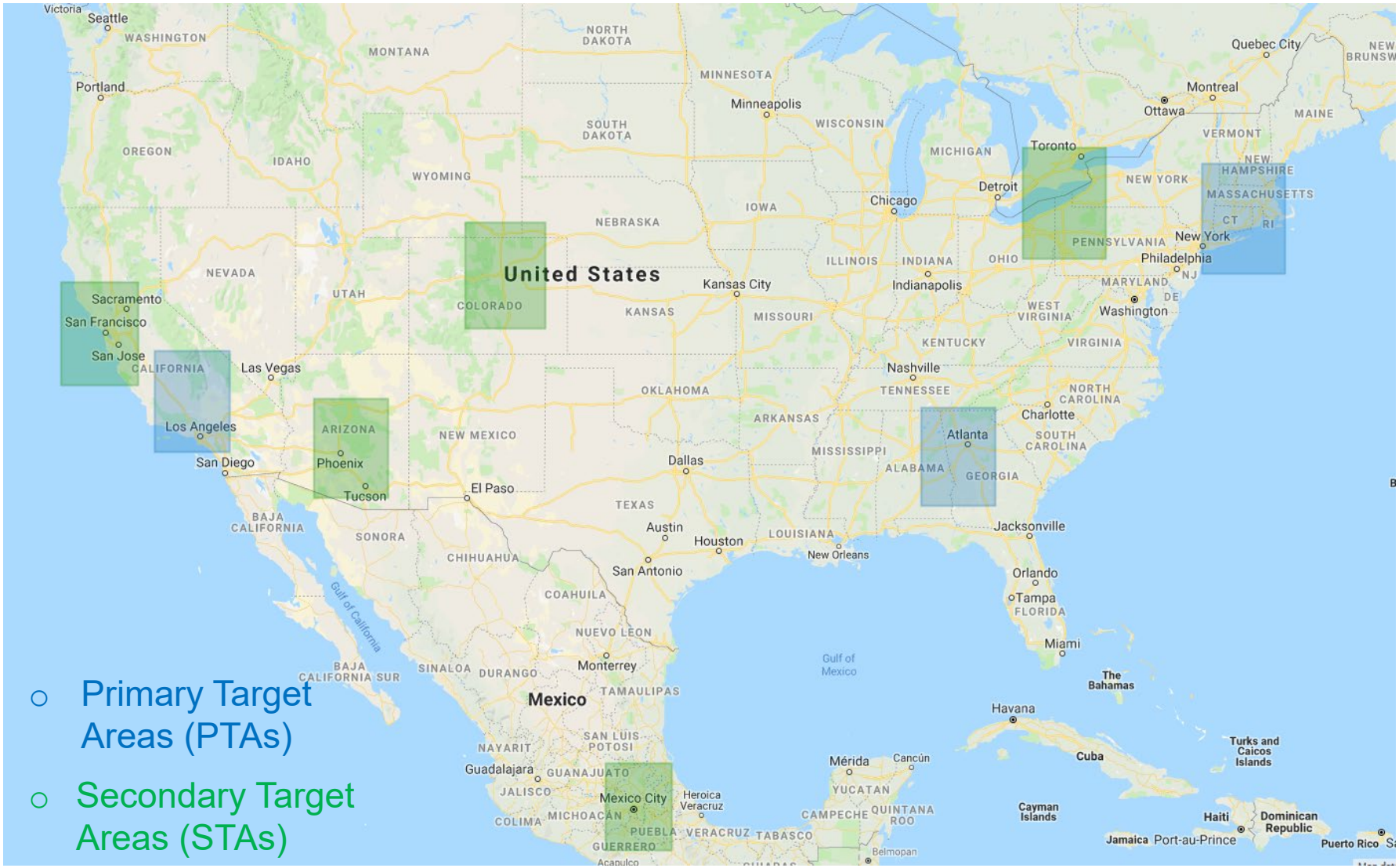
Privacy protected, not handled by NASA

MAIA investigation is target-based



- Primary Target Areas (PTAs):
- Secondary Target Areas (STAs):
- Calibration/Validation Target Areas (CVTAs)

North American target areas



- Primary Target Areas (PTAs)
- Secondary Target Areas (STAs)

Geostatistical Regression Model (GRM)

$PM_{2.5}$, PM_{10} monitor data

Collocated PM and predictor data are used to derive coefficients of Geostatistical Regression Models (GRMs).

Predictor weights are derived independently for each PTA.

A Bayesian multivariate framework is used.

The coefficients are updated as the mission progresses.

= α x Spatiotemporal terms

+ β x Aerosol optical depths (L2) or CTM PM (L4)

+ γ x Geospatial predictors (elevation, roads, vegetation)

+ δ x Spatiotemporal predictors (RH, PBLH, temperature, winds, additional aerosol parameters)

+ Errors

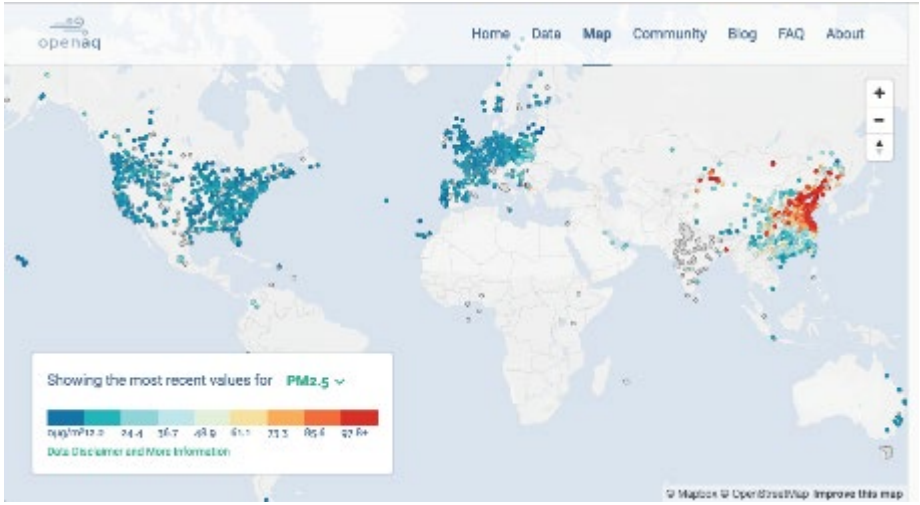
The calibrated GRMs are used to map PM at locations between monitors.

Surface Monitors are Essential for Producing the MAIA PM Data Products

- Surface monitors are used to transform the satellite column aerosol properties to surface Particulate Matter (PM) concentrations by type and species:
  - PM10 and PM2.5 total mass concentration
  - PM2.5 species:
    - sulfate, nitrate, organic carbon, elemental carbon, and dust
- Operational generation of MAIA PM products relies on availability of PM surface monitor measurements to calibrate the MAIA Geostatistical Regression Model (GRM) coefficients by type and species
- Total $PM_{2.5}$ and PM_{10} mass: measured continuously, data accessible online in near-real-time
- Speciated $PM_{2.5}$ mass fractions: measured using filters analyzed in chemical laboratories (mainly)
  - Most speciation data have a 6-12 month latency
  - Handling this latency is built into the MAIA data product generation flow

Approach for Identifying Sources of PM Data

- Conduct global inventory of existing monitors using industry standards:
  - **TOAR:** relational database of global AQ surface monitor observations; data products do not meet latency requirements
  - **OpenAQ-fetch:** open source software, a major tool that meets most of our development needs
- Establish/strengthen partnerships with data providers (gov't/academia/industry) to make data available to MAIA
- Deploy additional monitors where necessary:



https://openaq.org/

openaq

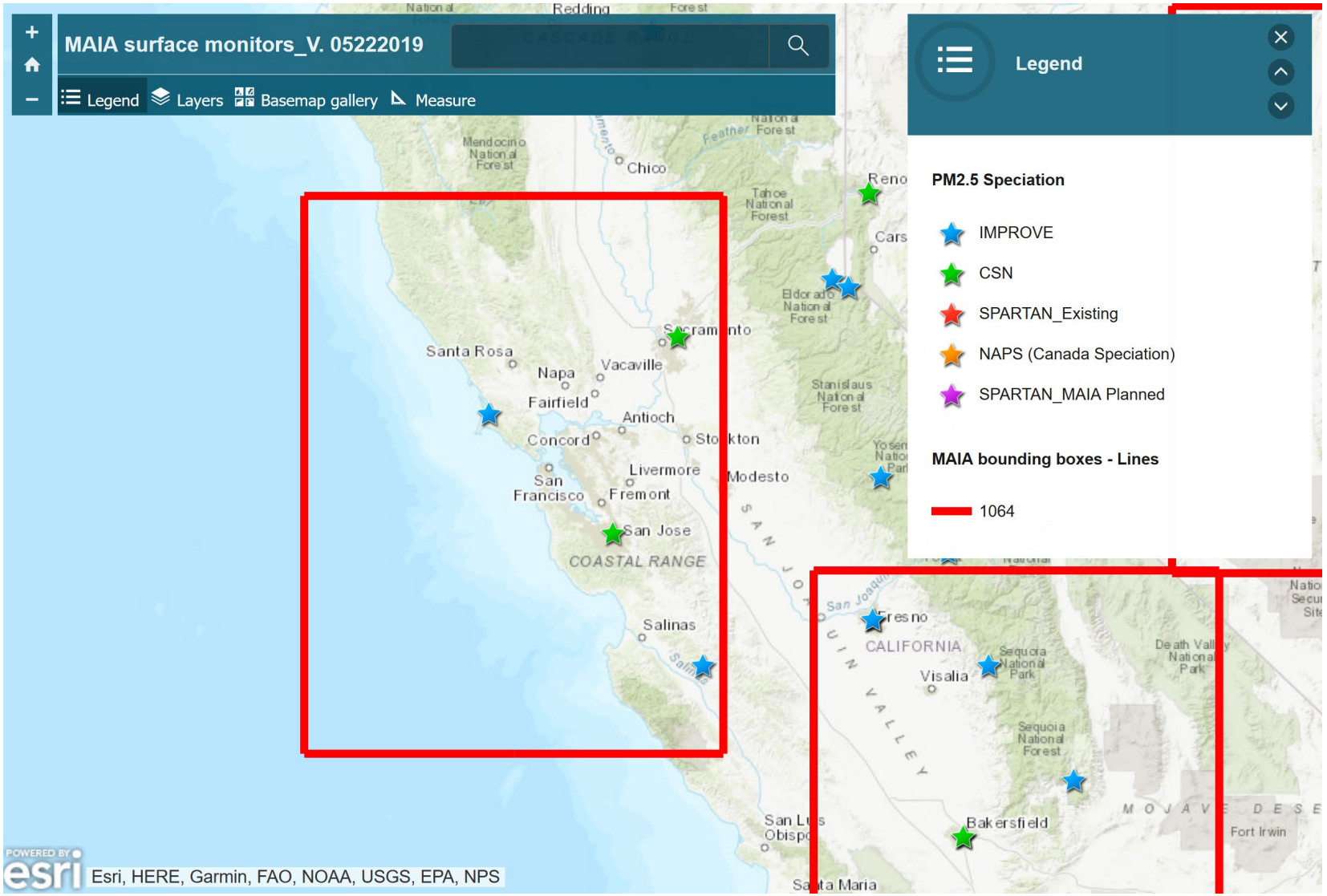
TOAR tropospheric ozone assessment report

