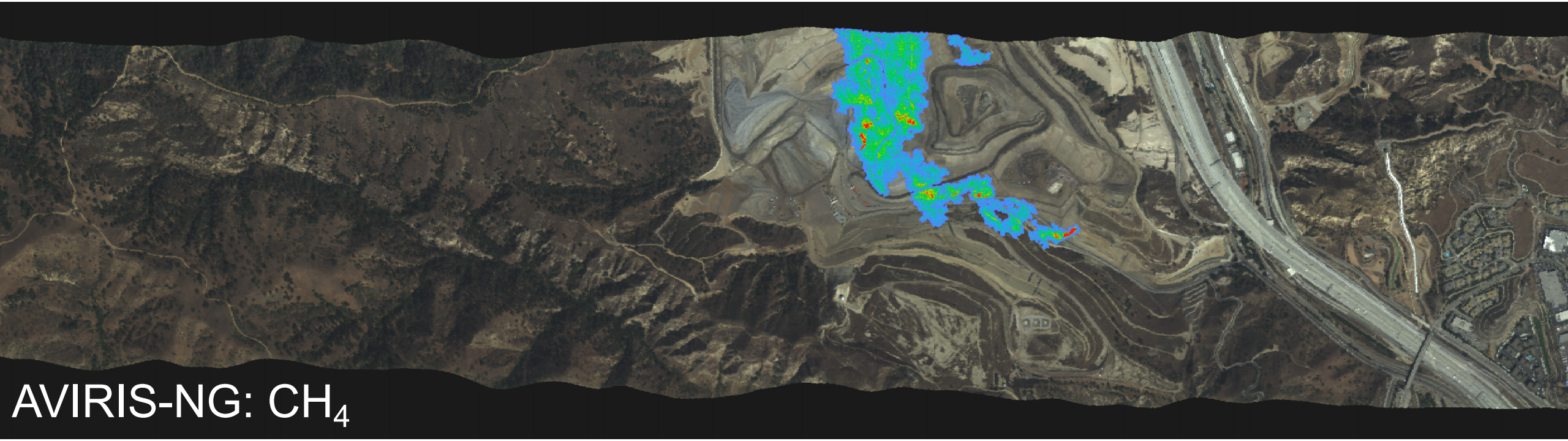
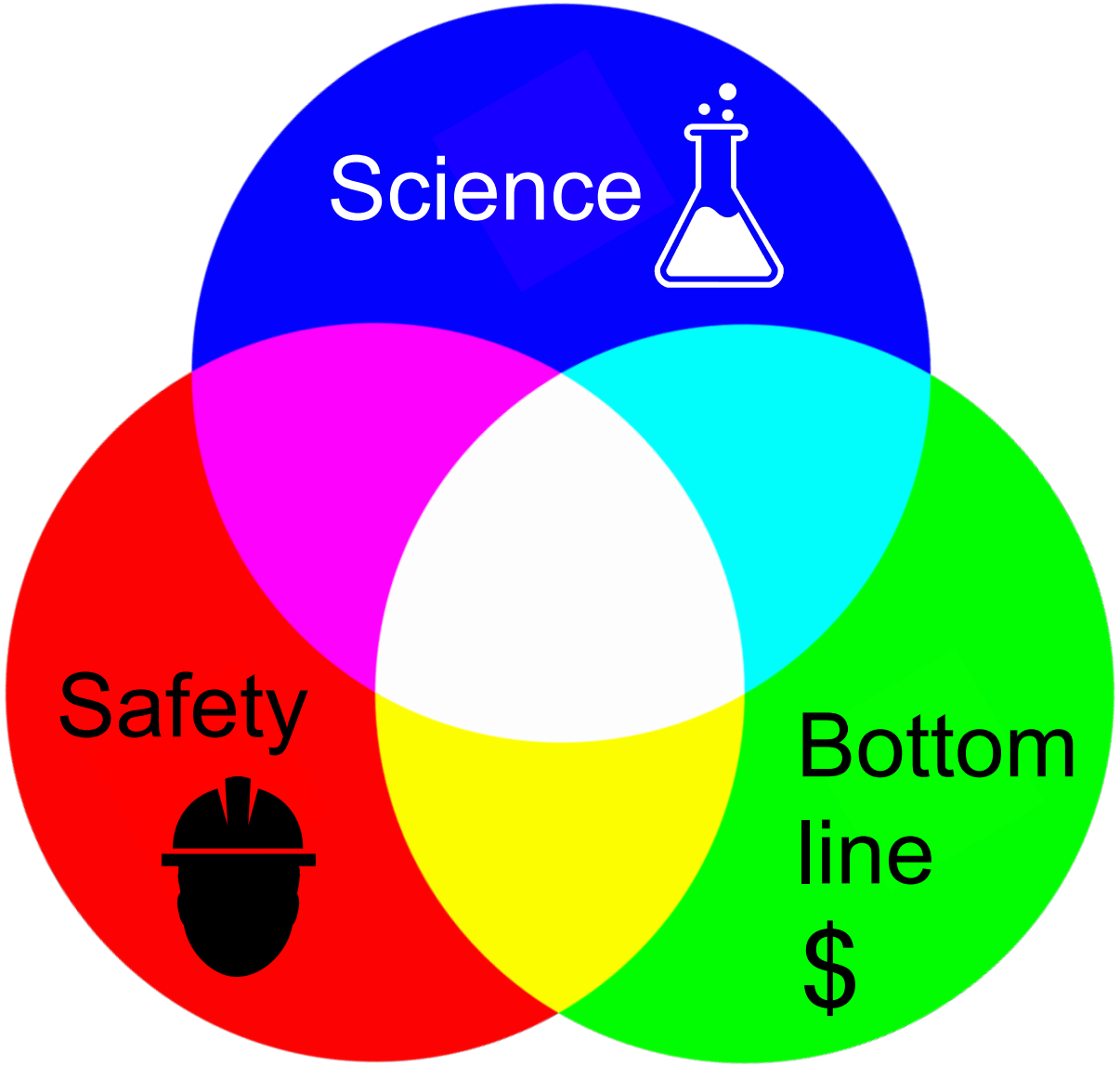
Characterizing methane emissions using remote sensing



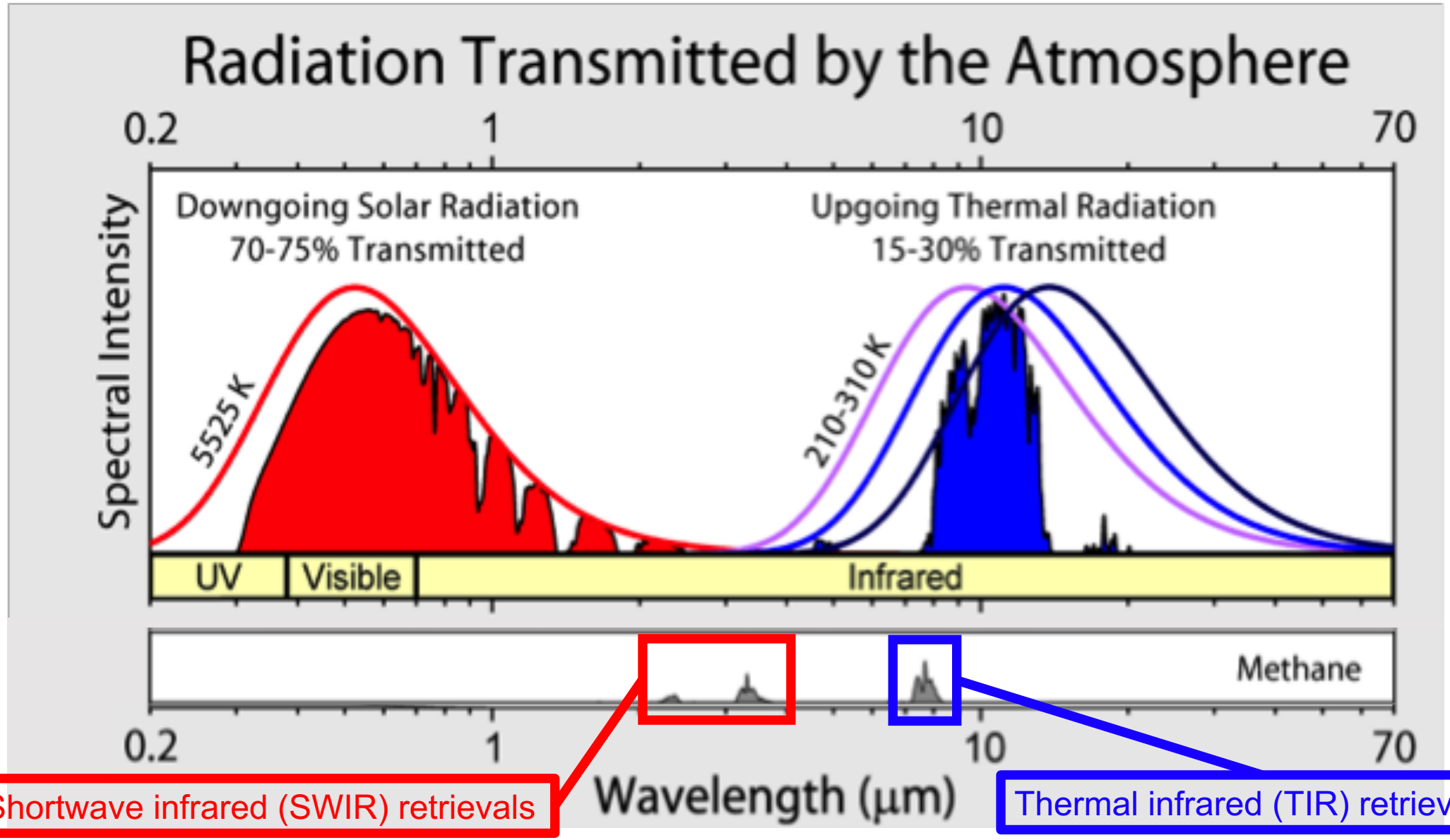
Thorpe, A.K.[1], Duren, R.M.[1]

[1]NASA Jet Propulsion Laboratory, California Institute of Technology

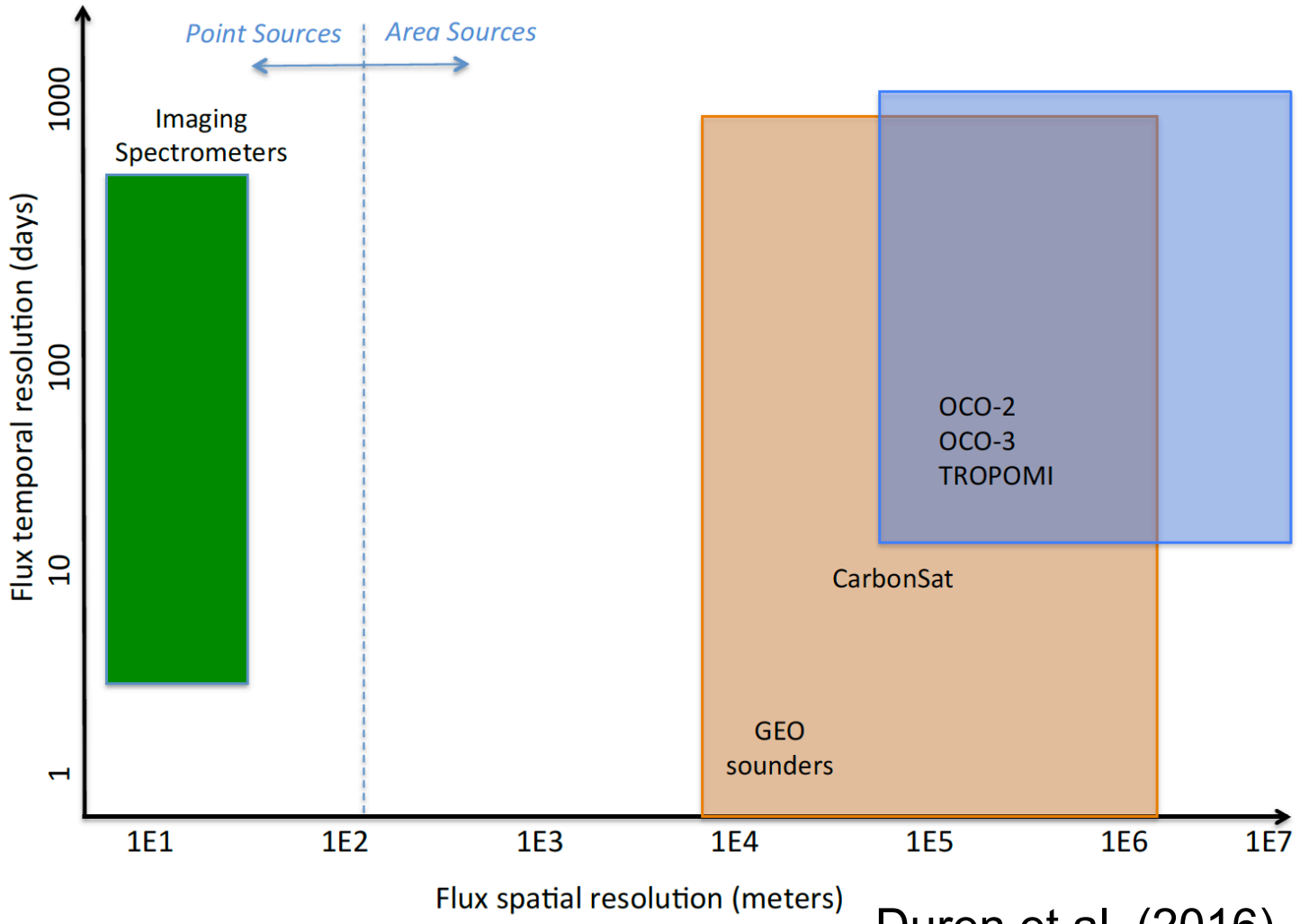
Motivation



Measurement strategies



Measurement strategies

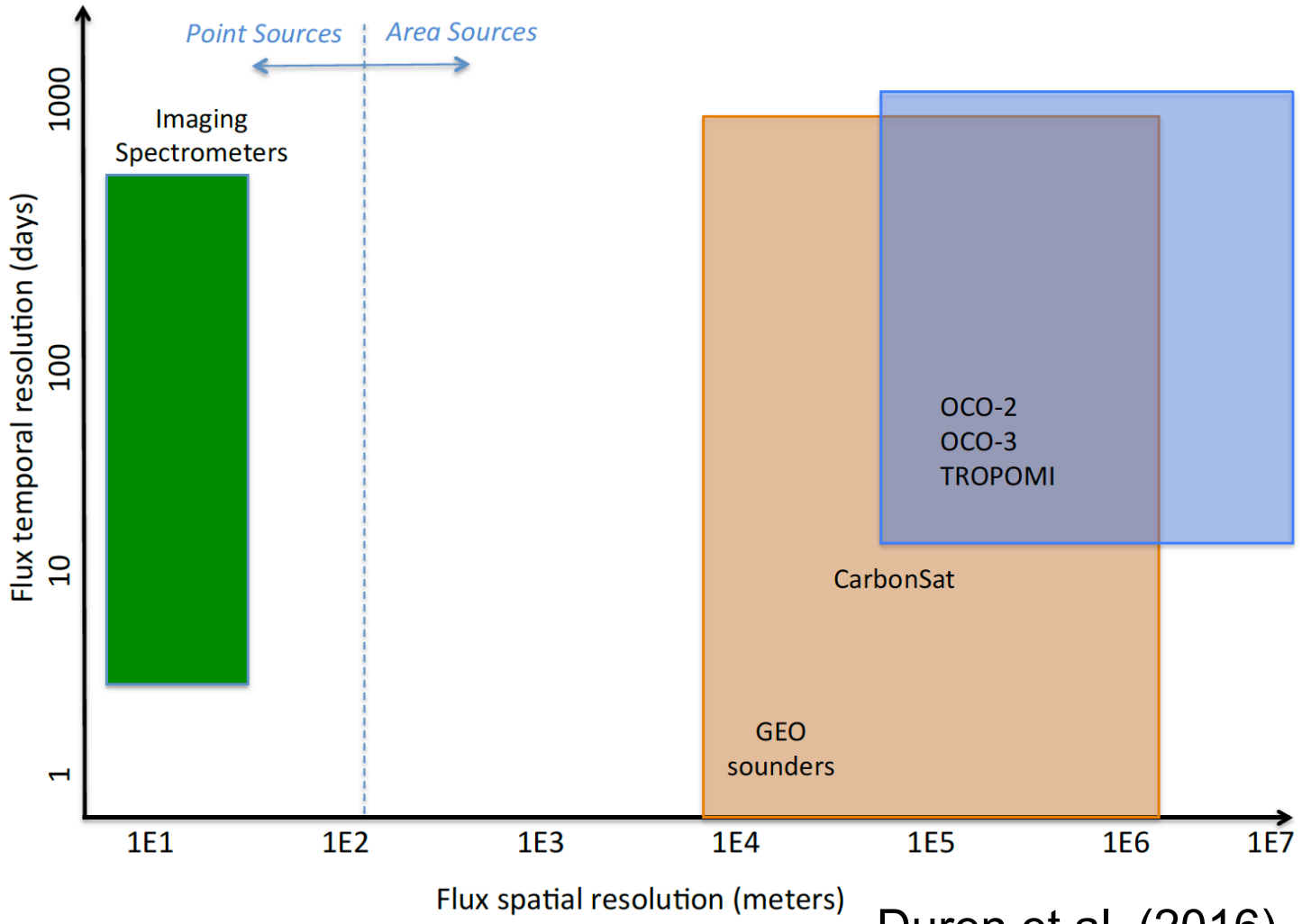


Duren et al. (2016)

