Policy/user needs for carbon monitoring systems

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Motivated and supported by NASA's Carbon Monitoring System (http://carbon.nasa.gov) and the interagency Megacities Carbon Project (http://megacities.jpl.nasa.gov)

topics

- Challenges to defining policy/user needs
- Different questions and response options
- Requirements-driven process example: urban carbon monitoring
- CMS User Needs Project
- Recommendations for decision makers

Challenges to defining policy & user needs

- Ideal world
  - One/few stakeholders
  - Stable human systems
  - Well-established policies → requirements
  - New $$$ for monitoring systems that meet the requirements

- Real world
  - Many (hundreds-thousands of) stakeholders
  - Transformational changes in human systems
  - Ongoing policy proliferation & evolution
  - What can be done with current/planned $?

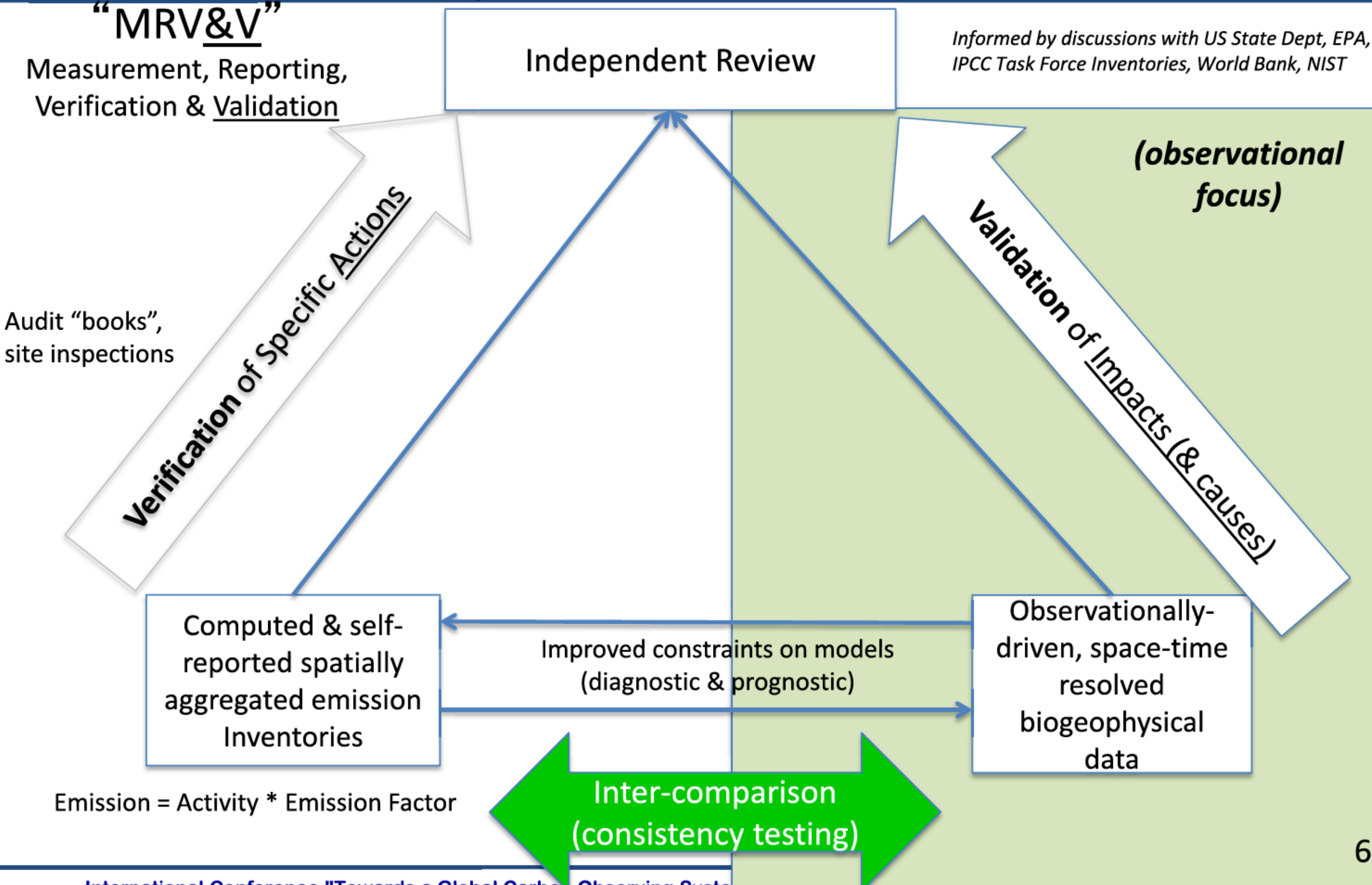
Types of questions & response options

- Policy/user questions (different flavors)
  - MRV (verify policy commitments are being met)
  - Validation (confirm policy efficacy & diagnose issues)
  - Formulation (guide future policy, commitments)
  - Communications (build support, voluntary action)

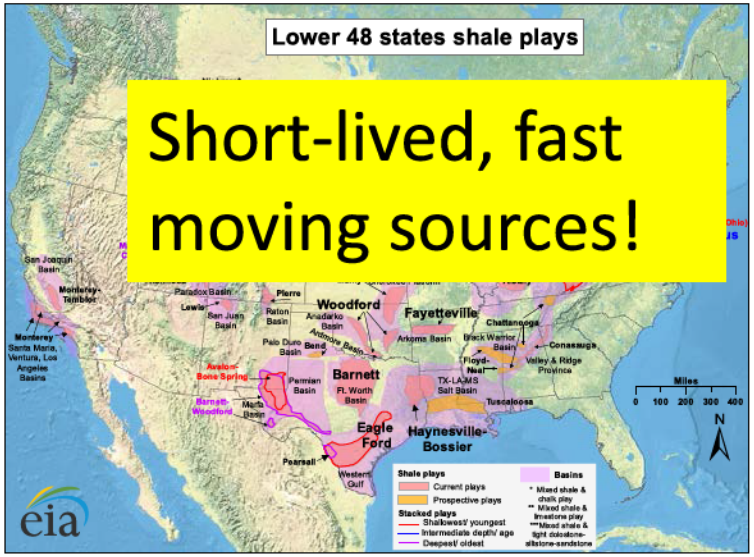
- Response options
  - Capability driven (what can we do today/soon?)
  - Requirements driven (what else needed to meet needs?)

Most likely will involve an "all of the above" response – probably a federation of monitoring *systems* rather than a single one-size-fits-all system

