Jet Propulsion Laboratory
California Institute of Technology

The Aliso Canyon Super-Emitter: Initial Results of Observations by AVIRIS-C and the Hyperion Spacecraft, with Implications for Global Spectroscopic CH_4 Monitoring

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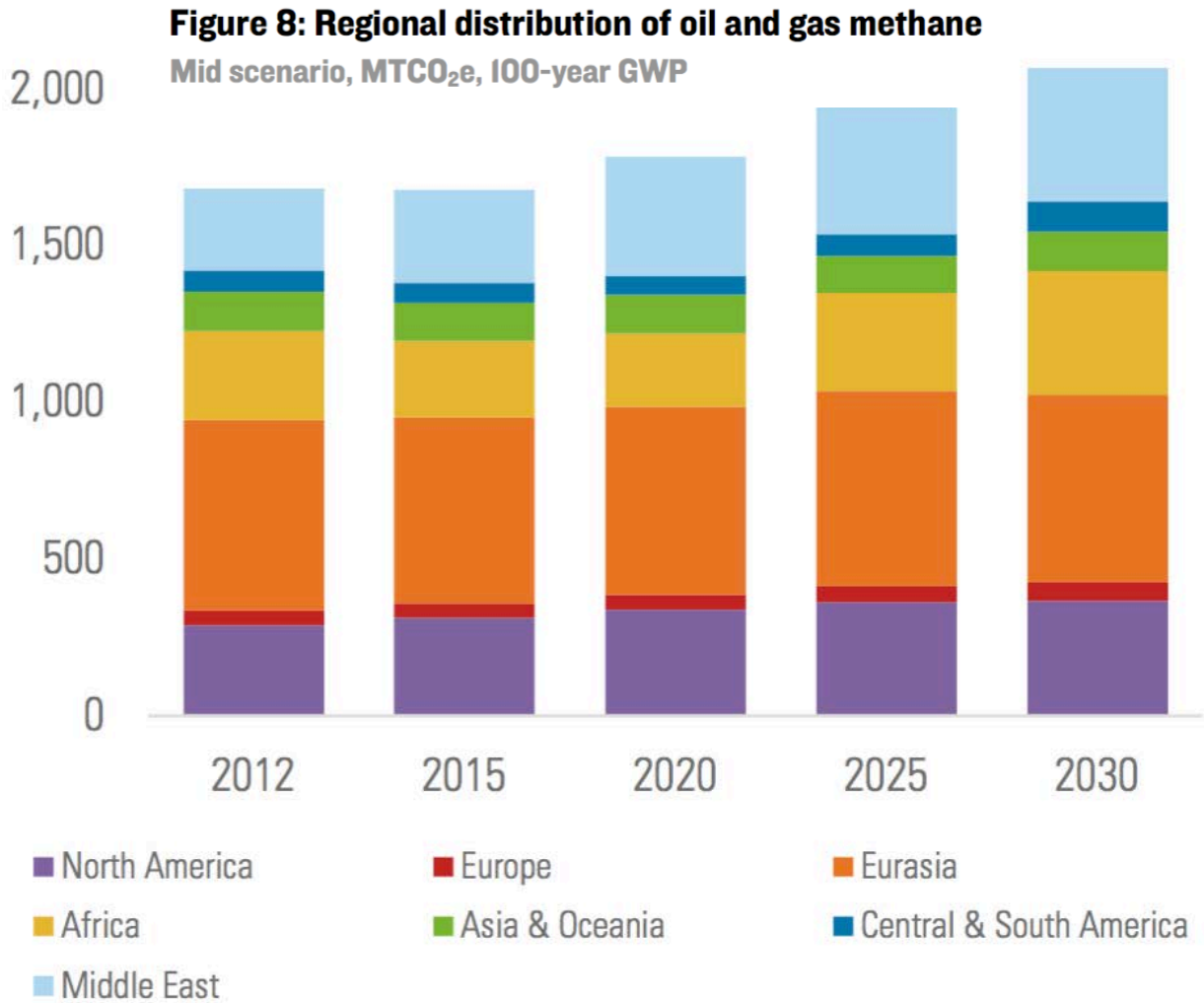
Agenda

1. Motivation for GHG point source imaging
2. Measurement technique, GHG point sources and the Aliso Canyon Leak
3. Emerging technologies and GHG monitoring campaigns

Magnitude of the CH_4 leak issue

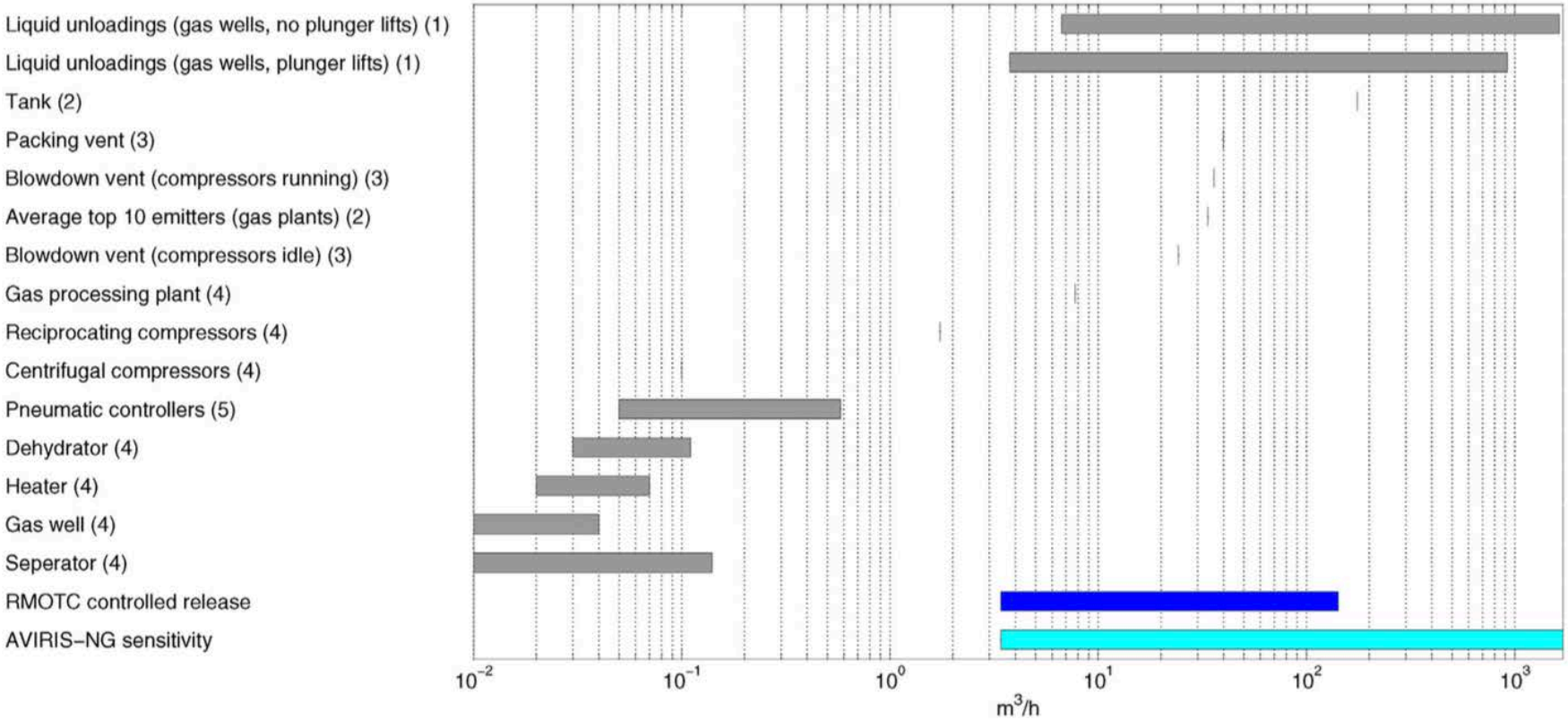
Potential global societal impacts in the **multiple billions of $USD, before accounting for gas revenue**, at $6.6 USD/t-$CO_2$ [2]

A growing burden of aging gas transmission infrastructure will require leak & explosion hazard monitoring.



