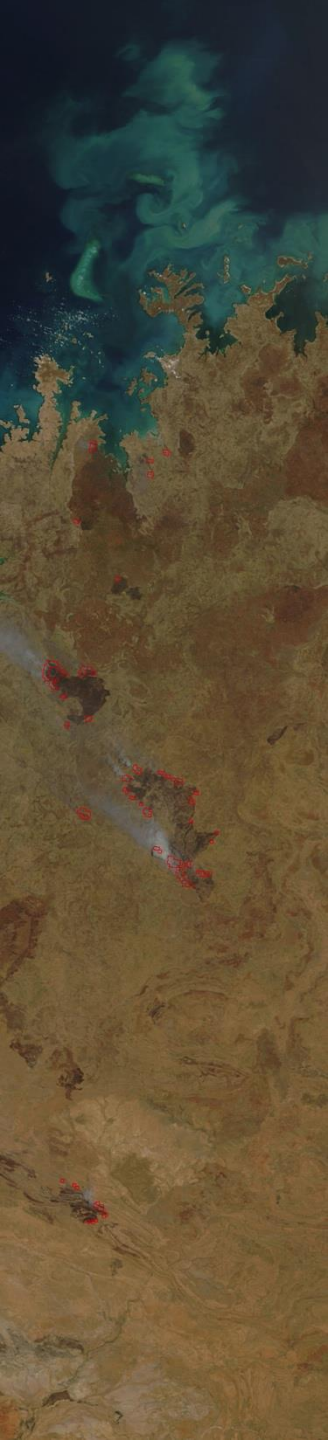


National Aeronautics and Space Administration

ARSET

Applied Remote Sensing Training

http://arset.gsfc.nasa.gov

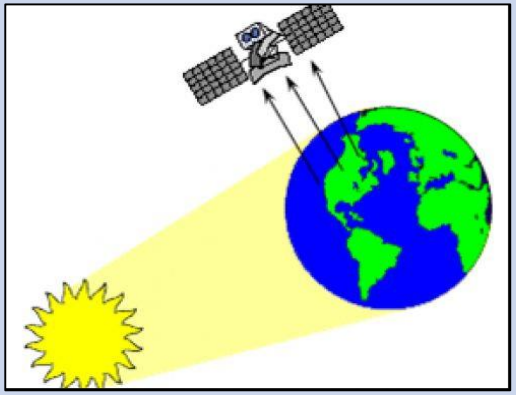
@NASAARSET

Introduction to Satellite Remote Sensing for Air Quality Applications

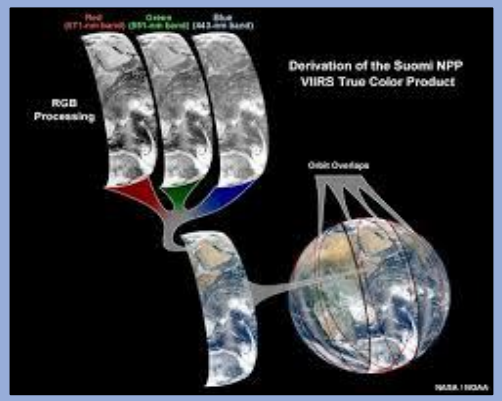
Webinar Session 4 – July 27, 2016

NASA Trace Gas Products for Health/Air Quality Applications

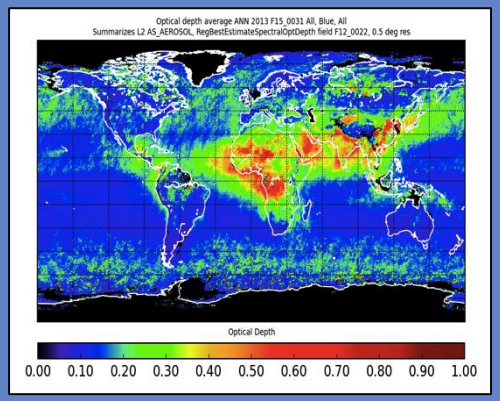
5 Weeks Webinar Series: Agenda



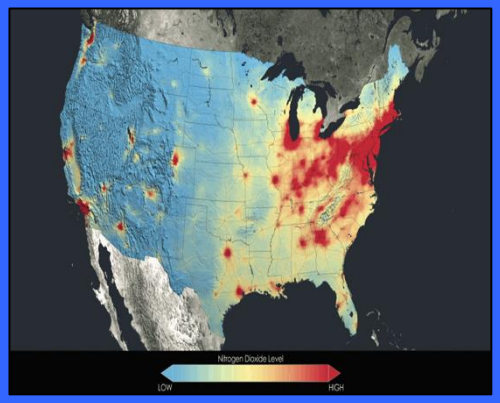
Week 1: Fundamental of Remote Sensing



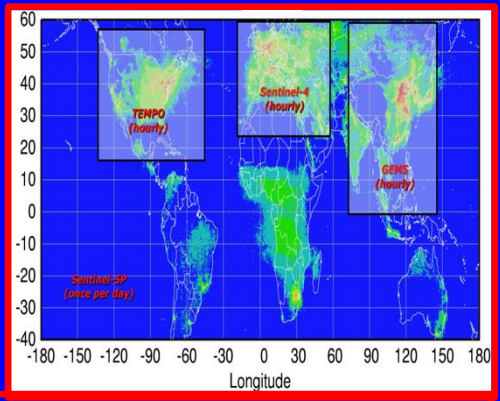
Week 2: Satellite Imagery



Week 3: Aerosol Data



Week 4: Trace Gas Data



Week 5: Future Capabilities

Today's Instructor: **Bryan Duncan**
Code 614
NASA Goddard Space Flight Center
Greenbelt, MD 20771, USA
bryan.n.duncan@nasa.gov

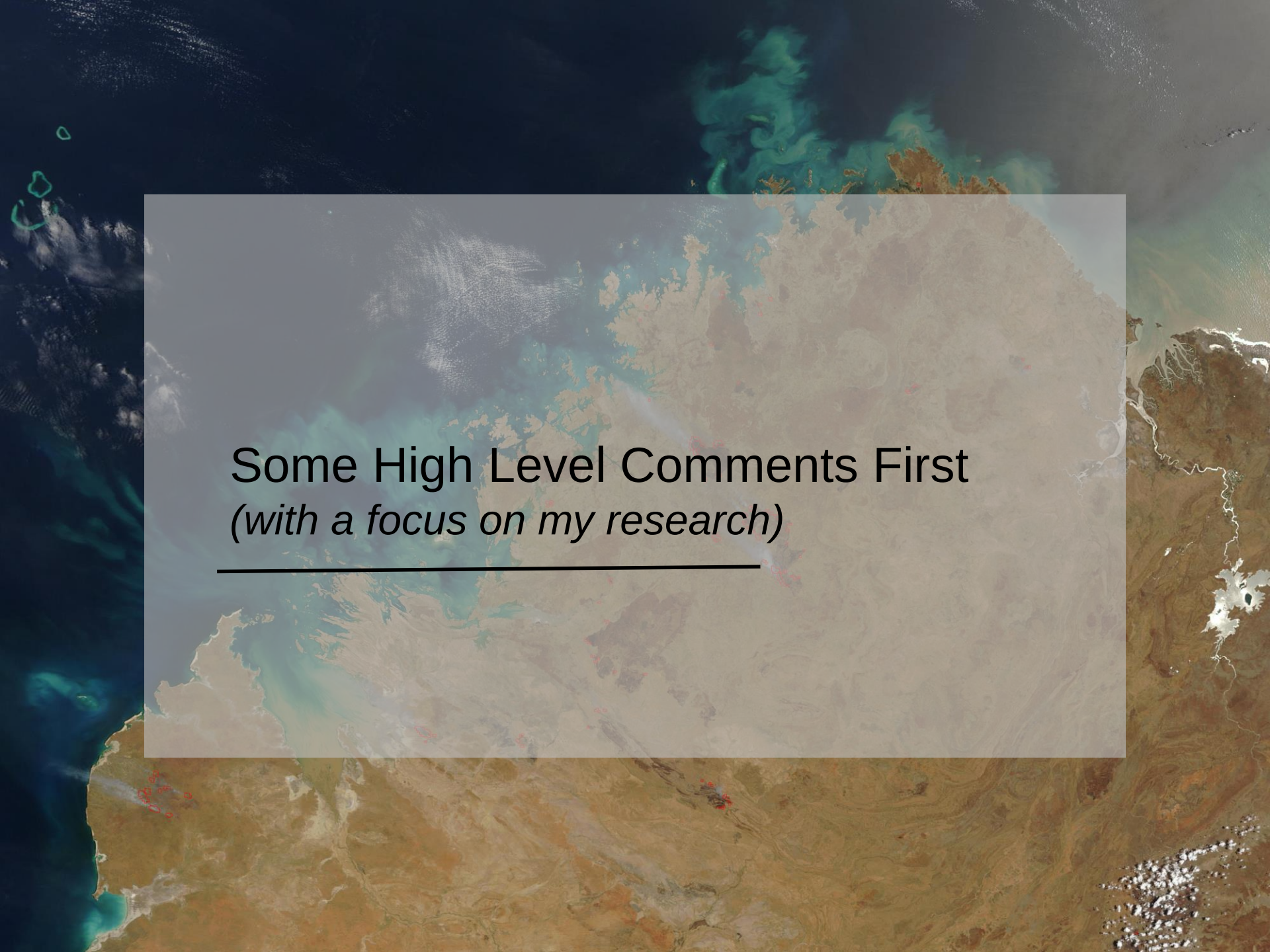
National Aeronautics and Space Administration

“NASA & Health/Air Quality”

Goddard Space Flight Center

Dr. Bryan Duncan

July 27, 2016; ARSET Webinar



Some High Level Comments First

(with a focus on my research)

Atmospheric Environment

Volume 94, September 2014, Pages 647–662

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]

Show more

doi:10.1016/j.atmosenv.2014.05.061

It's free to download:
http://www.sciencedirect.com/science/article/pii/S1352231014004270

Atmospheric Environment

Volume 77, October 2013, Pages 1011–1042

Review

Emissions estimation from satellite retrievals: A review of current capability

David G. Streets[a], Timothy Canty[b], Gregory R. Carmichael[c], Benjamin de Foy[d], Russell R. Dickerson[b], Bryan N. Duncan[e], David P. Edwards[f], John A. Haynes[g], Daven K. Henze[h], Marc R. Houyoux[i], Daniel J. Jacob[j], Nickolay A. Krotkov[e], Lok N. Lamsal[e], Yang Liu[k], Zifeng Lu[a], Randall V. Martin[l], Gabriele G. Pfister[f], Robert W. Pinder[m], Ross J. Salawitch[b], Kevin J. Wecht[j]

Show more

doi:10.1016/j.atmosenv.2013.05.051

It's not free to download:
http://www.sciencedirect.com/science/article/pii/S1352231013004007

NASA's Health & Air Quality Applied Sciences Team (H-AQAST) just formed!

NASA Air Quality Applied Sciences Team

Earth Science Serving Air Quality Management Needs

HOME | WHAT IS AQAST? | RESEARCH HIGHLIGHTS | SOCIAL MEDIA | CONTACT US

AQAST site search

Search

Google™ Custom Search

- Members
- Partners
- Projects
- Meetings
- Media Center
- Publications
- Presentations
- Newsletters
- Data and Tools

AQAST10 meeting at Research Triangle Park, North Carolina, January 5-7, 2016: click to access presentations.

AQAST is a NASA Applied Sciences Team of atmospheric scientists working in partnership with US air quality managers to exploit the power of Earth Science tools to address air quality issues. We conduct a wide range of projects using satellite data, suborbital data, and models, and work with air quality agencies at the local, state, regional, and national level. We are eager to hear from air quality managers about new issues where we may

Recent news

BUILDING THE AQAST LEGACY: A RETROSPECTIVE

Read this report to NASA on the 2011-2016 record of AQAST accomplishments, including surveys of air quality managers.

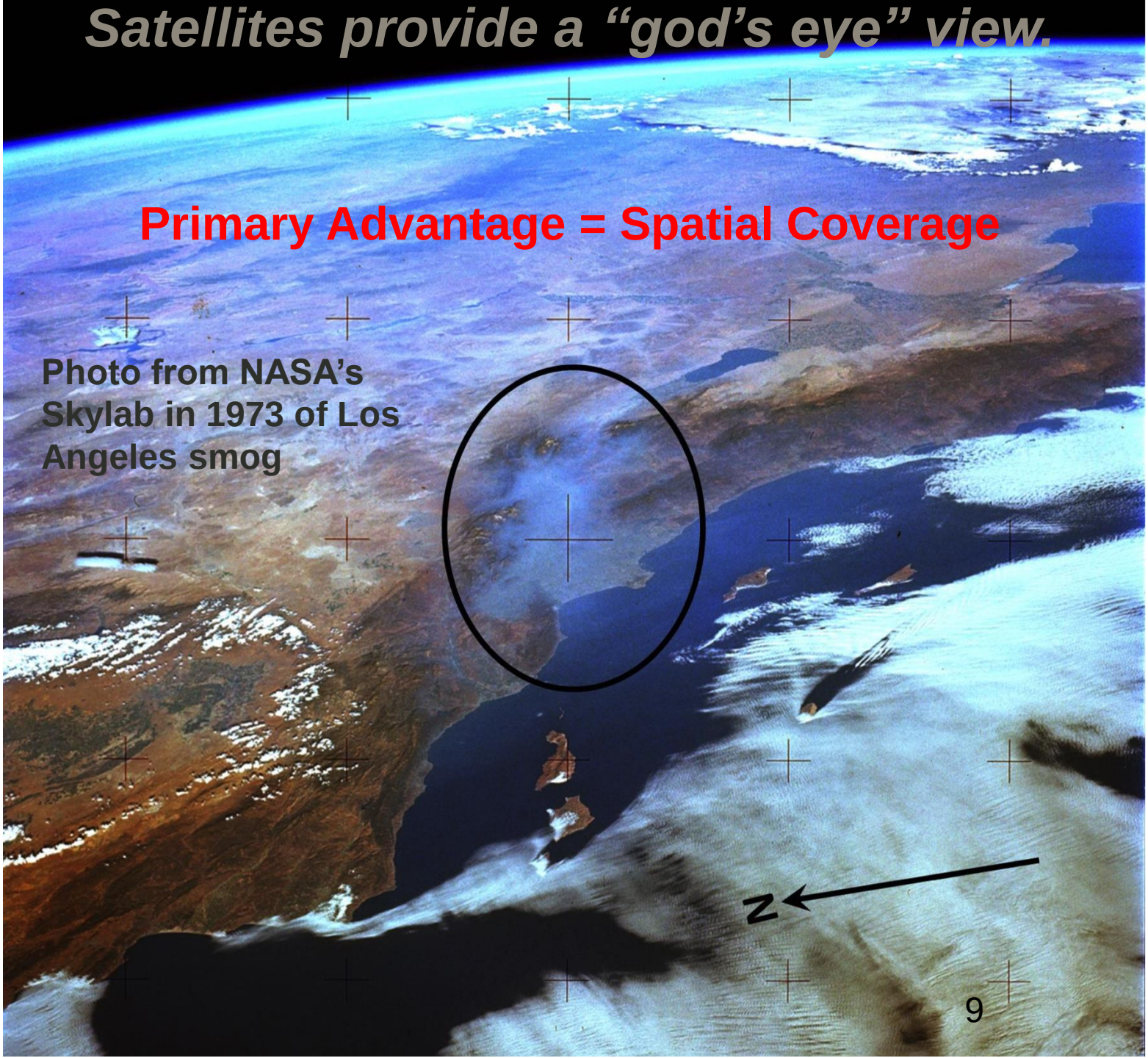
AQAST FOCUSES MEDIA ATTENTION ON GLOBAL EMISSION TRENDS.

AQAST members Russ Dickerson, Bryan Duncan, and Anne Thompson received considerable media attention at their December AGU press conference on global NO2 trends seen from space. See the articles from CNN and from the BBC.

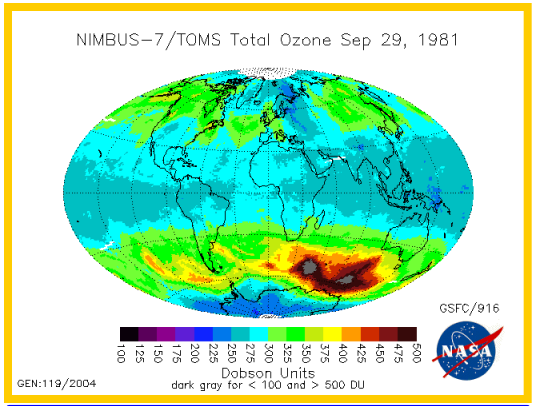
aqast.org

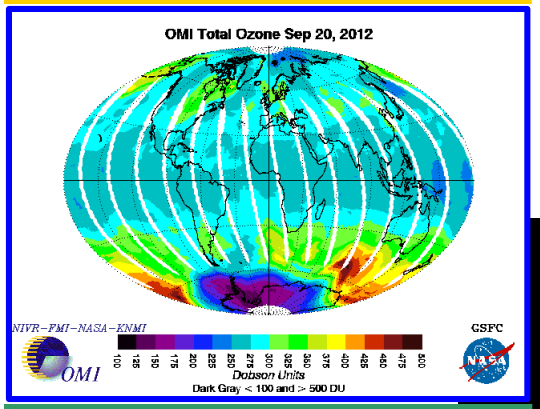
Current and Planned Missions

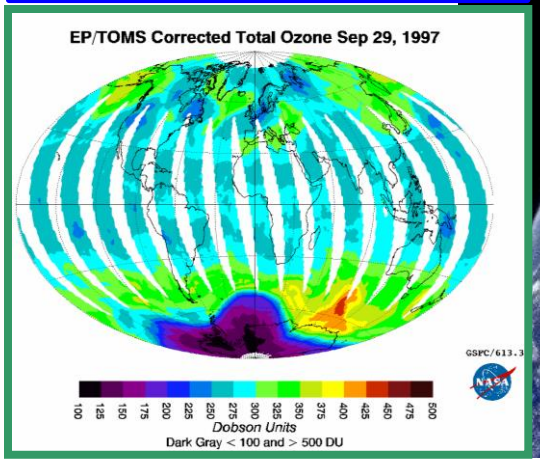
Satellites provide a "god's eye" view.



