The GeoCARB Mission

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Fate of Anthropogenic CO₂ Emissions (2004-2013 average)

\[ 32.4 \pm 1.6 \, \text{GtCO}_2/\text{yr} \quad 91\% \]
\[ 15.8 \pm 0.4 \, \text{GtCO}_2/\text{yr} \quad 44\% \]
\[ 10.6 \pm 2.9 \, \text{GtCO}_2/\text{yr} \quad 29\% \]
\[ 9.4 \pm 1.8 \, \text{GtCO}_2/\text{yr} \quad 26\% \]

Calculated as the residual of all other flux components

Source: CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2014; Global Carbon Budget 2014
Key Diagnostic of the Carbon Cycle

Evolution of the fraction of total emissions that remain in the atmosphere

![Graph showing the evolution of CO₂ partitioning over time. The graph plots CO₂ partitioning (PgC yr⁻¹) on the y-axis and time (y) from 1960 to 2010 on the x-axis. The graph indicates an increasing trend in CO₂ emissions with time. The total CO₂ emissions are represented by a solid black line, while the atmosphere's CO₂ partitioning is shown by a blue line with fluctuations.](image-url)
Global fossil fuel and cement emissions: 36.1 ± 1.8 GtCO$_2$ in 2013, 61% over 1990
- Projection for 2014: 37.0 ± 1.9 GtCO$_2$, 65% over 1990

Estimates for 2011, 2012, and 2013 are preliminary
Source: CDIAC; Le Quéré et al 2014; Global Carbon Budget 2014
The Central Questions on the CO$_2$ Forcing

Currently, 45% of all CO$_2$ emissions accumulate in the atmosphere: How might this change (because of climate or ...)?

Ocean removes 26%
Land removes 29%

Carbon must be managed, but if we are to manage carbon then we must measure carbon—you cannot manage that which you do not measure.
Challenging: Cost, Coordination, Calibration, Coverage (C^5), Plus

• **Transport Model and its Adjoint:** Errors, Biases, Low level transport, Vertical transport, Variability …

• **Observed Concentrations of CO_2:** Errors, Biases, Column Variability, Aerosols and Clouds, …

• **Numerical Issues:** Independence of Observations, Convergence and Model Scale, Prior Strength, …
The GeoCARB Instrument

- Measures CO, CO2, O2, CH4, and SiF
- Scanning IR slit spectrometer (0.76, 1.61, 2.06, 2.32μm)
- 3-5 km resolution

152 W
150 kg
10,500 kbps
WOB: 295°K
COB: 125°K
“Two” Spectrometers. The non-OCO channel for CH4 and CO has been Proven by an IIP-NASA
Accommodation of GeoCARB on Host Mission

• Hosted on a typical Geo-Communication spacecraft with added interface items to support instrument
  – Mounted directly to nadir deck
  – Data downlink via host channel
  – Standard attitude & orbit control

• Consumes relatively small amount of mass and power (S/C impacts chart)

• Physical accommodation
  – Requires large part of nadir deck
  – No impact on S/C equipment panels
  – Dedicated thermal radiator

• Electrical accommodation
  – Energy via standard 70 V DC power bus
  – On/off, basic health & safety command/telemetry via standard interfaces
GeoCARB on a 13kw Communications Spacecraft
– 3 km x 6 km pixel within 3,072 km x 6 km “slit print”
– 3 km E-W sampling
– 4.42 sec integration + step time

**Slit Projection**

EW width is 6 km
EW Step = 3 km

3 km footprint width NS and
6 km footprint length WE and
sampling in 3 km steps W to E

the spectrum of the 3 km x 6 km footprint is one row of pixels in the spectral direction corresponding to each of the 1024 pixels along the slit
Example GEO slots: $70^\circ E$, $110^\circ E$, and $90^\circ W$
Moving the slit from East to West, geoCARB provides continental-scale “mapping-like” coverage.
MODEL SET-UP: CONUS and Brazil

