Air Quality in North America and Africa

Measurement programs in the U.S. and how they might inform observations in an African megacity

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Workshop on a Pilot Design for Air Quality in Africa, June 2021

Outline

- Air Pollution Research in the U.S. – Clean Air Act, Emissions Trends & Research Strategies
- Why East Africa ? Recent and Future Global Emissions, Data Availability and Measurement Networks
- Measurement Needs & Some Thoughts on Instruments
- Sampling Strategies & Partnerships
- Concluding Remarks

The Need for Air Pollution Policy and Scientific Research

Air pollution in the U.S. was a significant issue in the mid-20th century

•In Los Angeles, CA, ozone levels reached their highest known level of 0.90ppm on September 13th, 1955.

•New York City experienced severe "smog" from November 23rd-26th, 1966. On November 24th, the most severe day of the "smog", the 24-hour mean value of SO_2 was >0.50ppm.

Los Angeles, CA on September 14th, 1955. *Los Angeles Times*, Archive

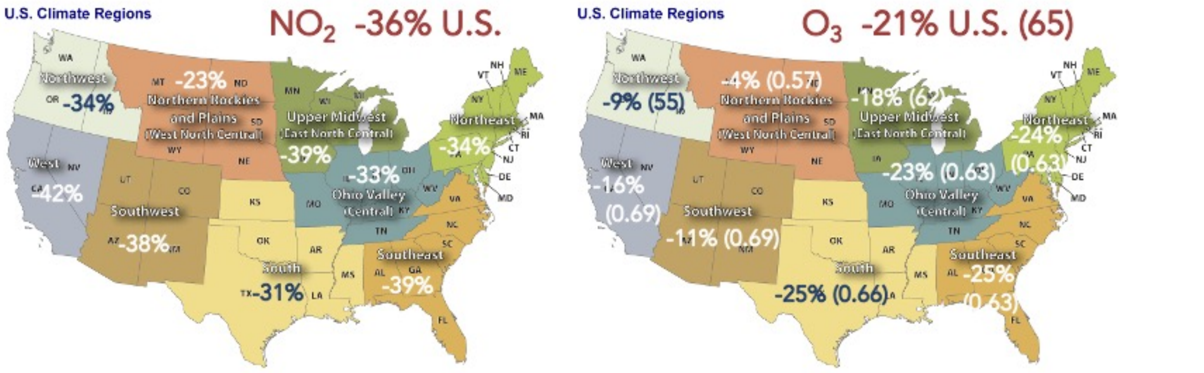
New York City on November 24th, 1966. *The New York Times*, Neal Boenzi

To address the issue, in 1963 the U.S. Congress passed the Clean Air Act, which established a nation wide air pollution control program

•In 1970, the National Environmental Policy Act established the U.S. Environmental Protection Agency (EPA) in order to implement the Clean Air Act.

•The Clean Air Act has been amended over the years in response to scientific research and human health impacts.

•Due to the Clean Air Act, tighter NOx and VOC controls in the U.S. have reduced surface ozone (O_3) in the U.S. by 21% since 2000 .

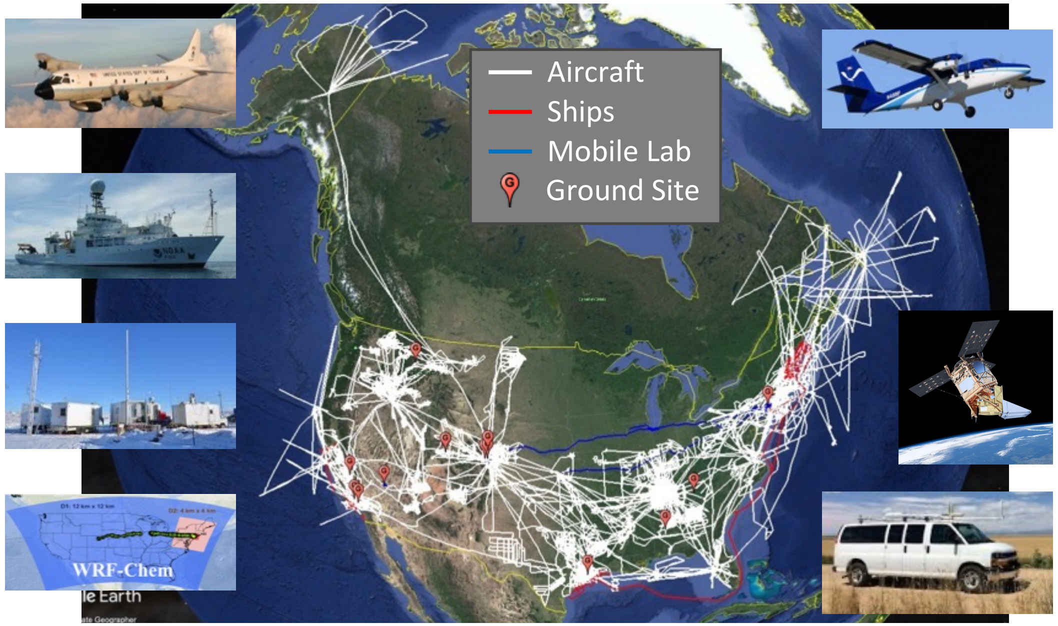


Regional percent decreases **2000-2019**. The numbers in parentheses show the 2019 4th highest MDA8 O_3