SPARTAN Global Particulate Matter Network

AirPhoton (SPARTAN) PM2.5 speciation monitor

  - Expansion of the **S**urface **PART**iculate m**A**tter **N**etwork (**SPARTAN**) $PM_{2.5}$ speciation network (in partnership with SPARTAN PI/MAIA Co-I Randall Martin, Washington University)
  - Exploring low-cost monitor options (e.g. Ethiopia)

San Francisco target area



Surface PM Monitor Requirements and Compliance Assessment

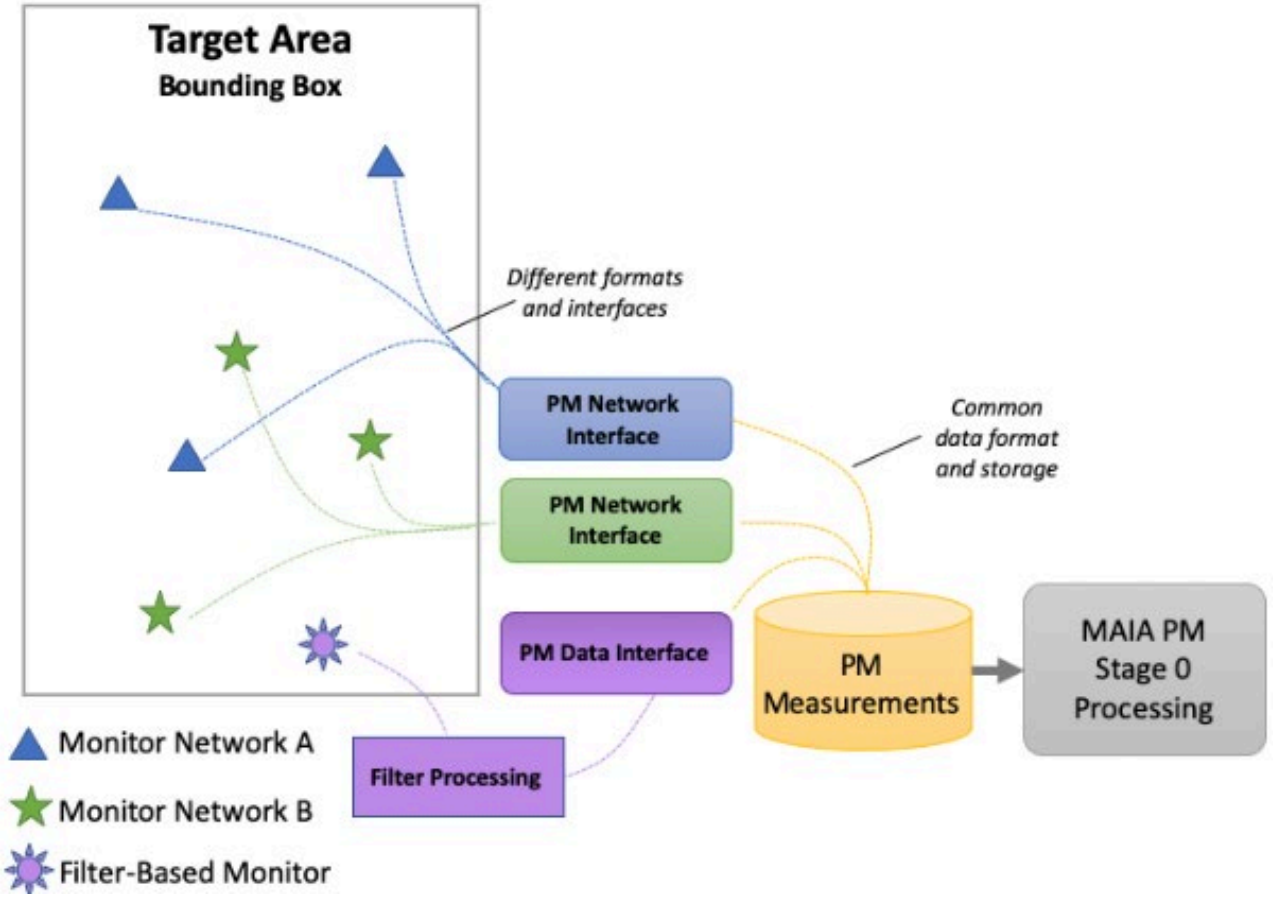
Category	Level 2 Project System Requirements		Compliance
Monitors within each PTA	Aerosol sunphotometers (AERONET)	≥1	See next chart
	Total $PM_{2.5}$, PM_{10} monitors	≥10 (PM2.5), ≥4 (PM10)	See next chart
	Speciated $PM_{2.5}$ monitors	≥ 2	See next chart
	Agreements for data access	Where needed	In progress
Spatial sampling	Total $PM_{2.5}$ and PM_{10} monitors	≥1 neighbor, ≥ 80 km away ≥1 neighbor, ≤120 km away	Comply
Sampling intervals for 24-hour averaged PM conc.	Total $PM_{2.5}$ and PM_{10}	Daily	Daily or finer
	Speciated $PM_{2.5}$	Every 3 days or better	CSN/IMPROVE 3 days SPARTAN/AMOD: 2 days on avg.
Data latency	Total $PM_{2.5}$ and PM_{10}	≤1 month of availability	Via online data access
	Speciated $PM_{2.5}$	≤12 months of availability	Via interface agreements to be established with providers
Data sources	Recognized government agencies (where available) Otherwise, deploy additional PM monitors whose performance is referenced to established standards		All PTAs except Ethiopia, where reference and low-cost sensors will be collocated

Surface PM Monitor Availability and Compliance Assessment

Target type	Target Name	# AERONET sun-photometers	# Continuous PM monitors		# PM2.5 speciation monitors (CSN, IMPROVE, SPARTAN)	# Co-located AERONET/ PM2.5 speciation monitors
			PM10	PM2.5		
PTA	USA-LosAngeles	9	33	34	9 (5 IMPROVE)	2-4
PTA	USA-Atlanta	1	7	14	7 (2 IMPROVE)	0-1
PTA	USA-Boston	6	9	31	12 (5 IMPROVE)	1 or 2
STA	USA-Phoenix	3	42	15	9 (8 IMPROVE)	1 (maybe 2?)
STA	USA-Denver	6	4	11	5 (1 IMPROVE)	2
STA	USA-SanFrancisco	2	6	40	4 (1 IMPROVE)	0
STA	USA-Toronto	1	1	27	17 (1 IMPROVE)	1
CVTA	USA-RailroadValley	1	0	0	1 (1 IMPROVE)	0

- Co-location between PM2.5 speciation monitors and AERONET sunphotometers is needed to test the algorithms that will be used by the MAIA investigation
- Currently, most target areas have very limited co-location between PM2.5 speciation monitors and AERONET sunphotometers

Methods for Surface Monitor Data Access are Established



Flexible design, adaptable to different data access methods/locations/protocols, and handling different data formats

Sources of Continuous $PM_{2.5}$, PM_{10} Data are Established

PTA	Source	URL used to obtain data
USA-LosAngeles	AirNow	https://docs.airnowapi.org/
USA-Atlanta	AirNow	https://docs.airnowapi.org/
USA-Boston	AirNow	https://docs.airnowapi.org/
ESP-Barcelona	EEA, EBAS	http://discomap.eea.europa.eu/map/fme/AirQualityExport.htm http://ebas.nilu.no/default.aspx
ITA-Rome	Arpae Emilia-Romagna, ARPALAZIO	https://dati.arpae.it/dataset/qualita-dell-aria-rete-di-monitoraggio/resource/a1c46cfe-46e5-44b4-9231-7d9260a38e68 http://www.arpalazio.net/main/aria/sci/annoincorso/chimici.php
ZAF-Johannesburg	SAAQIS	https://saaqis.environment.gov.za/Report/HourlyReports https://saaqis.environment.gov.za/Report/AutomaticData
ISR-TelAviv	Israel MoEP	https://www.svivaaqm.net:44301/v1/envista/
ETH-AddisAbaba	StateAir	http://dosairnowdata.org/dos/RSS/AddisAbabaCentral/AddisAbabaCentral-PM2.5.xml
IND-Delhi	CAAQM, StateAir	https://app.cpcbccr.com/caaqms/caaqms_landing_map_all http://dosairnowdata.org/dos/RSS/NewDelhi/NewDelhi-PM2.5.xml
CHN-Beijing	StateAir, pm25.in	http://www.stateair.net/web/rss/1/1.xml http://www.pm25.in/api/querys/all_cities.json?token=ydQFhKxavsfJtUW4LZBg
TWN-Taipei	Taiwan EPA	https://opendata.epa.gov.tw/webapi/api/rest/datastore

