Effects of Three-Dimensional (3D) Urbanization Patterns and Topography on Air Pollution Processes in Asia

Son V. Nghiem\textsuperscript{1} et al

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Pasadena, California, USA
Air Pollution Problems

COMPARE TO WORLD COVID PANDEMIC

World COVID Death Toll
Total cases: 670M
Total deaths: 6.83M < 7M/y by air pollution
Urbanization in 2D versus 3D

GHSL 2D rate of change misrepresents urbanization of Ho Chi Minh City

DSM 3D rate of change captures urbanization of Ho Chi Minh City

Decrease in city center

Increase in city center

Build-up in city center

Enable global observations without gaps in time and space with QuikSCAT radar, 1-km grid, 2000-2009

$$\overline{\sigma}_0 = \frac{1}{N} \sum_{i=1}^{N} \overline{\sigma}_0(\phi_i, t_i) = \frac{1}{N \Gamma_A} \sum_{i=1}^{N} \iint_A dxdy \, G(\phi_i, x, y) \, \sigma_0(\phi_i, t_i, x, y)$$

$$\sigma_0(\phi_i, t_i, x, y) = \overline{\sigma}_0(x, y) + \varepsilon(\phi_i, t_i, x, y)$$

$$\overline{\sigma}_0M = \frac{1}{\Gamma_A} \iint_A dxdy \left[ \sum_{i=1}^{N} \frac{G(\phi_i, x, y)}{N} \right] \overline{\sigma}_0(x, y)$$

$$R = \frac{1}{\Gamma_A} \iint_A dxdy \sum_{i=1}^{N} \left[ \frac{G(\phi_i, x, y)}{N} \varepsilon(\phi_i, t_i, x, y) \right]$$

Dynamic Atlas of Global Continuum for 4D Urban Observations: 3D (volume = lateral x vertical) + 1D in time
Verification - Príncipepe Island

DSM checked with island
Verification - Nukunonu Atoll in the South Pacific

DSM checked with atoll
Expansion of major urban areas in the US Great Plains from 2000 to 2009 using satellite scatterometer data

Lan H. Nguyen\textsuperscript{a}, Son V. Nghiem\textsuperscript{c}, Geoffrey M. Henebry\textsuperscript{a, b, *}

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LandScan

\section*{ABSTRACT}

A consistent dataset delineating and characterizing changes in urban environments will be valuable for socioeconomic and environmental research and for sustainable urban development. Remotely sensed data have been long used to map urban extent and infrastructure at various spatial and spectral resolutions. Although many datasets and approaches have been tried, there is not yet a universal way to map urban extents across the world. Here we combined a microwave scatterometer (QuikSCAT) dataset at $\sim$1 km posting with percent impervious surface area (%ISA) data from the National Land Cover Dataset (NLCD) that was generated from Landsat data, and ambient population data from the LandScan product to characterize and quantify growth in nine major urban areas in the US Great Plains from 2000 to 2009. Nonparametric Mann-Kendall trend tests on backscatter time series from urban areas show significant expanding trends in eight of nine urban areas with $p$-values ranging 0.032 to 0.001. The sole exception is Houston, which has a substantial non-urban backscatter at the northeastern edge of the urban core. Strong power law scaling relationships between ambient population and either urban area or backscatter power ($r^2$ of 0.96 in either model) with sub-linear exponents ($\beta$ of 0.911 and 0.866, respectively) indicate urban areas become more compact with more vertical built-up structure than lateral expansion to accommodate the increased population. Increases in backscatter and %ISA datasets between 2001 and 2006 show agreement in both magnitude and direction for all urban areas except Minneapolis-St. Paul (MSP), likely due to the presence of many lakes and ponds throughout the MSP metropolitan area. We conclude discussing complexities in the backscatter data caused by large metal structures and rainfall.
Validation of DSM 2D Urban Extent


