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

Fall HyspIRI Workshop
Caltech, Pasadena CA

Post Airborne Campaign Update

CO_2 and Methane EXperiment

NASA esa

Universität Bremen

BRI

Ames Research Center

JPL

CIRPAS
Center for Interdisciplinary Remotely-Piloted Aircraft Studies

USF

AEROSPACE

GFZ
Helmholtz Centre Potsdam

H211, LLC

LGR
Los Gatos Research
A MEMBER OF THE ABB GROUP

HELMHOLTZ ASSOCIATION

NASA Goddard

California Environmental Protection Agency
Air Resources Board

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[11] Jet Propulsion Laboratory (JPL)
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COMEX Grand Team

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The moral and logistical support

of

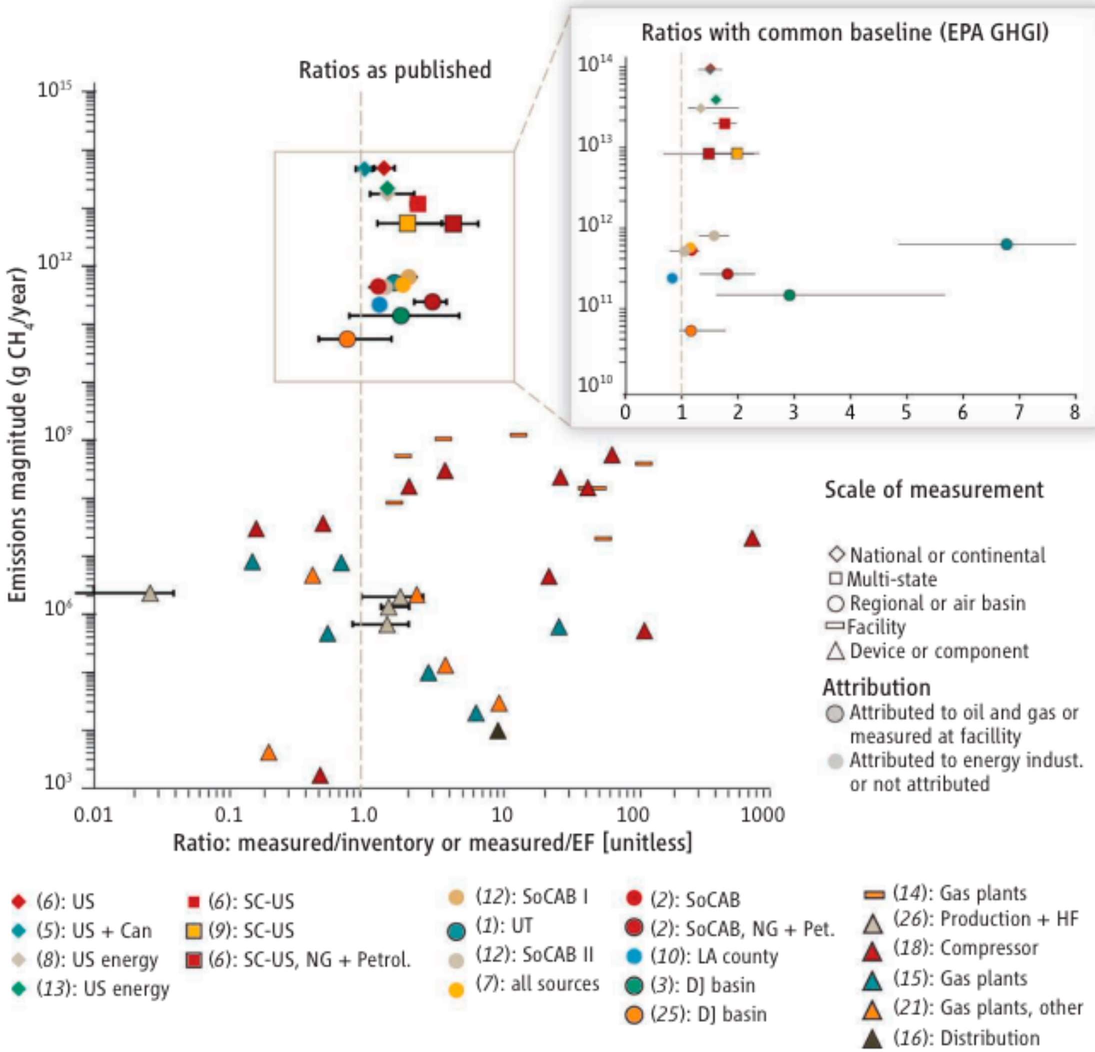
Rob Green and Michael Eastwood

And the Key NASA HQ Support

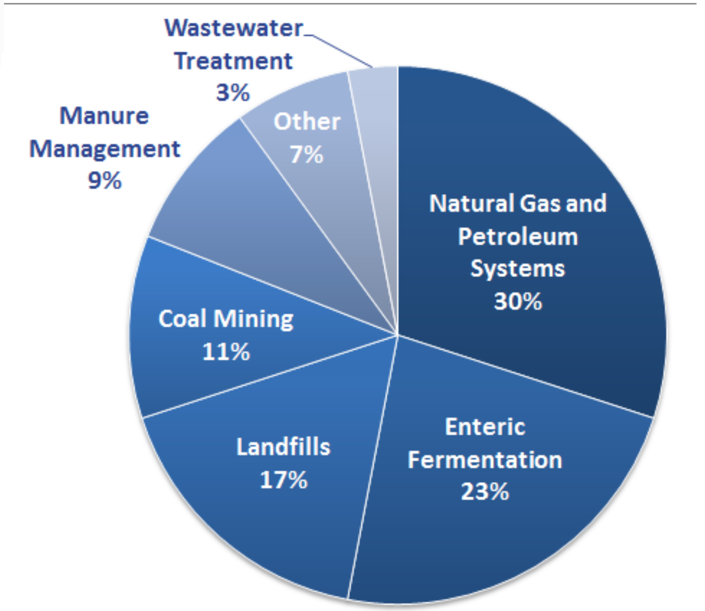
of

Woody Turner, Jack Kaye

A Budget Problem



EPA CH4 Budget



Brandt, A.R., Heath, G.A., Kort, E.A., O'Sullivan, F., Pétron, G., Jordaan, S.M., Tans, P., Wilcox, J., Gopstein, A.M., Arent, D., Wofsy, S., Brown, N.J., Bradley, R., Stucky, G.D., Eardley, D., Harriss, R., 2014. Methane Leaks from North American Natural Gas Systems. Science 343, 733-735.

