Satellite Air Quality Remote Sensing in South Africa

Theo Fischer
Satellite Air Quality Remote Sensing Consortium (CSIR Satellite Application Centre & Environmental Science Associates)
Satellite based air quality management in South Africa status quo:

- No formal satellite based air quality monitoring system
- Periodic involvement in international initiatives
- Sporadic academic interest
- Long medium and short term initiatives
The air quality management is
• concerned with the environmental protection/ environmental justice and
• key to balancing economical development and the health of communities:
  • Air quality monitoring (local, national, regional and trans-boundary)
  • Community health protection
  • Environmental compliance monitoring and law enforcement
  • Research and development
  • (or lack/ need for initiatives for the above in South Africa’s case)
South African Air Pollution Issues = Global Issues

- Greenhouse Gases
- Ozone Layer Impacts
- Aerosols
- Precipitation Effects
- Environmental Management & Enforcement

GLOBAL: climate change
REGIONAL: acid rain, tropospheric ozone, aerosols, greenhouse gases
LOCAL: air pollution health effects
Global Considerations: Green house gasses

Hot topic
Global Considerations: Green house gasses
Hot topic
Global Considerations: Green house gasses
Hot topic

New improved formula
SUPER SMOKE PLUS
General-purpose germination stimulant

CAPE SEED PRIMER

FOR BETTER RESULTS WHEN GERMINATING SEEDS
Particularly recommended for treating seeds of proteas, leucospermums (pincushions), leucadendrons, ericas (heaths), helichrysums (everlastings), restios (Cape grasses), lobelias, grasses, sedges, mesembs (vygies), streitziias (crane flowers) and many other species
Global Considerations: Green house gasses

Hot topic

### Global Considerations: Greenhouse Gasses

**THE TOP 20 CARBON DIOXIDE EMITTERS**

<table>
<thead>
<tr>
<th>Country</th>
<th>Total emissions (1000 tons of C)</th>
<th>Per capita emissions (tons/capita)</th>
<th>Per capita emissions (rank)</th>
<th>Growth (in %, 1990-96)</th>
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<tr>
<td>United States</td>
<td>1446777</td>
<td>5.37</td>
<td>(1)</td>
<td>(9.9)</td>
</tr>
<tr>
<td>Peoples Rep. of China</td>
<td>917997</td>
<td>0.76</td>
<td>(18)</td>
<td>40.0</td>
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<tr>
<td>Russia Federation</td>
<td>431090</td>
<td>2.91</td>
<td>(6)</td>
<td>-19.2 (since 1992)</td>
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<td>South Korea</td>
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<td>(11)</td>
<td>69.2</td>
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<td>(13)</td>
<td>1.1</td>
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<tr>
<td>Ukraine</td>
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<td>2.10</td>
<td>(12)</td>
<td>-37.0 (since 1992)</td>
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<td>(15)</td>
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<td>(10)</td>
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<td>(3)</td>
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<td>1.04</td>
<td>(16)</td>
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<td>North Korea</td>
<td>69412</td>
<td>3.09</td>
<td>(5)</td>
<td>4.0</td>
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</table>
Global Considerations: CO2

Global Considerations: NO2
Regional Considerations: Smoke & Aerosols

Coast of Mozambique – Zambezi River delta, Smoke from veldt fires blowing in on-shore winds.

Handheld photograph taken from an early Space Shuttle
Regional Considerations: Aerosols
Safari 2000
Regional Considerations: Aerosols
Safari 2000
Regional Considerations: Aerosol

NASA Ames Airborne Tracking
14-Channel Sunphotometer (AATS-14)
- Aerosol Optical Deph/Extinction (354-1558 nm, 12 wavelengths)
- Water Vapor Column/Density
- 24 data flights on CV-580

NASA Ames
Spectral Solar Flux Radiometer (SSFR)
- Up and downwelling flux
- 300-1700 nm, Resolution 8-12 nm, 1Hz
- On CV-580, ER-2 and Skukuza ground-site
Regional Considerations
Safari 2000

JRB Instruments
- FSSP100
- PCASP-100
- SPP-100
- CN TSI
- CCNC 100A
- O3, CO, SO2
- ABS
- Nephelometer
- JRB flew 28 data flights between August 15 and September 24 in 2000