y = 1.1241x^{0.8662}
R^2 = 0.96

Dallas-Ft.Worth: DSM Backscatter vs LandScan Ambient Population

DSM Correlation with Impervious Surface Area

<table>
<thead>
<tr>
<th>Urban Area</th>
<th>r²</th>
<th>cor</th>
<th>rho</th>
<th>tau</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dallas-Ft. Worth</td>
<td>0.70**</td>
<td>0.84**</td>
<td>0.52</td>
<td>0.43</td>
</tr>
<tr>
<td>Houston</td>
<td>0.83**</td>
<td>0.91*</td>
<td>0.90**</td>
<td>0.79**</td>
</tr>
<tr>
<td>Kansas City</td>
<td>0.87***</td>
<td>0.94***</td>
<td>0.98***</td>
<td>0.93***</td>
</tr>
<tr>
<td>Oklahoma City</td>
<td>0.87***</td>
<td>0.93***</td>
<td>0.88**</td>
<td>0.71*</td>
</tr>
<tr>
<td>Omaha</td>
<td>0.68*</td>
<td>0.82*</td>
<td>0.88**</td>
<td>0.71*</td>
</tr>
<tr>
<td>Wichita</td>
<td>0.79**</td>
<td>0.89**</td>
<td>0.76*</td>
<td>0.57</td>
</tr>
<tr>
<td>Des Moines</td>
<td>0.88***</td>
<td>0.94***</td>
<td>0.95**</td>
<td>0.86**</td>
</tr>
</tbody>
</table>

*, **, and *** for p-values less than 0.05, 0.01, and 0.001

Nguyen, Nghiem, and Henebry, RSE, 204, 524-533, 2018
Satellite scatterometer estimation of urban built-up volume: Validation with airborne lidar data

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School of Geographical Sciences and Urban Planning, Arizona State University, Tempe, Arizona, USA
NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA
Department of Environmental Studies, University of Illinois at Springfield, Springfield, Illinois, USA

Abstract

Accurately mapping urban infrastructure and extent is a high priority for resource management and service allocation as well as for addressing environmental, socioeconomic, and geopolitical concerns. Most available data products only document surficial (two-dimensional) land use and land cover (LULC), yet a substantial component of urban growth occurs in the vertical dimension. Light detection and ranging (lidar) data offer the potential for monitoring three-dimensional (3D) change, but the extreme lack of systematic lidar coverage worldwide inflicts considerable gaps in both spatial and temporal coverage. Satellite scatterometer (radar) data may serve as an alternative data source for characterizing urban growth and development in both the horizontal and vertical directions. The accuracy of these radar-based datasets for estimating building volumes remains to be validated quantitatively. For nine U.S. cities, we test whether scatterometer data can be used to estimate 3D urban built-up volume. We found strong, linear correlations between the lidar-derived and radar-derived building volume estimates for all cities with $r^2$ values as high as 0.98 when using spatial trend analysis. Given the high expense that limits lidar data acquisition to small areas at sporadic points in time, satellite scatterometer data provide a breakthrough method for monitoring both vertical growth and horizontal expansion of cities across the world with a continuous decadal time scale.
Validation of DSM 3D Buildings Volume

**DSM Result for 2006 vs Lidar Building Volume**

3D Building Model Function: \( B_v = 249547\sigma + 2579618 \)

Accuracy 0.2dB (3\( \sigma \)): \( 5 \times 10^4 \text{m}^3/\text{km}^2 = 5 \text{cm height (m}^2) \)

**Austin Buildings from Lidar Data**

Mathews, Frazier, Nghiem, Neumann, Zhao, IJAEOG, 77, 100-107, 2019

\[ R^2 = 0.97268 \]

**DSM Result for 2000-2009: Austin \( B_v \) grew by 9.3%/decade**
Validation of DSM 3D Buildings Volume

Validation with seven metropolitan areas distributed across the continental United States: Large differences among cities, located across a variety of ecoregions and environmental conditions.