The Budget Problem

Methane is a Global Problem
Needs a Global Solution

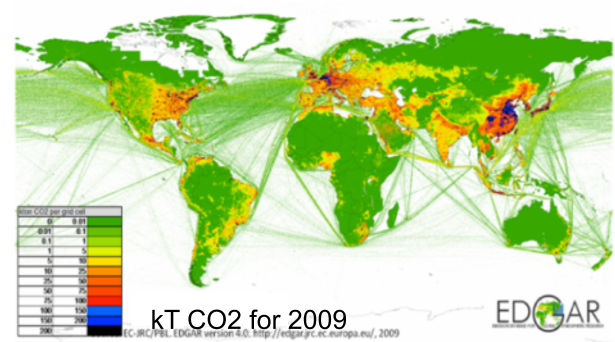
Data-starved models inform
Current (data starved) knowledge

Brandt, A.R., Heath, G.A., Kort, E.A., O'Sullivan, F., Pétron, G., Jordaan, S.M., Tans, P., Wilcox, J., Gopstein, A.M., Arent, D., Wofsy, S., Brown, N.J., Bradley, R., Stucky, G.D., Eardley, D., Harriss, R., 2014. Methane Leaks from North American Natural Gas Systems. Science 343, 733-735.

CarbonSat – ESA EE8 Candidate Mission

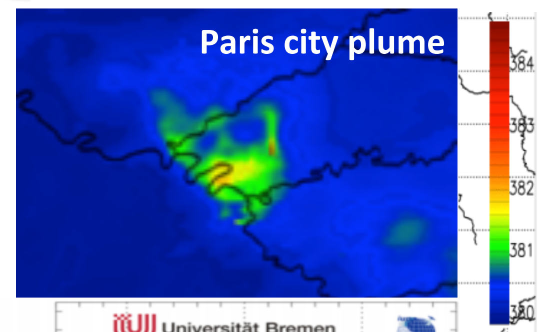
Proposed by IUP-Bremen H. Bovensmann et al. 2010 and selected as EE08 candidate by ESA in 2010

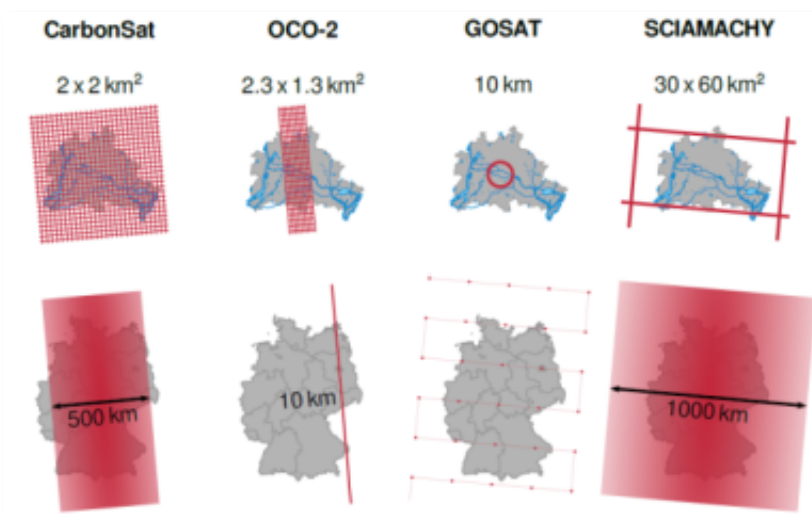
CarbonSat aims to support separating natural and anthropogenic fluxes with global **XCO_2 and XCH_4** (2^{nd}: vegetation fluorescence) data and **"imaging"** of strong localized CO_2 and CH_4 emission areas.

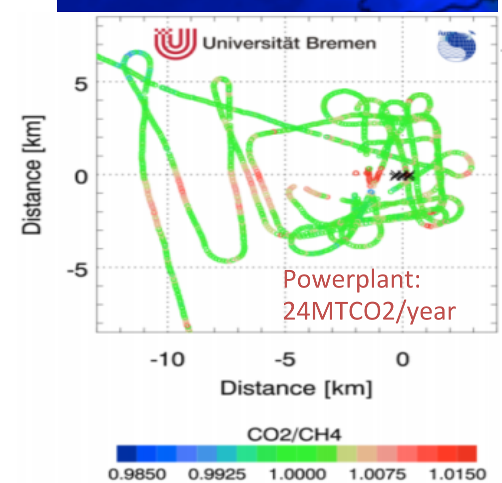


In combination with **inverse modeling** and robust **validation (TCCON)** this will address:

- 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**







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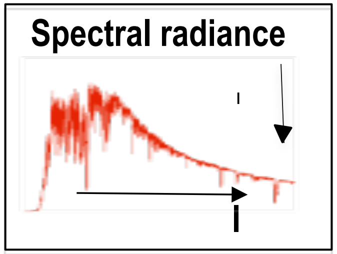


High spatial resolution and good coverage:

- **2×3 km² ground pixel, 180 – 240 km swath width**

Single error of column-averaged mixing ratios

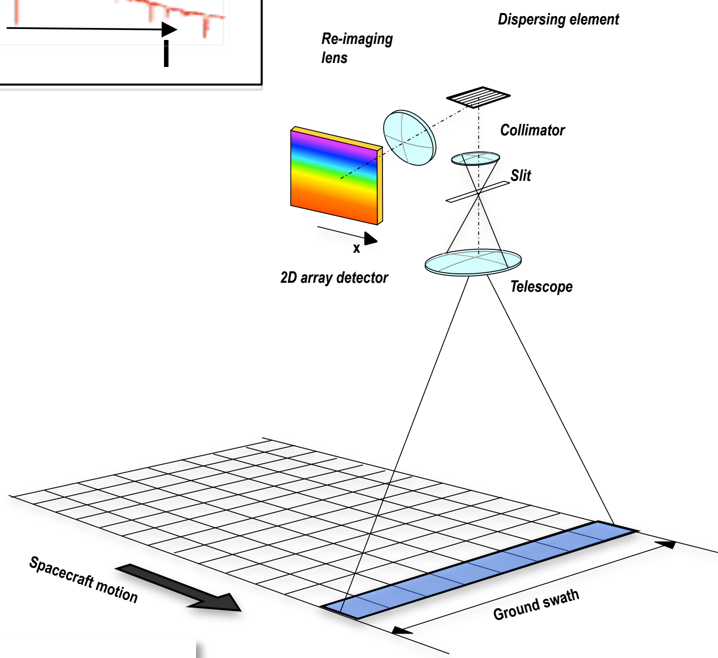
- **XCO_2 < 1 – 3 ppm, XCH_4 < 6 –12 ppb**

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**



COMEX Science Matrix

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).

1. Concurrent flights of AVIRIS NG and CIRPAS with MAMAP for Kern River Oil Field and Chino Dairy Complex with airborne *in situ* (Jun 4,13) and surface *in situ* (Jun 7,13).

2. Quantify CH_4 (CO_2) emissions over ocean using sun glint mode.

2. Successful concurrent sunglint flights of offshore CH_4 source by AVIRIS Classic and MAMAP (Jun 4).

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

1. Concurrent flights of AVIRIS NG and CIRPAS with MAMAP for Kern River Oil Field and Chino Dairy with airborne *in situ* (Jun 4,13) and surface *in situ* (Jun 7,13).

COMEX Mission

COMEX will calibrate / validate point source plume inverse-model derivation of greenhouse gas source emissions from *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.

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.

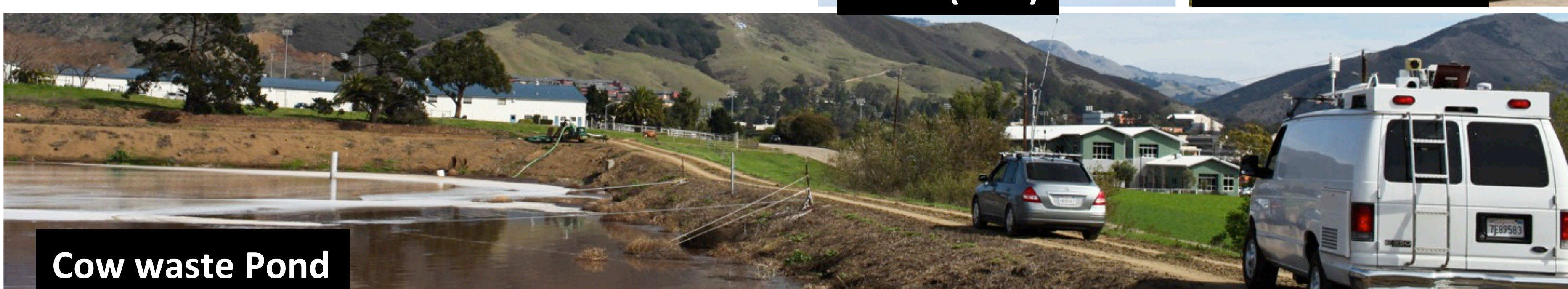
-> See Vigil et al poster


Mini-LHR (GSFC)


MACLab(BRI)


AJAX (ARC)


RAMVan (Aero)


Cow waste Pond

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)**

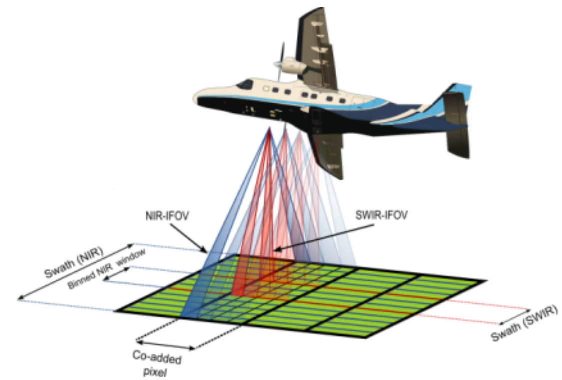
Methane Airborne Mapper MAMAP

developed by IUP Bremen in cooperation with GFZ Potsdam

MAMAP aims to support separating natural and anthropogenic fluxes with local **XCO_2 and XCH_4** data measuring gradients across localized CO_2 and CH_4 emission source.