Spatial Coverage

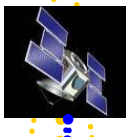






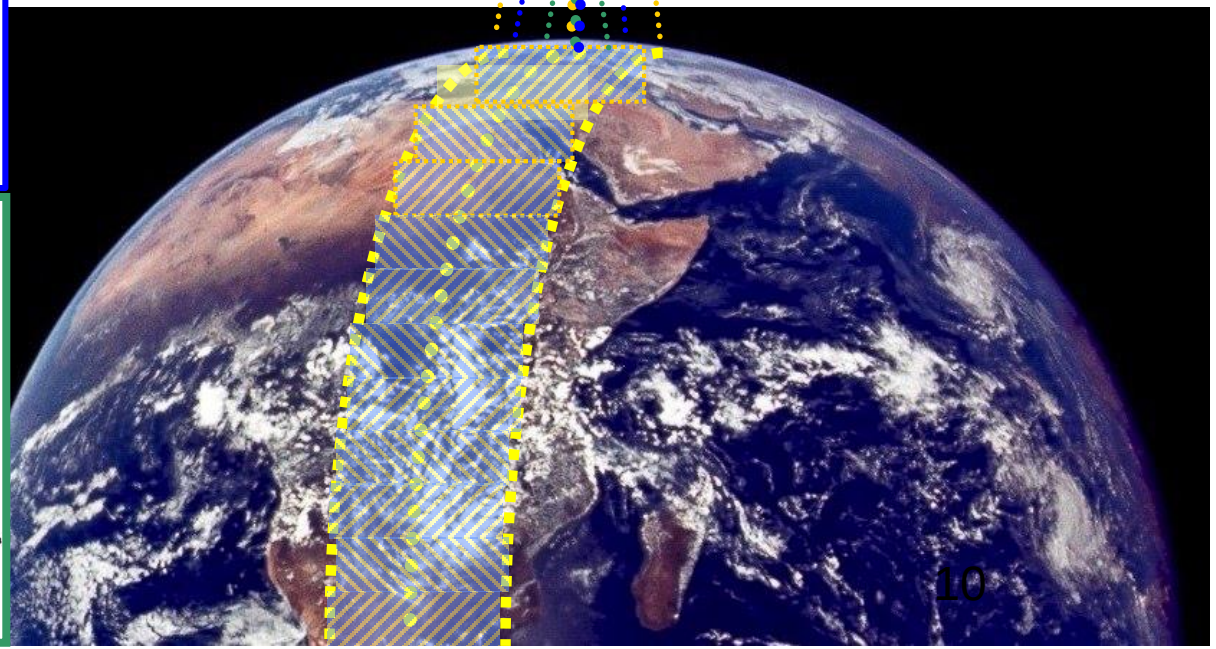
If the orbit is too low and/or the FOV is too small, complete global coverage cannot be obtained with only 16 orbits in a single day

Nimbus-7 TOMS Orbital Altitude: 955 km



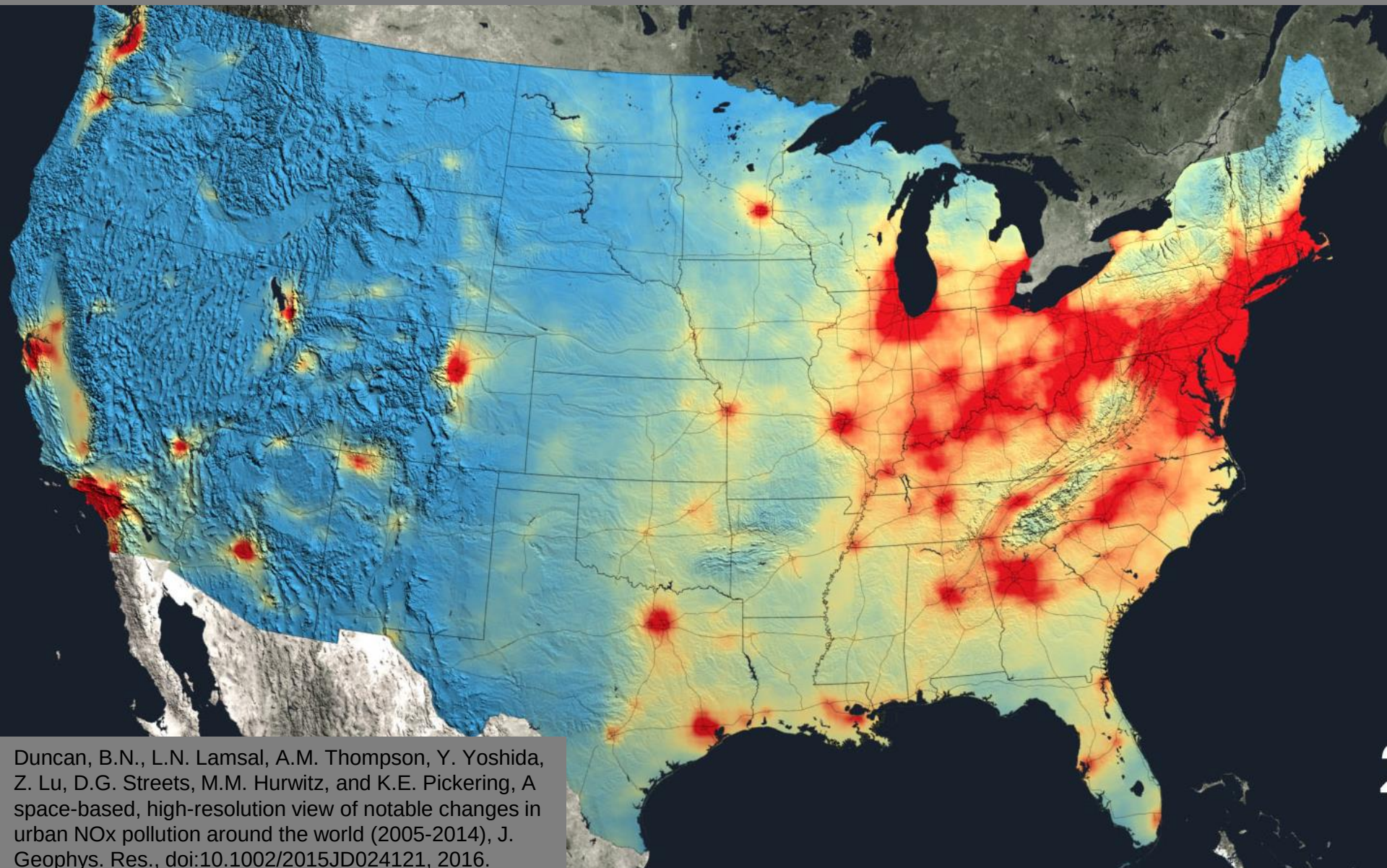
OMI Orbital Altitude: 705 km

EarthProbe TOMS (original) Orbital Altitude: 500 km



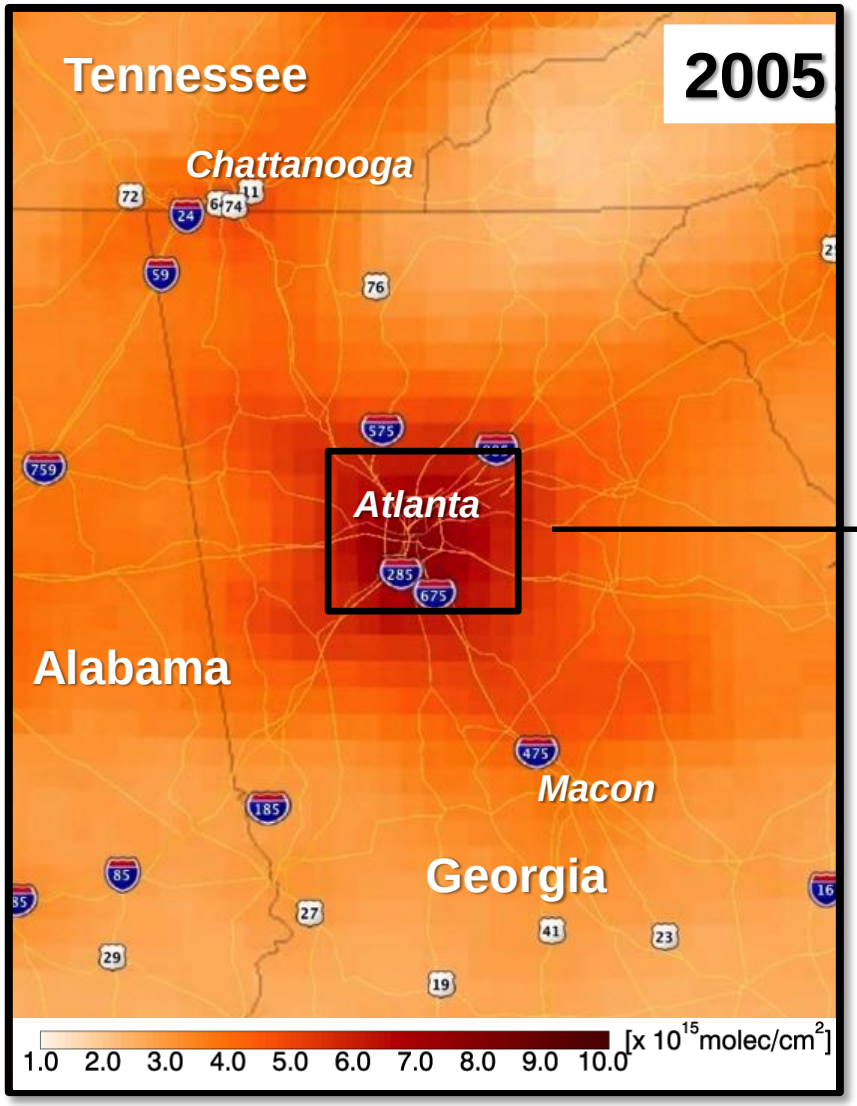
Nitrogen Dioxide (NO_2)

NO_2 is produced when coal & gasoline are burned, so it comes out of tailpipes & smokestacks. It is unhealthy to breathe and is correlated with morbidity & mortality, likely since it is co-emitted with air toxics & is a necessary ingredient for ozone formation.

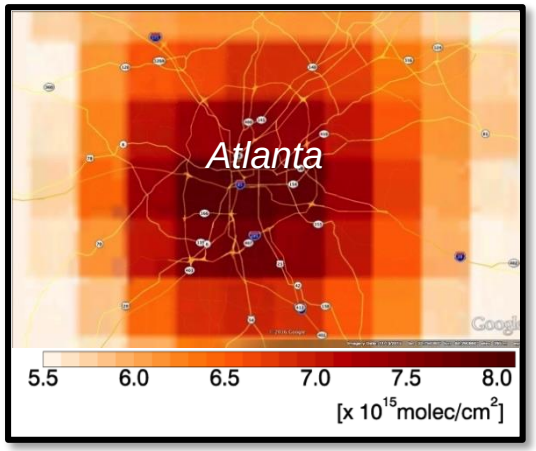


Duncan, B.N., L.N. Lamsal, A.M. Thompson, Y. Yoshida, Z. Lu, D.G. Streets, M.M. Hurwitz, and K.E. Pickering, A space-based, high-resolution view of notable changes in urban NOx pollution around the world (2005-2014), J. Geophys. Res., doi:10.1002/2015JD024121, 2016.

Nitrogen Dioxide (NO_2)
Ozone Monitoring Instrument



The satellite detects sub-urban spatial gradients in pollution within the Atlanta Metro area

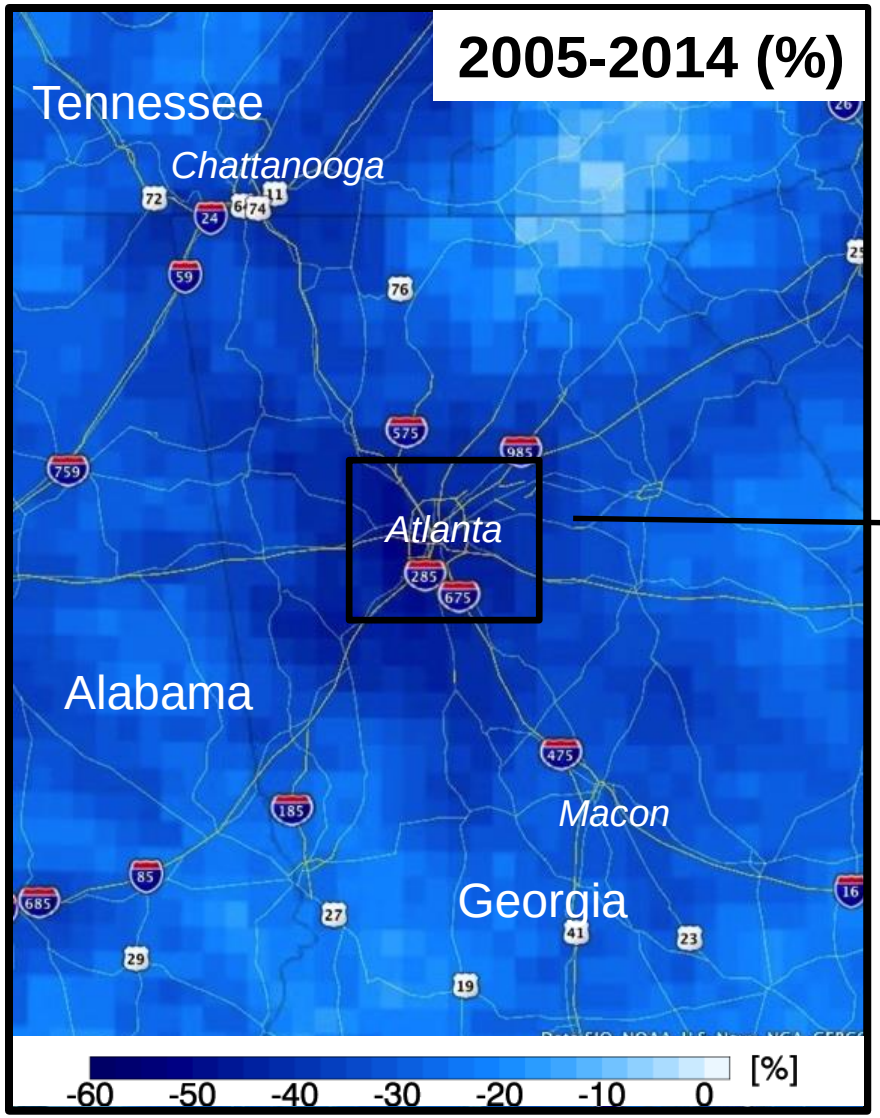


Pixel Resolution ~10x10 km^2

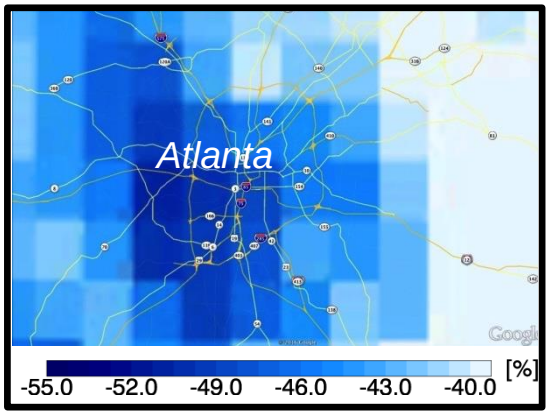
Nitrogen Dioxide (NO_2)

Ozone Monitoring Instrument

Decrease from 2005 to 2014 (%)



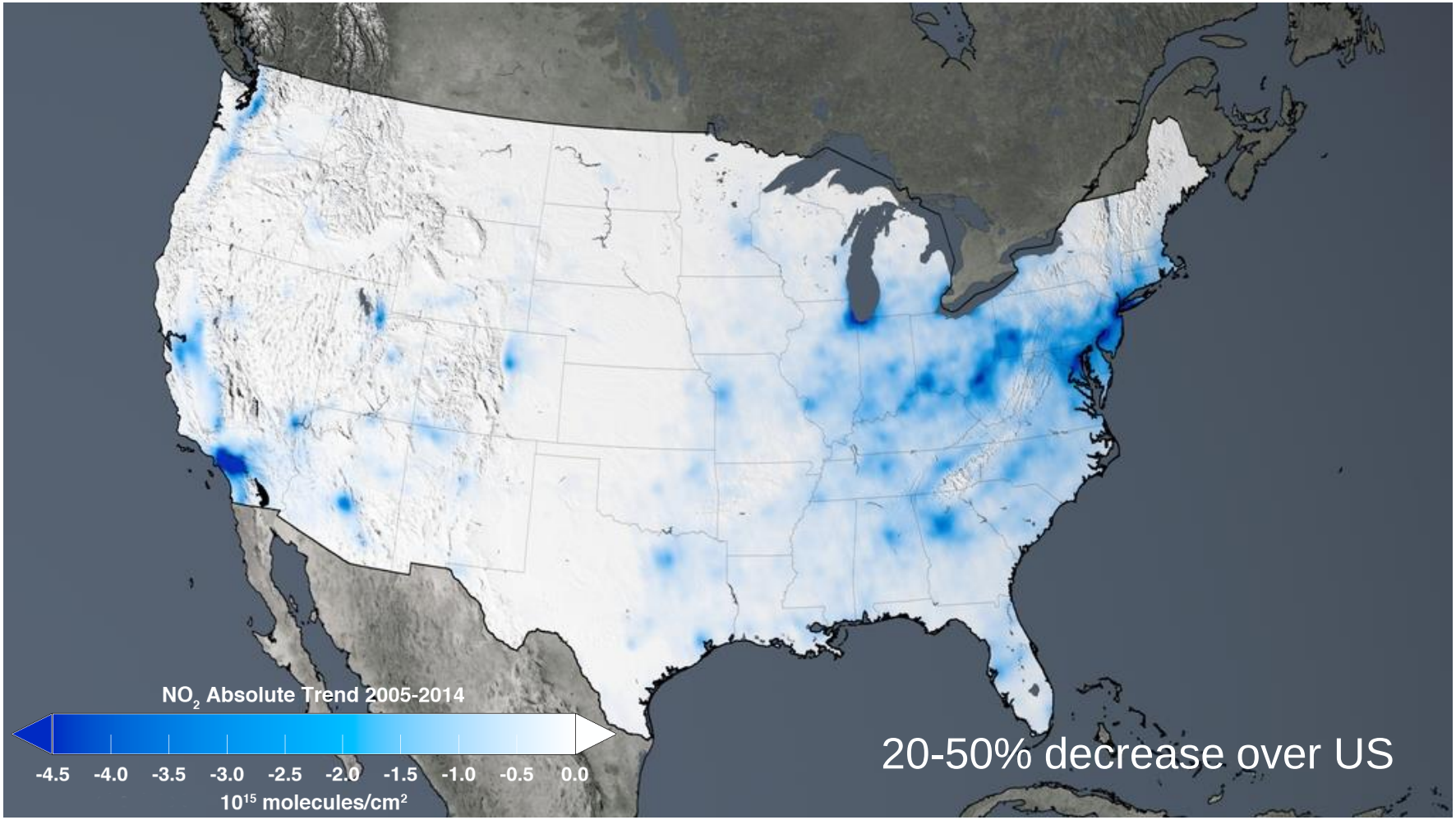
The satellite detects sub-urban spatial gradients in 1) pollution & 2) changes in pollution within the Atlanta Metro area.