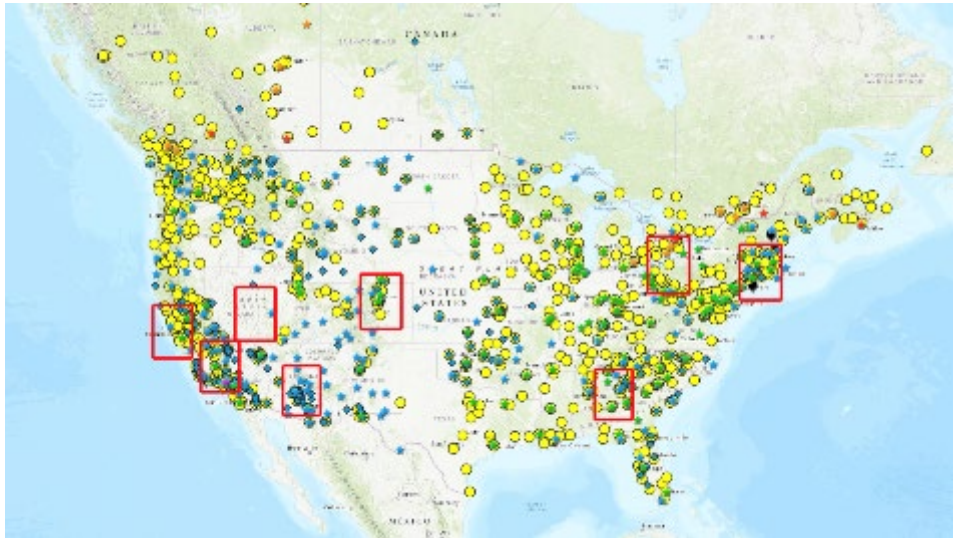
Sources of Speciated $PM_{2.5}$ Data are Established

CSN/ IMPROVE MetOne SASS	SPARTAN AirPhoton SS5i-PM2.5	AMOD 2.0 Colorado State University	AethLabs MicroAeth-alometer 350
Already exist in multiple MAIA targets	Delivery July 2019	Procurement in process	Coordinating with vendor and State Dept.

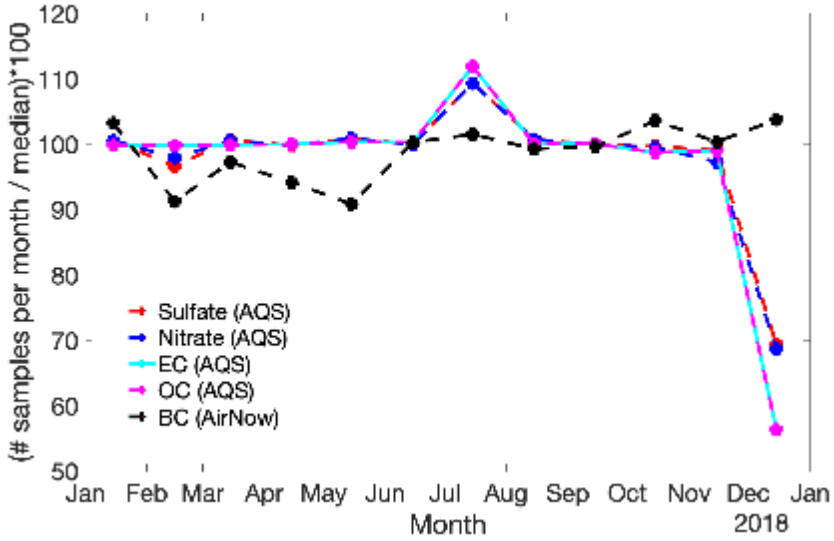
We are currently accessing data from existing speciation monitors (CSN/IMPROVE)
Additional monitors will be deployed where necessary

Implementation Progress for Surface Monitor Data Access in US Targets

Map of Monitor Locations and MAIA's U.S. Target Areas



% Samples Available per Month per PM2.5 species

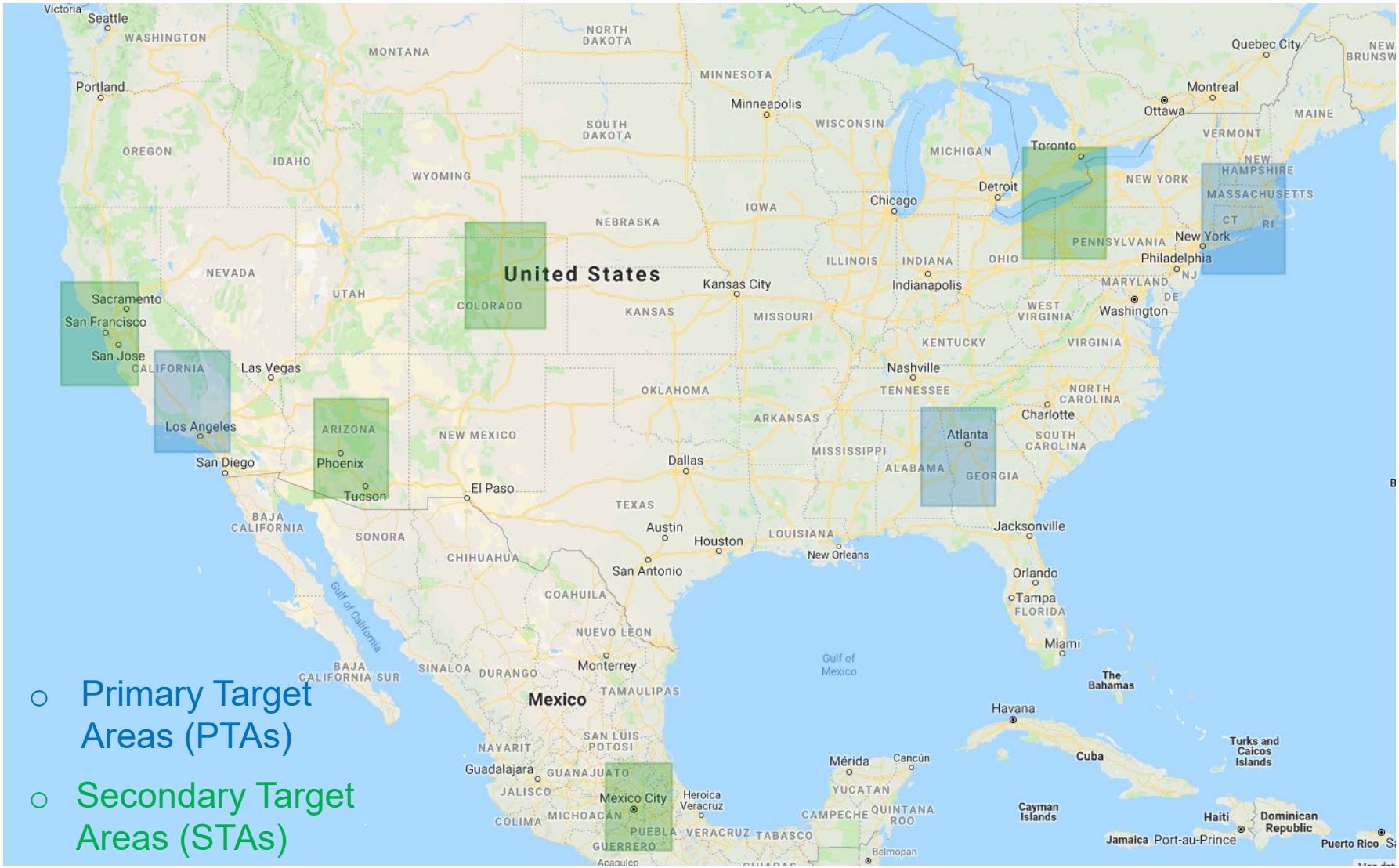


Target Type	Target name	Primary data sources
PTA	USA_Boston	AirNow (PM2.5, PM10): https://docs.airnowapi.org/ AQS (PM2.5 species): https://aqs.epa.gov/aqsweb/documents/data_api.html
PTA	USA_Atlanta	
PTA	USA_LosAngeles	
STA	USA_SanFrancisco	
STA	USA_Phoenix	
STA	USA_Denver	
STA	MEX-MexicoCity	

Summary

- Continued open access to PM surface monitor data (including data from the IMPROVE network) is critical to meeting MAIA objectives.
- MAIA will map PM mass and its major chemical components for a selected set of globally distributed targets, including 3 Primary Target Areas in the US (Los Angeles, Boston, Atlanta)
- MAIA satellite observations will be integrated with surface monitor PM measurements to produce PM maps at 1-km resolution.
- Latency of the surface monitor data (including IMPROVE network data) is important in the overall MAIA PM processing chain.
- The MAIA project will supplement the existing SPARTAN PM speciation network with additional stations and deploy other monitors as needed.
- Co-location of PM2.5 speciation monitors with AERONET sun-photometers is needed for initial end-to-end testing of the algorithms.

North American target areas



- Primary Target Areas (PTAs)
- Secondary Target Areas (STAs)

MAIA Secondary Target Areas

Secondary Target Areas (STAs) are designated for addressing MAIA's secondary science objectives (e.g., cities with major pollution, aerosol source regions, climatically important cloud regimes)

- Candidate set currently includes **19 sites**
- Selection criteria
  - Science value to the MAIA investigation
  - **Inputs obtained from Early Adopters**
  - Availability of surface monitor data and potential for air quality and/or health studies if aerosol or PM processing is relevant
  - Frequency of observation from orbit and manageability of conflicts with PTAs

Reminder: There are no program-level requirements to have STAs – PTA requirements must be fulfilled first to meet our commitment to NASA. STAs are used to satisfy project goals for enhanced science.