Combined with **inverse modeling it allows**:

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



Sensor:

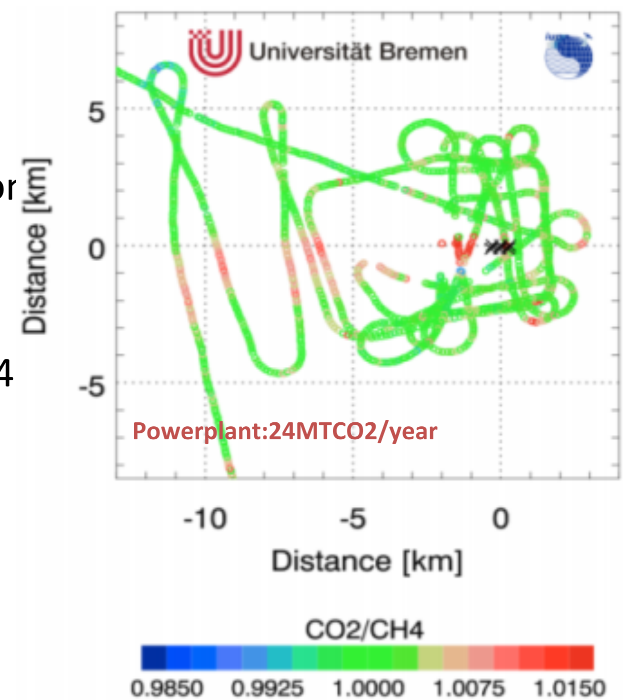
- 2-channel (NIR, SWIR-1) spectrometer
- Moderate spectral resolution (0.5-0.8 nm)
- Spatial resolution 30 – 50 m

Measurement principle:

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

Main data product:

- "column averaged dry air mole fractions" of CH_4 and 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.

Meteorology & Navigation

- Temperature
- Dewpoint
- Static Pressure
- Wind-Turbulence
- NovAtel
- TansVector
- C-Migets-II
- Radar Altimeter
- Heiman KT19.85

