609-A: Observation, Modeling, and Impacts of Emissions in West Africa

COSPAR Capacity Building Workshop, Kumasi, Ghana

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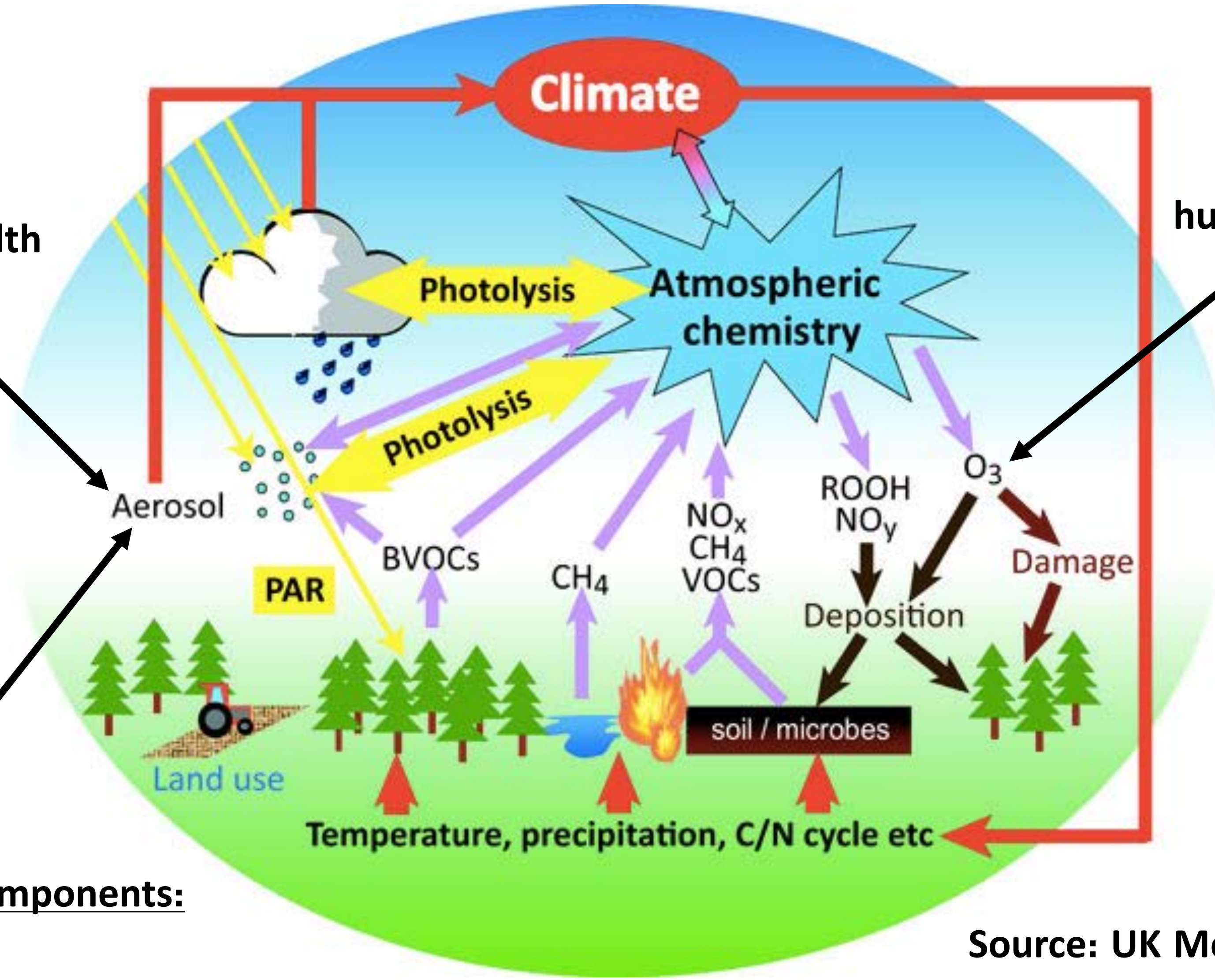
Chemistry of the Atmosphere

Impacts human health

Impacts human health



<u>Aerosol Components:</u>

Sulfate
Nitrate
Ammonium
Organics
Black Carbon

Source: UK Met Office

Atmospheric Chemistry Transport Models

Atmospheric chemical transport model infrastructure

Code: Fortran (historical, but also efficient for solving mathematical equations)

Input/output: mix of binary punch and NetCDF files (intention is to be 100% NetCDF)

Compile: a few minutes

Run time: depends on model version. Walltime is ~10-12 hours for 1 month (1 NODE, 8 CPUs)

Not very computationally demanding, but requires lots of space for input/output

Track version history: git

Debug: Totalview

Visualization software: IDL (costly), Python (free), NCAR Common Language or NCL (free), R (free).

Would we use an atmospheric chemistry model to address these research topics?

What is the surface concentration of ozone in Sierra Leone?

Contribution of land cover change to drought in West Africa.

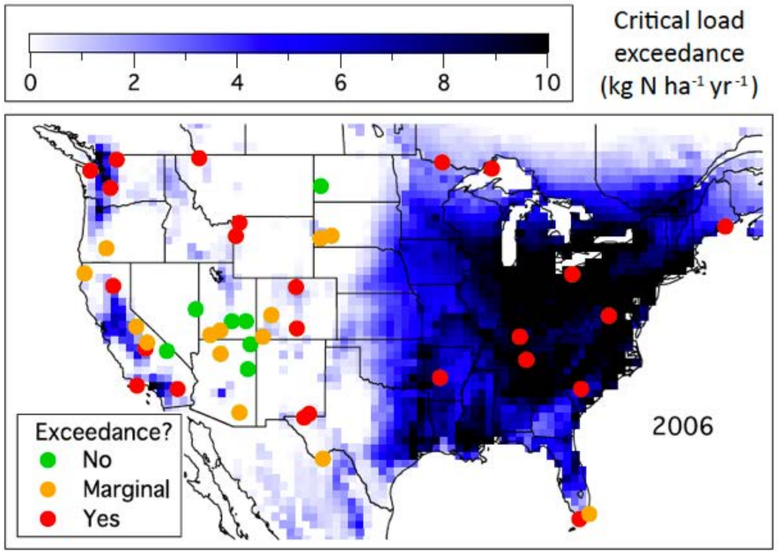
Human health effect of electronic waste burning in southern Ghana.

Shift in the ITCZ due to desertification in the Sahel.

Climate change impact of aerosols from intense seasonal fires in Africa.

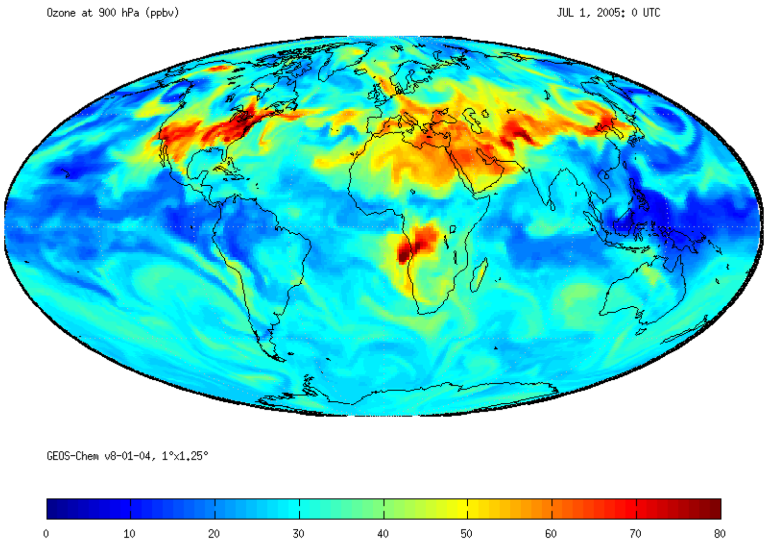
Example Model Output

Excessive nitrogen input to the Earth's surface:



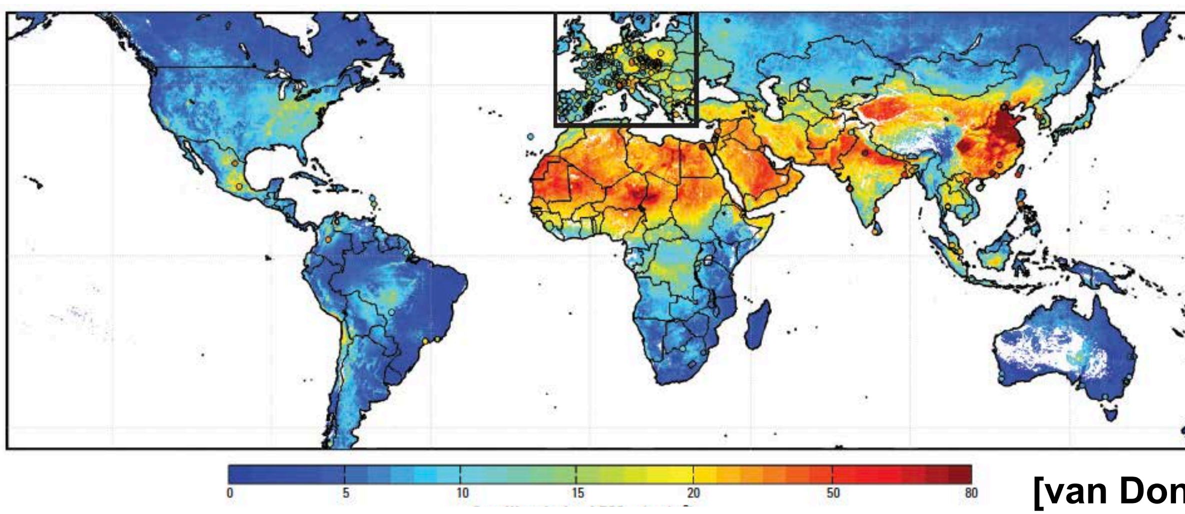
[Ellis et al., 2013]

Surface ozone concentrations:



[http://fizz.phys.dal.ca/~atmos/animation/]

Combine with satellite observations to derive surface particulate matter concentrations



[van Donkelaar et al., 2010]

GEOS-Chem Models that Exist are Many

Some examples:

Standard model: global air quality model (NO_x-O_3-VOC-aerosol chemistry) at **2x2.5 degrees** (~200x250 km) or 4x5 (~400x500 km) degrees.

Other specialized options:

SOA model: Standard model with explicit treatment of secondary organic aerosols

High-performance model: Standard model at high resolution (under development)

Nested models: Standard model, but at high resolution over a specific region (China, Europe, North America, **Africa**, West Africa) with boundary conditions at the coarse global resolution. High resolution dictated by resolution of meteorological fields

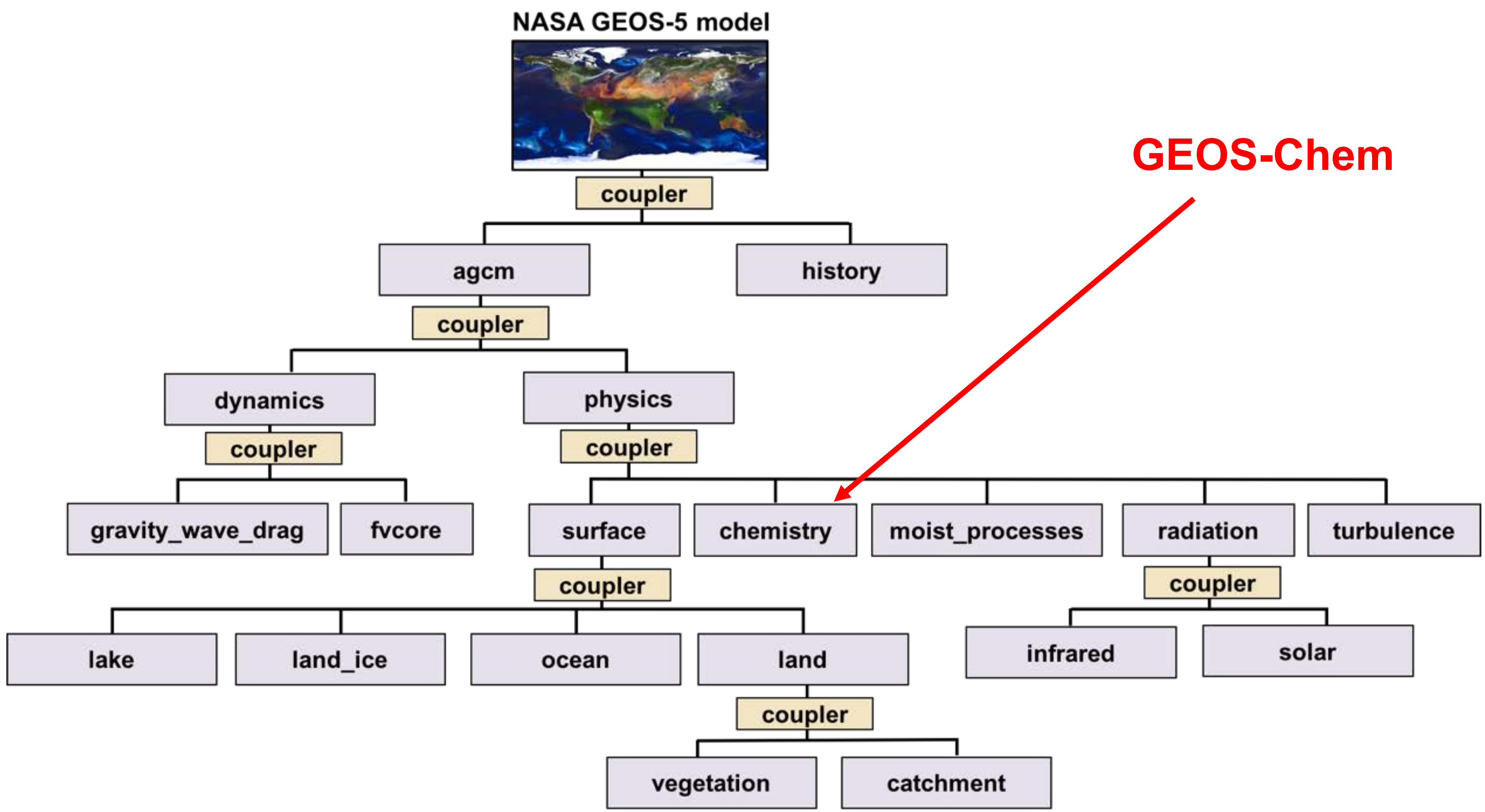
Others: Mercury, POPs, radon, Methane

RED: GEOS-Chem models used in my research

Major Development Initiative

Reformat GEOS-Chem to be used within the Earth System Modelling Framework (**ESMF**)

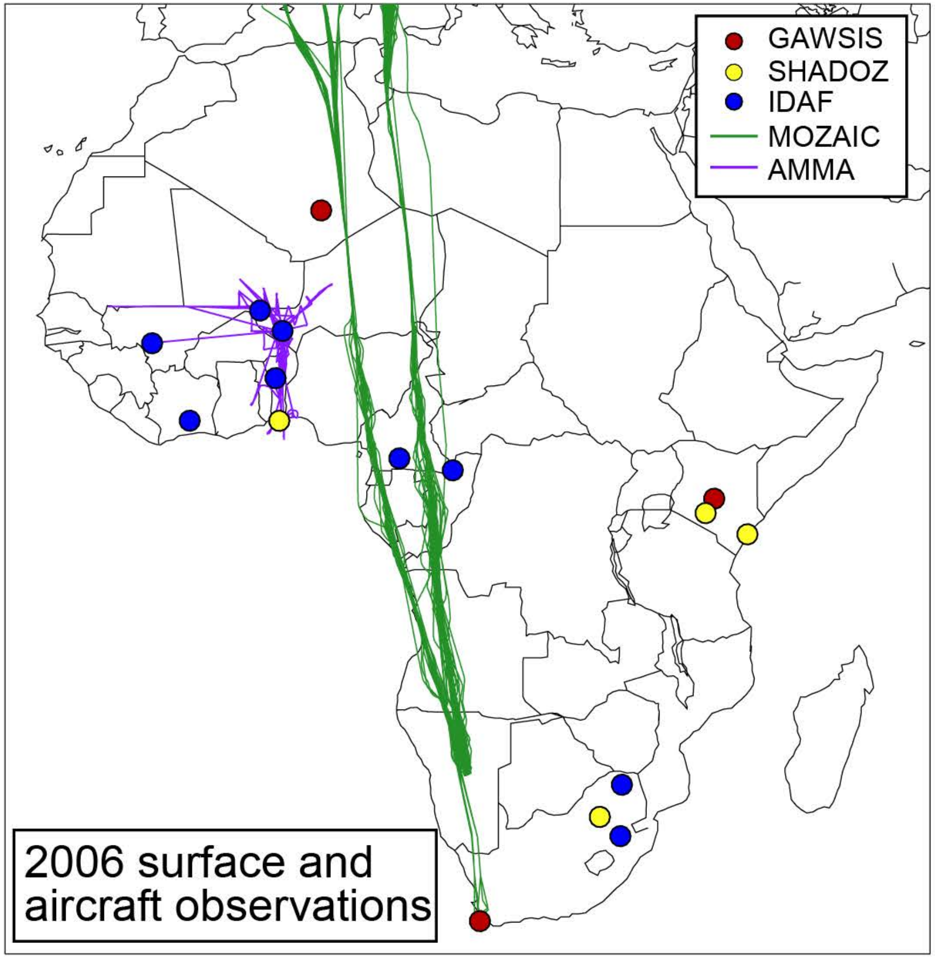
Dynamic representation of earth systems (ocean/forest/atmosphere) (**advantage**)
Plug-and-play framework to couple different model components (**advantage**)
Very high computational demand (**disadvantage**)