Measurement strategies

Moderate spectral resolution
Finer spatial resolution

Finer spectral resolution
Coarser spatial resolution

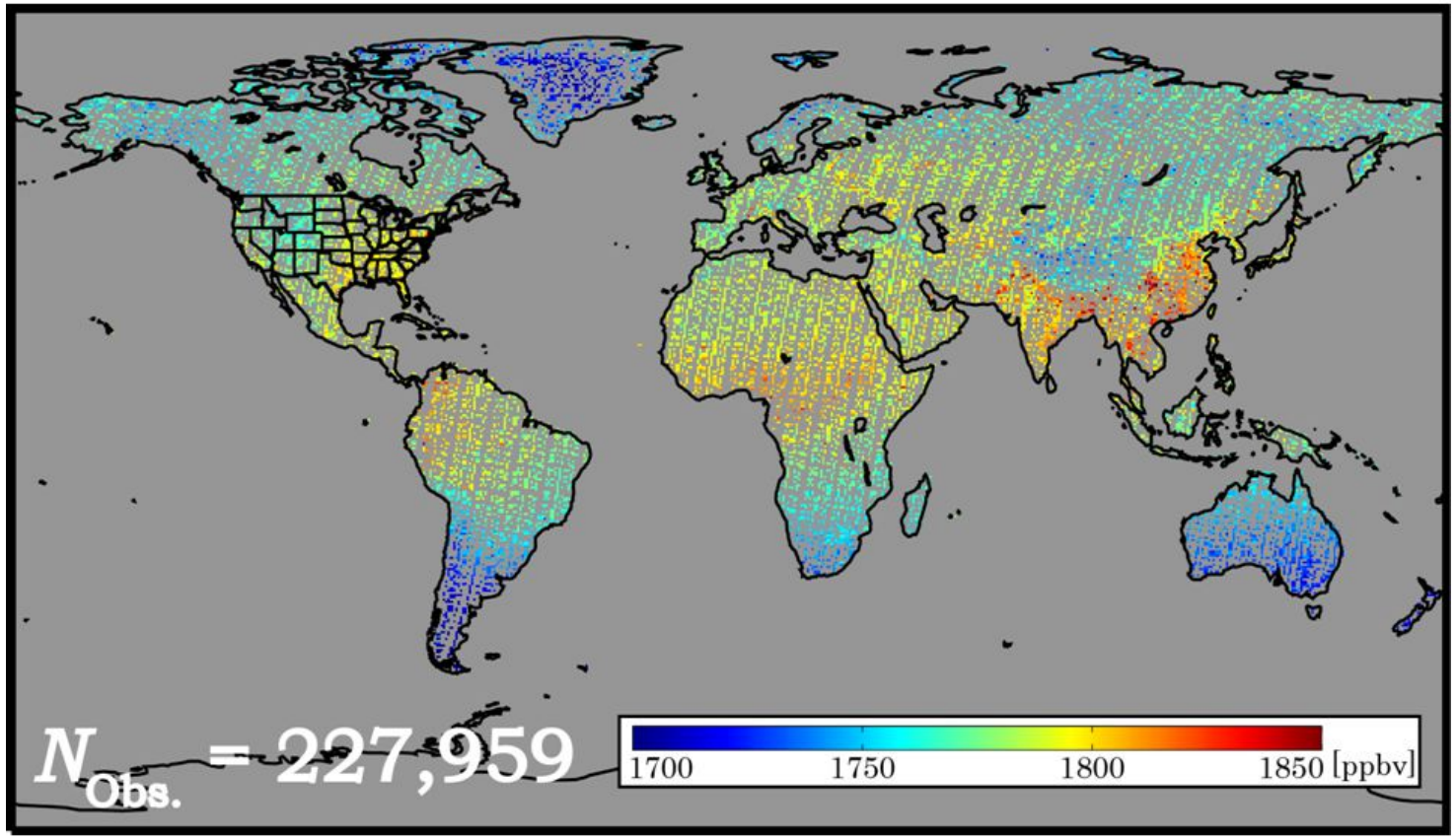


Duren et al. (2016)

Greenhouse Gases Observing Satellite (GOSAT)

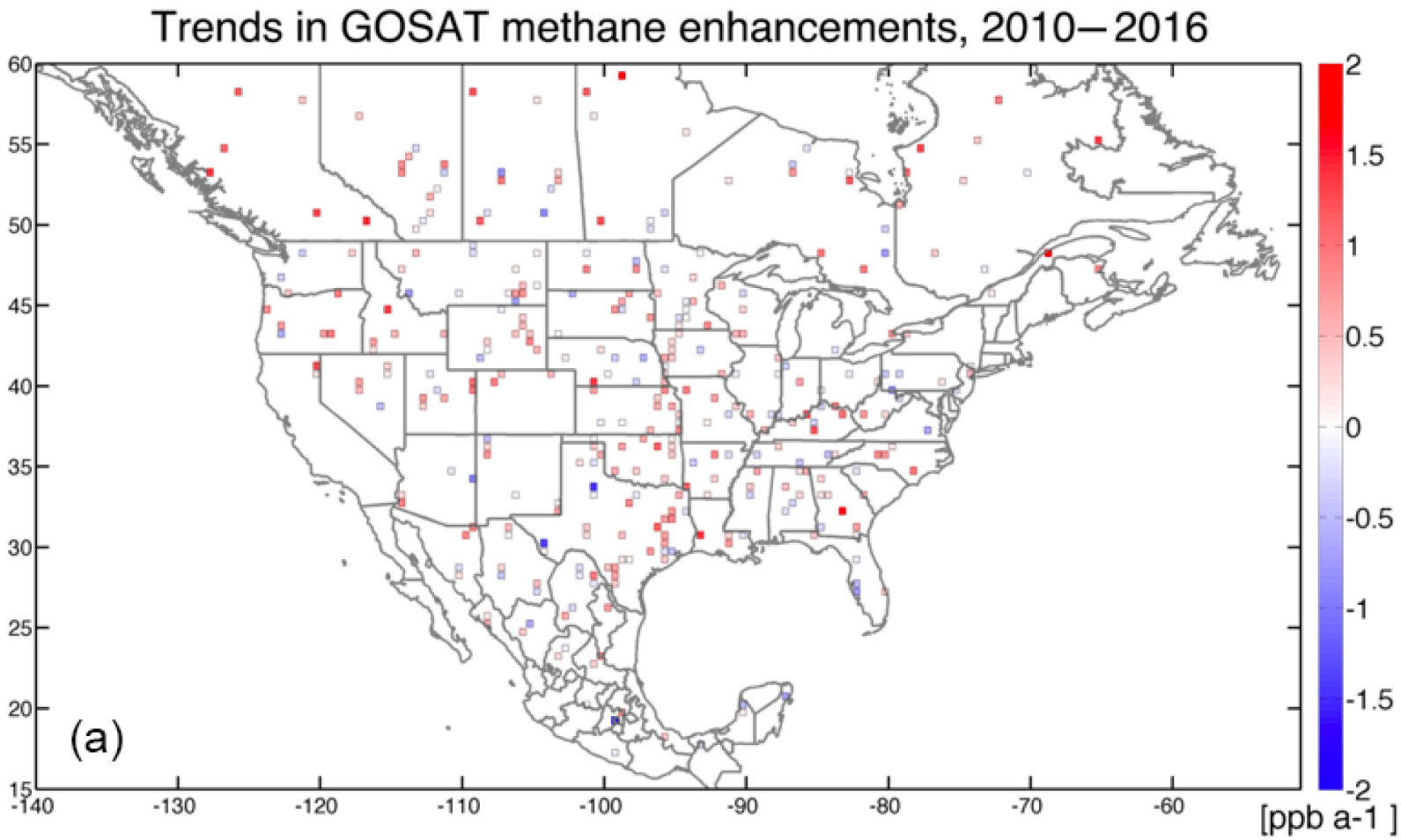
Instrument	**GOSAT/GOSAT-2**
County	Japan, JAXA
Launch date	Jan. 2009/Oct. 2018
Type	Fourier Transform Spectrometer (FTS)
CH_4 retrieval	1.56-1.72 nm
Spectral resolution	0.27 cm^{-1}
Spatial resolution	10.5 km diameter
Orbit type	Sun synchronous
Repeat interval	6 days

GOSAT methane column mixing ratios, Oct 2009-2010



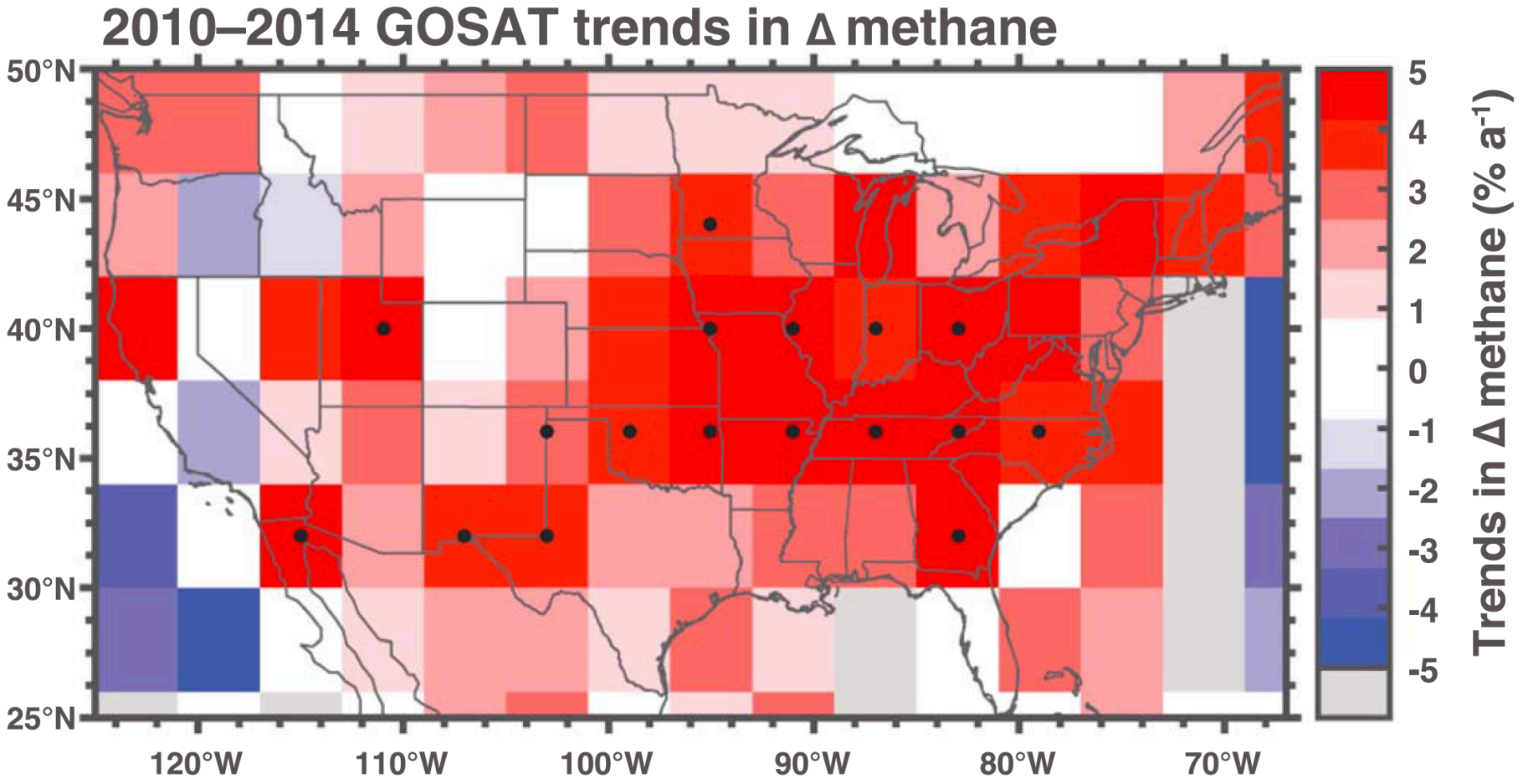
Retrieval from U. Leicester

GOSAT methane results



2010–2016 trends in GOSAT methane enhancements over North America. Ordinary least-squares linear regression trends for 0.5x0.5° grid cells with sufficient GOSAT observations. **The trends are not statistically significant at that resolution** (Sheng et al., 2018).

