FIELD CAMPAIGNS AND AIR QUALITY MONITORING

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WASCAL Course 608 – Part 1
TALK OUTLINE

- Science & Species: Air Quality Basics
  - Key Species
  - Scientific Issues that motivate campaigns

- Monitoring from Space
  - NO₂ – Decadal changes, environmental “success tale”
  - Ozone – Challenge and Status in tropical troposphere
  - HCHO - see Prof Marais’ Talk

- AQ Data & Field Campaigns
  - Example of AQ and SHADOZ in urban area (So. Africa)
KEY SPECIES IN “SMOG” OZONE FORMATION. NO₂ IS USUALLY LIMITING “PRECURSOR”

Note important **Natural and Anthropogenic** Nox / HC/ CO Sources

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SCIENTIFIC ISSUES RELATING TO AIR QUALITY

- **Monitoring**: continuous high-quality measurements of “criterion” pollutants: NO$_x$, O$_3$, CO, PM$_{2.5}$, SO$_2$, PM$_{10}$

- Scientific processes and mechanisms – particle formation, interactions with clouds, precipitation, deposition. **Study in Field Campaigns & Lab**

- Complexity of sources – natural, anthropogenic. Good models require accurate knowledge of global distribution. **Satellites** play role, LULC, fires, smoke, etc
SATELLITE TRACE GAS MONITORING: EXAMPLES

- Trace gas, aerosol monitoring from satellite advancing rapidly, still has limitations. Instruments do not measure “nose-level” pollutants.
- Global OMI NO$_2$ – Decade-plus (2004-) success story (Duncan et al., 2016)
- Tropospheric Ozone Products – Emerging, challenges.
  Illustrate with examples. Describe validation: Pandora, SHADOZ

CI = Cool Idea
SATELLITE NO$_2$ (AURA/OMI) IS PROXY FOR O$_3$ POLLUTION

- Strongest NO$_2$ sources in north hemisphere industrialized areas
- Other NO$_2$ sources include lightning, biomass burning (natural & human causes), wet soils. *(Not seen at this scale)*

- Regions & Cities studied in “NO$_2$ Change Paper, 2005-2014”
  Duncan, Lamsal, Thompson et al. *(JGR, 121, doi:10.1002/2015JD024121, Jan. 2016)*
Ten years, 2005-> 2014, Europe & North America mostly “cleaner,” Asia increased most
THREE REGIONAL EXAMPLES

http://airquality.gsfc.nasa.gov
1> All major US cities NO$_2$ decline, 20-40%, 2005-2014. Oil & gas regions are only NO$_2$ increases.

Figure courtesy of B. Duncan
OMI NO$_2$ Columns Compared to EPA Surface Monitors in Houston, Texas

Houston, Texas

Aura OMI  EPA AQS

Time

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South Africa: A More Complex Source Region

Industry

Mining: Coal, platinum, gold, etc.

Metallurgy

Electricity Generation

Chemical Production

NO₂ Changes (molec/cm²): 2005-2014
3> East Asia: NO$_2$ Changes (2005-2014). Cities Improve, Rural Worse

PEARL RIVER DELTA
1 Guangzhou (-44%)
2 Dongguan (-46%)
3 Shenzhen (-42%)
4 Hong Kong (-28%)

YANGTZE RIVER DELTA
1 Shanghai (-30%)
2 Suzhou (11%)
3 Nanjing (15%)
4 Hangzhou (NS)

Japan
1 Tokyo (-38%)
2 Nagoya (-43%)
3 Osaka (-39%)
4 Fukuoka (-26%)
5 Nagasaki (NS)

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Duncan et al., JGR, 2016
Monthly maps of column O$_3$ amounts useful in tropics for studying interannual variability but different products diverge widely (TOAR Assessment to evaluate. Stay tuned)

Positive trends reported over past 10-15 years (West et al, *Nature-Geoscience*, 2016) but Neu et al disagree

Ozonesondes in tropics are limited to SHADOZ ([http://tropo.gsfc.nasa.gov/shadoz](http://tropo.gsfc.nasa.gov/shadoz)). Vital for satellite validation. 19-yr data record is available for study of climatology and interannual variability.

