GeoCarb Mission Update

Berrien Moore III
GeoCarb: Built on Strong Partnerships
GeoCarb Mission: Overview

The GeoCarb Mission is designed to collect observations of the column averaged concentrations of carbon dioxide (CO$_2$), methane (CH$_4$), and carbon monoxide (CO), and solar induced fluorescence (SIF) from geostationary orbit (GEO) at a spatial resolution of 5-10 km over the Americas between 50º North and 50º South Latitudes as a hosted payload on a commercial communication satellite.

The Goal of the GeoCarb Mission is to provide observations and demonstrate methods to realize a transformational advance in our scientific understanding of the global carbon cycle.
Science Hypotheses

1. The ratio of CO$_2$ fossil source to biotic sink for CONUS is ~4:1
2. Variation in productivity controls spatial patterns of terrestrial sinks
3. Amazonian ecosystems are a large (~0.5-1.0 GtC/y) net sink for CO$_2$
4. Larger cities emit less CO$_2$ emission per capita than smaller ones
5. Amazonian ecosystems are a large (~50-100 MtC) net source for CH$_4$
6. The CONUS methane emissions are a factor of 1.6 ± 0.3 larger than in EDGAR and EPA databases

GeoCarb aims to fundamentally advance our understanding of how the carbon cycle behaves on regional scales.
Single slit, 4-Channel IR
Scanning Littrow Spectrometer
Bands: 0.76μm, 1.61μm, 2.06μm and 2.32μm
Mexico City: OCO-2 and GeoCarb

Example of a daily geoCARB E-W Scan

CO₂ Emissions
- > 10 Tg per yr
- 3 – 10 Tg per yr

Selectable E-W scan:
- 40.7 km in 1m
- 407 km in 10m
- 1222 km in 30m

Slit extends North/South 4°

OCO pass through region on day 1 & repeats on day 16

geoCARB slit steps E-W ½ pixel every 4.4625s

Next OCO Pass through Region 8 days later

Mexico City: OCO-2 and GeoCarb

Slit Projection

Next Step E-W

Current Step E-W

CO₂: OCO-2 and GeoCarb
A Day in the Life of GeoCarb

Lat 0.00000 / Lon -85.00449  Alt 35785.86 km
GeoCarb IGR Axes
19 Mar 2023 04:01:00.000
Simplified Instrument Overview

Single slit, 4-Channel IR Scanning Littrow Spectrometer Bands: 0.76μm, 1.61μm, 2.06μm and 2.32μm
Instrument Design Changes

- Based on analyses and trades, the following changes were made to the Baseline Instrument at PDR:
  - Modified ISS
    - Image Stabilization System (ISS) modified to use scan mirror fed by star tracker rather than active mirror fed by IMU
  - Removed Calibration Drum Assembly
    - Removal of cal drum mechanism and structure
  - Reduced Optical Aperture for system
    - Reduced optic substrate size of optics (varies by optic)
  - Remove SHEB
    - Use mechanical thermostats for survival heaters
  - Change from PID thermal control
    - Reduction in FSW complexity
  - Removed FPA thermal sensor
    - Redundant sensor, removes wires, reduces parasitics
  - Removed redundant power harness to S/C
    - SES agrees with minimal impact
  - In addition, the above changes allowed for electronics box reductions:
    - Combination of Mech 2 and Bridge board
    - Removal of 1 and ½ boards: Mech 2 and PZT driver circuits
    - Allowed for reduction of one whole row of boards (slots)
Simplified Instrument

• Optical redesign: reduction of SNR from smaller aperture area - **doubled stare time to meet SNR reqts**
  – SNR has margin in all channels, despite the presence of increased noise from thermal glow
  – Areal coverage rate retained by removal of double sampling

