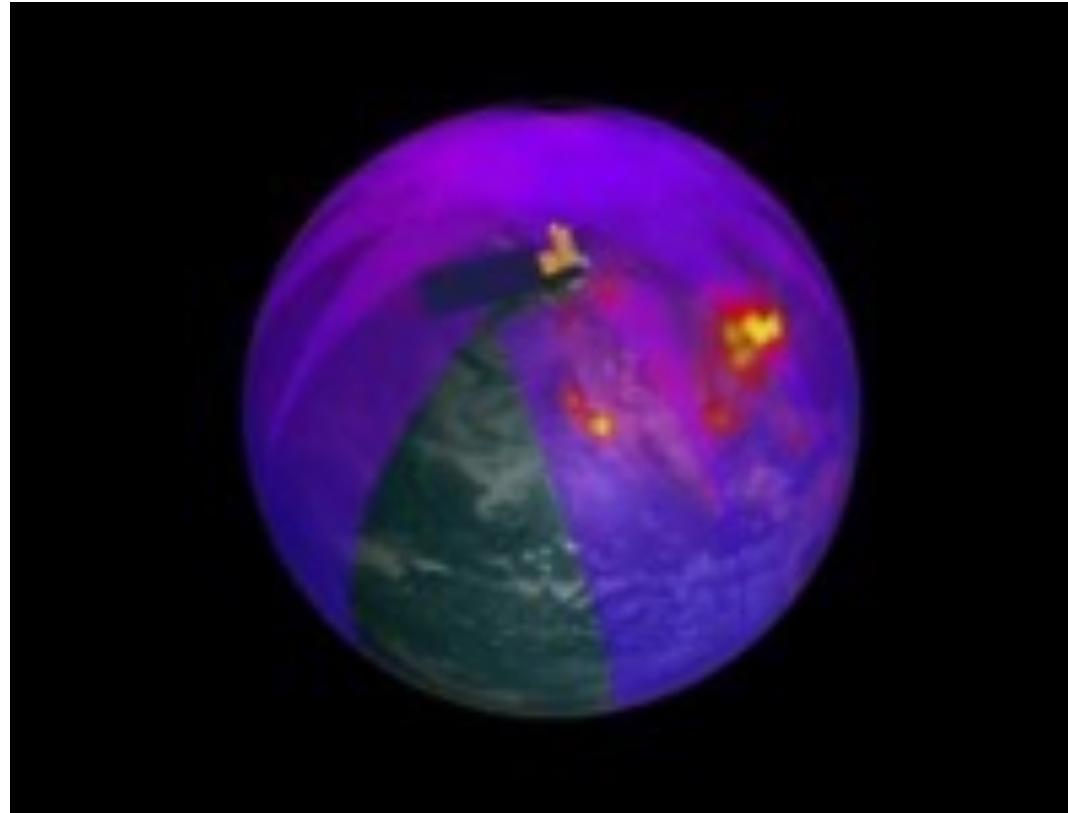


# Remote Sensing of the Atmosphere

NERC London DTP Induction Week



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30 September 2022

# UCL Atmospheric Composition and Air Quality Group

<https://maraisresearchgroup.co.uk/>



**Nana Wei**  
PhD



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PhD



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postdoc



**Eleanor Smith**  
PhD



**Gongda Lu**  
postdoc

# Atmospheric Composition and Air Quality Group



Projects

Group Info

Publications

Datasets

Presentations

Education

Media Coverage

Our group combines data from multiple platforms (models, aircraft, satellites, lab and field measurements) to better understand the influence of humans on atmospheric chemistry, air quality, and climate from urban to regional to global scales.

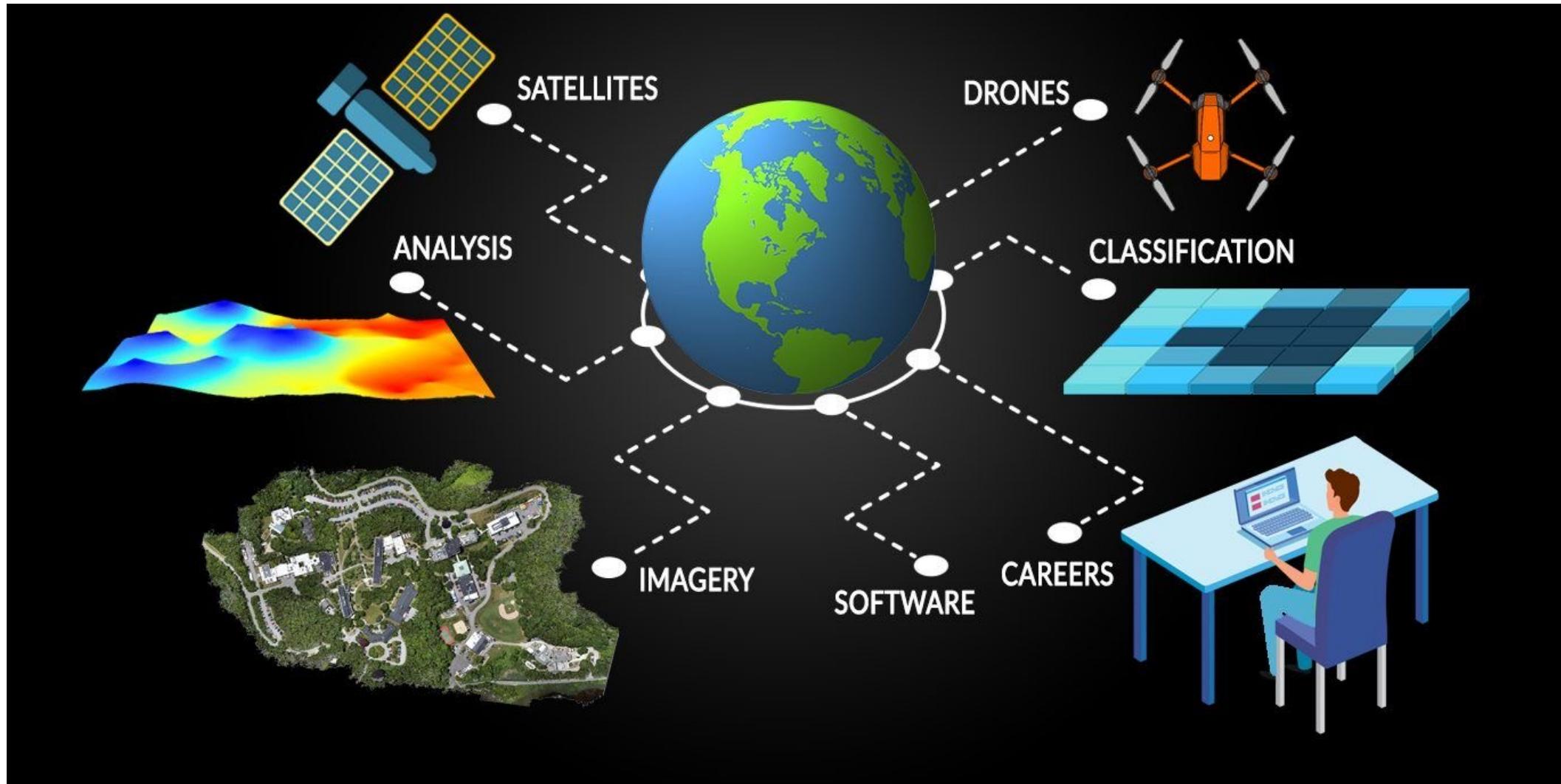
## Recent news and highlights from our group:



Our new MAX-DOAS instrument up and running on the Torrington Place rooftop at UCL

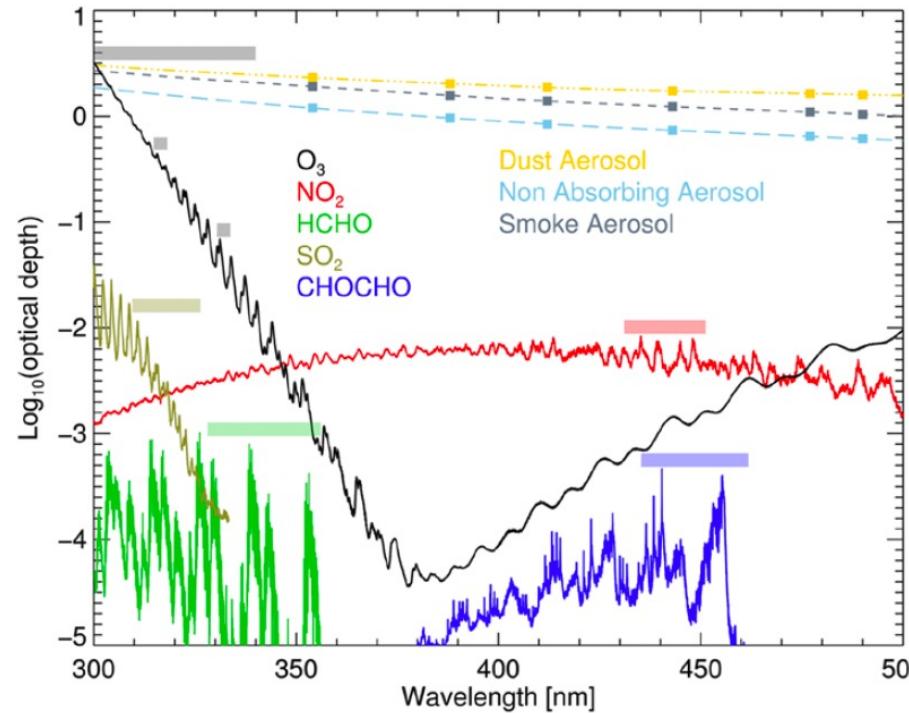
# Remote Sensing

Acquire information about an object with no physical contact



# Measure reflected and emitted radiation

UV-visible

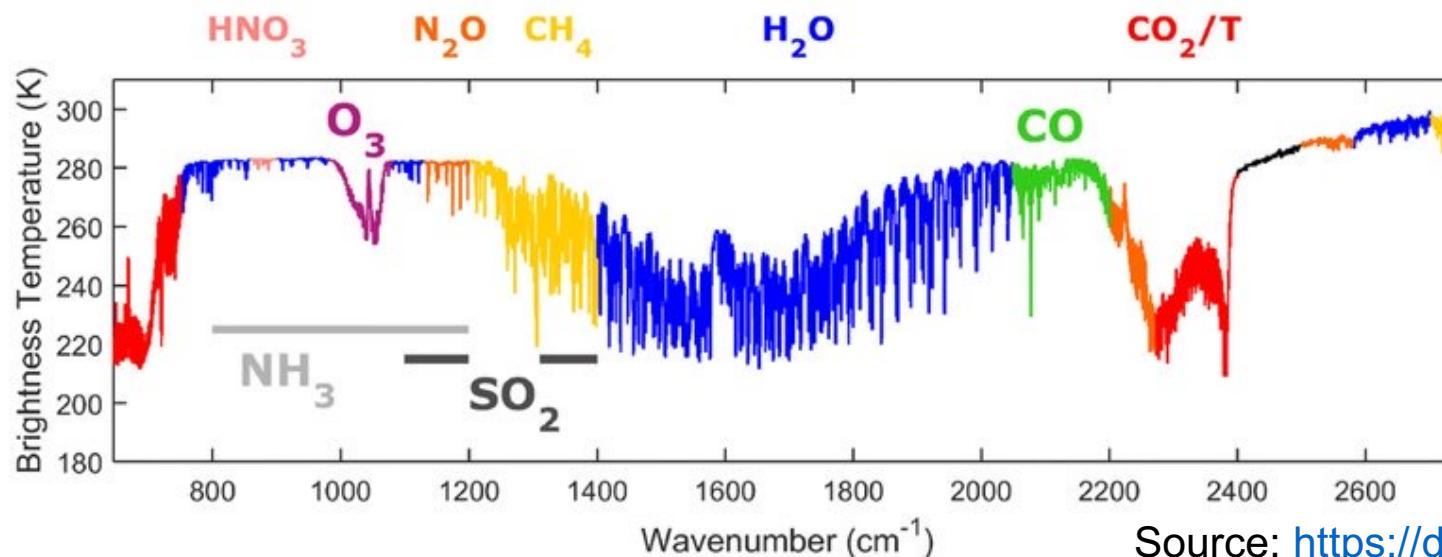


Nitrogen dioxide ( $\text{NO}_2$ )  
Formaldehyde ( $\text{HCHO}$ )  
Glyoxal ( $\text{CHOCHO}$ )  
Sulfur dioxide ( $\text{SO}_2$ )  
Ozone ( $\text{O}_3$ )

