Satellite Remote Sensing for Air Quality and Health

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HEI's Virtual Workshop on Health Applications for Satellite-Derived Air Quality: Opportunities and Potential Pitfalls

April 20 – May 18, 2022

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Key Takeaways

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- Satellite remote sensing offers many unique advantages, and can be a powerful tool, but it is still relatively new to air quality and health
- There is a increasing number of successful applications, and more exciting capabilities are to come
- Resources are there to get you started and provide technical support

Outline

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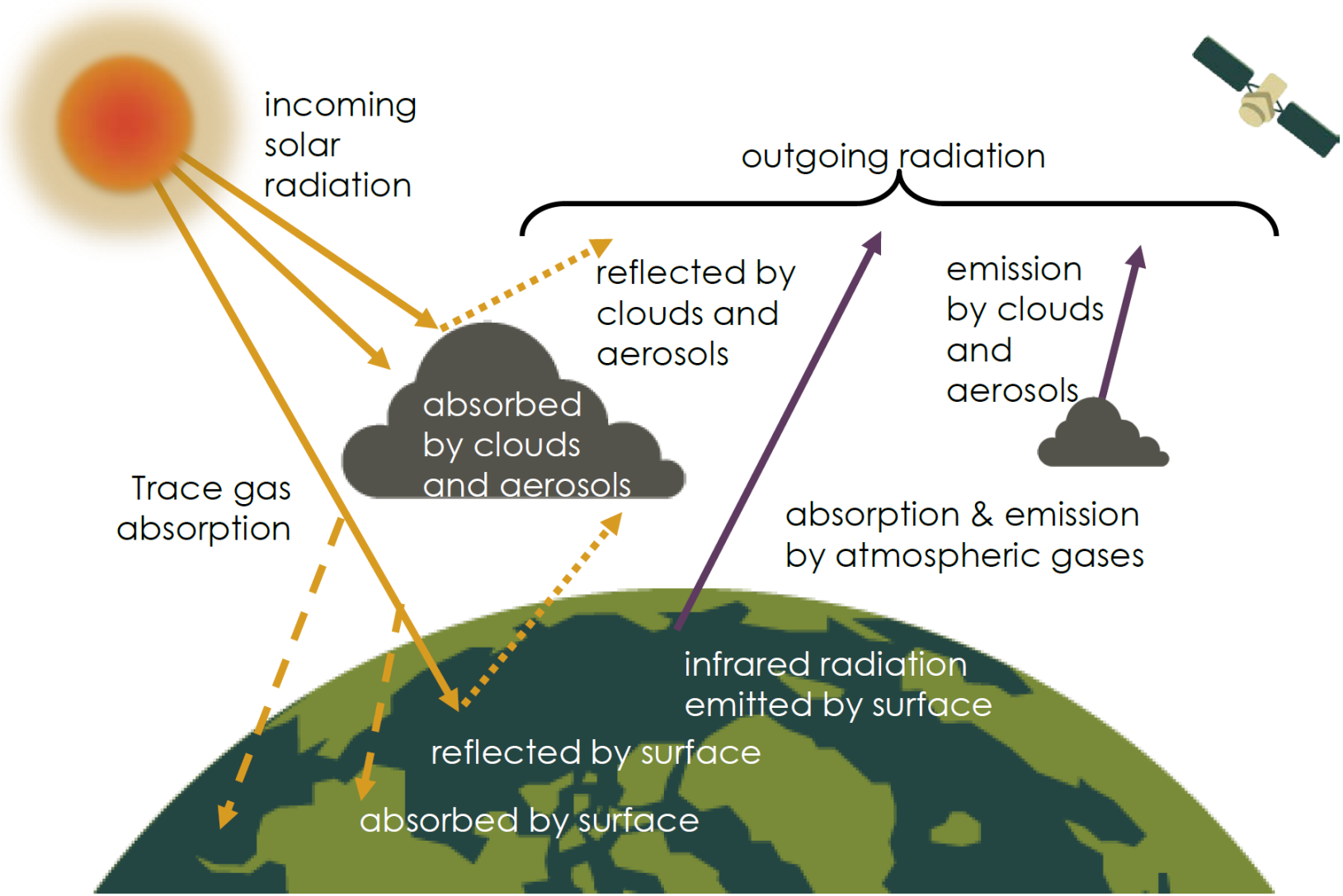
- Overview of satellite remote sensing
- Access to satellite data products
- Examples of health applications
- Emerging capabilities
- Challenges and opportunities

What do satellites measure?



Source: NASA's Applied Remote Sensing Training (ARSET) Program

Satellite retrieval of aerosol and trace gases

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- Satellites detect backscattered UV, visible, near IR, and/or emitted thermal IR radiation
- The intensity of reflected and/or emitted radiation to space is influenced by surface and atmosphere
- A retrieval algorithm (a model) works to infer physical quantities such as number density, partial pressure, and column amount based on the spectral signature for each atmospheric constituent

Satellite-retrieved atmospheric components

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- Aerosols: aerosol optical depth (AOD), fine mode fraction, absorbing AOD, particle size and shape indicators, smoke mask, vertical profile (lidar based, sparse coverage)
- Trace gases: NO2, SO2, O3 (limited sensitivity in PBL), CO, CH4, NH3, HCHO, CO2

- Data availability, spatial and temporal resolution, and accuracy vary

Accessing satellite data: starting point

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HAQAST

NASA HEALTH AND AIR QUALITY APPLIED SCIENCES TEAM
Connecting NASA Data and Tools with Health and Air Quality Stakeholders

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HOME / DATA AND TOOLS

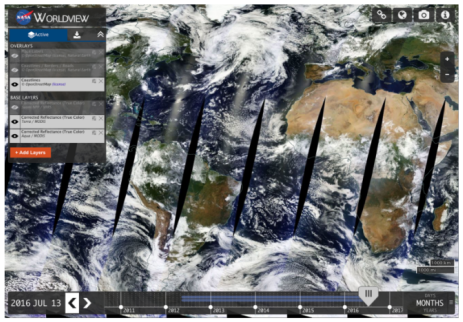
Data and Tools

NASA's data and tools are free to the public. On this page, you can find:

- Links to available NASA data and tools
- Other free data and toolsets
- Tutorials to get you started

For more general resources that may be of interest, please visit our links page.