Aerosol & Cloud Physics

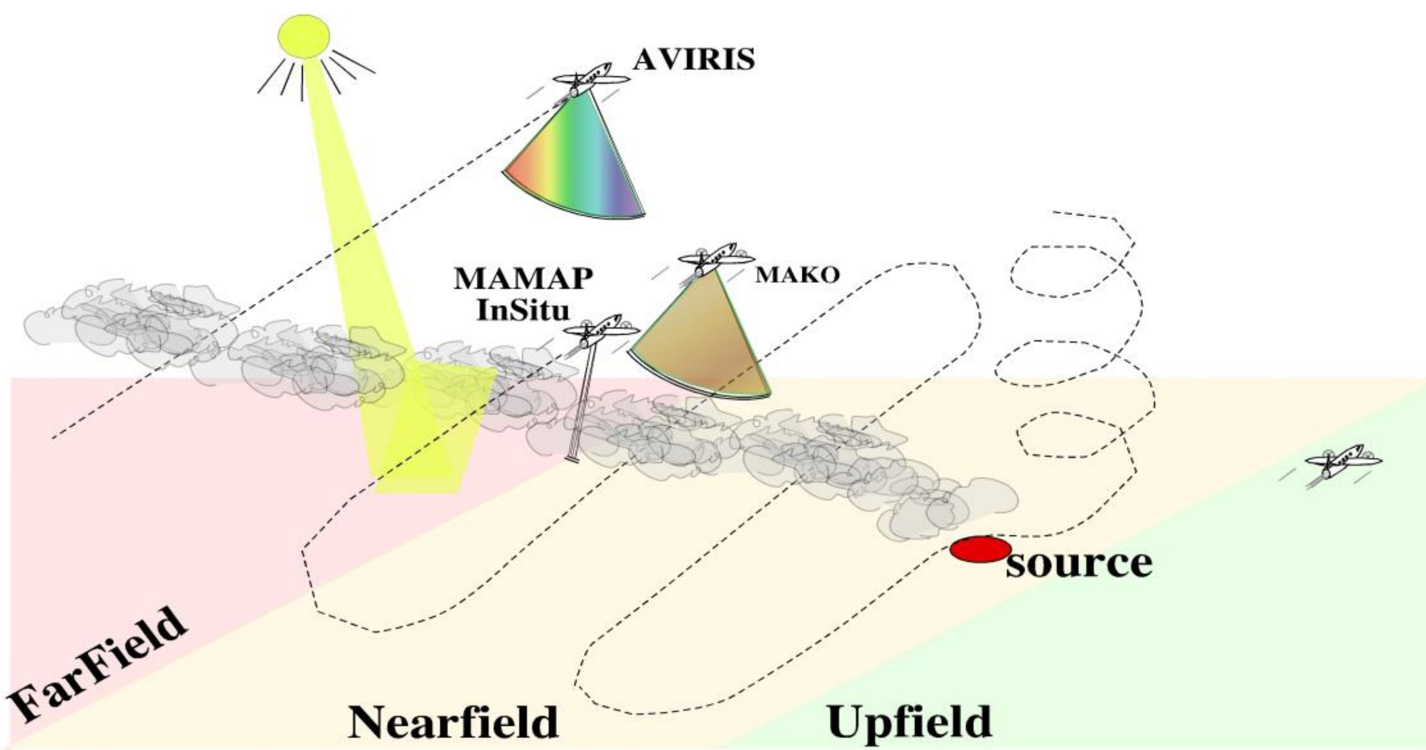
- PCASP

Guest Provided Instruments

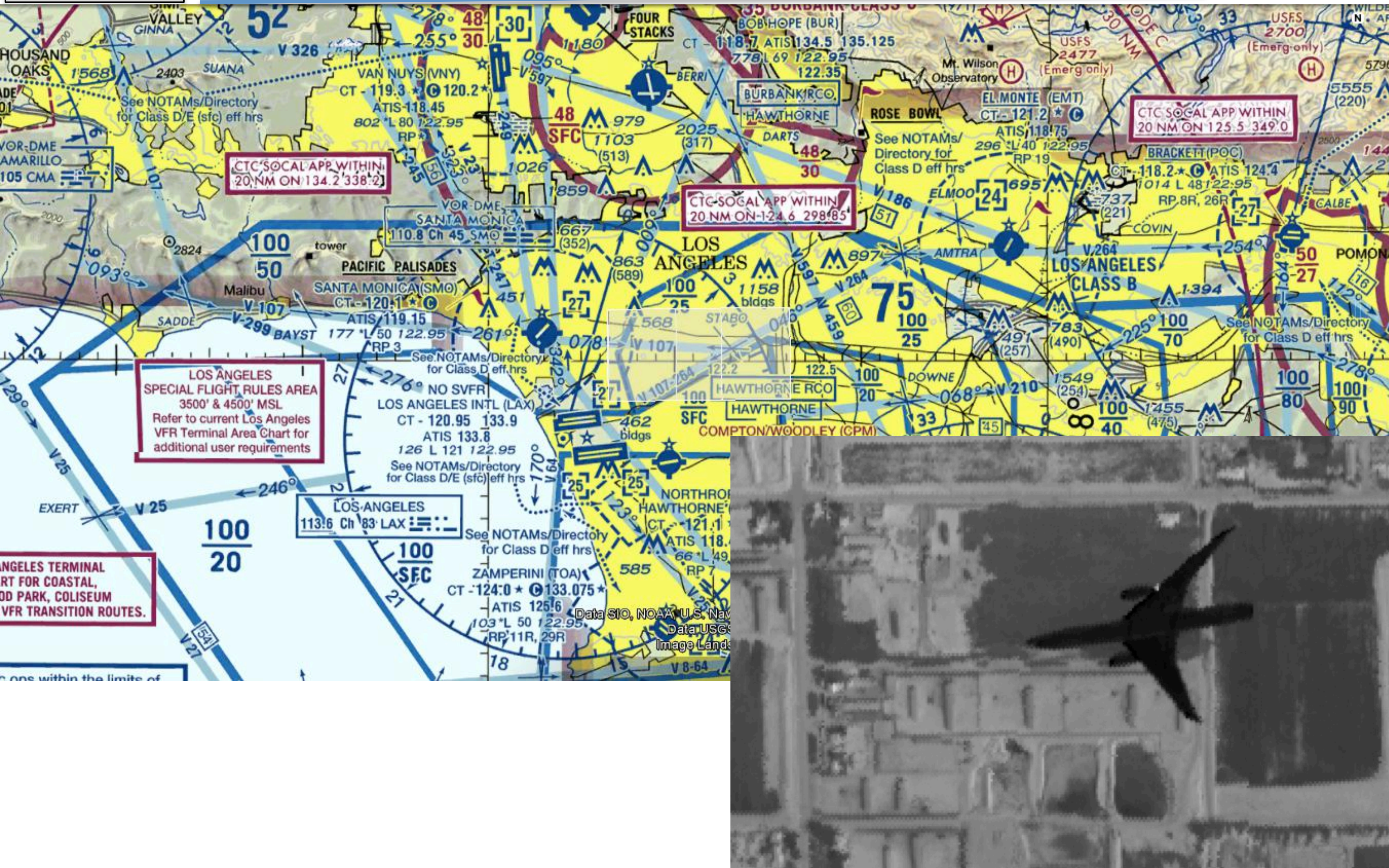
- PICARRO
- MAMAP
- LGR Isotope

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 realtime 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

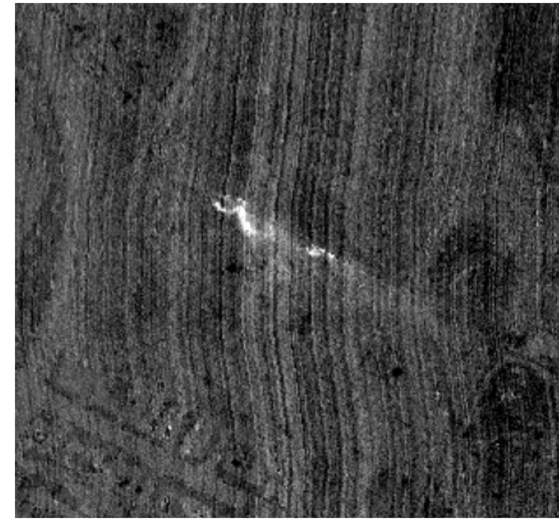
Vaisala roof sonic anemometer, sample line upgrade, NH_3 / O_3 and NO_2 machines on rear seat, (NH_3 machine uses LN2)