Verification *and* Validation



Example of transformational change: Natural gas and CH_4

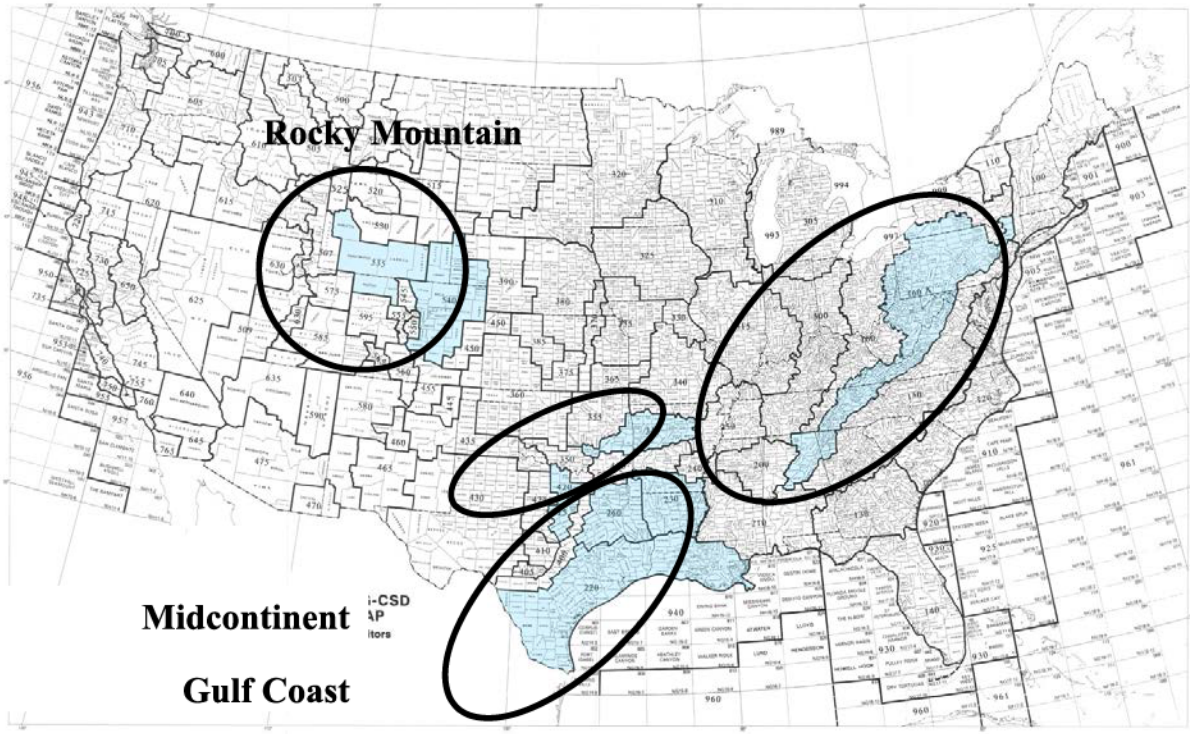


Short-lived, fast moving sources!

US today;
China, Europe, Australia, & S. Africa tomorrow?

Scope of EDF fracking study

D. Allen et al, PNAS, doi/10.1073/pnas.1304880110



How representative was the survey?(cooperating large companies vs random sample);
How will things change over time?

Need more spatially complete, sustained monitoring!

Table S6-2. Distribution of sampling locations, by region

Table 1. Comparison of sample set size to emission source populations

Source	No. of events/locations sampled	Total no. of events/locations
Well completions	27	8,077*
Gas well unloading	9	35,828†
Well workovers	4	1782 (11,663)‡
Wells	489	446,745§