Also Aerosol Optical Depth (AOD)

Source: <https://doi.org/10.1175/BAMS-D-18-0013.1>

Infrared (IR)



Ozone ( $\text{O}_3$ )  
Ammonia ( $\text{NH}_3$ )  
Sulfur dioxide ( $\text{SO}_2$ )  
Nitric acid ( $\text{HNO}_3$ )

Source: <https://doi.org/10.1111/12.2584500>

# Remote sensing of the atmosphere from the ground

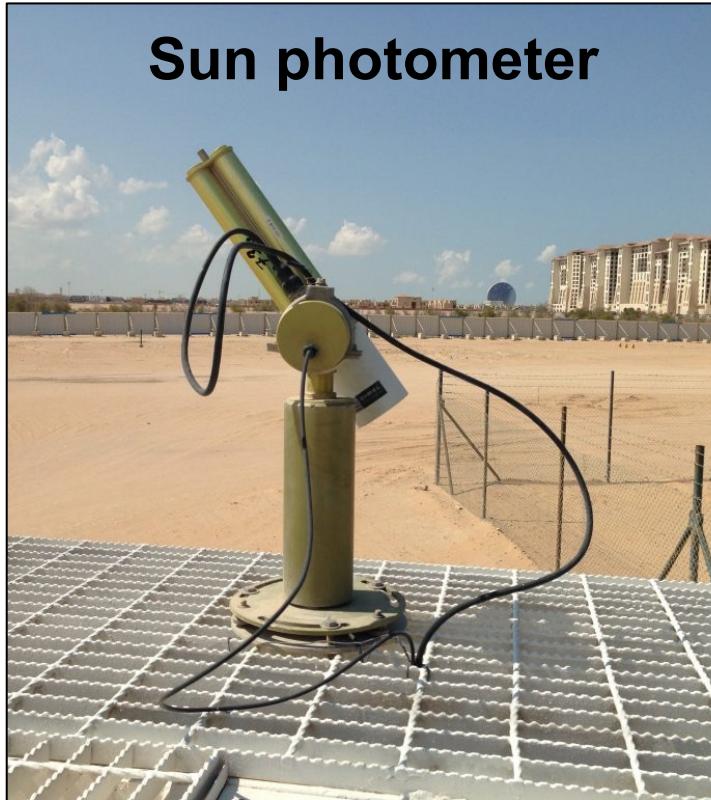
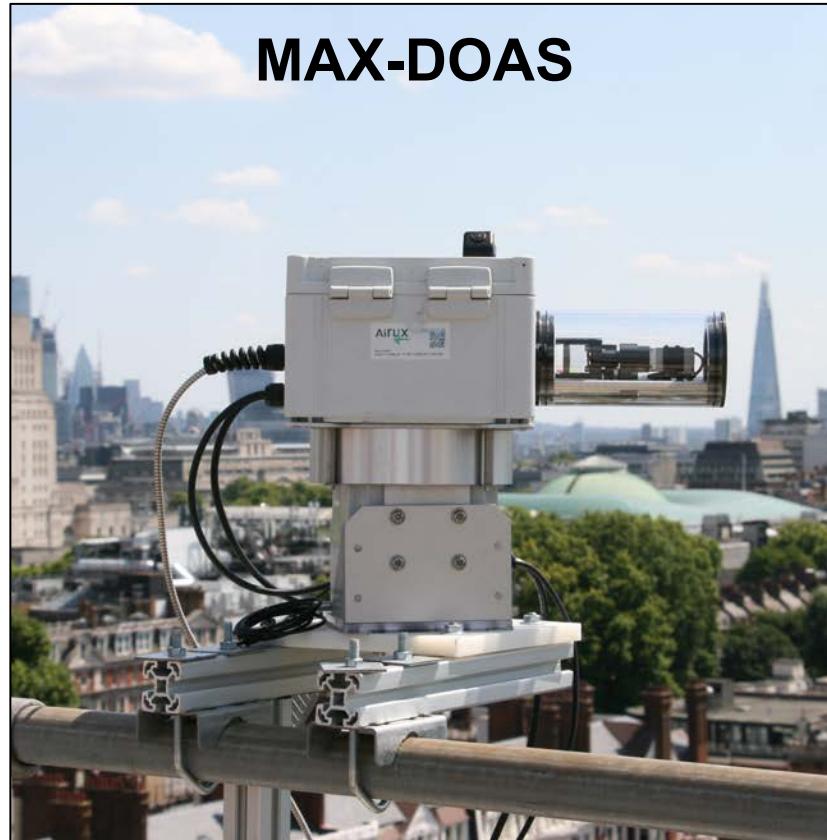
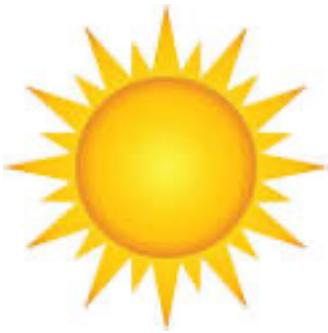
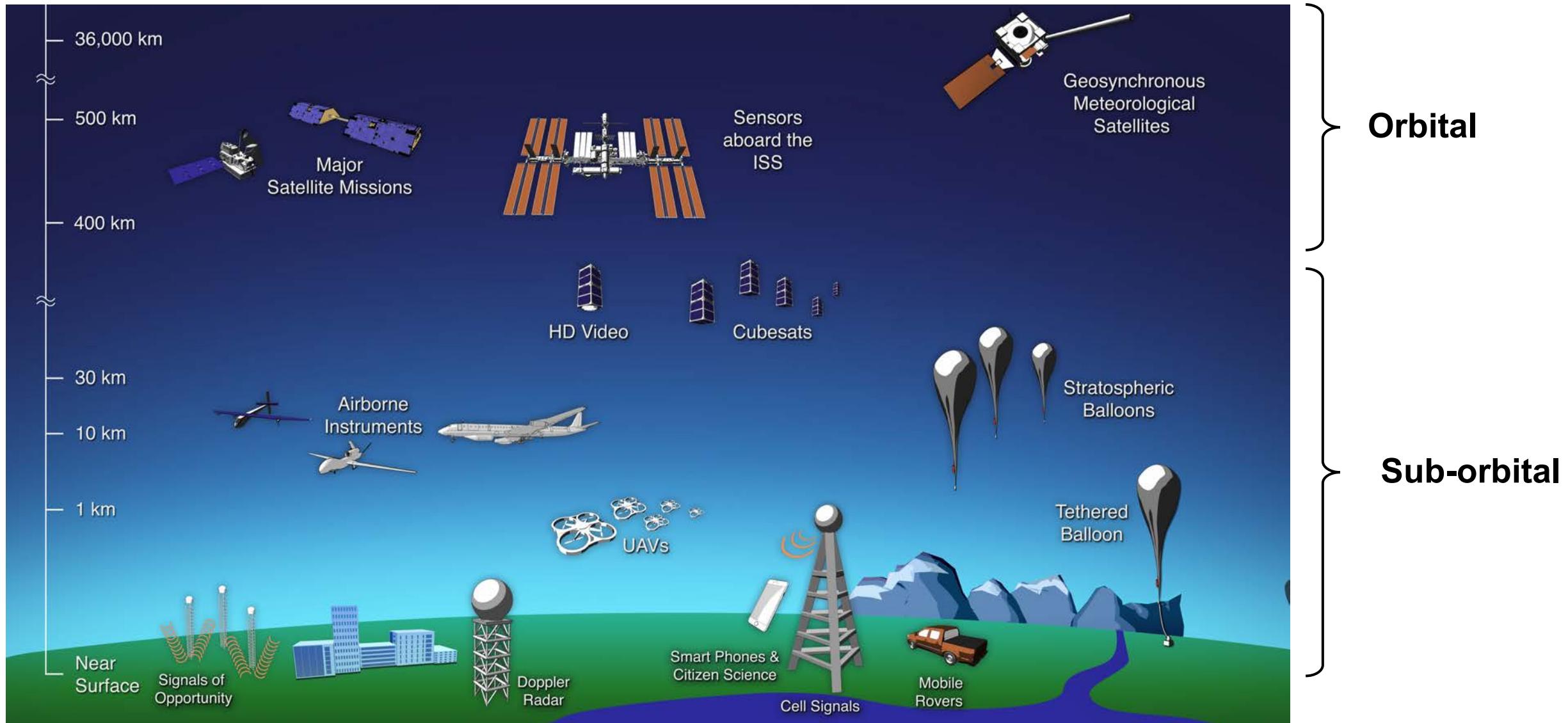


Photo of **our instrument** on the  
rooftop of a 10-story UCL building

# Remote sensing of the atmosphere from above





Public Health England

HCHO

# Health Matters

Air pollution: sources,  
impacts and actions

NMVOC

NH<sub>3</sub>

Health Matters

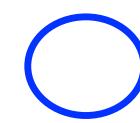
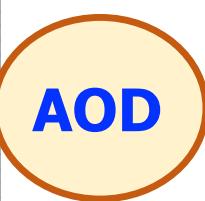
PM<sub>2.5</sub>