Pixel Resolution ~10x10 km^2

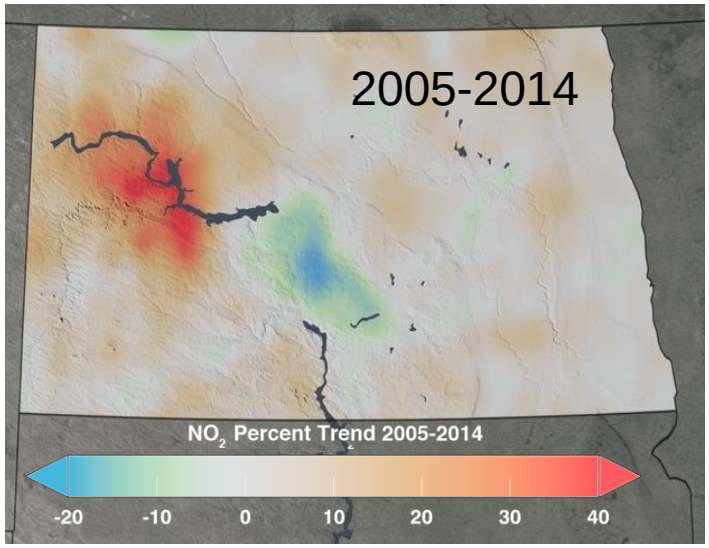
% Difference in OMI NO_2: 2005 - 2014

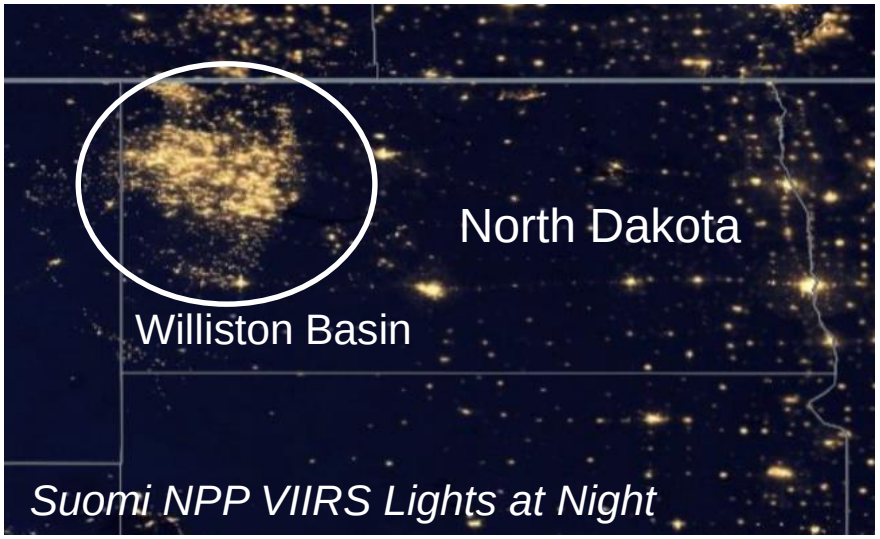
These NASA images are free and publicly available: http://svs.gsfc.nasa.gov/12094

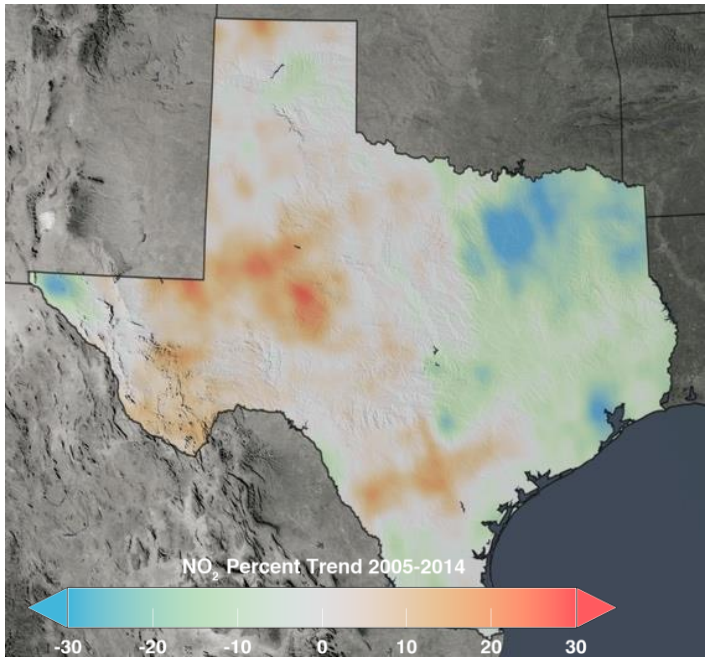


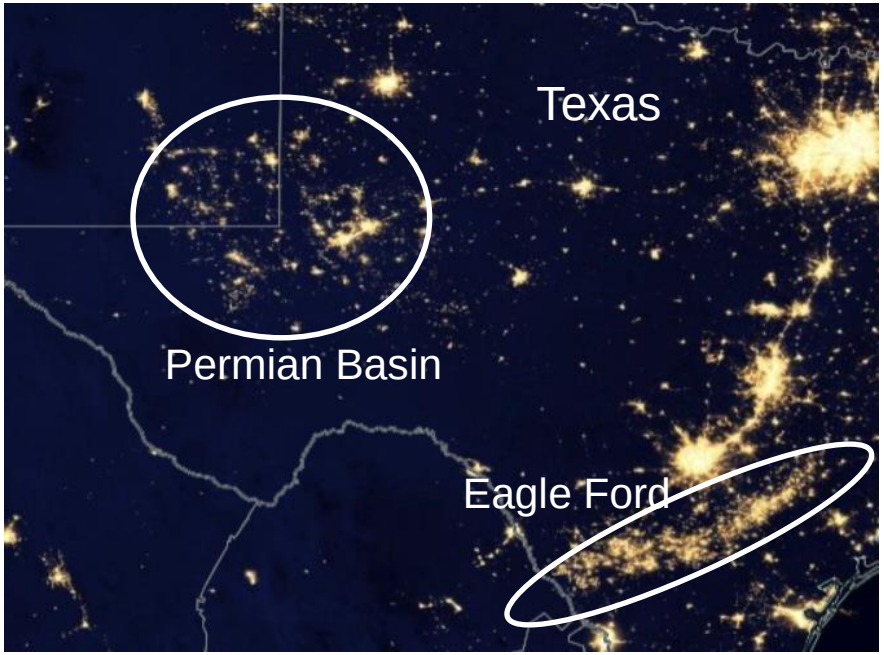
The Clean Air Act is working!

OMI Detects NO_2 Increases from ONG Activities



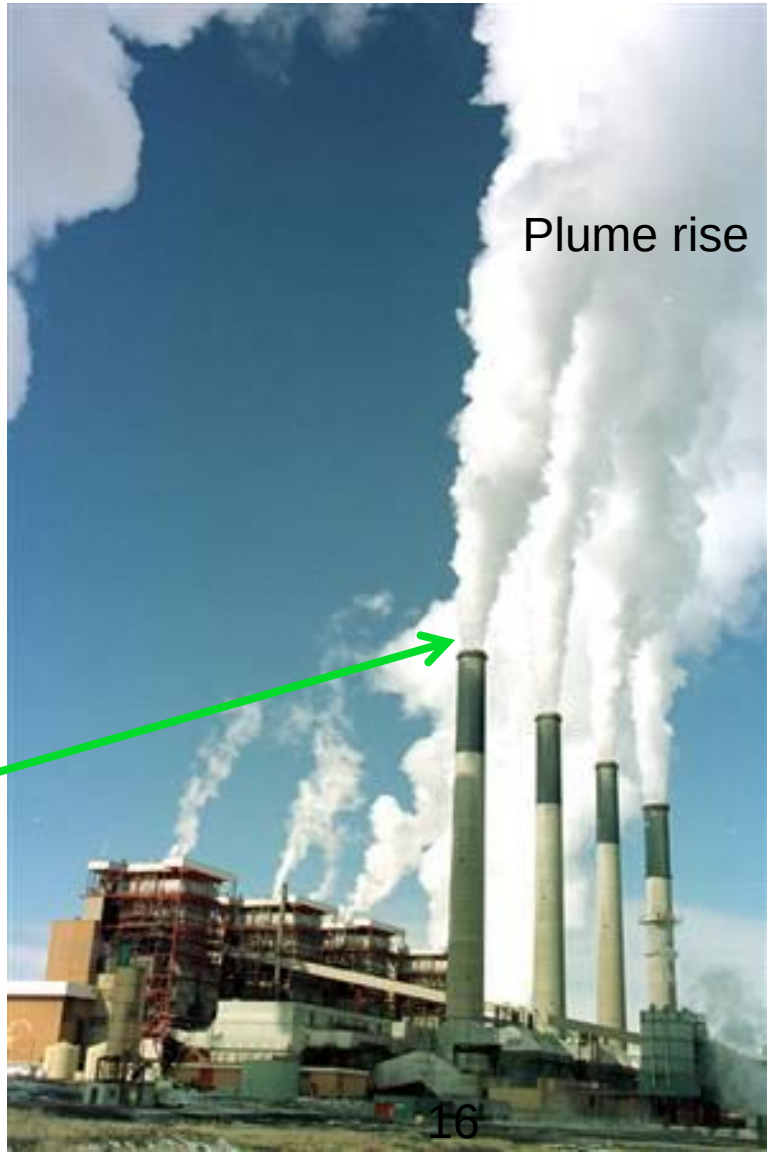






How do Aura Ozone Monitoring Instrument (OMI) column data relate to quantities familiar to the AQ community?

"Column" = total # molecules between the satellite and the Earth's surface (molecules/cm^2)



Emissions

"Nose-level" concentrations

Quantification of gas abundances

Satellite Tracer	Typical Units
OMI O_3, SO_2	Dobson Unit = 1 DU is 2.69×10^{16} ozone molecules/cm^2
OMI NO_2 AIRS and MOPITT CO	Molecules/cm^2 (i.e., Column)
TES CO, CH4 AIRS and MOPITT CO	Volume mixing ratio (e.g., ppbv)

National Ambient Air Quality Standards

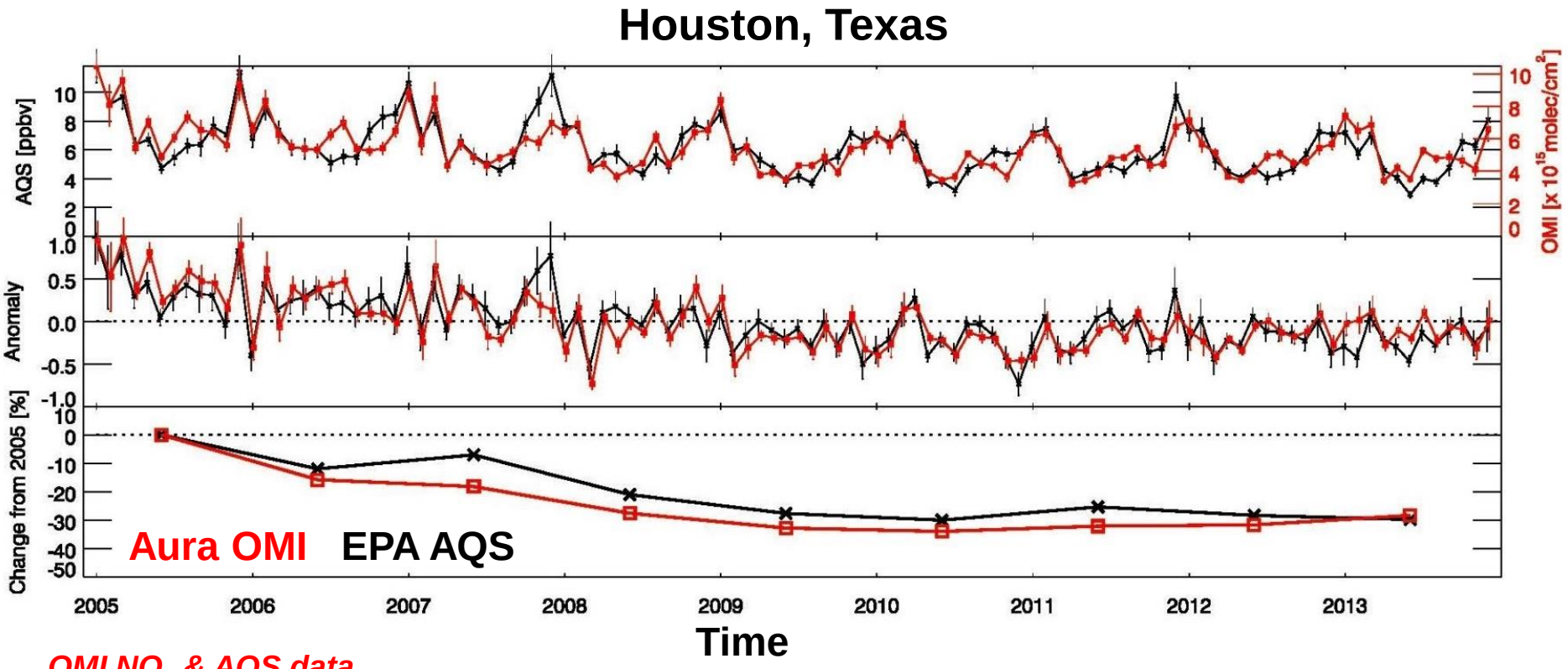
	Primary Standards		Secondary Standards	
Pollutant	**Level**	**Averaging Time**	**Level**	**Averaging Time**
Carbon Monoxide	9 ppm ($10\ mg/m^3$)			
	35 ppm ($40\ mg/m^3$)			
Lead	$0.15\ \mu g/m^3$ (2)			
	$1.5\ \mu g/m^3$			
Nitrogen Dioxide	0.053 ppm ($100\ \mu g/m^3$)			
Particulate Matter (PM_{10})	$150\ \mu g/m^3$			
Particulate Matter ($PM_{2.5}$)	$15.0\ \mu g/m^3$			
	$35\ \mu g/m^3$			
Ozone	0.075 ppm (2008 std)			
	0.08 ppm (1997 std)			
	0.12 ppm			
Sulfur Dioxide	0.03 ppm			
	0.14 ppm			

Note: None of the air quality standards for trace gases are in units typical of satellite measurements!

Remote Sensing applications for air quality has been done without consulting the needs of the air quality community.

A very hot topic of research is now is “How do we relate column measurements to ground level values and exposure?”

How do the OMI NO_2 data compare to EPA's surface levels?



OMI NO_2 & AQS data

Lamsal, L.N., B.N. Duncan, Y. Yoshida, N.A. Krotkov, K.E. Pickering, D.G. Streets, and Z. Lu, "U.S. NO_2 variations and trends (2005-2013) estimated from an improved Ozone Monitoring Instrument (OMI) tropospheric column data product mirror those estimated from AQS surface observations", doi: 10.1016/j.atmosenv.2015.03.055, Atmos. Environ., 2015.

OMI NO_2 & CEMS data

Duncan, B., Y. Yoshida, B. de Foy, L. Lamsal, D. Streets, Z. Lu, K. Pickering, and N. Krotkov, "The observed response of Ozone Monitoring Instrument (OMI) NO_2 columns to NO_x emission controls on power plants in the United States: 2005-2011", Atmos. Environ., 81, p. 102-111, doi:10.1016/jatmosenv.2013.08.068, 2013.

AURA EOS Project OZONE HOLE WATCH

Air Quality

Observations from Space

airquality.gsfc.nasa.gov

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AIR QUALITY FROM SPACE

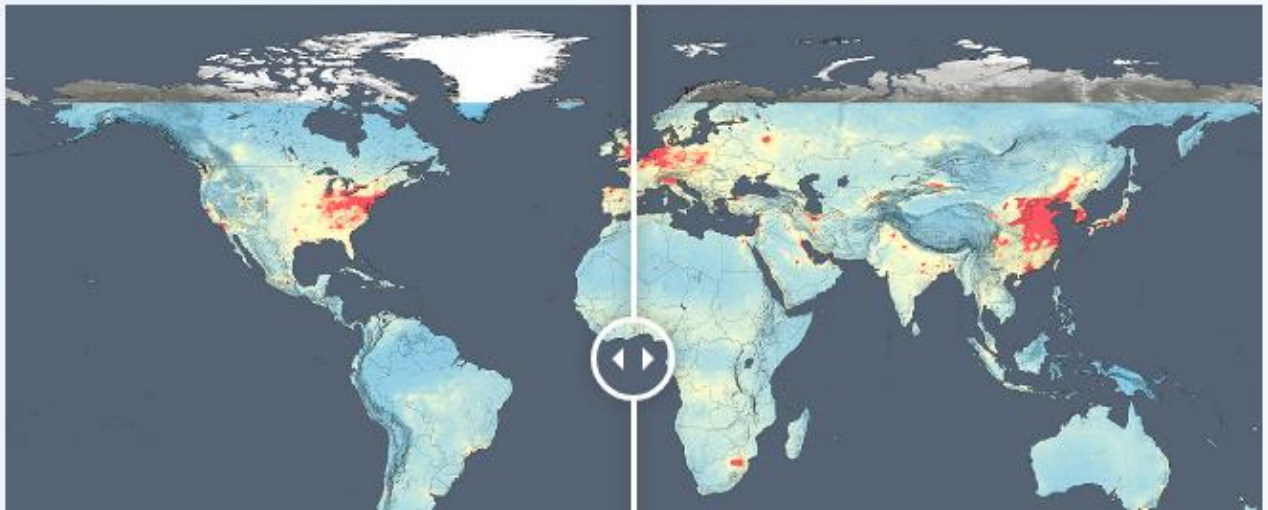
Only NO_2 for now, but plan to add others!

Welcome to the website! Currently, the website is devoted to one air pollutant, nitrogen dioxide (NO_2), which is unhealthy to breathe and a necessary ingredient for the formation of unhealthy levels of surface ozone, another important pollutant. Our intended audience is health and air quality managers, but there is a lot of content that will be of interest to many people, including plots of data for almost 200 world cities!

CLICK HERE TO SEE PRESIDENT OBAMA DISCUSS OMI NO_2 DATA!!!

What is the air quality like in your city and country? Just click on the "Data" tab above and then "World Regions" to see.

