Measurement strategies for understanding and forecasting air quality impacts of oxidised and reduced nitrogen pollutants: from “low-cost sensors” to ACTRIS/WMO-GAW grade fully traceable data

CF Braban

With content from colleagues at CEH including MM Twigg, YS Tang, E Nemitz, M A Sutton, Other contributors: NA Martin (NPL), Mat Heal (U. Of Edinburgh); SME partners: Ricardo EE and data providers

CEH Edinburgh, Bush Estate, Penicuik, Midlothian EH26 0QB
Air quality

Underpin science and policy with consistent measurement, integrated across scales
Measurement and QC Frameworks: e.g. NO₂

Global/WMO-GAW

European research infrastructure

European Long term monitoring

European compliance monitoring

National compliance monitoring (AURN)

Local authority compliance monitoring (LAQN)

Local authority and Agency AQ monitoring (other)

Citizen science

Photolytic analysers:
- direct spectroscopic measurement
- Correction for inlet errors etc.
- Part of international calibration/round robins
- ACTRIS protocol daily calibration with traceable standard
- expensive/implementation variable

On-line chemiluminescence analysers
- Method defined by European compliance protocols
- Part of national calibration
- expensive

Off-line diffusion tubes
- Gas captured on coating, analysed in laboratory
- Methods defined by Working Groups
- Can be part of national intercomparison and bias correction
- Affordable but low resolutions (weeks)

On-line electrochemical sensors
- Gas-surface interactions = Voltage change
- Field testing underway
- New working group being established
Measurement and QC Frameworks: e.g. PM

SMPS and research grade analysers:
- direct measurement
- Correction for inlet errors etc.
- Part of international calibration/round robins
- protocol with traceable standard
- expensive/implementation variable

TEOM/FIDAS analysers
- Type approved method defined by compliance protocols
- Part of national calibration
- expensive

High vol gravimetric
- PM captured on filter, weighed
- Methods defined by Working Groups
- bias correction for volatiles and composition of PM possible
- Affordable but lower resolution

“Low cost” PM analysers
- Use laboratory or local machine learned calibration for PM
- Field use increasing exponentially
- Dynamic range and effects of PM composition often ignored
- New working groups being established
<table>
<thead>
<tr>
<th>Technology</th>
<th>Type of deployment</th>
<th>Cost of measurement equipment+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffusion tube</td>
<td>deployed in triplicate, unskilled LSO used for changeover, £5 per sampler, triplicate, 4-weekly</td>
<td>£195</td>
</tr>
<tr>
<td>NOx Mb-chemiluminescence</td>
<td>AQ network; hourly data though higher resolution poss; mobile calibration doen servicing others</td>
<td>£10,000</td>
</tr>
<tr>
<td>NOx photolytic-chemiluminescence</td>
<td>ACTRIS, including automated calibration system, data QC by external partner paid by subscription; international calibration</td>
<td>£25,000</td>
</tr>
<tr>
<td>Electrochemical low cost sensor</td>
<td>local or personal deployment</td>
<td>~£40+ &quot;system&quot;</td>
</tr>
</tbody>
</table>
## Practicalities

<table>
<thead>
<tr>
<th>Technology</th>
<th>Set-up (days)</th>
<th>Cost using Field staff</th>
<th>Sample changing LSO</th>
<th>Field support LSO</th>
<th>Cost using Field staff</th>
<th>Consumable costs</th>
<th>Days for data handling</th>
<th>Cost using science staff</th>
<th>Data review senior scientist</th>
<th>Cost using senior scientist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffusion tube</td>
<td>0.50</td>
<td>£188</td>
<td>£300</td>
<td>n/a</td>
<td>n/a</td>
<td>0.25</td>
<td>115</td>
<td>0.20</td>
<td>115.00</td>
<td></td>
</tr>
<tr>
<td>NOx Mb-chemiluminescence</td>
<td>1</td>
<td>£375</td>
<td>n/a</td>
<td>1 day per month</td>
<td>£4,500</td>
<td>£500</td>
<td>6</td>
<td>2760</td>
<td>1</td>
<td>575</td>
</tr>
<tr>
<td>NOx photolytic-chemiluminescence</td>
<td>4</td>
<td>£1,500</td>
<td>n/a</td>
<td>0.5 days per month</td>
<td>£2,250.0</td>
<td>4000</td>
<td>15</td>
<td>6900</td>
<td>1</td>
<td>575</td>
</tr>
<tr>
<td>Electrochemical low cost sensor</td>
<td>0.50</td>
<td>£188</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>20</td>
<td>£9,200</td>
<td>5</td>
<td>2875</td>
</tr>
</tbody>
</table>

*using typical UK salary scale*
Low cost regime

<table>
<thead>
<tr>
<th>Technology</th>
<th>Data handling days pa</th>
<th>Data review senior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffusion tube</td>
<td>0.25</td>
<td>0.2</td>
</tr>
<tr>
<td>NOx Mb-chemiluminescence</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>NOx photolytic-chemiluminescence</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>Electrochemical low cost sensor</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>Electrochemical low cost sensor</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>Electrochemical low cost sensor</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Electrochemical low cost sensor</td>
<td>0.25</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Replace low cost sensor with Miniature automatic as more accurately reflects the new technologies.
Identifying state and Impacts: oxidised N deposition/emission