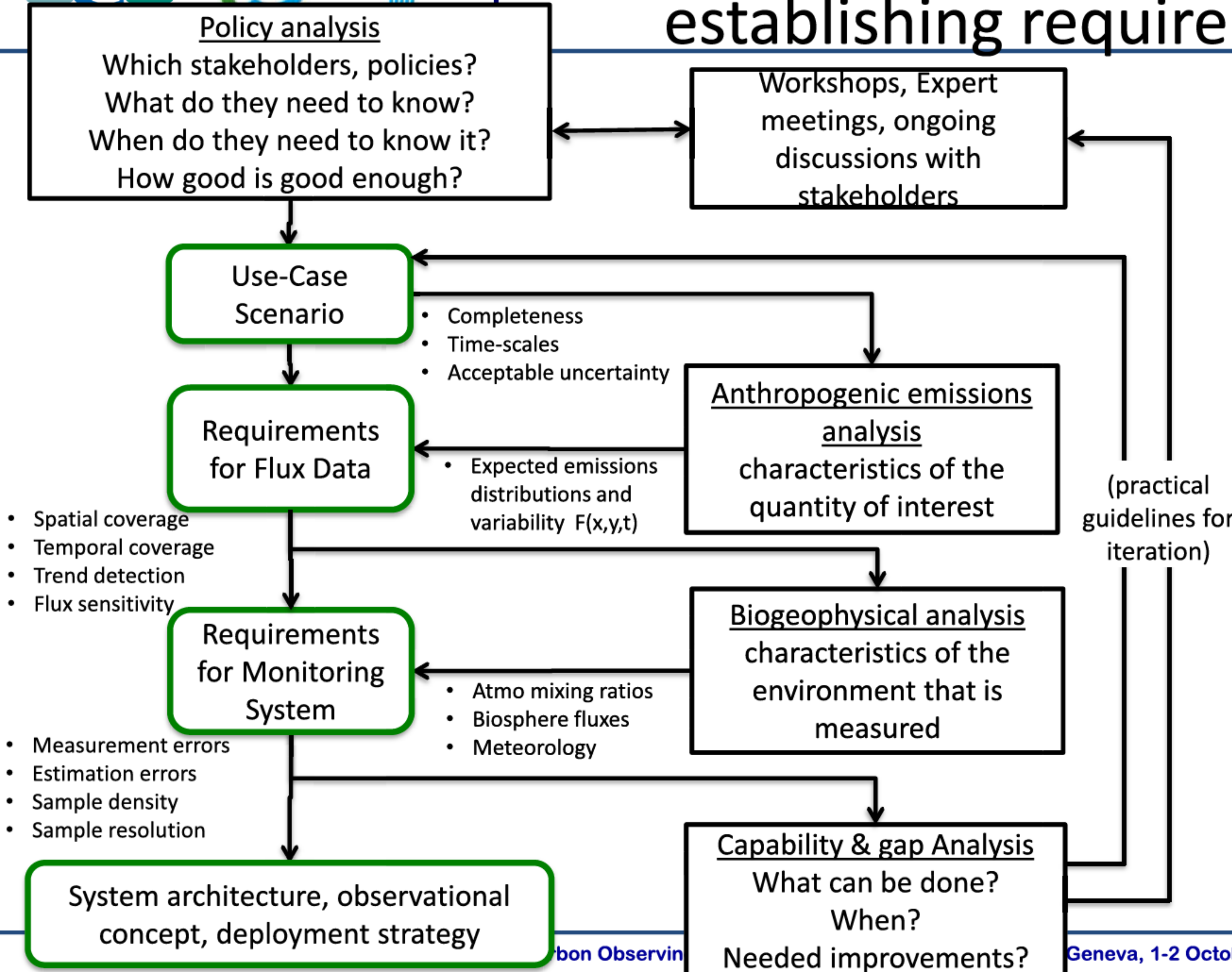
*Completions, with hydraulic fracturing reported in the 2011 National GHG Emission Inventory (1).
†Wells without plunger lift that have unloading events (the type of event sampled in this work) reported in the 2011 National GHG Emission Inventory (1).
‡Workover events with (and without) hydraulic fracturing reported in the 2011 National GHG Emission Inventory (1).
§Gas wells with and without hydraulic fracturing reported in the 2011 National GHG Emission Inventory (1); 513,000 on-shore natural gas wells are reported by the Energy Information Administration (20); see *SI Appendix*.