Before and After: World Nitrogen Dioxide Levels, 2005-2014

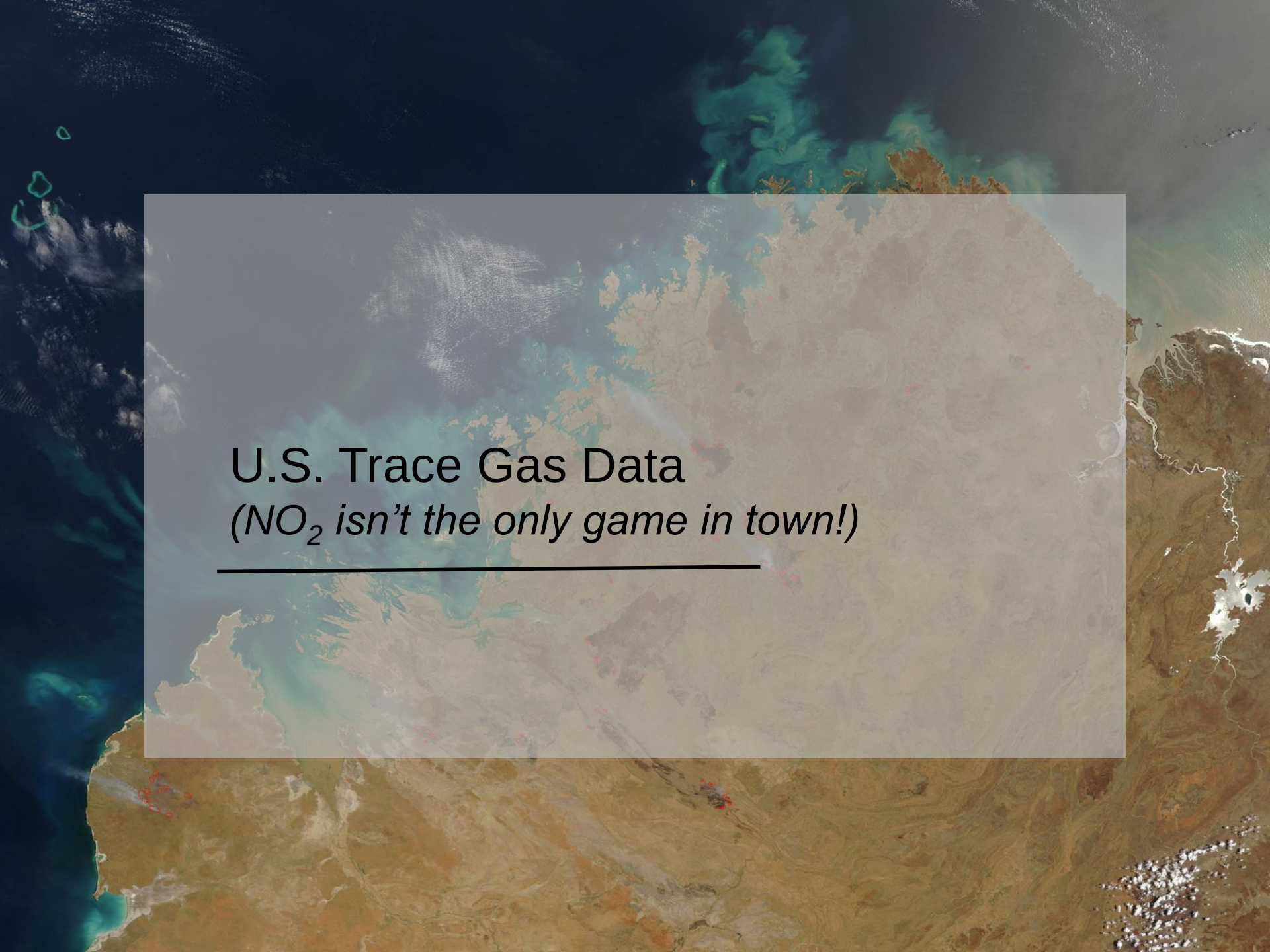


Air Quality Data on the Top 20 US Cities

Click above to quickly find recent data products and imagery for the Top 20 US Cities.

Air Quality for 195 World Cities

Click above to quickly find recent data products and imagery for the



U.S. Trace Gas Data

(NO_2 isn't the only game in town!)

Passive Remote Sensing Techniques

- There are several passive remote sensing techniques based on the viewing geometry of the instrument:

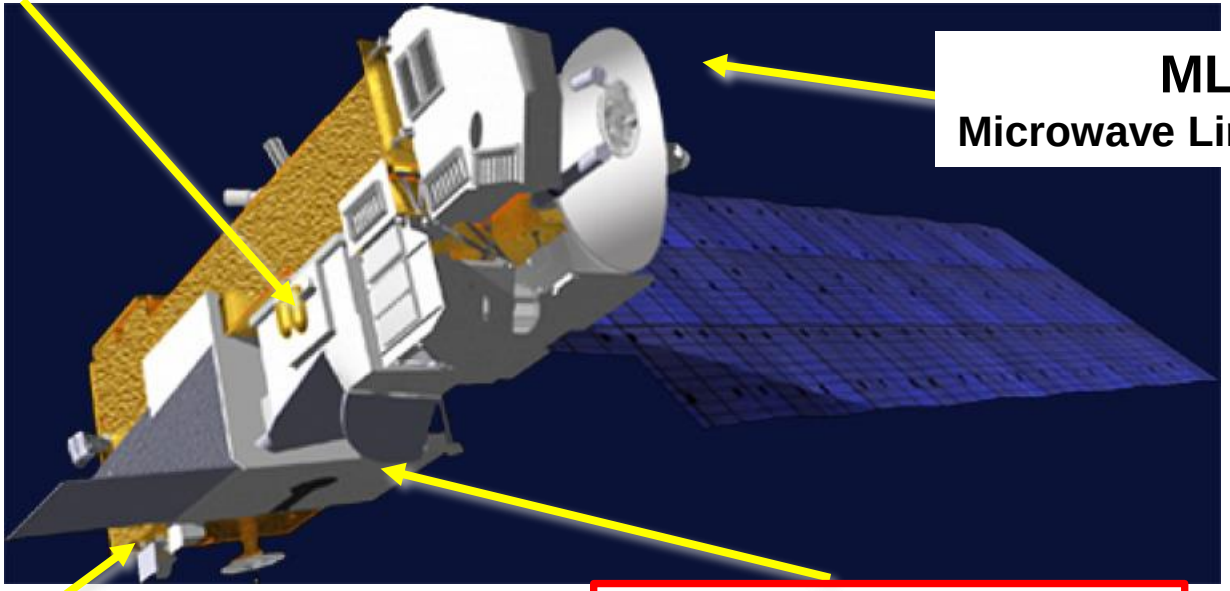
1. Backscatter ultraviolet (BUV) – i.e. OMI instrument
   - The BUV technique looks directly down at the atmosphere (nadir viewing) to measure the amount of shortwave solar radiation scattered back up to the satellite. Through this, OMI is able to measure total column amounts of NO_2, HCHO, Ozone, and SO_2
2. Limb emission (or limb viewing) - TES, AIRS, MOPITT instruments
   - This technique measures the longwave radiation (infrared or microwave) thermally emitted in the atmosphere along the line of sight of the instrument, from which they infer vertical profiles of trace gases.

Aura Satellite

- **Orbit: Polar: 705 km, sun-synchronous, 98° inclination, ascending 1:45 PM equator crossing time**
- **Launched July 15, 2004**

OMI measures UV & visible wavelengths of light backscattered from the Earth & atmosphere: NO_2, SO_2 and HCHO

HIRDLS
High Resolution Dynamics Limb Sounder (defunct)



MLS
Microwave Limb Sounder

OMI
Ozone Monitoring Instrument

TES
Tropospheric Emission Spectrometer

Current and Planned Missions

NASA/NOAA Satellites

Aura *(2004 launch)*

OMI (*columns*) = NO_2, SO_2, H_2CO, ~~O_3~~*

TES (*vertical profiles*) = O_3, CO, CH_4, HDO, PAN, NH_3, CO_2

Terra *(1999)*

MOPITT (*columns*) = CO

Aqua *(2002)*

AIRS (*layers*) = NH_3

Suomi NPP *(2011)*

OMPS (*columns*) = SO_2, H_2CO

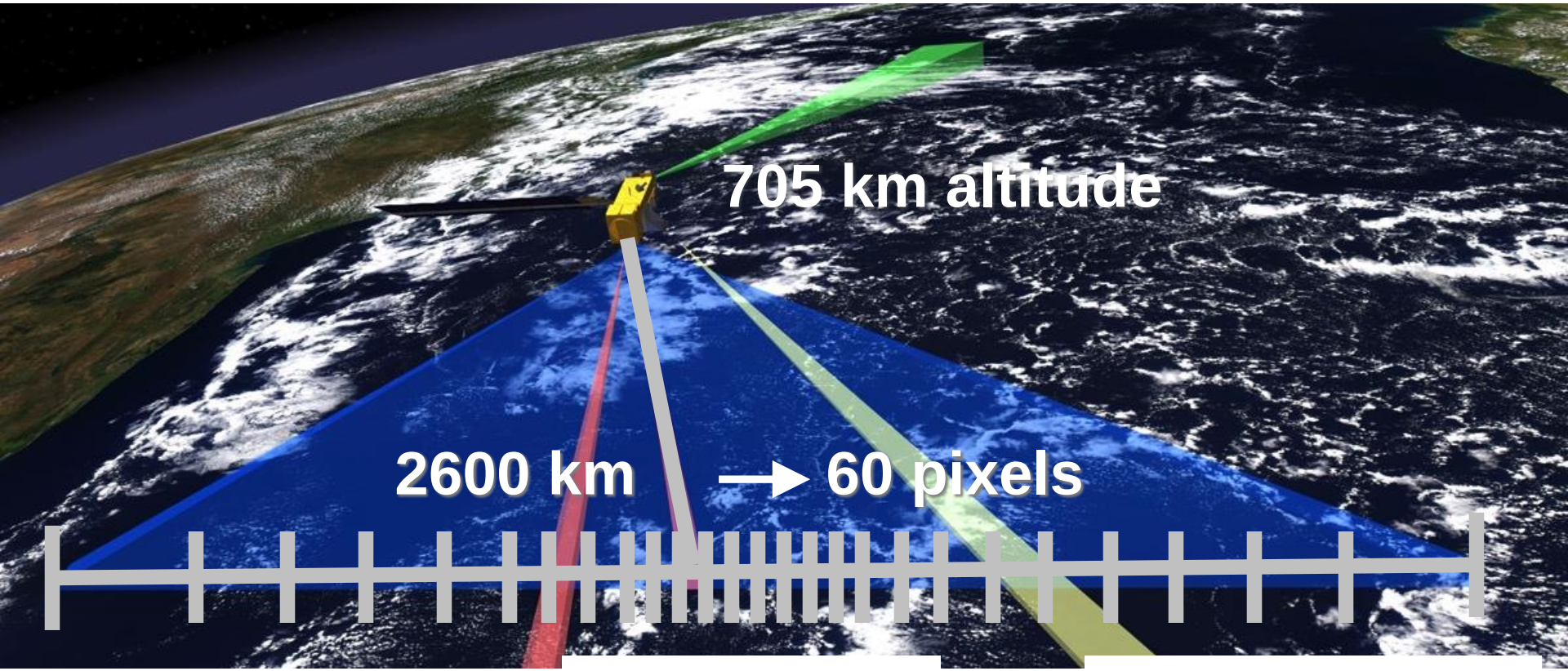
OCO-2 *(2014)*

CO_2 (*columns*) – data under development

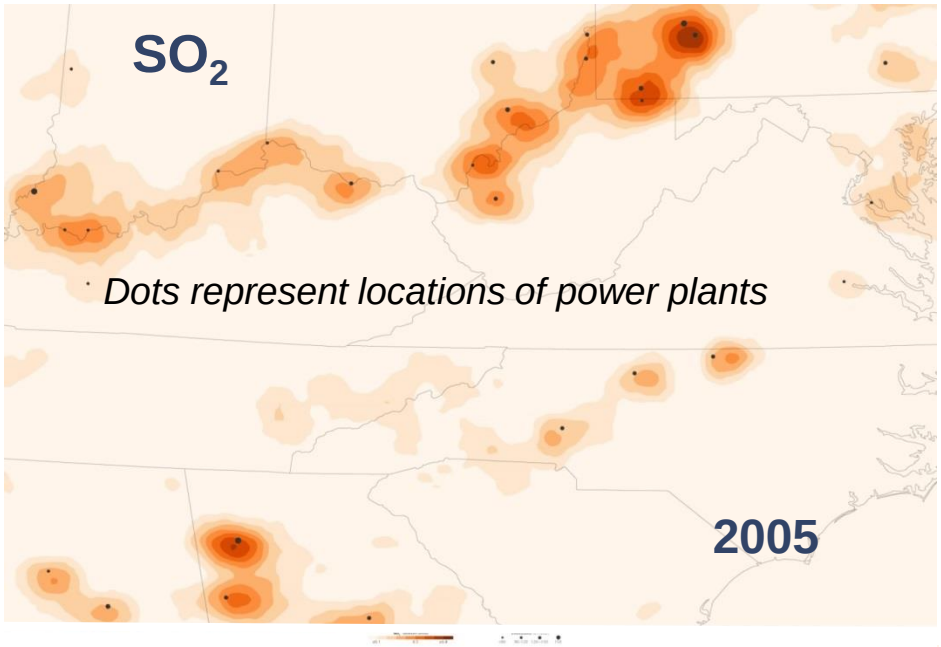
**Determining surface O_3 is not currently possible.*

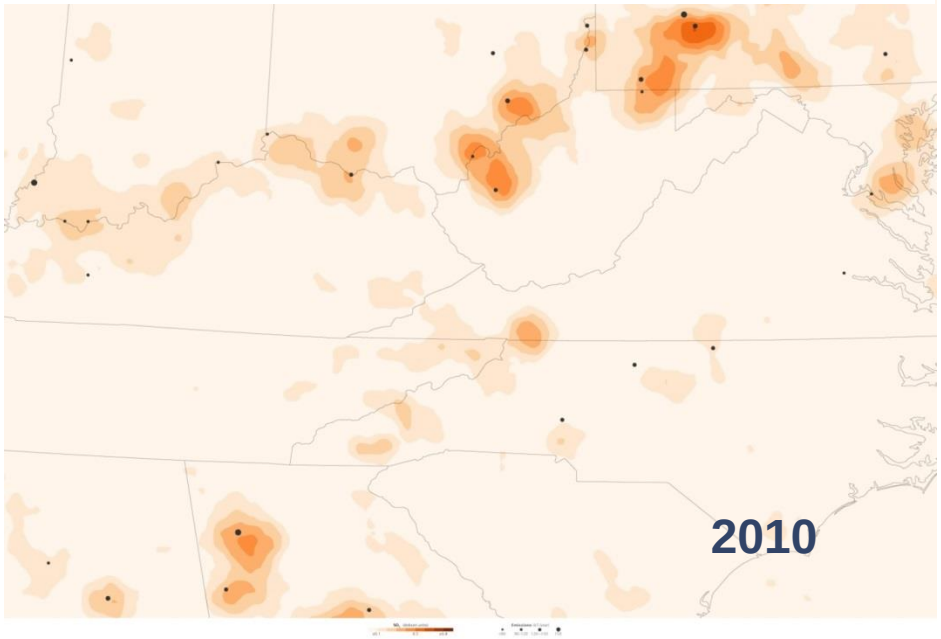
OMI Ozone Monitoring Instrument

- Dutch/Finnish Instrument
- Launched July 15, 2004
- Nadir solar backscatter spectrometer
- Spectral range UV/Visible 270-500 nm (resolution~0.5nm)
- Spatial resolution: 13X24 km footprint at nadir
- Swath width: 2600 km (global daily coverage)
- Local Overpass time = 13:45 (+/- 15 min)



OMI Sulfur Dioxide



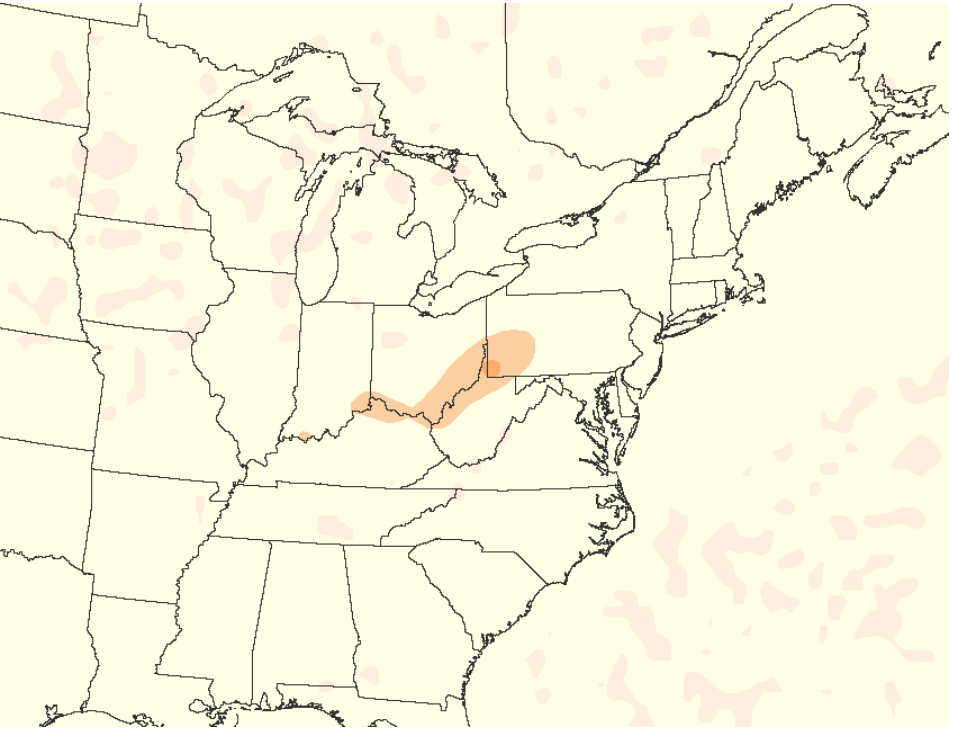


Can track volcanic SO_2 as well

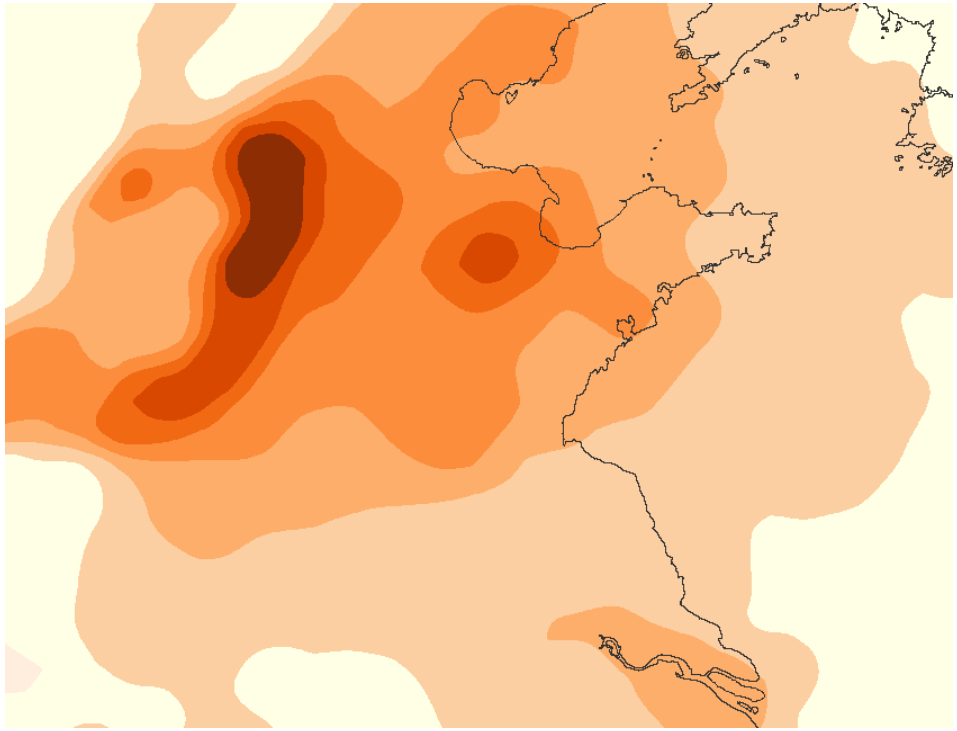
Data from the Dutch/Finnish Ozone Monitoring Instrument on NASA's Aura Satellite