Satellite Observations
(remote sensing, Earth observations)

Air Quality Monitoring Sites in Africa are Few

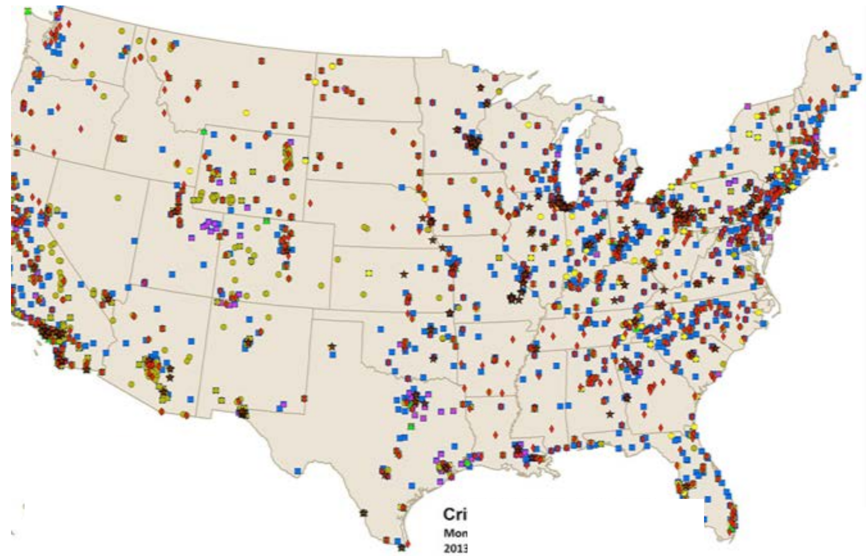
Surface and aircraft observations limited to a few international campaigns and networks



Country-level air quality monitoring and well-defined standards limited to South Africa

By comparison US has widespread monitoring sites, well-defined standards, and easy data access

Criteria Pollutant Monitoring Sites



- Lead
- Fine particles ($PM_{2.5}$)
- Coarse particles (PM_{10})
- CO
- NO_2
- SO_2
- Ozone

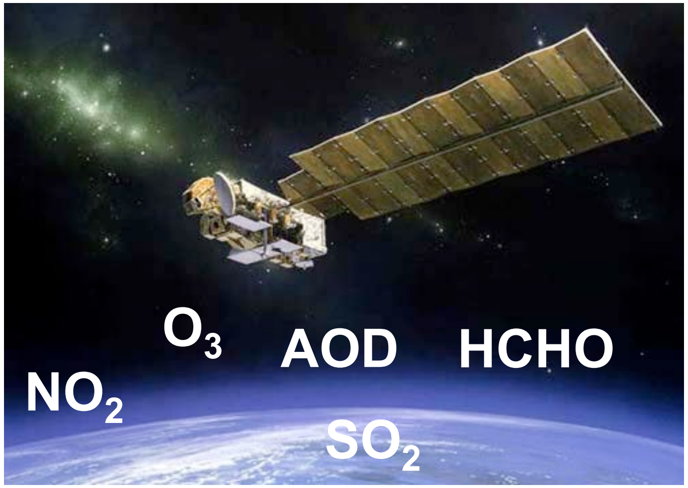
[US EPA, 2013]

Column densities from OMI

Provides the sum of molecules from the surface of the Earth to the top of the atmosphere

Ozone Monitoring Instrument (**OMI**) is onboard the NASA Aura platform

NASA Aura platform

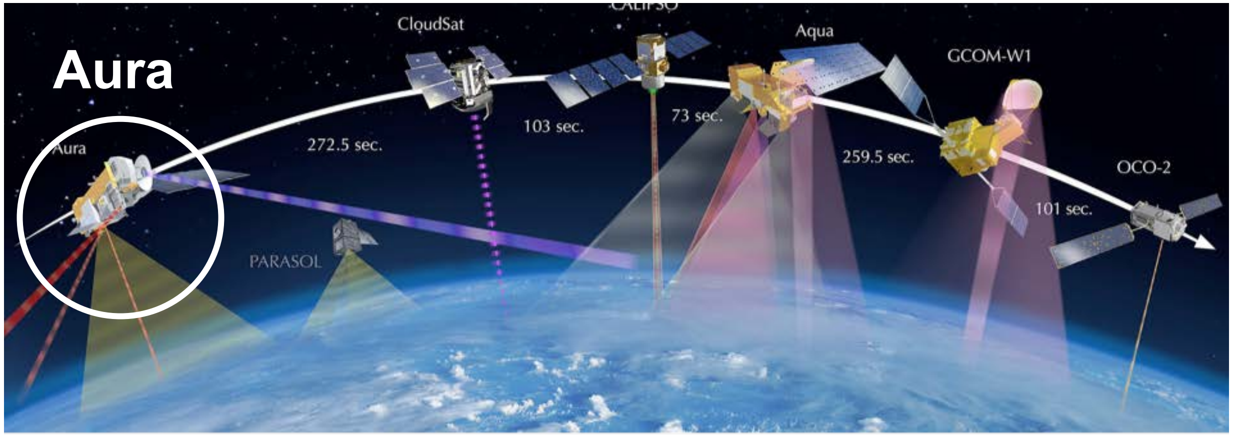


Launch:
July 2004

Overpass:
13h30 LT

Resolution:
13×24 km^2

Aura in the A-Train Constellation



Useful Links/Information

Giovanni, to visualize satellite observations: https://giovanni.gsfc.nasa.gov/giovanni/

NASA satellite products portal: https://disc.gsfc.nasa.gov/Aura/data-holdings/

UMD data products: http://glcf.umd.edu/data/

European website with satellite products:
TEMIS: http://temis.nl/index.php
QA4ECV: http://www.qa4ecv.eu/ecvs

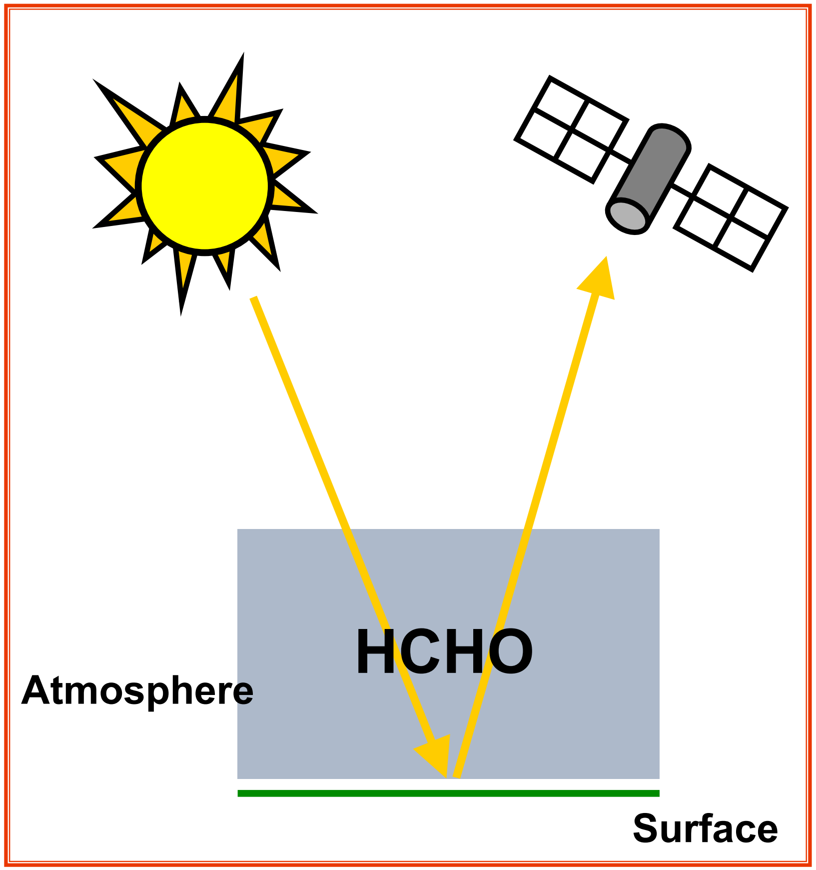
MOPITT: https://www2.acom.ucar.edu/mopitt

Open Source processing software: R, Python NCL (NCAR Common Language).

