

Predictors of Measurement Accuracy in the Remote Sensing of CO₂ Emissions

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August 15, 2012

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http://www.nasa.gov/images/content/285744main_PIA11066_full.jpg

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Conducting CO₂ Emissions Inventories from Space

- Ideally every emissions source is accounted for.
- Concentration measurements → modeled CO₂ fluxes (emissions)
- Current instruments not designed to measure *anthropogenic* CO₂, but to provide constraints on natural CO₂ sources/sinks or to perform entirely different mission objectives

Scale of Natural CO₂ Variations

Wyoming

Nebraska

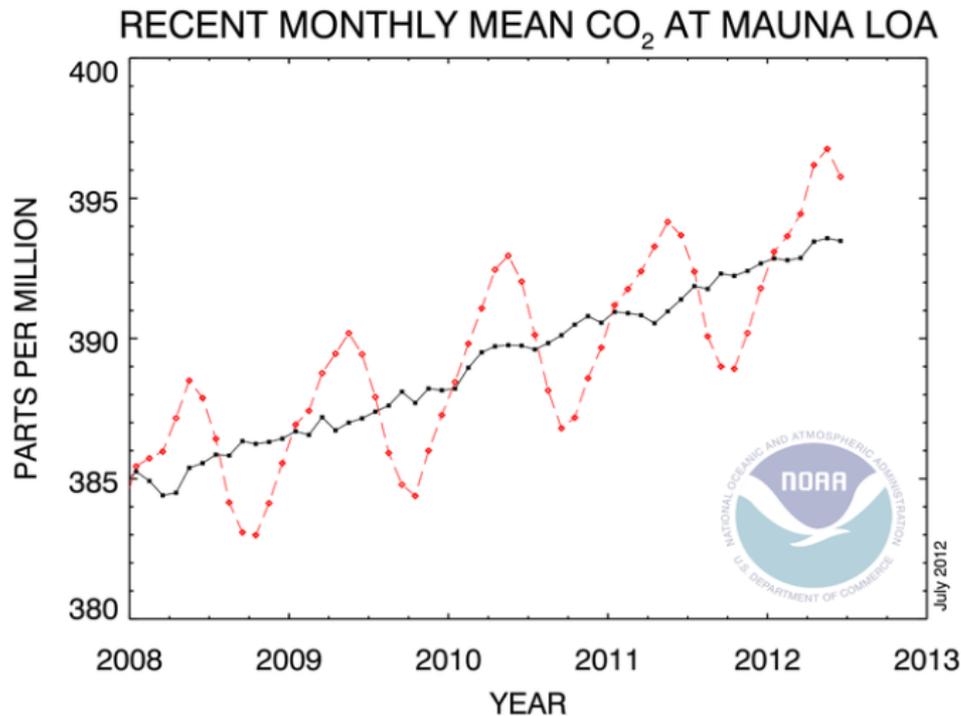
**Roosevelt
National
Forest**

**Fort
Collins**

Colorado

June 20, 2012 – Colorado's High Park Fire, captured by the MODIS instrument aboard NASA's Terra satellite.
Public domain image courtesy of NASA:
http://www.nasa.gov/mission_pages/fires/main/usa/colo-20120620.html

Scale of Anthropogenic CO₂ Emissions



- Anthropogenic CO₂ emissions must be detected against much larger variations in background CO₂ concentration.

Dr. Pieter Tans, NOAA/ESRL

(www.esrl.noaa.gov/gmd/ccgg/trends/) and Dr. Ralph Keeling, Scripps Institution of Oceanography (scrippsco2.ucsd.edu/).

Question

What properties of satellite instruments might enable them to achieve high anthropogenic CO₂ measurement accuracy?

- **Current instruments:** CO₂ measurement accuracy can be determined by comparison to ground and aerial CO₂ measurements.
- **Planned instruments:** CO₂ measurement accuracy estimated from simulated measurements.