OMI Sulfur Dioxide

Ohio River Valley

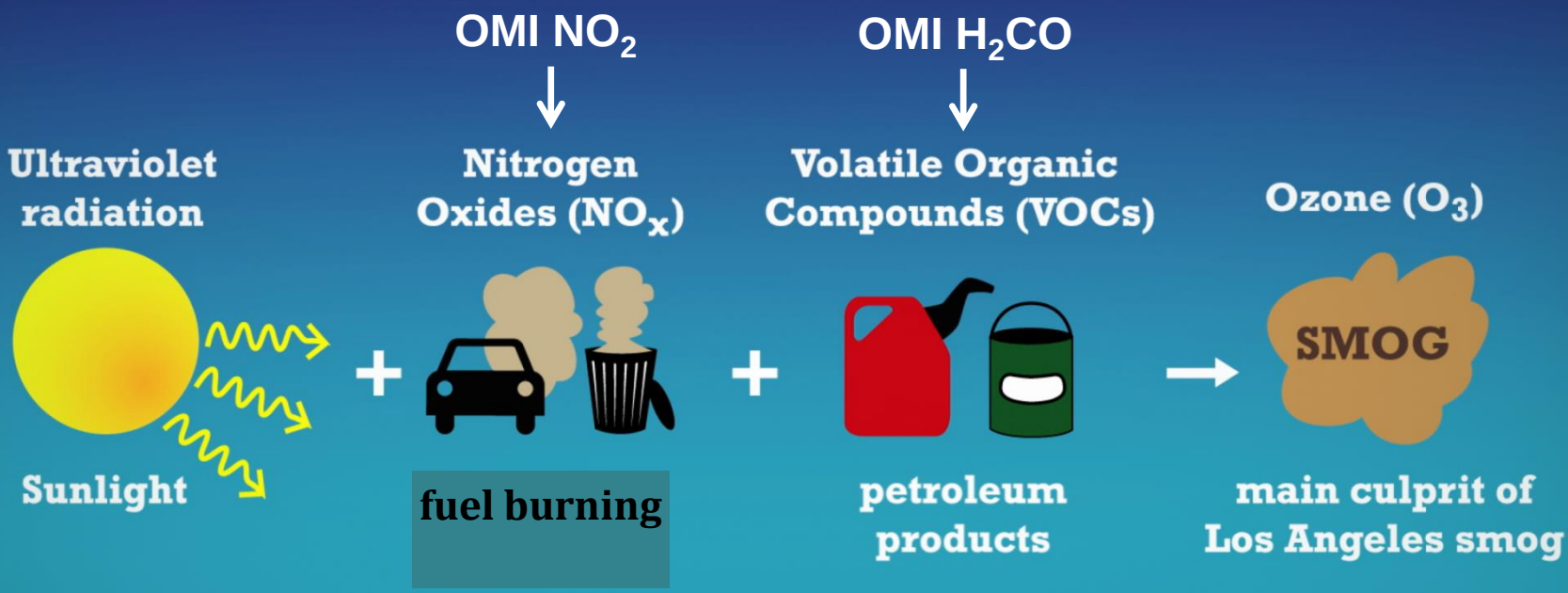


China



To put US air quality into a global perspective!

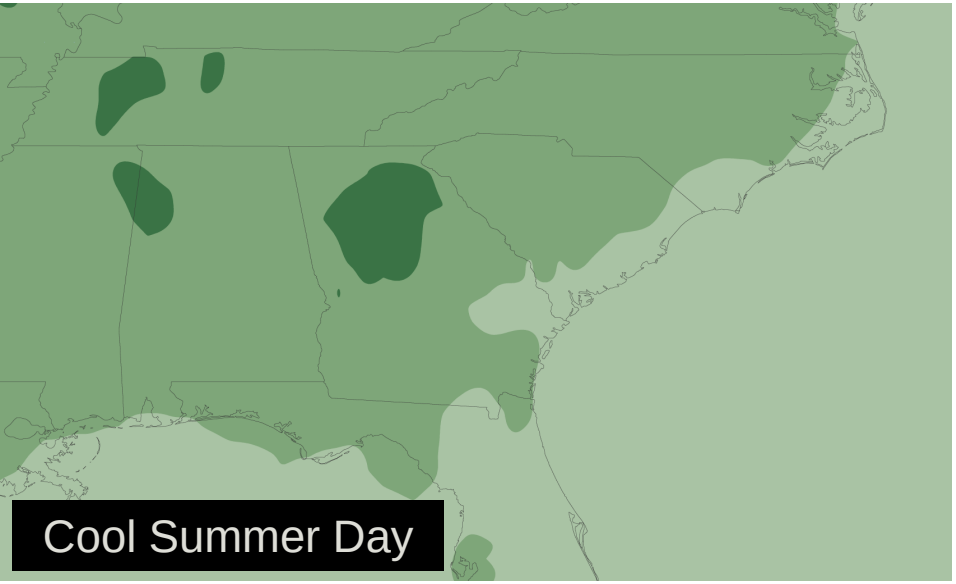
We can't infer "nose-level" ozone yet, but we do have information on ozone precursors: NO_x & VOCs

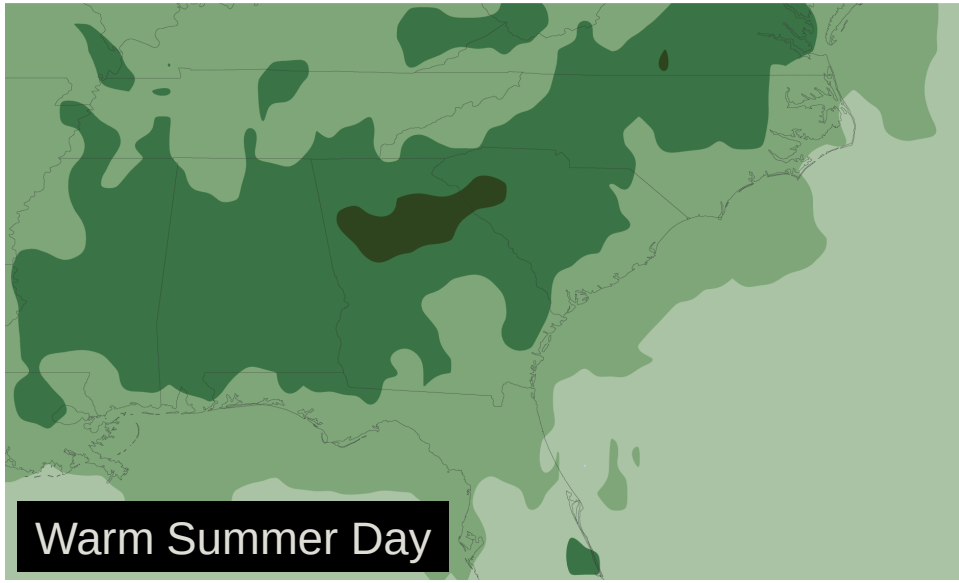


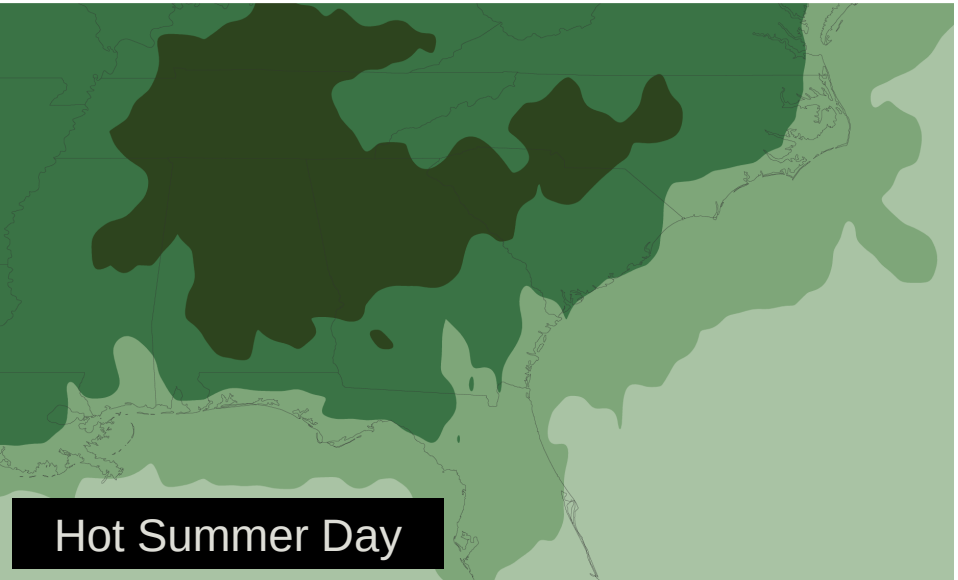
H_2CO is an oxidation product of most VOCs, so it is a good proxy for "VOC reactivity".
NO_2 is a reasonable proxy for NO_x = NO + NO_2.

So we have information on the sensitivity of ozone's formation to NO_x and VOCs.

OMI Formaldehyde (HCHO)



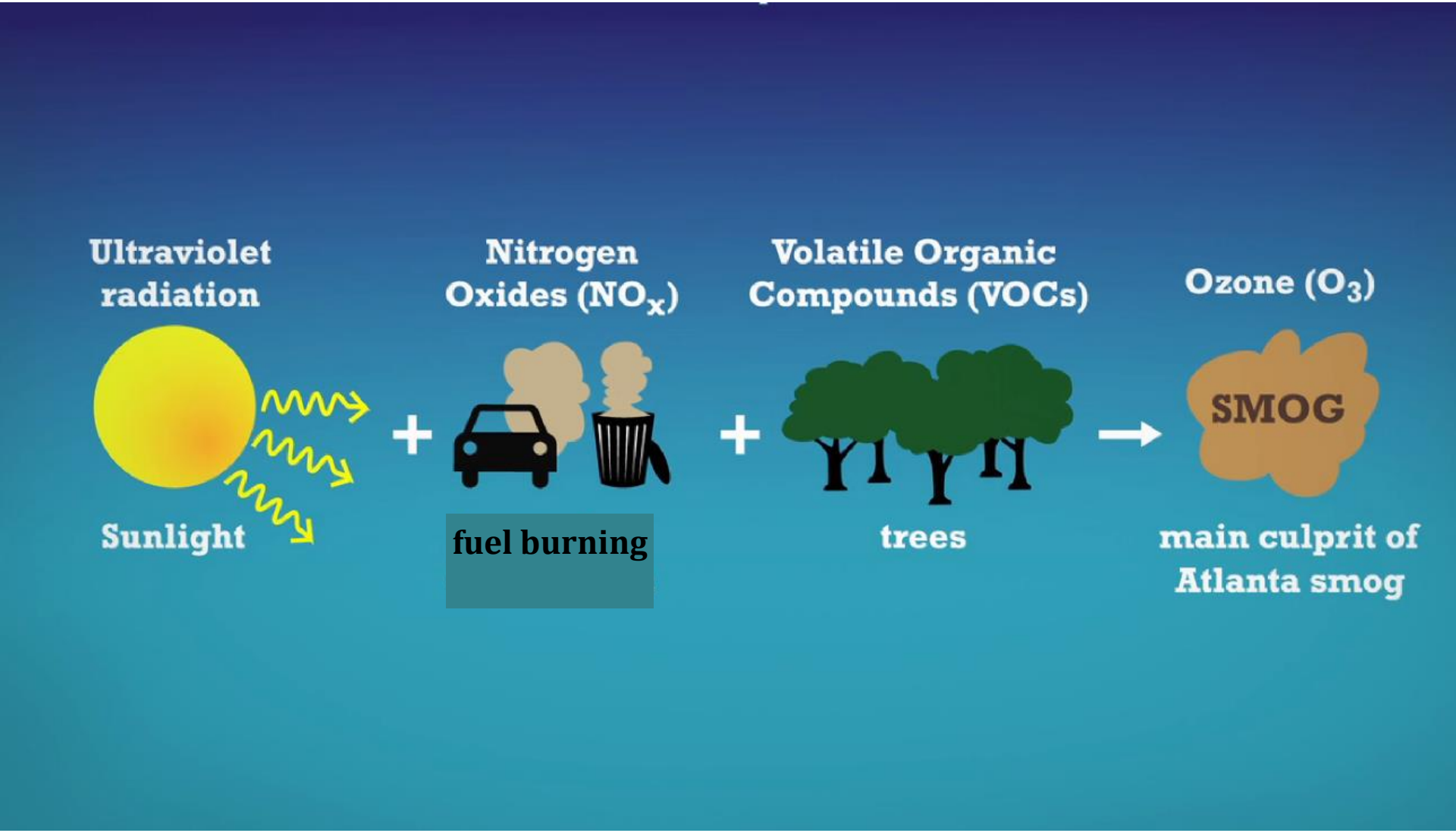




Low High

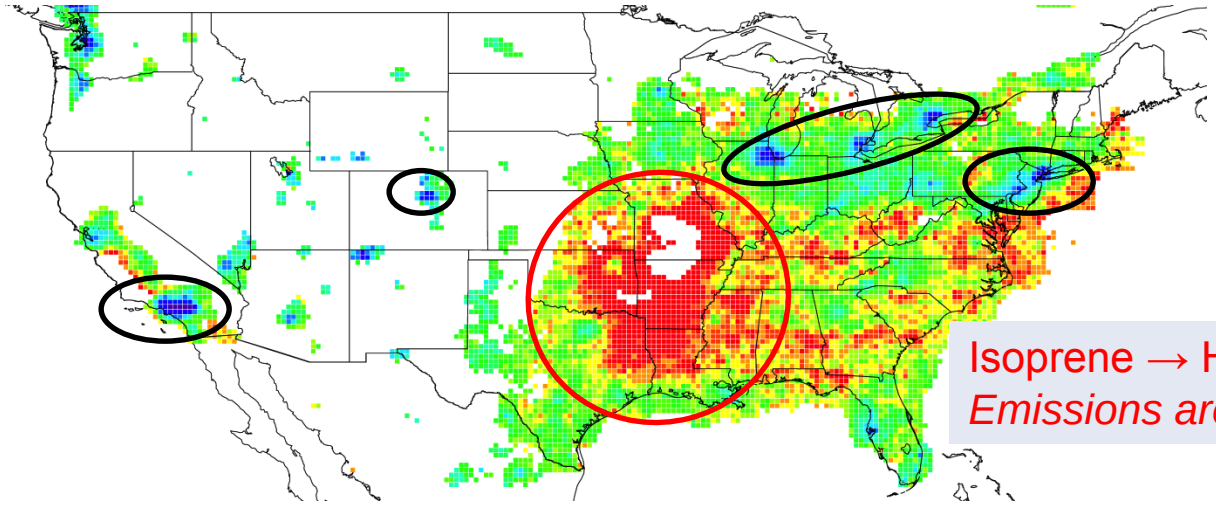
HCHO is a proxy for the emissions of isoprene, a natural VOC that often dominates ozone formation chemistry.

Reducing VOCs from Cars/Factories is Ineffective



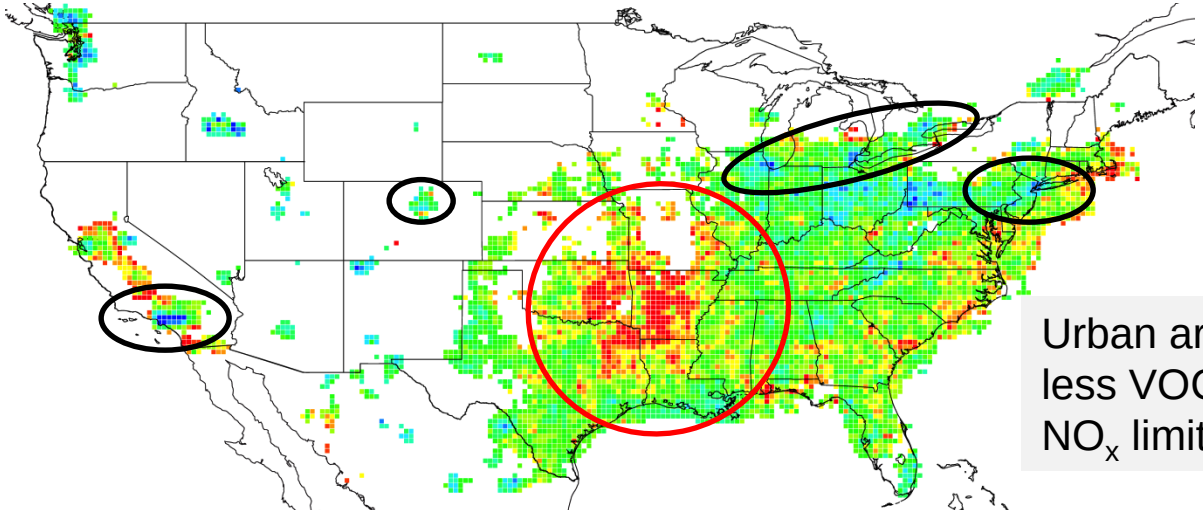
OMI HCHO/NO_2: *A Proxy for Ozone Formation Sensitivity*