My email address: e.a.marais@bham.ac.uk

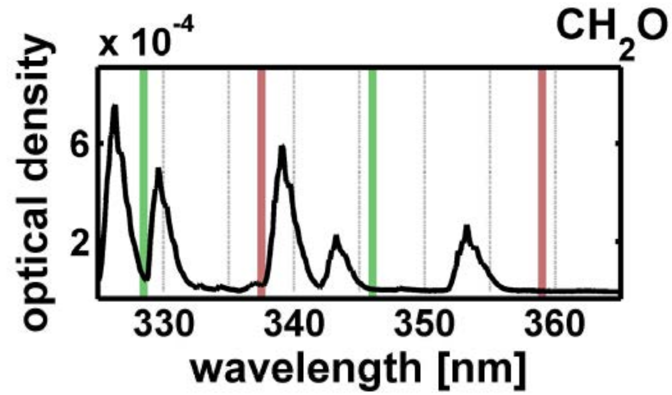
Steps to Retrieve Space-based column density observations

Instrument views solar backscattered radiation



Column density: molecules cm^{-2}

Fit spectrum to get **slant column** (Ω_s)



[De Smedt et al., 2008]

Compute air mass factor (**AMF**) to get **true vertical column** (Ω_v)

$$\mathrm{AMF} = \mathrm{AMF_G} \int_0^\infty \omega(z) S_z(z)\, dz$$

Geometric AMF

Scattering weights

HCHO shape factor

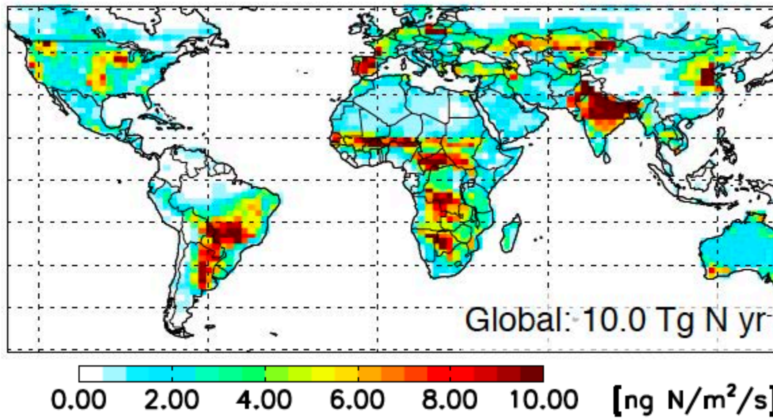
$$\Omega_V = \Omega_S / \mathrm{AMF}$$

[Palmer et al., 2001]

Many Applications of Satellite Observations

Top-down emission estimates

Nitrogen oxides (NO_x) from soils estimated with OMI tropospheric NO_2

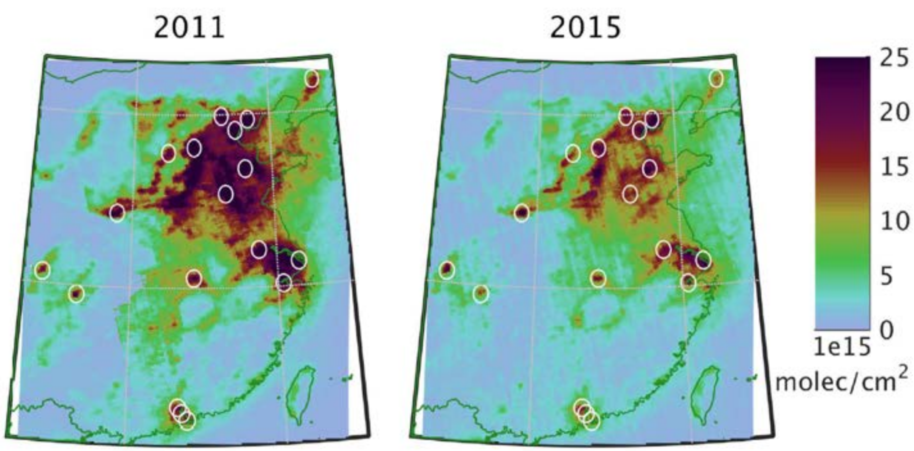


[Vinken et al., 2014]

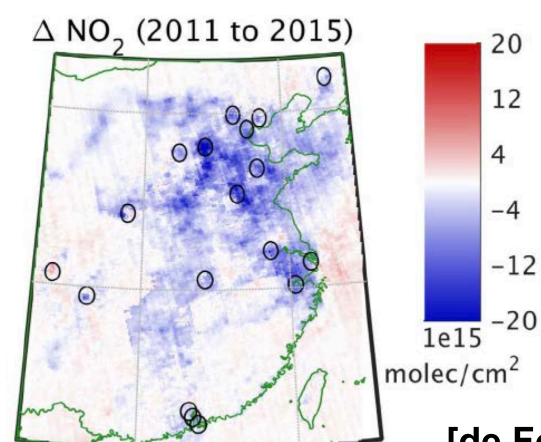
Trends in air pollution from the long record of satellite observations

Nitrogen oxides (NO_x) from soils estimated with OMI tropospheric NO_2

Absolute Values



Change from 2011 to 2015



[de Foy et al., 2016]

Funding Opportunity for Women from Developing Countries

Schlumberger Faculty for the Future

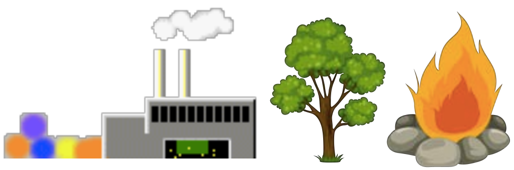
http://www.facultyforthefuture.net/

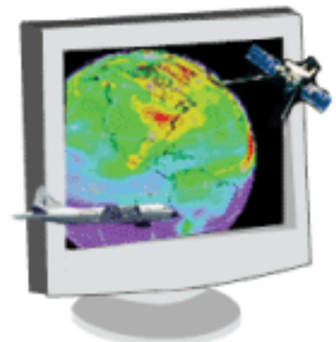
Air Quality in Nigeria: A Space-based Perspective

Atmospheric chemical transport models

GEOS-Chem as an example

Emissions/Sources





Meteorology
(offline/online)

Chemistry
Transport
Dry/wet deposition

3D global/regional atmospheric concentrations

What emissions should be included in this model?

What meteorology should be included in this model?