JRA Instruments
- FSSP100
- PCASP 100
- O3, NO, CO, CN, SO2
- Nephelometer TSI-3563
- Trace cannisters
- VOC cannisters
- JRA flew 39 data flights between August 15 and September 24 in 2000

Precipitation

Aerocommander 690

Aerosols
Regional Considerations: Aerosol
Safari 2000
Regional Considerations: Aerosol Safari 2000

SAFARI-2000 Test bed: Aerosol retrieval from satellites

Ozone Column, Absorbing Aerosol Index, Aerosol Optical Depth (380 nm), Single Scatter Albedo (380 nm)

Aerosol Optical Depth over water and land (0.557 mm), aerosol type

MODIS
Moderate-resolution Imaging Spectroradiometer

• over water (AOD at 6 wavelengths +1 extrapolated, some size characteristics)
• over land (AOD at 2 wavelengths + 1 interpolated)
AOD Validation with AATS-14

MODIS
Moderate-resolution Imaging Spectroradiometer

- Schmid et al 2003. Coordinated airborne, spaceborne, and ground-based measurements of massive thick aerosol layers during the dry season in southern Africa
MODIS over water (AOD at 6 wavelengths +1 extrapolated, some size characteristics)

Schmid et al 2003. Coordinated airborne, spaceborne, and ground-based measurements of massive thick aerosol layers during the dry season in southern Africa
MODIS over land (AOD at 2 wavelengths + 1 interpolated)

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Schmid et al. 2003. Coordinated airborne, spaceborne, and ground-based measurements of massive thick aerosol layers during the dry season in southern Africa.
MISR AOD over land (4 wavelengths), aerosol type

- Schmid et al 2003. Coordinated airborne, spaceborne, and ground-based measurements of massive thick aerosol layers during the dry season in southern Africa
Regional Considerations: Aerosol

Safari 2000

ACTIVE FIRES AND FIRE SCAR DETECTION
Comparison of MISR (700 km) & Air MISR (20 km altitude) Timbavati Prescribed Fire, 20 Sep 2000
Regional Considerations: Aerosol transport

Safari 2000

Effects of regional veld fires (tropical regions of Zambia and Angola) on air quality over South Africa.

Smoke and haze exiting off east coast September 4 2000

Provided by the SeaWiFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE
Satellite: OrbView-2 Sensor: SeaWiFS
Image Date: 09-04-2000
Image captured by CSIR Satellite Application Centre

Scot Kneen & Annegarn October 2005
Regional Considerations: Smoke transport
Safari 2000

Inter-continental transport routes
8-day transport originating in Kruger National Park, 8 Sep 2000
Regional Considerations: Smoke transport

Fires and smoke over central Mozambique
28 Sep 2005
Courtesy NASA, MODIS
Regional Considerations: Dust transport

“Desert Storm” (African version)
Wind-blown dust as a large scale aerosol source in southern Africa.
Namibia, June 6, 2000

SeaWiFS, NASA Goddard Space Flight Center, and ORBIMAGE.
The Sea-viewing Wide field-of-view Sensor (SeaWiFS)

Scot Kneen & Annegarn October 2005
Regional Considerations: Dust transport

Distribution of areas with high dust-storm activity and major dust trajectories. (Modified after Coudé-Gaussen (1984).)

Source: Pye, Aeolian Dust
Regional Considerations: Dust transport

RS image of Saharan dust storm off north west Africa, September 2005

Courtesy NASA, MODIS

Scot Kneen & Amegnarn October 2005
Local Considerations:
Coal burning for cooking and warming

What is the nature of the white smoke?
Local Considerations:
Coal burning for cooking and warming

Typical combustion aerosol from low temperature coal combustion – condensed VOCs
Local Considerations: Dust from mine dumps
Local Considerations: Dust from mine dumps

Mineral particle

5 µm
Local Considerations: Dust from mine dumps
Regional Considerations: Precipitation

**MEAN ANNUAL PRECIPITATION (mm)**
After Dent, Lynch & Schulze (1989)

**MEDIAN RAINFALL (mm) JANUARY**
Regional Considerations: Precipitation

Cloud and precipitation process studies using instrumented aircraft and meteorological radars

- **Natural cumulus clouds** in region shown to be mostly inefficient in producing water particles of raindrop size
- **Realisation that inadvertent cloud modification over a paper mill** provided the clue to possible intervention to enhance raindrop formation and increase the efficiency of the rainfall process.
Regional Considerations: Precipitation

**Cloud and precipitation process studies** using instrumented aircraft and meteorological radars

- Paper mill pollution precipitated a **switch in research focus** from glaciogenic to hygroscopic seeding during the first year of NPRP-SAREP.