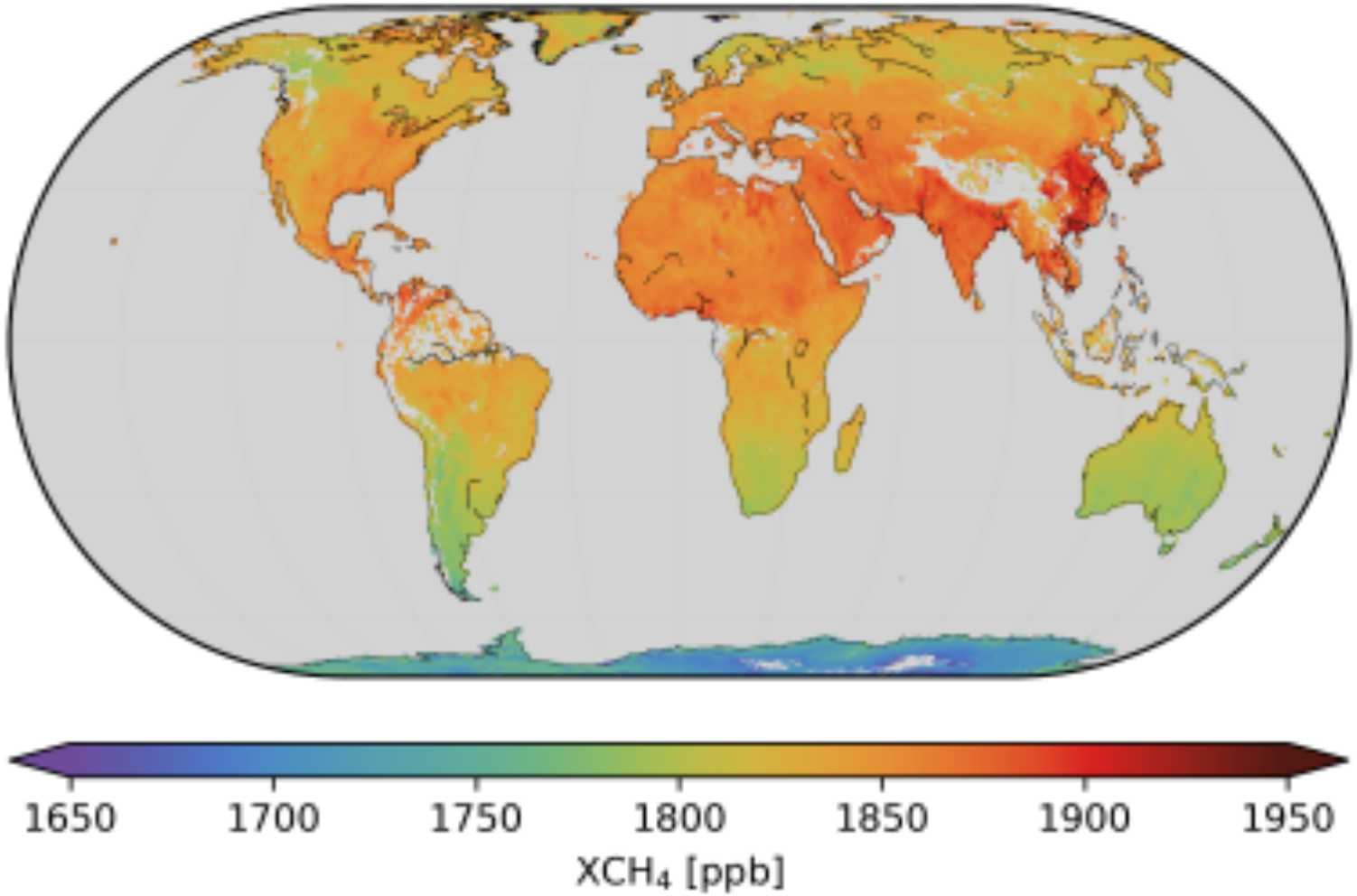
GOSAT methane results



The 2010–2014 trend in U.S. methane enhancements as seen from GOSAT. Trends computed on a 4x4° grid. Statistically significant trends ($p < 0.01$) are indicated by a dot (Turner et al., 2016).

TROPOspheric Monitoring Instrument (TROPOMI) satellite

Instrument	**TROPOMI**
Country	Netherlands, ESA/NSO
Launch date	Oct. 2017
Type	Grating pushbroom spectrometer
CH_4 retrieval	2299-2390 nm
Spectral resolution	0.25 nm
Spatial resolution	7x7 km; 2600 km swath
Orbit type	Sun synchronous
Repeat interval	Global coverage daily



CH_4 total column mixing ration averaged from May 2018 to January 2019 (Image credit: TROPOMI website).

TROPOMI satellite

Instrument	**TROPOMI**
Country	Netherlands, ESA/NSO
Launch date	Oct. 2017
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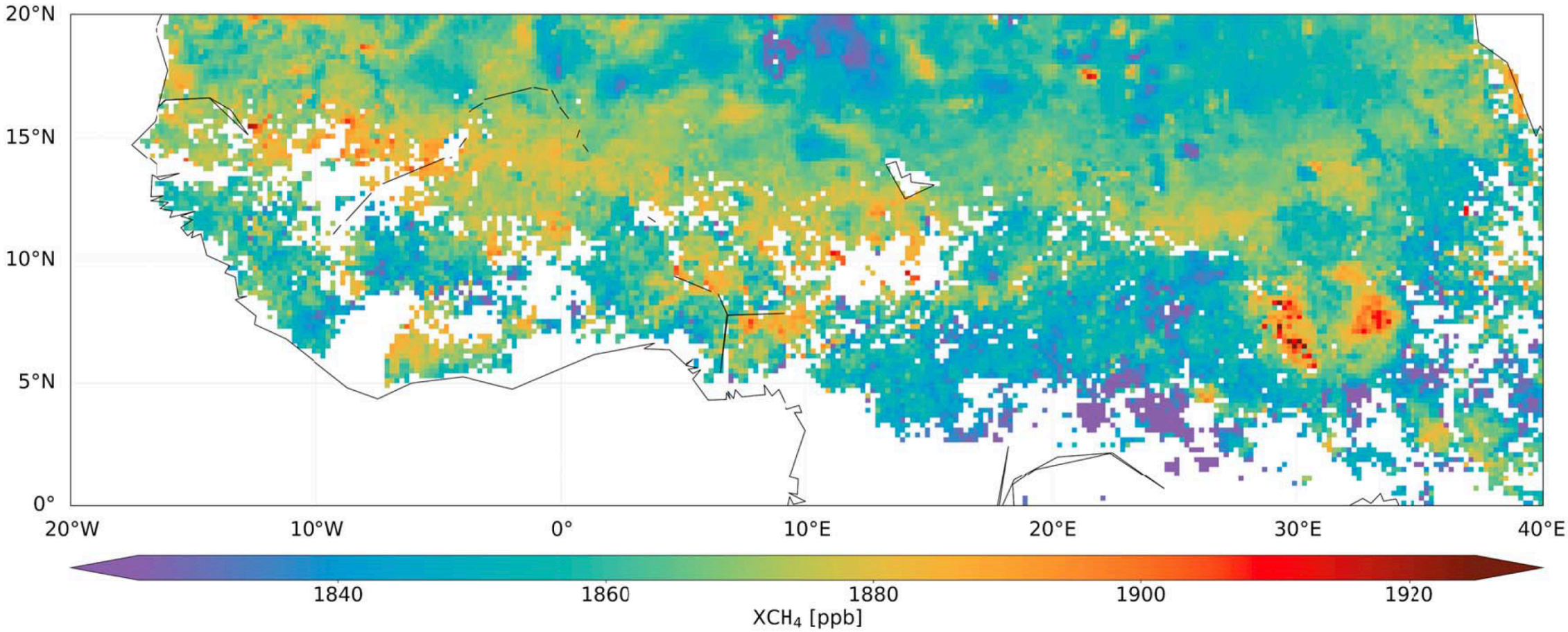
Orbit type	Sun synchronous
Repeat interval	Global coverage daily

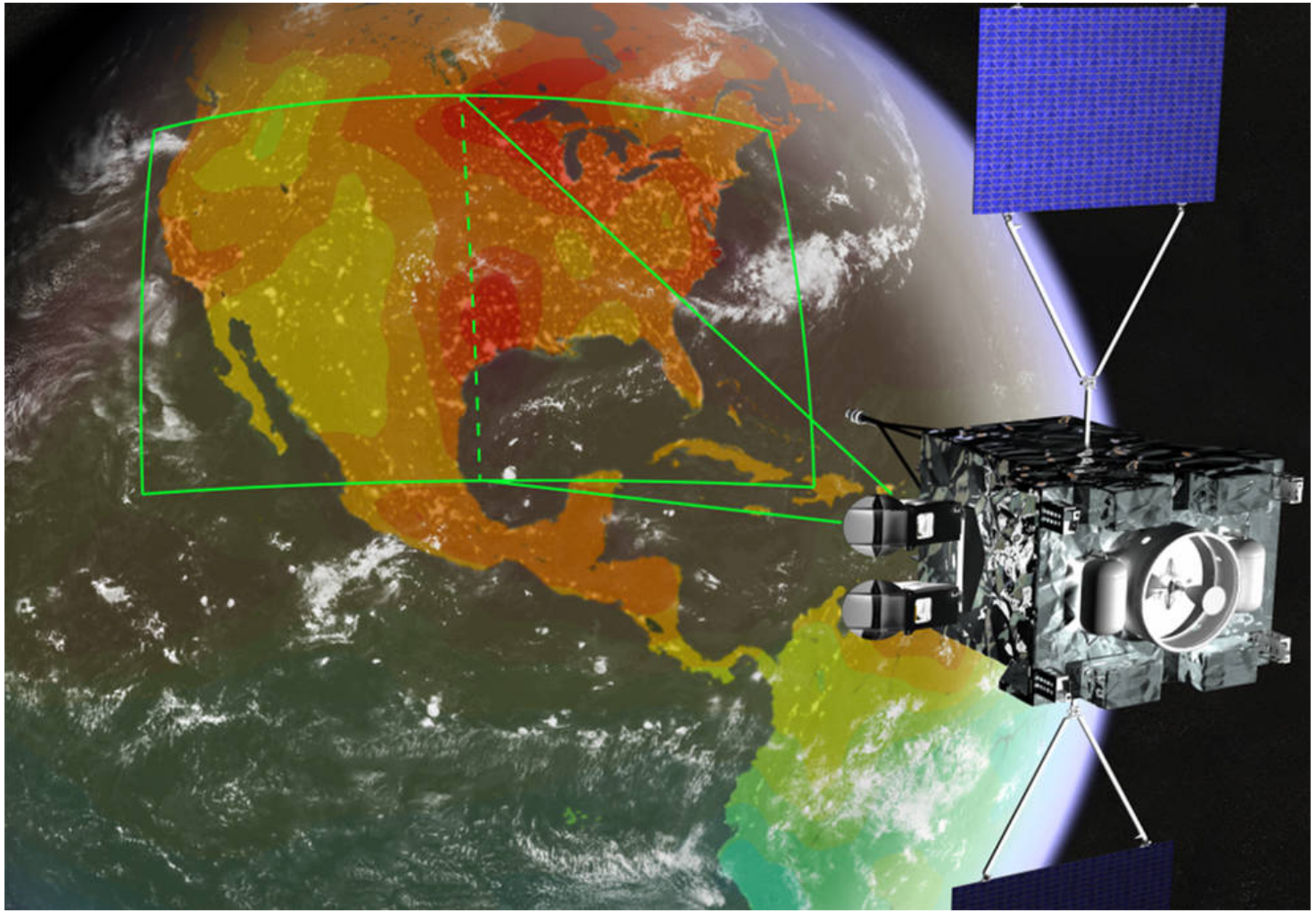
TROPOMI methane results



TROPOMI XCH4 over western and central Africa averaged from 12 November to 30 December 2017 (Hu et al., 2018). **Similar hotspots are observed over the United States, but remain unpublished to date.**

Geostationary Carbon Cycle Observatory (GeoCARB) satellite

Instrument	**GeoCARB**
Country	USA, NASA
Launch date	2022
Type	Grating pushbroom spectrometer
CH_4 retrieval	2300-2345 nm
Spectral resolution	0.22 nm
Spatial resolution	TBD, 5-10 km; 2800 km swath
Orbit type	Geostationary
Repeat interval	Selected coverage daily (USA: 2.25 hours)



Artist's illustration of a concept for NASA's GeoCarb mission. Image credit: NASA/Lockheed Martin/University of Oklahoma.

Other methane satellite instruments

Shortwave infrared (SWIR) sensor:

- SCIAMACHY (SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY), DLR/NSO/ESA, 2012 end of mission

Active sensor:

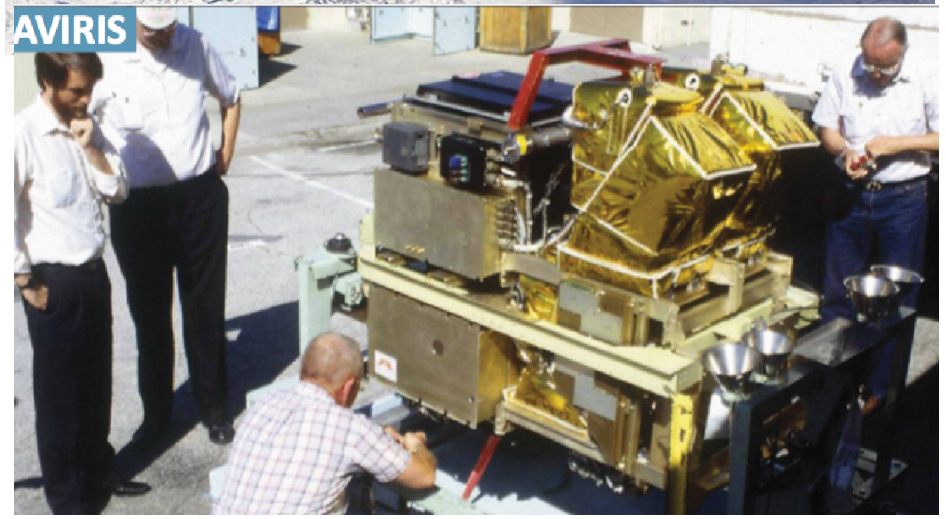
- Methane Remote Sensing Lidar Mission (MERLIN), 1645 nm laser, DLR/CNES, 2021 launch

Thermal infrared (TIR) sensors:

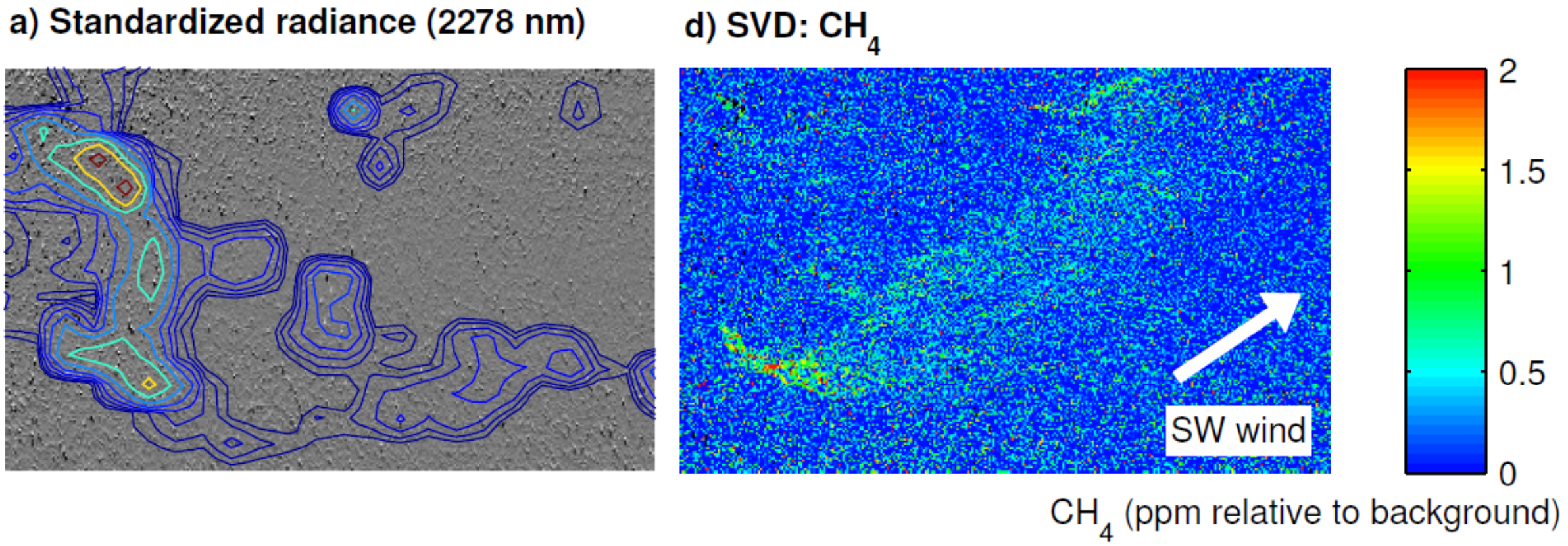
- Atmospheric infrared sounder (AIRS), NASA, 2002 launch
- Tropospheric Emission Spectrometer (TES), NASA, 2004 launch
- Infrared Atmospheric Sounding Interferometer (IASI), CNES/EUMETSAT, 2006/13/18 launch