EXCELLENT VALIDATION FOR 7 CITIES IN 6 STATES and DC

<table>
<thead>
<tr>
<th>City</th>
<th>Lidar Year</th>
<th>Lidar Area</th>
<th>Pop. (2010)</th>
<th>$r^2$</th>
<th>r</th>
<th>$\rho$</th>
<th>$\tau$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlanta, GA</td>
<td>2003</td>
<td>79 km²</td>
<td>420,003</td>
<td>0.76</td>
<td>0.86</td>
<td>0.90</td>
<td>0.73</td>
</tr>
<tr>
<td>Austin, TX</td>
<td>2006</td>
<td>390 km²</td>
<td>720,390</td>
<td>0.97</td>
<td>0.99</td>
<td>0.99</td>
<td>0.91</td>
</tr>
<tr>
<td>Buffalo, NY</td>
<td>2004</td>
<td>342 km²</td>
<td>261,310</td>
<td>0.69</td>
<td>0.83</td>
<td>0.86</td>
<td>0.67</td>
</tr>
<tr>
<td>Detroit, MI</td>
<td>2004</td>
<td>347 km²</td>
<td>713,777</td>
<td>0.81</td>
<td>0.90</td>
<td>0.93</td>
<td>0.78</td>
</tr>
<tr>
<td>San Antonio, TX</td>
<td>2003</td>
<td>640 km²</td>
<td>1,327,407</td>
<td>0.97</td>
<td>0.98</td>
<td>0.97</td>
<td>0.87</td>
</tr>
<tr>
<td>Tulsa, OK</td>
<td>2008</td>
<td>1,329 km²</td>
<td>391,906</td>
<td>0.84</td>
<td>0.92</td>
<td>0.93</td>
<td>0.77</td>
</tr>
<tr>
<td>Washington, DC</td>
<td>2008</td>
<td>8,297 km²</td>
<td>601,723</td>
<td>0.98</td>
<td>0.99</td>
<td>0.98</td>
<td>0.91</td>
</tr>
</tbody>
</table>

$r^2$: coefficient of determination in linear model; $r$: Pearson correlation coefficient; $\rho$: Spearman rank correlation coefficient; $\tau$: Kendall rank correlation coefficient. All correlations significant with p-values < 0.01.
Transformative Urban Changes of Beijing in the Decade of the 2000s

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Abstract: The rapid economic growth, the exodus from rural to urban areas, and the associated extreme urban development that occurred in China in the decade of the 2000s have severely impacted the environment in Beijing, its vicinity, and beyond. This article presents an innovative approach for assessing mega-urban changes and their impact on the environment based on the use of decadal QuikSCAT (QSCAT) satellite data, acquired globally by the SeaWinds scatterometer over that period. The Dense Sampling Method (DSM) is applied to QSCAT data to obtain reliable annual infrastructure-based urban observations at a posting of ~1 km. The DSM-QSCAT data,
Beijing Urban Extent from DSM

2000

2001

2002

2003

2004

2005

2006

2007

2008

2009
Beijing Building Volume Pattern
Beijing DSM with road network (grey) and Night-Light urban extent (black).

Ngheim et al., Book Chapter, Springer 2014
Beijing Urban Change and NO$_2$

Sorichetta, Nghiem, Masetti, Linard, and Richter, Transformative Changes of Beijing in the Decade of the 2000s, 2020.
Annual Growth of the Beijing Building Structure Extent in the Decade of the 2000s


Urban building structure extent change from previous year (km²)

Year
2001 2002 2003 2004 2005 2006 2007 2008 2009

Growth Reduction Policy* Pre Olympic* Olympic* Post Olympic*
Beijing Urban Development Index (UDI) vs NO$_2$

UDI represents both lateral expansion and vertical build-up

$$NO_2 \text{ column} = 6.5959 \times UDI + 68.0828 \text{ with } R^2 = 0.821$$

$$\rho = 0.906$$

Sorichetta, Nghiem, and Masetti, Transformative Changes of Beijing in the Decade of the 2000s, 2020.
Decadal DSM 3D urban building volume data products were successfully used as input to the urban-climate-nested Gas-Aerosol-Transport-Radiation-General-Circulation-Mesoscale-and-Ocean Model (GATOR-GCMOM, developed by Jacobson et al.) to physically examine and quantitatively assess air pollution due to urbanization.
3D Modeling — GATOR-GCMOM from global circulation to urban scale

• GATOR-GCMOM is used to simulate the global, regional, and urban climate and air pollution health impacts resulting from urbanization. The goal is to investigate effects on climate and air quality of annual changes in the extent of urbanization over regions of mega urbanization in Asia and to compare with other regions in the 2000s.