• Prior Fluxes: Statistical Perturbations of “Truth” Fluxes

• Truth Fluxes
  o CDIAC fossil fuel emissions
  o CASA-GFED terrestrial fluxes and fire emissions
  o Takahashi ocean fluxes

• Uncertainty Covariance
  o LPJ – CASA
  o NCAR Ocean Biogeochemistry Model – Takahashi

• Concentrations are created by running the transport model TM5 at $1^\circ \times 1^\circ$ forward with the truth fluxes and ECMWF ERA-Interim meteorology

• Concentrations are sampled with a pressure-weighted averaging kernel to produce simulated $X_{CO2}$
CONUS and Generally: Error Assumptions

• Individual observations: Random and Systematic errors components
• Random errors uncorrelated among observations in the same model 1°x1° grid box, Systematic errors are assumed to be perfectly correlated within the same grid box. Random error: \( \sigma_p \sim 0.35 - 1.3 \) ppm depending on air mass (m) and aerosol optical depth (\( \tau \))
• System error: \( \sigma_{sys}(m) = 0.3 \text{ppm} + 0.2 \text{ppm} \times (m-2) \)
• The mean value of \( X_{CO2} \) at 1°x1° then has an error \( \sigma_{xco2} = \sqrt{\sigma^2_{sys} + (1.3\sigma_p)^2/n} \), where the ad hoc error inflation 1.3 is chosen from comparisons of GOSAT/OCO-2 with TCCON.
• \( \sigma_{xCO2} \) varies from \( \sim 0.5 \)ppm at low view and zenith angles and multiple high SNR soundings to \( \sim 3 \)ppm for a large airmass factor and a minimal number of low SNR soundings.
• Exclude soundings when two-way slant \( m\tau(in) + m\tau(out) \) is \( >0.6 \).
• To account for correlations between systematic errors of neighboring 1°x1° mean values for \( X_{CO2} \), we further inflate the 1°x1° errors by 2.5, which was derived assuming a spatial de-correlation length of 2° for the \( X_{CO2} \) systematic error.
CONUS CO$_2$ Flux Uncertainty Reduction

Prior uncertainty for June

Corresponding error reduction

Error reduction for flat prior uncertainty 2.5 kgC per m$^2$/yr
Brazilian CO2 Sink Experiment

- **CO₂ Fertilization**
  - 5% GPP Inflation for Tropical PFTs
  - Spatially heterogeneous effect

- Includes persistent cloudiness of Amazon as seen by CALIPSO

- Fertilization signal is clearly recoverable.
The GeoCARB Mission: Summary

- Measure CO$_2$, CH$_4$, and CO concentrations with high accuracy by reflected sunlight via a 4 Channel Grating Spectrometer (essentially the OCO instrument plus a CH4 & CO channel in a GEO orbit)
- View from GEO enables continual precise concentration measurements at least daily at very fine spatial scales
- Determination of concentrations enables CO$_2$, CH$_4$, and CO flux calculations with:
  - Temporal resolution days
  - Spatial resolution of 10 kilometers or better
- Provide demonstrations of flux calculations relevant to policy and mitigation at power plant to country scales
The GeoCARB Mission: Other Advantages

- Urban areas can be sampled multiple times daily;
- Fluxes estimated with GeoCARB observations will be less vulnerable to transport errors;
- Observations are dense in time and space supporting connectivity to processes;
- Coordination with GEO weather satellites (e.g., GOES) allows for scan strategies that maximize visibility, and
- Finally, daily SIF measurements yield crop- and ecosystem-stress information at high time resolution (early-warning systems).
ONE OTHER MATTER

- Carbon Workshop in March 2015 at the University of Oklahoma recommended conducting OSSE that would consider different configurations of ground and space-based observing systems.
- In the US, an informal working group involving GSFC, JPL, CSU, and OU (and possibly others) is beginning to “scope out” what we might contribute.
- Given the highly international characteristic of these issues in would be ideal if there might be other teams conducting OSSEs as well as helping to provide essential datasets (e.g., high resolution diurnal cloud masks).
- The more the merrier; more importantly, different insights and approaches will lead to new discoveries!!