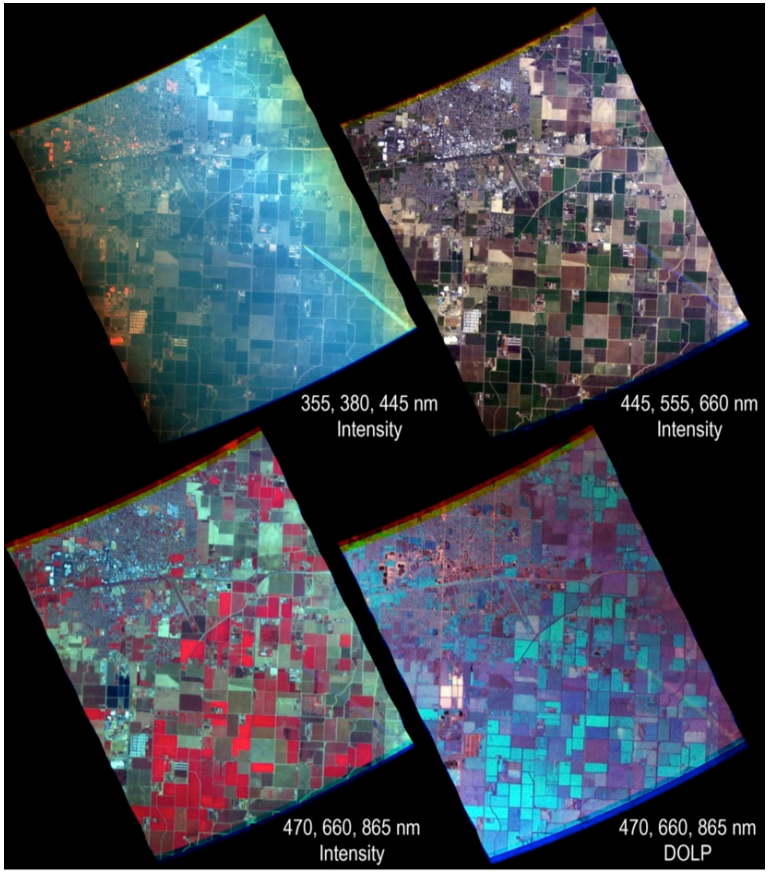
MAIA's Early Adopter program

- Phase C (now – June 2020)
  - MAIA Applications Plan (now available!)
  - Gather potential Early Adopters
  - Hold initial workshops
- Phase D (June 2020 - launch!)
  - Continue to develop Early Adopter relationships and hold workshops
  - Develop test data products and share with Early Adopters
  - Begin developing user guides, tutorials, and short courses
  - Add applications info to the MAIA website
- Operations (launch - 2025)
  - Hold workshops, short courses, and tutorials
  - Add and maintain user resources

MAIA data product summary

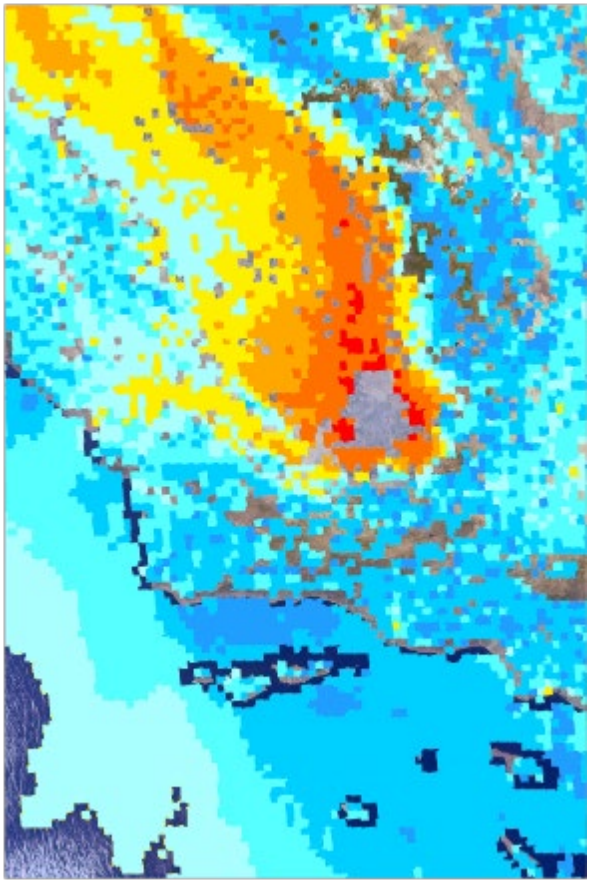
01010100 01101000
01101001 01110011
00100000 01101001
01110011 00100000
01110100 01101000
01100101 00100000
01110010 01100001
01110111 00100000
01100100 01100001
01110100 01100001
00100000 01100110
01110010 01101111
01101101 00100000
01001101 01000001
01001001 01000001

Level 0 data: raw bits from the instrument

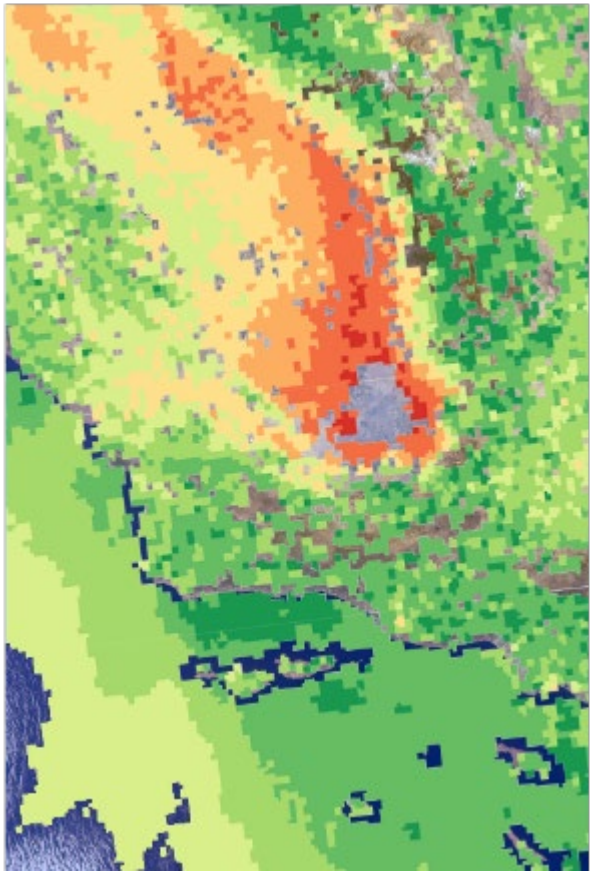


Level 1 data: what the instrument is actually "seeing", mapped, ~250 m

MAIA data product summary

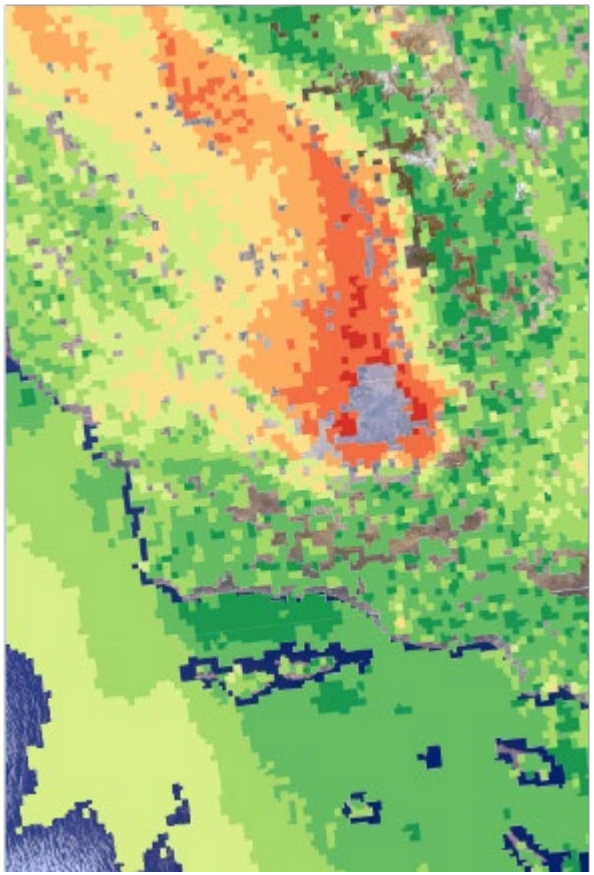


Level 2 aerosol data: AOD, other aerosol properties, mapped, ~1 km



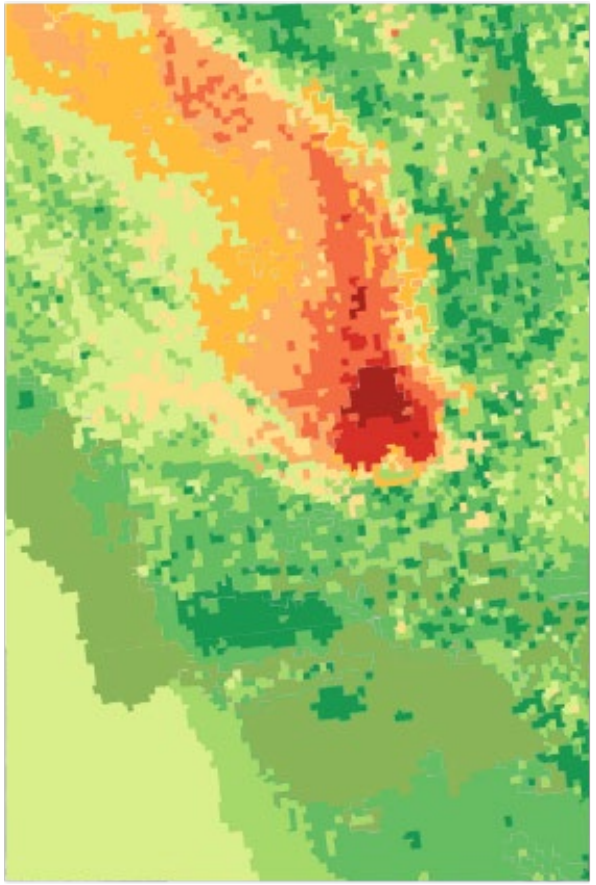
Level 2 PM data: PM concentrations, mapped, ~1 km, daily averaged **(days of overpass)**