And if you are brand-new to working with satellite data, please visit our Getting Started page, which will orient you to the uses, as well as the limits of satellite data.



NASA Worldview

Jump To

GETTING STARTED | TOOLS | DOWNLOAD DATA | TUTORIALS

HAQAST website provides answers to questions from many early-stage users

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Getting Started

Why satellite data? | What can I use satellite data for? | How do I get started?

Satellite data have been available to complement ground-based measurements for certain pollutants since the mid-1990s, but their use has been rare in the air quality management community. A number of barriers limit the adoption of satellite data outside of a fairly narrow group of atmospheric researchers, including: the fact that that satellites measure the "column" of air above the surface, rather than ground-level concentrations; that data from existing satellites are not available on an hourly basis akin to monitors; that satellite data are not provided at the resolution or gridding appropriate for utilization by regional air quality modelers; and that satellite data do not fit into the methods for compliance with the Clean Air Act set forth by the U.S. Environmental Protection Agency.

Still, ground-based measurements have limitations. With the exception of major cities, monitors are sparsely located across the United States. While most urban areas have at least one monitor for ozone (O_3) and fine particulate matter ($PM_{2.5}$), rural areas typically have no monitors, and there are no monitors over water bodies. Outside of the U.S., even large cities may have few or no air pollution monitors. For pollutants that regularly fall below the NAAQS, like carbon monoxide (CO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2), monitor placement is especially limited, even though these pollutants react in the atmosphere to create O_3 and/or $PM_{2.5}$, and serve as key markers for regulated emissions.

Satellite data are available from two types of platforms: polar-orbiting and geostationary. Polar-orbiting satellites cover the whole earth, with coverage typically once a day or less. Geostationary satellites rotate with the earth, and "see" the region with which they rotate. This allows geostationary satellites to observe more frequently over a smaller area (e.g., North America). From the perspective of a local air manager, the frequency of coverage can be as high as sub-hourly for geostationary instruments as compared to typical once-per-day or less for polar-orbiting satellites.

Accessing raw NASA data

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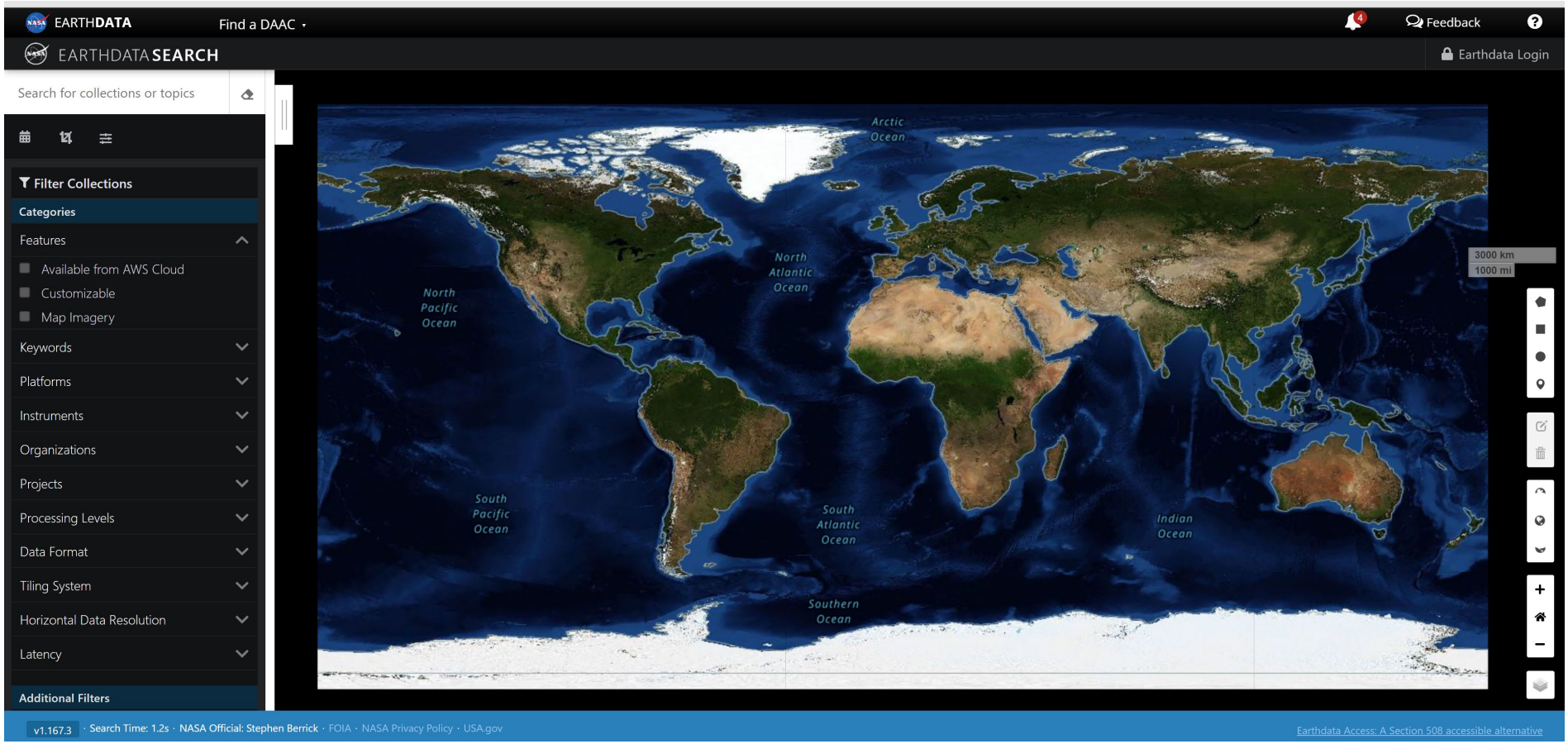