2005

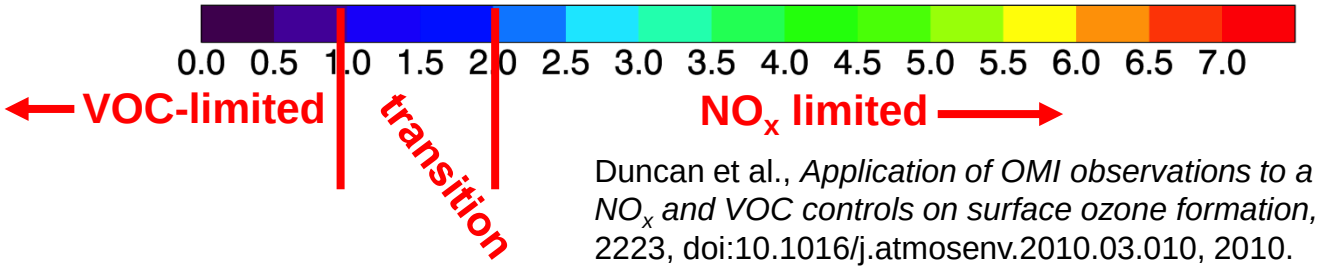


Isoprene → HCHO
Emissions are T-dependent

2013

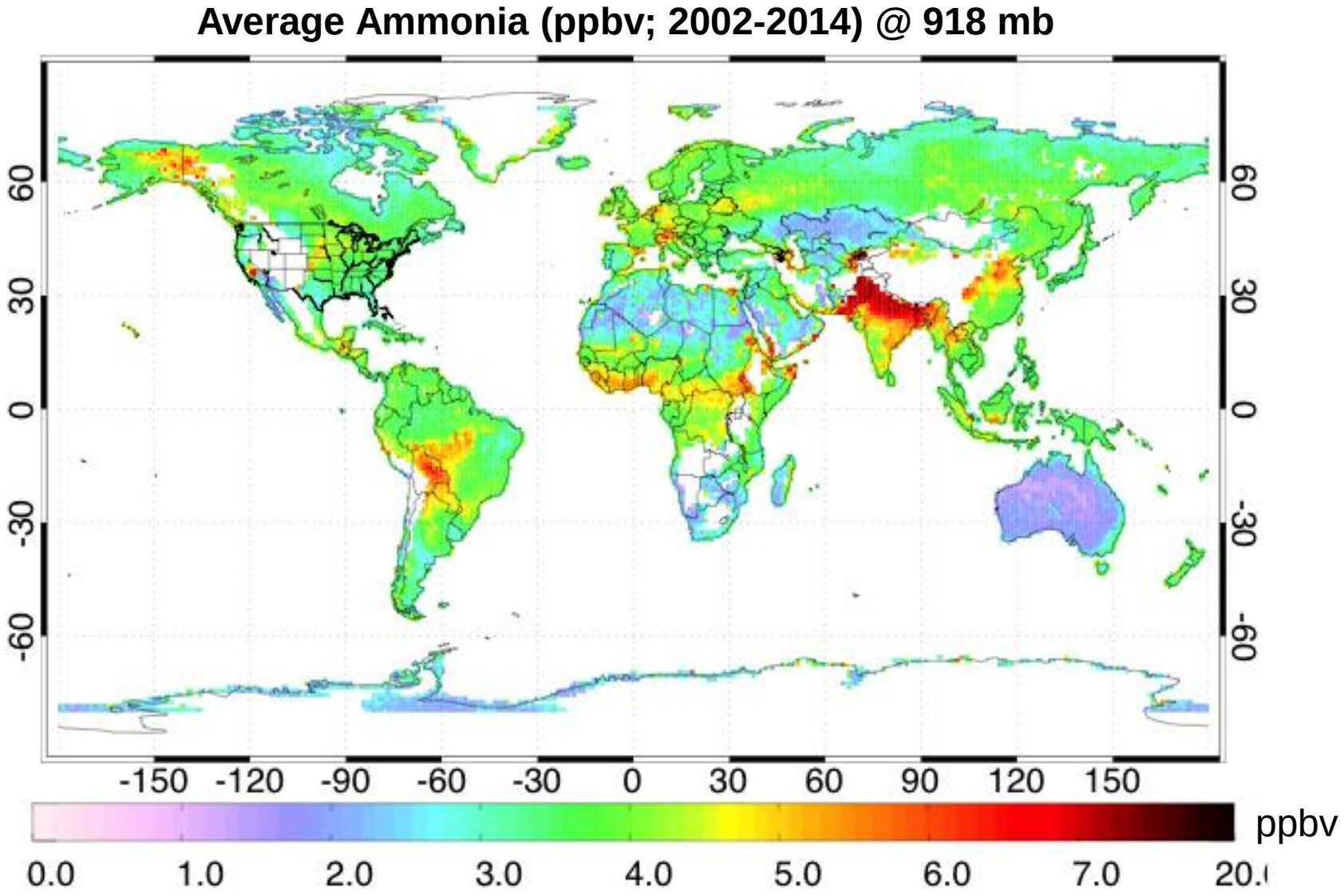


Urban areas becoming less VOC-limited : more NO_x limited.



Duncan et al., *Application of OMI observations to a space-based indicator of NO_x and VOC controls on surface ozone formation,* Atmos. Environ., 44, 2213-2223, doi:10.1016/j.atmosenv.2010.03.010, 2010.

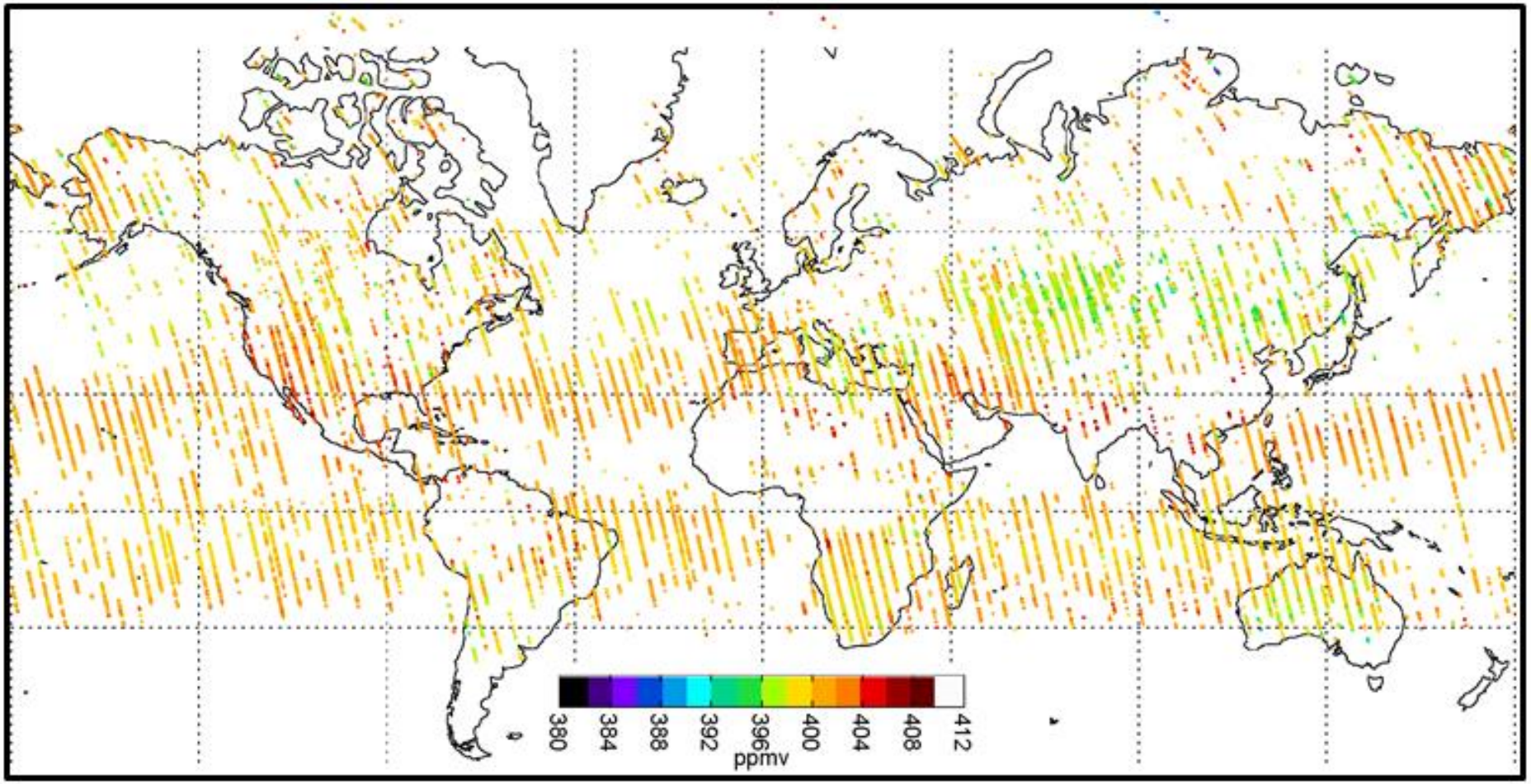
AIRS Ammonia (NH_3) Data Product (2002 - 2014)



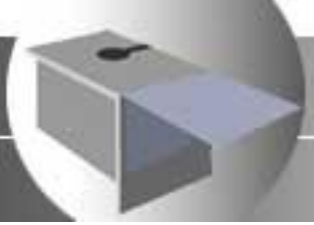
Warner et al., *The global tropospheric ammonia distribution as seen in the 13-year AIRS measurement record*, Atmos. Chem. Phys., 16, 5467–5479, doi:10.5194/acp-16-5467-2016, 2016.

OCO-2: CO_2 (ppmv)

June 16-30, 2015



Courtesy Randy Kawa (NASA)

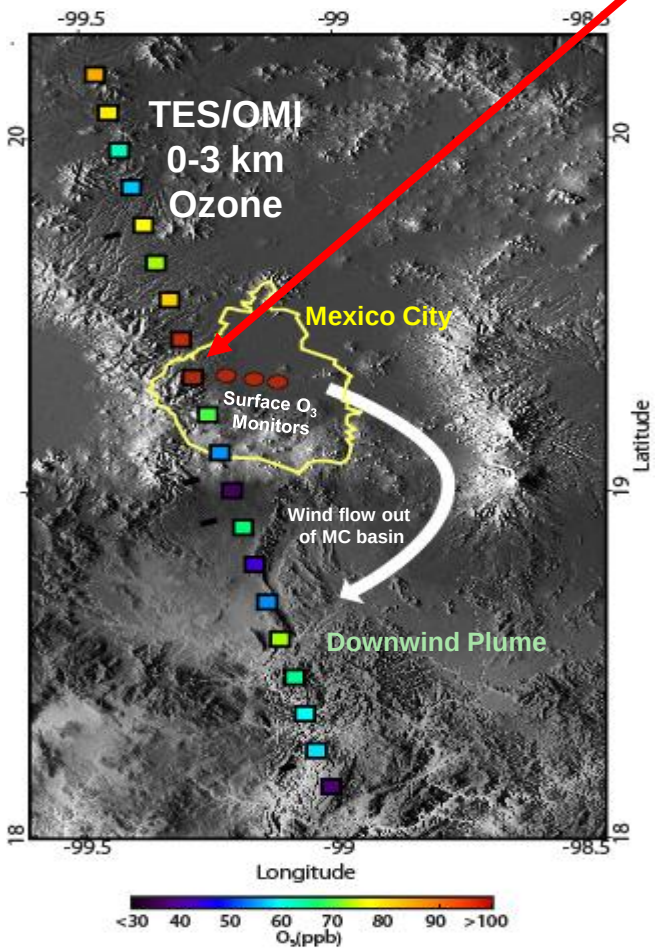


Emerging TES AQ products:

What	Where	Why
Formic Acid	Surface to 700 hPa	Ozone production, aerosol pre-cursor and biogenic tracer
Methanol	Surface to 700 hPa	Ozone production, aerosol pre-cursor and biogenic tracer
CO Profiles using MLS and TES	Surface to 10 hPa	Biomass burning and Convection
Ozone profiles using TES and OMI Radiances	Surface to 10 hPa	Improved Lower Troposphere and Upper Troposphere ozone estimates during all seasons

Tropospheric Emission Spectrometer (TES) megacity measurements help quantify urban pollution production, transformation & export

Since Jan 2013, TES has used its unique targeting capabilities to measure a suite of pollutants in 19 of the world's megacities, including Mexico City

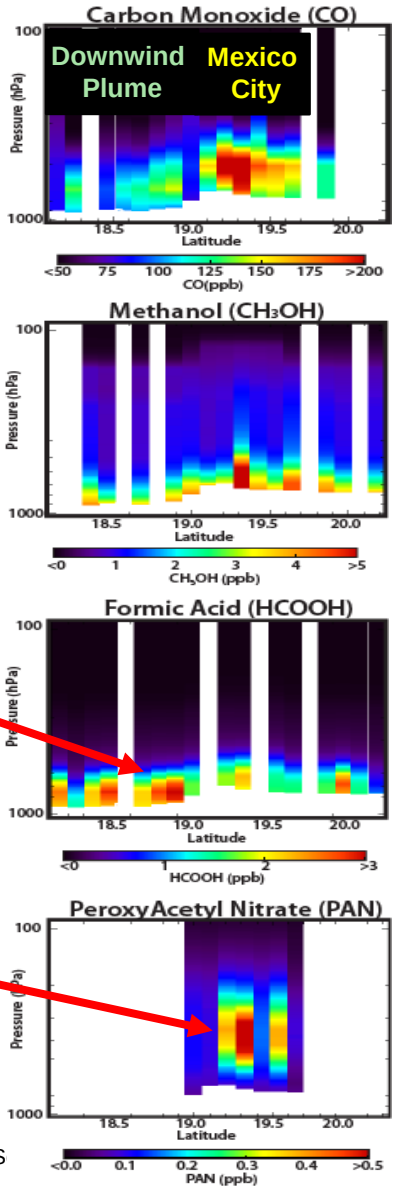


Megacity Pollution: The jointly retrieved TES/OMI near-surface ozone product shows very high ozone (~120 ppb) in Mexico City on a day with stable, stagnant air in the boundary layer.

TES carbon monoxide, methanol, & formic acid (ozone precursors) are also elevated, as is the nitrogen reservoir peroxyacetyl nitrate (PAN)

Chemical Transformation: Downwind, TES data show that most trace gases are diluted in the plume, but formic acid concentrations are higher than in the city, which may indicate secondary production from organic aerosol

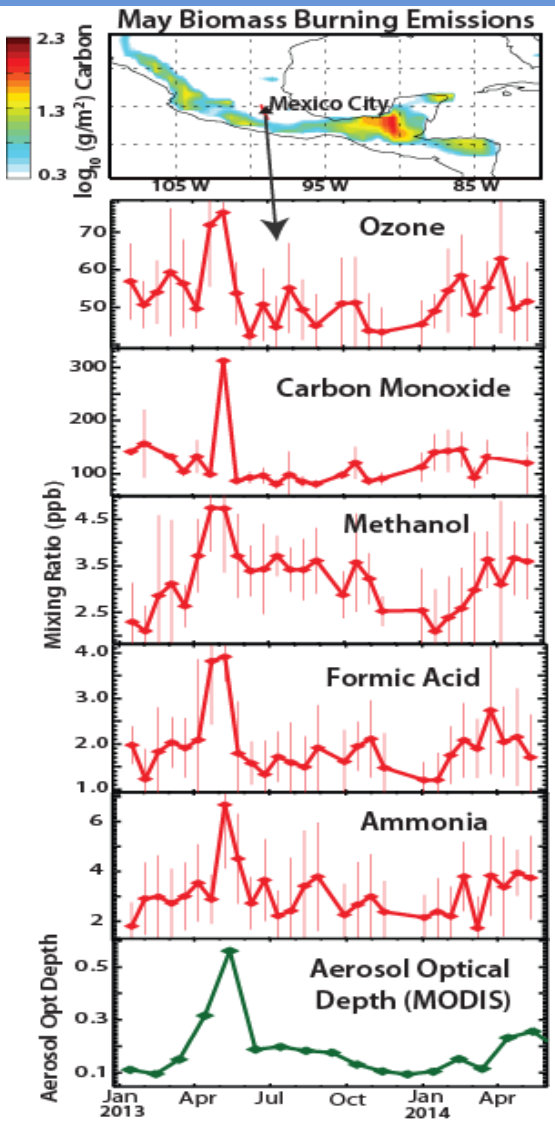
Export Potential: PAN drives ozone production far from source regions, so the large PAN concentrations suggest that Mexico City pollution has larger-scale impacts



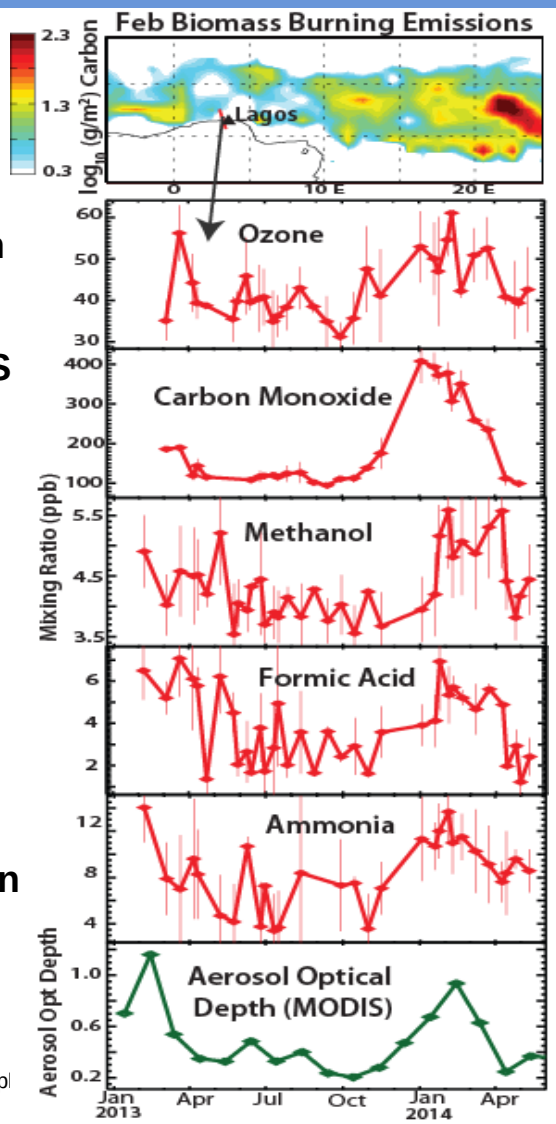
Aura Tropospheric Emission Spectrometer (TES) megacity measurements identify large biomass burning contribution to urban pollution

The suite of TES observations allows quantification of the impact of seasonal biomass burning pollution on the already poor air quality of the world's megacities.