AMOG version X

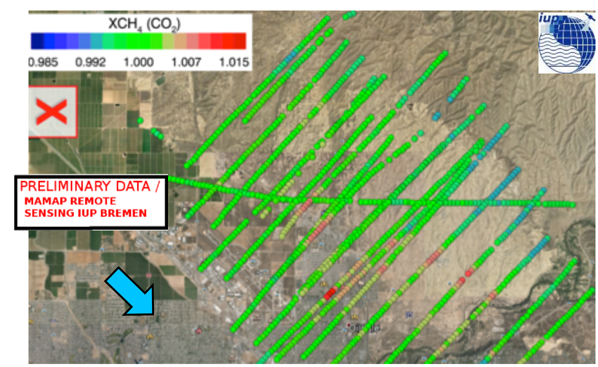
Problems: Heat – 108F in Bakersfield!!! Performance additions (1000 lbs over stock), 3.2kW alternator, Limo-dark tinting, sunroof for cryogenics, solar panel spoilers, backseat 8000 btu AC, high speed network and backup, etc.

June COMEX Ops

Date	CIRPAS MAMAP	ER2 AVIRIS C	TwinOtter AVIRIS NG	AJAX InSitu	AMOG
30-May Fr	Harris				
3-Jun Tu	Kern				
4-Jun We	COP	COP,Kern			
7-Jun Sa					Chino, Puente
9-Jun Mo	Kern				
10-Jun Tu				Kern	
13-Jun Fr	Kern	LA Basin	Kern		Kern



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.

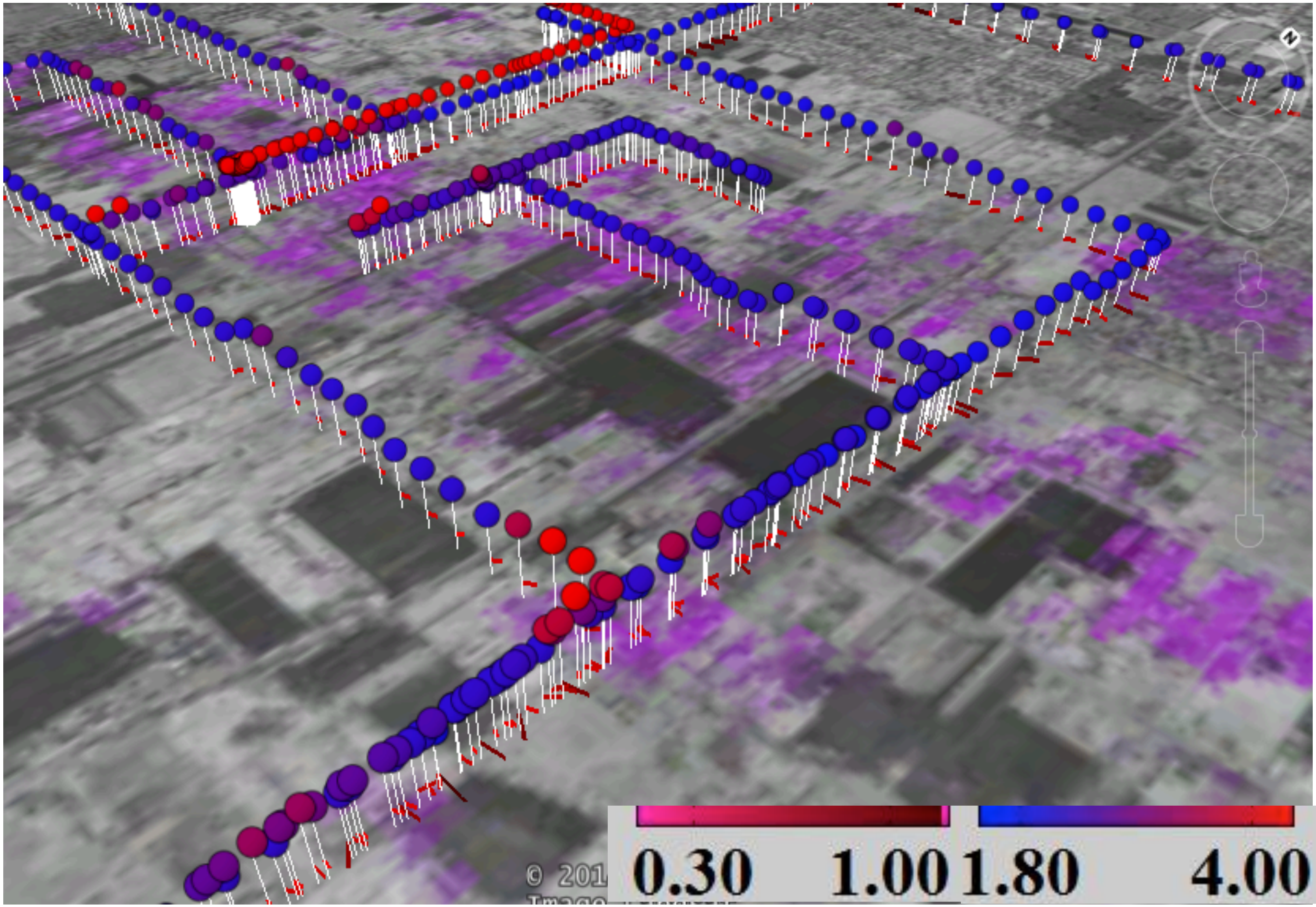
July COMEX Ops (Mako & AMOG)

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.