AOD

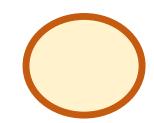
SO<sub>2</sub>

NO<sub>x</sub>

NO<sub>2</sub>

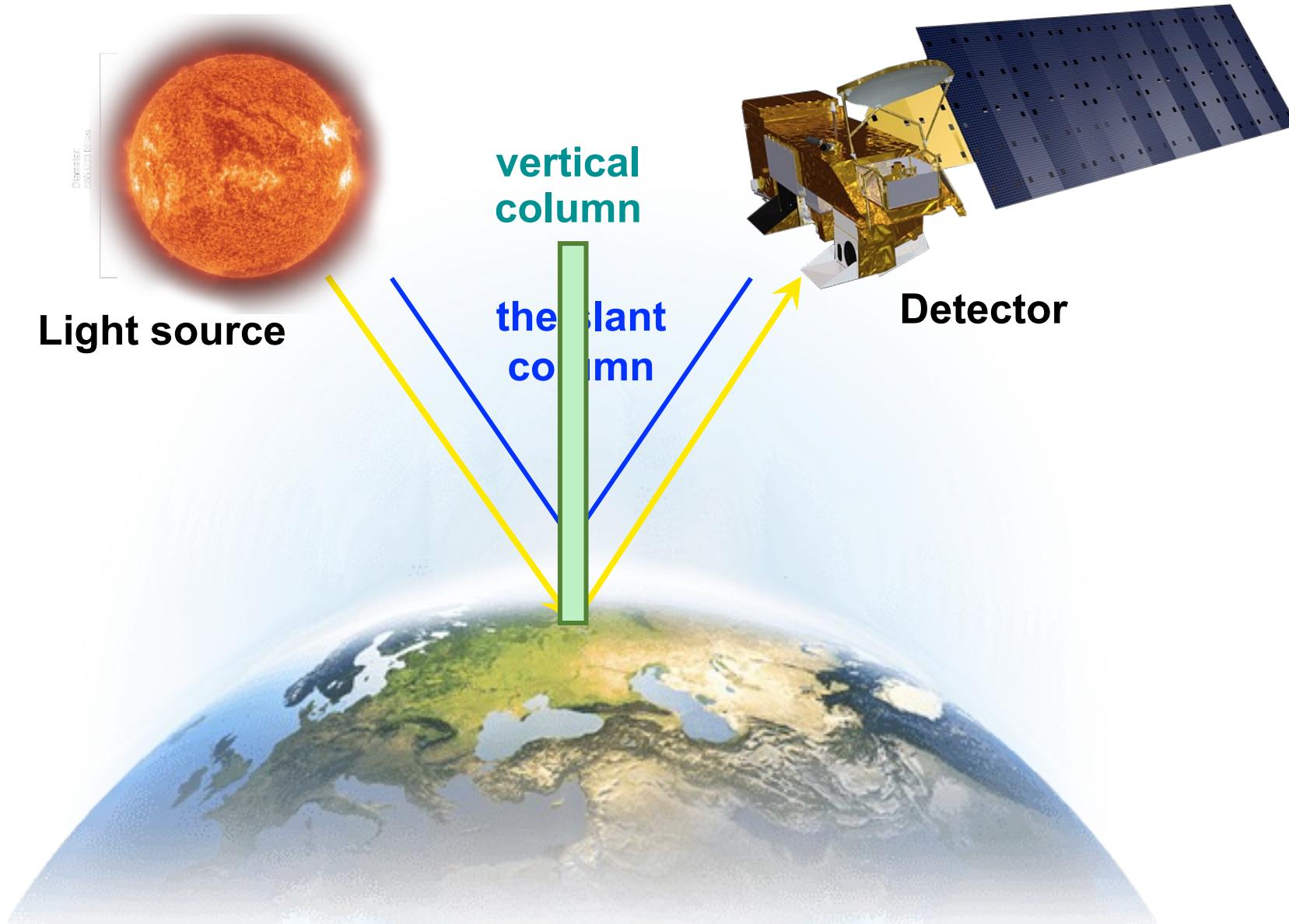


Directly detected with remote sensing



Indirect (proxy) detected

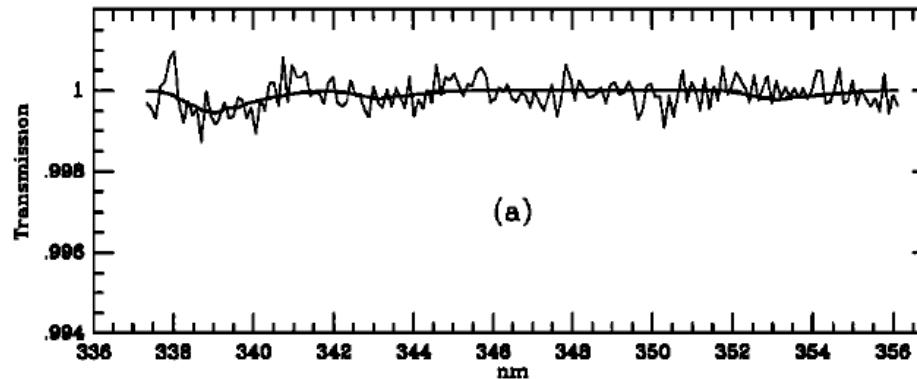
# Space-based remote sensing of the atmosphere



# Spectral Fit along a slant column

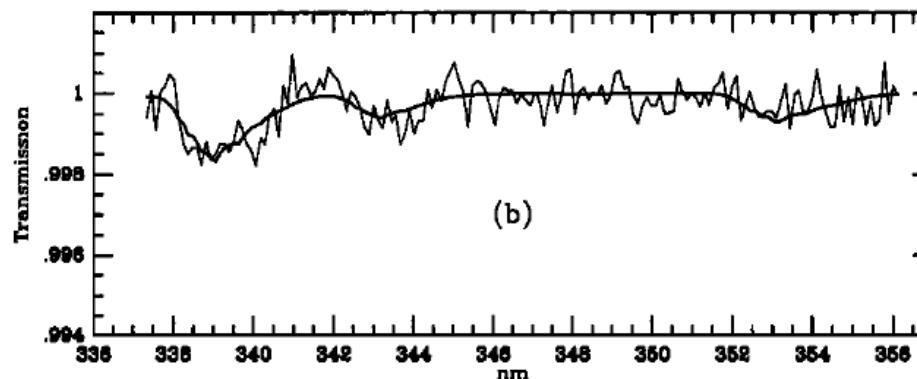
**Formaldehyde (HCHO):**

Prompt, high-yield oxidation product of non-methane volatile organic compounds



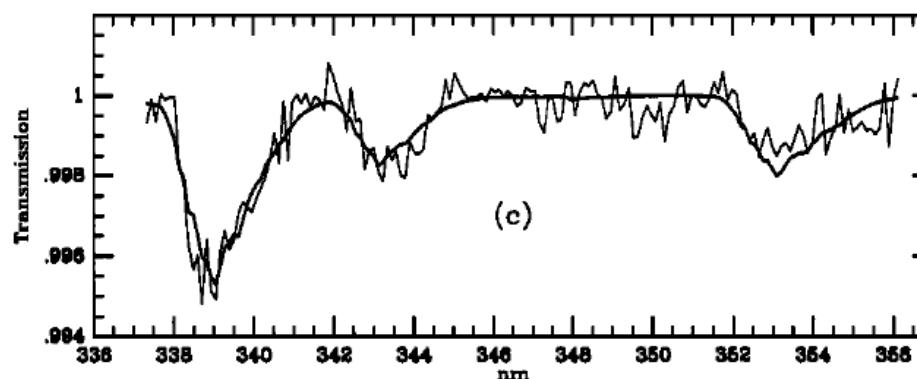
(a)

$1.0 \times 10^{16}$  molecules HCHO cm<sup>-2</sup>



(b)

$3.0 \times 10^{16}$  molecules HCHO cm<sup>-2</sup>

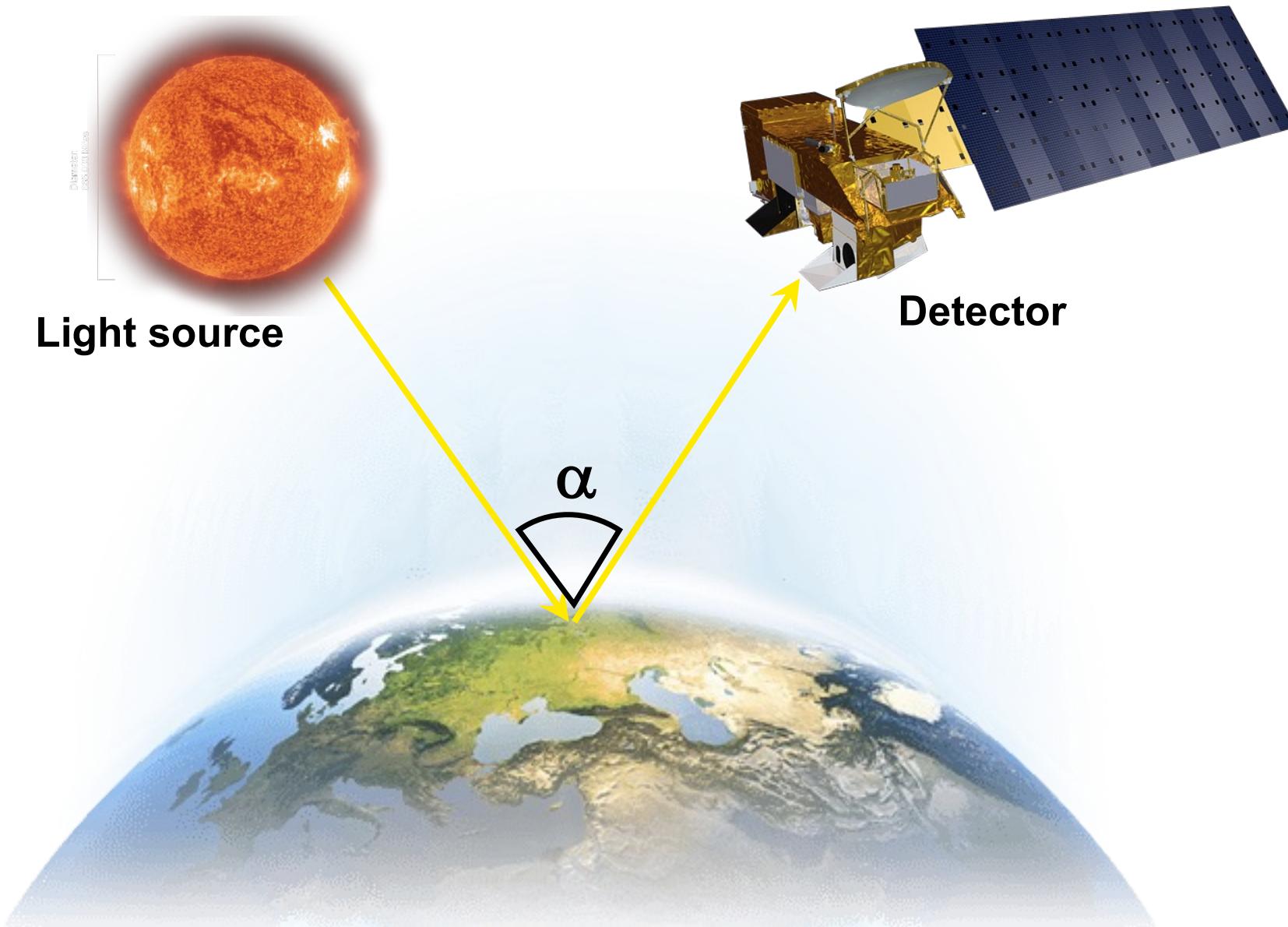


(c)

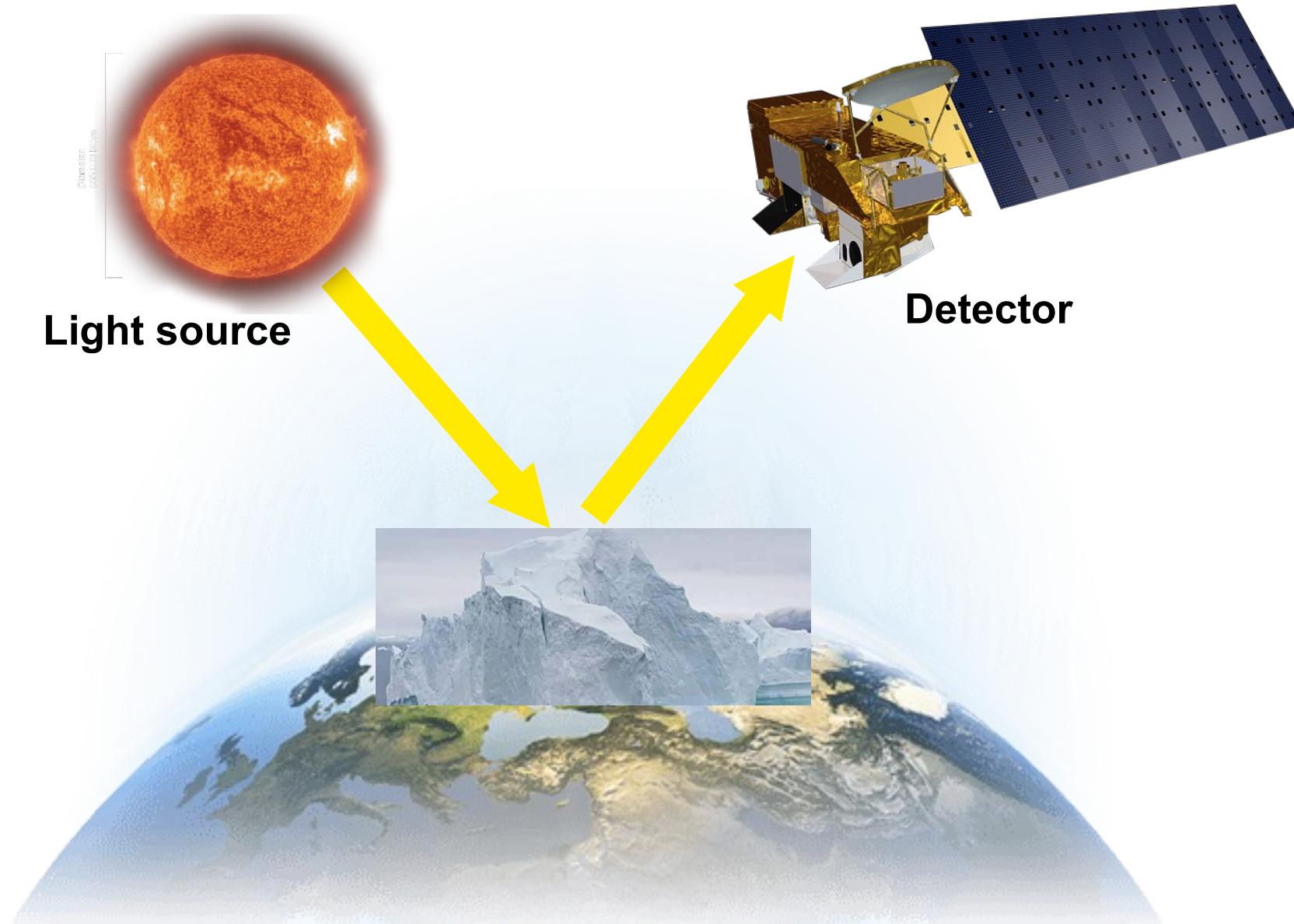
$8.4 \times 10^{16}$  molecules HCHO cm<sup>-2</sup>