<table>
<thead>
<tr>
<th>Atmospheric components</th>
<th>Surface processes</th>
<th>Surface sink</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO₂</td>
<td>HONO + HC or NO₂</td>
<td>Plants, soils, microbes, groundwater etc.</td>
</tr>
<tr>
<td>NO₂</td>
<td>NO₂⁺ → HONO</td>
<td></td>
</tr>
<tr>
<td>NO₂⁺ → HONO</td>
<td>HONO</td>
<td></td>
</tr>
<tr>
<td>HONO</td>
<td>HONO</td>
<td></td>
</tr>
<tr>
<td>HONO</td>
<td>NO₃⁻</td>
<td></td>
</tr>
<tr>
<td>HNO₃</td>
<td>HONO → NO₂⁻</td>
<td></td>
</tr>
</tbody>
</table>

HC or HCₐx or HNO₃

hv + H₂O
Urban nested approaches: NO$_2$ example

Bristol

LAQM

AURN

https://laqm.defra.gov.uk/
- FUNDED & managed locally
- QA supported centrally

Quality assurance provides confidence in data


2 urban supersites in the UK currently, due possibly to increase

Managed and funded by national Government

QA supported centrally

NERC SCIENCE OF THE ENVIRONMENT

Centre for Ecology & Hydrology
NATIONAL ENVIRONMENT RESEARCH COUNCIL
NH₃ concentration (µg m⁻³)

NH₄⁺ concentration (µg m⁻³)

Note: Agricultural sector assigned to activity which occurs in >45% of area of sampler. If none >45%, assigned “mixed”
EMEP, WMO-GAW & ACTRIS sites:

- UK supersites under the European Monitoring and Evaluation programme (Level II/III)
  - concentrations, surface/atmosphere exchange fluxes of trace gases and aerosols
  - contribute to all Defra AQ networks.

- Scotland’s Auchencorth Moss is a Regional Station within the World Meteorological Organisation Global Atmosphere Watch programme (WMO-GAW) and is also in ICOS and ACTRIS networks.
For air quality understanding: not just the surface is important!

Nested EMEP model can be run locally at high resolution
But also regionally/globally separating long-range transport and regional emissions

12:00 on the 30th March 2014

12:00 on the 4th April 2014

Yellow Saharan dust (>1 µg m⁻³)
Green Nitrate PM (>1 µg m⁻³)

Vieno et al. 2016, ACP
Getting data used... national and regional level strategy helps apply data to multiple uses

- **UKEAP monitoring measurements**
- **Modelling and mapping pollutant concentrations and deposition**
- **Critical Loads and exceedence mapping**
- **Databases**
  - EMEP
  - WMO-GAW
  - UK-Air
- **EU compliance modelling (PCM)**
- **Secondary Inorganic Aerosol**
- **National and international assessments atmospheric pollution and deposition to the environment e.g. RoTaP, UNECE**
- **Air pollution information service APIS**
  - [http://www.apis.ac.uk/](http://www.apis.ac.uk/)
- **Local Environmental Impact Assessments and planning**
- **Screening tools e.g. SCAIL**
  - [http://www.scaill.ceh.ac.uk/](http://www.scaill.ceh.ac.uk/)
- **Public access to data**

**MODEL COMPARISON and VERIFICATION**
Measurements need to be fit for purpose(s):

- air quality (human health impacts),
- ecosystem impacts
- climate impacts
- personal exposure

Evidence for an equable atmosphere; measurement data good enough to be useful for verification/validation of models

provide evidence required to assess status for impact relevant to location and region
Current situation...future pilots and networks in Africa?

- fixed calibrated station approach broadly works where installed, **necessary for other types of measurement validation**
- **Regional** deposition network
- We know lots of measurement gaps (chemical, spatial, temporal, fluxes)
- spatial resolution of pollutant concentration measurements
- there is little systematic personal exposure assessment with measurements
- Hot spot strategies for emission or exposure to identification and reduce problems
- **Cost effective, locally/nationally relevant** quality assurance is key to successful roll-out of AQ for Africa strategy
- Air quality modelling can inform locally and regionally where to measure and possible target
- Local knowledge essential for all monitoring and research measurements

Pilot projects could bring together community stakeholders
Identify priority areas
Agree data access and QA levels
Couple the process across the measurement levels
Pilot study in Nairobi (PI: Marsailidh Twigg)

Taking forward the United Nations Environment Assembly (UNEA) resolution: Pilot to determine air quality drivers for Sub-Saharan Africa (AQDNairobi)

• Linking citizen science using passive samplers and miniature automated (MA) PM measurements in Informal Settlements

• Establishing long term trace gas and PM composition background measurements

Map of sites in Nairobi
The future

• Note: no country in the world has got this right yet…

• Identify where different measurement paradigms can be supported so that AQ measurements become cost effective and locally relevant *whilst* being useful for model verification.

• NRT vs off-line analysis: where both can work together.

• Use expertise to collaborate to find solutions