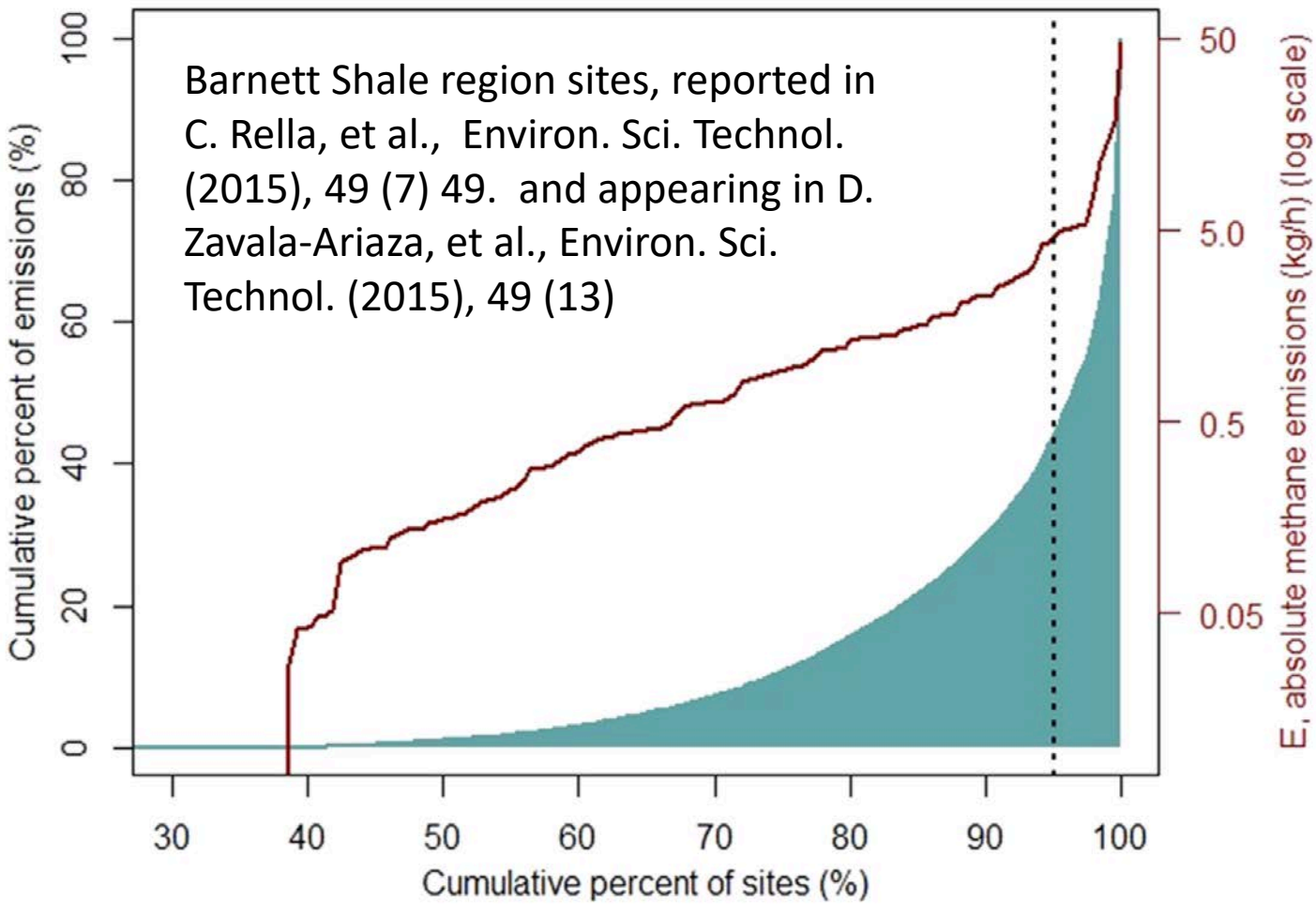
[1]: Larsen et al., Rhodium Report 2015 (image)
[2]: Waldhoff et al., Economics 2015

CH_4 emissions vary in magnitudes and scales



[Thorpe et al., RSE 2016], data from [Allen et al., 2015] and EPA reports.

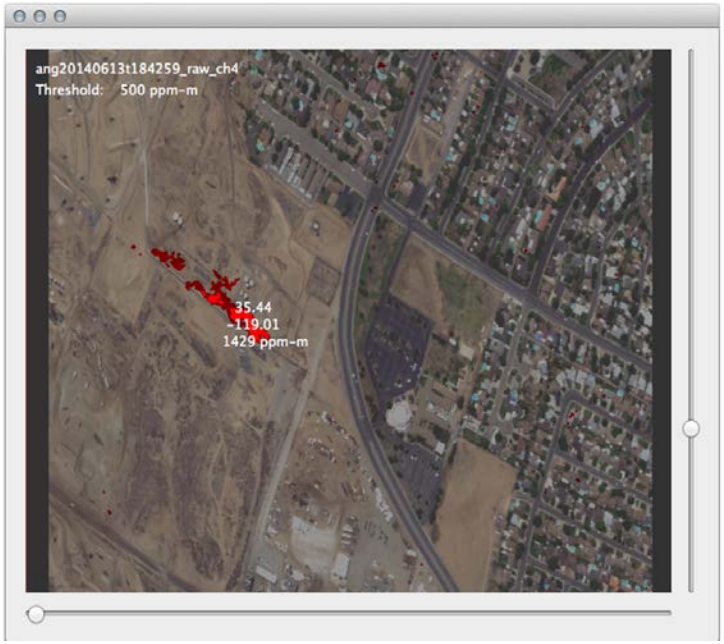
Superemitters: Threat & Opportunity



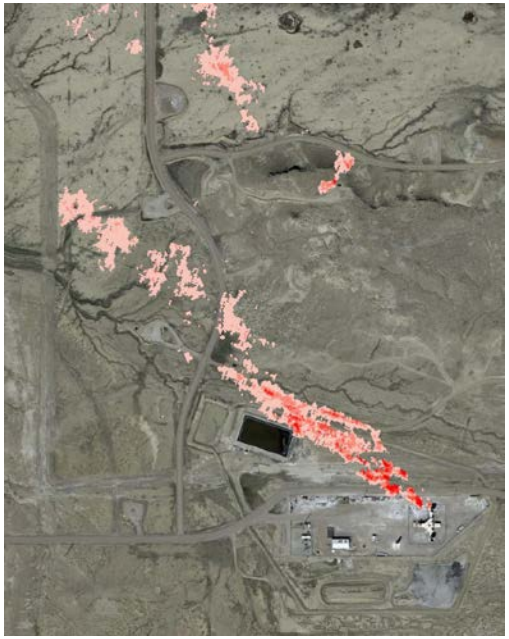
Role of imaging spectroscopy

- Wide coverage for monitoring & survey
- Identify, localize, attribute sources
- Quantitative flux estimation, sometimes
- Can also characterize dairies, landfills, and CO_2 combustion (beyond this presentation)