- **Cloud physics studies**, using both instrumented aircraft and radar, revealed consistent differences in behaviour and properties of natural and hygroscopically seeded clouds.
Regional Considerations: Precipitation

Precipitation

JRB Instruments
- FSSP100
- PCASP-100
- SPP-100
- CN TSI
- CCNC 100A
- O3, CO, SO2
- ABS
- Nephelometer

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Aerocommander 690

South African National Precipitation Research and Rainfall Enhancement Programme (NPRP-SAREP) 1990 - 2000
Regional Considerations: Precipitation

SA Hygroscopic seeding methodology

- Hygroscopic seeding methodology based on pyrotechnic flares designed and locally manufactured to produce appropriately sized hygroscopic particles upon being fired.
- Aircraft flares enables the seeding with hygroscopic particles in the strong updraft region below cloud base.
- Microphysical results revealed the desired broadening of cloud droplet spectra above cloud base and subsequent occurrence of large drops at the –10°C level.
- Numerical experiments confirmed the efficiency of conversion of cloud droplets into precipitation size drops through coalescence.
Regional Considerations: Precipitation

Rainfall production (ktons/10-min interval) by seeded vs non-seeded storms over the life of a storm

![Graph depicting rainfall production over time for different regions.](image-url)
Regional Considerations: Precipitation

Benefit-cost analyses of area-wide seeding

- It was revealed in 10,000km² target area that approximately 290 potentially seedable clouds may be expected in a season.
- Based on semi-operational experiment, 25% of clouds would have to be successfully seeded in order to achieve a 7-10% increase in rainfall over the target area.
- Sufficient experience gained in order to estimate appropriate operational costs.
- Benefits (hydrological, agricultural, forestry) estimated through simulation modelling.
- Cost-benefit analyses of cloud seeding operations highly favourable in terms of runoff augmentation, crop yields and timber yields.

Cost of particulate pollution???
Regional Considerations: Precipitation

Cost of particulate pollution???
SAWS Aerocommanders studied aerosol-cloud interactions using in-situ aerosol, CCN and cloud measurements (Aerosol Recirculation and Rainfall Experiment (ARREX) and SAFARI 2000)

- Wet season campaigns Jan 1999, Mar 2001, dry season August/September 2000
- CCN concentrations are generally higher in the late dry season than in the wet season; highest concentrations are found in the northern regions of the subcontinent due to the burning of savanna biomass
- South of 20°S, industrial emissions are sufficient to account for CCN levels throughout the year.
- Biomass burning particles are efficient CCN - median diameter of the accumulation mode is large (up to 0.19 mm)
- Recently-emitted industrial aerosols are less soluble and have a smaller median diameter (0.11 mm)
Regional Considerations: Precipitation

Cost of particulate pollution???

- Twice as many aerosols act as CCN in the dry season (68%) than in the wet season (34%). The fraction is highest in the dry season over the tropical regions (>80%), where smoke aerosol predominates.

- The microphysical properties of clouds that form in unpolluted environments was compared with clouds that form in airmasses contaminated with industrial or biomass burning aerosols.

- It was found that high concentrations of accumulation mode particles retard precipitation production, and time taken for the onset of coalescence is significantly delayed in polluted airmasses.
Regional Considerations: Precipitation

Cost of particulate pollution???

- It was found that high concentrations of accumulation mode particles retard precipitation production, and time taken for the onset of coalescence is significantly delayed in polluted airmasses.

- Furthermore, modelling results suggest that the presence of even very low concentrations of giant CCN effectively stimulate coalescence, even in highly polluted conditions.

- Industrial aerosols have the greatest impact on cloud properties downwind of the Highveld industrial area.