MAIA data product summary



Concentrations of:

- Total PM_{10}
- Total $PM_{2.5}$
- Sulfate $PM_{2.5}$
- Nitrate $PM_{2.5}$
- OC/EC $PM_{2.5}$
- BC $PM_{2.5}$
- Dust $PM_{2.5}$



Level 2 PM data: PM concentrations, mapped, ~1 km, daily averaged **(days of overpass)**

Level 4 PM data: PM concentrations, daily averaged, mapped, **gap-filled**, **every day**, ~1 km

Take-aways

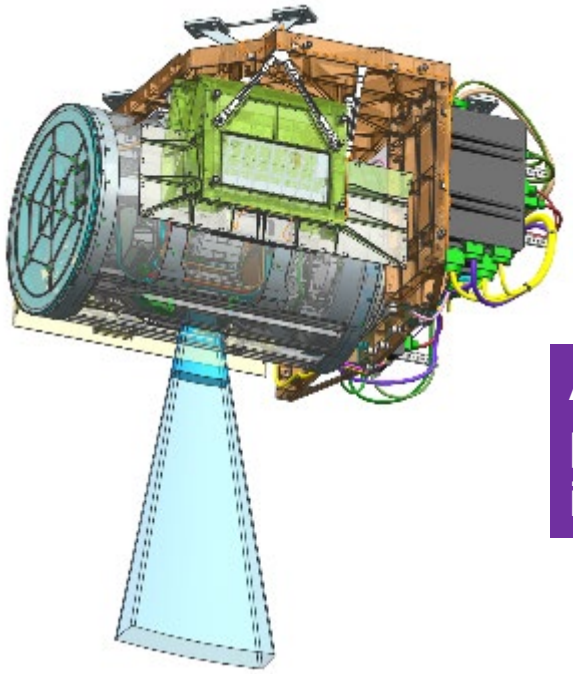
- What is most important/relevant to MAIA:
  - Timely data access
    - We need access to PM2.5 species data within 1 year of collection
  - Matchups between PM2.5 speciation monitors and AERONETs
    - Currently, only a few stations are co-located
- Questions:
  - What is the current reporting protocol / expected data latency for IMPROVE station data?
  - Are there future changes to data access/availability we should be aware of? If so, what is best way to stay informed?
  - Is the IMPROVE community open to prioritizing data access/availability from IMPROVE sites that overlap with some of our PTAs (and possibly STAs)?
  - How can we improve co-location between PM2.5 speciation monitors and AERONETs (requires coordination with AERONET PI: B. Holben)?

MAIA website: https://maia.jpl.nasa.gov

- Check out the MAIA Applications Plan and MAIA Early Adopters Workshop Report
- Join the Community Contacts List to be an Early Adopter! Email anastan@jpl.nasa.gov

Backup

MAIA instrument provides multiangular, multispectral, polarimetric imagery



The instrument contains a pushbroom multispectral/ polarimetric camera on a 2-axis gimbal

Along-track (scan) axis provides multiangle imagery (±70º at Earth)

Cross-track (pan) axis enables ≥3 revisits/week per target (on average)

Band (nm)	365	387	415	442	550	645	749	762.5	866	945	1040	1610	1885	2125
Polarimetric				✓		✓					✓			

Aerosol absorption

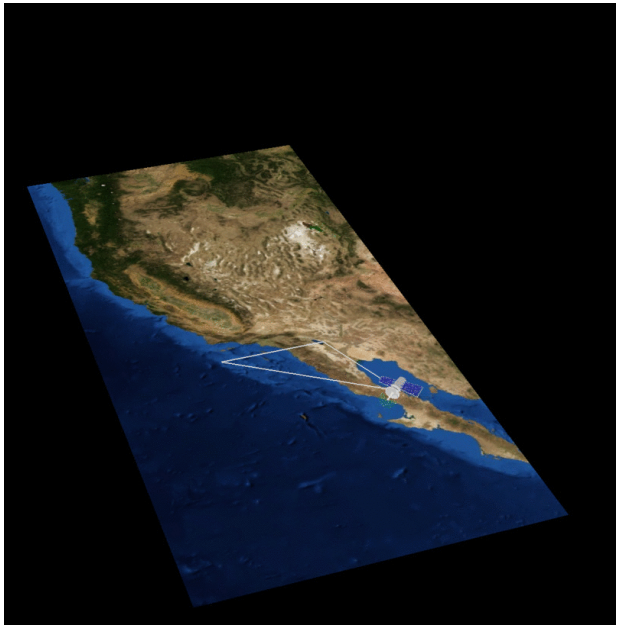
Fine particles cloud screening

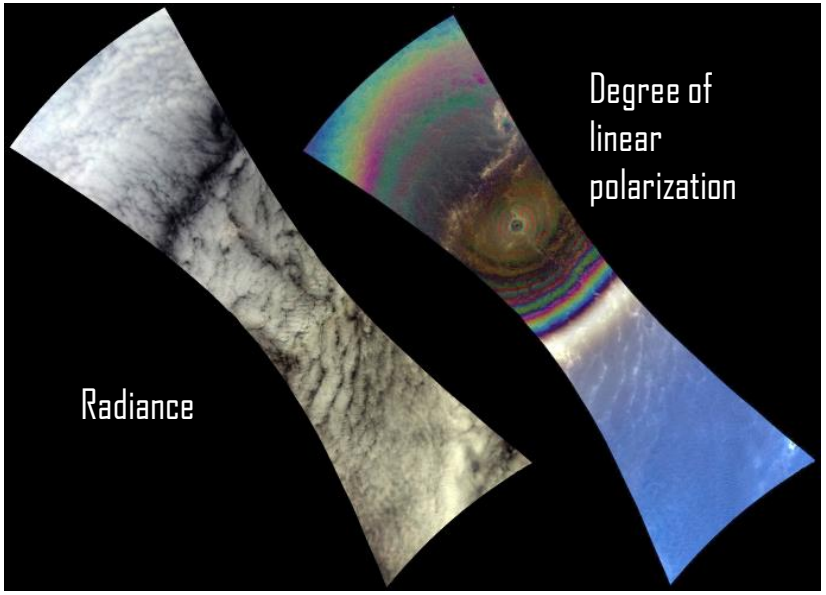
Water vapor

Coarse particles, cirrus

MAIA Earth observation modes

- Most Earth targets will be observed in "step and stare" mode
  - The scan axis allows observing at 5 – 9 view angles in sequence
  - The pan axis allows observations of targets off the sub-satellite track





Sweep mode is used for study of cloud micro-physics to support MAIA secondary investigation objectives

MAIA data product summary

Level	Description	First production; Latency	Anticipated Users
0	Downlinked instrument telemetry	6 months; <24 hours	MAIA team
1	Calibrated and georectified Stokes parameters describing radiance and linear polarization; view and solar geometry; latitude and longitude	6 months; <36 hours	MAIA team, non-aerosol users (e.g. cloud or land surface researchers)
2a	Cloud mask and cloud-screened total and fractional aerosol particle properties at time of satellite overpass	12 months; <48 hours	Aerosol researchers, exposure researchers, MAIA epidemiologists
2b	24-hr averaged concentrations of coarse PM, fine PM, and fine PM components on days and locations coincident with cloud-free and quality-controlled instrument observations of the MAIA PTAs	12 months; <72 hours	Exposure researchers, MAIA epidemiologists
4	Spatially and temporally gap-filled 24-hour averaged concentrations of daily coarse PM, fine PM, and fine PM components over the MAIA PTAs	18 months; <72 hours	Epidemiologists, air quality modelers, air quality managers

These are the currently projected performances; subject to change

MAIA data product summary

Spatial resolution: ~250 m for Level 1; ~1 km for Level 2 and 4

Temporal resolution:

- Overpass time: Late morning for most targets
- Overpass frequency: ~3.5 times per week for PTAs, and less than this for STAs.
- MAIA L0, L1, and L2 data will be produced for the time of overpass
- MAIA L4 data (daily averaged) will be produced for each day, **but will have better quality on days with an overpass**

Data product format: NetCDF

Preliminary/final products: The GRM producing the L2 and L4 PM products will be regenerated periodically to improve performance with more MAIA and surface monitor data. Therefore, preliminary data made with the current GRM will be available within a few days of overpass, but the final and best quality products will not be produced until end of prime mission.

AOD accuracy requirement: "The MAIA Project's mid-visible column AOD shall be retrieved with 1-sigma uncertainty given by ±max(0.05, 20%*AOD)."

PM accuracy requirement: "The MAIA Project derived PM concentrations shall have regression slopes compared to collocated surface monitor data between 0.5 and 1.5 after 2 years of data collection, when the matchups are statistically aggregated over all PTAs."