• **Removal of Secondary Solar Calibration Drum: redundancy to assess changes in primary diffuser – already planned lunar observations will be sufficient**
  – Lunar observations will be used to assess changes in the calibration over time. This methodology has been demonstrated by OCO-2. Working with lunar cal experts to adapt the OCO-2 approach for GeoCarb sampling

• **Removal of IMU: expected pointing knowledge is reduced by ~0.1km, but it still meets MDRA requirements**

We meet all Level 1 requirements and satisfy the mission hypotheses with the Replanned Project, though with some reduced margin
Instrument Overview

Single slit, 4-Channel IR
Scanning Littrow Spectrometer
Bands: 0.76μm, 1.61μm, 2.06μm and 2.32μm
Host Spacecraft

• Working with SES to ensure maximum compatibility of GeoCarb with candidate host spacecraft
  – Enveloping candidate spacecraft environments
    • Mechanical, thermal, EMI/EMC, and contamination
  – Accommodate 100V spacecraft busses
  – Simplifying instrument to spacecraft interfaces
  – Simplifying satellite integration and test operations
  – Streamlining the instrument concept of operations
Launch Services: Currently June 2023 to 103º West

- Launch services are provided by SES
  - Procured and managed by SES separately from the Spacecraft contract
  - SES has recent experience with a variety of commercial launch vehicles:
    - SpaceX (Falcon 9)
    - Ariane 5 ECA
    - Soyuz
    - Proton Breeze M
  - Launch services include:
    - All applicable licensing and permitting
    - TIMs and applicable reviews
    - Launch site integration and testing
    - Launch and early orbit support
System Data Flow Block Diagram

Organization and External Interface View

Ground ICDs are preliminary at PDR, baselined at CDR
Significant Accomplishments Since PDR

• **Project**
  - Project Re-planned in order to increase cost reserves by $5.8M
    - Instrument simplified
    - Science prioritization
    - Ground system processing reductions and optimization
    - Completed assessment and impact on Level 1 & 2 requirements
    - Updated concept of operations
    - Revised project plan to increase project cost reserves
  - Conversion of LM subcontract to Firm Fixed Price to reduce risk of future cost growth *(in process)*
  - Host management strategy is a) to assure SES a mass not to exceed 176kg (roughly 25% growth over proposal mass); b) to assume a cost by SES not to exceed 25% growth over proposal.

• **Science:**
  - **Significant improvement in end-to-end modeling**
    - Improved model used for in-depth study of scene inhomogeneity, instrument calibration/characterization, and error budgets
    - Level 2 retrievals coupled to performance results from the instrument model

• **Instrument**
  - Instrument simplified to achieve to reduce risk, mass and cost
  - Slit homogenizer baselined
  - Still meets Level 1 requirements
  - Engineering progress continues to mature the instrument baseline

• **Ground System**
  - Determined cost savings from the reduction in data rate due to the instrument descope
  - Exploring cost reduction opportunities through the use of cloud-based and existing NASA computing resources – retrieval timing tests, throughput *(in process)*
### Significant Changes

<table>
<thead>
<tr>
<th>Item</th>
<th>PDR CBE/MEV</th>
<th>DPDR CBE/NTE</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument Mass (CBE/MEV)</td>
<td>186 kg / 213 kg</td>
<td>157 kg / 176 kg</td>
<td>-16% / -17%</td>
</tr>
<tr>
<td>Instrument Power (CBE/MEV)</td>
<td>406 W / 538 W</td>
<td>393 W / 521 W</td>
<td>-3% / -3%</td>
</tr>
<tr>
<td>Data Rate</td>
<td>18.7 Mbps</td>
<td>9.3</td>
<td>-50%</td>
</tr>
<tr>
<td>Unencumbered Cost Reserves</td>
<td>$7M</td>
<td>$21.3M</td>
<td>+304%</td>
</tr>
<tr>
<td>Funded Schedule Reserve</td>
<td>71 days</td>
<td>71 days</td>
<td>0%</td>
</tr>
</tbody>
</table>