Properties of Satellite Instruments

- **Repeat cycle**
 - time before the same location is re-imaged
 - SSM events more likely to be captured with increased frequency
- **Spectral resolution**
 - the smallest wavelength difference that the instrument can resolve
 - Tradeoff between spectral and spatial resolution



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<http://www.gps.gov/multimedia/images/>

Properties of Satellite Instruments

- **Spatial resolution**
 - the size of each pixel on the ground
 - tradeoff between spatial and temporal resolution
- **Swath width**
 - the width of the instrument's field of view, as projected onto the ground

Approach

Find studies that describe actual or estimated CO₂ measurement accuracies of satellite instruments.

Then apply anthropogenic emissions monitoring requirements to determine which instruments, if any, will be useful for obtaining the accurate measurements necessary for conducting this monitoring.

Approach

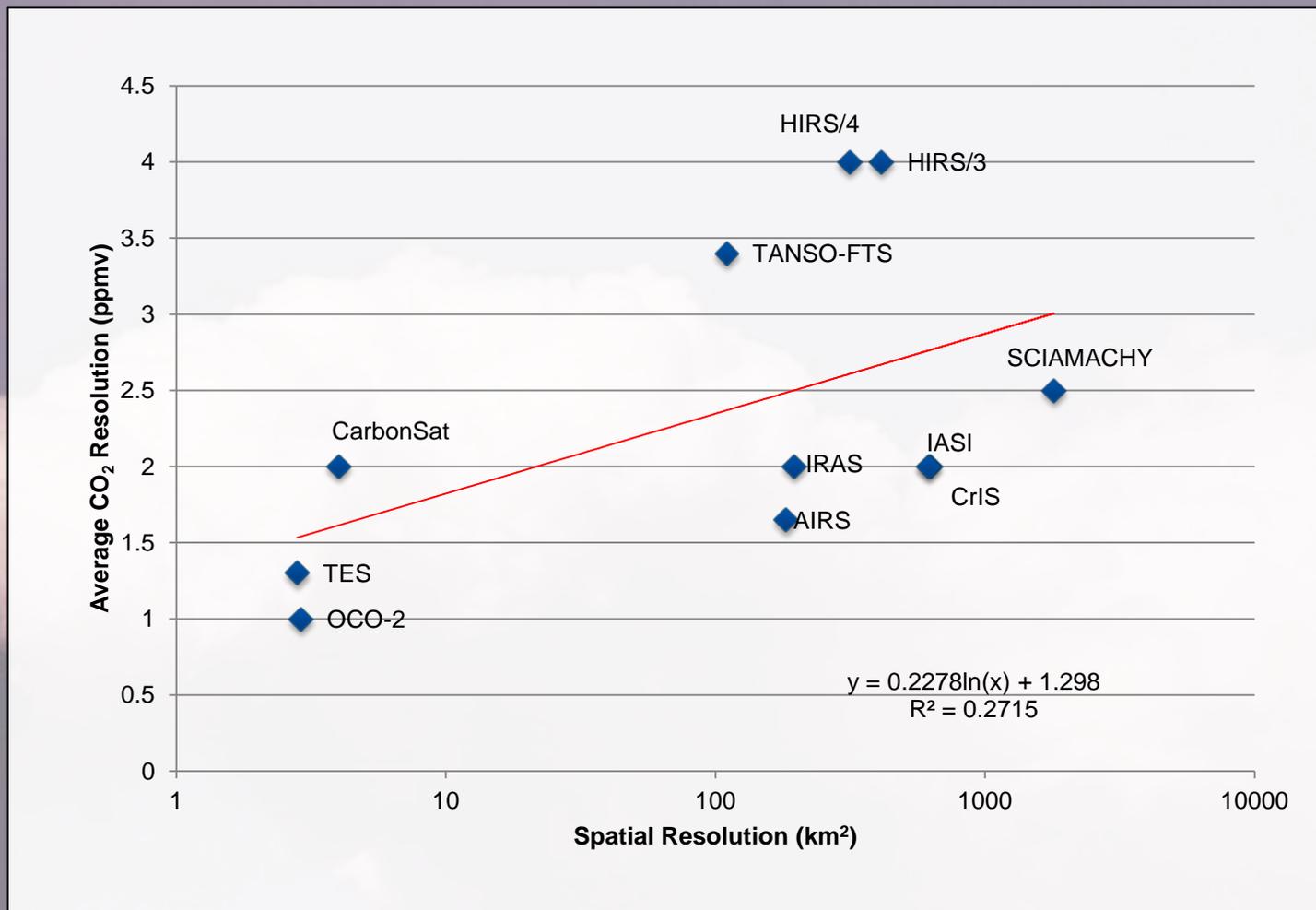
1. Researched studies describing the CO₂ measurement accuracy of 15 instruments being flown on 25 current and planned satellite missions until 2020.
2. Gathered data on the properties of these instruments.
 - Repeat cycle (not relevant to single CO₂ measurements)
 - Spectral ranges (all instruments had sufficient coverage in one or more CO₂ absorption bands)
 - Spectral resolution (variable across many bands)
 - Spatial resolution (used in this study)
 - Swath width (used in this study)