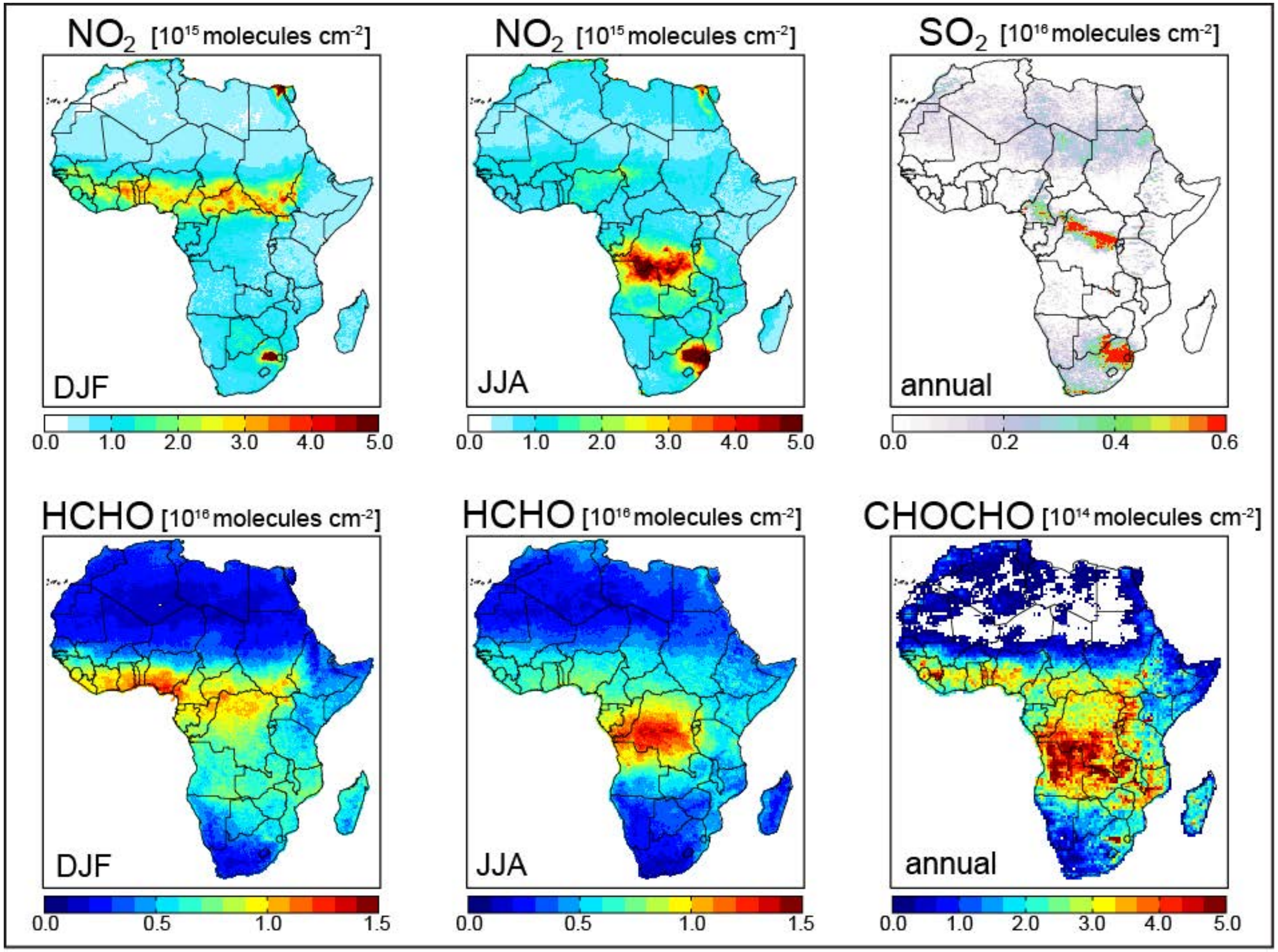
Satellite Observations of Atmospheric Composition

Column densities from space-based observations of solar backscattered UV-vis radiation

VOCs

OH

HCHO



VOCs

OH

CHOCHO

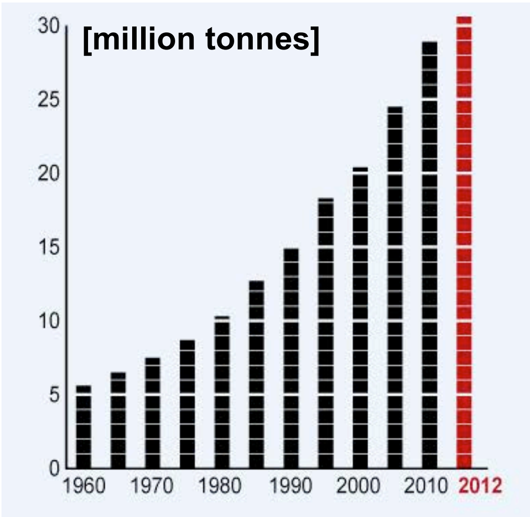
NO_x ($NO_x \equiv NO + NO_2$) surface sources from tropospheric NO_2 column densities

Reactive VOCs from formaldehyde (HCHO) and glyoxal (CHOCHO) column densities

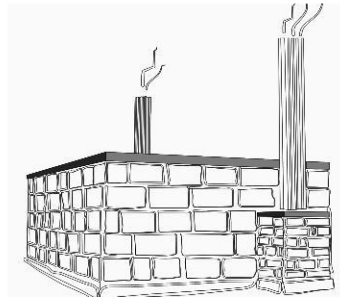
SO_2 surface sources (volcanoes and anthropogenic activity)

Energy Mix and Pollution in Nigeria

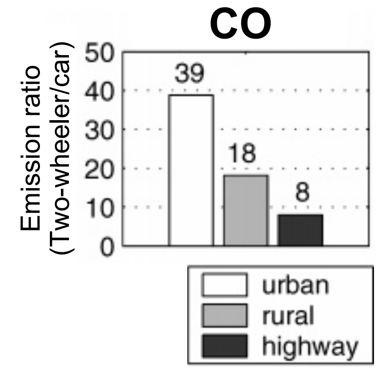
Charcoal making: a growing industry



[FAOSTAT, 2014]

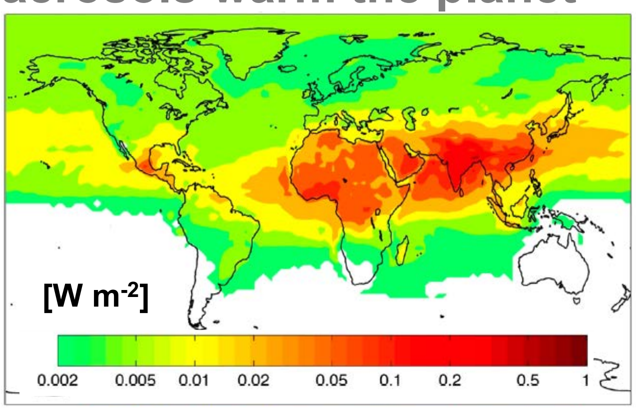


Proliferation of two wheelers: more polluting than cars



[Vasic and Weilemen, 2006]

Kerosene for lighting: emitted aerosols warm the planet

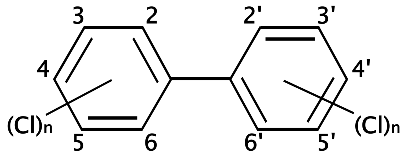


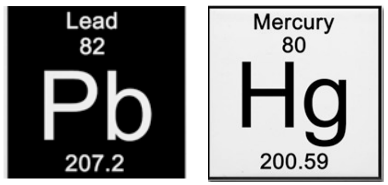
[Lam et al., 2013]

Solid Biofuels for Cooking: dominant source of energy

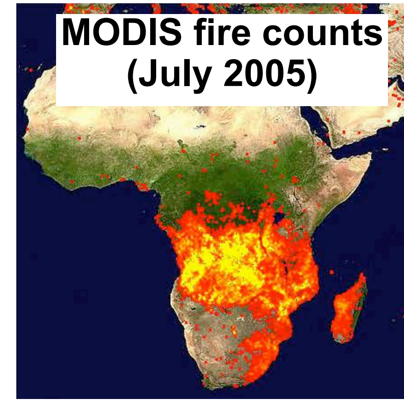
Other Sources of Pollution

Trash and e-waste burning





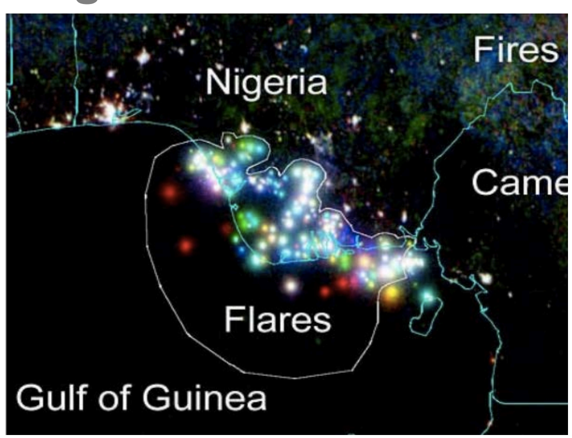
Agricultural waste and savanna fires



[Giglio et al., 2003]

