Measurement requirements for geostationary observations of pollutants with the NASA GSFC GeoChem instrument

William Brune, Randy Kawa, Scott Janz, James Gleason, and P.K. Bhartia and Jack Fishman, …

collaborative poster in Session 4 (this session):
Air Quality Science and Regulatory Efforts Require Geostationary Satellite Measurements
Kenneth E. Pickering, Dale J. Allen and Jeffrey W. Stehr
Science Questions From GeoTRACE proposal

What are the effects of local and regional pollution on the global atmosphere, and what are the effects of global pollution on regional air quality? [NASA 2000]

- What are the spatial and temporal emission patterns of the precursor chemicals for ozone and aerosols?
- What are the influences of weather in transforming and dispersing emissions, ozone, and aerosols into the global pollution?
- What is the evolution of ozone and aerosol, from chemical formation and transport to losses by chemistry and deposition?
- What are the regional budgets for carbon monoxide, ozone, and aerosols over North America?

Focus:
urban/regional air quality
Science Measurement Requirements

→ Need to resolve small scale emission features, nonlinear photochemical transformations, and interaction with rapidly changing diurnal meteorology.

• Measure main gaseous & particle pollutants of lower troposphere.
• Address key uncertainties in understanding & forecasting pollution:
  • interactions of emissions, chemistry, & deposition with planetary boundary growth & decay
  • human & natural emissions
  • air chemistry & surface deposition
  • interactions of pollutant transport & weather systems.

Requirements: ⇒ continuous measurements with high temporal & horizontal spatial resolution for continental regions with pollution.
Needs for air quality measurements

Scales of phenomena - revisit time vs. contiguous area

globe
hemisphere
continent
region

minute hour day week month year

pollution transport
climate change

* all at high horizontal resolution, higher resolution for smaller scales
Needs for air quality measurements

Scales of phenomena - revisit time vs. contiguous area

- globe
- hemisphere
- continent
- region

- minute
- hour
- day
- week
- month
- year

* all at high horizontal resolution, higher resolution for smaller scales
Needs for air quality measurements

Scales of phenomena - revisit time vs. contiguous area

globe
hemisphere
continent
region

minute hour day week month year

country, region, urban pollution

climate change, solution transport

* all at high horizontal resolution, higher resolution for smaller scales
Measurement Concept

Measure key tropospheric pollutant species at high temporal and spatial resolution over the US from geosynchronous orbit. Two instruments are needed.

- Measured species (tropospheric column, with low resolution):
  - O\(_3\), NO\(_2\), H\(_2\)CO, SO\(_2\), C\(_2\)H\(_2\)O\(_2\), & aerosol by UV/visible spectrometer
  - CO by near-infrared spectrometer or gas correlation radiometer

- Horizontal sampling: 2.5-km resolution; 5000x2500 km field of regard

- Temporal sampling: hourly during daylight

- Measurements go to the ground

- Technologies are mature now.

- Use with GOES & surface weather data

- See between the clouds (or wait for them to pass)
Spatial Resolution (GeoChem and OMI)

- GeoChem Pixel: 2.5 km x 2.5 km
- OMI Pixel (on orbit now): 13 km x 24 km

http://earth.rice.edu/mtpe/geo/geosphere/hot/MODIS/Chesapeake_MODIS.html

Spectrometer Performance Specifications

**Target Capabilities.** Channel 1 and 2 products measured with time resolution ≤ 500 ms/image line. Channel 3 unlikely to be included

<table>
<thead>
<tr>
<th>Product</th>
<th>Channel 1 UV/VIS 310-500 nm @1 nm*</th>
<th>Channel 2 VIS/NIR 480-900 nm @2.0 nm*</th>
<th>Channel 3 SWIR 2200-2400 nm @0.2 nm*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product</td>
<td>SNR</td>
<td>Res. [km]</td>
<td>SNR</td>
</tr>
<tr>
<td>Column O$_3$</td>
<td>200</td>
<td>2.5</td>
<td>O$_3$ boundary</td>
</tr>
<tr>
<td>Column SO$_2$</td>
<td>500</td>
<td>2.5</td>
<td>NO$_2$ boundary</td>
</tr>
<tr>
<td>Column CH$_2$O</td>
<td>500</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Column NO$_2$</td>
<td>2000</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>Aerosols</td>
<td>200</td>
<td>2.5</td>
<td></td>
</tr>
</tbody>
</table>

*Spectral sampling grid will be ≤ 1/3 of a resolution element*
Requirements and Design Parameters

• Geosynchronous Orbit for CONUS (35,786 km above the equator)
• Scan
  – Field of regard = 5000 km by 2500 km
  – Complete east to west & fly back for CONUS scan in 1 hour
• Telescope
  – One telescope feeds all spectrographs
  – Anamorphic ratio = 4 to 1 (spatial versus spectral)
  – IFOV 4 degrees by 0.004 degrees
  – Horizontal sampling = 2.5 km
  – IFOV is 2525 km by 2.5 km at nadir
• Two Channels
  – UV / Vis and Vis /NIR Spectrographs
  – Each spectrograph has its own slit
• One detector array for each channel
  – Frame transfer silicon CCD array with 1K x 1K pixels
  – Pixel pitch = 18 microns
• Dichroic beamsplitter to spit the beam between spectrographs
Requirements & Design Parameters (cont.)