Source: Chance et al. 2000,  
<https://doi.org/10.1029/2000GL011857>

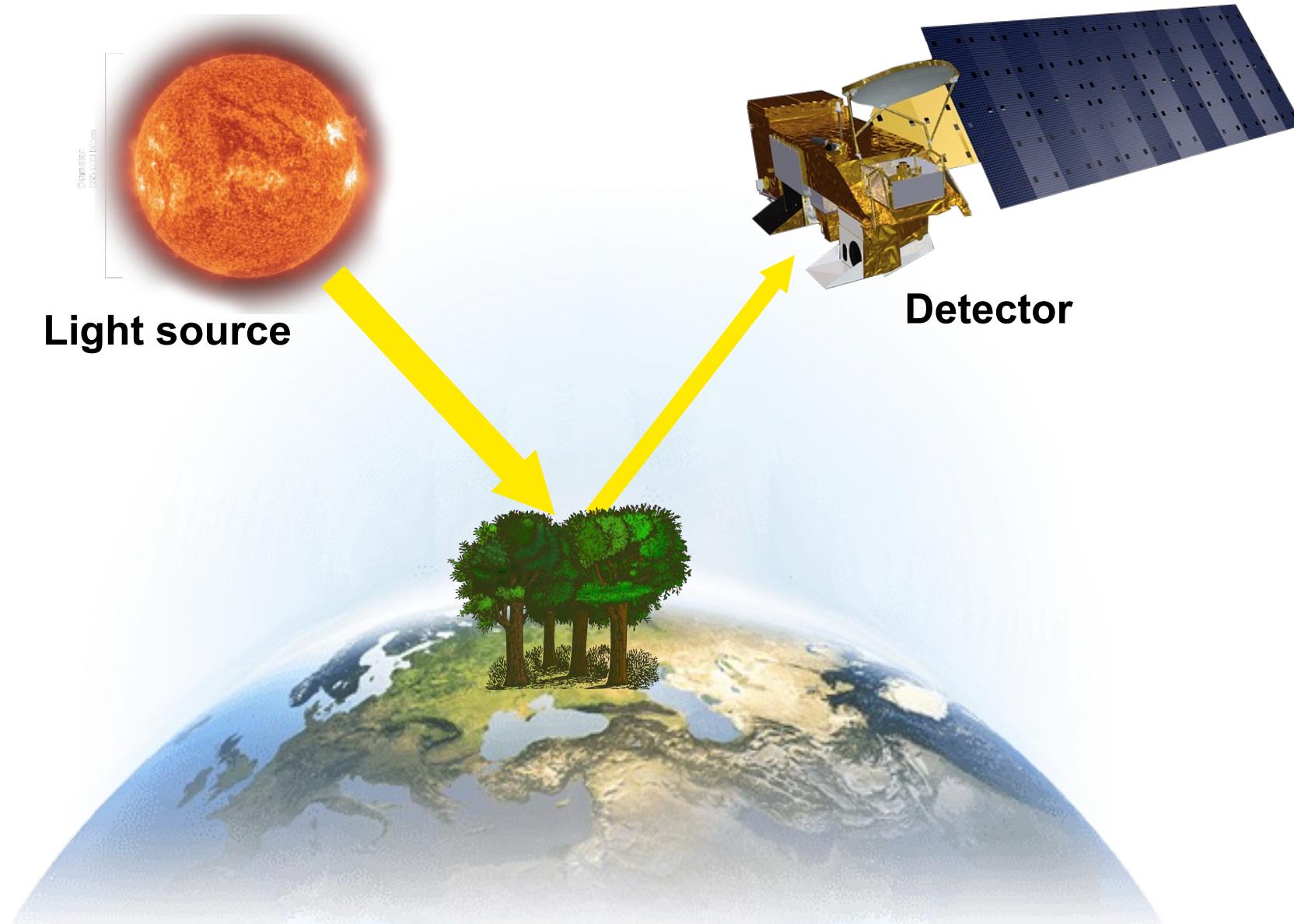
# Slant Column Geometry



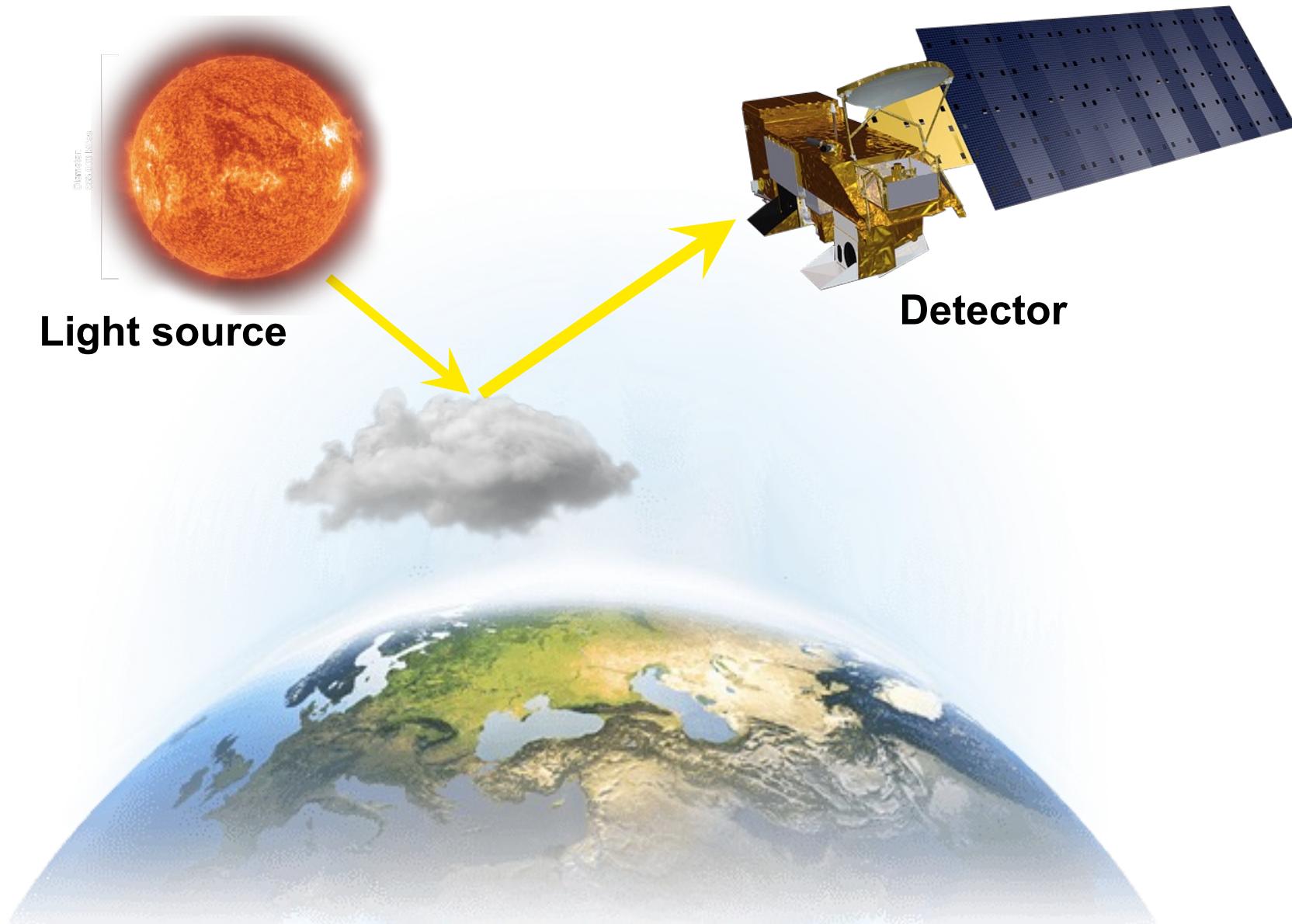
# Surface Reflectivity



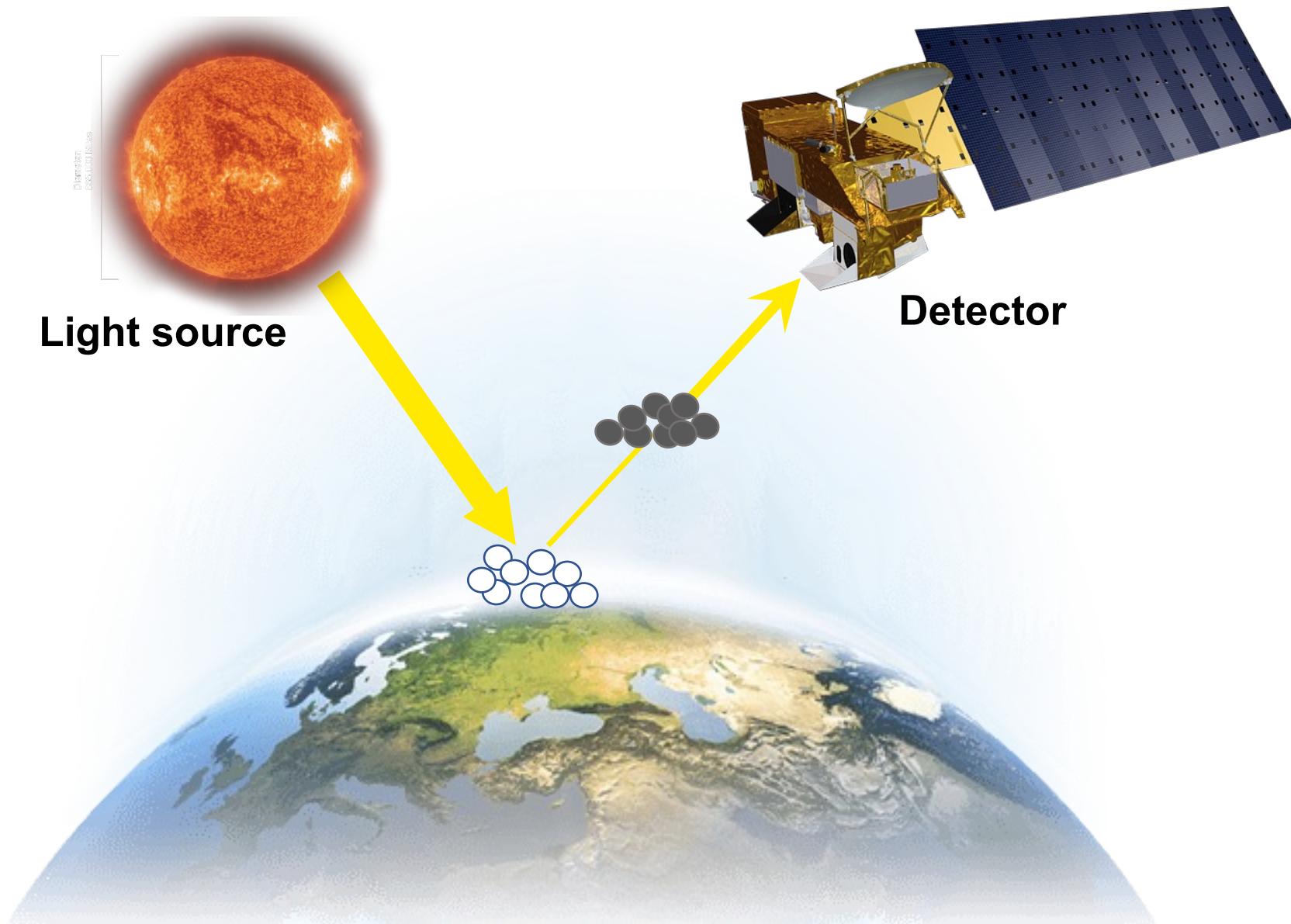
# Surface Reflectivity



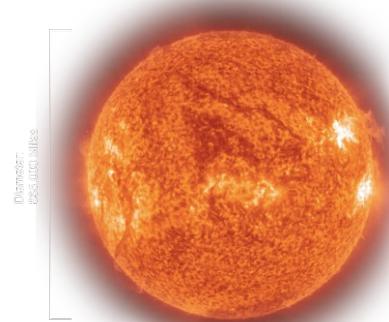
# Clouds



# Aerosols

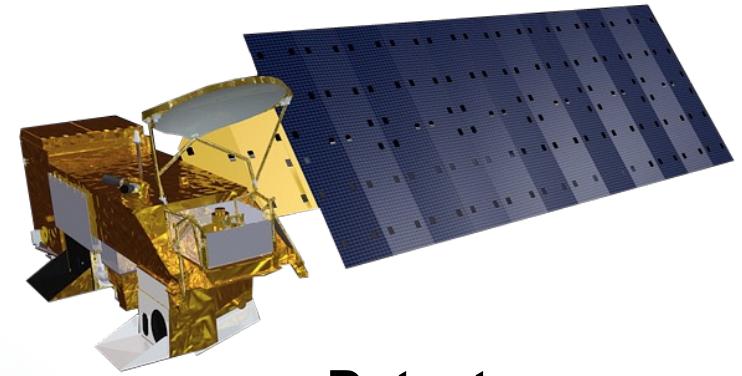