If you have never heard of HDF or netCDF file formats

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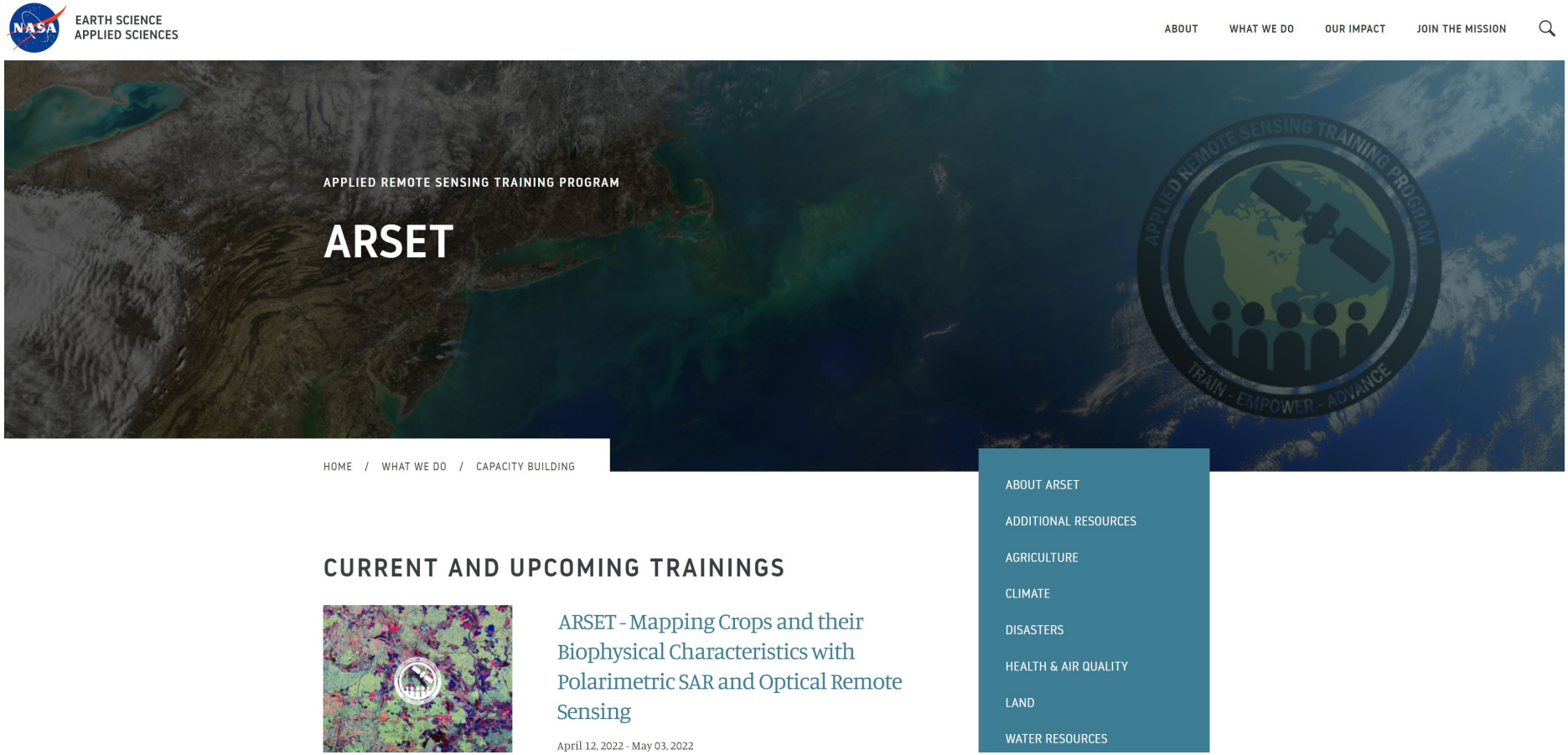

SATELLITE DATA ≠ AIR POLLUTANT CONCENTRATION

Quantitative air pollution exposure assessment with satellite data

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- Overall strategy
  - Identify satellite parameters strongly correlated with air pollutant
  - Perform gap filling by CTM simulations or other means
  - Include meteorology and land use as covariates to improve and stabilize performance
  - Use ground truth for model training
  - Generate pollution maps with model predictions.
- Maturity: $PM_{2.5}$ > NO_2 > O_3 and other trace gases