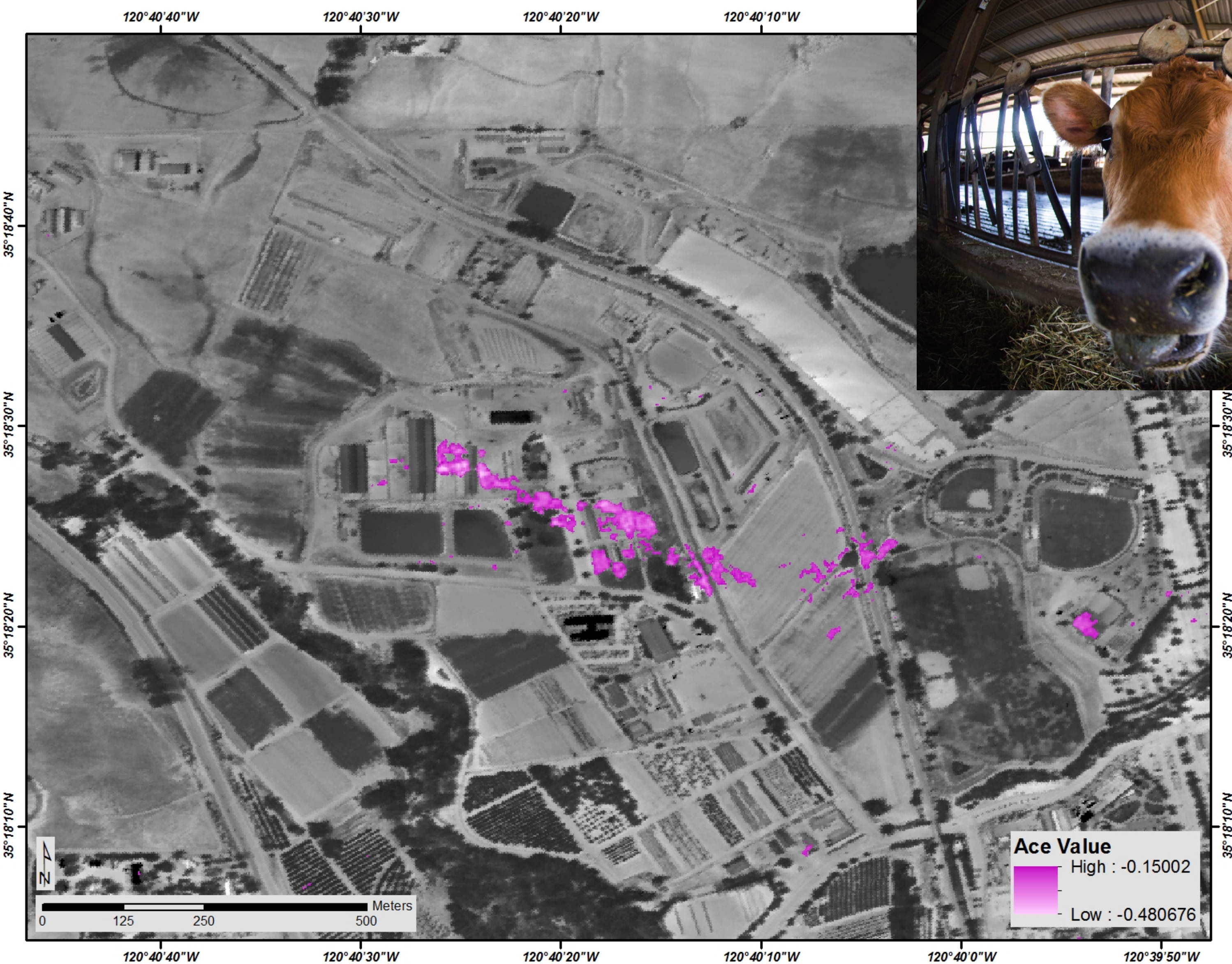
Mako participates in COMEX with support provided by The Aerospace Corporation's *Independent Research and Development Program*.

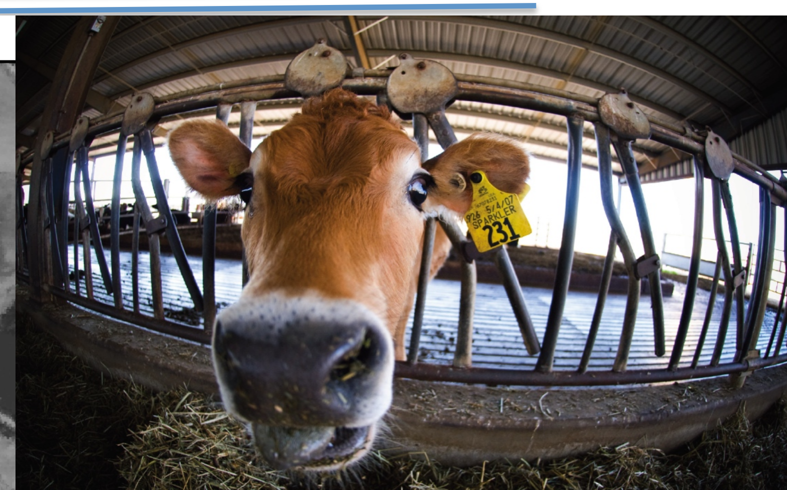
TIR Imaging Spectroscopy w/AMOG validation
Chino Dairy Complex



Wind (m/s) CH4 (ppm)