# “True” Vertical Column



**Light source**

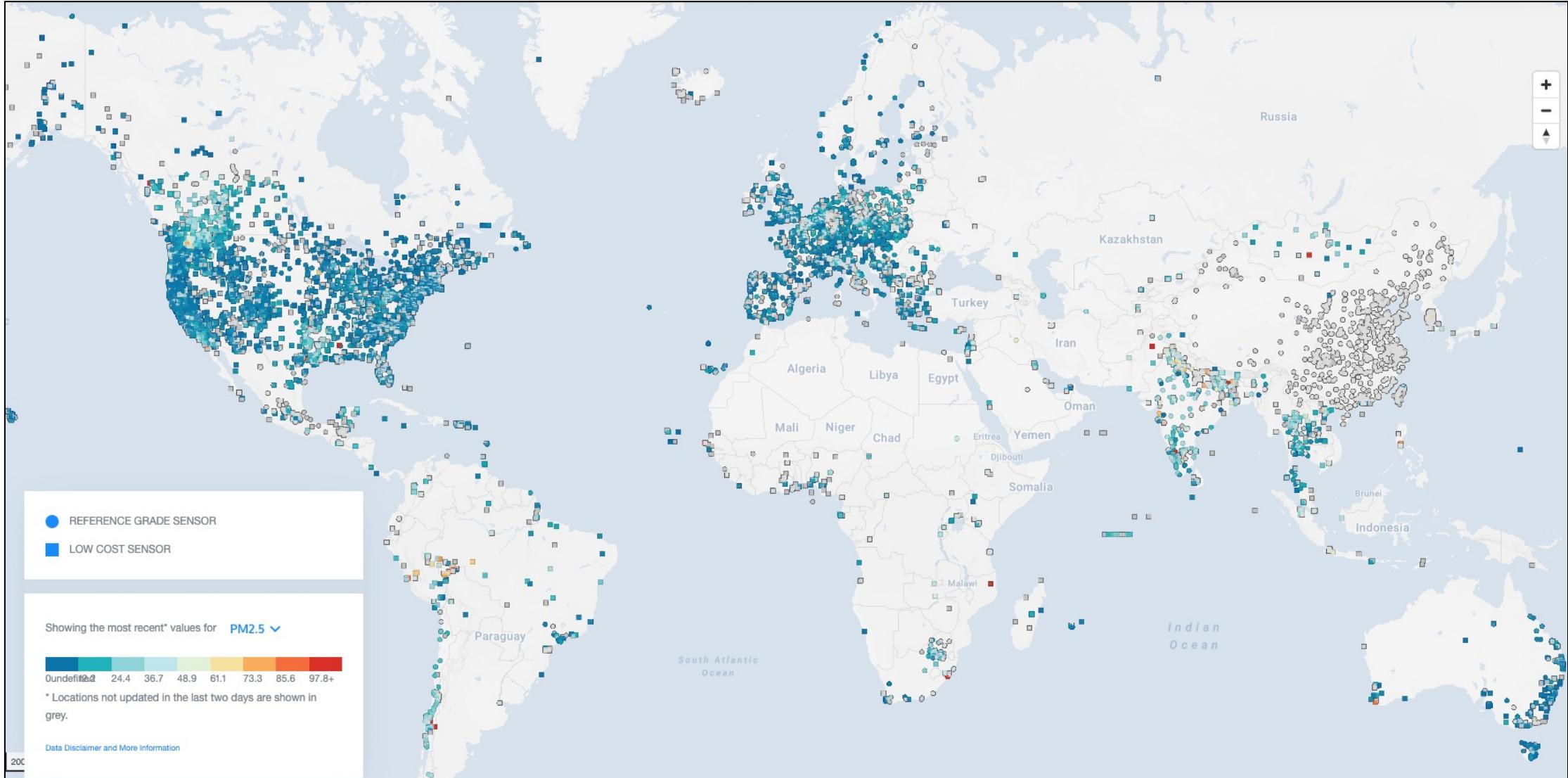
Vertical column  
abundance



**Detector**

- Evaluate models
- Estimate emissions
- Understand air pollution
- Derive trends
- Monitor changes in air pollution

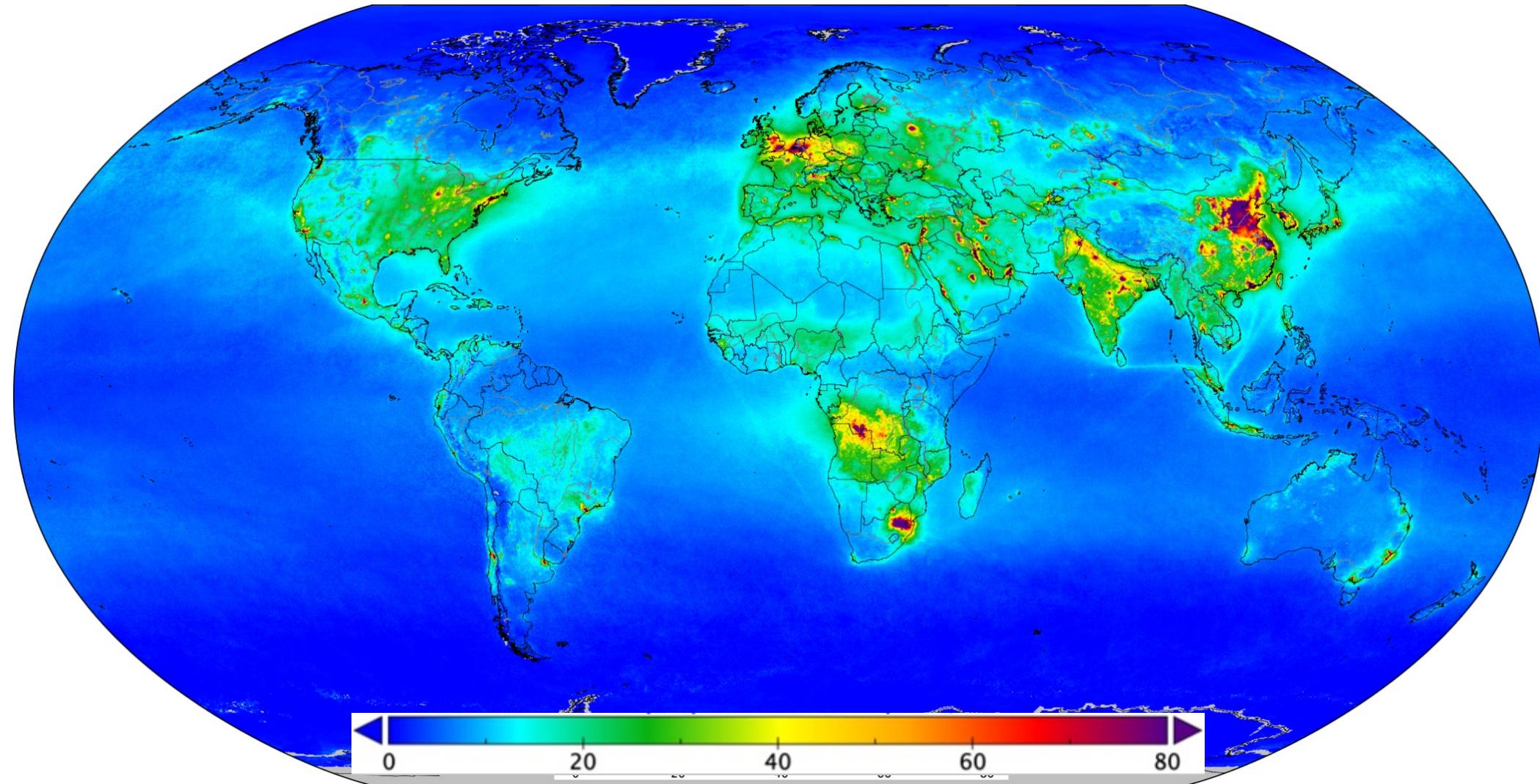
# In-situ measurements have large gaps



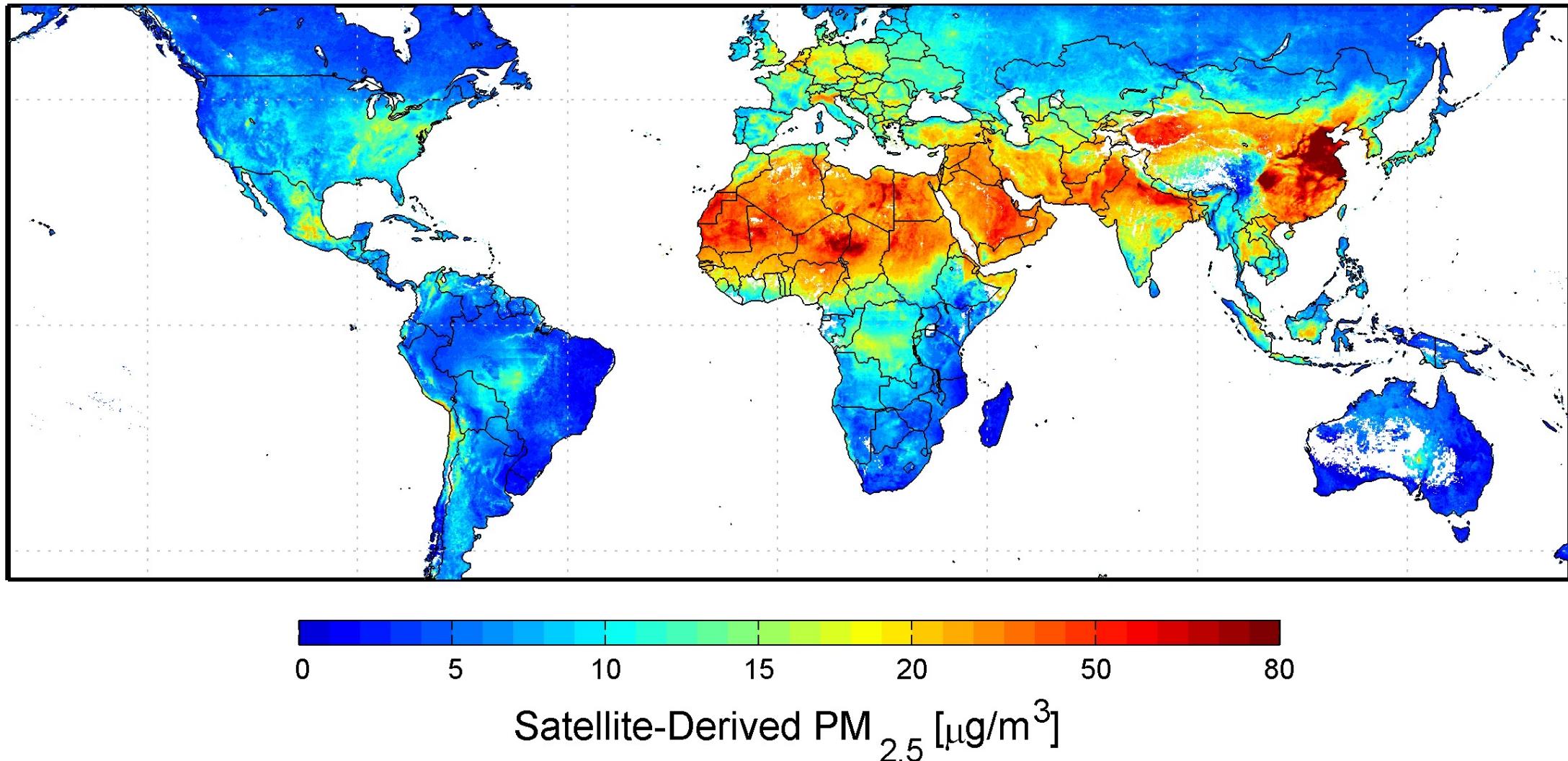
[Source: OpenAQ, <https://openaq.org/#/map>, accessed 29 Sept 2022]