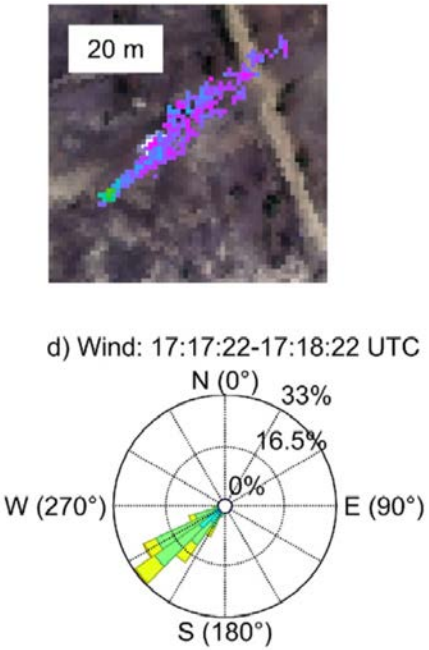
Many prior examples of CH_4 imaging spectroscopy



Real-time plume detection and mapping
(Thompson et al., AMT 2015)

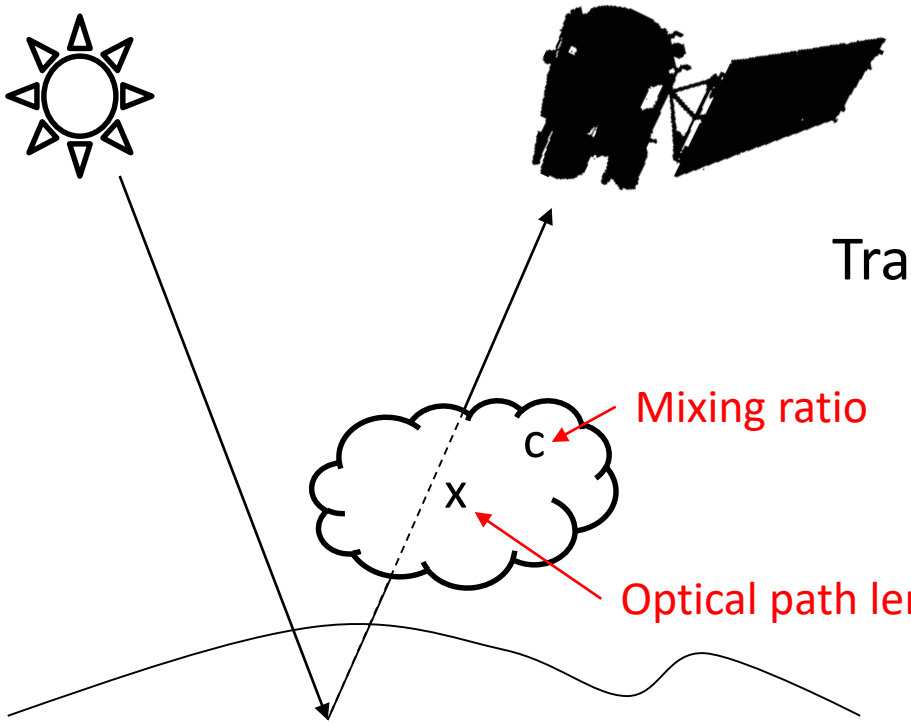


Four Corners airborne campaign
(Frankenberg et al., PNAS 2016)



REMOTC sensitivity study
(Thorpe et al., RSE 2016)