Mako TIR Imaging Spectroscopy of Cal Poly Dairy – NH3 filterlex





August COMEX Ops

August COMEX Ops

				Target	BOX	CIRPAS*	AVIRIS NG*	AVIRIS C	Alpha*	AMOG
Day 0	21-Aug		*Engineer*	Kern	SB1	4.8				
Day 1	23-Aug	Sa	*Transit*	S. Bellridge / Midway Sunset	SB3/SB4	4.6				
	24-Aug	Su		No Flights						
Day 2	25-Aug	Mo		COP	SB2	4.8				
Day 3	26-Aug	Tu		Kern	SB1	4.8		Overfly one Leg@Kern		
Day 4	27-Aug	We		Puente-Baldwin	LA3 - LA7	4.8				
Day 5	28-Aug	Th		Olinda/Puente	LA5	2.8				
Day 6	29-Aug	Fr		LA Basin /Carson	LA8 / L2	2.9		SB Box-tbc	0.68	Mojave
	30-Aug	Sa		Hard down day						
	31-Aug	Su		Hard down day						
Day 7	1-Sep	Mo		Olinda/BKK	LA5	3.4				
Day 8	2-Sep	Tu		Kern	SB1	5	5.5		XXX	
Day 9	3-Sep	We		Chino	LA1	*5*	6			Kern
Day 10	4-Sep	Th		Kern	SB2	*5*	6			Chino
Day 11	5-Sep	F	*Transit*	transit only		*2*				

Atmo-Correct Experiment

Five lines from 20,000 to 1,500 ft AGL (20k, 15k, 7.5k, 5k, 2.5k, 1-1.5k – ATC)

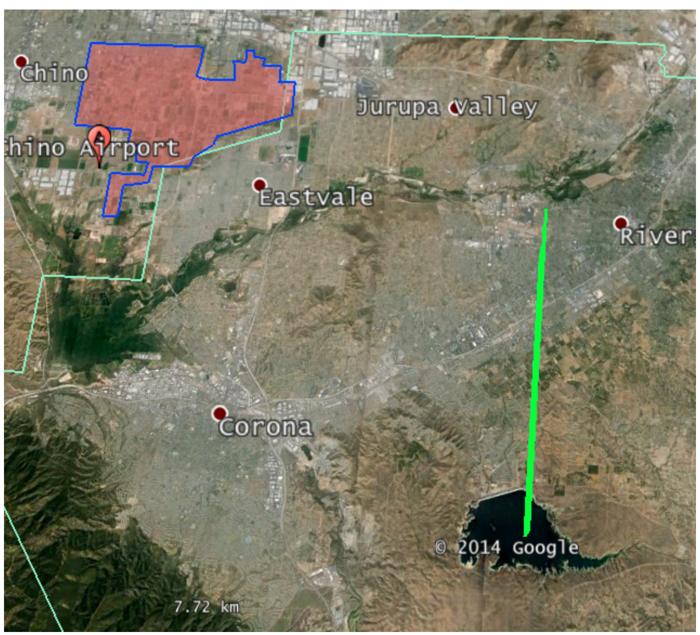
~12 km each 8 min, about 8 min each descent – 16*6 = 110 min

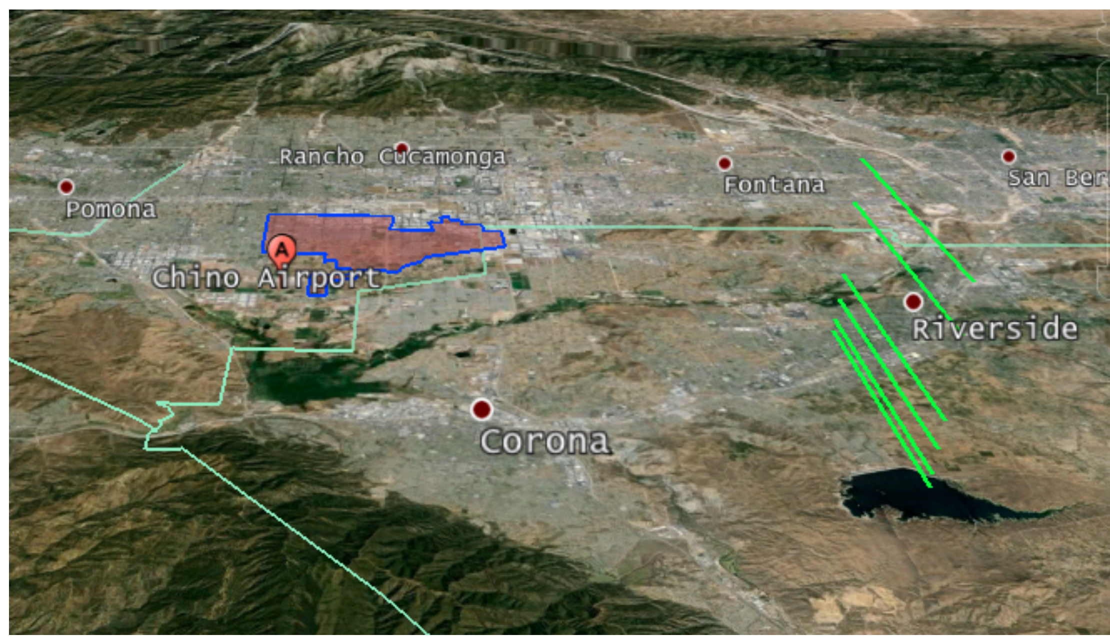
- Transit to rise to 20k
- Solar noon +/- 1 hr (same air up-down) based on forecast for intermediate winds
- CIRPAS profiles boundary layer and 2500 ft above:

→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





COMEX August 2014

Key COMEX Insights

- Upon site arrival conduct a profile to identify location of the boundary layer (CH_4 is constrained).
- Nocturnal 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

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.