Flaring (wasting) of natural gas

Distinguish flares from lights and other fires:



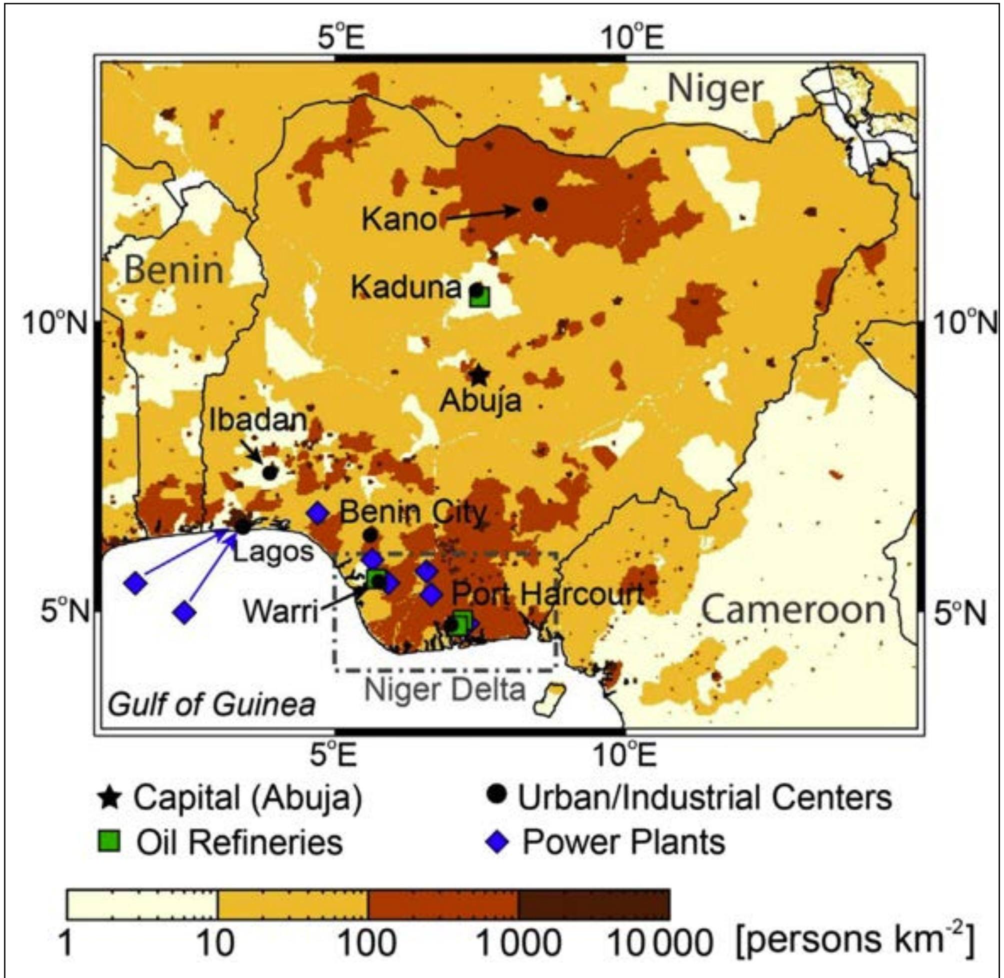
[Elvidge et al., 2009]

Artisanal Oil Refining:

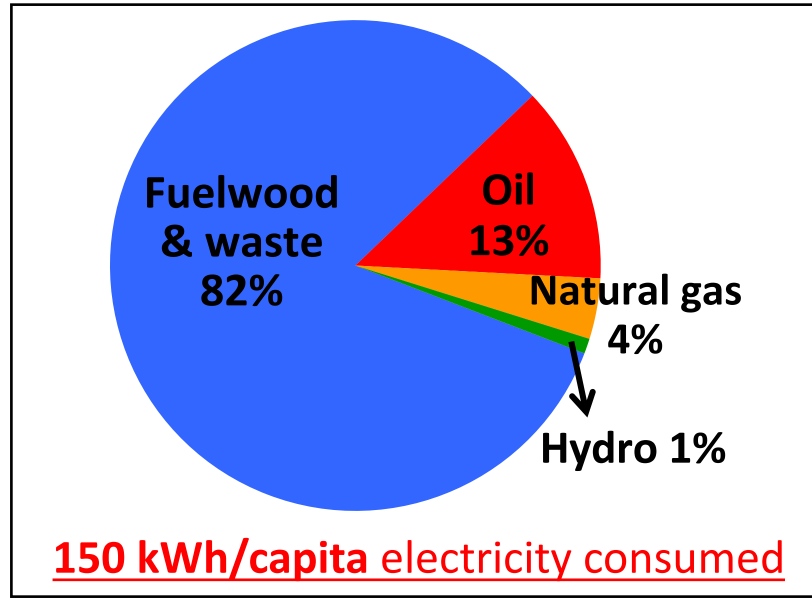
Large informal sector

Energy Mix in Nigeria

Population distribution in 2000



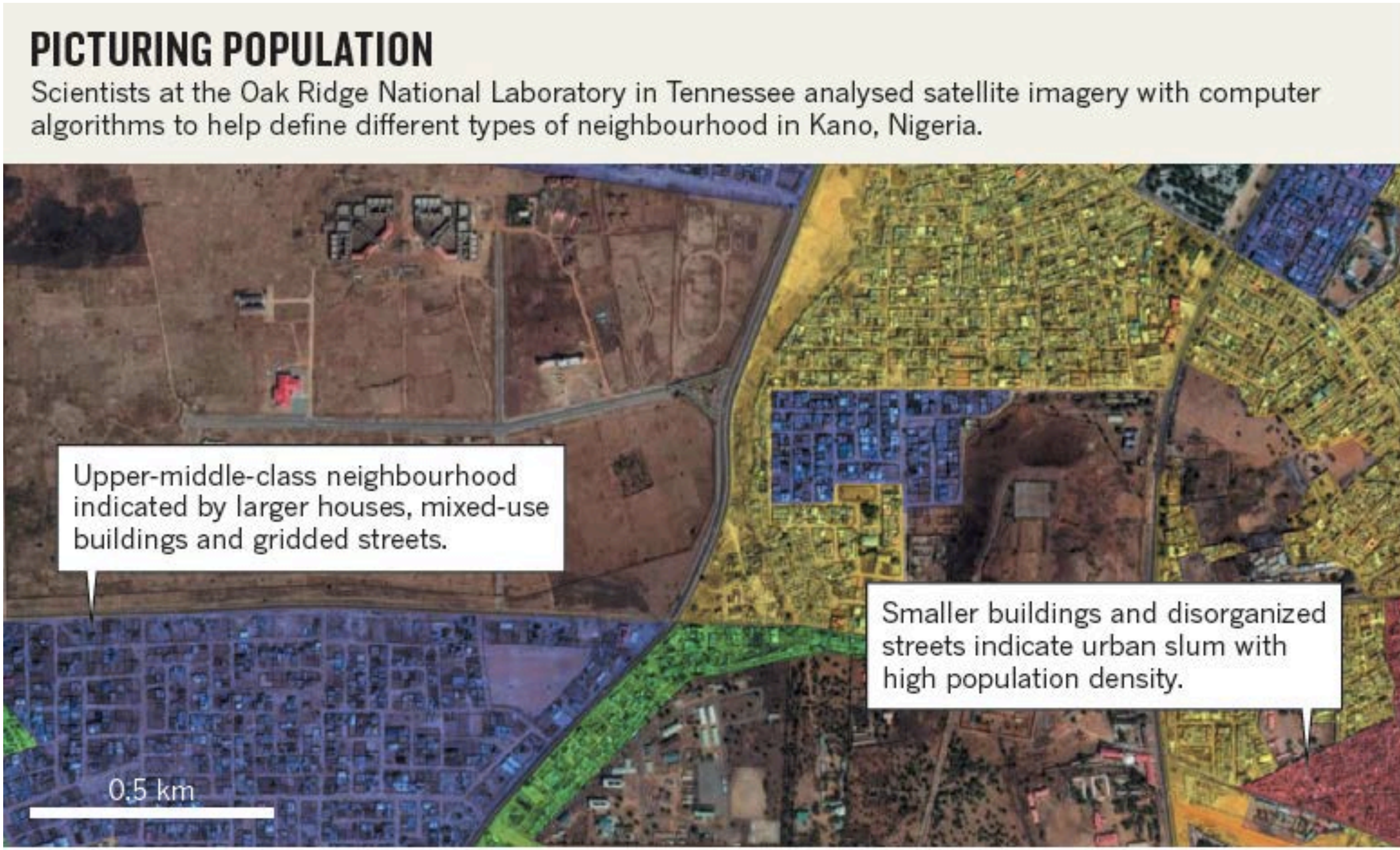
Energy Mix in 2010



[EIA, 2012]