Measuring point source greenhouse emissions remotely

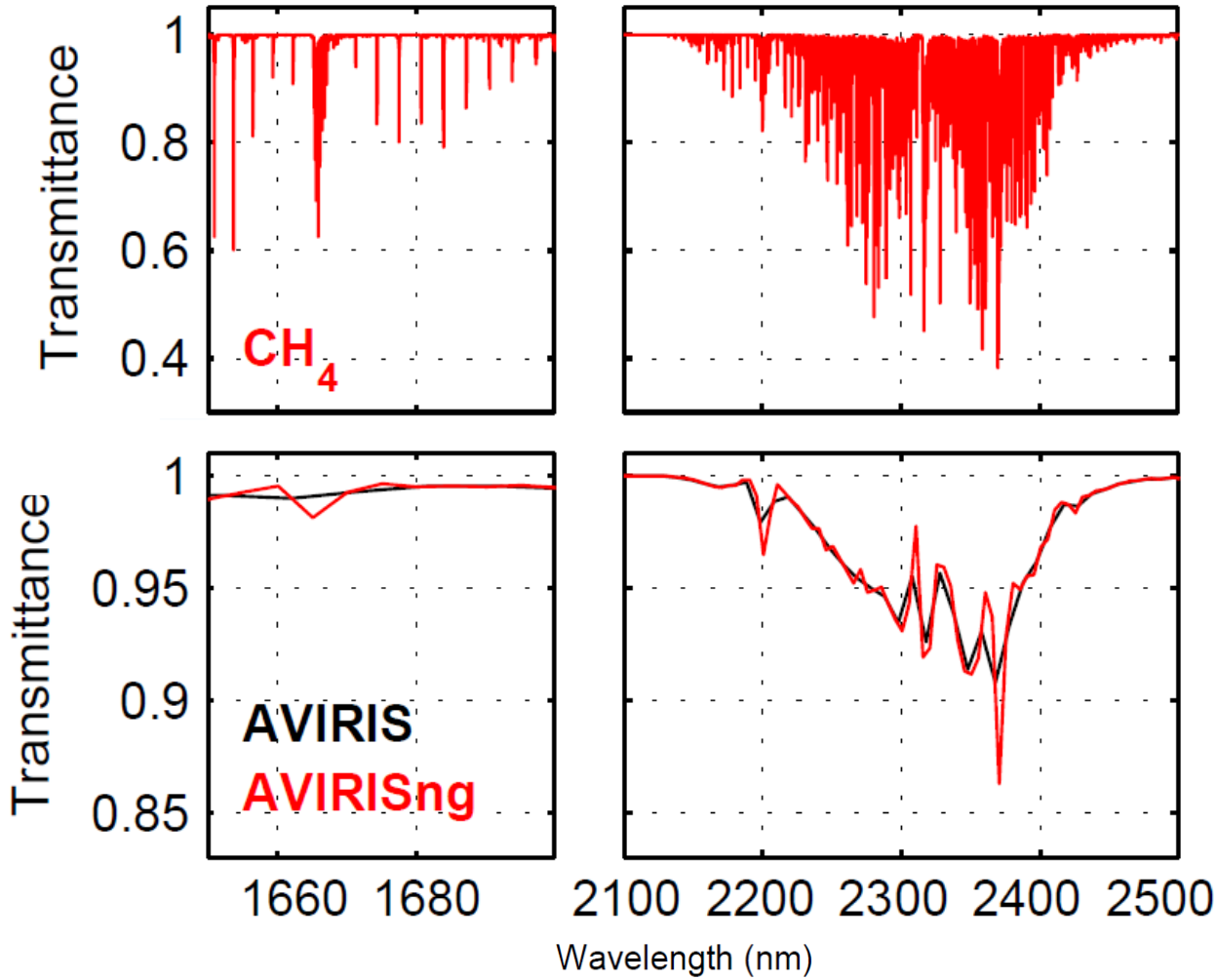


Mixing ratio
length in ppm m

$$\text{Transmission} \ \alpha \ e^{-\kappa c x}$$

Absorption coefficient

CH_4 absorption signatures



Detection via matched filter

Matched filter applied independently in each column

$$\hat{\alpha}(\mathbf{x}) = (\mathbf{x} - \mu)^T \Sigma^{-1} \mathbf{t} / (\mathbf{t}^T \Sigma^{-1} \mathbf{t})$$

Detection via matched filter

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Mixing ratio length

Tested spectrum

Background mean

Background covariance

target

Detection via matched filter

Matched filter applied independently in each column

$$\hat{\alpha}(\mathbf{x}) = (\mathbf{x} - \mu)^T \Sigma^{-1} \mathbf{t} / (\mathbf{t}^T \Sigma^{-1} \mathbf{t})$$

Mixing ratio length

Tested spectrum

Background mean

Background covariance

target

Using the target signature

$$\mathbf{t} = \partial \mathbf{x} / \partial \ell = -\mu e^{-\kappa \ell} \kappa = -\mu \kappa$$

Detection via matched filter

Matched filter applied independently in each column

$$\hat{\alpha}(\mathbf{x}) = (\mathbf{x} - \mu)^T \Sigma^{-1} \mathbf{t} / (\mathbf{t}^T \Sigma^{-1} \mathbf{t})$$

Mixing ratio length

Tested spectrum

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Background covariance

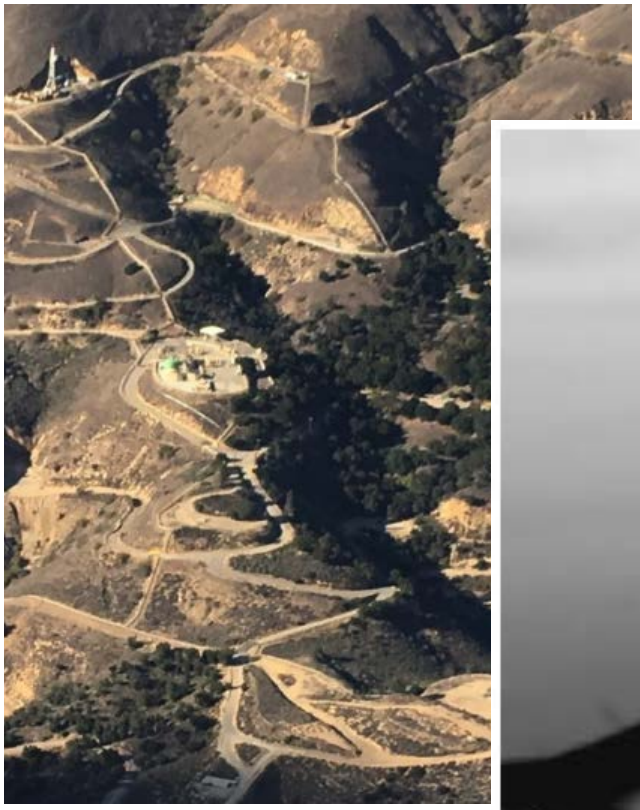
target

Using the target signature

$$\mathbf{t} = \partial \mathbf{x} / \partial \ell = -\mu e^{-\kappa \ell} \kappa = -\mu \kappa$$

Unit absorption coefficient

The Aliso Canyon CH_4 release

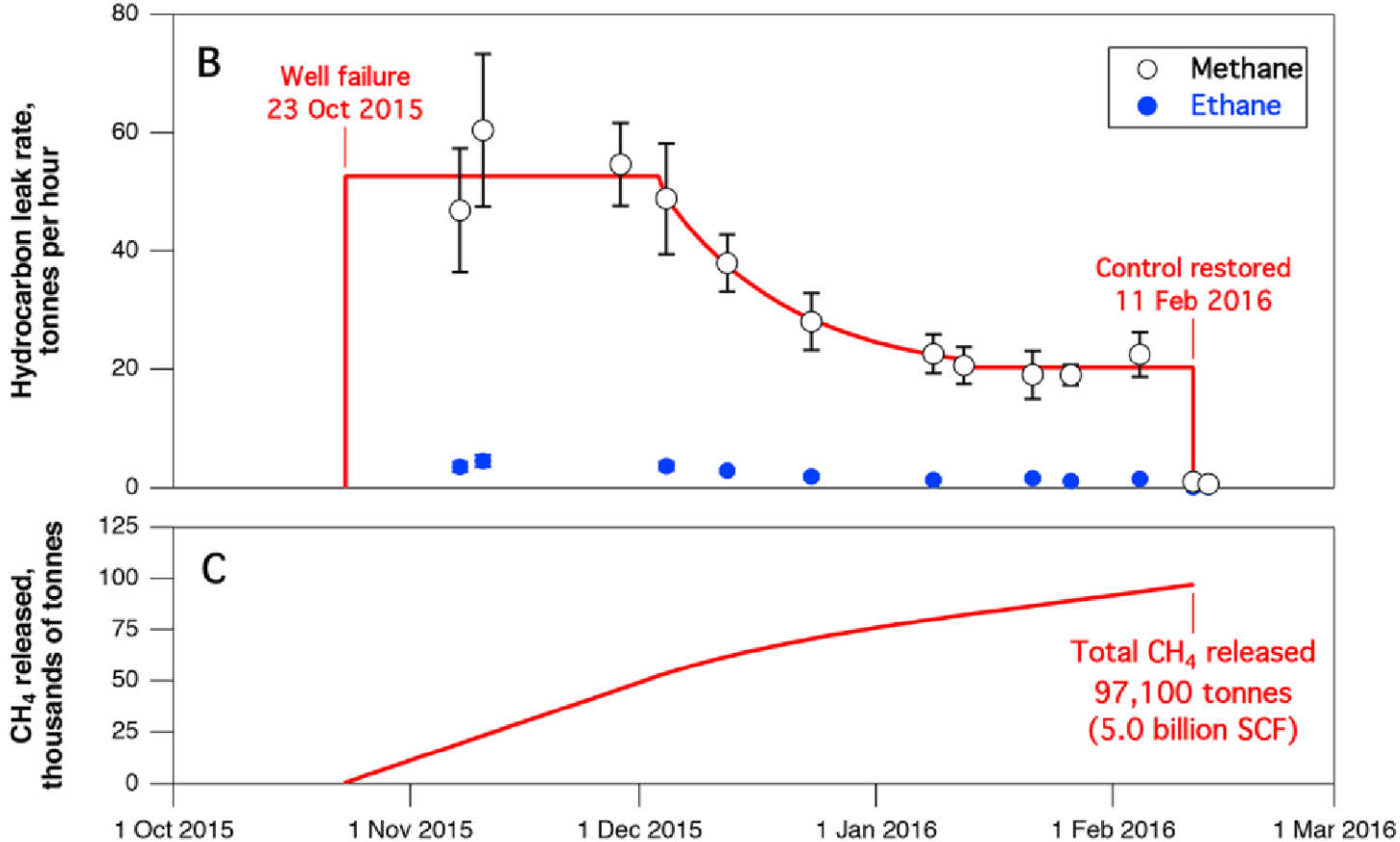


(NOAA)