Mexico City: April-May Biomass burning on the Yucatan Peninsula



Lagos: December-March Biomass burning in Central Africa



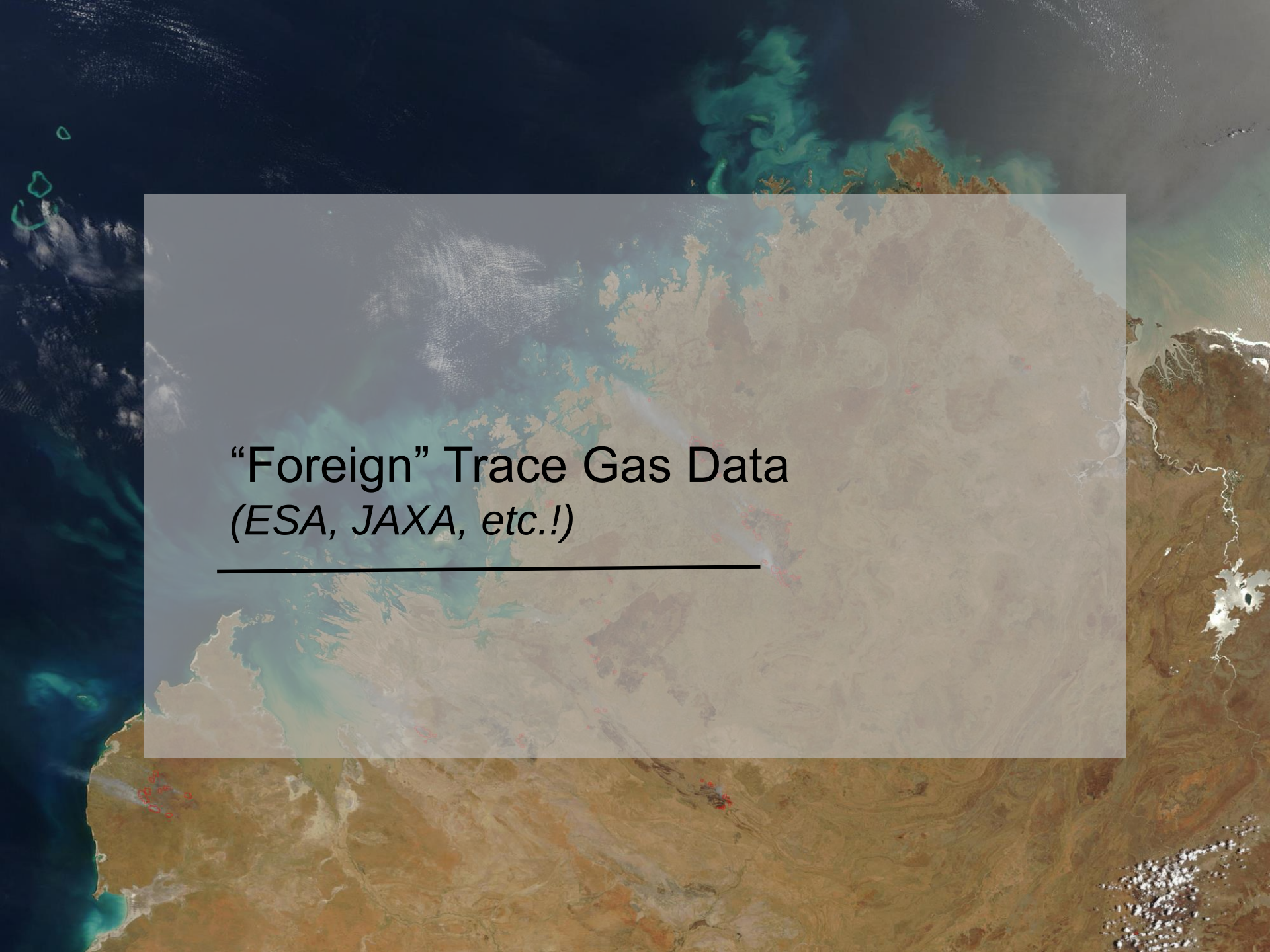
TES megacity measurements show peak ozone levels during biomass burning season in Mexico City, Mexico and Lagos, Nigeria.

Concomitant biomass burning products (TES carbon monoxide, methanol, formic acid, ammonia) and smoke (from MODIS aerosol optical depth) suggest that nearby fires contribute significantly to urban ozone.

Lagos carbon monoxide, formic acid, and ammonia have higher peak values than Mexico City, but ozone is lower. These differences in chemical regime are being investigated.

Methanol and formic acid are more variable in Lagos than Mexico City, likely due to large sources of volatile organic compounds associated with oil and gas extraction in the region (Marais et al., 2014).

Appl



“Foreign” Trace Gas Data
(ESA, JAXA, etc.!)

Foreign Satellites

EUMETSAT

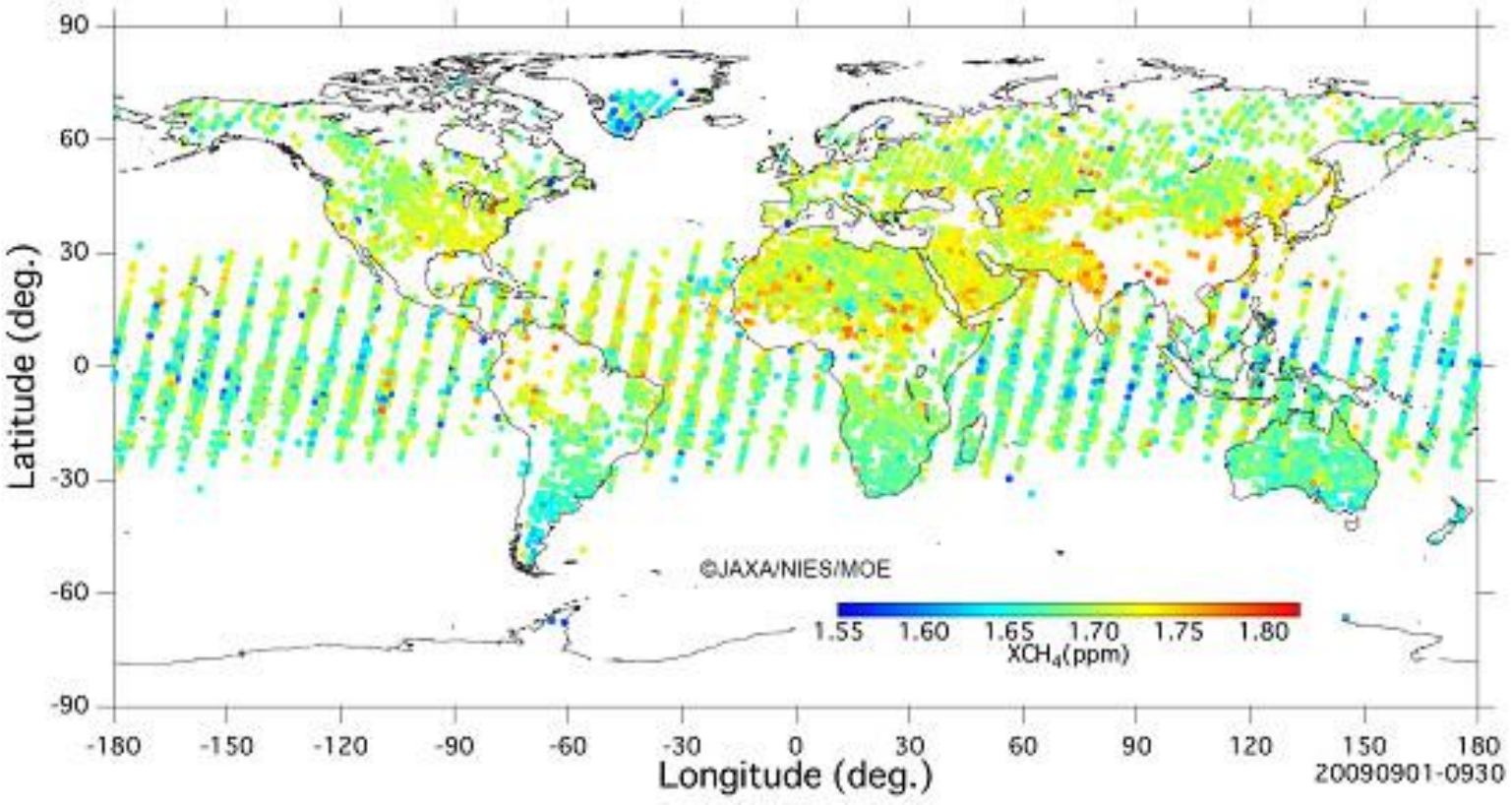
GOME-2 (*columns*) - similar to OMI
IASI *(vertical profiles)* - similar to TES

GOSAT

CH_4, CO_2 (*columns*)

ESA = European Space Agency + individual countries
JAXA = Japan Space Agency
KARI = Korean Aeronautics Research Institute

GOSAT CH_4



Future Trace Gas Data

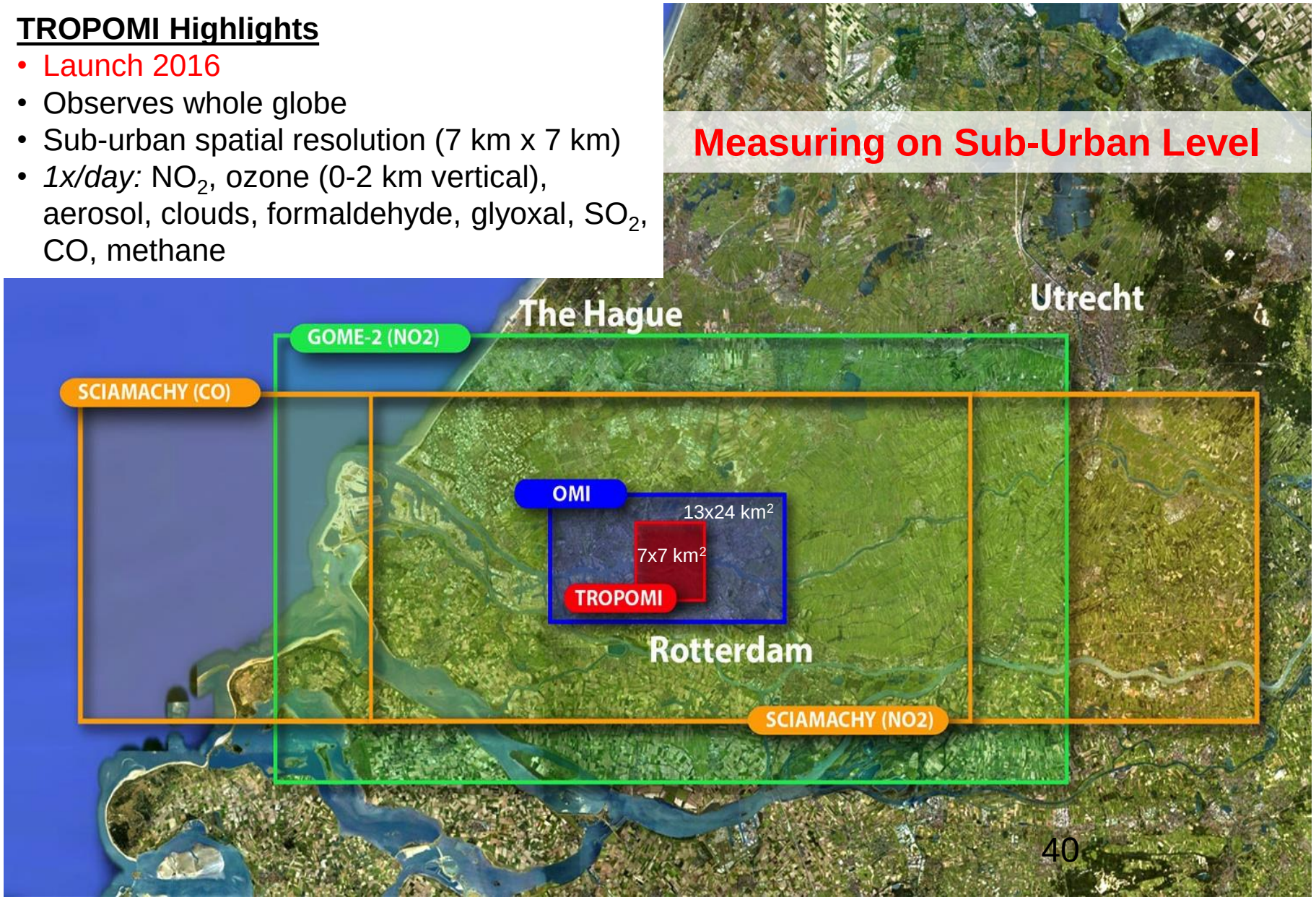
(In the works!)

Upcoming Instruments

European Space Agency TROPOMI

TROPOMI Highlights

- Launch 2016
- Observes whole globe
- Sub-urban spatial resolution (7 km x 7 km)
- *1x/day:* NO_2, ozone (0-2 km vertical), aerosol, clouds, formaldehyde, glyoxal, SO_2, CO, methane



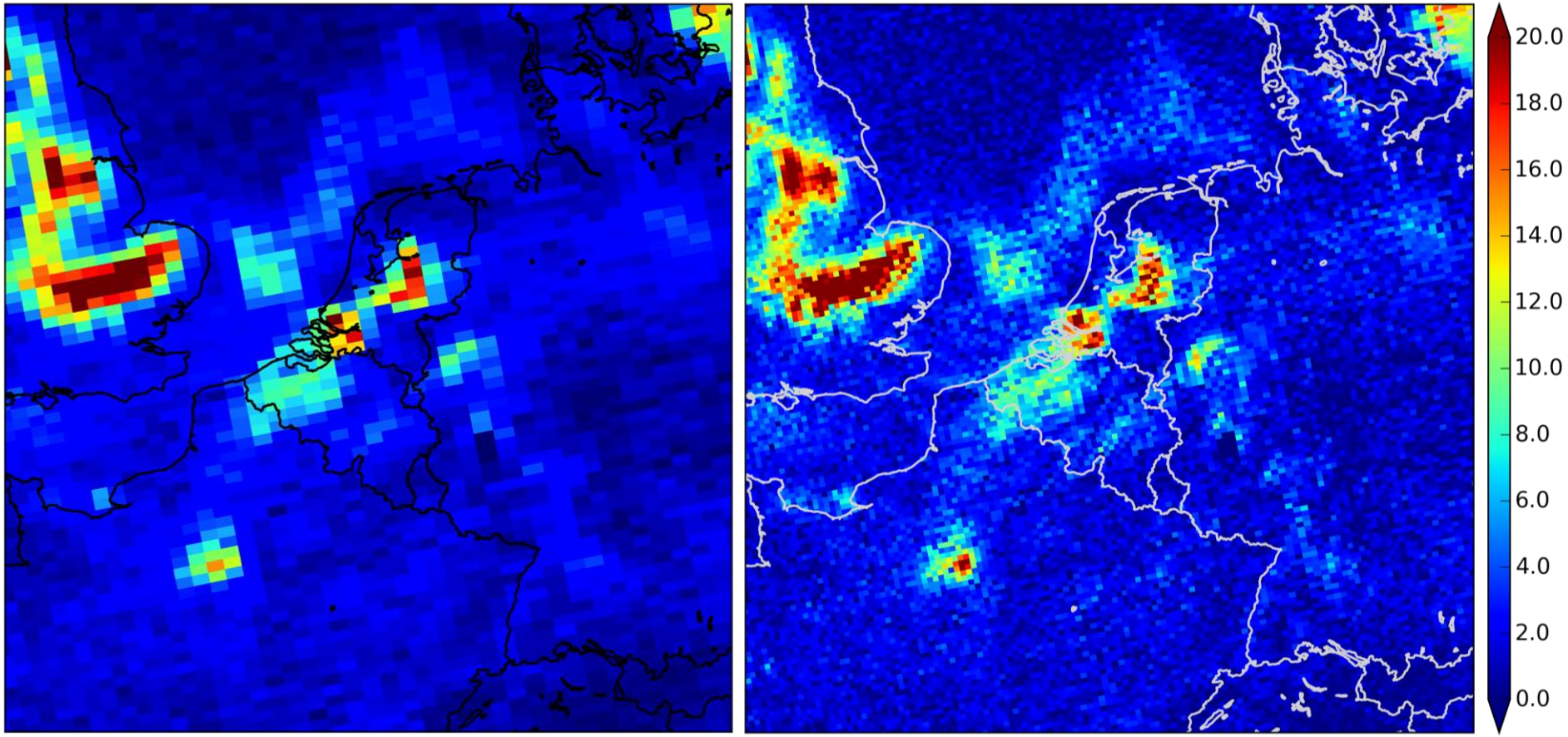
Upcoming Instruments

European Space Agency TROPOMI

Improving Spatial Resolution!

OMI (now)

TROPOMI (launch 2016)



Upcoming Instruments

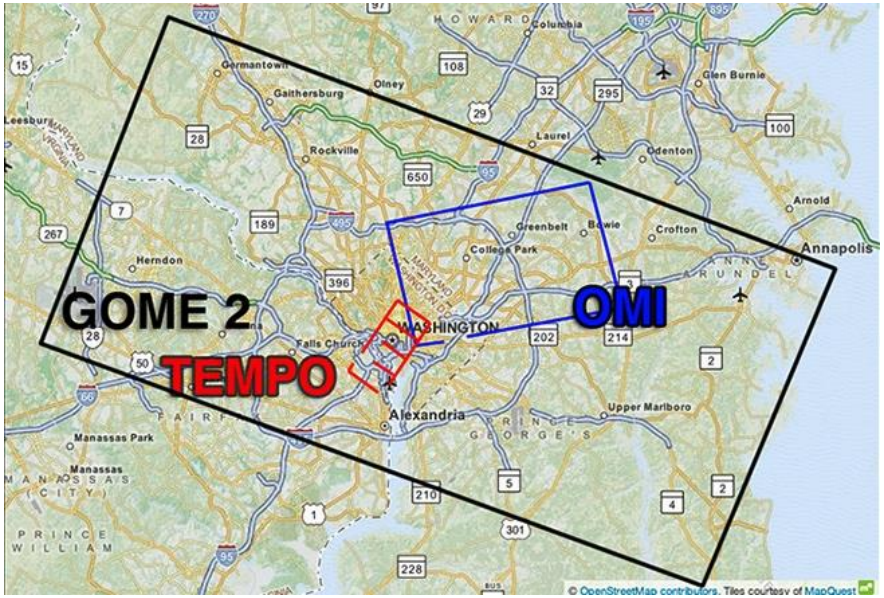
NASA TEMPO

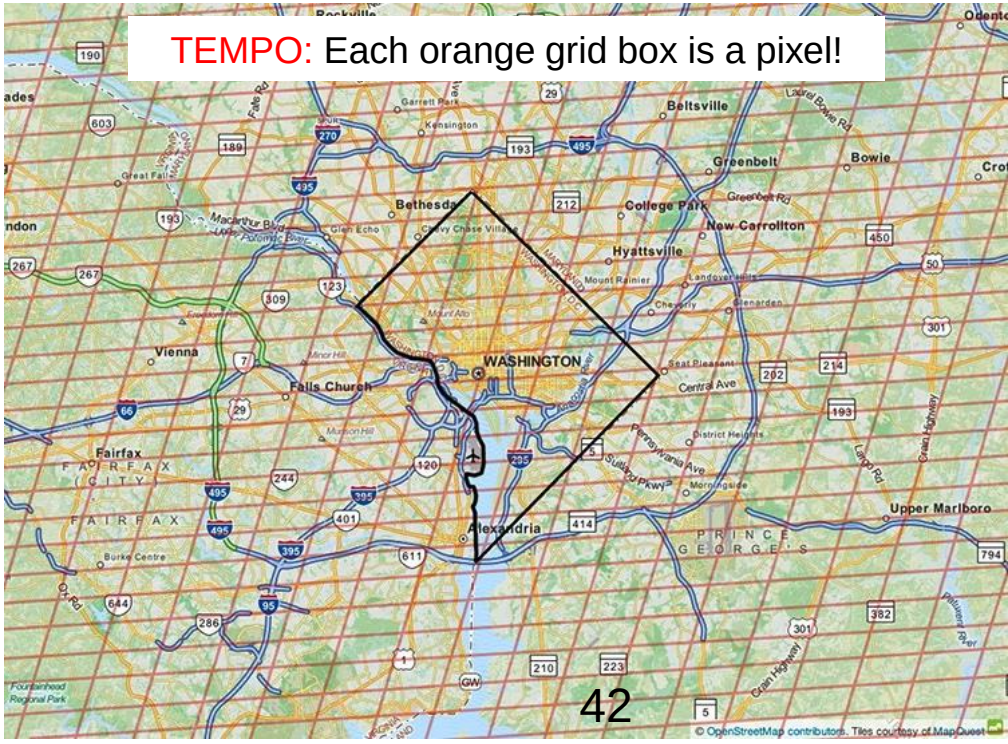
Korea & ESA will each launch their own geosynchronous satellites for air quality.