• This model nests climate, meteorological, gas, aerosol, and radiative parameters simultaneously from the global through urban scale. Simulates meteorology and its feedback among gases, aerosol particles, cloud hydrometeor particles, surfaces, and radiation. Gas processes include emissions, photochemistry, gas-to-particle conversion, gas-to-hydrometeor conversion and exchange, gas-ocean exchange, advection, convection, molecular diffusion, turbulent diffusion, and dry deposition.

• At the land surface, each subgrid soil class is divided into vegetated and bare soil. Snow can accumulate on both soil and vegetation. For bare and vegetated soil, the surface energy balance equation accounts for latent heat, sensible heat, solar, thermal-IR, and energy fluxes.

• Oceans are represented in 3-D for some calculations and 2-D for others. A 2-D time-dependent mixed-layer ocean dynamics model driven by surface wind stress is used to solve for mixed-layer velocities, heights, and horizontal energy transport in each cell. The scheme conserves potential enstrophy, vorticity, energy, and mass and predicts gyres and major currents. Air ocean exchange, vertical diffusion, 3-D ocean equilibrium chemistry and pH are solved among the Na-Cl-Mg-Ca-K-H-O-Li-Sr-C-S-N-Br-F-B-Si-P system.
Ring of impact from the mega-urbanization of Beijing between 2000 and 2009

Mark Z. Jacobson¹, Son V. Nghiem², Alessandro Sorichetta³,⁴, and Natasha Whitney¹

¹Department of Civil and Environmental Engineering, Stanford University, Stanford, California, USA, ²Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA, ³Geography and Environment, University of Southampton, Southampton, UK, ⁴Institute for Life Sciences, University of Southampton, Southampton, UK

Abstract The transient climate, soil, and air quality impacts of the rapid urbanization of Beijing between 2000 and 2009 are investigated with three-dimensional computer model simulations. The simulations integrate a new satellite data set for urban extent and a geolocated crowd-sourced data set for road surface area and consider differences only in urban land cover and its physical properties. The simulations account for changes in meteorologically driven natural emissions but do not include changes in anthropogenic emissions resulting from urbanization and road network variations. The astounding urbanization, which quadrupled Beijing urban extent between 2000 and 2009 in terms of physical infrastructure change, created a ring of impact that decreased surface albedo, increased ground and near-surface air temperatures, increased vertical turbulent kinetic energy, and decreased the near-surface relative humidity and wind speed. The meteorological changes alone decreased near-surface particulate matter, nitrogen oxides (NOₓ), and many other chemicals due to vertical dilution but increased near-surface ozone due to the higher temperature and lower NO. Vertical dilution and wind stagnation increased elevated pollution layers and column aerosol extinction. In sum, the ring of impact around Beijing may have increased urban heating, dried soil, mixed pollutants vertically, aggravated air stagnation, and increased near-surface oxidant pollution even before accounting for changes in anthropogenic emissions.
3D GATOR GCMOM – Beijing
Quantifying changes in 2000-2009

Albedo Change

Soil Moisture Change

Ground Temperature

Surface Air Temperature

Surface Rel. Humidity

15-m Wind Speed

Surface Ozone

Aerosol Spec. Extinction
“Ring Around the Beijing”

- Increasing urban heat
- Drier soil condition
- More air stagnation
- Worse smog condition
- More ozone pollution
- More pollutant mixing upward
Short-Term Impacts of the Megaurbanizations of New Delhi and Los Angeles Between 2000 and 2009

Mark Z. Jacobson¹, Son V. Nghiem², and Alessandro Sorichetta³

¹Department of Civil and Environmental Engineering, Stanford University, Stanford, CA, USA, ²Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, ³WorldPop, School of Geography and Environmental Science, University of Southampton, Southampton, UK