http://blogs.edf.org/

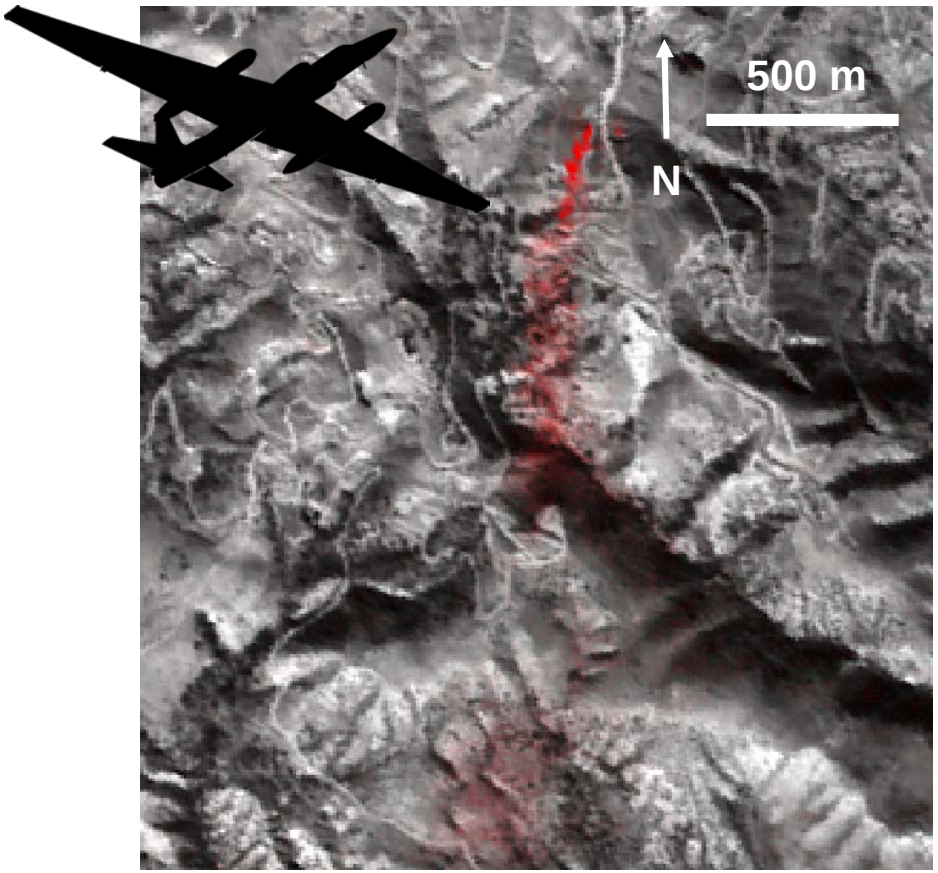
Leak rate estimated from airborne mass balance

Conley et al., *Science* 2016

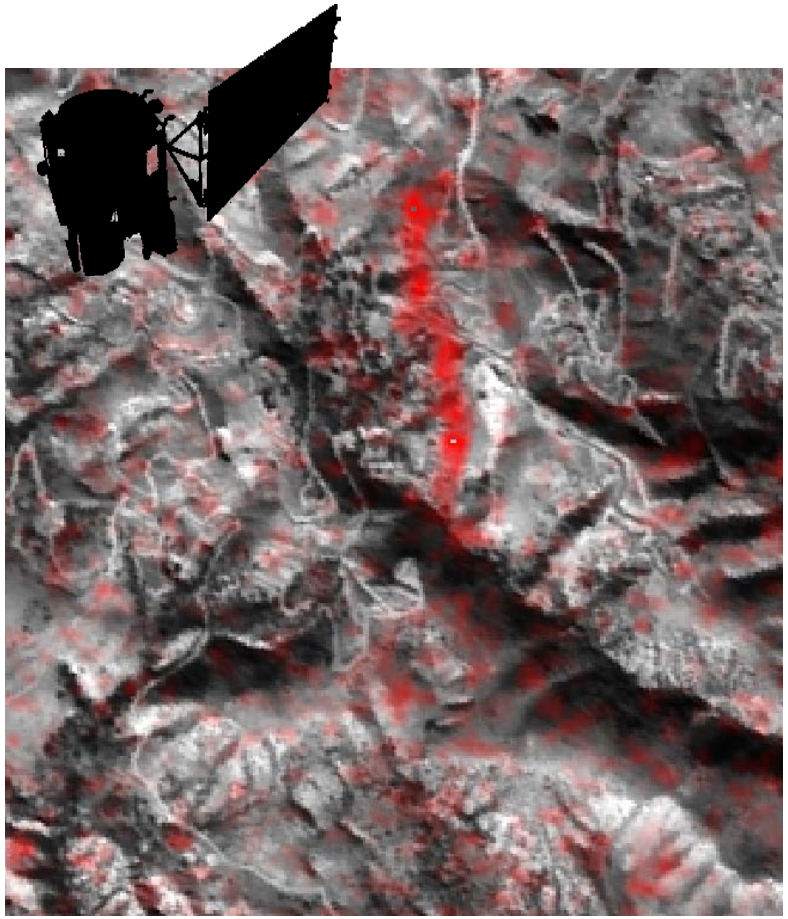


“Next morning” post-flight results

ER-2 at 6.6 km altitude, 1/12/2016



EO-1 Spacecraft at LEO, 1/1/2016



Thompson et al., *Geophys. Res. Lett.* (2016, accepted)

Integrated methane enhancement

- Total estimated above-background methane mass
- Inversely proportional to windspeed (Green et al., 1980)

$$IME = k \sum_{i=0}^{n} \hat{\alpha}(i) S(i)$$

Integrated methane enhancement

- Total estimated above-background methane mass
- Inversely proportional to windspeed (Green et al., 1980)