MDA8 = maximum daily 8 h average epa.gov/air-trends

U.S. Air Pollution Research: NOAA Chemical Sciences Laboratory

NOAA CSL air pollution research

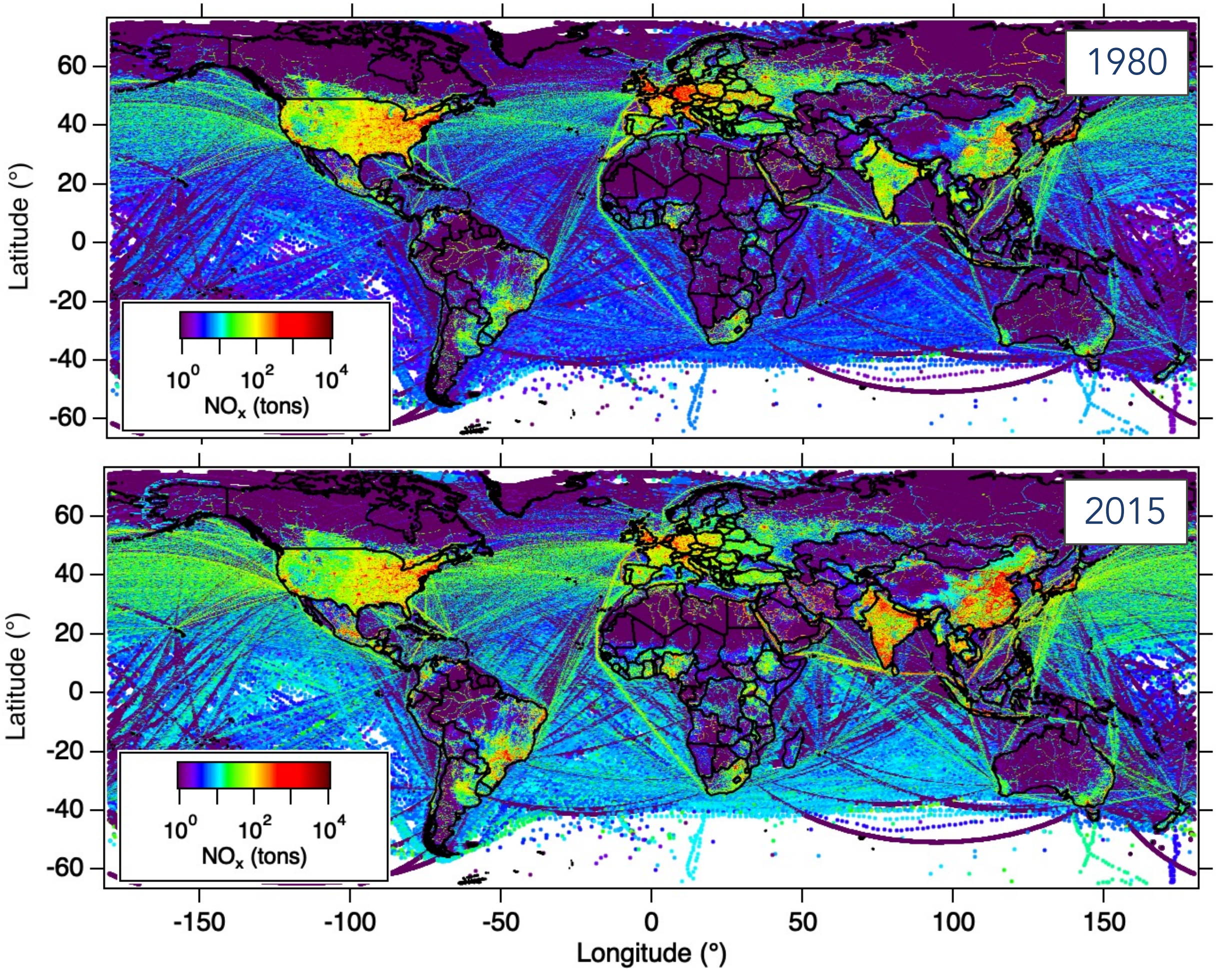


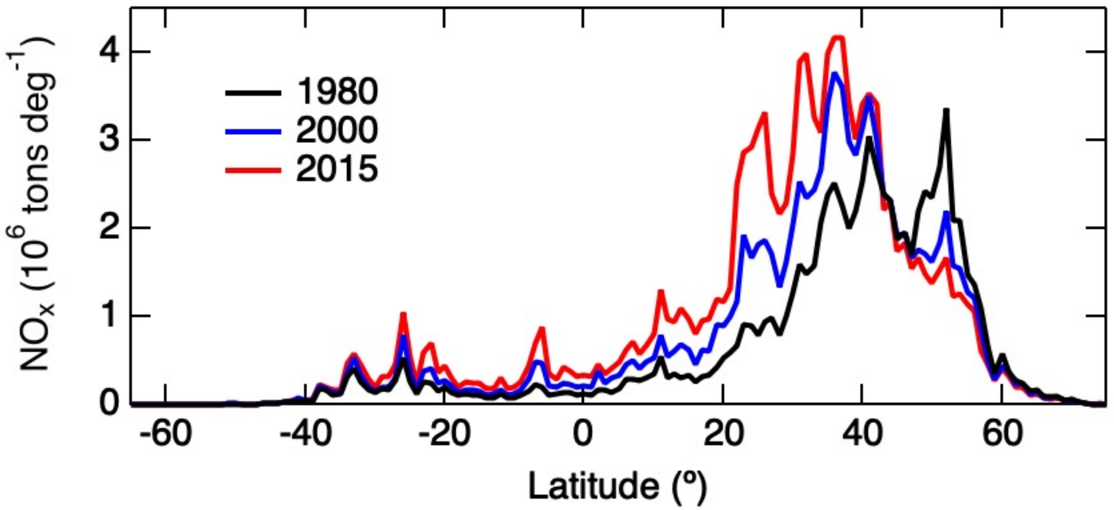
- AQ research requires sustained effort spanning decades & sampling locations multiple times
- Changes in policies, economy, measurement technology, natural events, climate change, etc.
- Field intensives bridge the gap between monitoring and models for process understanding

