Remote Sensing of Spatial Distributions of Greenhouse Gases in the Los Angeles Basin

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The Los Angeles air basin is a significant anthropogenic source of greenhouse gases and pollutants including CO$_2$, CH$_4$, N$_2$O, and CO, contributing significantly to regional and global climate change.

Recent legislation in California, the California Global Warming Solutions Act (AB32), established a statewide cap for greenhouse gas emissions for 2020 based on 1990 emissions.

Verifying the effectiveness of regional greenhouse gas emissions controls requires high-precision, regional-scale measurement methods combined with models that capture the principal anthropogenic and biogenic sources and sinks.

We present a novel approach for monitoring the spatial distributions of greenhouse gases in the Los Angeles basin using high resolution remote sensing spectroscopy.

We participated in the CalNex 2010 campaign to provide greenhouse gas distributions for comparison between top-down and bottom-up emission estimates.
Azimuthal Scan FTIR Spectrometer (0.7-2.5 µm)

- Spectral range: 4000 – 14000 cm⁻¹
- Species: CO₂, CH₄, N₂O, CO, H₂O, HDO
- Maximum spectral resolution: 0.02 cm⁻¹

16” Cassegrain Telescope (removable)

Long: 118.057°W
Lat: 34.221°N
Alt: 1.7 km
Reflection Points Selected for CLARS-FTS

- about 2 hours/cycle
- 4 – 5 cycles/day
- ~ 100 m Spatial Resolution

CO2 in-Situ
PI: Prof. Sally Newman
CLARS FTS measures slant column densities (in molecules/cm²) of greenhouse gases along light path.

The light path transverses through the boundary layer twice.

Distant reflection points have a much longer path though the boundary layer than the nearby points.

Simultaneous measurements of O₂ column abundance and surface pressure contains the light path at each reflection point.
Measurements made on 31 days during CalNex (in blue)
No measurements available when cloudy because CLARS FTS needs solar light as light source
Measurements for long term record are continuing
Sample CLARS FTS GHG Spectra
Reflectance from Land Surface

- **CO₂**
  1.6 µm

- **CH₄**
  1.7 µm

- **N₂O**
  2.3 µm

- **O₂**
  1.3 µm
Spectral Fitting to Determine CO$_2$ Slant Column Density
# Measurement Precisions

<table>
<thead>
<tr>
<th>Species</th>
<th>Slant Column-averaged Volume Mixing Ratio (Typical Range)</th>
<th>Retrieval Precision (Random Error)</th>
</tr>
</thead>
<tbody>
<tr>
<td>XCO$_2$</td>
<td>380-500 ppmv</td>
<td>± (0.5-1) %</td>
</tr>
<tr>
<td>XCH$_4$</td>
<td>1800-2200 ppbv</td>
<td>± (0.5-1) %</td>
</tr>
<tr>
<td>XCO</td>
<td>20-200 ppbv</td>
<td>± (2-4) %</td>
</tr>
<tr>
<td>XN$_2$O</td>
<td>250-350 ppbv</td>
<td>± (2-4) %</td>
</tr>
</tbody>
</table>

- XGAS = 0.2095x[Slant Column Density of GHG] / [Slant Column Density of O$_2$]
- Random error includes only the precision of the fitted spectra.
- Systematic error sources:
  - errors in spectroscopic parameters
  - higher-order uncertainties in optical path due to aerosols (O$_2$ measurement corrects first-order scattering effects)
XGAS = 0.2095x[GHG] /[O2]

- Ideal weather condition
- Near full day coverage
- XGAS for all targets on the pointing list are included
CH₄:CO₂ Correlation on May 29th, June 17th, June 20th, 2010

**May 29th, 2010**

\[ \text{XCH}_4 = 9.347 \times \text{XCO}_2 - 1869.1285 \]

67 data points

**June 17th, 2010**

\[ \text{XCH}_4 = 5.9833 \times \text{XCO}_2 - 466.9104 \]

60 data points

**June 20th, 2010**

\[ \text{XCH}_4 = 7.6789 \times \text{XCO}_2 - 1183.7488 \]