Current health study plans in the PTAs (subject to update)

USA-LosAngeles	Cause-specific mortality
	Low birth weights, preterm deliveries
USA-Atlanta	Respiratory morbidity
USA-Boston	Mortality, heart attack, stroke, pneumonia
	Birth weight, gestational age
	Mortality, heart attack, stroke, pneumonia
ESP-Barcelona	Multiple outcomes from primary care ctrs.
ITA-Rome	Cause-specific mortality, disease-specific hospitalizations (cardiovascular/respiratory disease, diabetes, neurological disorders)
	Same as above
ZAF-Johannesburg	Cause-specific mortality due to ischemic heart disease, stroke, pneumonia, COPD, diabetes
ISR-TelAviv	Mortality, heart attack, stroke, pneumonia
	Birth weight, gestational age, congenital anomalies
	Mortality, heart attack, stroke, pneumonia

ETH-AddisAbaba	Preeclampsia, low birth weight and tuberculosis, child mortality/growth/lung function/cognition
Northern China	Atherosclerotic cardiovascular disease (ASCVD) including nonfatal myocardial infarction, coronary heart disease death, fatal/nonfatal stroke
Northern India	Cardiovascular mortality, cardiovascular and respiratory morbidity and hospitalization, possibly lung function in children and adults
Taiwan	Preterm birth, low birth weight, small for gestational weeks, and maternal pregnancy complications (preeclampsia, hypertension)

Acute | Subchronic | Chronic

MAIA simulated data products progress

Motivation/Objective: to provide MAIA Early Adopters with test data products, so they can provide feedback and prepare to integrate the actual MAIA products into their work post-launch

Tasks:

- Select proxy input datasets to stand in for MAIA data system inputs (see next slide)
- Make needed adaptations to MAIA algorithms in development to handle the proxy inputs
- Test the MAIA data system production with the modified algorithms
- Validate the results
- Package and distribute the results to Early Adopters

Timeline: initial version of test data products ready by ~October 2020

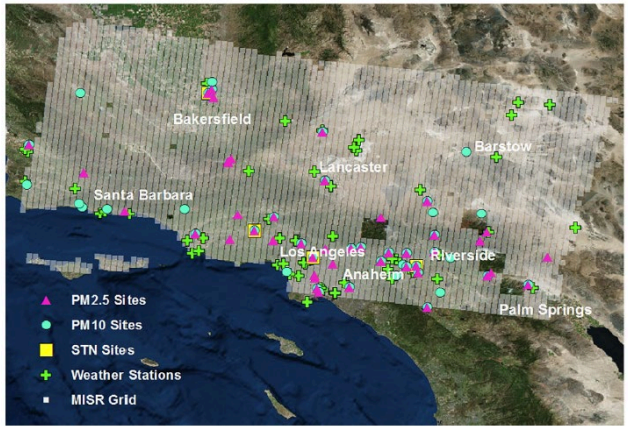


Figure 1. Map showing MISR 4.4 km grids, locations of EPA surface monitors measuring particulate matter, and weather stations in Southern California (from Franklin et al., 2018)

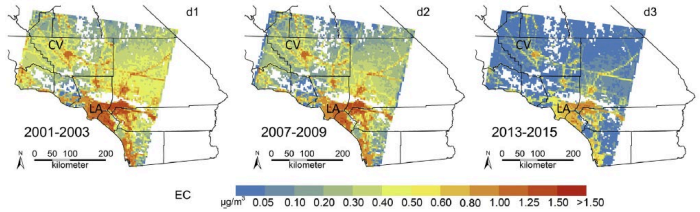
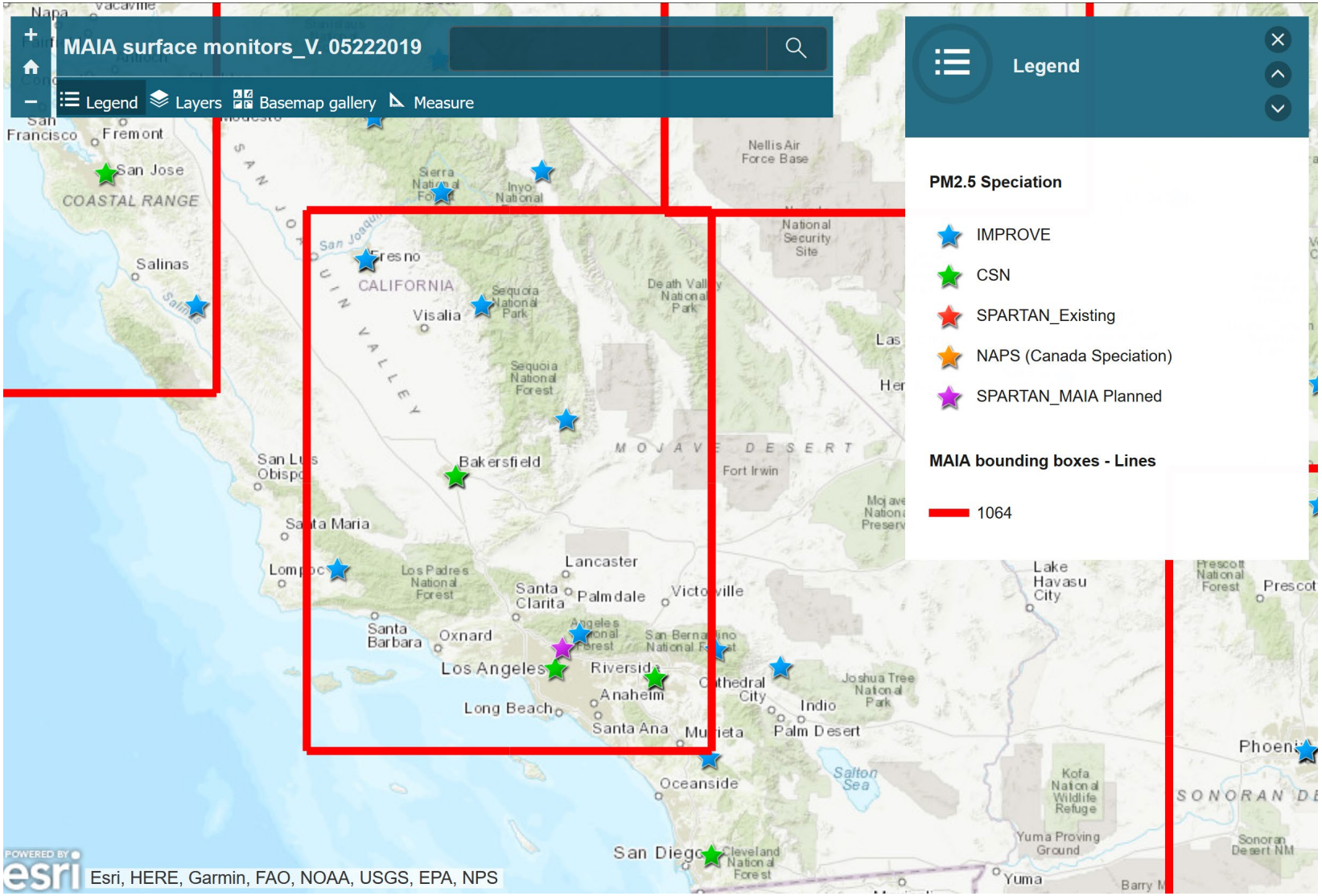
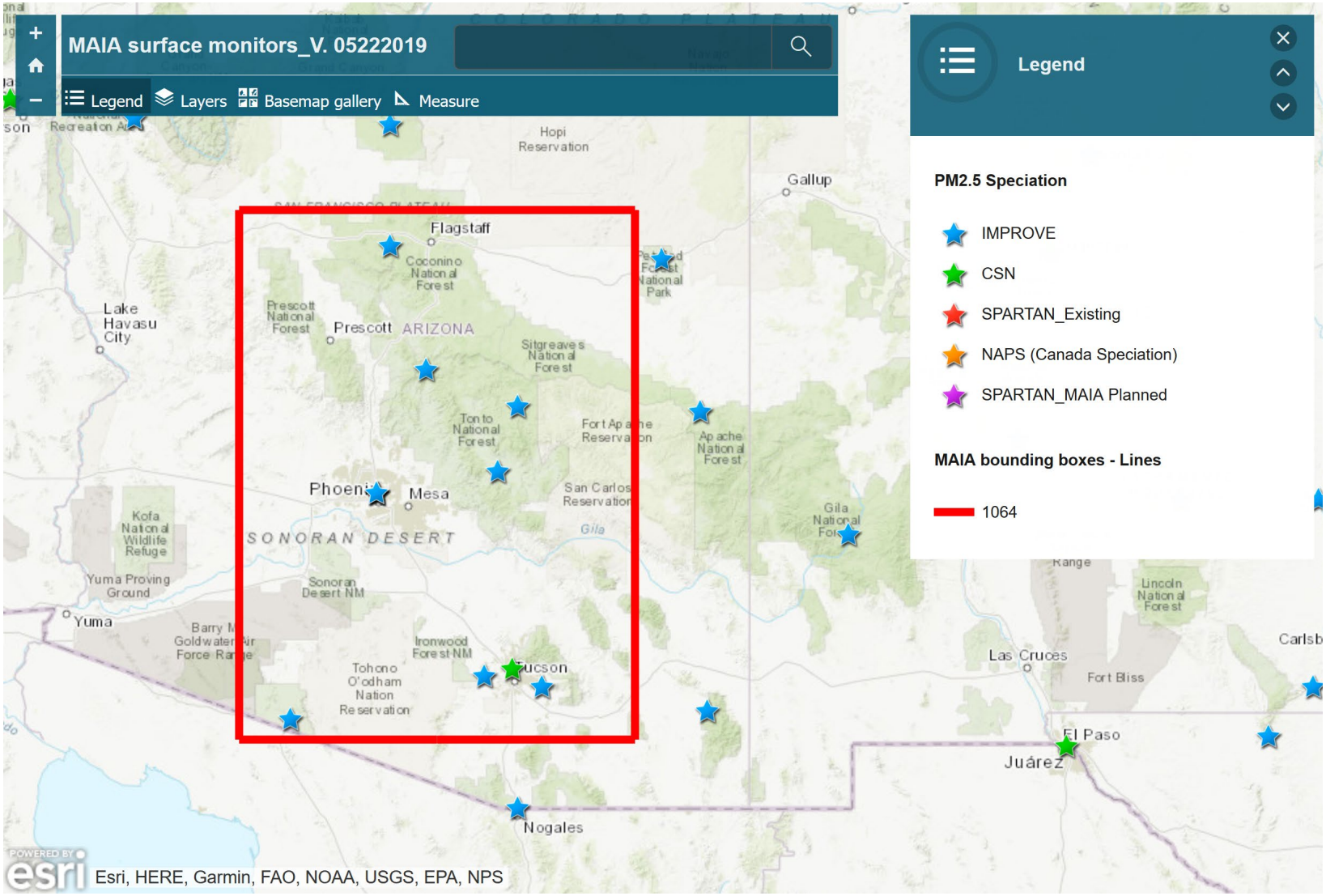


Figure 2. Map of 3-year averaged annual mean concentrations of ground-level $PM_{2.5}$ Elemental Carbon fractions in Southern California for three time periods, 2001-2003, 2007-2009, 2013-2015 (modified from Meng et al., 2018).