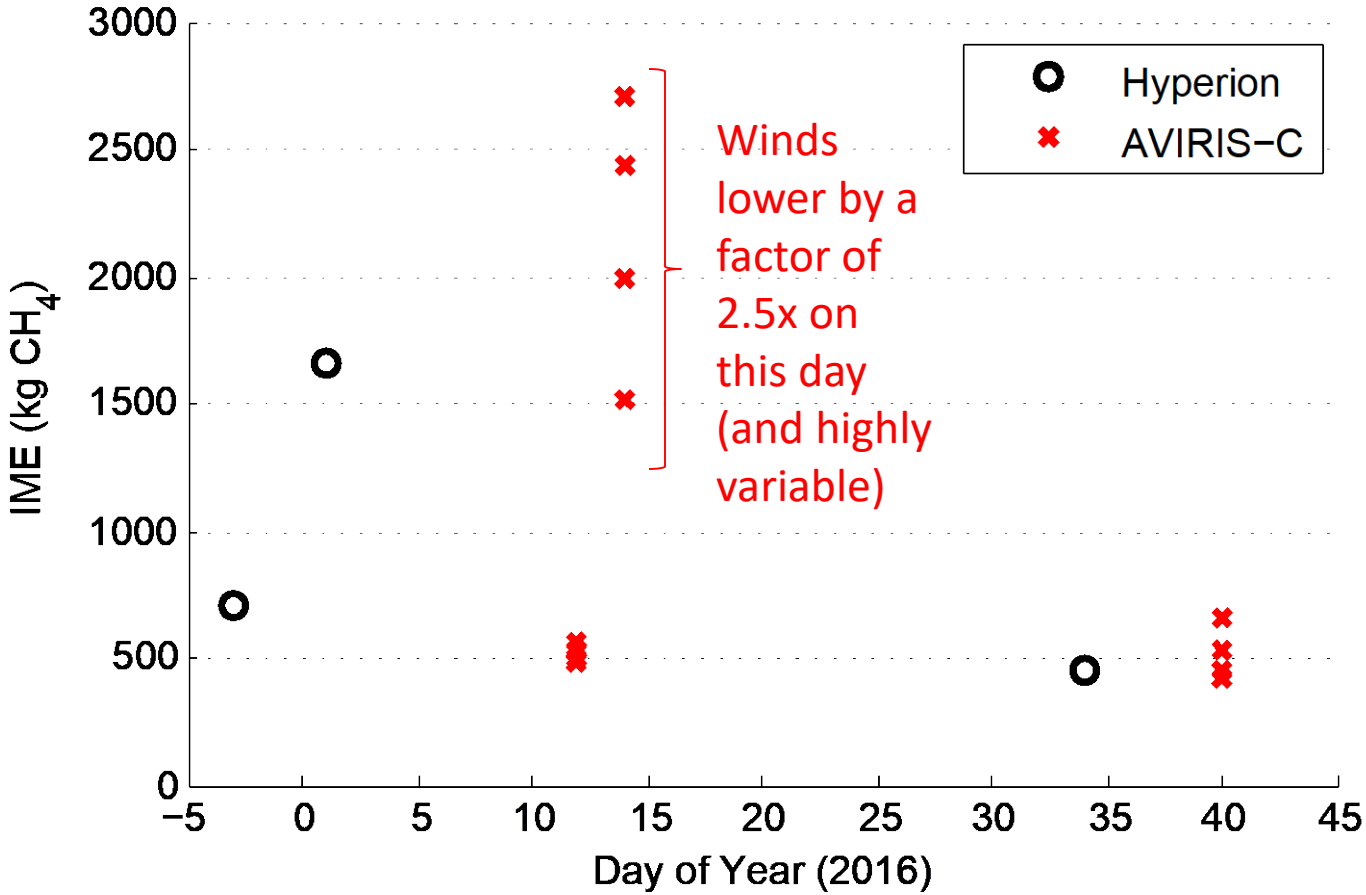
$$IME = k \sum_{i=0}^{n} \hat{\alpha}(i) S(i)$$