- Biomass burning emissions mainly modify clouds in the northern regions of the subcontinent at the beginning of the wet season.
Regional Considerations: Precipitation

• Precipitation Research and Rainfall Enhancement Programme was discontinued in South Africa in 2000. It lives on in other parts of the world.
Regional Considerations: Precipitation

- Scientist hypothesize the project will be resurrected by politicians midway through the next drought. Scientists will return from all over the earth. The use of Cloudsat and other A Train satellites is already anticipated.
Project ISKY
Project Objectives:

Short term
• To assess the feasibility of developing an Air Quality and Compliance Monitoring system in South Africa using locally received remote sensing data (including South African satellites), fused with ground based measurements, used in conjunction with dispersion models.

Long term
• To develop a local daily air quality web based map and system for identification of areas of frequent non-compliance to ambient air quality standards.
Project ISKY
International initiatives:

EU --- I CAROS

US --- IDEA/ 3D AQS / USAQ
Project ISKY

The EU ICAROS and IDEA/ 3D AQS / USAQ has demonstrated:

- accurate estimates of particulate load atmospheric load in terms of columnar aerosol optical thickness
- emission inventorisation and snapshots of plumes which depict the real dispersion patterns and pathway (versus the estimated pathways obtained by modelled simulation)
- verification of dispersion models through of comparison dispersion model output against remotely sensed air pollution data
- optimise configuration of ground based monitoring networks
- cost savings to be realised using earth observation methods in determining air quality (3 to 10 times lower than the cost of a ground-based monitoring network with the same spatial resolution (Sarigiannis et al., 2002).
Main Project Objectives:

PHASE 1

Objective 1: Review current and near future technical capabilities of how satellites for use in:
  • air quality monitoring
  • atmospheric chemistry; and
  • air quality enforcement

Objective 2: Preliminary evaluation of the potential for fusion of air quality data sources (ground-based analytical measurements, remote sensing data and atmospheric modelling)

Objective 3: Demonstration project in DEAT priority air pollution area
Main Project Objectives:

PHASE 2

Objective 1: A local expanded air quality product (similar to existing products from US (IDEA/ USAQ) and the EC (ICAROS) fused with ground based monitoring and dispersion model information

Objective 2: The use of the air quality product for environmental compliance monitoring and enforcement

Objective 3: Community health warning system and air pollution maps and exposure/ morbidity maps

Objective 4: Cost benefit analysis - the financial benefits to government and health benefits to society that can be realised through augmentation by satellite based monitoring
MODIS Wavelength vs Detection Capability

- Demonstrated ability to detect $O_3$, $H_2O$ and Particulate Matter $\geq 2.5\mu m$
- Daily revisit with accessible archive data from 2001
- 36 spectral bands
- 250m – 1km resolution

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Spatial Resolution</th>
<th>Spectral Resolution</th>
<th>Pollutant to be measured</th>
<th>Temporal Revisit</th>
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<tbody>
<tr>
<td>Modis</td>
<td>250m-1km</td>
<td>36</td>
<td>$W$ vapour, PM $&gt;2$micron, ozone</td>
<td>Daily</td>
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</table>
Data from Satellite Sensors received in SA:

Moderate Imaging Sounder (MODIS)
- Low Spatial Resolution High Spectral and Temporal Sensor-

Modis Image Example showing dust storm on 26 feb 2000

Ground view

Seawifs Satellite view
AIRS Wavelength vs Detection Capability

- Demonstrated ability to detect SO$_2$, CO$_2$, O$_3$, NO$_x$, H$_2$O, CH$_4$ and Particulate Matter $\geq$ 2.5µm
- Daily revisit with accessible archive data from 2001
- 2378 spectral bands
- 20km resolution

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<th>Pollutant to be measured</th>
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<tr>
<td>Airs</td>
<td>20km</td>
<td>2378</td>
<td>CO$_2$, SO$_2$, W vapour, PM $&gt;$2micron, NOx, Ozone</td>
<td>Daily</td>
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</table>
Plume over Witbank as detected by Landsat

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Spatial Resolution</th>
<th>Spectral Resolution</th>
<th>Pollutant to be measured</th>
<th>Temporal Revisit</th>
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<tr>
<td>Landsat</td>
<td>30m</td>
<td></td>
<td>7 W vapour, Paticulate matter</td>
<td>16days</td>
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High Spatial Resolution Low Spectral and Temporal Sensor Component: Spot 2,4,5
## Locally Received Remote Sensing Sensor Specifications