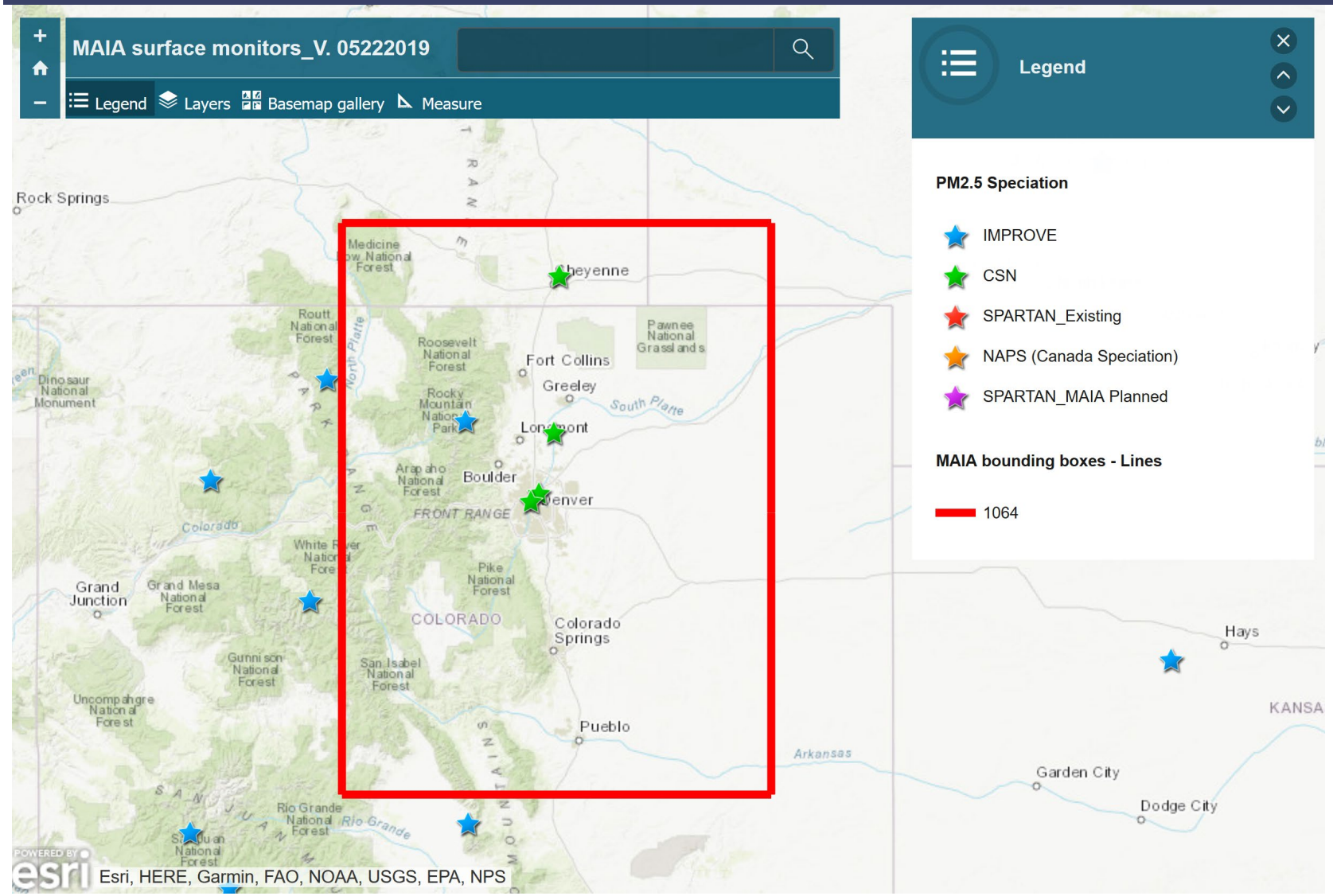
Los Angeles target area



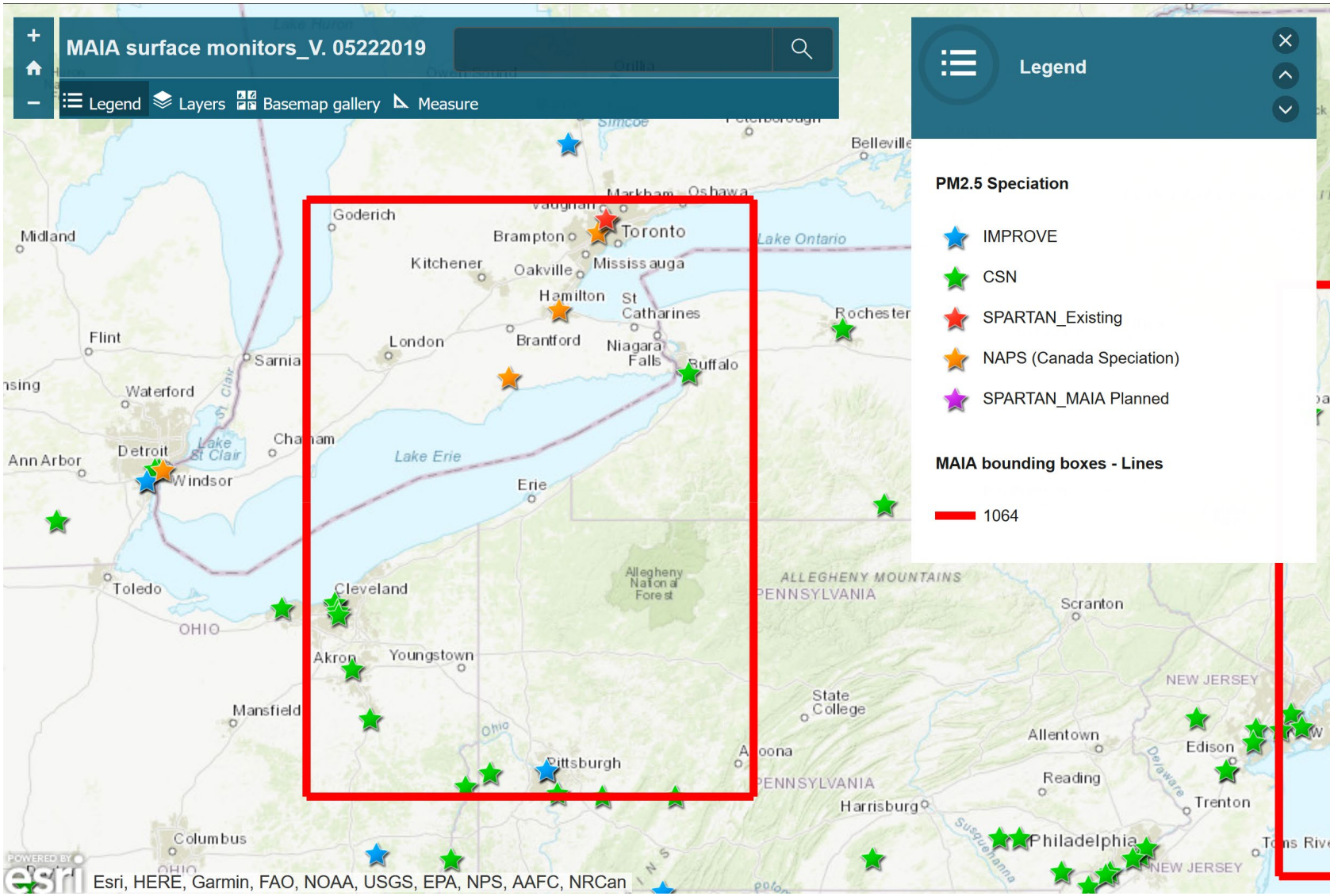
Phoenix target area



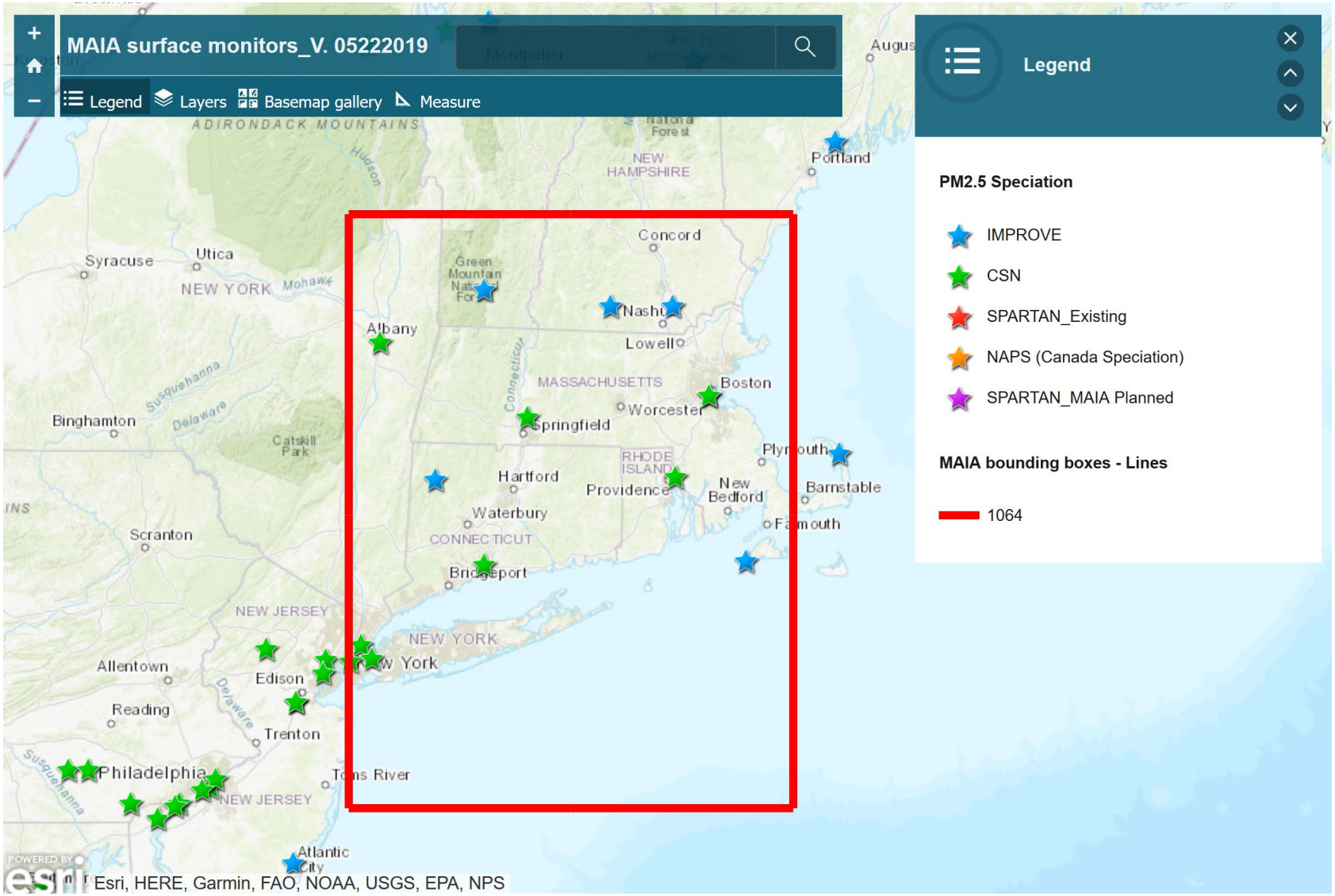