Abstract Urban areas are expanding worldwide due to increasing population, standard of living, and migration from rural areas. This study uses satellite and road data to quantify the urbanization of two megacities, New Delhi and Los Angeles, between 2000 and 2009. It then estimates, with a three-dimensional nested global-through-urban climate, weather, and air pollution model, Gas, Aerosol, Transport, Radiation, General Circulation, Mesoscale, and Ocean Model, the short-term atmospheric impacts of such urbanization alone. The simulations account for changes in meteorologically driven natural emissions, but not anthropogenic emissions, between 2000 and 2009. New Delhi’s urban extent, defined based on the physical existence of its built structures and the transitional gradient from buildings to rural areas rather than on abrupt administrative borders, increased by ~80% and Los Angeles’s by ~22.5% between 2000 and 2009. New Delhi experienced a larger increase in its urban extent relative to its population during this period than did Los Angeles. In both megacities, urbanization increased surface roughness, increasing shearing stress and vertical turbulent kinetic energy, decreasing near-surface and boundary layer wind speed, contributing to higher column pollution levels. Urbanization may also have increased downward solar plus thermal infrared radiation fluxes to the ground and consequently upward latent and sensible heat fluxes from the ground to the air, increasing near-surface air temperatures. As such, urbanization alone may have had notable impacts on both meteorology and air quality.
GATOR-GCMOM (Gas, Aerosol, Transport, Radiation, General Circulation, Mesoscale, and Ocean Model) results for New Delhi, using DSM urban change input, showed “ring effects” with high turbulent kinetic energy and low wind: More mixing and stagnant air, more severe air pollution.
Formaldehyde in the Troposphere over Asia

Formaldehyde (HCHO) is a gas pollutant and it can cause cancer.

It is a precursor of Hydoxymethane Sulfonate (HMS) giving mass to particulate matters (PM).
Severe in both Hanoi and Ho Chi Minh City
TROPOMI Formaldehyde – 8/2018
Persist in Hanoi, clear-up in Ho Chi Minh City
Worsen in China and South Korea

Topography in the DMZ

Mountain chain (photo by Nghiem)
Formaldehyde Sources

Geophysical Research Letters

Biomass burning as a source of formaldehyde, acetaldehyde, methanol, acetone, acetonitrile, and hydrogen cyanide

Rupert Holzinger, Carsten Warnke, Armin Hansel, Alfons Jordan, Werner Lindinger, Dieter H. Scharffe, Gunnar Schade, Paul J. Crutzen

First published: 15 April 1999 | https://doi.org/10.1029/1999GL900156 | Citations: 278

Abstract

Using a novel experimental technique, based on proton transfer reaction mass spectrometry, from measurements of emissions from laboratory scale biomass burning experiments, we have estimated the source strengths of several potential HO₂, non-herbaceous

energies

Real-Time Measurements of Formaldehyde Emissions from Modern Vehicles

Ricardo Suarez-Beteta 1,2,3, Tominaso Selleri 1,2,3, Roberto Gloria 1, Anastasios M. Melas 1, Christian Ferrarese 4, Jacopo Franzetti 1, Bertold Arlit 1, Naoki Nagura 4, Takaaki Hanada 4, and Barouch Giechaskiel 1

Abstract: Formaldehyde (HCHO), a carcinogenic carbonyl compound and precursor of tropospheric ozone, can be found in vehicle exhaust. Even though the continuous measurement of HCHO has been recommended, the real-world emissions from the road transport sector are not commonly available. The main reason for this knowledge gap has been the difficulty to measure HCHO in real-time and during real-world testing. This, for instance, increases the uncertainty of the O₃ simulated by air quality models. The present study investigates real-time HCHO measurements comparing three Fourier Transform Infrared spectrometers (FTIRs) and one Quantum Cascade Laser InfraRed spectrometer (QCL-IR) directly sampling from the exhaust of one gasoline passenger car, one Diesel commercial vehicle and one Diesel heavy-duty vehicle.
## GEMS
Geostationary Environment Monitoring Spectrometer