constant

Estimated mixing ratio length for pixel i

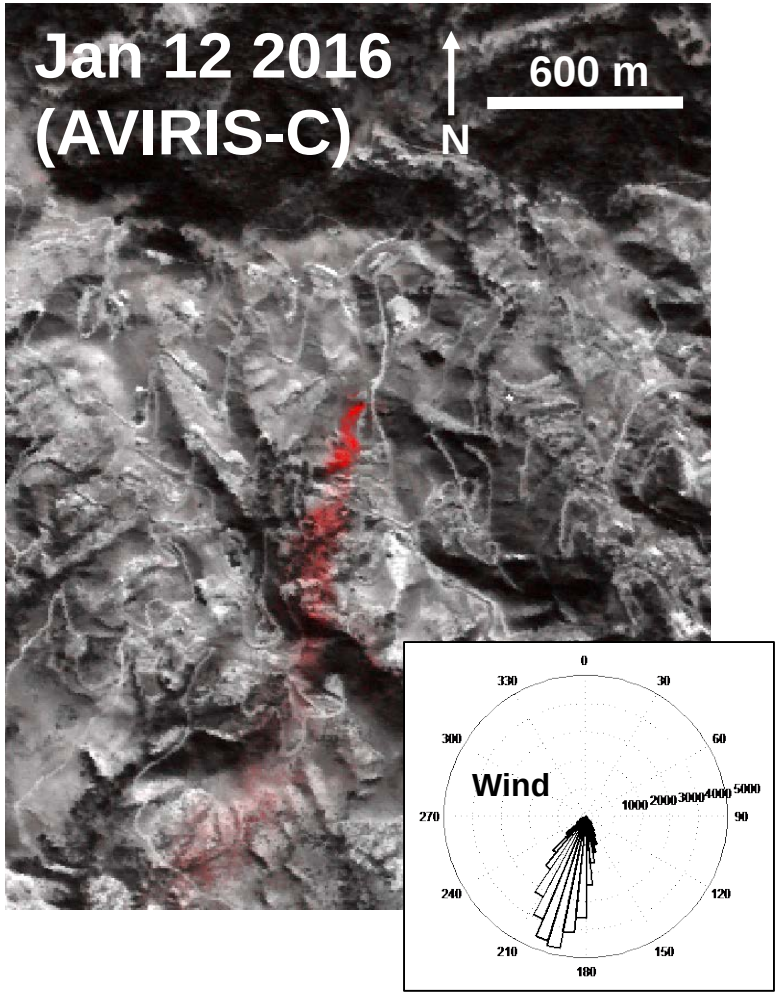
Pixel area

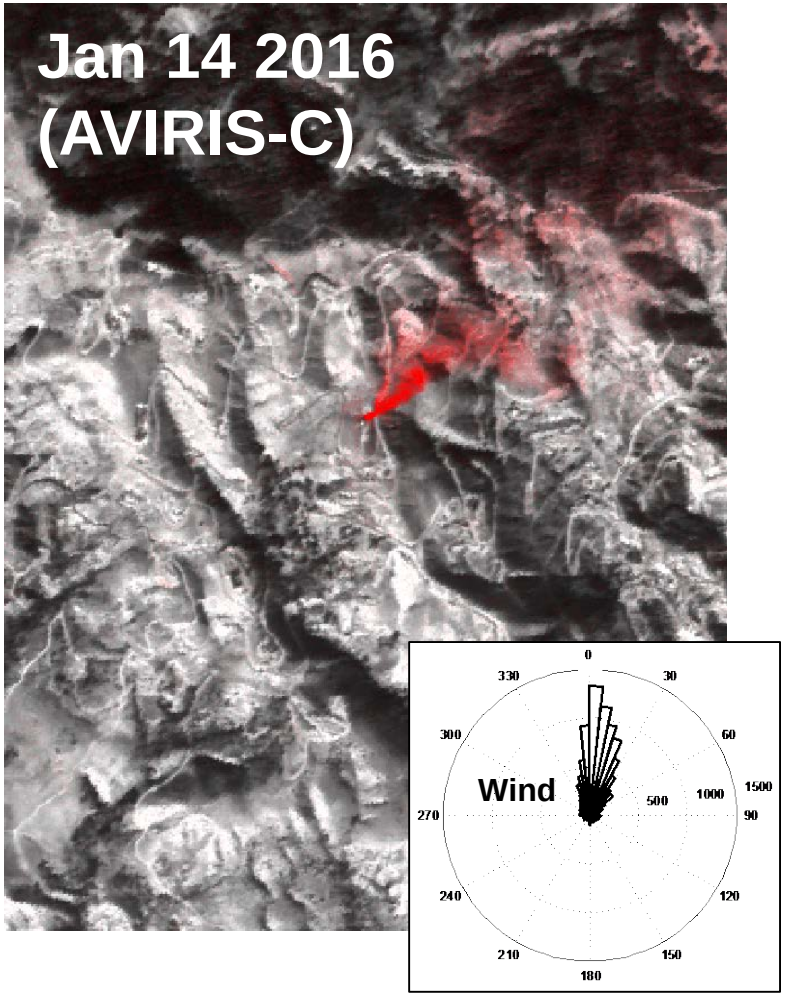
Integrated Methane Absorption



Thompson et al., *Geophys. Res. Lett.* (2016, accepted)