- Southern Oxidant Experiment (SOS), 1995 & 1999
- Texas Air Quality Study (TexAQS), 2000 & 2006
- New England Air Quality Study (NEAQS), 2002 & 2004
- California Research at the Nexus of Air Quality & Climate (CalNex), 2010
- Southeast Nexus (SENEX), 2013
- Las Vegas Ozone Study (LVOS), 2013 & 2017
- Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ), CA 2013 & CO 2014
- Wintertime Investigation of Transport, Emissions, and Reactivity (WINTER), 2015
- Shale Oil and Natural Gas Nexus (SONGNEX), 2015
- California Baseline Ozone Transport Study (CABOTS), 2016
- Utah Winter Fine Particulate Study (UWFPS), 2017
- New York Investigations of Consumer Emissions (NYICE), 2018
- Fire Influence on Regional to Global Environments and AQ (FIREX-AQ), 2019
- COVID Air Quality Study (COVID-AQS), 2020
- Southwest Urban NOx and VOC Experiment (SUNVEx), 2021
- Atmospheric Reactions and Emissions Observed from Megacities to Marine Areas (AEROMMA), 2023

Historical and Future Global Emissions Changes

Global NO_x Emissions

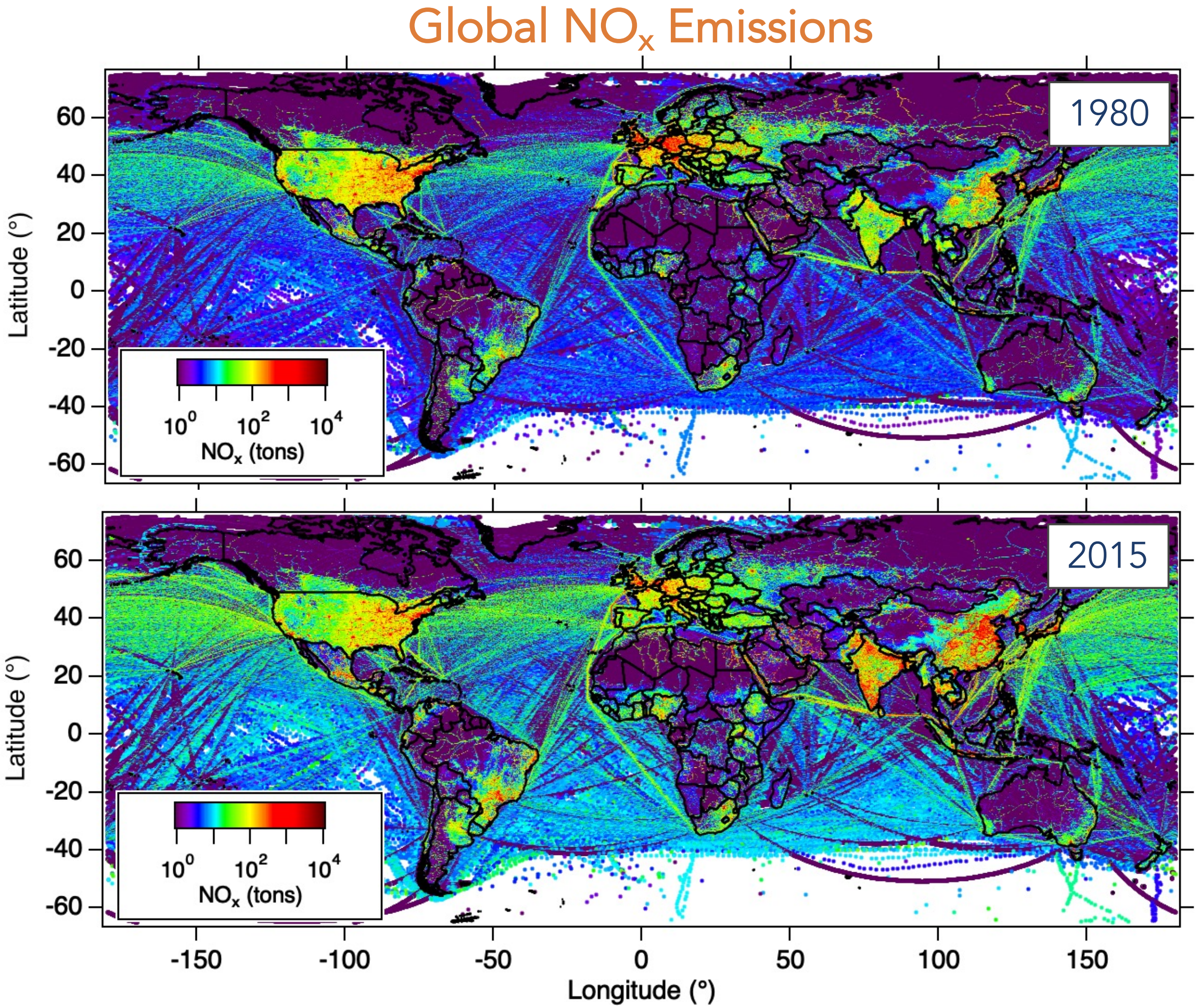


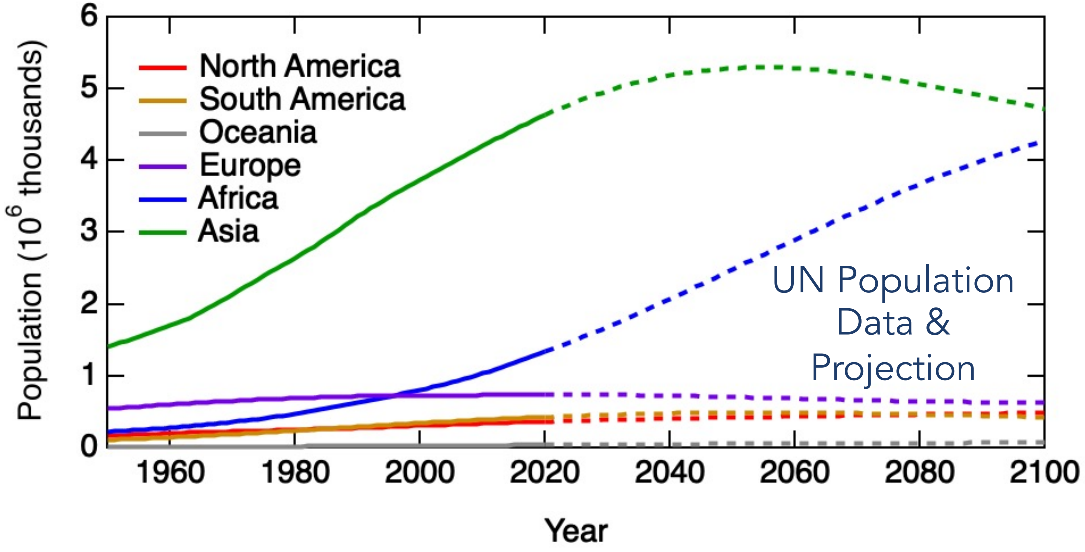


EDGAR Database: https://edgar.jrc.ec.europa.eu/index.php

- 82% increase in global NO_x emissions, 1970 – 2015
- Recent increases associated with global shift from North to South
- Zhang et al., Nature Geosci., 2016: Southward shift in emissions responsible for larger change in global O_3 burden than changes in total NO_x or total CH_4

Historical and Future Global Emissions Changes





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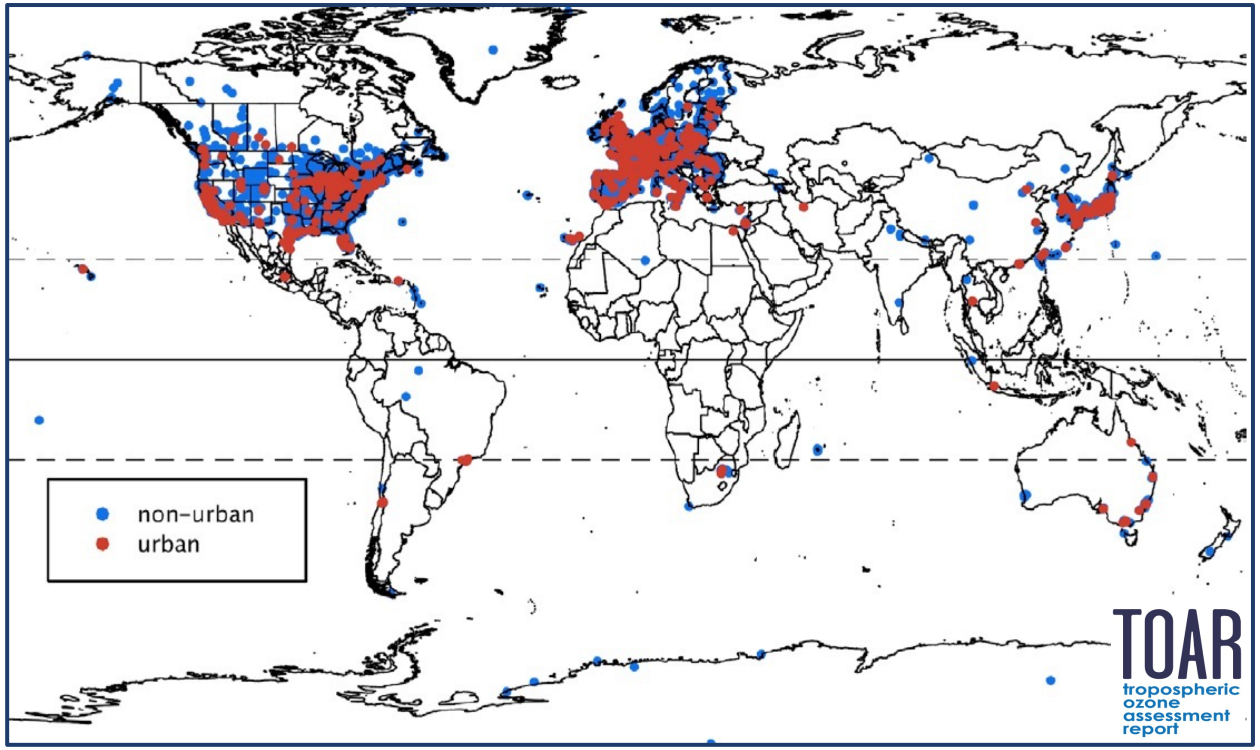
Acceleration of North to South emissions trend important for global atmospheric composition and air quality