Satellite-driven spatial $PM_{2.5}$ modeling

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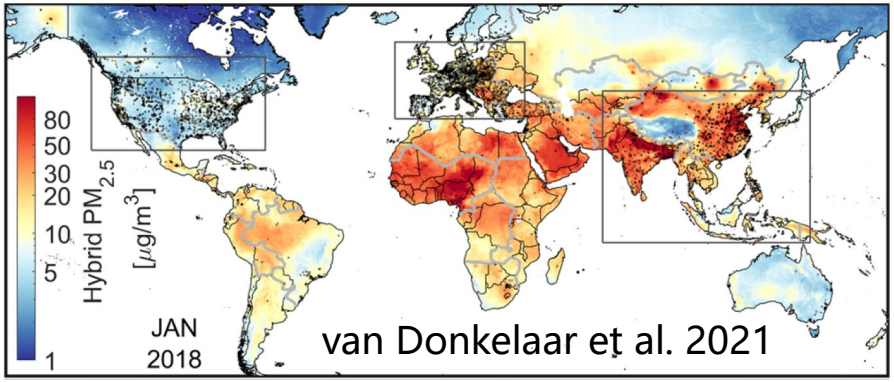
- Predictors
  - Satellite data: AOD, NDVI, elevation, etc.
  - Met fields: weather station data, gridded reanalysis
  - Land cover, population, traffic, etc.
- Generate continuous $PM_{2.5}$ fields in space and time
- High spatial (1 km) and temporal (hourly to daily) resolution
- High accuracy, have been increasingly used in both acute and chronic health effects research

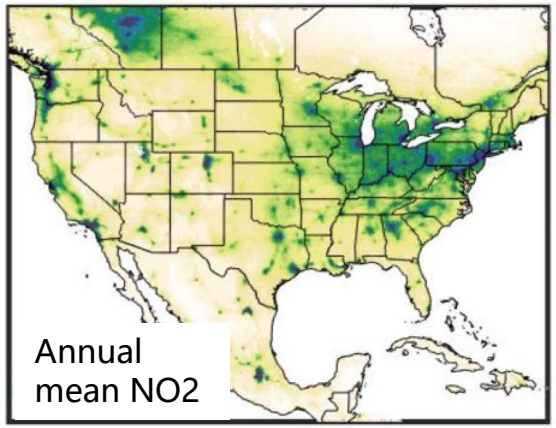
- **Model development / performance depends on quality and distribution of ground $PM_{2.5}$ measurements**

Model structures

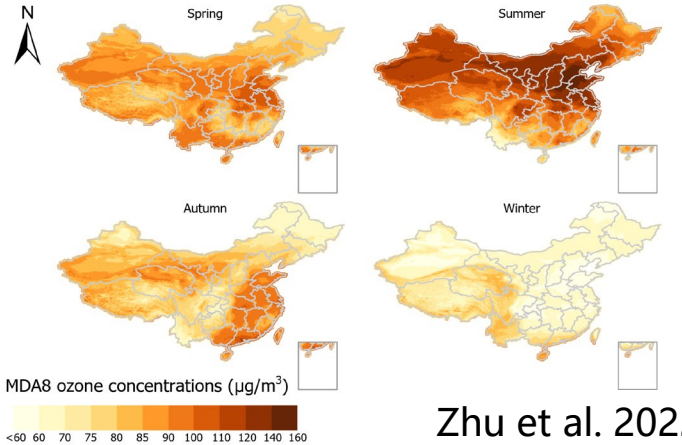
- Statistical models
  - Multivariate regression
  - Mixed-Effects Models
  - GAM, GWR, hybrid
  - Multi-stage models
  - …
- Machine learning models
  - Random Forests
  - Gradient boosting
  - Neural network
  - Deep learning
  - …



van Donkelaar et al. 2021



Cooper et al. 2020



Zhu et al. 2022

In-depth reviews

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Atmospheric Environment 94 (2014) 647–662

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Review

Satellite data of atmospheric pollution for U.S. air quality applications: Examples of applications, summary of data end-user resources, answers to FAQs, and common mistakes to avoid

Bryan N. Duncan [a,*], Ana I. Prados [a,b], Lok N. Lamsal [a,c], Yang Liu [d], David G. Streets [e], Pawan Gupta [a,c], Ernest Hilsenrath [b,f], Ralph A. Kahn [a], J. Eric Nielsen [g], Andreas J. Beyersdorf [h], Sharon P. Burton [h], Arlene M. Fiore [i], Jack Fishman [j], Daven K. Henze [k], Chris A. Hostetler [h], Nickolay A. Krotkov [a], Pius Lee [l], Meiyun Lin [m], Steven Pawson [a], Gabriele Pfister [n], Kenneth E. Pickering [a], R. Bradley Pierce [o], Yasuko Yoshida [a,g], Luke D. Ziemba [h]

Environment International 144 (2020) 106057

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

Review article

Review: Strategies for using satellite-based products in modeling $PM_{2.5}$ and short-term pollution episodes

Meytar Sorek-Hamer[a,b,*], Robert Chatfield[a], Yang Liu[c]

ANNUAL REVIEWS

Annual Review of Biomedical Data Science

Satellite Monitoring for Air Quality and Health

Tracey Holloway,[1,2] Daegan Miller,[1] Susan Anenberg,[3] Minghui Diao,[4] Bryan Duncan,[5] Arlene M. Fiore,[6] Daven K. Henze,[7] Jeremy Hess,[8] Patrick L. Kinney,[9] Yang Liu,[10] Jessica L. Neu,[11] Susan M. O'Neill,[12] M. Talat Odman,[13] R. Bradley Pierce,[2,14] Armistead G. Russell,[13] Daniel Tong,[15] J. Jason West,[16] and Mark A. Zondlo[17]