Natural Gas: Evolving policy & CH_4 monitoring strategies

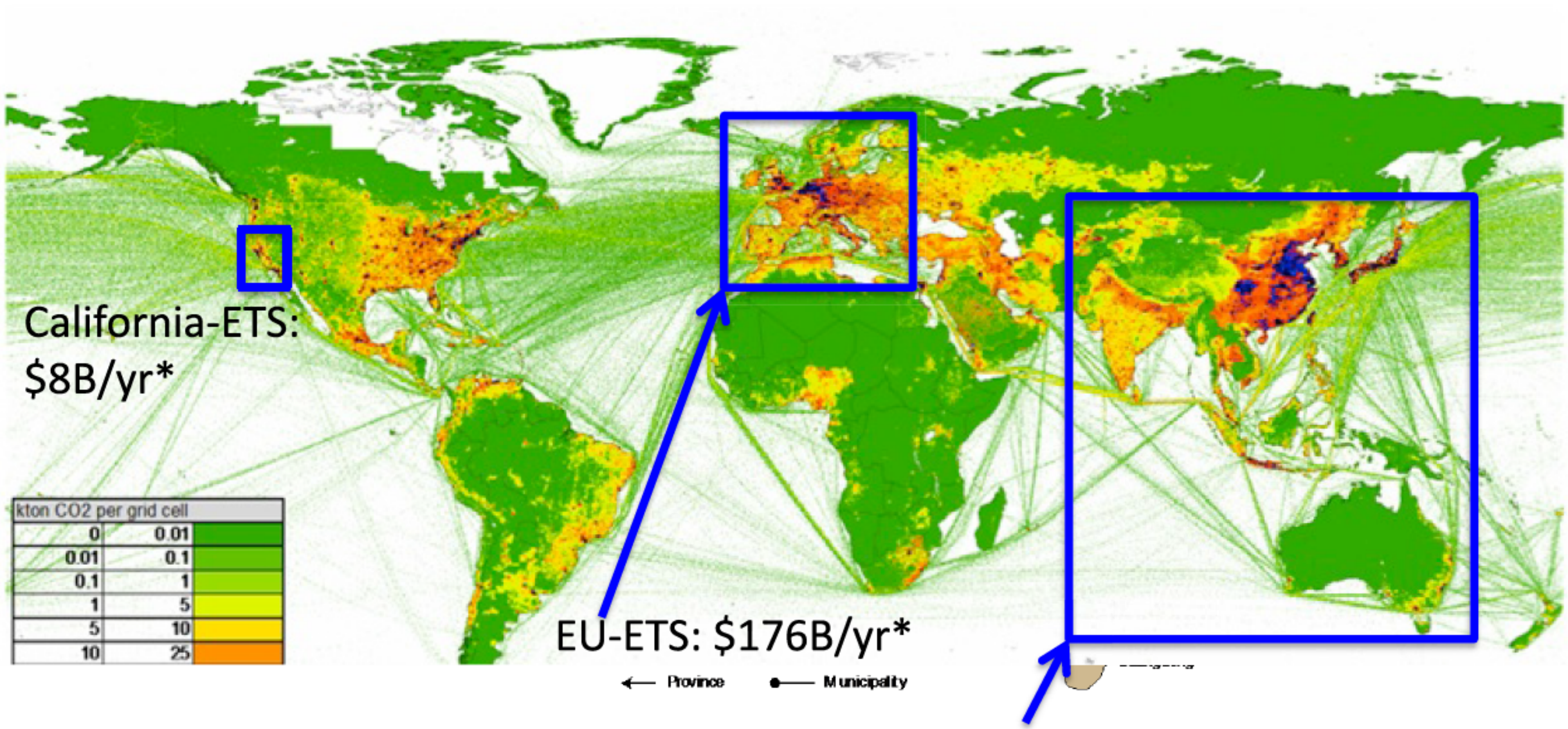
- Verification? Facility-level monitoring with cheap in-situ sensors (~500,000 in US)
  - Like CEMs for power plants
  - Except the sources are more dynamic

- Validation? Sustained basin-level monitoring with mass balance and inverse methods
  - In-situ networks and airborne surveys
  - Satellite mapping (column observations)

General process for establishing requirements



Use-case scenario: Linking emerging, ***sub-national*** carbon trading systems



**Based on CDIAC 2011 emissions data and recent World Bank report citing 2011 global carbon trading totaled 10.2 GtCO2 & $176B.[14]*

Asia-Pacific ETS: China+Australia+S.Korea+India+Japan+Indonesia: $245B/yr*

Can market confidence be grounded in a monitoring system that Validates reported $FFCO_2$ emissions (independent check on sub-national MRV systems)?