Data Availability in East Africa

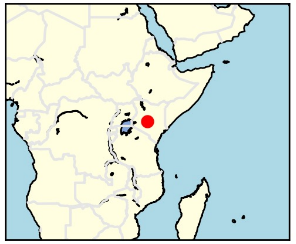
Tropospheric Ozone Assessment Report (TOAR)

- Fleming et al., Elementa (2018): TOAR sites through 2014 heavily concentrated in Europe and N. America, with fewer sites elsewhere (data from monitoring network in China more recently available, 2013-2019)
- Data availability in East Africa limited to non-existent
- GAW station at Mt. Kenya background site, 2002-2011, is the only record in the TOAR database



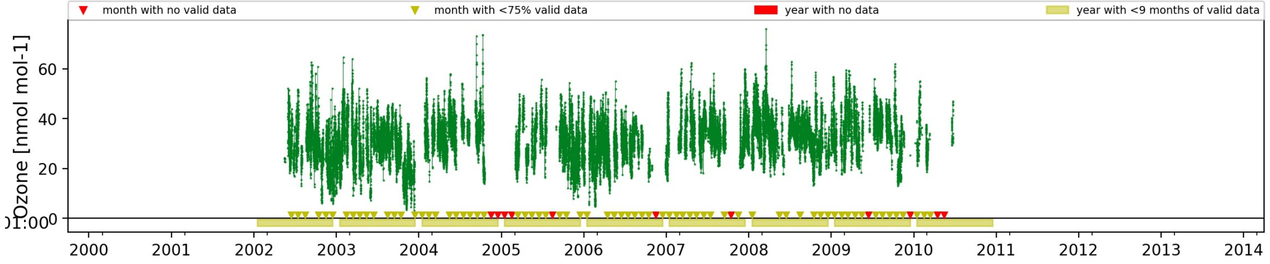
Lack of data for fastest growing region of the world represents a significant gap for emissions, processes, etc.

Lack of trend analysis represents an international environmental justice issue



station type:	background
station area type:	remote
station category:	Global
data from 17 May 2002 18:00 to 23 Jun 2010 (	
N years:	9
N years with > 75% data:	0
N hours:	31889

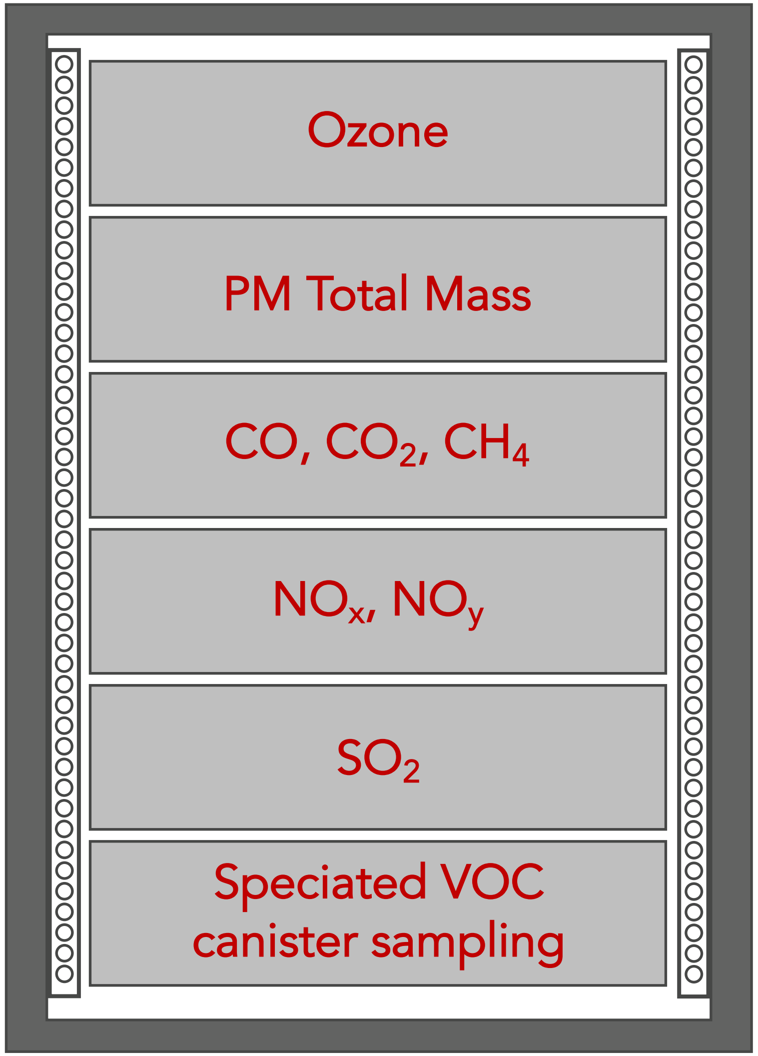
GAW Mt. Kenya(MKN100S00) O3
-0.06°N 37.30°E 3678 m