Denver target area



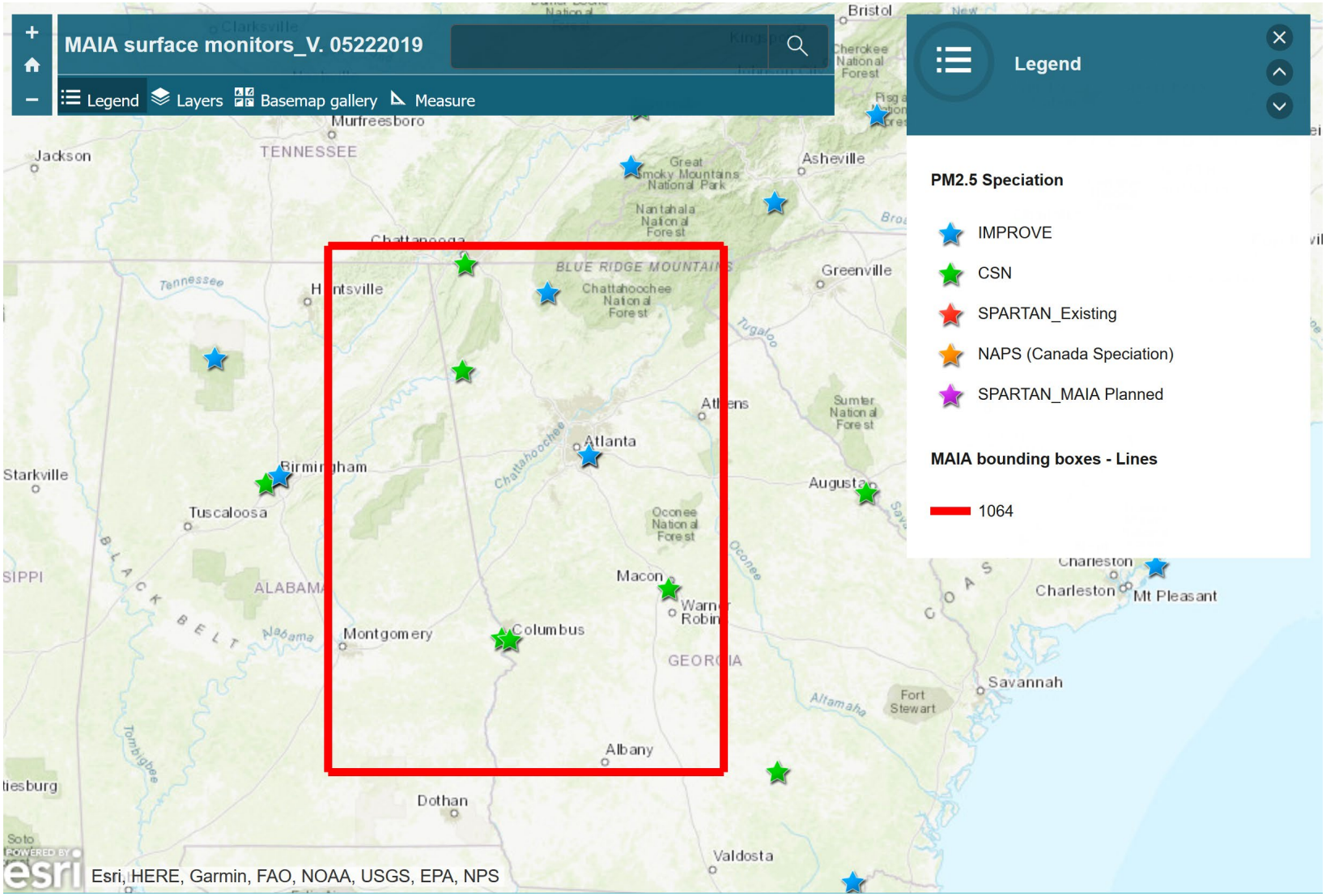
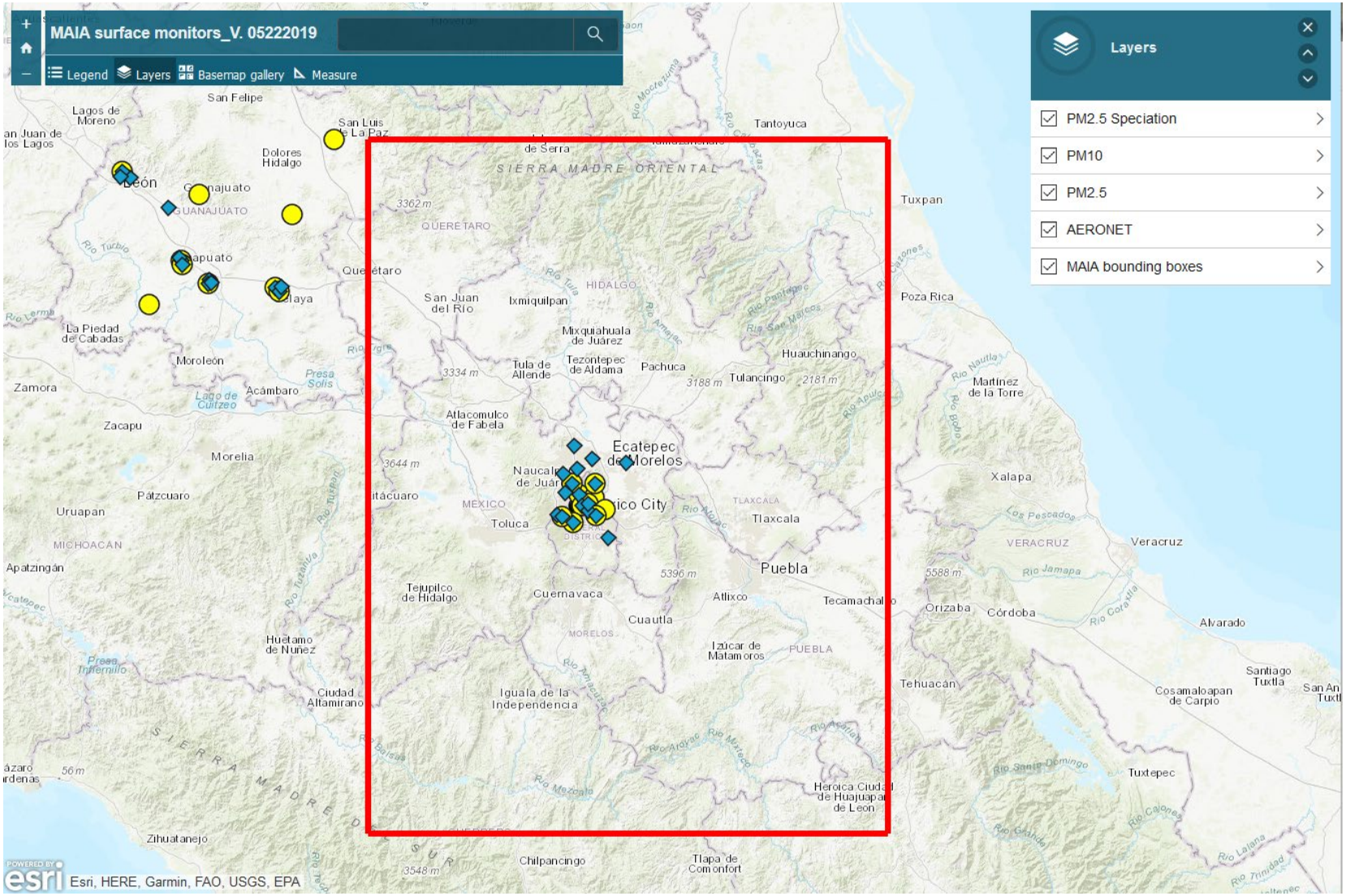
Toronto target area



Boston target area



Atlanta target area



Mexico City target area