Replanned efforts have significantly increased the financial health and key contingencies of GeoCarb while maintaining performance that satisfied the Level 1 Requirements and Mission Objectives.
# Key Level 1 Requirements

<table>
<thead>
<tr>
<th>Req ID PLRA</th>
<th>Project Level 1 Requirements</th>
<th>Baseline</th>
<th>Threshold</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1.1.a / 4.1.2.a</td>
<td>Retrieve estimates of the column-averaged dry air mole fractions XCO2, XCH4, XCO and SIF from space-based measurements over cloud-free scenes</td>
<td>XCO2, XCH4, XCO, SIF</td>
<td>XCO2, SIF</td>
<td>XCO2, XCH4, XCO, SIF</td>
</tr>
<tr>
<td>4.1.1.b.a / 4.1.2.b.a</td>
<td>The bias corrected, clear-air, multi-sounding GeoCarb retrieval estimates for XCO2 will demonstrate multi-sounding precision better than</td>
<td>&lt;0.3%</td>
<td>&lt;0.6 %</td>
<td>0.2%</td>
</tr>
<tr>
<td>4.1.1.b.b / 4.1.2.b.b</td>
<td>The bias corrected, clear-air, multi-sounding GeoCarb retrieval estimates for XCH4 will demonstrate multi-sounding precision better than</td>
<td>&lt;0.6%</td>
<td>N/A</td>
<td>0.4%</td>
</tr>
<tr>
<td>4.1.1.b.c / 4.1.2.b.c</td>
<td>The bias corrected, clear-air, multi-sounding GeoCarb retrieval estimates for XCO will demonstrate multi-sounding precision better than</td>
<td>&lt;10% or 12 ppb (whichever is greater)</td>
<td>N/A</td>
<td>8%</td>
</tr>
<tr>
<td>4.1.1.c / 4.1.2.c</td>
<td>Retrieval estimates of solar induced fluorescence (SIF) with NESR (W/m²/µm/sr)</td>
<td>&lt;0.75</td>
<td>&lt;1.0</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>4.1.4.a</td>
<td>Geostationary orbit longitude</td>
<td>85° W ± 20°</td>
<td>N/A</td>
<td>103° W</td>
</tr>
<tr>
<td>4.1.4.c</td>
<td>Space-based measurements shall have spatial resolution at the sub-satellite point (single sounding)</td>
<td>&lt; 60 km²</td>
<td>&lt;100km²</td>
<td>&lt; 60 km²</td>
</tr>
</tbody>
</table>
“End to End” Simulator

Instrument Performance Model

Simulated Spectra

Level 2 Req’ts

Synthetic Retrievals

Level 3/4 Req’ts

Inferred fluxes

Atmospheric inversion model

Mission Objectives

GeoCarb Science Time Meeting – June 2, 2019
Use of the Simulation System

• Propagate instrument characteristics into L2 retrieval errors
  – Trace L1 requirements (e.g., XCO$_2$) downward to instrument performance requirements (Level 3-4)
    • Radiometric Calibration
    • Spectral Calibration
    • Polarization response knowledge
    • Image navigation and registration
  – Separate random and systematic error effects
  – Examine different error effects on data quality filtering
  – Value of the Slit Homogenizer

• Propagate L2 retrieval errors into flux estimates
  – Trace L1 requirements upward to Science Objectives
  – Examine data throughput impacts on Science Objectives
Slit Homogenizer Status

- **Low risk approach for SH development**
  - Leveraging from ESA Sentinel-5
    - ILS distortion simulation algorithms
    - One of the SH vendors (WinLight) fabricated Sentinel 5 SH
    - Same test laboratory (ITO)
  - Two vendors (LightMachinery and WinLight) have developed prototype SH
    - Both have heritage developing SH or similar optical elements for flight
    - Using 2 vendors to develop SH prototypes reduces risk
      - Prototypes are being tested at ITO, will inform flight model selection
  - Schedule risk is mitigated by identifying key SH decision points in the IMS
    - We will design and procure 3 SH depths (and associated fold mirrors) if prototype testing is not available to finalize SH geometry
    - Decision on single SH design needed by Oct 2019 to not impact instrument schedule
      - Flight slit homogenizer environmental testing by January, 2020 (prior to integration and prior to CDR)