Proposed In-Situ Measurement Package(s)

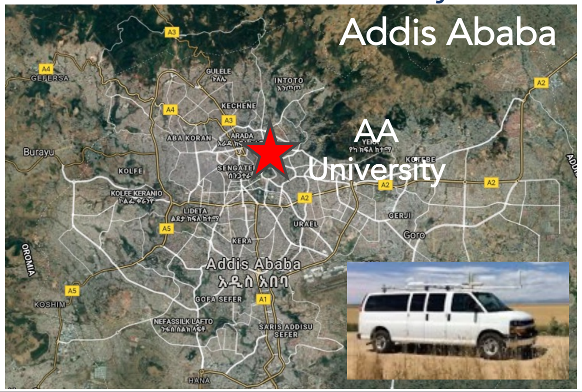
Tier 1: Single instrument rack, well calibrated standard monitoring data

- Ozone - monitoring grade, UV absorption
- PM total mass – Microbalance or optical counter (e.g., POPs)
- CO, CO_2, CH_4 – Commercial CRDS
- Nitrogen oxides – Chemiluminescence or CAPS, include NO_x and NO_y
  - Note issues with converters and careful calibrations !
- Sulfur dioxide – Commercial pulsed fluorescence
- Speciated VOCs – Canister sampling GC analysis locally or remotely
  - Sparsest data in global monitoring networks
  - Most difficult, but also most useful data in Tier 1
  - Canisters could be supported by international collaboration for analysis



Advantage: Flexible placement & timing – potential for collaboration between international & local investigators to calibrate, operate, archive and manage data, etc.

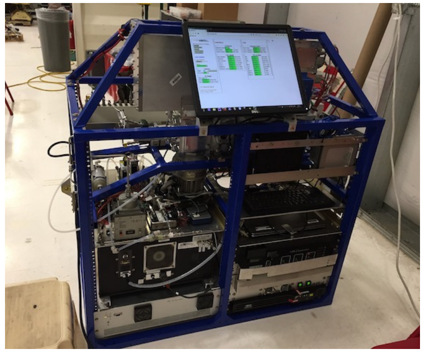
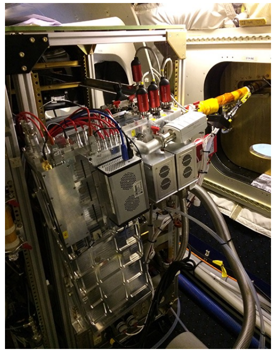
Disadvantage: Marginal advance beyond monitoring level data



Proposed In-Situ Measurement Package(s)

Tier 2: Speciated PM composition & Size, Speciated VOCs, Speciated Reactive Nitrogen, Atmospheric Radicals, Aerosol Optics

- High Resolution AMS or ACSM – Sulfate, nitrate, ammonium, organics (xOA)
- Aerosol Size Distributions – Nucleation, accumulation, coarse modes
- PTR ToF – High time resolution speciated VOCs
  - Canister sampling or equivalent still required
- Iodide ToF CIMS – Oxygenated VOCs, Speciated Nitrogen, Halogens
  - Enables day (e.g., PAN) / night chemistry (e.g. N_2O_5)
- Gas phase acids & bases - NH_3, HCl, HNO_3 - QCLS or CRDS
- Radical species – OH, HO_2, RO_2, Reactivity, NO_3 – FAGE, CRDS, etc.
- Black Carbon – SP2; Brown Carbon – CRDS, PAS, PiLS + UV

Advantage: Scientifically comprehensive approach to emissions & processes

Requirements: Dedicated field intensive & site - International and local measurement teams on location for fixed measurement period

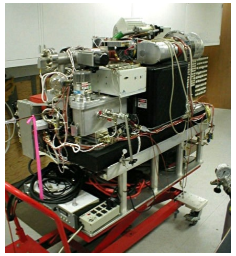

CalNex ground site, Pasadena, CA 2010


Instrument Tiers: Cost and Data Quality

Slide courtesy of Ru-Shan Gao

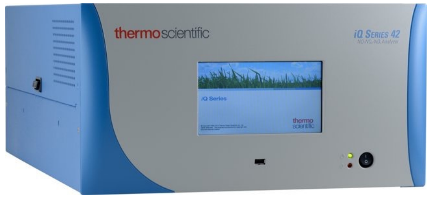
> $100 k

Research Grade: Much of Tier 2 from last slide. Requires operator, expertise, intensive data analysis; Often custom built or modified commercial; Provides the most science

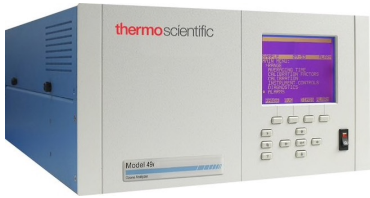



$10-50 k

Monitoring Grade: Much of Tier 1 from last slide. Operates unattended with periodic calibration; Basis for nationwide networks in U.S., Europe, China; Basic ***but reliable*** data



NO_x, NO_y



O_3

$1 k

1k Instruments: More reliable than low cost sensors, more affordable than commercial monitoring grade. Is this class of instruments achievable or useful?

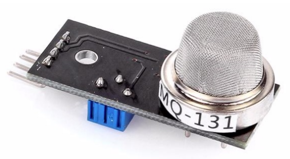
What goes in this box ?