- Time and Step resolution
  - 5000 km / 2.5 km per scan line = 2000 scan lines (images) per scan
  - Integration time plus time to move scan mirror and settle on next line = 3600 sec / 2000 lines = 1.8 seconds per scan line
  - Move mirror to next line and settle = driven by mechanism design = 0.5 second. This number may be able to be reduced.
  - Integration time baselined at one second for this study. If move to next line and settle is 0.5 seconds, then integration time could increase to 1.8 – 0.5 = 1.3 seconds.
- Two-axis scan
- Step resolution (east/west) to meet 2.5 km spatial resolution
- Required step resolution (north/south) much less (could be of order of 1 degree)
UV/Vis AutoCAD Assembly Baseline
GeoChem - ISAL Baseline - October 2005

From Dennis Evans

Swarzschild Aspheric Corrector 3
Field Flattener Lens & Slit
Band 1/Band 2 Dichroic

Band 1
Band 2

Herschelian Mirror
Calcite Depolarizer Module
Swarzschild Mirror 2

Offner Mirror 1
Offner Mirror 3
Gratings
Fold Flats
Band 2
Band 1
Detector
Detector

From Dennis Evans
GeoChem characteristics for 5 km resolution

<table>
<thead>
<tr>
<th>Overall Requirements</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>GOES station</td>
<td>East</td>
</tr>
<tr>
<td>Pointing</td>
<td>&lt; 1 arcsec/s</td>
</tr>
<tr>
<td>Expected mission life</td>
<td>3 years</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>UV/Vis instrument</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>0.8 x 0.5 m (d x h cylinder)</td>
</tr>
<tr>
<td>Mass</td>
<td>50 kg</td>
</tr>
<tr>
<td>Power</td>
<td>100 W</td>
</tr>
<tr>
<td>Data rate</td>
<td>4 Mb/s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SWIR/IR instrument</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>0.5 x 0.5 x 0.5</td>
</tr>
<tr>
<td>Mass</td>
<td>40 kg</td>
</tr>
<tr>
<td>Power</td>
<td>200 W</td>
</tr>
<tr>
<td>Data rate</td>
<td>10 Mb/s</td>
</tr>
</tbody>
</table>

(A possible better approach is to reduce the field of regard to <1000 km and the resolution to < 1 km and target. Would be useful for Ocean and Ecology communities.)
Emerging Conclusions for Discussion

- LEO is better than 1 GEO for long-range pollution transport, global coverage, & climate change.
- GEO is better than LEO for urban to regional pollution (hour timescales & regional horizontal scales).
- Good vertical resolution is needed for long-range pollution transport but not for urban to regional pollution (PBL / FT will do).
- Good horizontal resolution (< 1 km?) is essential for both GEO and LEO.
- Must see to the ground for urban / regional air quality. GEO & LEO are complementary; both are needed, just as they are for weather.
- We have LEO with untapped potential; we need GEO.
A process to define optimum GEO instruments

- **Determine current and future applications**
  - chemical forecasting for regulatory purposes
  - chemical transport model improvement
  - dispersion monitoring for health warnings
  - applications other areas (oceans-productivity, ecology-growth, etc.)

- **Run models to find and test measurement needs for applications**
  - sub-hour temporal resolution
  - horizontal spatial resolution of order of future models (< 1km)
  - good spectral resolution from UV to Visible to near IR
  - some horizontal resolution by some means (PBL, residual layer, higher FT)
  - quantitative down to the surface

- **Define instrument capabilities to meet measurement needs**
  - done initially in individual groups, then jointly

- **Run test bed to see if instruments aid applications**
  - define case studies for everyone to use
  - designate people to run the test bed

- **Iterate**
A process to define optimum GEO instruments

determine applications

run test bed to see if instruments aid applications

design, build, fly, & use GEO instruments

run models to find & test measurement requirements for applications

define instrument capabilities to meet requirements
Getting GeoChem to orbit – a new approach

All systems go. Commence reel-up of GeoChem to orbit.

I told you we’d find a good use for this lunar base.
Diurnal O$_3$ movie

1 second delay
Hourly Surface Ozone Concentrations (ppmv)

Ozone column abundance in PBL (0.0 - 1.5 km)

Ozone column abundance in free troposphere (1.5 - 8.0 km)

Total ozone column abundance (0.0 - 12.0 km)