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<th>Spatial Resolution</th>
<th>Spectral Resolution</th>
<th>Pollutant to be measured</th>
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<tr>
<td>Airs</td>
<td>20km</td>
<td>2378</td>
<td>CO₂, SO₂, W vapour, PM &gt;2micron, Nox, Ozone</td>
<td>Daily</td>
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<td>Modis</td>
<td>250m-1km</td>
<td>36</td>
<td>W vapour, PM &gt;2micron, ozone</td>
<td>Daily</td>
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<tr>
<td>Hyperion</td>
<td>30m</td>
<td>223</td>
<td>W vapour, PM &gt;2micron, Nox, Ozone</td>
<td>1-2 days</td>
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<tr>
<td>Landsat</td>
<td>30m</td>
<td>7</td>
<td>W vapour, Paticulate matter</td>
<td>16days</td>
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<tr>
<td>Spot2/4</td>
<td>20m</td>
<td>4</td>
<td>W vapour, Paticulate matter</td>
<td>5 days</td>
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<tr>
<td>Spot 5</td>
<td>10m</td>
<td>4</td>
<td>W vapour, Paticulate matter</td>
<td>5 days</td>
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<tr>
<td>Sumbandilasat</td>
<td>6.5m</td>
<td>6</td>
<td>O₃, Particulate Matter, W vapour</td>
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### Image Results 1998-2006

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<th>Sasolburg</th>
<th>Vereeniging</th>
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<tr>
<td>Total</td>
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<td>SPOT 4</td>
<td>26</td>
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<td>SPOT 2</td>
<td>29</td>
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<td>Landsat</td>
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<td>68</td>
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<td>Grand total</td>
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<tr>
<td>Av/ annum</td>
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<td>19.28571</td>
<td>20.428571</td>
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High Spatial Resolution Low Spectral and Temporal Sensor Component: Sumbandilasat (Launch date: late 2007???)

The Department of Science and Technology Frontiers Program have endorsed the use of simulated Sumbandilasat imagery (from hyperion) to assess the satellite’s potential in air quality monitoring.
Hyperion
High spectral,
Medium spatial
Resolution
(Existing)

Sumbandila
High spectral,
High spatial
Resolution
(Simulated)

SPOT / Landsat
High spectral,
High spatial
Resolution
(Existing)

AIRS/MODIS
High spectral,
Low spatial
Resolution
(Existing)

ICAROS
Atmospheric Air
Quality Product
(Existing)

A-IRS/MODIS
Atmospheric Air
Quality Product
(Simulated product)

Air Quality
Priority pollutants over
Priority Air
Pollution Areas
(Simulated)

Vaal Triangle Priority Area
(Particulate matter, Ozone, Sulphur dioxide, Carbon Monoxide)
Priority pollution areas and the use of satellite images: Landsat SPOT Sumbandilasat Quickbird

1. Vaal Triangle Priority Pollution Area
2. Durban South Basin Multi Point Pollution Area
3. Mpumalanga Highveld
Vaal Triangle Priority Pollution Area

May 2006

Vereeniging

May 2006

Vereeniging
Landsat TM RGB: 321 050718 Mittal Vereniging
Landsat ETM+ RGB: 321 011003 Mittal Vereniging
### Spot Archive: January/February and May/June 2006
4 months Clean summer images vs Polluted winter images

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<th>J</th>
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<td>135</td>
<td>402</td>
<td>060530</td>
<td>X</td>
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</tbody>
</table>

Unprocessed SPOT Images over period in question

Spot Coverage showing Study Area and Pollution Sites
Durban South Basin Multi Point Pollution Area

Quickbird 12 June 2002 (Sapref)
Durban South Basin Multi Point Pollution Area

17 October 2006 (Sapref)
Durban South Basin Multi Point Pollution Area

Simbundilasat simulated from Quickbird (lacking multispectral ability)
Durban South Basin Multi Point Pollution Area

Simbundilasat simulated from Quickbird (lacking multispectral ability)

12 June 2002 (Sapref)
Mpumalanga Highveld

25 September 2006 (Eskom Duvha)

08 November 2006 (Eskom Duvha)
Spot 2 RGB: 321 060530 Witbank
Spot 2 Panchromatic 060523 Witbank
Thank you