Development in this class underway at NOAA CSL

$0.1 k

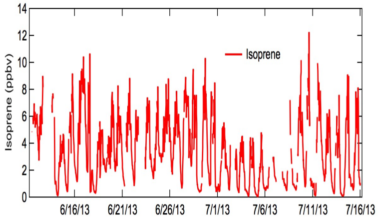
Low Cost Sensors: Proposed for regions outside of major global economies. Inexpensive, simple to operate. Data quality often poor (except for PM); measurement strategy based on large numbers of sensors

CO	**VOCs**	**O_3**	**$PM_{2.5}$**	**NO_2**



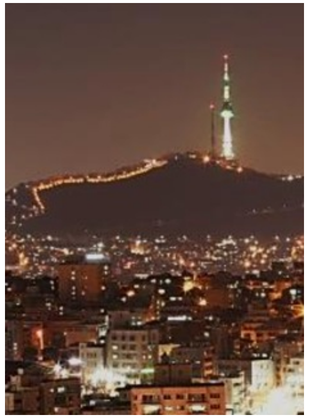
Sampling Strategies

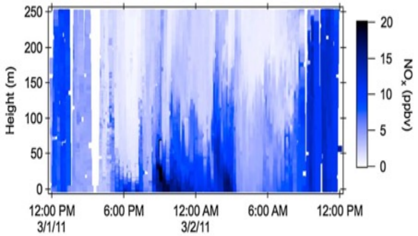
Ground Sites
Urban / Rural / Forested



Isoprene in a Southeastern U.S. Forest (Centreville, AL)

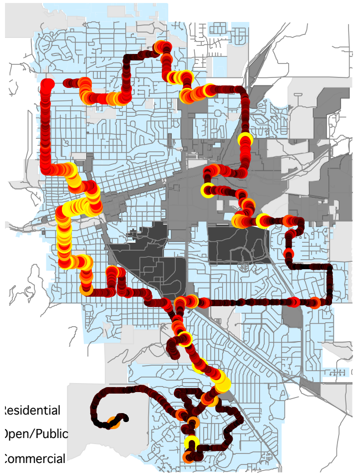
Tall Towers
Wide Footprint / Residual Layer





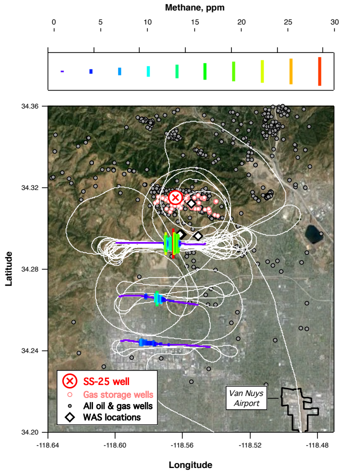
Vertical Distribution of NO_x from a tall tower (Weld County, CO)

Mobile lab
Local



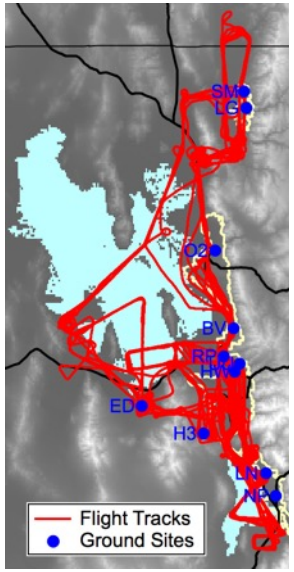
Drive track colored by mobile fleet emissions (Boulder, CO)

Light aircraft
Local



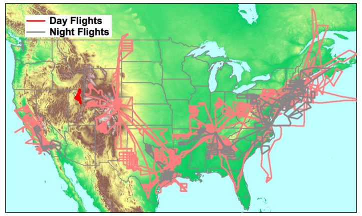
Flight track colored by *Aliso Canyon CH_4 emissions (Los Angeles, CA)*