# Satellite observations offer global coverage

Vertical column densities of NO<sub>2</sub> [ $\mu\text{mol m}^{-2}$ ]



# Satellite observations used to derive PM<sub>2.5</sub>

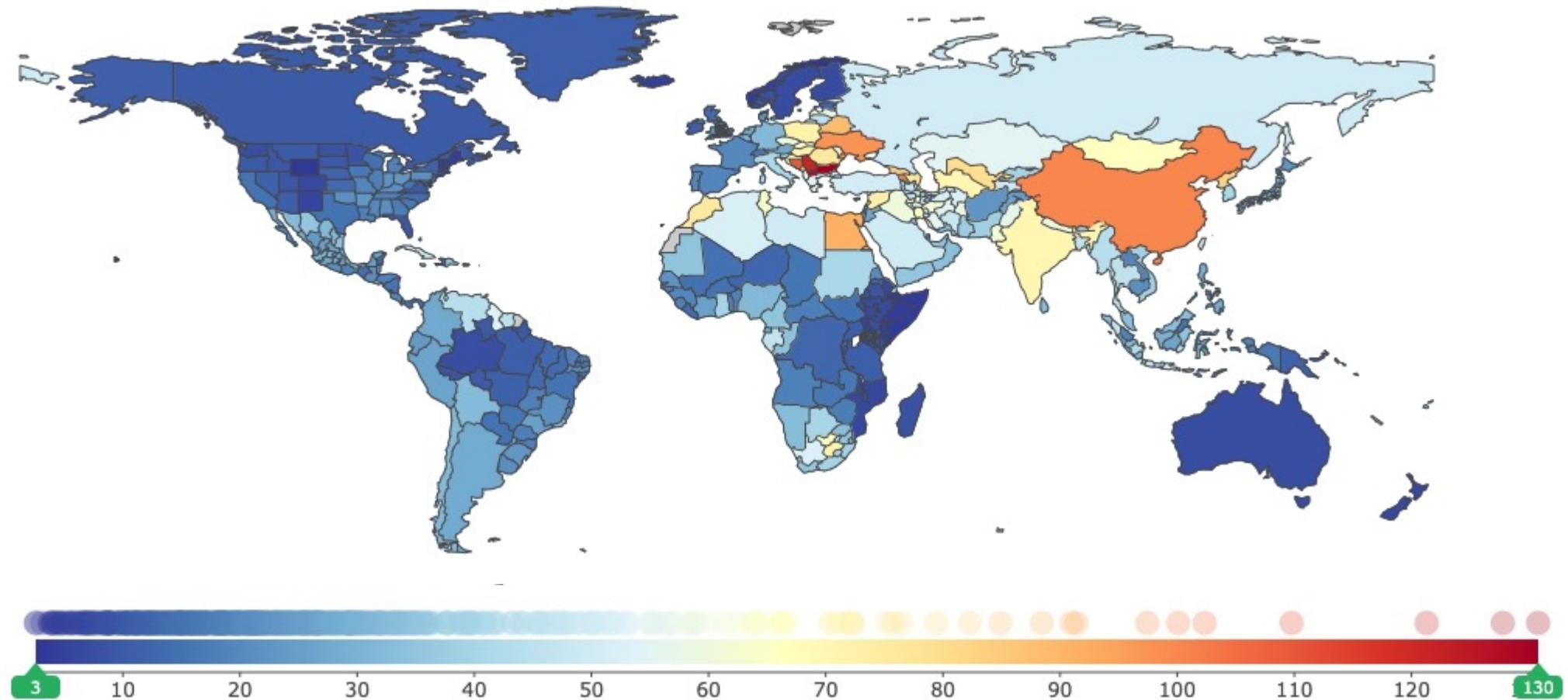


[Source: <https://doi.org/10.1016/j.envres.2012.08.005>]

# Application beyond scientific research

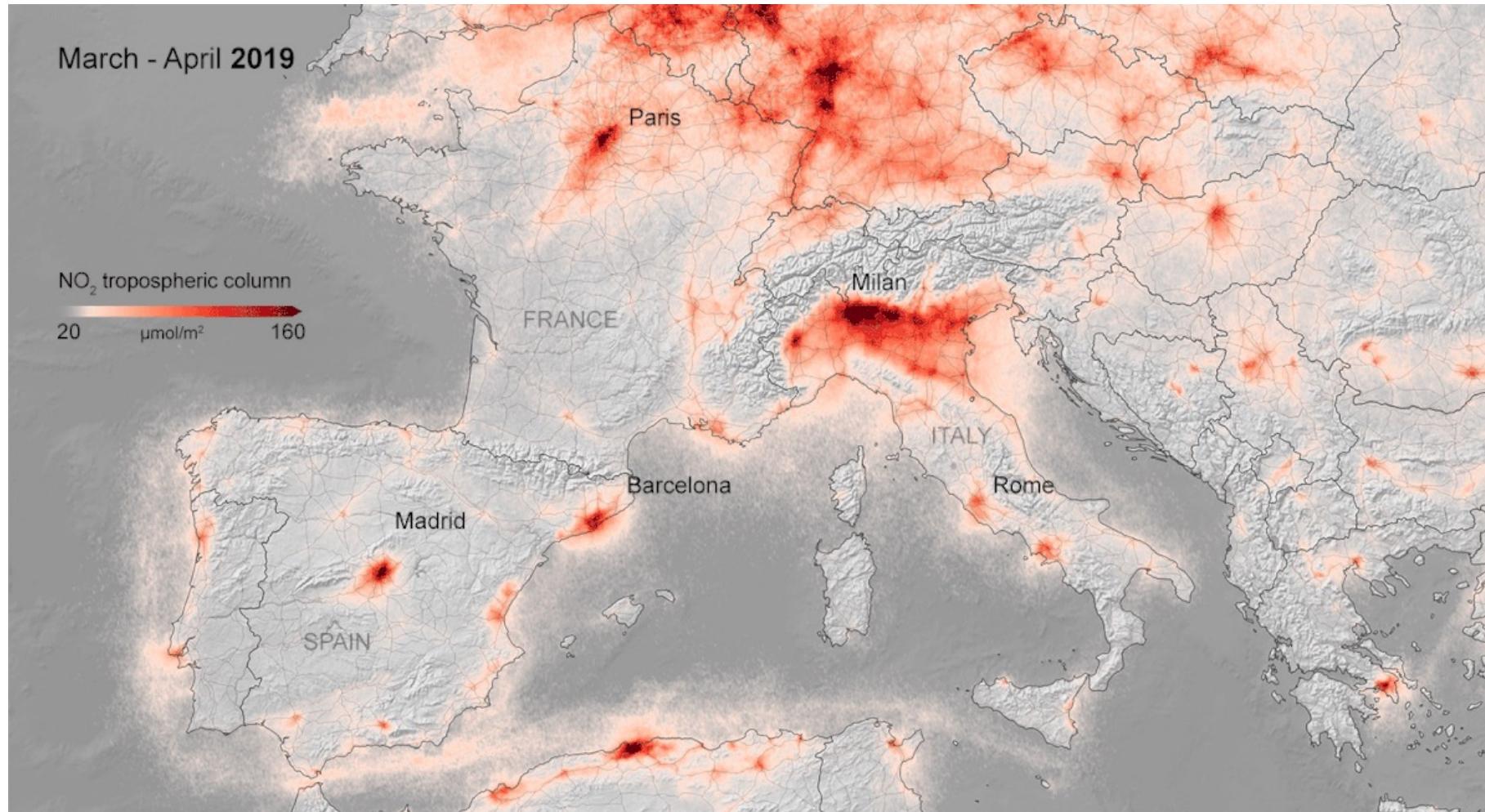
Public health burden of exposure to fine particles (PM<sub>2.5</sub>): <https://vizhub.healthdata.org/gbd-compare/>

Premature deaths per 100,000 attributed to exposure to ambient (outdoor) PM<sub>2.5</sub>



# Application beyond scientific research

Abrupt decline in air pollution during COVID-19 lockdowns

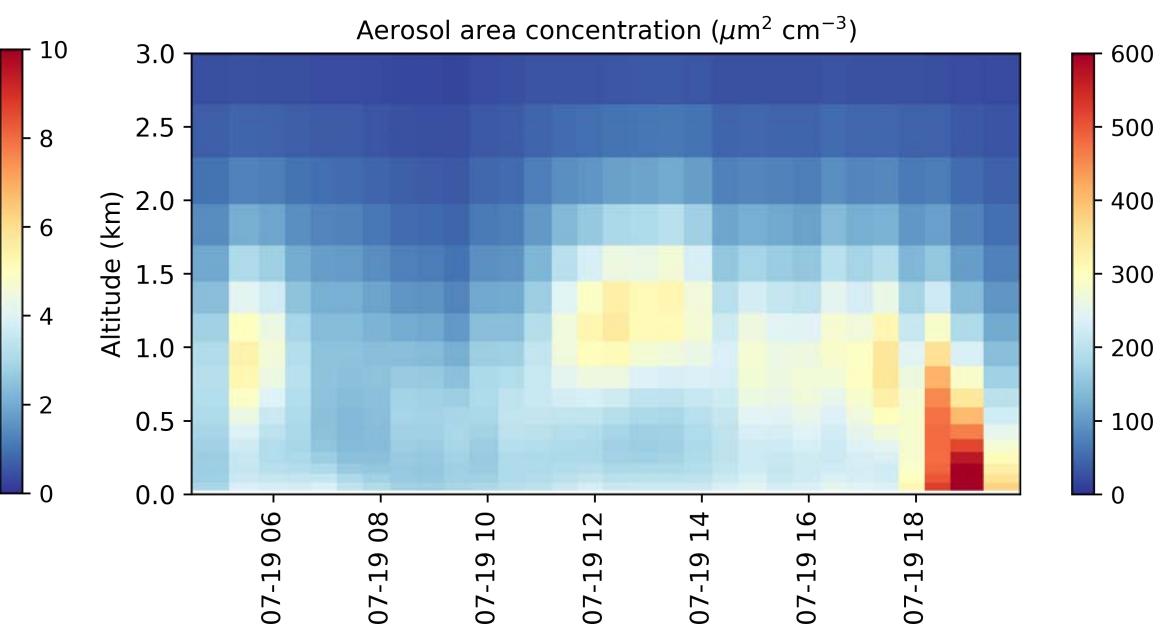
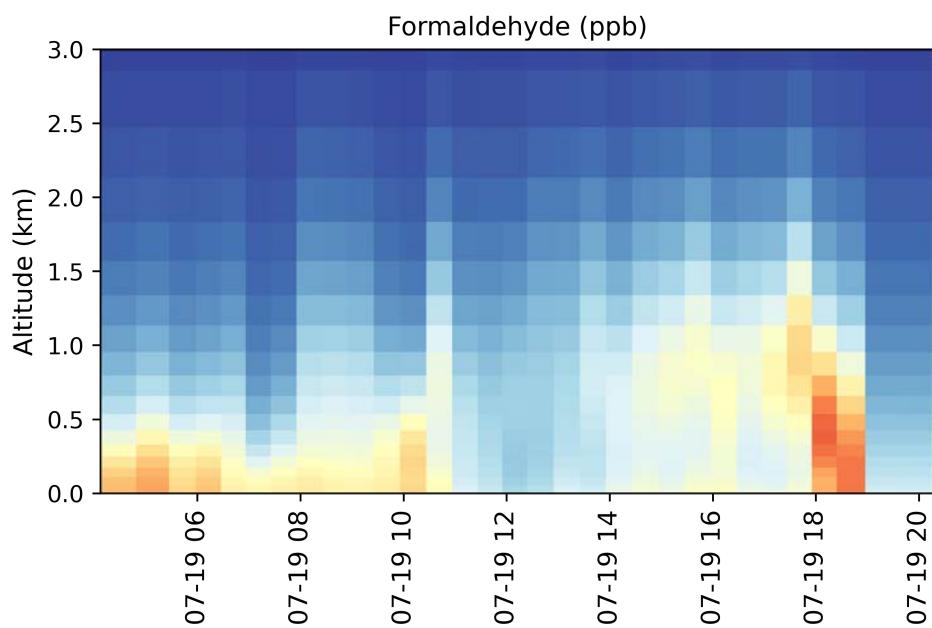