- On board GEO-KOMPSAT2B
- World first UV-Vis hyperspectral sensor in space

<table>
<thead>
<tr>
<th>Wavelength range</th>
<th>300-500nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>FWHM</td>
<td>0.6nm</td>
</tr>
<tr>
<td>Time resol.</td>
<td>hourly</td>
</tr>
<tr>
<td>Spatial resol.</td>
<td>3.5km x 8km (Seoul)</td>
</tr>
<tr>
<td>FOR</td>
<td>5,000km x 5,000km (5°S - 45°N, 75°E - 145°E/East Asia)</td>
</tr>
<tr>
<td>Major products</td>
<td>SO$_2$, NO$_2$, O$_3$, HCHO, AOD</td>
</tr>
</tbody>
</table>

Hanlim Lee, 2023
GEMS Total NO$_2$ VCD

00:45 UTC
07:45 LT

GEMS NO$_2$ VCD [$10^{16}$ molecules cm$^{-2}$]

00:45 UTC
07:45 LT

GEMS NO$_2$ VCD [$10^{16}$ molecules cm$^{-2}$]

23:45 UTC
07:45 LT

GEMS NO$_2$ VCD [$10^{16}$ molecules cm$^{-2}$]

Saraburi

Bangkok

Rayong

Hanoi

Nam Dinh

Hai Phong

Manila

Dagupan

Park J.S. and Lee H., under review, Nature Geoscience
In-Situ Ambient Particulate Matter Monitoring for the MAIA Mission

JPL deployed PM monitors in selected MAIA target areas around the world to augment existing monitoring networks.

Study areas include Hanoi

Example photos of the MAIA monitoring sites around the world

https://maia.jpl.nasa.gov/ Multi-Angle Imager for Aerosols (MAIA)
Satellite mission to study human health and improve lives
In-Situ Ambient Air Monitoring at the Jet Propulsion Laboratory

- Monitors the physical and chemical properties of a wide range of air pollutants.
- Supports the MAIA flight mission and several in-house projects at JPL.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Measured Parameter(s)</th>
<th>Measurement Type</th>
<th>Measurement Interval</th>
<th>Data Latency</th>
<th>Measurement Start Date</th>
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</thead>
<tbody>
<tr>
<td>Alph photon Nephelometer MPP100</td>
<td>Multi-Angle, Multi-wavelength Polarized Aerosol Scattering</td>
<td>Continuous</td>
<td>2 minutes</td>
<td>Real-time</td>
<td>Jun 2022</td>
</tr>
<tr>
<td>Aeroqual AQY</td>
<td>NO2, O3, PM2.5</td>
<td>Continuous</td>
<td>1 hour</td>
<td>Real-time</td>
<td>Nov 2022</td>
</tr>
<tr>
<td>Aerosol Dynamics Scanning Electrical Mobility Spectrometer (SEMS)</td>
<td>Ultrafine Particle Number Size Distribution (8 - 420 nm)</td>
<td>Continuous</td>
<td>1 minute</td>
<td>Real-time</td>
<td>Aug 2022</td>
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<tr>
<td>Davis Vantage Pro2 Weather Station</td>
<td>T, RH, WS/WD, Dew Point, Barometric Pressure, etc.</td>
<td>Continuous</td>
<td>15 minutes</td>
<td>Real-time</td>
<td>March 2021</td>
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<tr>
<td>Aeth Labs microAeth MA350</td>
<td>Multi-wavelength Particle Absorption</td>
<td>Continuous</td>
<td>1 minute</td>
<td>Real-time</td>
<td>March 2021</td>
</tr>
<tr>
<td>PurpleAir PA-II</td>
<td>PM1, PM2.5, PM10 Mass</td>
<td>Continuous</td>
<td>2 minutes</td>
<td>Real-time</td>
<td>Nov 2020</td>
</tr>
<tr>
<td>GRIMM EDM 164</td>
<td>Size-resolved PM Mass and Number (0.25 - 32 um)</td>
<td>Continuous</td>
<td>15 minutes</td>
<td>Real-time</td>
<td>Nov 2020</td>
</tr>
<tr>
<td>Colorado State University Aerosol Mass and Optical Depth (AMOD)</td>
<td>PM2.5, Aerosol Optical Depth</td>
<td>Continuous</td>
<td>2 minutes</td>
<td>Real-time</td>
<td>Nov 2021</td>
</tr>
<tr>
<td>PM2.5 Chemical Components (e.g., Sulfate, Nitrate, Elemental Carbon, Organic Carbon, Metals, etc.)</td>
<td>24-hr Integrated</td>
<td>Every 3rd Day</td>
<td>3-6 Months</td>
<td></td>
<td></td>
</tr>
<tr>
<td>QuantAQ, Modulair-PM</td>
<td>Size-resolved PM Mass and Number (0.35 - 40 um)</td>
<td>Continuous</td>
<td>1 minute</td>
<td>Real-time</td>
<td>Mar 2022</td>
</tr>
<tr>
<td>AlPhoton S55 (as part of SPARTAN network)</td>
<td>PM2.5 Chemical Components (e.g., Sulfate, Nitrate, Elemental Carbon, Organic Carbon, Metals, etc.)</td>
<td>24-hr Integrated</td>
<td>Every 3rd Day</td>
<td>3-6 Months</td>
<td>Nov 2021</td>
</tr>
<tr>
<td>QuantAQ, Modulair</td>
<td>Size-resolved PM Mass and Number (0.35 - 40 um), CO, NO, NO2, O3, CO2</td>
<td>Continuous</td>
<td>1 minute</td>
<td>Real-time</td>
<td>Sep 2022</td>
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<tr>
<td>CIMEL Sun Sky Lunar Multispectral Photometer (as part of AERONET network)</td>
<td>Aerosol Optical Depth, Volume Size Distribution, Complex Refractive Index, Shape Factor, Water Vapor Content</td>
<td>Continuous</td>
<td>2 minutes</td>
<td>Real-time</td>
<td>Oct 2022</td>
</tr>
<tr>
<td>*2B Technologies NOx Monitor</td>
<td>NO, NO2, NOx</td>
<td>Continuous</td>
<td>5 minutes</td>
<td>Real-time</td>
<td>Nov 2021</td>
</tr>
<tr>
<td>*Serinus S1 SO2 Monitor</td>
<td>SO2</td>
<td>Continuous</td>
<td>5 minutes</td>
<td>Real-time</td>
<td>Nov 2021</td>
</tr>
</tbody>
</table>