Approach

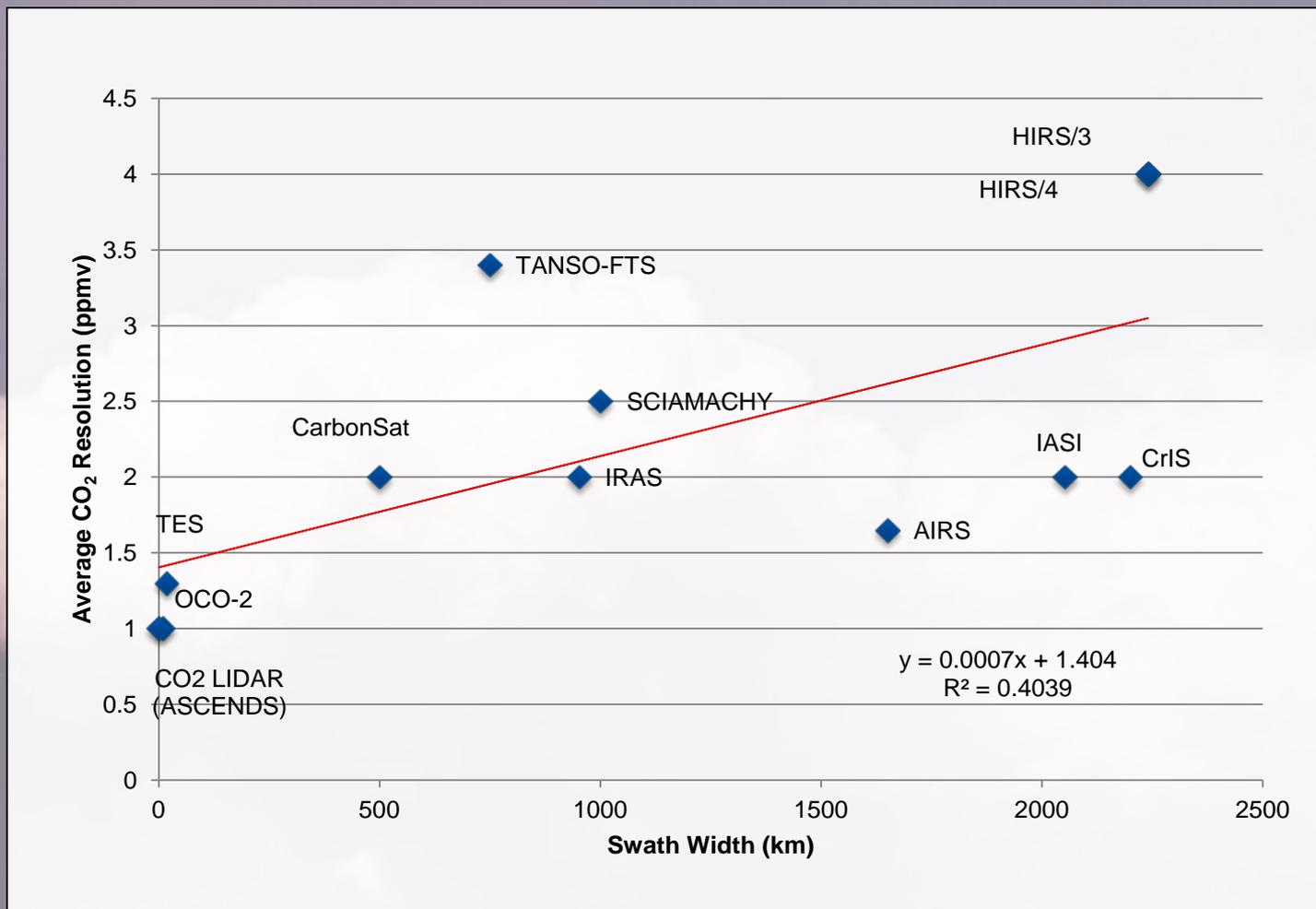
3. Researched studies describing the measurement requirements for anthropogenic emissions monitoring:
 - A spatial resolution of 2x2 km (4 km²) or less is necessary to visualize plumes from point sources (Bovensmann *et al.* 2010)
 - A 90% confidence level (+/- 20% uncertainty) in anthropogenic emissions was deemed possible with a combination of satellite observations, accurate meteorological data, and a ground sensor network (JASON 2011)