“Paradoxical” South African trends from Balashov et al. (2014) & Thompson et al. (2014)
Integrated Ozone Observations. Ozonesonde at Left

Measure Model Predict

- Satellites with ground-based (eg Dobson) instruments for total column
- Profile validation - partial columns (lidar, aircraft); only sondes measure surface to 5-10 hPa (35 km) with 50-100 m vertical resolution
TROPOSPHERIC OZONE SATELLITE PRODUCTS: CHALLENGE OF MANY SENSORS & IMPRECISE DATA

- TOAR highlights Y. Zhang et al. (Nature Geosci., 2016), suggesting large tropo. O$_3$ trends as emissions shift equatorward. Used MOZAIC-IAGOS data, OMI/MLS, Hanoi SHADOZ sondes

- TES-IASI tropo. ozone shows significant post-2010 decline in northern hemisphere

- Other products (& models!) show divergent trends (Upper)


Figure 4.3.1.1 Time series of TCO (DU) per latitude bands (60N-60S, 0-60N, 0-60S, 0-30N, 0-30S) with TOST (top right), OMI/MLS (top left), OMI (bottom right), SCIAMACHY (bottom left). TOAR draft figure, do not cite

Thompson et al., 2012
Combined TES/IASI 700-300 hPa O$_3$
[Oetjen et al., ACP, 2016]
OMI-MLS TRENDS (OWEN COOPER ET AL.). IGAC/TOAR REPORT, 2017

2005-2015 (JJA)

White dots indicate statistically significant trend


CAVEAT! SONDES DISPLAY NO O$_3$ INCREASES IN CANADA

2008-2013 (JJA)

To match IASI record

*In Wespes et al., ACP, 2016.*
“Tropospheric ozone satellite” Products, mostly TOMS or OMI-based, are not ideal but may be usable for exploratory studies.

https://acd-ext.gsfc.nasa.gov/Data_services/cloud_slice/

Monthly maps, some software for Trends analysis

DATA: OMI/MLS tropospheric ozone (original product)
DATA: GMAO assimilated OMI/MLS tropospheric ozone profile product
MOVIES: Global tropospheric ozone movies from OMI/MLS showing the large year-round wave-one pattern in the tropics (maximum in the Atlantic), NH extra-tropical maximum around June-August (including the Mediterranean "crossroads" peak region) and SH extra-tropical maximum around September-November
EXAMPLE OF TROPICAL SONDE DATA IN SHADOZ (SO. HEMISPHERE ADDITIONAL OZONE SONDES, HTTP://TROPO.GSFC.NASA.GOV)

- Who, what, where, how of SHADOZ. Sample profile: Right
- Example of trends study and ground-based AQ data from southern Africa. Balashov et al, 2014; Thompson et al, 2014
WHY, WHERE, HOW: SHADOZ START IN 1998. 2017: > 7000 PROFILES

- “Strategic” ozonesonde network coordinates launches in space & time for specific scientific purposes
- Satellite Requirements: Validate O$_3$ profiles from TOMS/ UARS/SBUV (90s), ENVISAT, Aura, NPP, MetOp (2000->)
- Scientific Needs: Where does total ozone wave-one originate – in stratosphere or troposphere? => Requires zonal coverage of stations. PRACTICAL CONSTRAINTS
  - Operational – host supplies ground stations, launch gas, personnel
  - NASA, NOAA supply *some* sondes – ALL data archived @ GSFC
  - Data distribution: open, timely, user-friendly format
  - Leveraging resources has led to sustained network success
EXAMPLE OF SONDE & AQ DATA FOR TRENDS STUDY: SOUTHERN AFRICAN FREE TROP & SURFACE OZONE. FIND A “PARADOX”**

- Ozone profiles over SA Highveld from sondes (1990-2007; Clain et al., 2009) published, but with sampling artifacts and inadequate trends.