Remote Sensing of Environment 269 (2022) 112827

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Review

A review of statistical methods used for developing large-scale and long-term $PM_{2.5}$ models from satellite data

Zongwei Ma [a,*], Sagnik Dey [b,c], Sundar Christopher [d], Riyang Liu [a], Jun Bi [a], Palak Balyan [b], Yang Liu [e,*]

Examples of health applications

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Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015

Aaron J Cohen*, Michael Brauer*, Richard Burnett, H Ross Anderson, Joseph Frostad, Kara Estep, Kalpana Balakrishnan, Bert Brunekreef, Lalit Dandona, Rakhi Dandona, Valery Feigin, Greg Freedman, Bryan Hubbell, Amelia Jobling, Haidong Kan, Luke Knibbs, Yang Liu, Randall Martin, Lidia Morawska, C Arden Pope III, Hwashin Shin, Kurt Straif, Gavin Shaddick, Matthew Thomas, Rita van Dingenen, Aaron van Donkelaar, Theo Vos, Christopher J L Murray, Mohammad H Forouzanfar†

Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019

GBD 2019 Risk Factors Collaborators*

Research

A Section 508–conformant HTML version of this article is available at https://doi.org/10.1289/EHP9044.

Long-Term Exposure to Low-Level NO_2 and Mortality among the Elderly Population in the Southeastern United States

Yaoyao Qian,[1*] Haomin Li,[2*] Andrew Rosenberg,[1] Qiulun Li,[1] Jeremy Sarnat,[1] Stefania Papatheodorou,[3] Joel Schwartz,[3,4] Donghai Liang,[1] Yang Liu,[1] Pengfei Liu,[5] and Liuhua Shi[1]

LETTER

https://doi.org/10.1038/s41586-018-0263-3

Robust relationship between air quality and infant mortality in Africa

Sam Heft-Neal[1], Jennifer Burney[2], Eran Bendavid[3] & Marshall Burke[1,4,5]*

The NEW ENGLAND JOURNAL of MEDICINE
ESTABLISHED IN 1812 JUNE 29, 2017 VOL. 376 NO. 26

Air Pollution and Mortality in the Medicare Population

Qian Di, M.S., Yan Wang, M.S., Antonella Zanobetti, Ph.D., Yun Wang, Ph.D., Petros Koutrakis, Ph.D., Christine Choirat, Ph.D., Francesca Dominici, Ph.D., and Joel D. Schwartz, Ph.D.

RESEARCH

Long term exposure to ambient fine particulate matter and incidence of stroke: prospective cohort study from the China-PAR project

Keyong Huang,[1,2] Fengchao Liang,[1] Xueli Yang,[1] Fangchao Liu,[1] Jianxin Li,[1] Qingyang Xiao,[3] Jichun Chen,[1] Xiaoqing Liu,[4] Jie Cao,[1] Chong Shen,[5] Ling Yu,[6] Fanghong Lu,[7] Xianping Wu,[8] Liancheng Zhao,[1] Xigui Wu,[1] Ying Li,[1] Dongsheng Hu,[9] Jianfeng Huang,[1] Yang Liu,[10] Xiangfeng Lu,[1] Dongfeng Gu[1,2]

BMJ, first published as 10.1136/bmj.j6720 on

Effective scales of AQ monitoring technology for health

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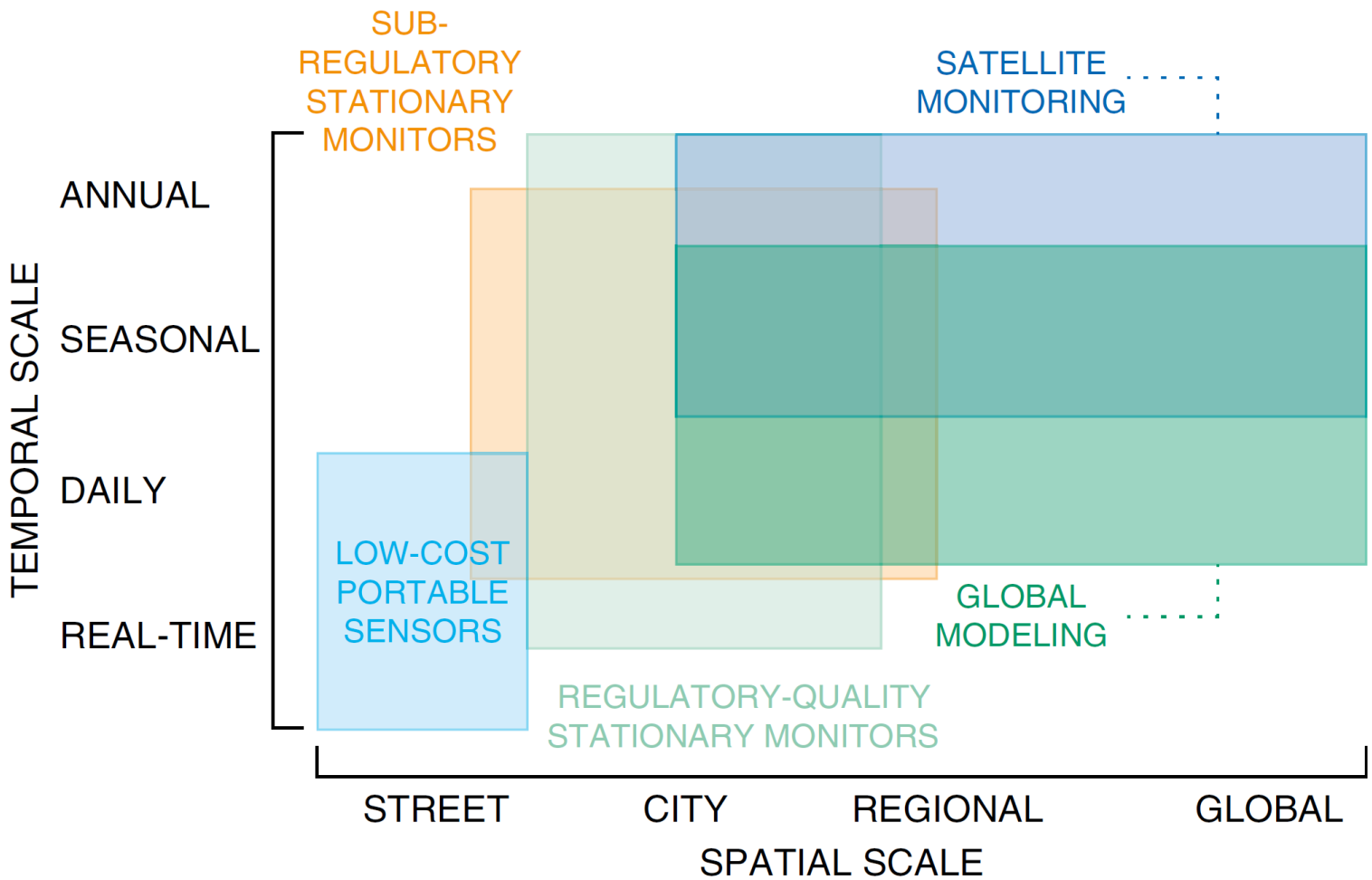