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)

Instrument	**AVIRIS**
Country	USA, JPL/NASA
Operation period	1987-present
Type	Grating whiskbroom spectrometer
CH_4 retrieval	2100-2400 nm
Spectral resolution	10 nm
Spatial resolution	Varies with flight altitude, 9-20 m; 5-12 km swath
Aircraft type	Primarily NASA ER-2
Repeat interval	Variable based on flight plans

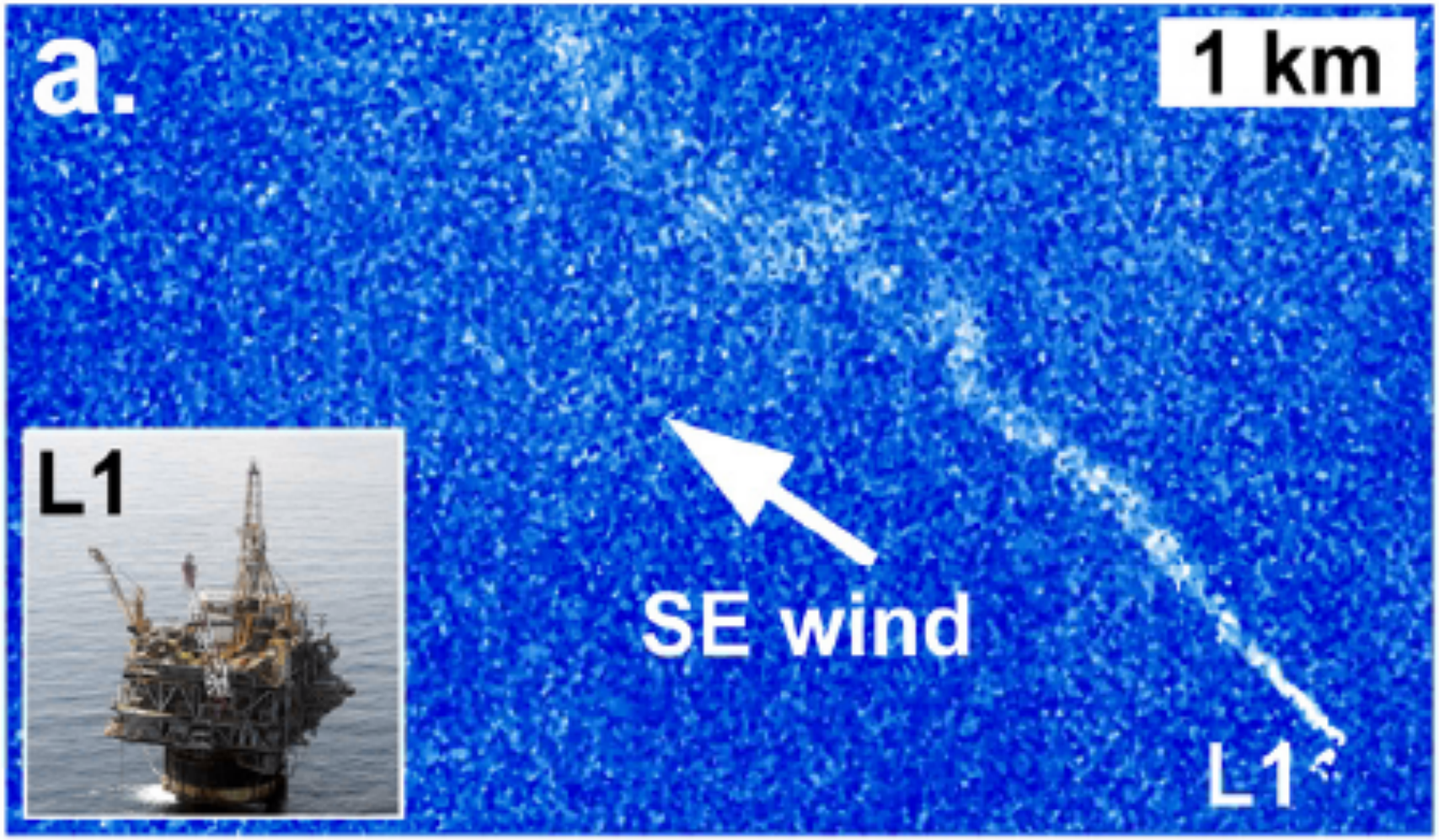


AVIRIS methane results



Right: Methane plumes observed from natural emissions at Coal Oil Point (offshore Santa Barbara, CA). Left: Standardized radiance with sonar contours indicating locations of seeps (Thorpe et al., 2013, 2014)

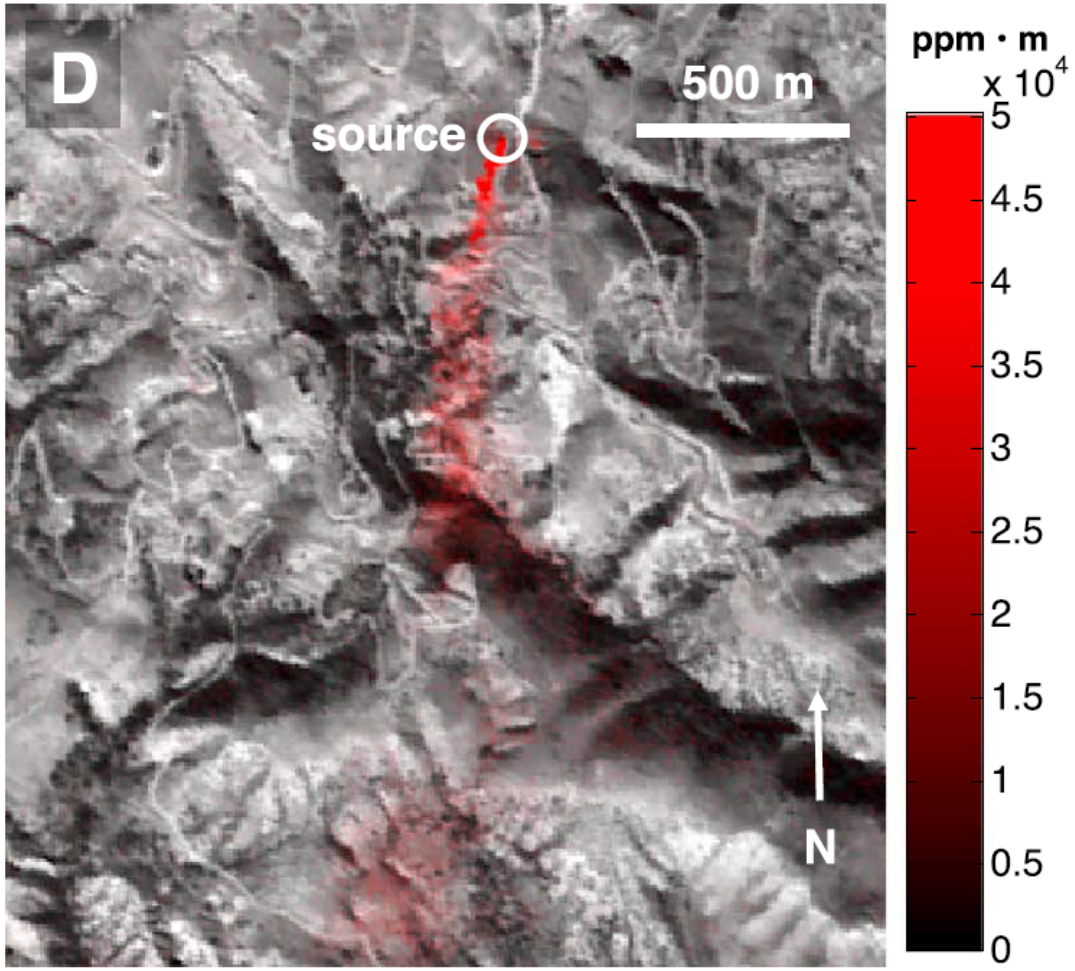
AVIRIS methane results



Methane plume from oil platform that employs cold venting rather than flaring gas (Thorpe et al., unpublished).

AVIRIS methane results

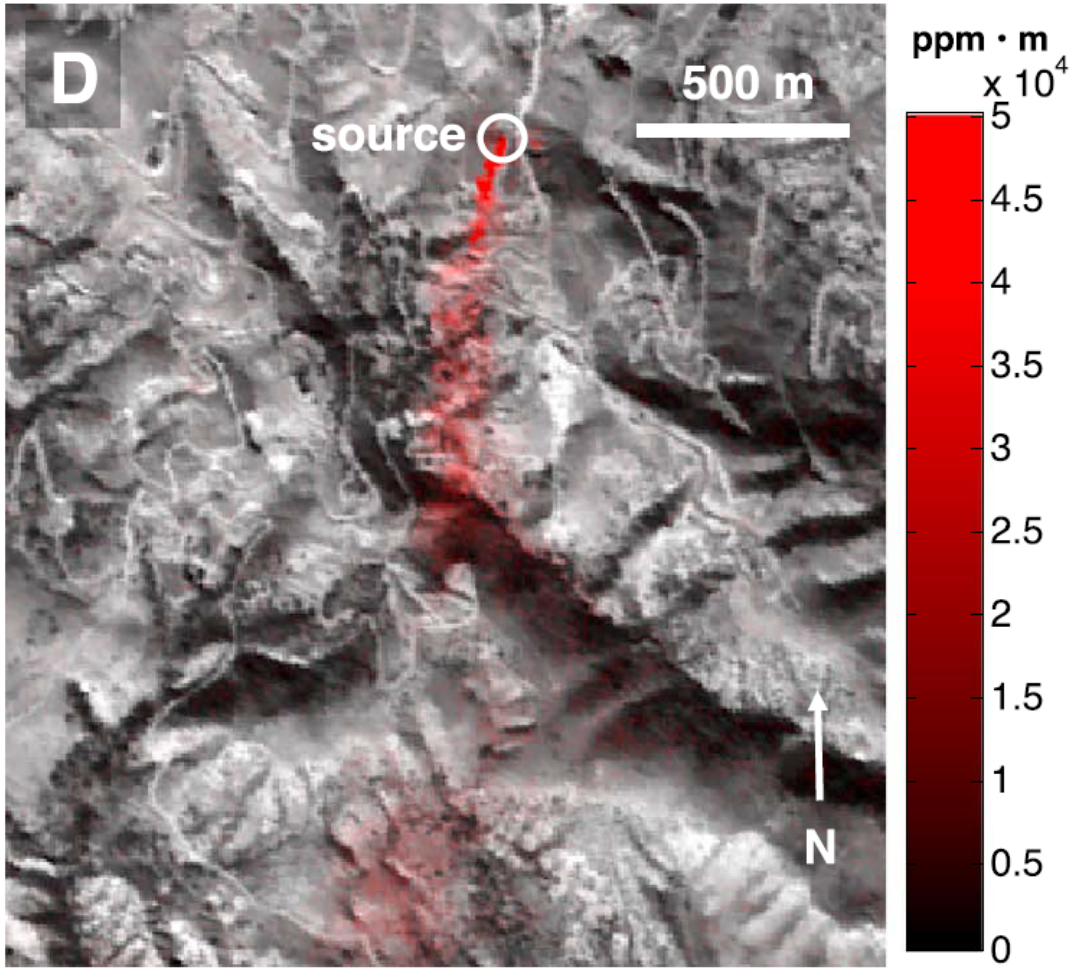
AVIRIS (10 nm): 1/12/16, 20:25 UTC
Aircraft at 6.6 km above ground level



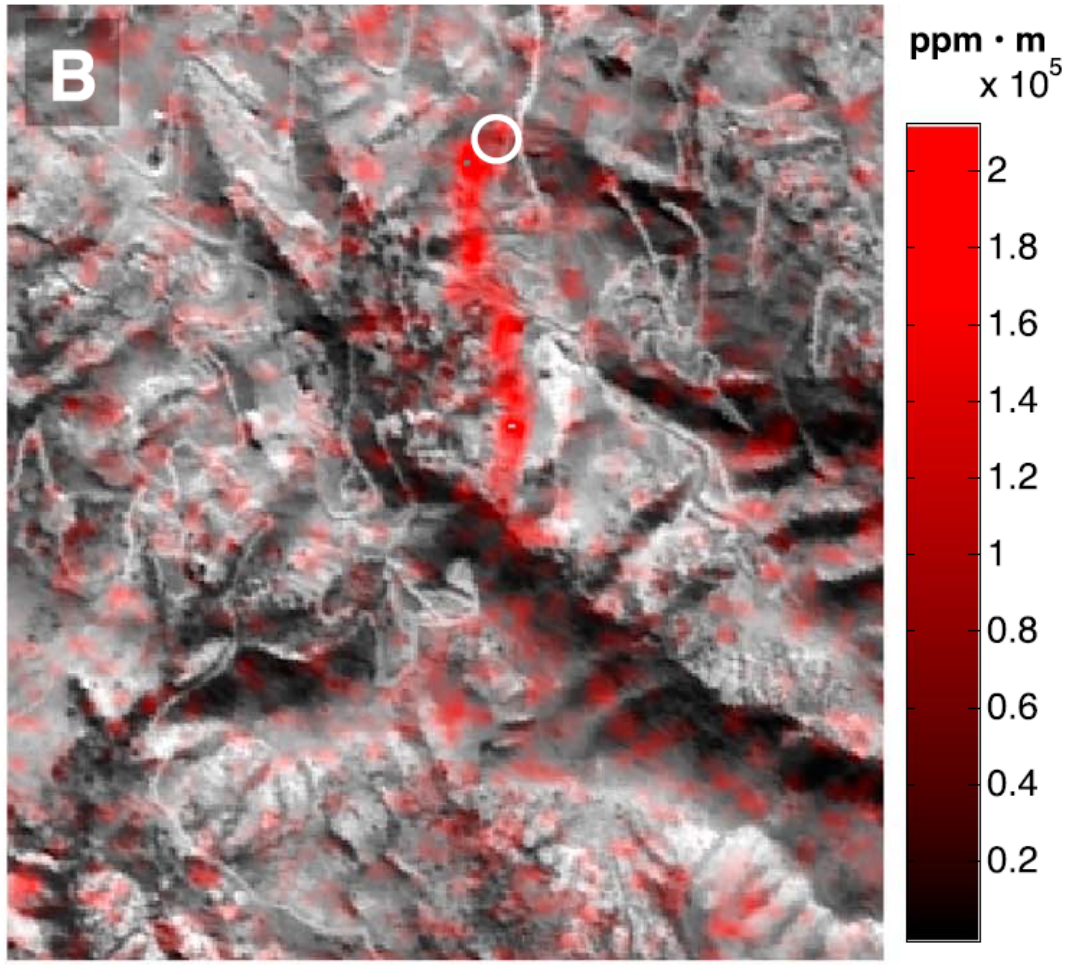
Methane plume from Aliso Canyon leak observed with imaging spectrometers (Thompson et al., 2016).

