COMEX Update – A validation/comparison campaign of imaging and non-imaging spectroscopy to observe and quantify methane emissions with application to the HyspIRI and CarbonSat Satellites
CO₂ and Methane EXperiment
Contributors

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Rob Green and Michael Eastwood

And the Key NASA HQ Support of
Woody Turner, Jack Kaye
A Budget Problem

Methane is a Global Problem
Needs a Global Solution

Data-starved models inform
Current (data starved) knowledge

CarbonSat – ESA EE8 Candidate Mission
Proposed by IUP-Bremen H. Bovensmann et al. 2010 and selected as EE08 candidate by ESA in 2010

CarbonSat aims to support separating natural and anthropogenic fluxes with global $XCO_2$ and $XCH_4$ ($2^{nd}$: vegetation fluorescence) data and “imaging” of strong localized $CO_2$ and $CH_4$ emission areas.

In combination with inverse modeling and robust validation (TCCON) this will address:

- Better top-down constrain on regional and country scale flux inversions (focus land biosphere fluxes)
- MegaCity scale top-down constraints
- Local scale top-down constraint
- Optics: 3-cannel (NIR, SWIR-1, SWIR-2) imaging spectrometer
CarbonSat – ESA EE8 Candidate Mission
Proposed by IUP-Bremen H. Bovensmann et al. 2010 and selected as EE08 candidate by ESA in 2010

CarbonSat aims to support separating natural and anthropogenic fluxes with global XCO2 and XCH4 (secondary: vegetation fluorescence) data and “imaging” of strong localized CO2 and CH4 emission areas.

High spatial resolution and good coverage:
• 2×3 km² ground pixel, 180 – 240 km swath width

Single error of column-averaged mixing ratios
• XCO2 < 1 – 3 ppm, XCH4 < 6 –12 ppb

Orbit: LEO Sun-synchronous, around 11:30 hrs LT
Modes: Nadir imaging (main); for land & ocean,
• Sun-glint; for optimised ocean coverage

Launch: 2020+, lifetime 3–5 years
### Science Goals

1. **Spatial and spectral resolution tradeoffs and synergies for CH$_4$ and CO$_2$ anomaly detection and flux inversion in the context of upcoming hyperspectral (HysPIRI) and Greenhouse Gas missions (CarbonSat).**

2. **Quantify CH$_4$ (CO$_2$) emissions over ocean using sun glint mode.**

3. **Quantify impact of surface spectral reflectance non-uniformity on trace gas retrievals.**

<table>
<thead>
<tr>
<th>Image</th>
<th>Text</th>
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<tbody>
<tr>
<td>![Satellite Image]</td>
<td>1. Concurrent flights of AVIRIS NG and CIRPAS with MAMAP for Kern River Oil Field and Chino Dairy Complex with airborne <em>in situ</em> (Jun 4,13) and surface <em>in situ</em> (Jun 7,13).</td>
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<td>![Sun Glint Image]</td>
<td>2. Successful concurrent sunglint flights of offshore CH$_4$ source by AVIRIS Classic and MAMAP (Jun 4).</td>
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<td>![Airborne In Situ Image]</td>
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**References:**

- AVIRIS NG and CIRPAS with MAMAP for Kern River Oil Field and Chino Dairy
- AVIRIS Classic and MAMAP
- Concurrent flights with MAMAP
- Sun glint mode
- Trace gas retrievals
COMEX Mission

COMEX will calibrate / validate point source plume inverse-model derivation of greenhouse gas source emissions from \textit{in situ} and remote sensing data for future remote sensing satellite missions (HyspIRI and CarbonSat) that use Short Wave InfraRed absorption features for trace gas retrievals.

COMEX will demonstrate natural synergies between HyspIRI and CarbonSat.

\textit{These synergies apply to other combinations of hyperspectral and atmospheric spectroscopy space-borne and airborne platforms}
Natural Synergies

Hyperspectral for atmospheric spectroscopy:

- High spatial resolution spectral surface albedo for improved trace gas retrieval
- Improved Information on sub-pixel clouds particularly low clouds
- Impact of shadowing

Atmospheric spectroscopy for Hyperspectral:

- Atmospheric corrections
- Additional ecological parameter like vegetation fluorescence
- Cross calibration
- Combined eco-parameter and trace gas interpretation

These type of synergies apply to other combinations of hyperspectral (HyspIRI, ENMAP, etc.) and atmospheric spectroscopy (CarbonSat, Sentinel 5P, etc.) space-borne and related airborne sensors
COWGAS

A COMEX-PreCursor Activity

-> Focus on a well-described, isolated, strong source.