Source: Cromar et al. Ann Am Thorac Soc. 2019

Off the shelf datasets to explore

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SOCIOECONOMIC DATA AND APPLICATIONS CENTER (SEDAC)

A Data Center in NASA's Earth Observing System Data and Information System (EOSDIS) — Hosted by CIESIN at Columbia University

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Air Quality Data for Health-Related Applications

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Collection Overview

Data Sets (2)

1 of 1
Prev | Next

Daily 8-Hour Maximum and Annual O3 Concentrations for the Contiguous United States, 1-km Grids, v1 (2000–2016)

Daily and Annual PM2.5 Concentrations for the Contiguous United States, 1-km Grids, v1 (2000–2016)

Datasets | Atmospheric Composit

u/acag/datasets/

GIS related | Grants application | Emory | RS course | EPA | Public Datasets | MAIA | HAQAST | Wildfires

Washington University in St. Louis

Atmospheric Composition Analysis Group

RESEARCH PUBLICATIONS & PRESENTATIONS GEOS-CHEM SATELLITES DATASETS SPARTAN GROUP INFO

Datasets

Freely accessible information and data have greatly advanced scientific development during the past decade. We have posted several of our products in the spirit of this belief.

Users are asked to familiarize themselves with corresponding publications and contact principle researchers (as provided within subsequent sections) to ensure the most up-to-date and appropriate use of information.

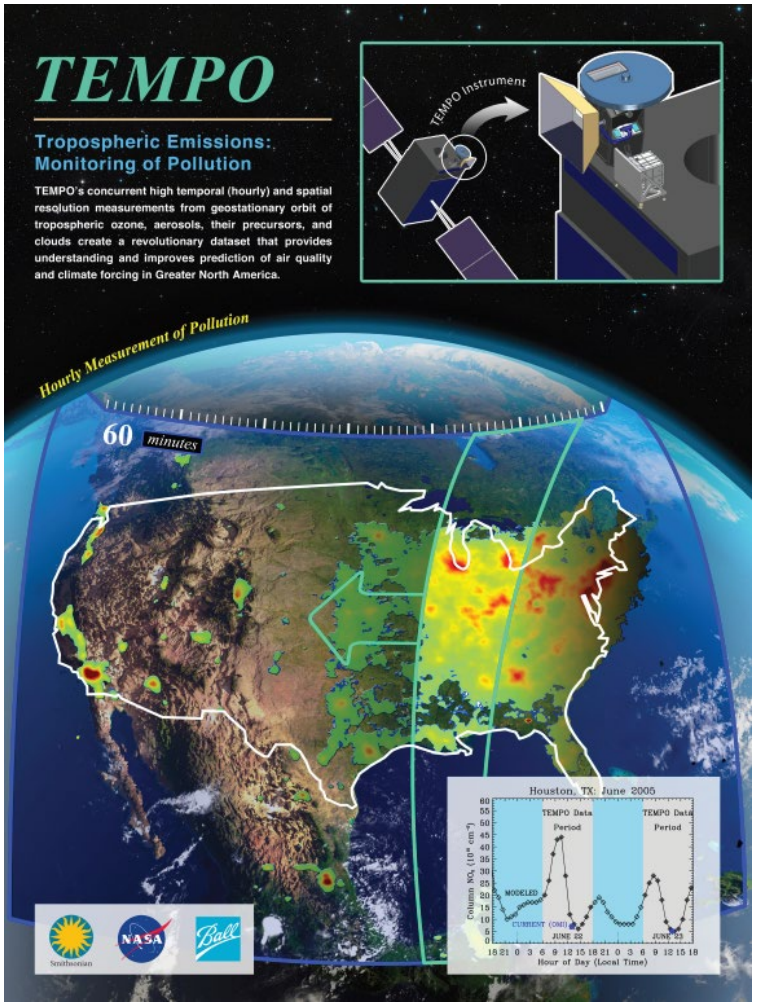
Datasets

- Surface PM2.5
- GBD-MAPS – Global
- Surface NO2
- Historical PM2.5 across North America
- Inverse Visibility
- OM/OC Dataset
- Surface Area
- NOy Deposition
- Dry Deposition
- AMF Code