[Source: ESA]

**Research group projects using remote  
sensing and related research tools**

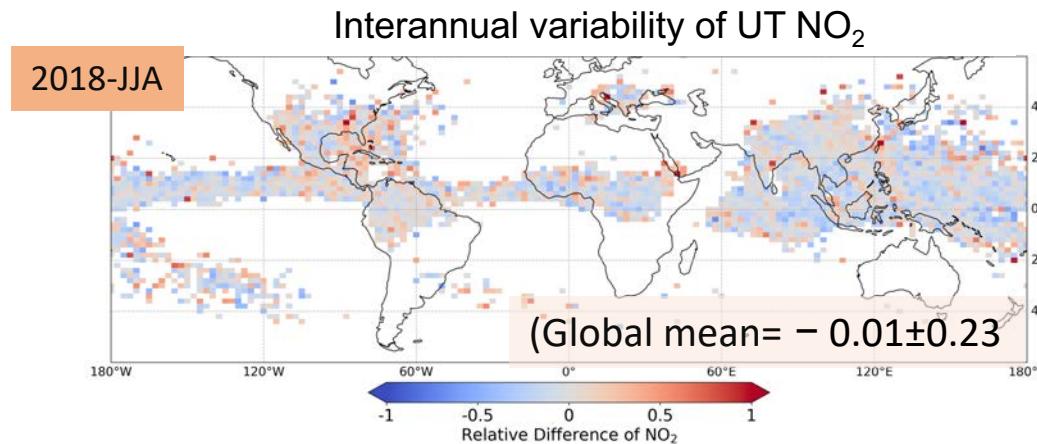


## Examining the vertical extent of heatwave and wildfire pollution

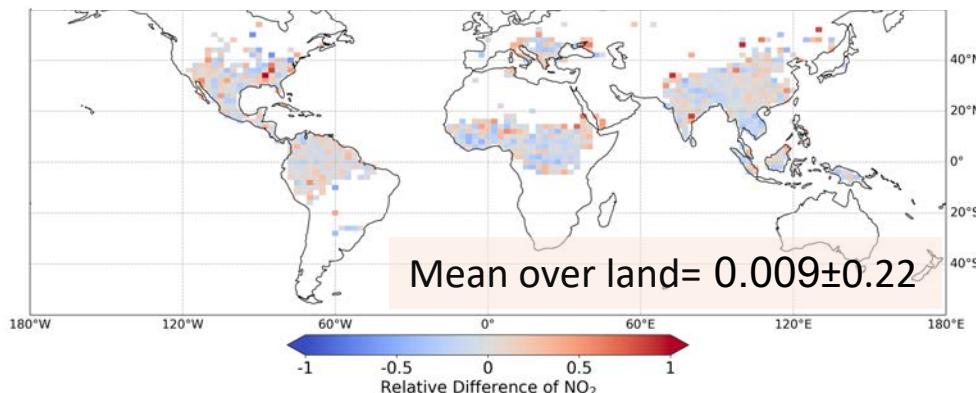


# Seasonal and Interannual variability of NO<sub>x</sub> determined with cloud-sliced TROPOMI NO<sub>2</sub> data

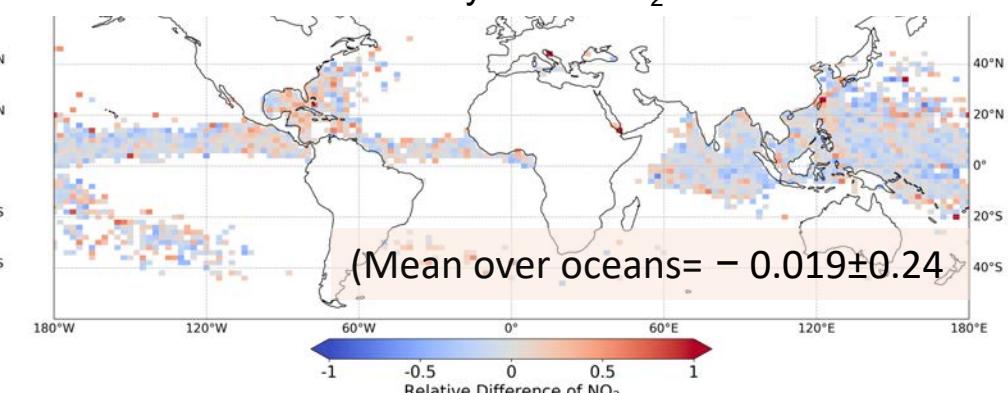
We're using new data of NO<sub>2</sub> concentrations to quantify for the first time year-to-year variability in NO<sub>x</sub> in the global upper troposphere



Interannual variability of UT NO<sub>2</sub> over land



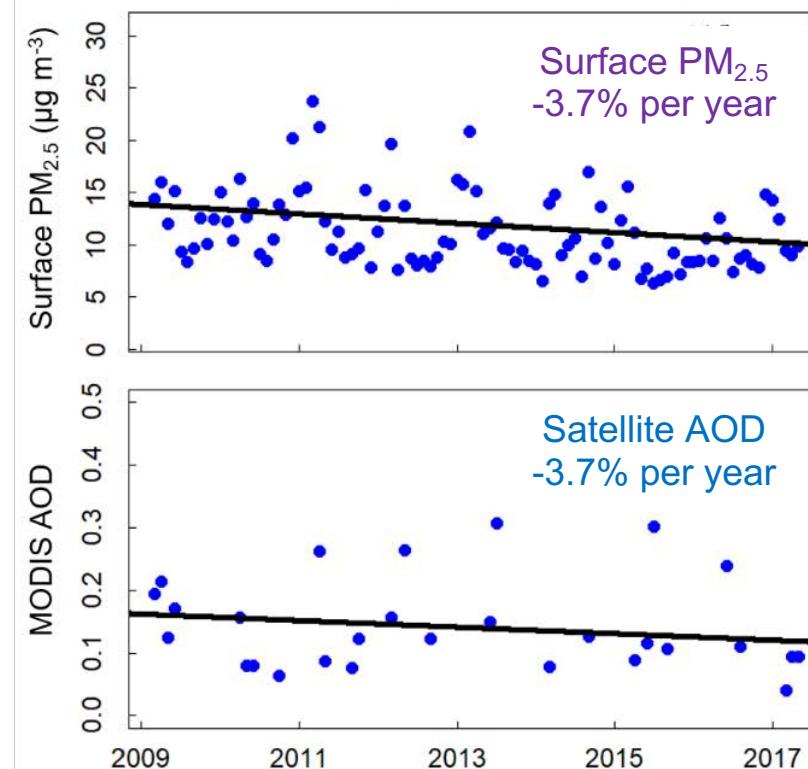
Interannual variability of UT NO<sub>2</sub> over oceans



# Application of remote sensing to quantify trends in air quality in cities

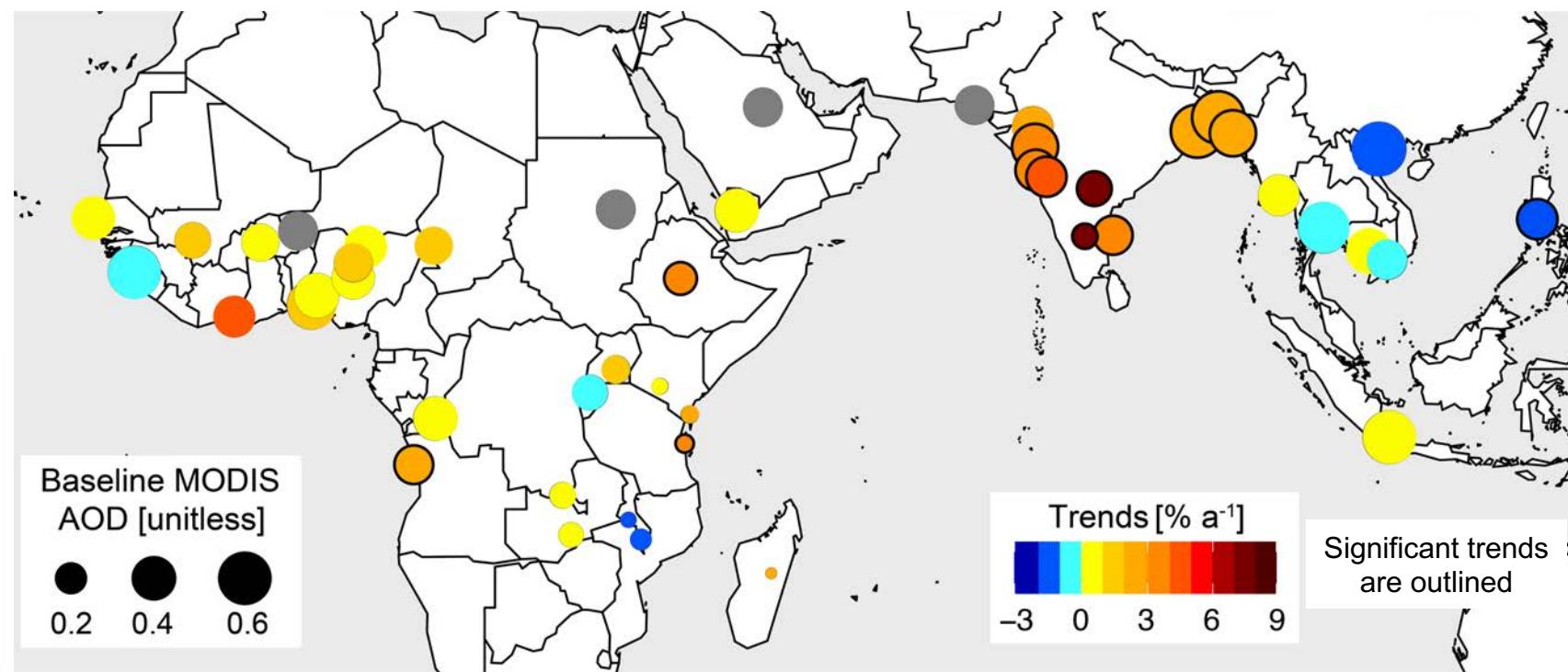
We evaluate satellite observations with surface measurements and use the quality assured data to identify rapid air quality degradation in the future megacities of the world.

Satellite AOD vs surface PM<sub>2.5</sub>  
Birmingham (2009-2017)



AOD reproduces long-term  
trends in surface PM<sub>2.5</sub>

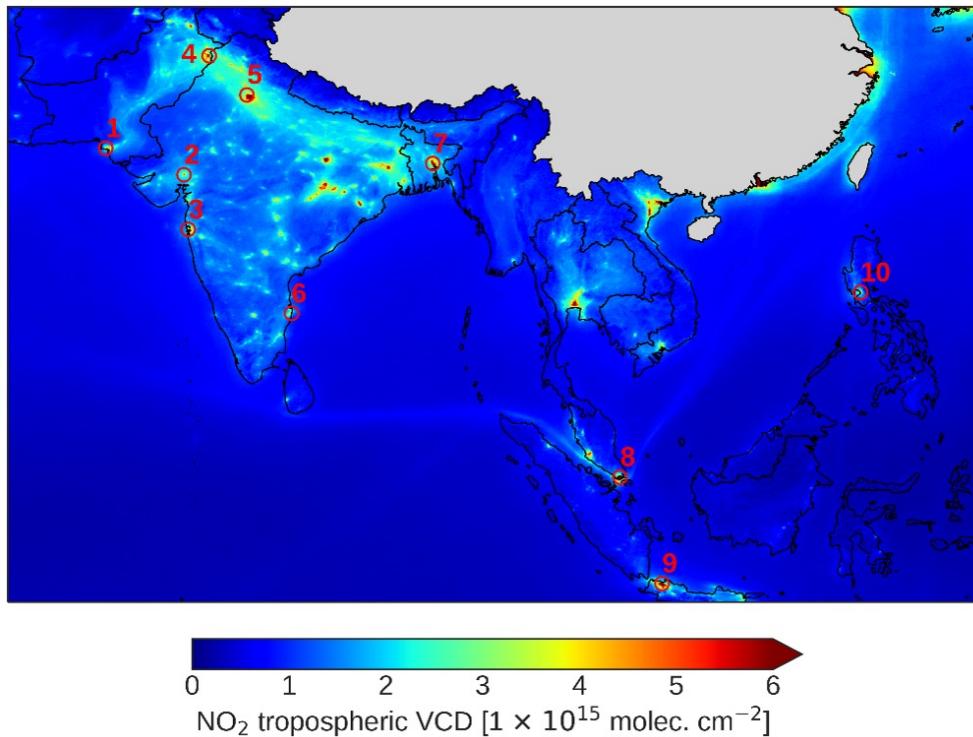
Long-term (2005-2018) trends in surface PM<sub>2.5</sub> in fast-growing tropical cities