Med. aircraft
Local – Regional



Wintertime air quality *(Salt Lake City, UT)*

Heavy aircraft
Regional - Contintental

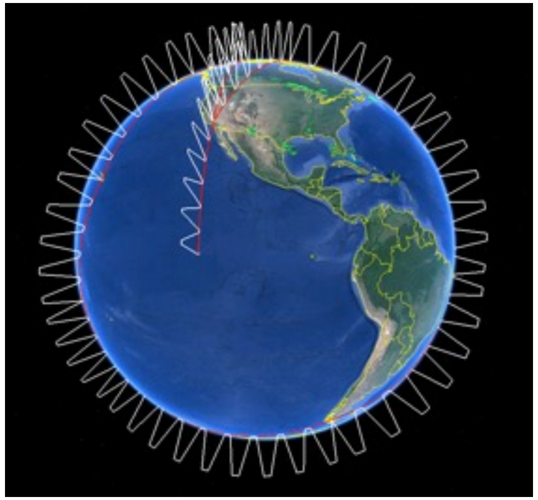


Regional to continental scale air quality studies

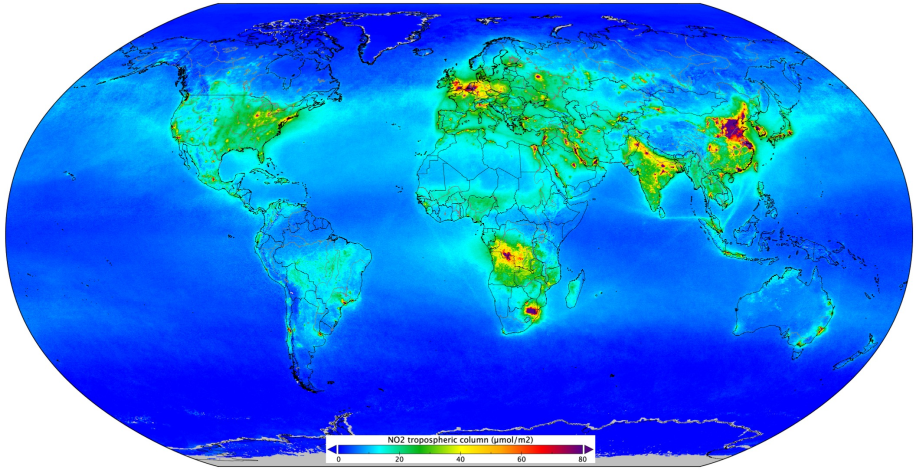
Increasing complexity & cost →

Connecting to the Wider Scale

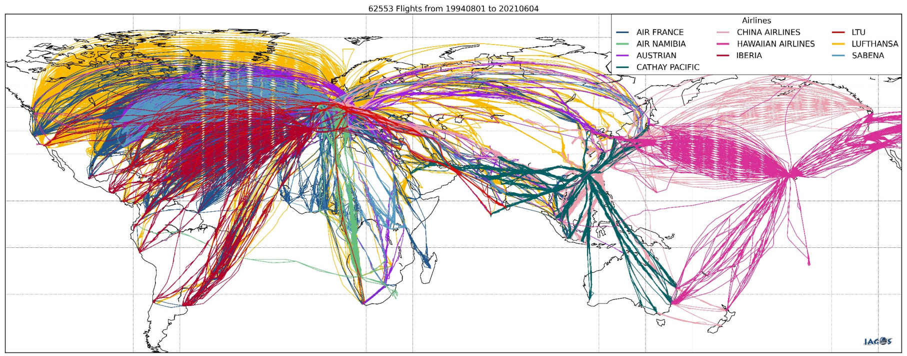
NASA ATom (Atmospheric Tomography)



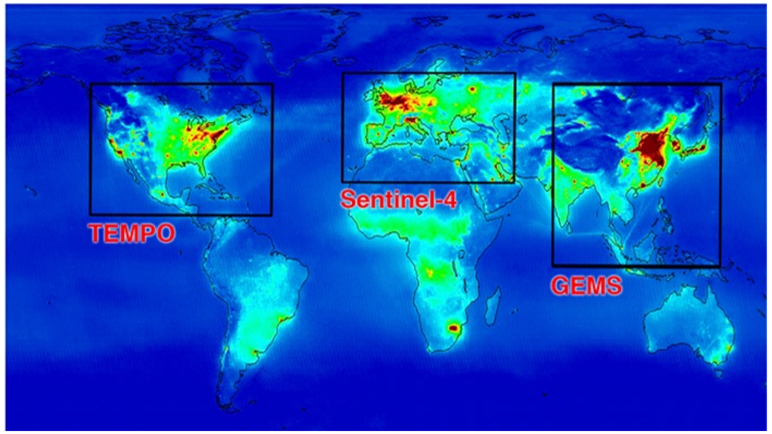
TropOMI Global Atmospheric Composition Maps



IAGOS / CARIBIC Commercial Aircraft



Geostationary Satellite Constellation



Any effort to fill data gap in East Africa will connect and contribute to global observing system

Partnerships & Stakeholders

Opportunity for partnerships between institutions in the U.S. and East Africa or other regions

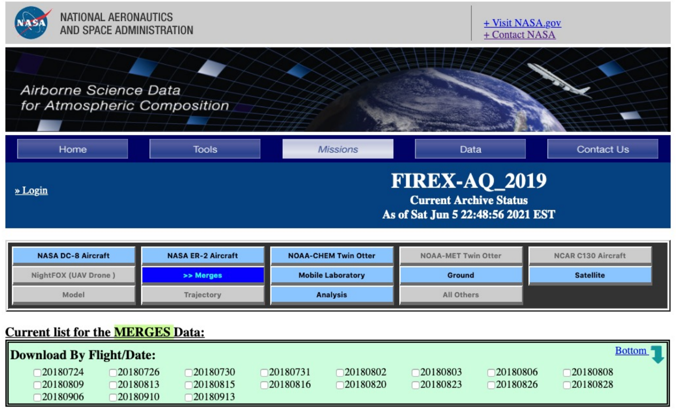
- Major U.S. laboratories & funding agencies represented at this workshop
- U.S. & African universities, including HBCUs
- IGAC, NGOs, other international organizations with interest in air quality, health, emissions, climate, etc.

Scientific exchange, training & student mentoring

Data sharing

- Addressing East African data gap important to all collaborators above
- Data quality control, sharing and archiving protocols an important part of collaborative process

Example screenshot for NASA data archive from 2019 FIREX-AQ project



Concluding Remarks

- Half a century of scientific research in the U.S. has underpinned policies leading to dramatic improvements in air quality.
- Africa represents a highly under-sampled and rapidly growing world region – atmospheric composition observations are urgently needed to understand regional, continental and global impacts and address international environmental justice.
- Observation strategies will depend on available resources and logistical support. Instruments at several scales of cost & complexity can be considered.
- Partnerships & the global observing network. Opportunities for interactions between African and North American air quality and atmospheric science communities.

Thanks !

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