AVIRIS methane results

AVIRIS (10 nm): 1/12/16, 20:25 UTC
Aircraft at 6.6 km above ground level



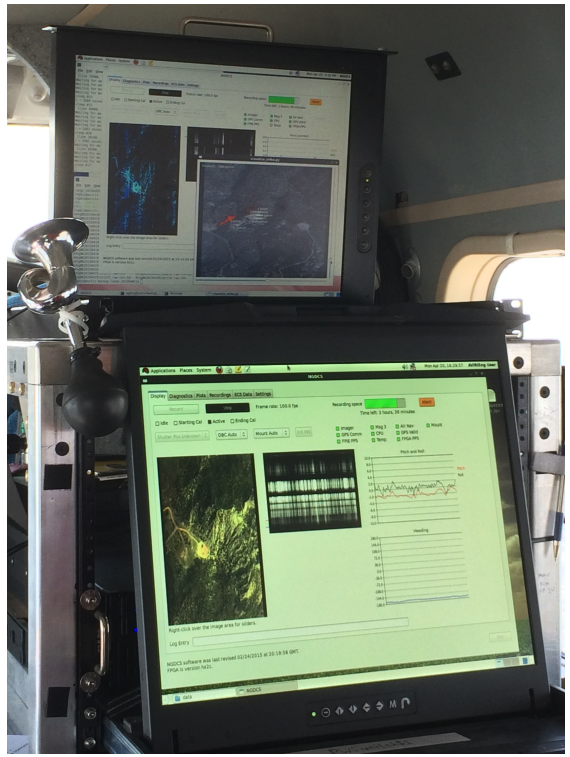
Hyperion (10 nm): 1/1/16, 16:39 UTC
Satellite in low Earth orbit



Methane plume from Aliso Canyon leak observed with imaging spectrometers (Thompson et al., 2016).

Next Generation Airborne Visible/Infrared Imaging Spectrometer (AVIRIS-NG)

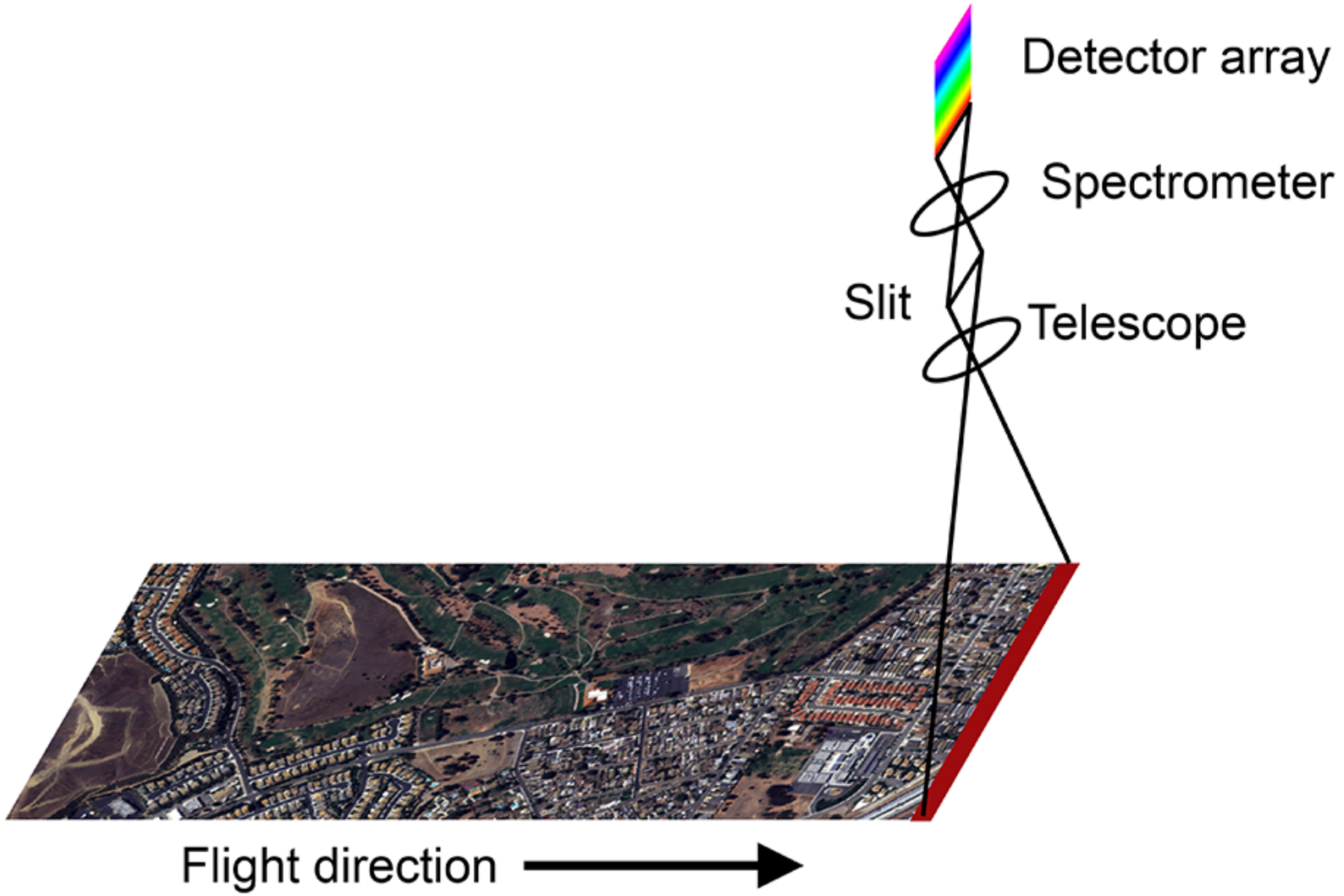
Instrument	**AVIRIS-NG**
Country	USA, JPL/NASA
Operation period	2013-present
Type	Grating pushbroom spectrometer
CH_4 retrieval	2100-2400 nm
Spectral resolution	5 nm
Spatial resolution	Varies with flight altitude, 3-8 m; 2-5 km swath
Aircraft type	Primarily King Air B-200
Repeat interval	Variable based on flight plans



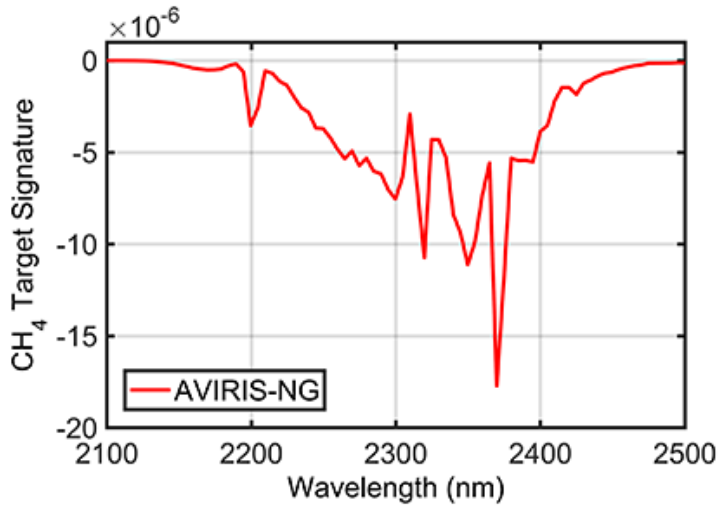
AVIRIS-NG Next Generation Data Capture System (NGDCS)

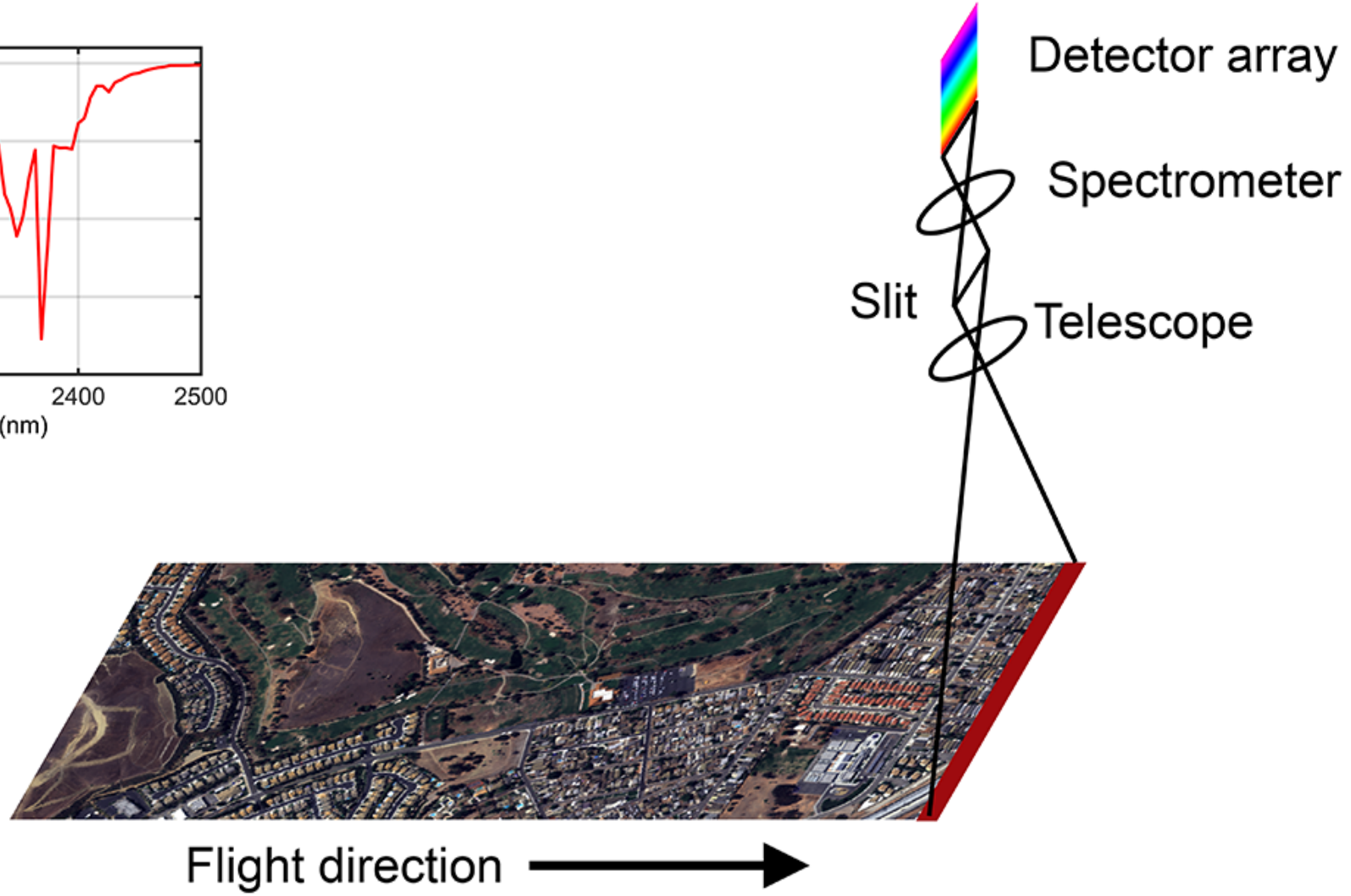
AVIRIS-NG real time quantitative methane mapping (Thompson et al. 2015)

Imaging spectrometer AVIRIS-NG



Imaging spectrometer AVIRIS-NG



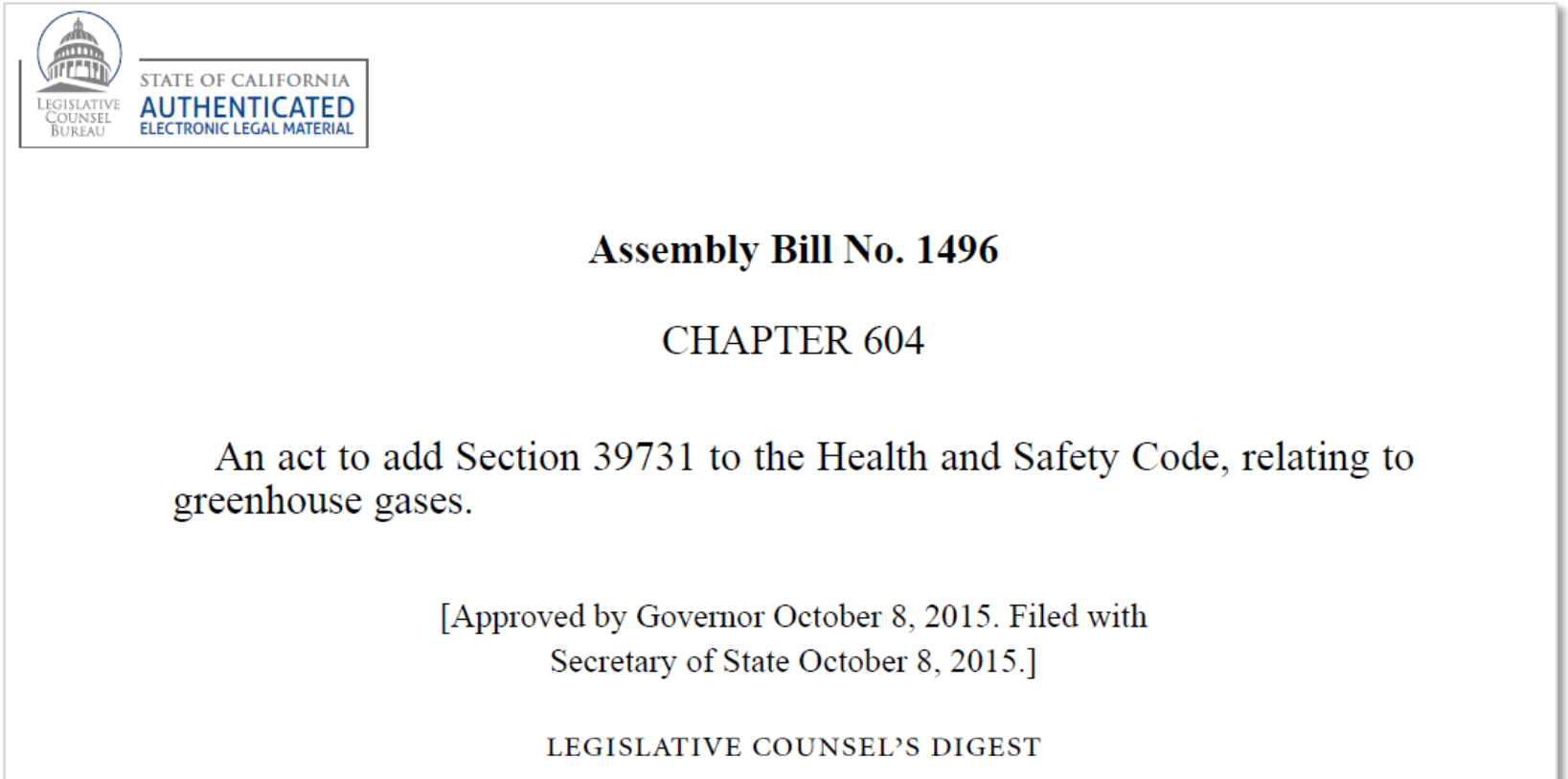


California Assembly Bill No. 1496

Approved by Governor Jerry Brown

Requires monitoring and measurement of high emission methane "hot spots"