Anthropogenic emissions analysis (temporal)

Fast changing sub-national emitters: stabilization & growth

Entity	Recent change	Stated CO2 Emission Stabilization Targets	PROJECTED CHANGE (2011-2020)
State of California (US)	-8% (2008-2010)	1990 levels by 2020, then 80% below those levels by 2050	**TBD**
Guangdong Province (China)	+11% (2006-2011)	19.5% reduction in carbon *intensity* below 2015 levels by 2020	+48 to +159% (if BAU)
Maharashtra State (India)	+99% (2006-2011)	20% reduction in carbon *intensity* below 2005 levels by 2020	+68 to +116% (if BAU)
Shanghai	+8% (2006-2011)	17% reduction in carbon *intensity* below 2015 levels by 2020	+13 to +35% (if BAU)
Los Angeles	not available	30% below 1990 levels by 2030	-38%
Paris	-1% (2005-2008)	25% below 2004 levels by 2020	-20%

Duren and Miller, Environ Sci Tech, 2013, in prep

Suggests a need to detect 10% change over 5 years (95% confidence interval) for high priority ***sub-national*** entities

Anthropogenic emissions analysis (spatial)

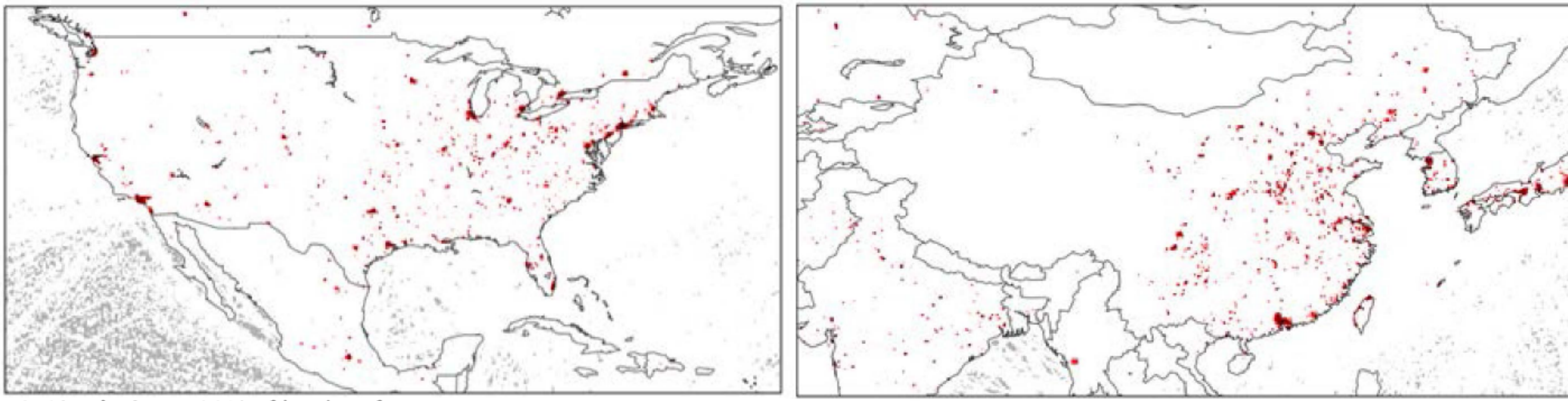
urbanization has concentrated > half the world's population and >70% of Fossil fuel CO_2 emissions into sub-national areas: cities and heavily industrialized provinces/states

2008, EDGAR; 10km flux thresholds 1000 (top) and 20 $gCm^{-2}yr^{-1}$ (bottom)