Approach

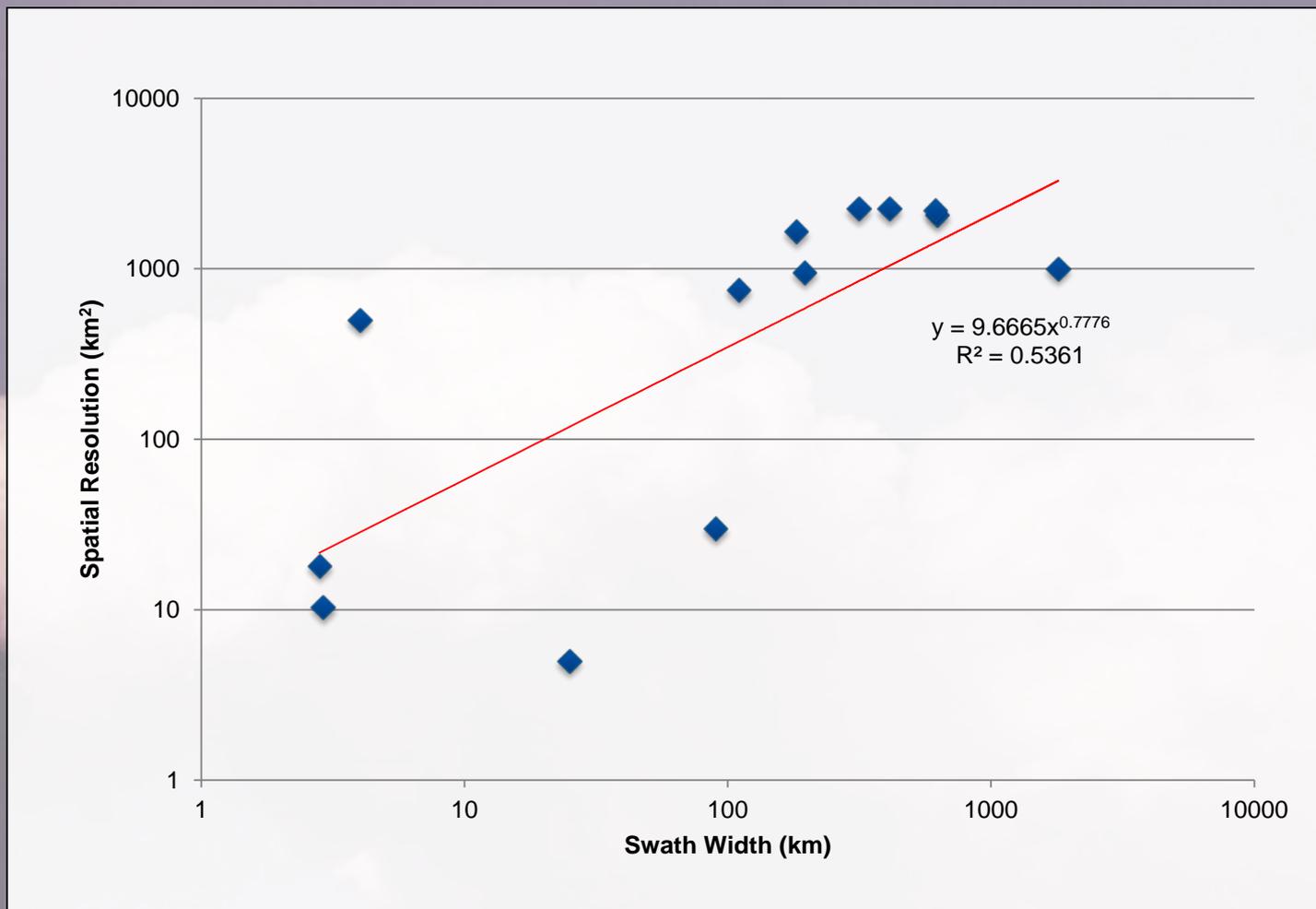
4. Developed multiple regression models in R to find which properties were good predictors of CO₂ measurement accuracy.
 - Exploratory plots indicated one or more log transformations would be useful.
 - Developed single-predictor models for each of the two independent variables, two-predictor models with both variables, then two-predictor models with an interaction term between both variables.
 - The smallest value of Akaike's information criterion (AIC) was used to determine the model of best fit to the data (Burnham and Anderson 2002).