76 data points
XCO$_2$ Distribution over LA Air Basin on May 29$^{th}$, 2010
XCO$_2$ Distribution over LA Air Basin on May 29$^{th}$, 2010
XCO$_2$ Distribution over LA Air Basin on May 29$^{th}$, 2010
XCO$_2$ Distribution over LA Air Basin on May 29$^{th}$, 2010

XCO$_2$ from CLARS FTS measurements On May 29th, 2010 (ppm)

380  390  400  410  420  430  440

CLARS Site

Power Plant 1

Power Plant 2

Power Plant 3

3:45 PM
CO₂ Measurements From NOAA WP3 Flight During CalNex 2010

- 8 days over LA basin
- NOAA Picarro and Harvard University QCLS
- Picarro measurements are shown in figure
- Blue line: individual measurement
- Green line: averaged values

April 30th 2010 - June 22nd 2010

Latitude: 33.75°N - 34.185°N
Longitude: 117.5°W - 118.5°W

CO₂ VMR: use 300 to 500 ppm
CO₂ Measured by Picarro on NOAA P3 Plane During CalNex 2010

May 30th, 2010
NOAA Picarro

High CO₂ VMR

Lat x Long: 0.01° x 0.01°
Mean CO₂ VMR surf to 1.5km
VMR Used: 300 to 500 ppm
Validation Method

- **Challenges when compare in situ measurements to CLARS FTS measurements directly**
  - Spatial differences (vertical and horizontal directions)
  - Temporal differences

- **Possible solution**
  1. Use in situ measurements to validate simulations of WRF-VPRM and WRF-CHEM models
     - The status and results of modeling work will be present by Dr. ChangHyoun Park et al. (Poster #20) on Wednesday afternoon
  2. Use simulations of WRF-VPRM and WRF-CHEM models to validate CLARS FTS
     - Integrate slant column density within those model grid boxes along CLARS FTS viewing direction
     - Compare to the CLARS FTS measurements
Integration Slant Column Density in Each Grid Box of Model - Ongoing

- **Ray tracing program**
  - Based on Smits' algorithm
  - **Input**
    - Coordinates of origin [lat, long, alt]
    - Incident angle of sun light to grid box
    - Coordinates of grid box boundary
  - **Output**
    - light travel distance inside grid box
    - coordinates of outlet point

- **Compute the slant column density within each grid box**
  - $\text{GHG SC (molecules/cm}^2\) = \text{GHG(molecules/cm}^3\) \times \text{light path (cm)}$
During CalNex campaign (May 14th to June 20th, 2010), CLARS FTS made measurements on 31 days (out of 38 days).

Measurements are continuing after CalNex campaign for long term record.

$\text{XCO}_2$, $\text{XCH}_4$, $\text{XCO}$, $\text{XN}_2\text{O}$ are computed using measured column densities. The XGAS show correlations that will be used to determine the emission rates of GHG.

Validation/improvement of retrieval method using correlative data (ground-based and aircraft) are ongoing.

The WRF-VPRM and WRF-CHEM models for Los Angeles are being developed by the group of Qinbin Li at UCLA. The model will directly assimilate GHG and CO slant columns to derive top-down emissions (poster P20 by Dr. ChangHyoun Park et al. on Wednesday afternoon).
Acknowledgements

- Drs. Geoffrey C. Toon and Jean-Francois Blavier at JPL
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- California Air Resources Board
- NASA
- UCLA JIFRESSE
- Your Attention

Los Angeles Air Basin December 31st, 2009
Optimal Estimation Formulism  [Rodgers 2000]

\[ S = (K^T S_e^{-1} K + S_a^{-1})^{-1} \]

Where
- \( S \) is a \( n \) by \( n \) covariance matrix
- \( K \) is a \( n \) by \( m \) Jacobian matrix
- \( S_e \) is a \( m \) by \( m \) covariance matrix of measurement noise
- \( S_a \) is a \( n \) by \( n \) covariance matrix of a priori uncertainty
- \( n \) is the number of parameters contributing to measurement uncertainty
- \( m \) is the number of spectral data points