- Continuous surface ozone and NO\textsubscript{x} record in “power plant” region of SA Highveld since 1990 not previously examined for interannual variability and trends.

- “Paradox” means - Large ozone trends over southern African region, but not at SA Highveld monitoring sites.

- Reconcile by looking more closely at isolated satellite NO\textsubscript{2} “hot spot” in So. African Highveld, highest NO\textsubscript{2} in Africa and SH.

** Based on two papers: Balashov et al, *JGR*, 2014; Thompson et al., *ACP*, 2014. See also Clain et al., 2009; J. Liu et al., 2015.

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METEOROLOGICAL & CHEMICAL INFLUENCES ON OZONE POLLUTION (LEFT). SA HIGHVELD MONITORING SITES (RIGHT)

Balashov et al., 2014

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MONTHLY MEAN SURFACE OZONE (UPPER) AND NO$_x$ / NO$_x$ ANOMALY (LOWER) FROM 5 STATIONS IN SA HIGHVELD “POWER PLANT” REGION – LITTLE OR NO TREND!

Ozone (above) shows strong ENSO but no trends, 1990-2007. Ozone & NO$_x$ levels are moderate.

Balashov et al., *JGR*, 2014
SA SHADOZ – MOZAIC PROFILE DATA (UPPER)
RÉUNION PRE- AND SHADOZ SONDES (LOWER)

SA Record, 1990-2007
Monthly Means, 4-11 km
Trends at 100-m resolution, with running 3-mo. averages

Reunion record, 1992-2011
Monthly Means, 4-15 km
Trends analysis, 100-m resolution, Running 3-month averages
SA TREND (1990-2007): FREE TROPOSPHERIC OZONE FROM IRENE SHADOZ/MOZAIC JHB

- Hatched regions only statistically significant. Based on monthly means & 100-m vertical resolution
- At 4-5 km, (upper) possible trend artifact (changing launch time)
- In 6-11 km layer + (20-30%)/decade O₃ JJA increase! No Sept-Oct biomass fire season trend!
- Causes? Emissions changes hard to track. Long-range Transport: back-trajectories* (lower) reveal concentrated ozone origins from South America where mega-cities growing in emissions ?%/decade

Thompson et al., 2014

*May-Aug sonde launch dates
Many trace species, gases & particles, are monitored by satellite, eg. NO$_2$ “trends and changes”
- Only space view tracks global change, intercontinental transport
- Limitations in remote sensing of “nose level” pollution necessitate surface and ground-based monitoring

Satellite products for boundary-layer ozone, a key component of AQ as well as a greenhouse gas (GHG), are many & evolving, possibly contradictory, due to different techniques used and sampling strengths
- Need more ground-based data of high quality & known uncertainty. *A research opportunity!*
- Stay tuned!
LOOKING AHEAD!! ACKNOWLEDGMENTS

- What are the BIG questions about pollution in West Africa?
- How does atmospheric composition over West Africa connect to changes in land-use, biosphere, water cycle & climate?

- Thanks: NASA, NOAA. WASCAL!!!!
- B. N. Duncan et al: “Satellite data of atmospheric pollution…” dx.doi.org/10.1016/j.atmosenv2014.05.061
RÉUNION TREND (1992-2011): LARGER WINTER TREND THAN SA. ALSO NO BIOMASS FIRE SEASON TREND.

- Hatched trends significant. More than 35%/decade \( \text{O}_3 \) increase, 8-13 km (left) in winter; lesser trend in summer, Dec-Jan. As for SA no Sept-Oct trend.

- Back-trajectories (5-day, GSFC model) point to mixture of South American, African/Madagascar, and South Asian sources (right). Sources more northerly than SA sources.

- Note: Are increases observed from space? Seen in models?