-> Collect column CH$_4$ data thermal (mobile) & fixed-location (SWIR), *in situ* surface mobile & airborne data, and surface & airborne winds and met data.

-> Plume Inversion modeling to derive source strength.

-> Radiative transfer modeling to Twin Otter, ER2, and orbital altitudes of observed plume to characterize detection limits and orbital instrumental design characteristics.

-> Relate emissions to dairy operations.

-> See Vigil et al poster
Overall COMEX Airborne Campaign

• 30 May–13 Jun (AVIRIS NG, AVIRIS Classic, AJAX, CIRPAS, MAMAP, AMOG)
• 22-25 Jul (Mako, AMOG)
• 23 Aug – 5 Sep (AVIRIS NG, AVIRIS Classic, AJAX, CIRPAS, MAMAP, AMOG)
Methane Airborne Mapper MAMAP

developed by IUP Bremen in cooperation with GFZ Potsdam

MAMAP aims to support separating natural and anthropogenic fluxes with local \( \text{XCO}_2 \) and \( \text{XCH}_4 \) data measuring gradients across localized \( \text{CO}_2 \) and \( \text{CH}_4 \) emission source.

Combined with inverse modeling it allows:

- Independent top-down constraint of emissions from strong point sources

Sensor:

- 2-channel (NIR, SWIR-1) spectrometer
- Moderate spectral resolution (0.5-0.8 nm)
- Spatial resolution 30 – 50 m

Measurement principle:

- absorption spectroscopy using scattered/reflected solar radiation (SCIAMACHY, OCO-2, GOSAT, Carbonsat)

Main data product:

- “column averaged dry air mole fractions” of \( \text{CH}_4 \) and \( \text{CO}_2 \) (XCH4 XCO2) via proxy approach with typical uncertainty of 0.3%
CIRPAS Twin Otter Payload

In support of demonstrating these synergies, the CIRPAS Twin Otter will field an instrument suite to characterize the atmosphere to validate and improve atmospheric correction algorithms (and assumptions) in HyspIRI and MAMAP data.

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<th>Guest Provided Instruments</th>
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<td>• PICARRO</td>
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Planes to Deconflict

- ER-2 (2 Boxes, ~2 flight days)
- CIRPAS Twin Otter (~15 flight days + 4 weather days)
- Twin Otter AVIRIS NG (~2+ flight days, details TBD)
- Alpha Jet (4 days + 1 weather day)
LA Basin Airspace – very crowded
AMOG version VI

Objective: CH$_4$ plume emission strength derivation from mobile surface measurements using real-time multiple gas fingerprinting and wind/met data.

2-100 Ahr batteries and 3kW inverter in trunk, sound proofing, thermal isolation of pump box plus 500 cfm under bumper exhaust. heated sample lines, fast temperature and pressure sensors.

AMOG Surveyor near cow shelter at the CalPoly Dairy during COWGAS.

- CalpOly Winter greenhouse GAS - campaign
AMOG version VI

Vaisala roof sonic anemometer, sample line upgrade, NH$_3$ / O$_3$ and NO$_2$ machines on rear seat, (NH$_3$ machine uses LN2)
Problems: Heat – 108F in Bakersfield!!! Performance additions (1000 lbs over stock), 3.2kW alternator, Limo-dark tinting, sunroof for cryogenics, solar panel spoilers, backseat 8000 btu AC, high speed network and backup, etc.
June COMEX Ops

Matched filter reveals plume and highlights plume structure including source transiency and transport induced heterogeneity.

MAMAP realtime CH$_4$ data collected simultaneous with AVIRIS NG shows clear CH$_4$ plumes.
Mako flew over a number of COMEX sites-of-interest during July 22-25 at 12 kft AGL (2-m GSD):

- San Luis Obispo Research Dairy (COWGas Site, a COMEX precursor expt.).
- Kern River Oil Field.
- Chino Dairy Complex.
- Long Beach, Tesoro, Carson, and El Segundo Refineries.
- Coal Oil Point Seep Field, offshore Santa Barbara Channel.