Goal of informing relevant policies and programs within California



LEGISLATIVE COUNSEL BUREAU
STATE OF CALIFORNIA
AUTHENTICATED
ELECTRONIC LEGAL MATERIAL

Assembly Bill No. 1496

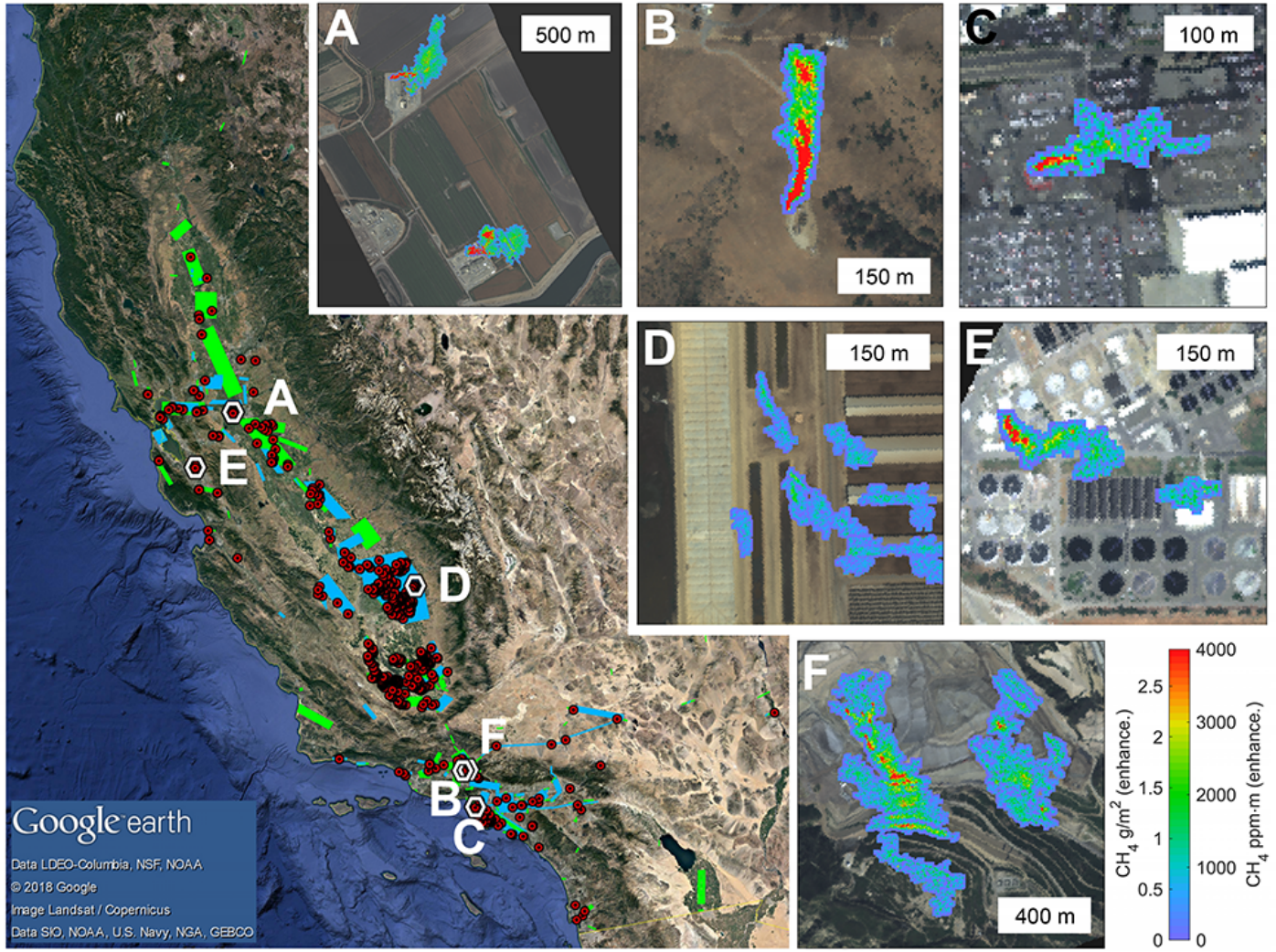
CHAPTER 604

An act to add Section 39731 to the Health and Safety Code, relating to greenhouse gases.

[Approved by Governor October 8, 2015. Filed with Secretary of State October 8, 2015.]

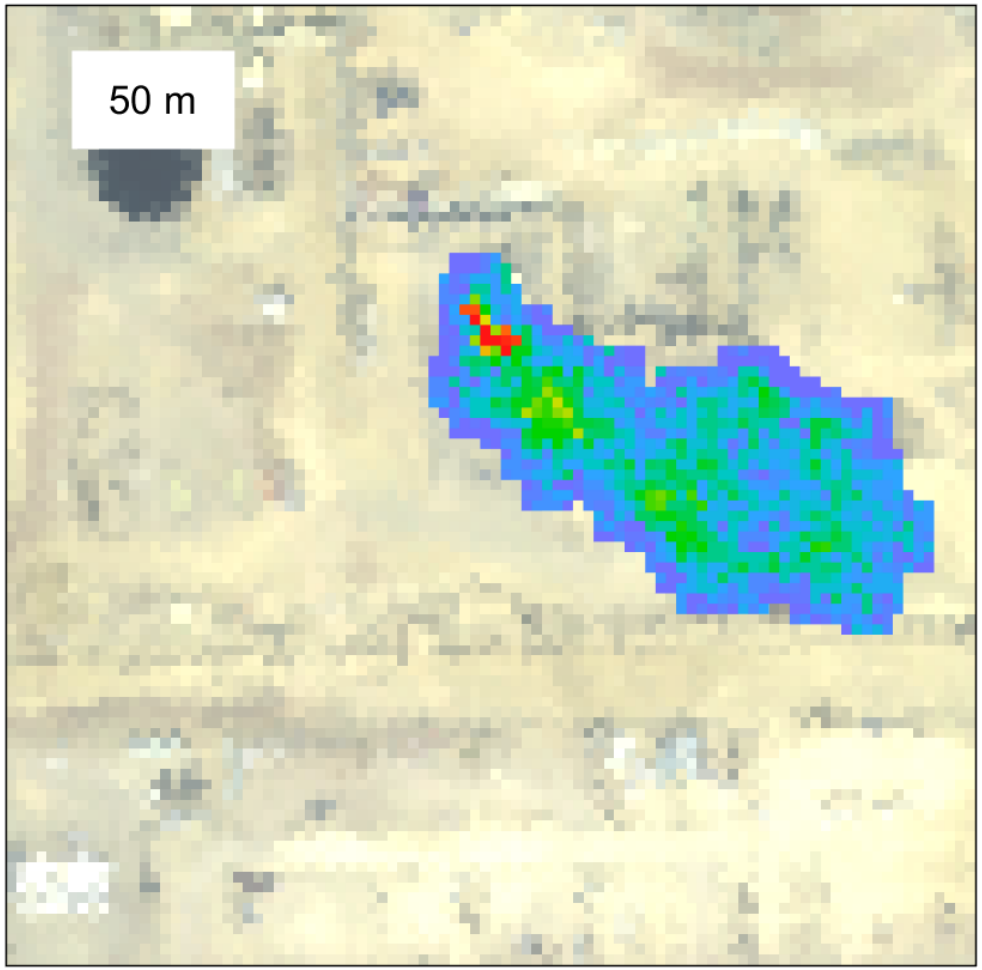
LEGISLATIVE COUNSEL'S DIGEST

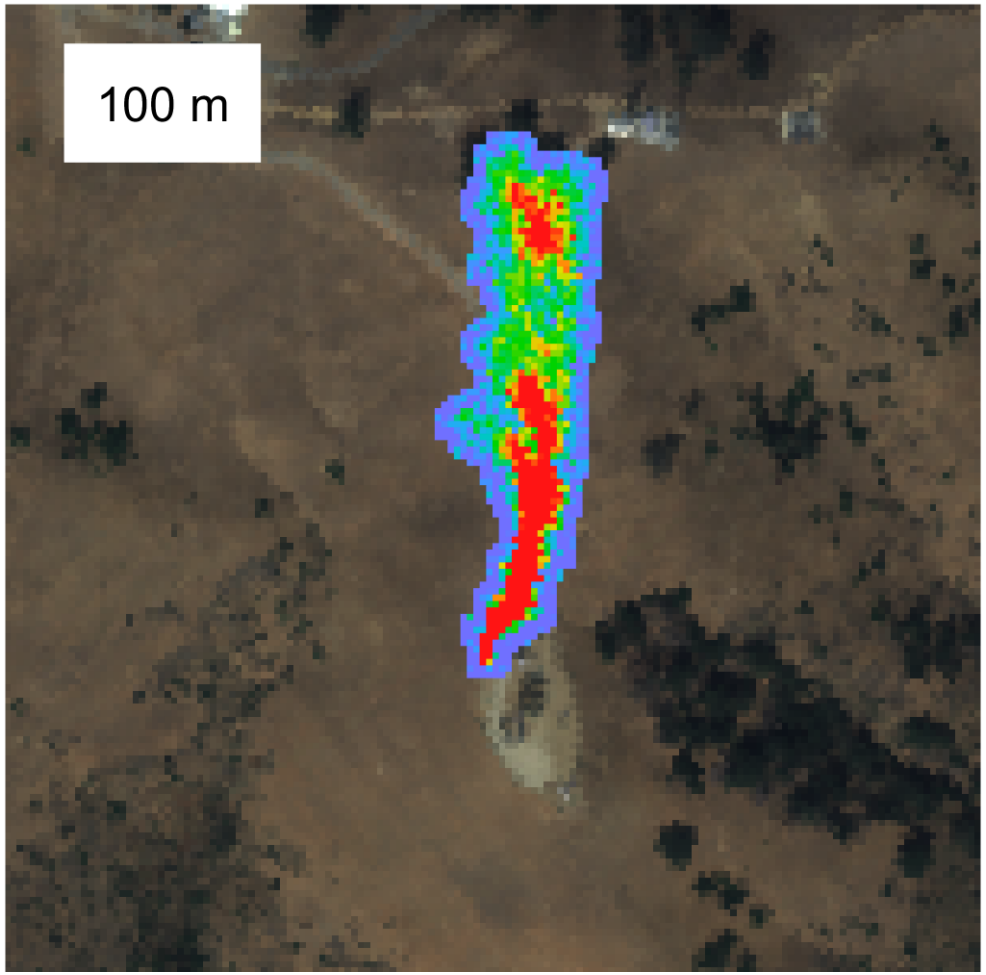
California Baseline Methane Survey

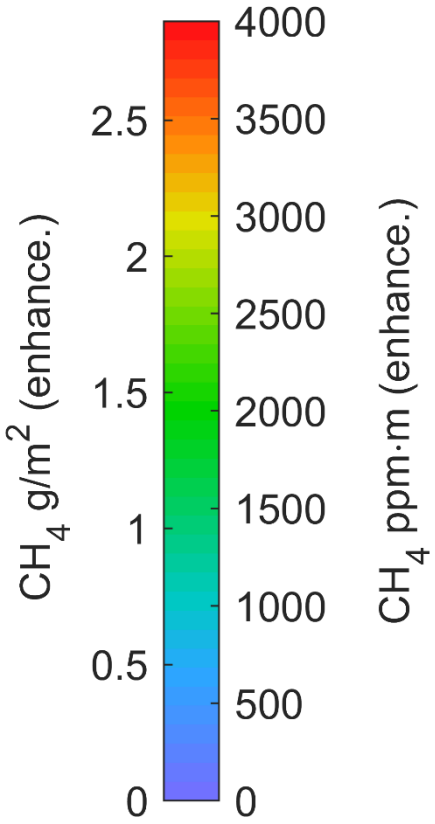


Between 2016 and 2018, AVIRIS-NG covered the portions of California shown in blue and green and identified more than 1,000 methane plumes (red points), including from a natural gas storage facility (A), oil well (B), liquified natural gas tank (C), dairy manure management (D), wastewater treatment plant (E), landfill (F) (Duren et al., in revision).

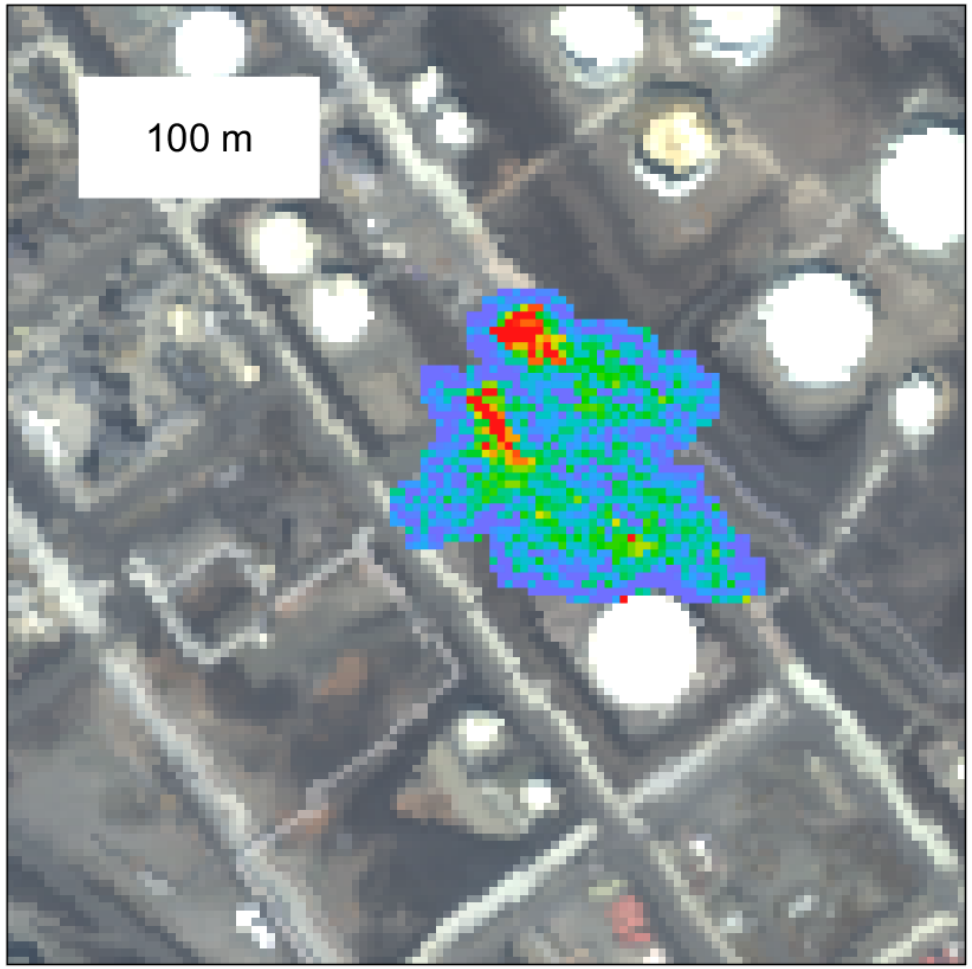
Energy sector (oil & gas fields)