- **We have a backup plan in-place should the SH be undesirable**
  - Backup plan (install a standard slit with a flat fold mirror) is low-cost and may be implemented late (Jan 2020)
  - Meets threshold mission requirements
PI Assessment

- Successful project-wide Re-plan reduced costs and risks across all segments.
- Reduced instrument complexity, mass, and data-rate while meeting all Level 1 Requirements
- Host management strategy is a) to assure SES a mass not to exceed 176kg (roughly 25% growth over proposal mass); b) to assume a cost by SES not to exceed 25% growth over proposal. Hosting uncertainties are being further mitigated through:
  - Regular interaction with our preferred host SES and other potential candidate hosts
  - Incentivize LM to have mass below 176kg (in process)
- Science segments are proceeding more quickly than anticipated due to close collaboration with other missions (e.g. OCO-2/3) and well established teamwork, which enables speedy closure for opportunities and changes
- PI assesses GeoCarb budget as “yellow” due to cost reserves being smaller than 25% (21.9% at D-PDR). This is an acceptable level of risk for a Class D project; however, the PI decided (1 May 2019) to Convert the LM contract to a Fixed Price Contract to reduce further the risk of cost growth.
Summary

• The GeoCarb Project has matured significantly during Phase B
  – A revised PLRA better reflects the scientific goals of the mission
  – The instrument design is far better than preliminary design maturity
  – Scientific algorithms are well beyond typical missions at this stage
  – Program-wide Replan - significant reductions in instrument complexity, mass and data rate, which decreases hosting costs
  – Conversion of LM contract to FFP reduces risk of future cost growth
  – Working with SES and GEOshare to identify additional launch opportunities

• Medium risk, but Extremely High Reward!
  – The scientific outcomes will be unprecedented as we revisit the western hemisphere land masses every day – the information we will provide on the carbon cycle in the Amazon and in North America will be revolutionary
  – We will demonstrate the feasibility of a PI-led commercially hosted payload mission with a focus on Earth Science

GeoCarb has made great progress in all mission segments and through wise team-wide decisions after PDR. We are ready to proceed to Phase C/D. KDP-C is 18 July!!
Science Team Posters at IWGGMS

- Atmospheric Variations in Column Integrated CO2 On Synoptic and Seasonal Time Scales Over the U.S. (Wang)
- The Ability of GeoCarb to Constrain the Interannual Variability of Carbon Gases over the Amazon (Weir)
- Progress in Atmospheric Carbon Monitoring Using NASA’s Goddard Earth Observing System (GEOS) Model and Data from the OCO and GOSAT Missions (Weir)
- Characterization of OCO-2 and ACOS-GOSAT Biases and Errors for Flux Estimates (Kulawik)
- Simulation-retrieval Experiments over the Western Hemisphere with the GeoCarb Greenhouse Gas Retrieval Algorithm (McGarragh)
- Seasonal and Diurnal Opportunities for XCH4, XCO2, and XCO for the Amazonian Rainforest Region Allowing Sampling and Validation (Chatfield)
- Comparison between MOPITT and OCO-2 Flux Inversions: Analyze of CO-CO2 Correlation (Peiro)
- Characterizing and Mitigating the Impact of Model Transport Errors on CO2 Flux Estimates in the Assimilation of XCO2 Data from OCO-2 (Jones)
- NASA's Carbon Cycle OSSE Initiative - Informing future space-based observing strategies through advanced modeling and data assimilation (Ott)
See You at Launch!!!!!!

ありがとうございました

THANK YOU