Tropospheric Emissions: Monitoring of Pollution (TEMPO)

Level	Product	Major Outputs	Res km^2
L2	Cloud	Cloud fraction, cloud pressure	2.0 x 4.75
	O_3 profile	O3 profile, total/strat/trop/0-2 km O3 column, errors	8.0 x 4.75
	Total O_3	Total O3, AI, cloud fraction	2.0 x 4.75
	NO_2	SCD, strat./trop. VCD, error, shape factor, scattering weights	2.0 x 4.75
	H_2CO	SCD, VCD, error, shape factor, scattering weights	2.0 x 4.75
	$C_2H_2O_2$		2.0 x 4.75
	H_2O		2.0 x 4.75
	BrO		2.0 x 4.75
	SO_2	SCD, VCD (PBL,TRL,TRM,TRU,STL)	2.0 x 4.75
	Aerosol	AAI, AOD, SSA	8.0 x 4.75
L3	Gridded L2	Same as L2	TBD
L4	UVB	UV irradiance, UVI	TBD
	AQ Index	Air quality index	TBD

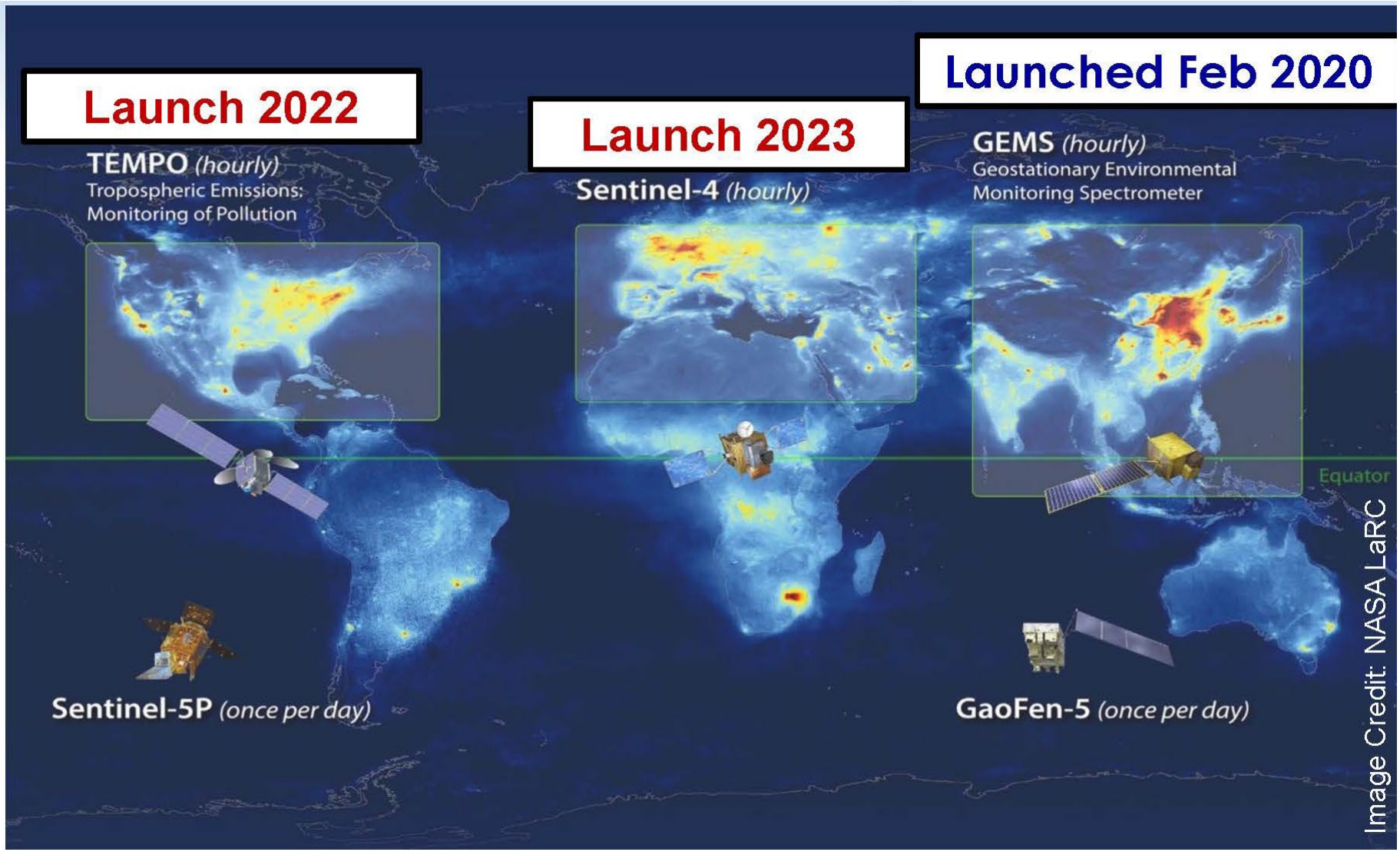
Frequency: hourly



Courtesy of Aaron Naeger and Xiong Liu of the TEMPO team

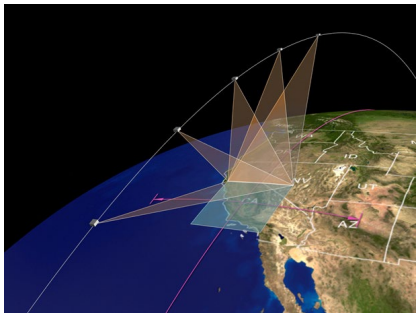
Global pollution monitoring constellation