Large and significant increases of 3-8 % per year in PM<sub>2.5</sub> over the  
Indian subcontinent and in 3 African cities

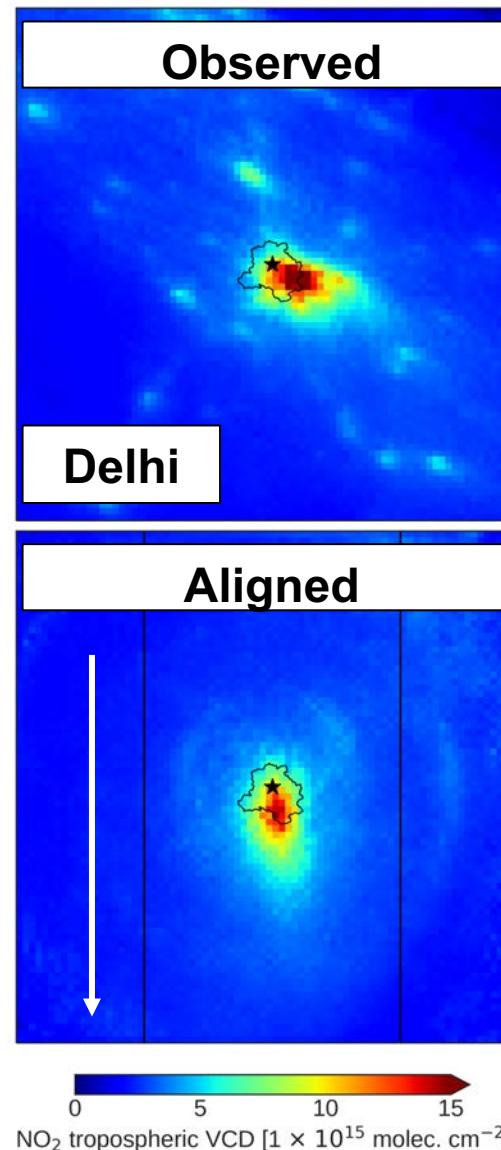
# Estimating NO<sub>x</sub> Emissions in Cities in Asia using a Plume-Rotation Technique

## 1. Identify NO<sub>2</sub> pollution hotspots



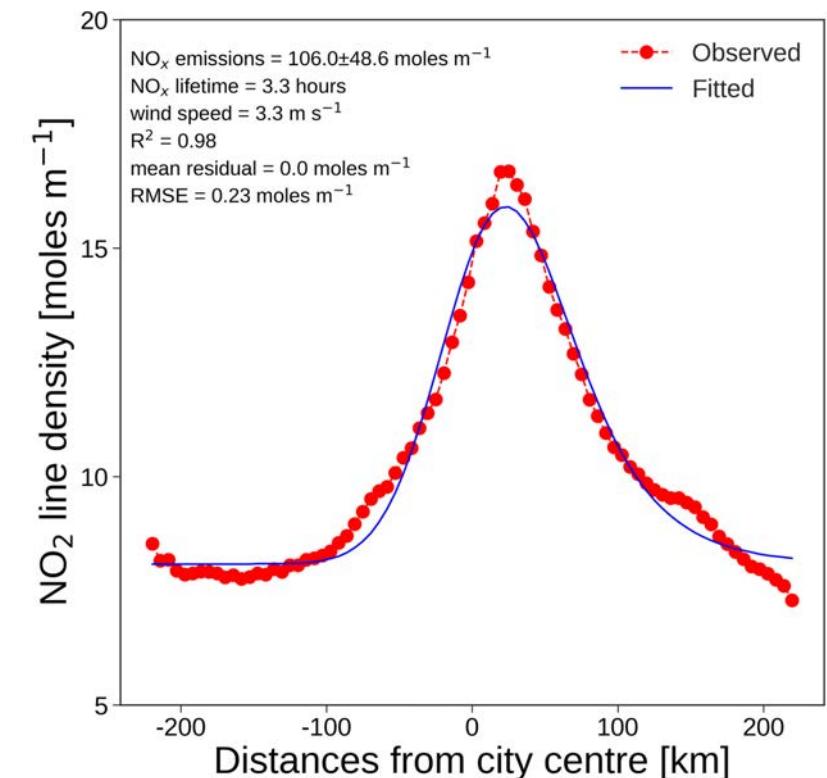
NO<sub>x</sub> is emitted during high-temperature combustion by cars, power plants and ships

## 2. Align NO<sub>2</sub> plumes



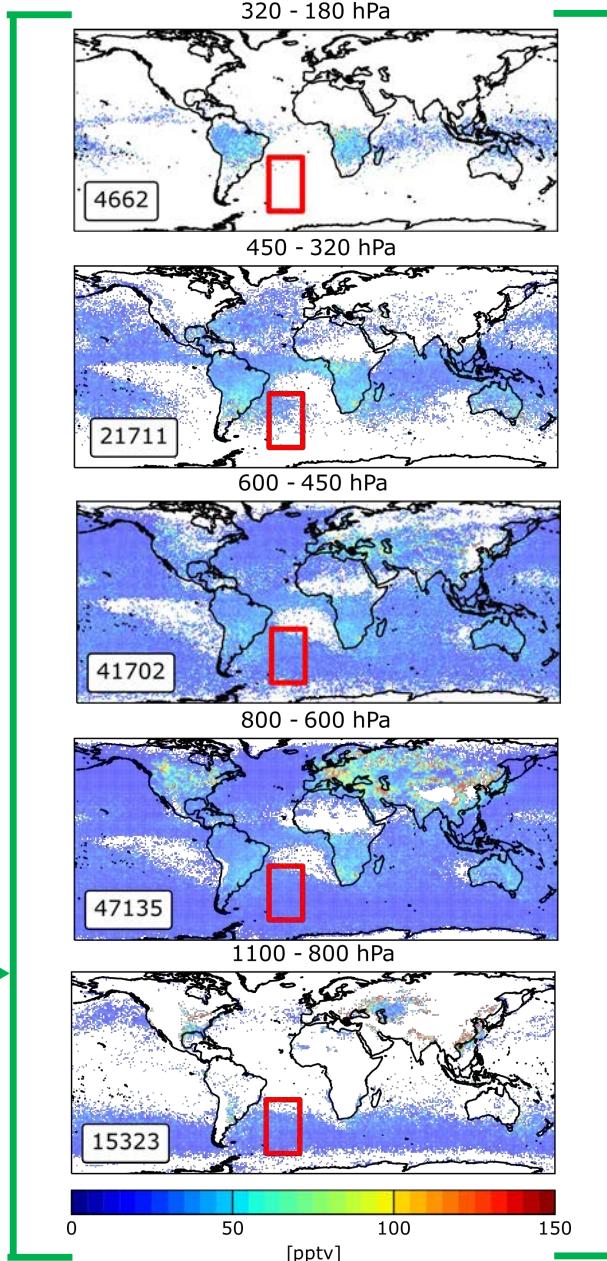
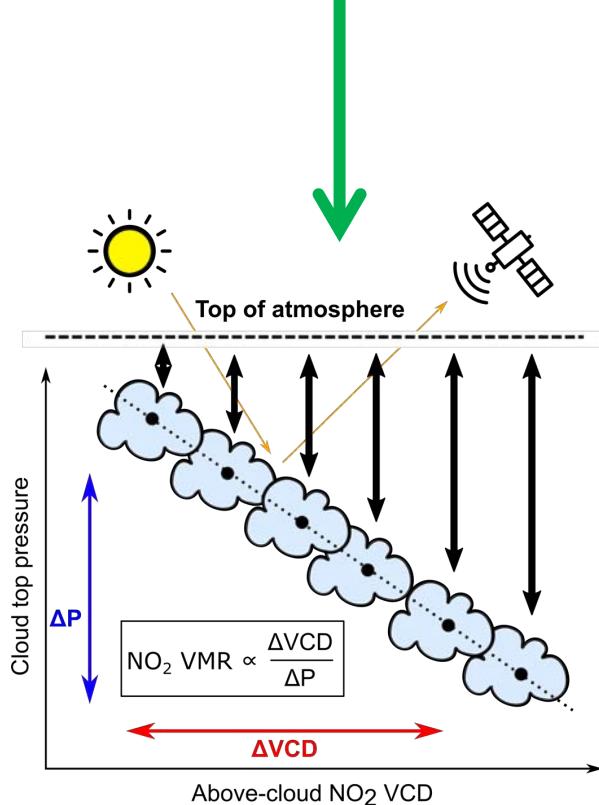
## 3. Estimate NO<sub>x</sub> emissions

$$F(x | a, x_0, \mu_x, \sigma_x, B) = \frac{a}{2x_0} \exp\left(\frac{\mu_x}{x_0} + \frac{\sigma_x^2}{2x_0^2} - \frac{x}{x_0}\right) \operatorname{erfc}\left(-\frac{1}{\sqrt{2}} \left[ \frac{x - \mu_x}{\sigma_x} - \frac{\sigma_x}{x_0} \right]\right) + B$$

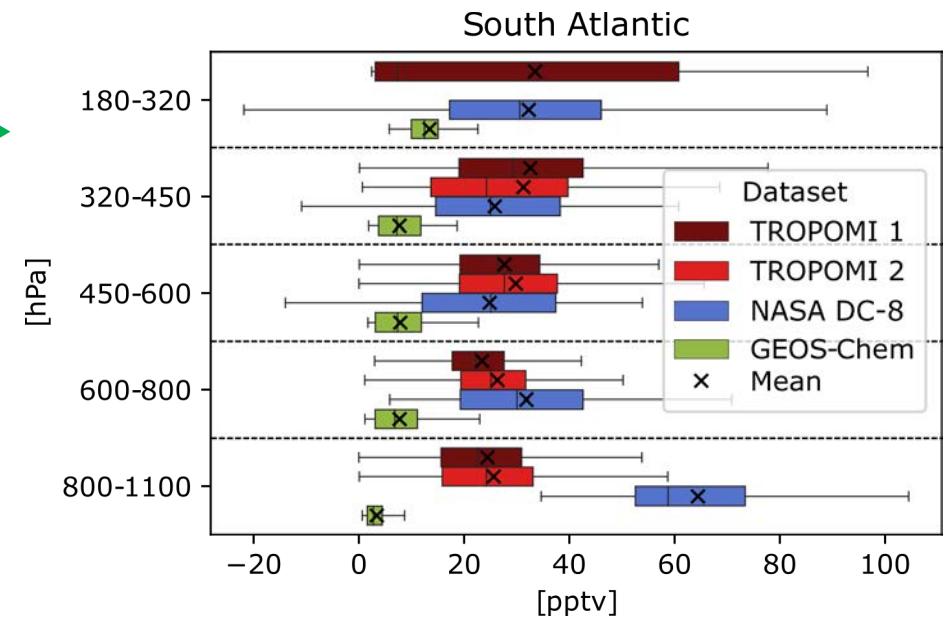


Delhi NO<sub>x</sub> = 100 kilotonnes in 2019

## Using the cloud-slicing technique to obtain NO<sub>2</sub> data from the TROPOMI instrument aboard the Sentinel-5P satellite



Mean and median cloud-slicing results compared to aircraft observations from NASA DC-8 and simulations from the GEOS-Chem model



Data for DJF 2018 to 2021 are shown here with the box plots representing the median value with the 5<sup>th</sup>, 25<sup>th</sup>, 75<sup>th</sup> and 95<sup>th</sup> percentiles.

Email: rebekah.horner.20@ucl.ac.uk



# Contact us to find out more about the other research we do:

- Influence of **rockets** on stratospheric ozone and climate
- Health burden of **fossil fuels** on global and national scales
- Ecosystem and health impact of **agricultural emissions** of ammonia in the UK
- **Urban** sources of **fine particles** in UK cities
- Emissions estimates of **emergent pollution sources** like powerships in South Africa

## To get in touch:

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NWW: North West Wing