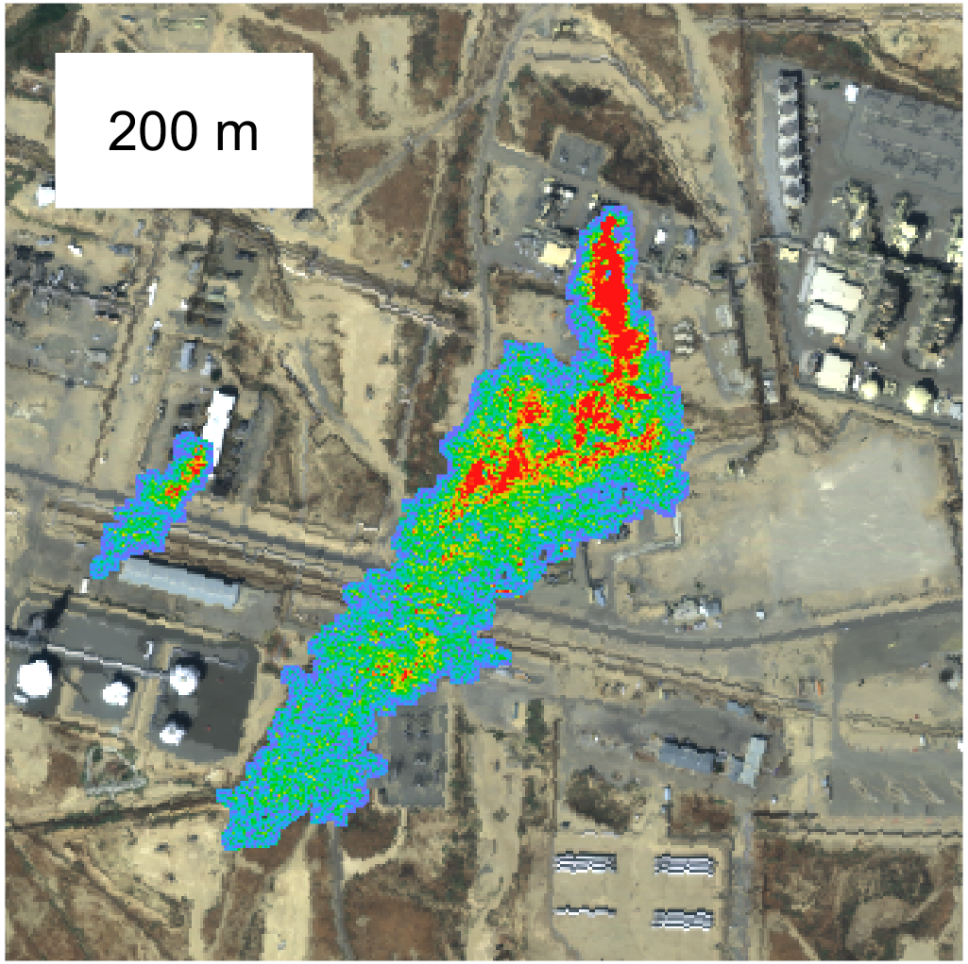


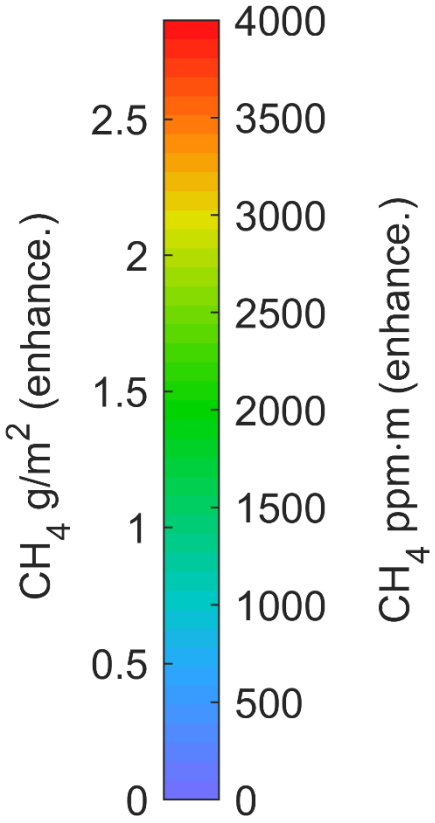




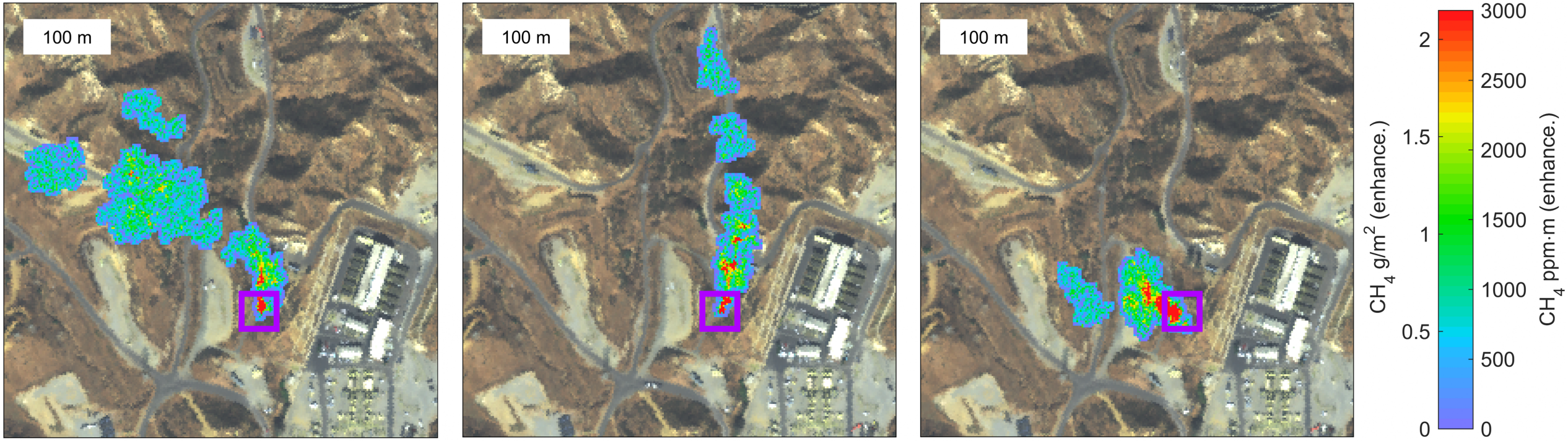
Energy sector (refineries)







Reducing emissions at a gas storage facility

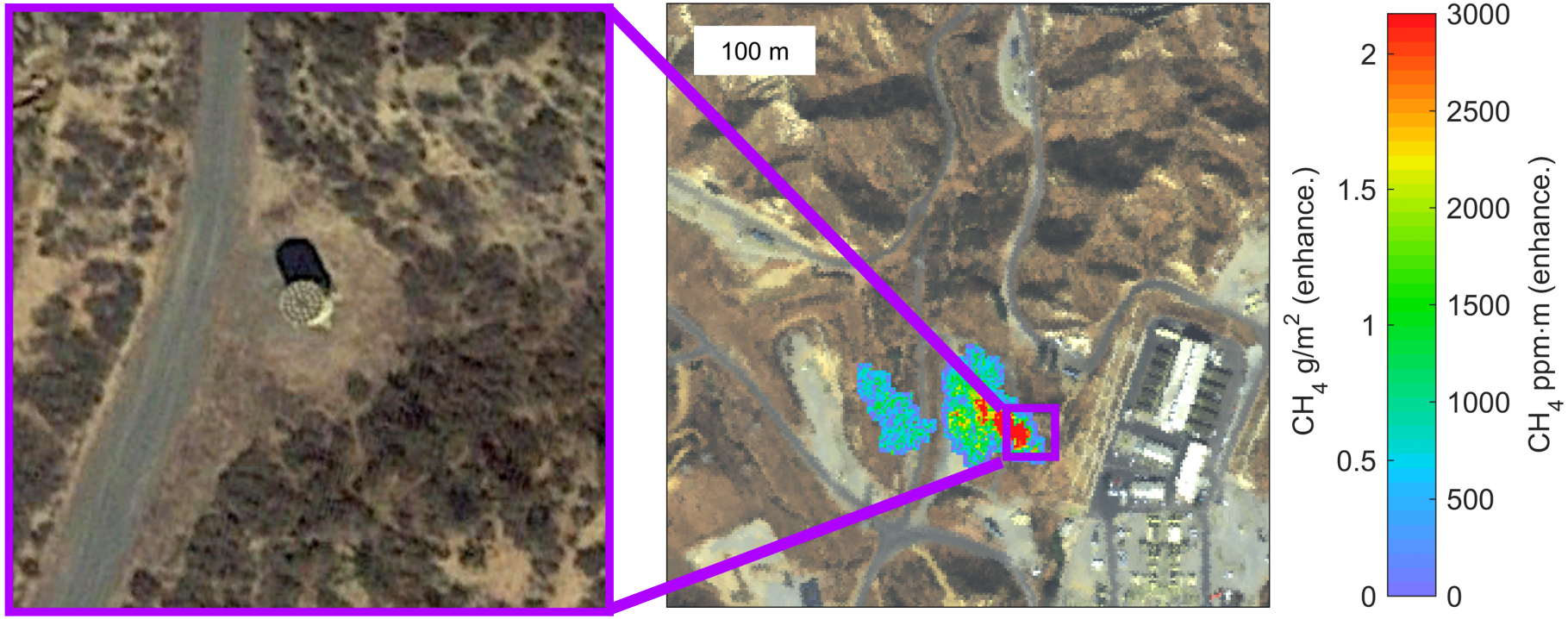


Oct. 26 2017, 19:21:42 UTC

Oct. 26 2017, 19:37:33 UTC

Oct. 26 2017, 19:45:12 UTC

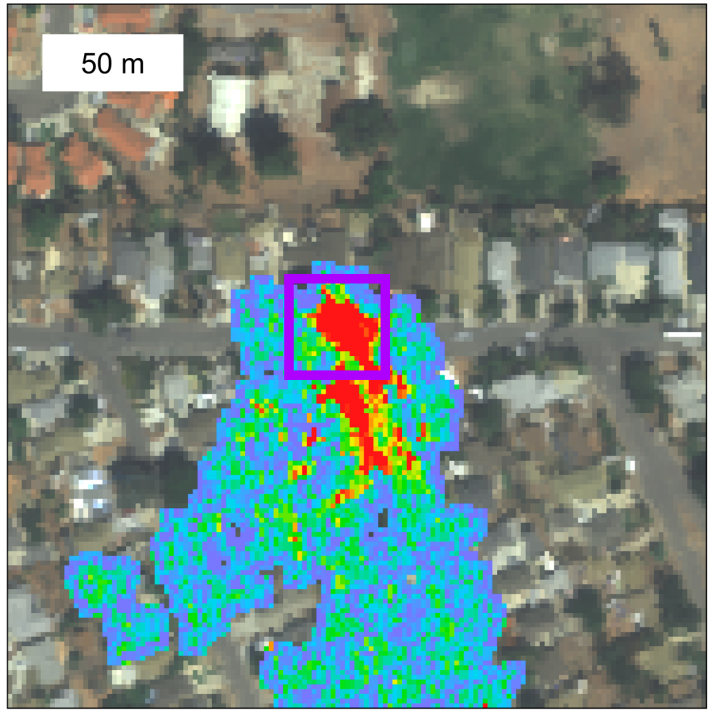
Reducing emissions at a gas storage facility