Mako participates in COMEX with support provided by The Aerospace Corporation’s Independent Research and Development Program.
TIR Imaging Spectroscopy w/AMOG validation
Chino Dairy Complex
August COMEX Ops
# August COMEX Ops

<table>
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<tr>
<th>Day 0</th>
<th>21-Aug</th>
<th>Engineer</th>
<th>Target</th>
<th>BOX</th>
<th>CIRPAS*</th>
<th>AVIRIS NG*</th>
<th>AVIRIS C Alpha*</th>
<th>AMOG</th>
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<tr>
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<td>23-Aug</td>
<td>Sa</td>
<td>Transit</td>
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<td>Day 2</td>
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<td>Mo</td>
<td>COP</td>
<td>SB2</td>
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<td>26-Aug</td>
<td>Tu</td>
<td>Kern</td>
<td>SB1</td>
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<td>Day 4</td>
<td>27-Aug</td>
<td>We</td>
<td>Puente-Baldwin</td>
<td>LA3 - LA7</td>
<td>4.8</td>
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<td>Day 5</td>
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<td>Th</td>
<td>Olinda/Puente</td>
<td>LA5</td>
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<td>Day 6</td>
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<td>Fr</td>
<td>LA Basin /Carson</td>
<td>LA8 / L2</td>
<td>2.9</td>
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<td>SB Box-tbc</td>
<td>0.68</td>
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<td>1-Sep</td>
<td>Mo</td>
<td>Olinda/BKK</td>
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<td>3.4</td>
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<td>Tu</td>
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<td>5.5</td>
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<td>We</td>
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<td>LA1</td>
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<td>6</td>
<td>Kern</td>
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<td>4-Sep</td>
<td>Th</td>
<td>Kern</td>
<td>SB2</td>
<td>5</td>
<td>6</td>
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<td>Day 11</td>
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<td>transit only</td>
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Atmo-Correct Experiment

Five lines from 20,000 to 1,500 ft AGL (20k, 15k, 7.5k, 5k, 2.5k, 1-1.5k – ATC)
~12 km each 8 min, about 8 min each descent – 16*6 = 110 min
• Transit to rise to 20k
• Solar noon +/- 1 hr (same air up-down) based on forecast for intermediate winds
• CIRPAS profiles boundary layer and 2500 ft above:

→1. Chino Dairy Area
→2. Bakersfield Area

Includes mixed scene elements – Urban, dirt & dry veg, water (lake/river), vegetated (agriculture)

Ground Team: the intrepid Keely Roth
**Key COMEX Insights**

- Upon site arrival conduct a profile to identify location of the boundary layer ($\text{CH}_4$ is constrained).
- Nocturnal $\text{CH}_4$ “pooling” may be significant, potentially complicating interpretation (of daytime data).
- AVIRIS NG atmospheric correction experiment (five altitudes from 20k to Boundary Layer) will improve radiative transfer calculations (w/HyspIRI). Co-fly with AVIRIS Classic on ER2
- Central California Valley is *hot*, which affects airborne and surface instruments.

**COMEX-AUGUST - Priority Targets**

*(Agricultural, Industrial, Natural):*

**Refinery:** *None* *(No significant emissions!!)*

**Oil Field:** Kern River, S. Bellridge, Kern Front, Baldwin Hills

**Landfill:** Puente Hills, Olinda, Scholl Canyon

**Dairy:** Chino Dairy complex

**Geology:** Coal Oil Point seep field (Marine), La Brea Tar Pits (Land)

**COMEX data and modeling feed into top-of-atmosphere, radiative transfer calculations to improve space-based sensors and algorithms and efforts to derive emission fluxes from space.**
October-November COMEX Ops

AMOG Cleanup – Chino, CalPoly, La Brea

AMOG Support of GOSAT

GOSAT Targeted Pixels
Publication Plan

Manuscripts planned next six months for submission:

Oil Field Emissions (Kern) – Gerilowski et al., Leifer et al., Fischer et al.,
Landfill Emissions Krautwurst et al., Vigil et al.
Husbandry (Cow) Emissions Leifer et al., Lundquist et al.
Imaging spectroscopy Hu et al.
Highlights

- Early results indicate that imaging spectroscopy can characterize terrestrial CH$_4$ releases from common point sources – assists in defining spatial detection thresholds for CarbonSat and HyspIRI.

- Real-time, first order algorithm will enable real time detection of plumes for better multi-aircraft campaigns and adaptive surveying.

- California refineries are (relatively) low emission.

- Production is a significant source; however, spatial and temporal heterogeneity challenge interpretation by individual instruments and approaches.

- At 100+F, dairy complexes are highly aromatic. So are oil fields.

- Never forget legal.