Inefficient **energy mix** and wasted natural gas

New Population Distribution Maps

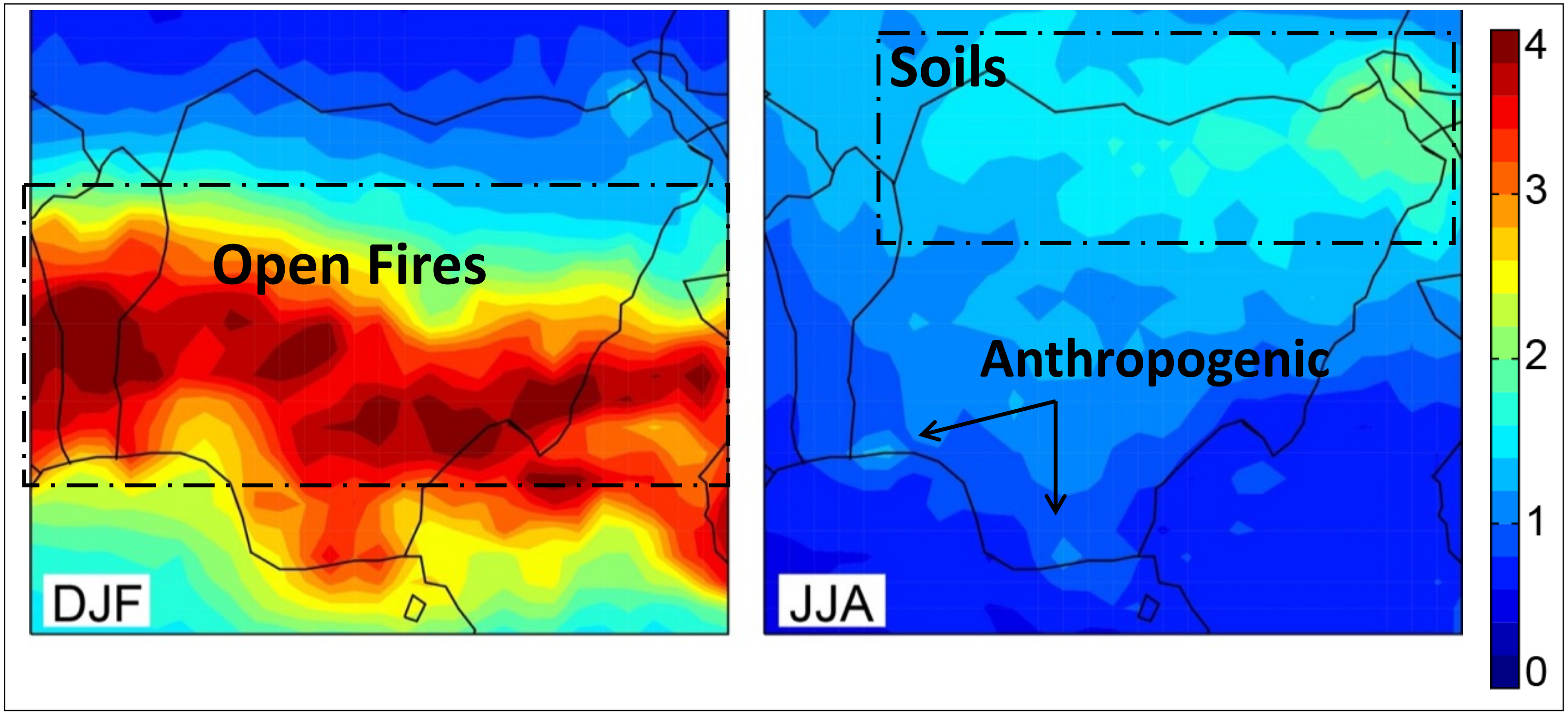


[J. Tollefson, Nature (News In Focus), 2017]

Seasonal Pollution in Nigeria

Seasonal enhancements from **open fires** (Dec-Feb) and **soils** (Jun-Aug)

OMI tropospheric NO_2 in 2005-2007 [10^{15} molecules cm^{-2}]



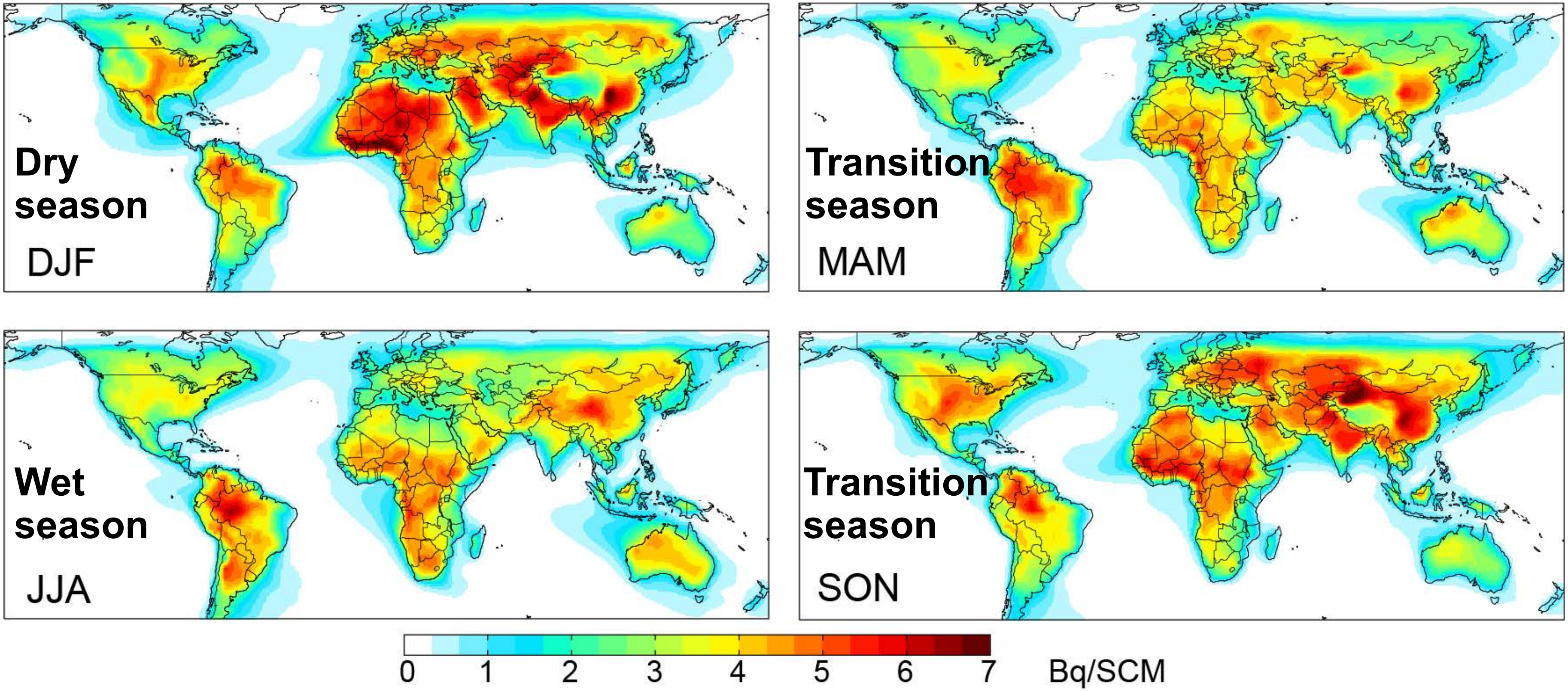
Meteorological features in each season

Temperature inversion (**Harmattan winds**)	**West African Monsoon**
Severely restricted ventilation	Efficient ventilation

Meteorology is also important

Unprecedented persistent stagnation in the dry season from natural inversion established by warm northeasterly winds

Seasonal mean (2006) GEOS-Chem Radon-222 (^{222}Rn)