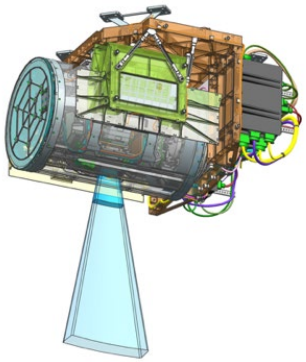
TEMPO is the North American component of an international GEO AQ constellation

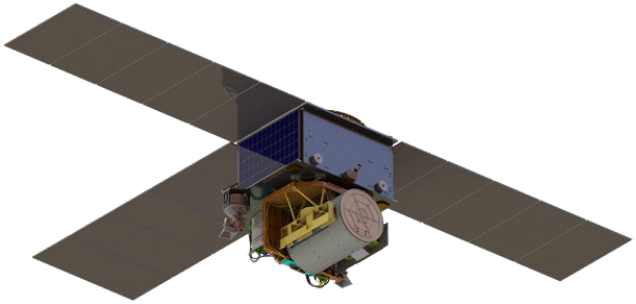


Multi-Angle Imager for Aerosols (MAIA)

- **Objective**: Assess linkages between different PM types and birth outcomes, cardiovascular and respiratory disease, and premature deaths.
- MAIA represents the first time NASA has partnered with epidemiologists and health organizations to study human health and improve lives.
- Launch expected in mid-2020s







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

MAIA Products and Coverage

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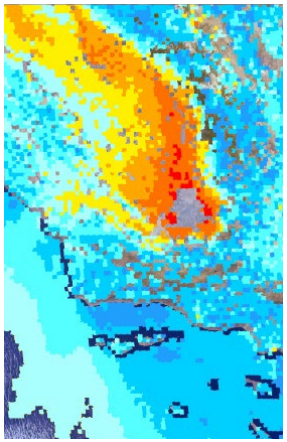
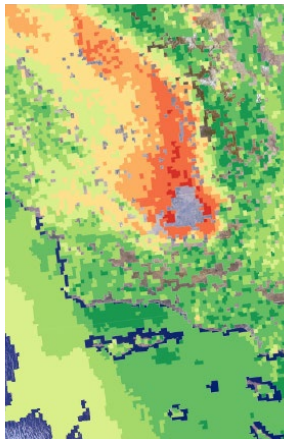
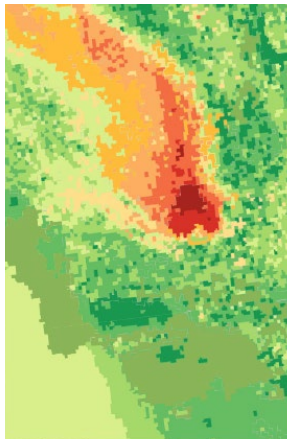


Level 2 aerosol: AOD and other properties on days of overpass



Level 2 PM: ground-level concentrations on days of overpass



Level 4 PM: ground-level concentrations, daily averaged, gap-filled, 1 km

Primary Target Areas
- USA-LosAngeles
- USA-Atlanta
- USA-Boston
- ESP-Barcelona
- ITA-Rome
- ZAF-Johannesburg
- ISR-TelAviv
- ETH-AddisAbaba
- IND-Delhi
- CHN-Beijing
- TWN-Taipei
- KOR-Seoul

Secondary Target Areas
- USA-Hilo
- PAC-OceanStCu
- USA-SanFrancisco
- USA-Phoenix
- USA-Denver
- MEX-MexicoCity
- CAN-Toronto
- PER-Lima
- COL-Medellín
- CHL-Santiago
- BRA-SãoPaulo
- SEN-Dakar
- GHA-Accra
- ATL-OceanStCu
- NGA-Lagos
- ZAF-CapeTown
- SRB-Belgrade
- KEN-Nairobi
- ETH-Harar
- KWT-KuwaitCity
- IND-Chennai
- BGD-Dhaka
- THA-Bangkok
- VNM-Hanoi
- MNG-Ulaanbaatar
- AUS-Sydney

Calibration/Validation Target Areas
- USA-RailroadValley
- LBY-Libya4
- NAM-Gobabeb

Level 2/4 PM parameters: Total PM10, Total PM2.5, PM2.5 speciation (Sulfate, Nitrate, OC, EC/BC, Dust) at 1 km resolution

The field is still very young

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Pub Date	Web of Science Search Terms in Topic		
	PM2.5 + Mortality	PM2.5 + Mortality + Satellite	PM2.5 + Mortality + AOD
1994 -	6284	472	149
2013 -	5120	444	137
2018 -	3566	336	93

Challenges and Opportunities

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- Challenges
  - Communication barriers between data producers and users
  - Many products need “translation” for health applications
  - Data structure can be more “user friendly”
- Opportunities
  - Continued interactions between health researchers and representatives of RS community
  - Integration across air quality monitoring technology platforms
  - Characterizing the impact of exposure error on health effect estimates

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THANK YOU!

Yang Liu
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