* Installed at a nearby building

Contact information:
Sina Hasheminassab
sina.hasheminassab@jpl.nasa.gov
In-Situ Air Monitoring by JPL from Mountain Top over LA Basin

California Laboratory for Atmospheric Remote Sensing (CLARS)

Data Products:
- CH₄, CO₂, N₂O
- H₂O, HDO
- CO, O₂, AOD
- ¹³CO₂, ¹³CH₄
- SIF

Two measurement modes:
1. Direct sun (Spectralon)
2. Basin

Stan Sander, JPL, 2023
Hourly Maps of Carbon Monoxide by JPL in the Los Angeles Basin

In-Situ Measurements of PM2.5 in Hanoi and Ho Chi Minh City (Data from US Embassy)

PM2.5 at the US Embassy in Hanoi, and US Consulate in Ho Chi Minh City.

Tran, Chauhan, and Singh, IGARSS, 2022
Air Pollution Solutions

Renewable Energy: Off-Shore Wind Powers

DSM Wind Power Map for Hawai`i Offshore Region in the Pacific (Nghiem and Neumann, 2011)

Bạc Liêu Offshore Wind (the first and largest in Vietnam)

<table>
<thead>
<tr>
<th>Phase</th>
<th>Annual power production</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&gt;20 million kWh</td>
</tr>
<tr>
<td>2</td>
<td>130 million kWh</td>
</tr>
<tr>
<td>3</td>
<td>373 million kWh</td>
</tr>
</tbody>
</table>

June 2013 to March 2020: 1 billion kWh

https://vi.wikipedia.org/wiki/Nh%C3%A0_m%C3%A1y_%C4%91i%E1%BB%87n_gr%C3%B3_B%E1%BA%A1c_Li%C3%AAu
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