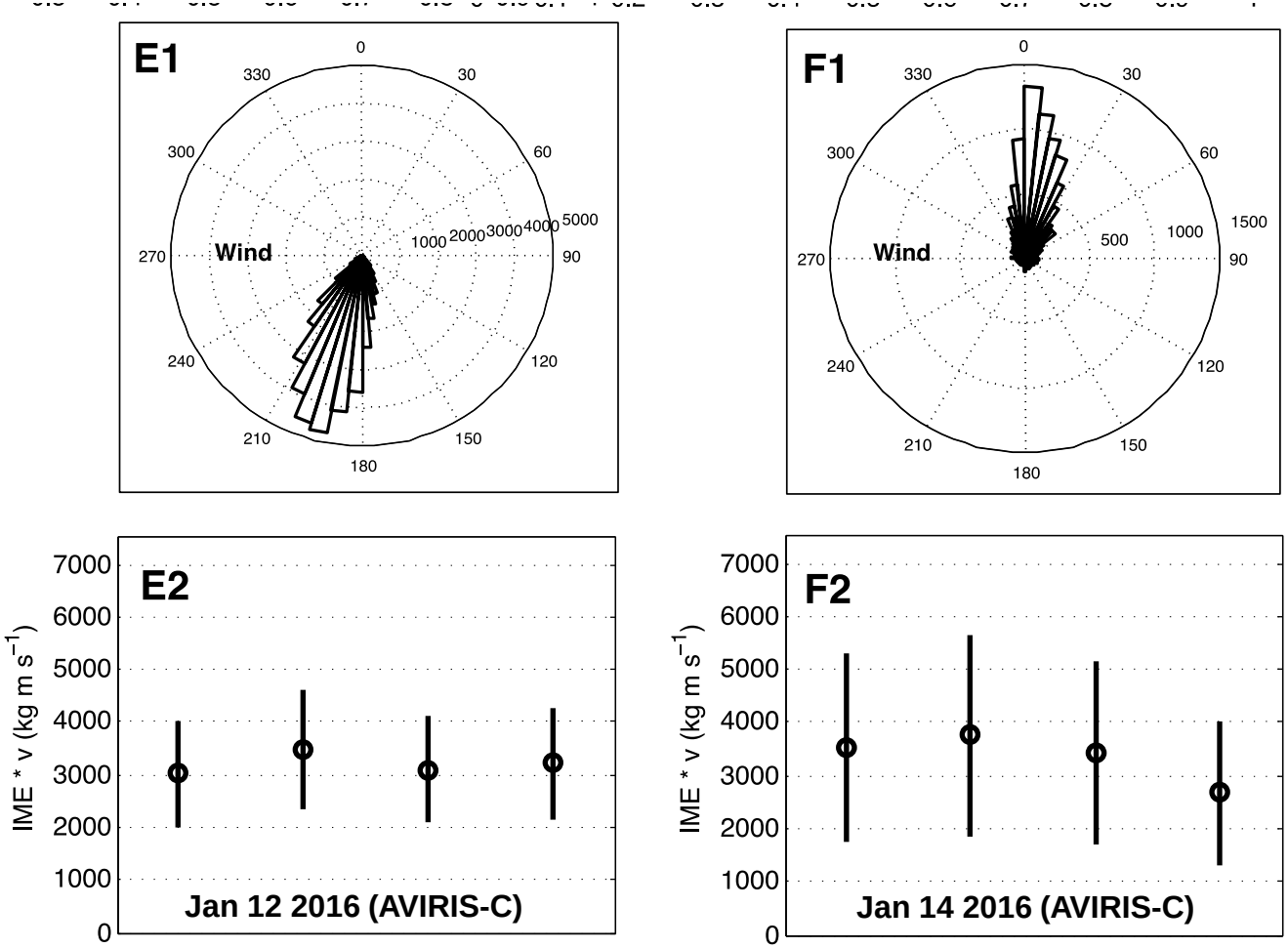
Wind directions



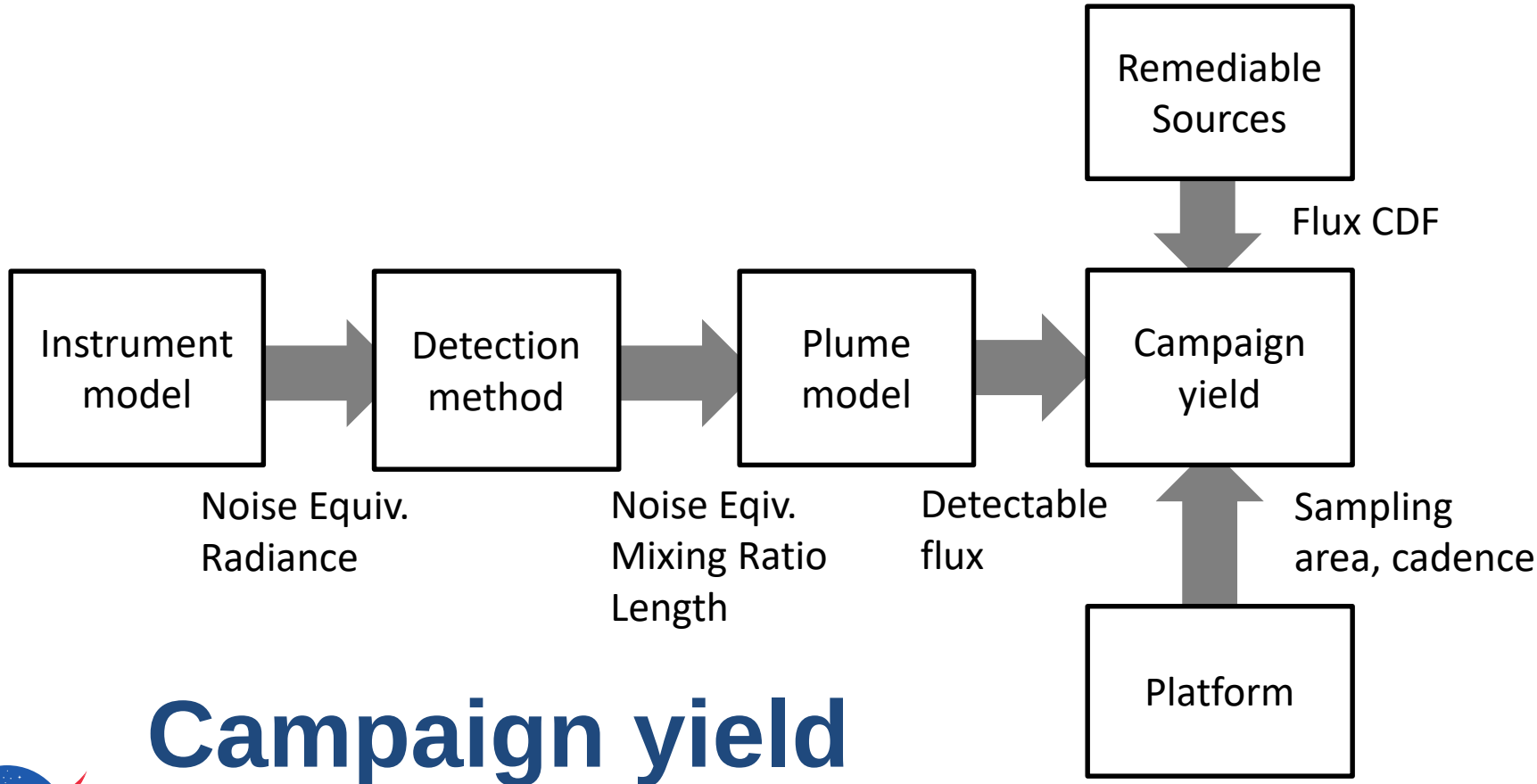


Thompson et al., *Geophys. Res. Lett.* (2016, accepted)

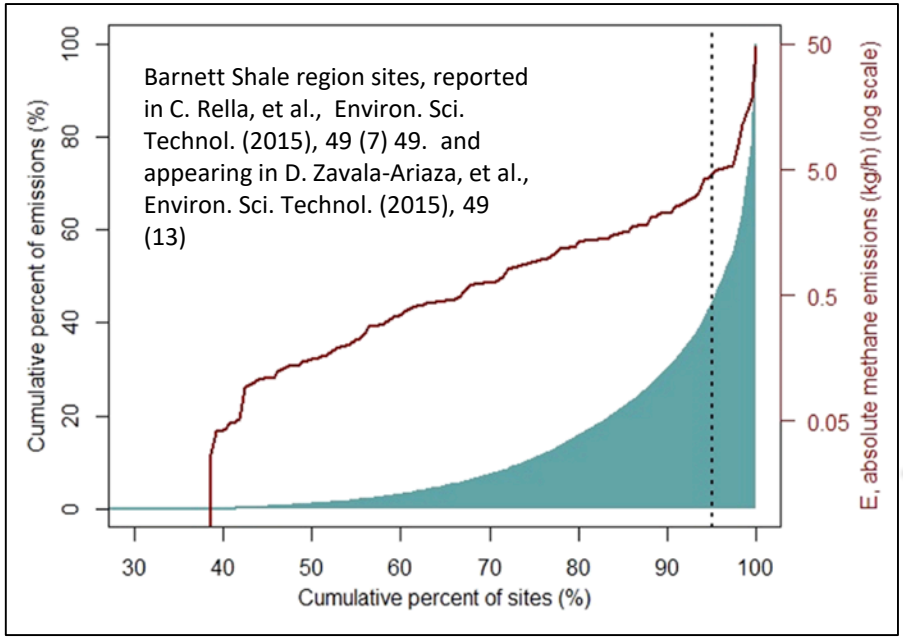
Wind-corrected IME



Thompson et al., *Geophys. Res. Lett.* (2016, accepted)



Campaign yield



Remediable Sources

Flux CDF

Instrument model → Detection method → Plume model → Campaign yield

Noise Equiv. Radiance

Noise Eqiv. Mixing Ratio Length

Detectable flux

Sampling area, cadence

Platform

Campaign yield

The Broad View

[Duren et al., NASA Earth Science Decadal Survey RFI, http://sites.nationalacademies.org/DEPS/esas2017

	System	Source population	Fraction sampled	Emissions above threshold	Detectable flux (kg/hr)	GSD (m)	Cadence (days)
Sources	Tier1	CO2: tens of thousands of facilities (global)	99%	>80%	200,000	30	30
		CH4: 10,000,000 facilities (global)	99%	30%	1,000	30	30
	Tier2	Ch4: 1,000,000 facilities (key regions)	>90%	90%	10	5	730
	Tier3	CO2: tens of thousands of facilities1a (global)	>50%	>90%	20,000	10	15
		CH4: 10,000,000 facilities (global)	>50%	50-90%	50	10	15
Instruments	OCO-2	CO2: tens of thousands of facilities (global)	<1%	<1%	2,000,000	~2,000	30
	TROPOMI	CH4: 100,000 known large facilities (global)	~20%	<10%	20,000	7,000	10
	EnMAP	CH4: 100,000 known large facilities (global)	0.20%	<1%	1,700	30	30
	Carbon-Sat	CO2: tens of thousands of facilities1a (global)	~20%	99%	2,000,000	2,000	3
		CH4: 100,000 known large facilities (global)	~25%	30%	2,300	2,000	3

Future technologies

- **Hardware**
  - Improved sensitivity with purpose-built instruments
- **Software**
  - Synthesis with other source databases
- **Algorithms**
  - Improved covariance matrix estimation
  - Plume segmentation with Convolutional Neural Networks
  - Flux estimation with Gaussian and/or CFD simulations

Preliminary Conclusions

- Targeted orbital VSWIR imaging spectroscopy at 30m resolution is useful for testing and cataloguing super-emitters
- Global mapping at 30 m GSD could image 30% of CH_4 and > 80% CO_2 emissions.
- *Operationally-useful* hazard detection & remediation would probably require dedicated instruments with higher sensitivity, cadence

Preliminary Conclusions, contd.

- Conservative estimates of the “remediable leak fraction” suggest widespread comprehensive monitoring could recover **order billion $USD worth of lost revenue and radiative forcing potential**
- **The monitoring challenge will increase** with the growing burden of new & aging gas infrastructure – suited to regional efforts that include airborne platforms.

Thanks!

- Robert O. Green, Michael Eastwood, Andrew Thorpe, Riley Duren, the AVIRIS team, Brian Bue, Christian Frankenberg, Charles Miller and Andrew Aubrey, all from JPL & Caltech;
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