Measurement accuracy and spatial resolution
of CO₂-sensing satellites



Measurement accuracy and swath width
of CO₂-sensing satellites



Variation of instrument spatial resolution with swath width

Results

- Swath width is a better predictor of measurement accuracy than spatial resolution, though models including both outperformed single-predictor models.
- The best model included an interaction term between spatial resolution and swath width.

log10(CO2Acc) ~ SpatRes * SwathWidth					-28.457
	Estimate	Std. Error	t value	Pr(> t)	
(Intercept)	5.157e-02	6.332e-02	0.814	0.42603	
SpatRes	5.800e-04	1.763e-04	3.291	0.00406	**
SwathWidth	3.347e-04	5.905e-05	5.668	2.24e-05	***
SpatRes:SwathWidth	-5.912e-07	1.558e-07	-3.796	0.00132	**
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

$CO_2Acc = CO_2$ measurement accuracy (ppmv)

SR = spatial resolution (km²); SW = swath width (km)

Key Findings

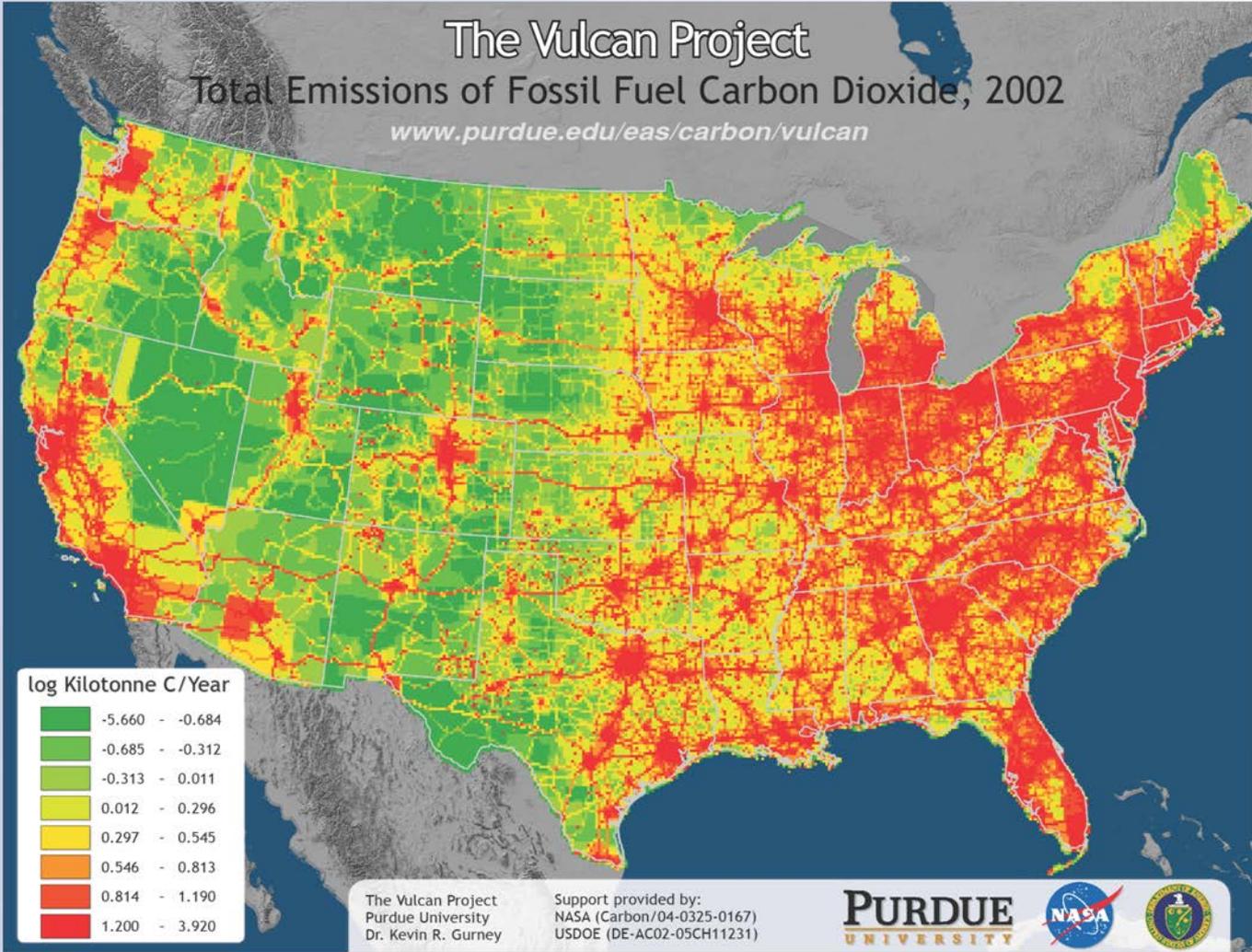
- A satellite instrument's CO₂ measurement accuracy is dependent on the combination of two properties: swath width and spatial resolution.
- Higher accuracy is correlated with smaller swath widths and finer spatial resolution.
- An ideal instrument for monitoring anthropogenic CO₂ emissions will need a spatial resolution of 2x2 km or less to identify point sources (i.e. plumes).
- To reduce the time needed to cover an area, the instrument should have as wide a swath width as possible without sacrificing measurement accuracy.

The Most Accurate Instruments

- Only 3 of the 15 instruments investigated meet the spatial resolution and accuracy requirement posed by Bovensmann *et al.* (2010) for the monitoring of anthropogenic point sources.

Instrument	Status	CO ₂ Accuracy	Spatial Resolution	Swath Width	Notes
TES	Current until 2013	1.3 ppmv	2.809 km ²	18 km	mid-troposphere sensitive; can measure CO ₂ but would require a good transport model
OCO-2	Planned (2013)	1 ppmv expected	2.9025 km ²	10.3 km	
CarbonSat	Planned (2018)	2 ppmv expected	4 km ²	500 km	

Enhancing Ground-Based Inventories



More Information

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