TEMPO Highlights

- Launch 2019
- Observes N. America in daylight hours
- Sub-urban spatial resolution (2 km x 4.5 km)
- *Hourly:* NO_2, ozone (0-2 km vertical), aerosol, clouds
- *3x/day:* formaldehyde, glyoxal, SO_2

Much better spatial resolution than previous satellite instruments.





Some Fundamentals

(Things to know about satellite data!)

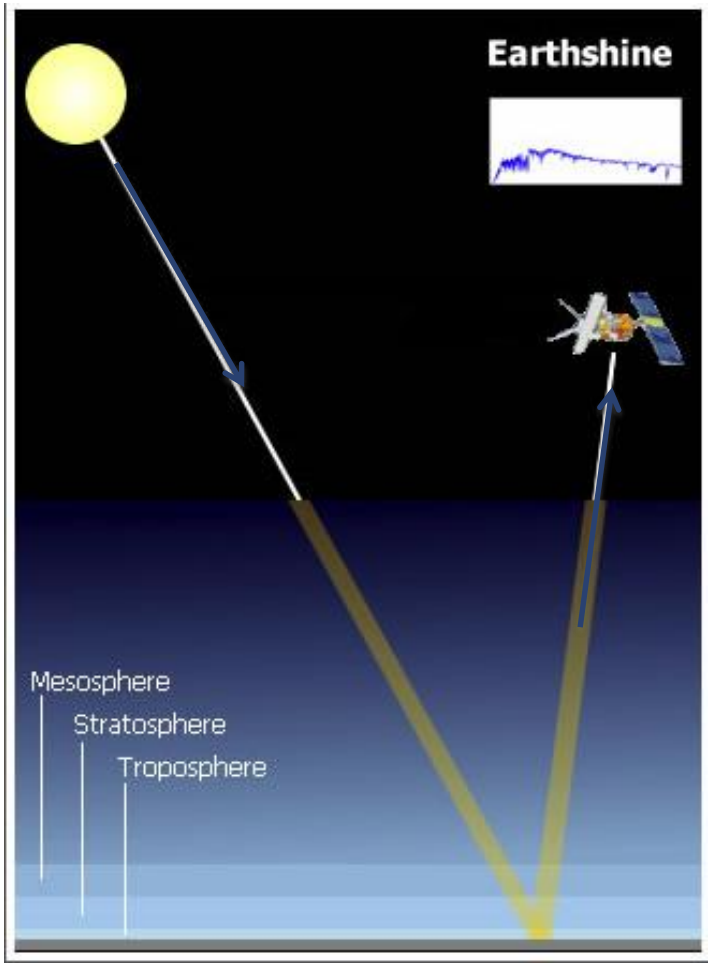
NASA's Tour of the Electromagnetic Spectrum

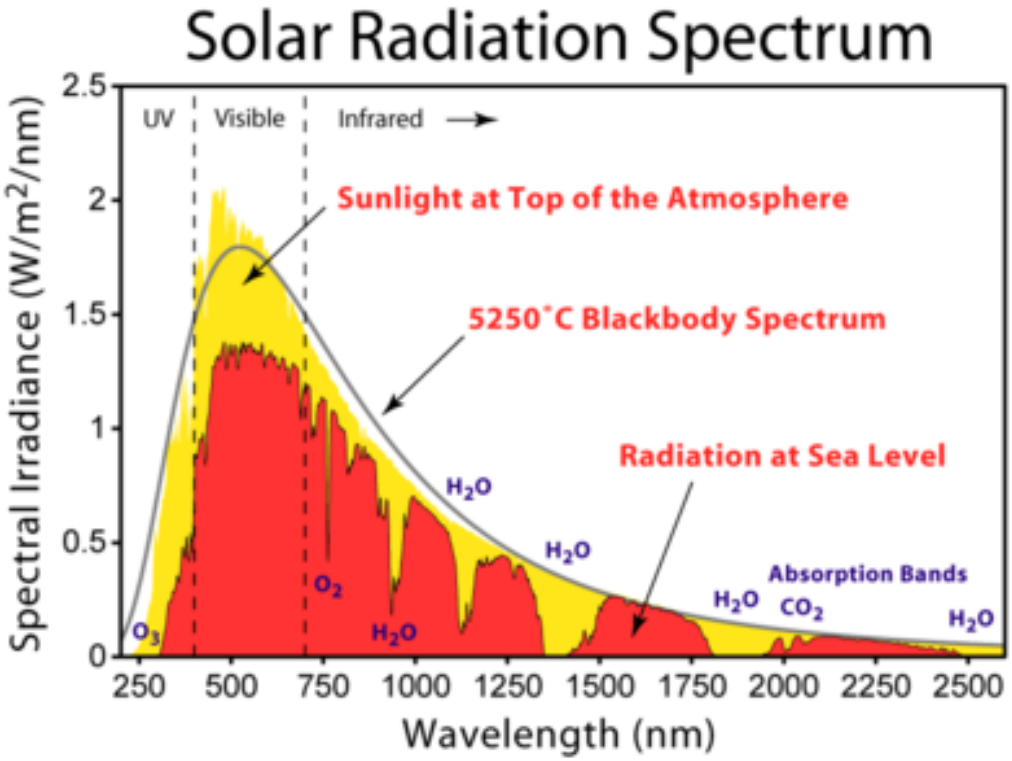
A great, easy-to-understand book about how satellites work.

You can download the pdf file or use the on-line version:
http://missionscience.nasa.gov/ems/

You can also look at an informative video:
https://www.youtube.com/watch?v=HPcAWNlVl-8

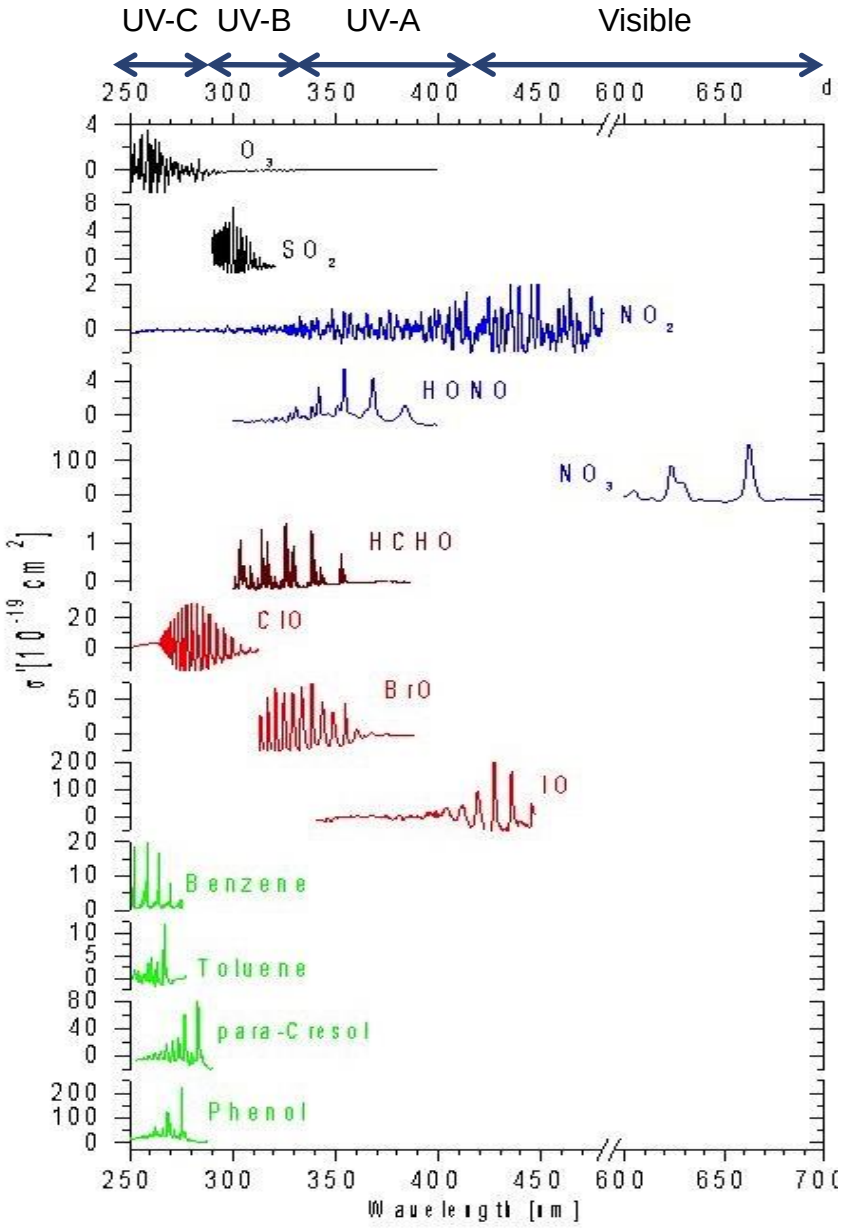
How Satellites Measure Trace Gases

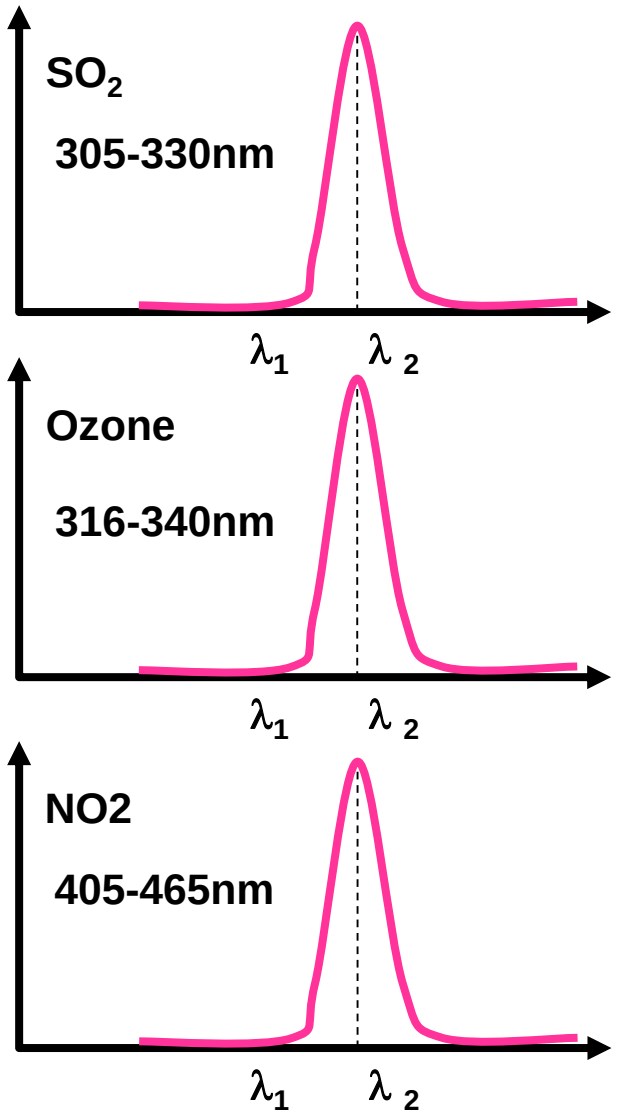




Unlike remote sensing of aerosols, which use the signature of aerosol scattering, remote sensing of trace gases uses the signature of gas absorption

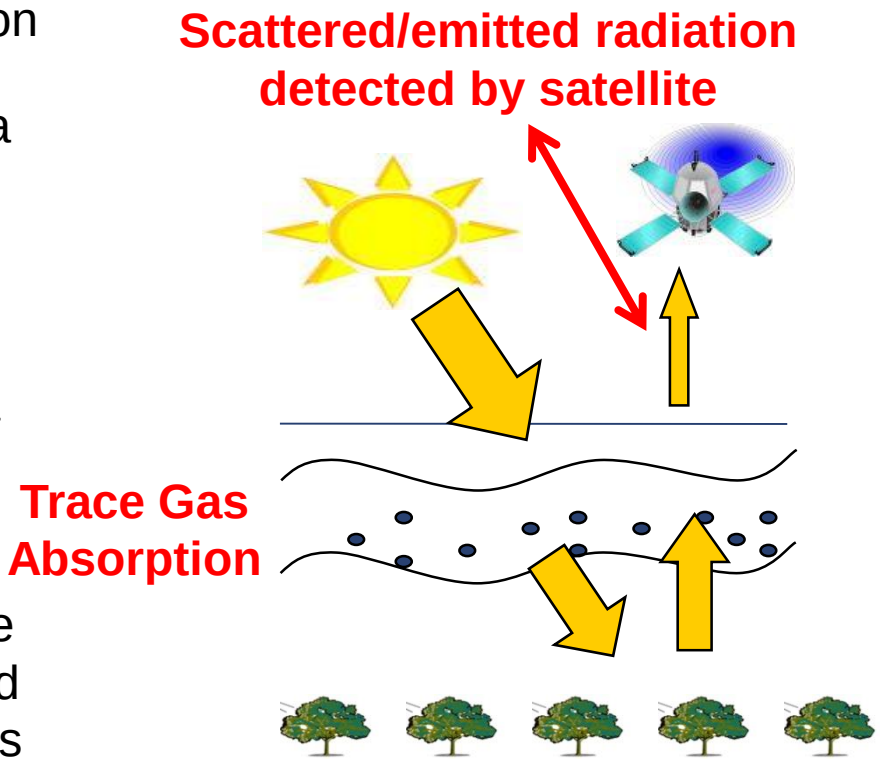
Satellite Measurements Take Advantage of Distinct Absorption Spectra





To summarize …

1. Satellites detect backscattered solar radiation and/or emitted thermal radiation
2. We know the distinct absorption spectra of each trace gas
3. By knowing how and by what amount different molecules absorb radiation at different wavelengths, we can identify a “fingerprint” for each atmospheric constituent
4. Based on the radiation measured by the instrument, retrieval algorithms are used to infer physical measurements (such as number density, partial pressure, column amount) of different gases



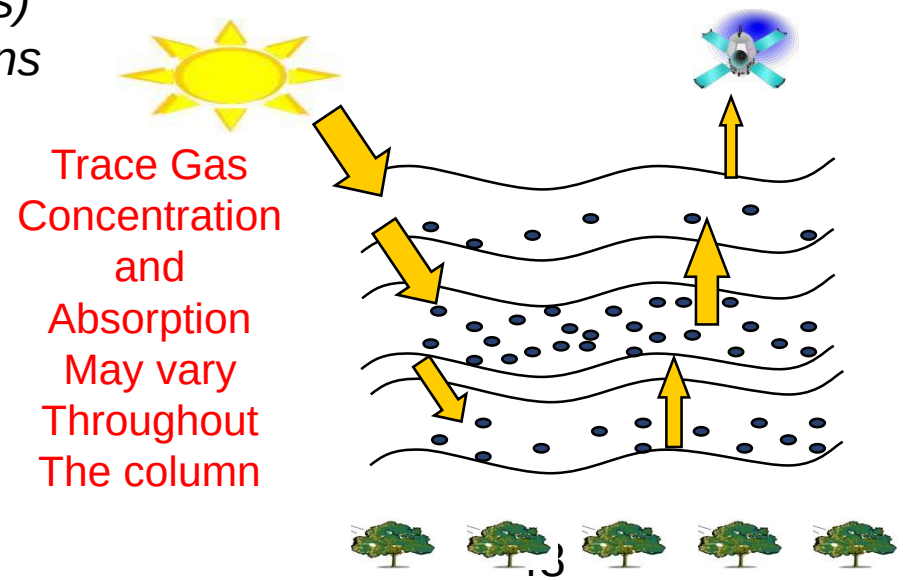
Limitations to Consider

Sensors have limited sensitivity:

- *Spectral limits in interference*
- *Clouds interfere*
- *Aerosols interfere*
- *Limited sensitivity in parts of the vertical column of the atmosphere*
- *Lack of data for validation*

Trace gas concentrations vary throughout the atmosphere due to:

- *Meteorology/Transport*
- *Chemistry (gas, heterogeneous)*
- *Polluted vs. non-polluted regions*
- *Exceptional events*



Proper Use of Remote Sensing Products Requires Knowledge of:

- Column and/or layer product
- Where in the column there is sensitivity
- If it is a layer product, what the vertical resolution of the layers is
- How the products average horizontally, vertically and temporally
- Product and pixel resolution
- Product coverage
- Measurement frequency
- Overpass time

Final Remarks

Satellite data are powerful for health and air quality applications.

However, it is very important to understand the strengths and limitations of the data for a particular application.

Without proper knowledge, it is very easy to misuse and abuse the data!

Please do not be afraid to ask for help, information, guidance, etc.

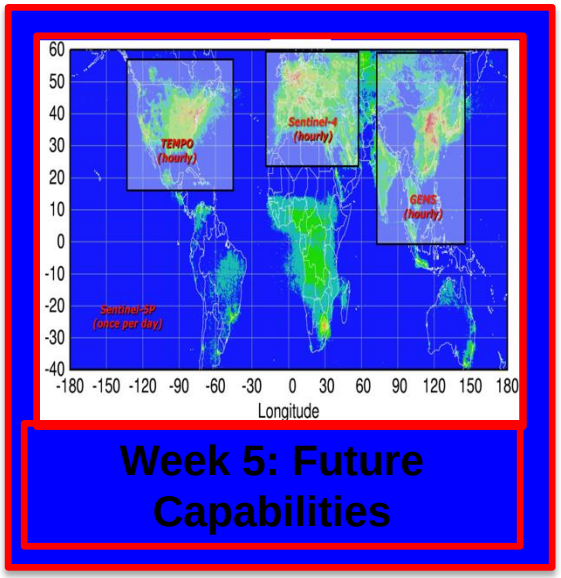
There are many resources available to the data end-user. Make use of them!!!


NO ASSIGNMENTS

Next Week

Future Capabilities

- **Geostationary aerosol products**
- **Future satellite capabilities for air quality monitoring**
- **Course review**



All the materials and recordings will be available at

http://arset.gsfc.nasa.gov/airquality/webinars/introduction-satellite-remote-sensing-air-quality-applications

Contact

- Pawan Gupta (pawan.gupta@nasa.gov) for the technical questions
- Brock Blevins (brockbl1@umbc.edu) for material access, future trainings, and other logistic