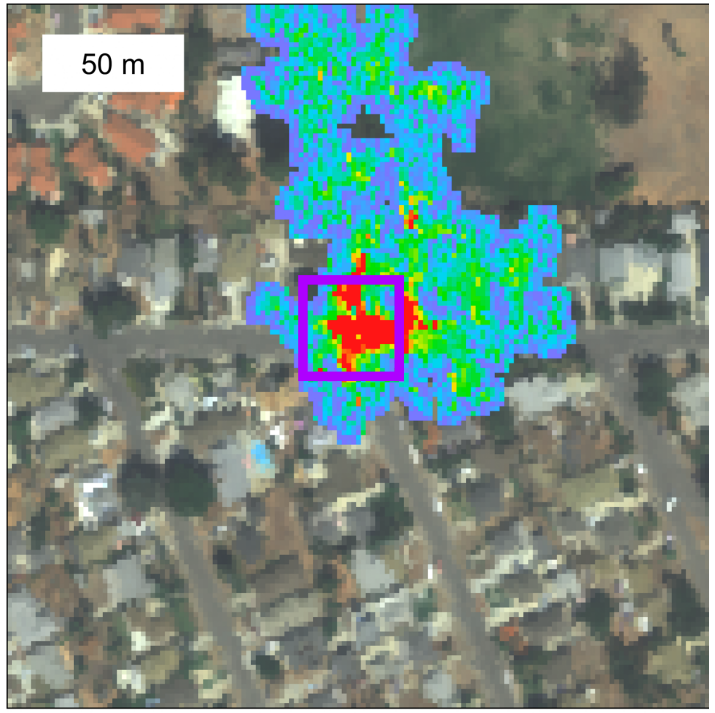
Google Earth, Oct. 2 2016

Oct. 26 2017, 19:45:12 UTC

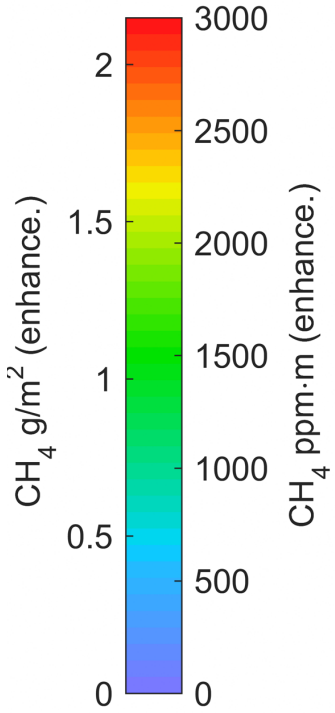
Natural gas leak mitigation



Sept. 15 2016, 18:52:10 UTC



Sept. 15 2016, 19:09:43 UTC



Natural gas leak mitigation

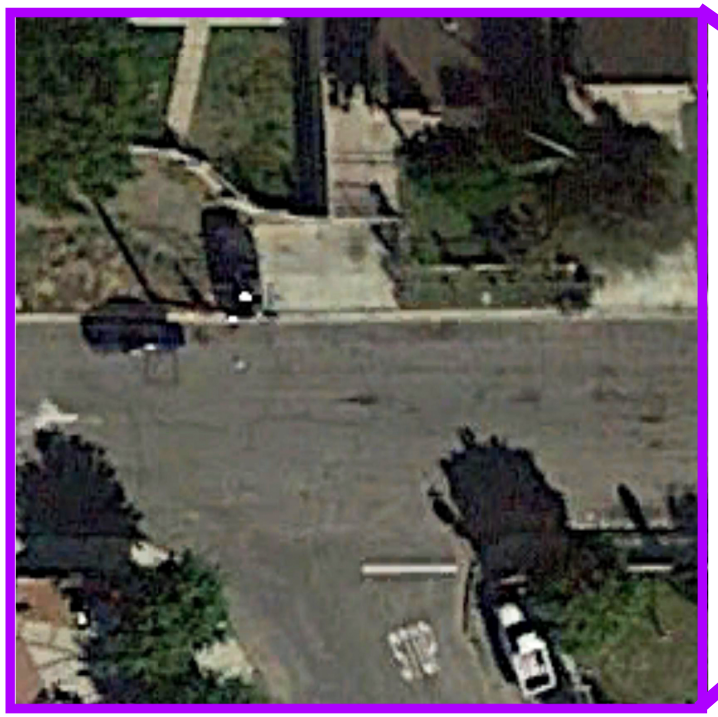
Natural gas leak mitigation

Sept. 15 2016, 18:52:10 UTC

Sept. 15 2016, 19:09:43 UTC

Sept. 25 2016, 19:34:34 UTC

Natural gas leak mitigation



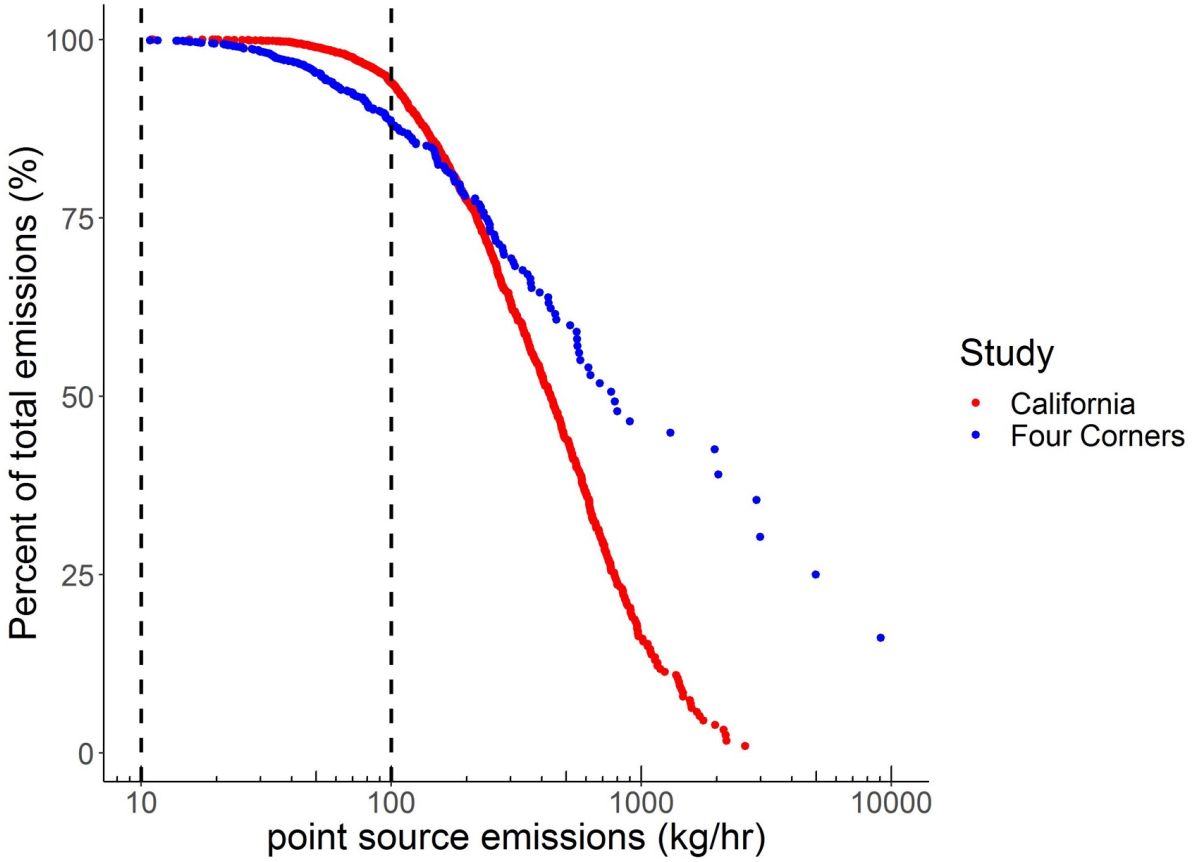
Google Earth, Feb. 2 2016

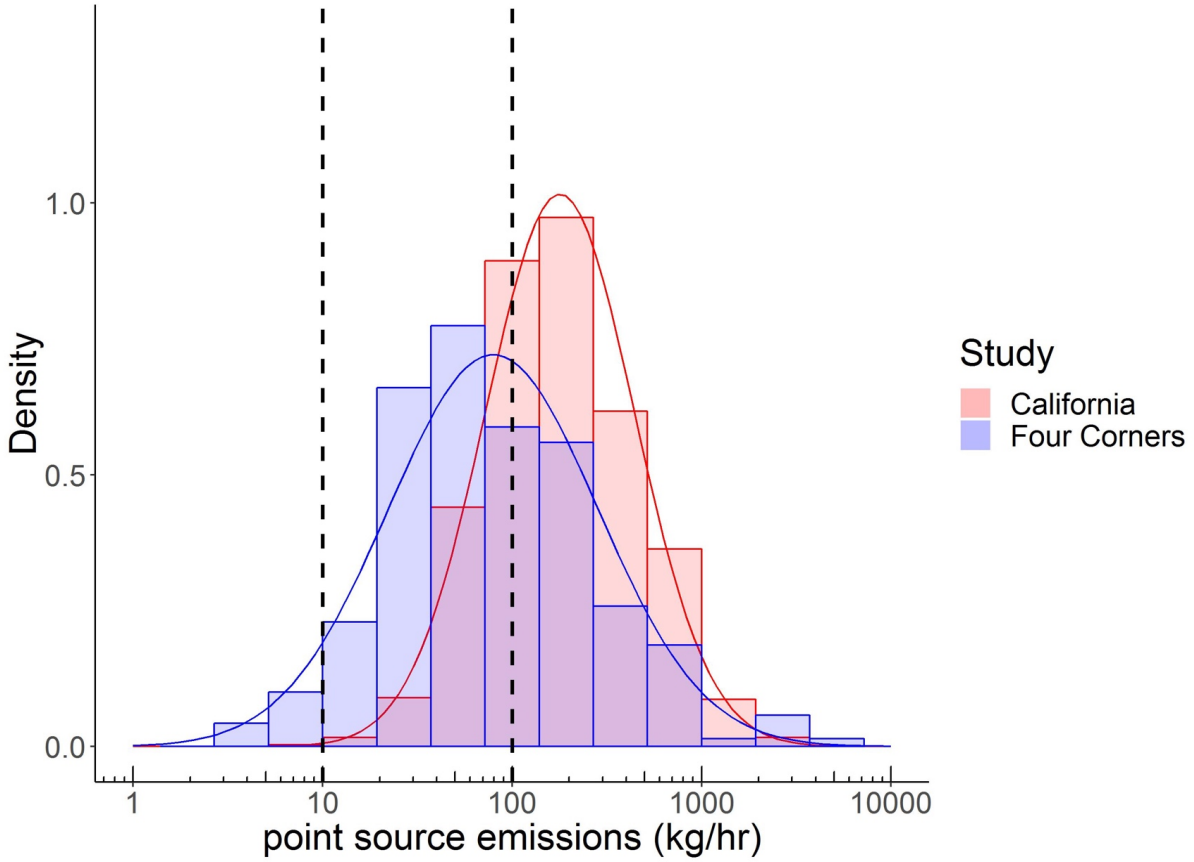
Sept. 25 2016, 19:34:34 UTC

California Baseline Methane Survey results

1) Over 272,000 facilities surveyed spanning oil & gas, dairy, and landfill sectors.
2) Emissions were calculated for 564 methane point sources.
3) Estimated emissions from methane point sources in California is 0.618 $TgCH_4$ yr^{-1} (95% confidence 0.523-0.725) equivalent to 34-46% of 2016 methane inventory.
4) Methane point source emissions in California are dominated by landfills (41%) followed by dairies (26%) and the oil and gas sector (26%).
5) Super-emitter activity occurs in every surveyed sector (10% of point sources contributed ~60% of point source emissions).

Super-emitter behavior





(Duren et al., in revision)

California Baseline Methane Survey results

- Manuscript under review (Duren et al., in review).
- Report to CEC/CARB funding agencies (publication date TBD).

Continued stakeholder engagement

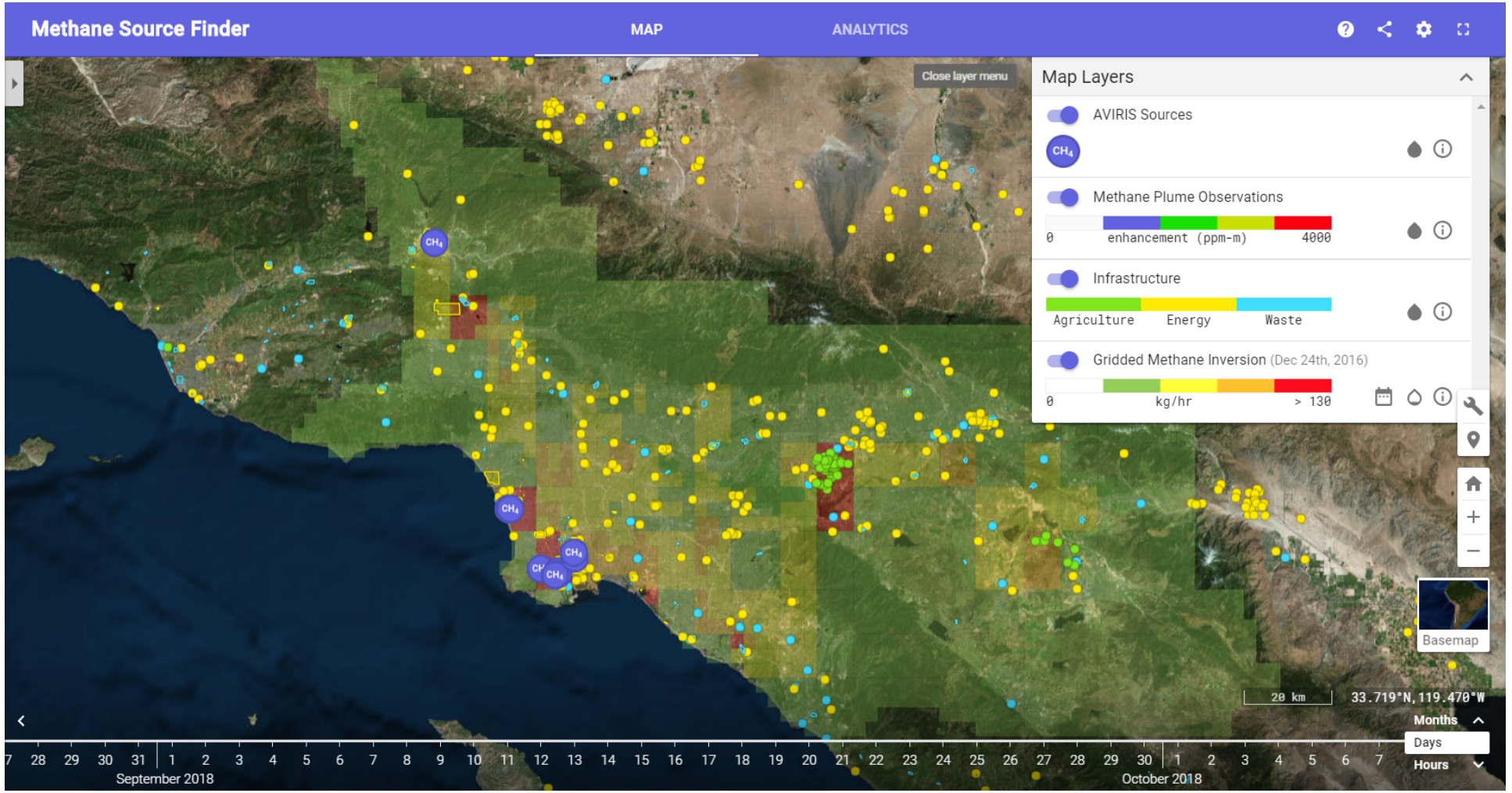
CA Baseline Methane Survey

Energy sector

Waste management sector

Dairy groups

Methane Source Finder web portal



Web based data portal with multiple methane data products (gridded emissions data, plumes from imaging spectrometers, infrastructure layers). Website will go live this Summer 2019.

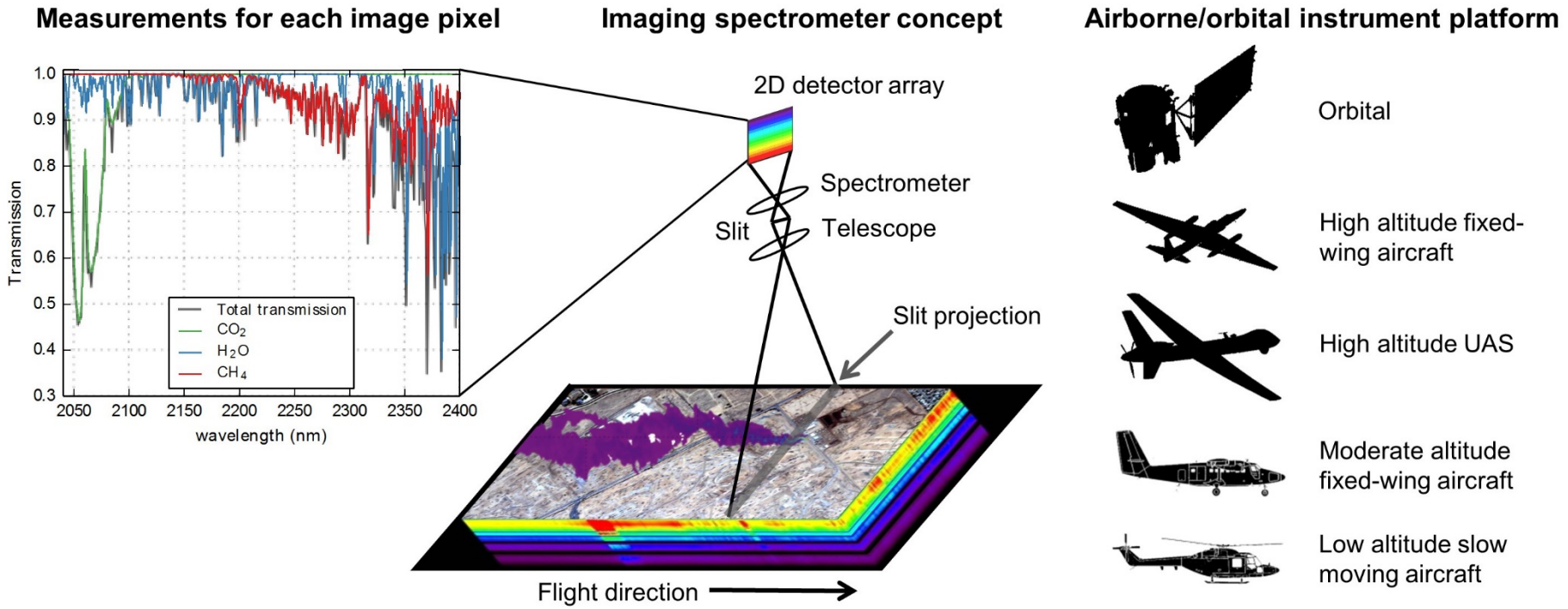
Planned imaging spectrometers with methane sensitivity

Instrument	Primary country	Launch target	Spectral range	Spectral resolution	Spatial resolution	Swath	Revisit	Additional info
PRISMA (PRecursore IperSpettrale della Missione Applicativa)	Italy (ASI)	2019	400-2500 nm	10 nm	30 m	30 km (at 620 km altitude)	7 days	Link
HISUI (Hyperspectral Imager SUIte)	Japan, JAXA	Early 2020 (International Space Station)	400-2500 nm	10 – 12.5 nm	20-30 m	20 km (at an altitude of 400 km)	~5 days	Link
EnMAP (Environmental Mapping and Analysis Program)	Germany, DLR	End 2020	420-2450 nm	-VNIR: 420 nm to 1000 nm (~6.5 nm) -SWIR: 900 nm to 2450 nm (~10 nm)	30 m	30 km (at 653 km altitude)	4 days	Link
EMIT (Earth Surface Mineral Dust Source Investigation)	USA, JPL/NASA	2021 (International Space Station)	380-2510 nm	TBD (likely 5-10 nm)	30 m	~37 km (at 408 km altitude)	4 days	Link
SBG (Surface Biology and Geology, previously HyspIRI)	TBD	TBD (likely 2020-2025)	TBD (likely 380-2510 nm)	TBD (likely 5-10 nm)	TBD (likely 30 m)	Minimum 30 km, but likely much greater (at low Earth orbit)	TBD	Link

From airborne to spaceborne: Decadal Survey

Earth System Explorer-Targeted Observable: Greenhouse Gases

"Low Earth Orbit observation of [CH4 and CO2] plumes from point sources using SWIR spectrometers with very high spatial resolution (less than 50 m) over limited viewing domains." (NRC, 2018)



Thorpe et al., 2016