^{222}Rn: **Uniform source** from non-frozen soils

Loss is by **radioactive decay**

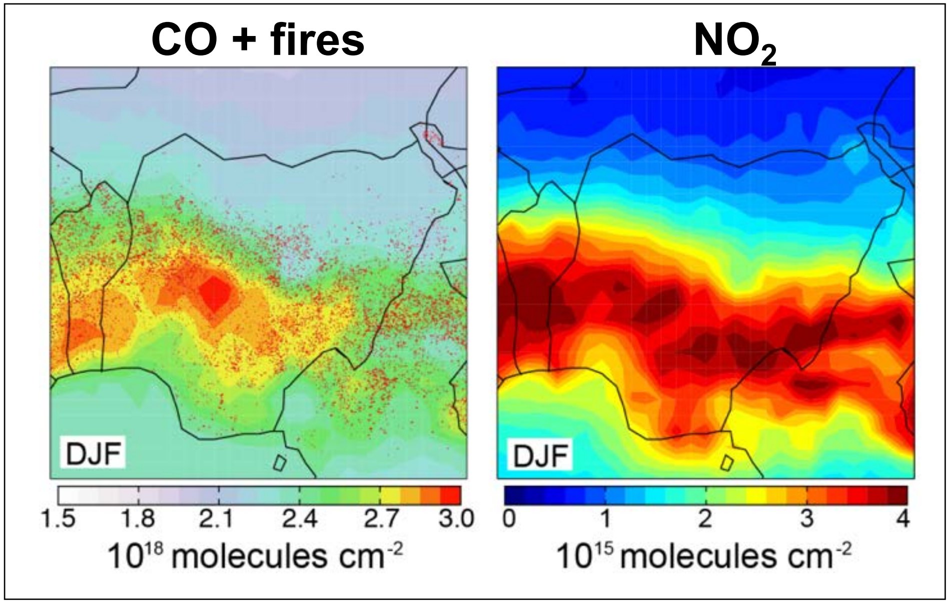
Interpretation: High values indicate **stagnation** leading to build up of pollution

GEOS-Chem Radon simulation [Jacob et al., 1997]

Atmospheric Composition in Nigeria

Annual mean satellite data for 2005-2007 at 0.5×0.5° (GOME-2 is 2007 only)

CO and NO_2 are dominated by **open fires** (but AIRS boundary layer sensitivity is low)

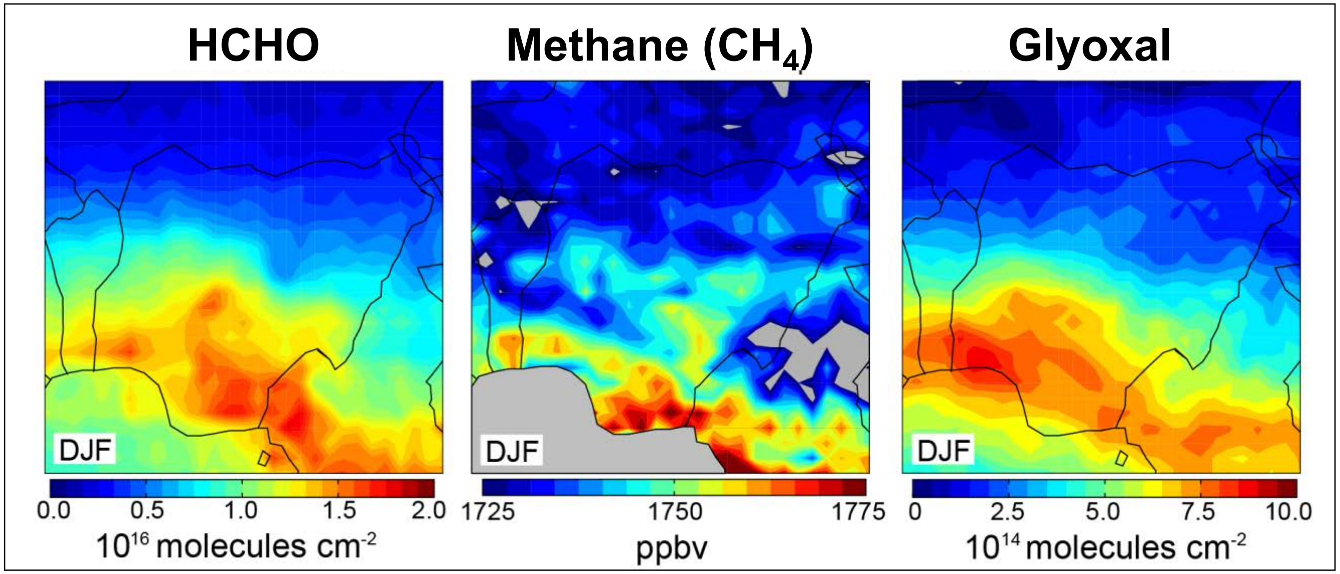


Evaluate **NMVOC emissions** with HCHO and CHOCHO:

NMVOC oxidation	→	**HCHO**
Aromatic oxidation	→	**CHOCHO**

Niger Delta CH_4 and HCHO hotpots indicate extensive **gas leakage**, **venting** and **flaring**.

Lagos CHOCHO and HCHO hotspots from reactive aromatics (**vehicle and generator emissions**)



Aircraft measurements of air pollutants

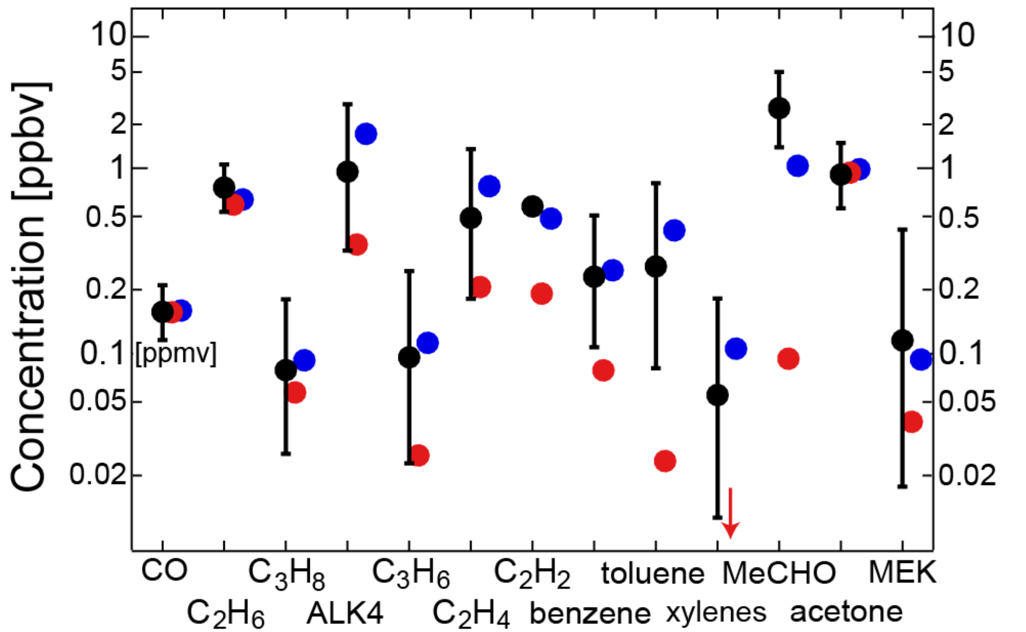
Research aircraft

Instruments onboard

Constraints on Nigerian Emissions

Satellite observations and AMMA aircraft observations provide **constraints on emissions** in Nigeria

NMVOC and CO concentrations over Lagos below 1 km on 8 August 2006



MeCHO ≡ acetaldehyde
MEK ≡ methyl ethyl ketone
ALK4 ≡ ≥C_4 alkanes

[NMVOC measurements by James Hopkins]

Model (2×2.5° simulation) underestimates aromatic, acetaldehyde and higher alkanes.

Model bias is **due to emissions**, rather than dilution or transport (good agreement with CO, acetone and shorter alkanes)

The corrected **Nigerian NMVOC emissions are 5.7 Tg C a^{-1}** (*a priori* emissions =1.6 Tg C a^{-1})

EDGAR v4.2 **CH_4 oil & gas emissions** are also increased from 1.7 Tg CH_4 a^{-1} to **5.5 Tg CH_4 a^{-1}**.