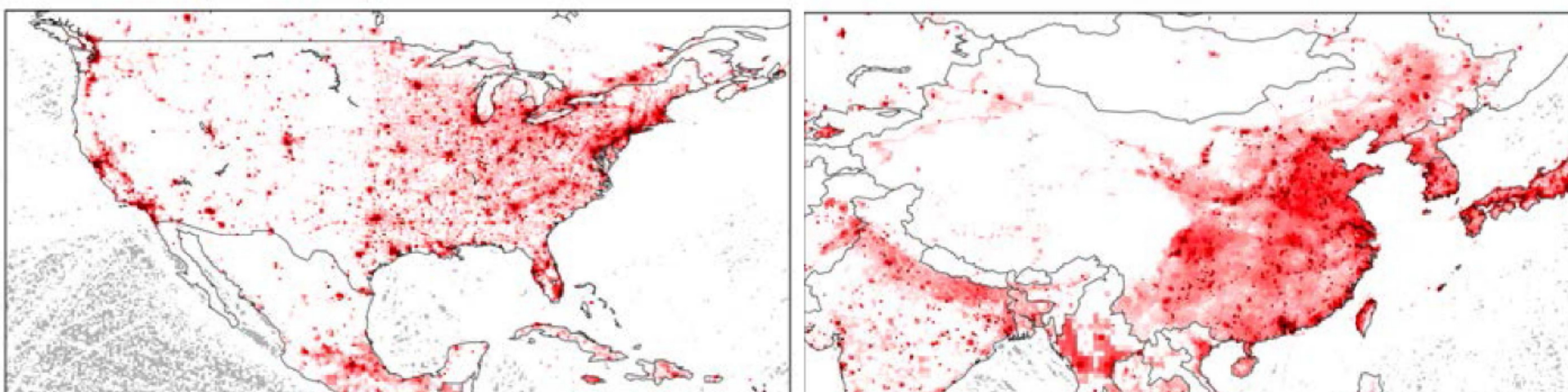
Monitoring System

70-80% solution: 2% of land surfaces

Duren and Miller, Environ Sci Tech, 2013, in prep



95% solution: >33% of land surfaces



Good enough? Regional focus (concentrate surface networks & satellite observations on priority cities/provinces) with flux sensitivity of ~ 1000 $gCm^{-2}yr^{-1}$ at <10 km

Requirements Traceability Matrix for global, urban carbon monitoring system (70% solution)

Policy Scenario	$FFCO_2$ Data Requirements	Monitoring System Requirements
A **monitoring system focused on the fastest changing sub-national emitters**, operating by 2020, providing accurate, independent, and transparent $FFCO_2$ data to support assessment of mitigation policy efficacy and **validation of local and regional MRV systems for carbon emissions trading programs.** **Validation of multi-year $FFCO_2$** trends for the majority of emitters. **Attribution of major anthropogenic emission sectors** distinct from total $FFCO_2$ and biogenic fluxes.	Capable of detecting a **10% trend in $FFCO_2$ emissions over 5 years** at 95% confidence interval for 70% of emitters. **CO_2 flux detection sensitivity: ≤ 1000 $gCm^{-2}yr^{-1}$ at 10km** for ≥ 2% of populated land-surfaces. Quantify CO_2 **annual emissions for top 30% of sub-national emitters with ≤ ±10% total uncertainty**, 95% confidence interval **Characterize time-variability of major emission sectors with ≥3 samples per day on average, ≥70% completeness** over a year (accommodate gaps due to weather, clouds, and periods of peak biosphere activity)	**Urban surface network:** • **30 largest cities world-wide** • 10 stations per city (typically) • **Continuous in-situ monitoring of CO_2 and CO mixing ratios** • Total Integrated Error ≤ 2 ppm/yr (CO_2), 2 ppb(CO) • **Weekly whole-air sampling & ^{14}C analysis** • **Continuous wind and ABL depth measurements** **Satellite network:** • **Low earth orbiting satellite with urban target mode** (1000+ observations per visit), 3 day revisit • **3 geostationary instruments (Asia, Americas, Europe/Africa),** mapping entire coverage area 4 visits/day (w/50% clouds), lat: 60N to 35S • **Total *integrated* error over 25 x 25 km^2** for each city and power plant target: **column-averaged mixing ratios ≤ 0.3 ppm/yr (CO_2)**, ≤ 1ppb (CO) **High-res modeling & data system:** • **1km, hourly CO_2, CO emissions data** • Mesoscale transport models • Transparent, traceable access to data • Latency ≤ 18 months

Duren and Miller, Environ Sci Tech, 2013, in prep

System architecture for global urban carbon monitoring system

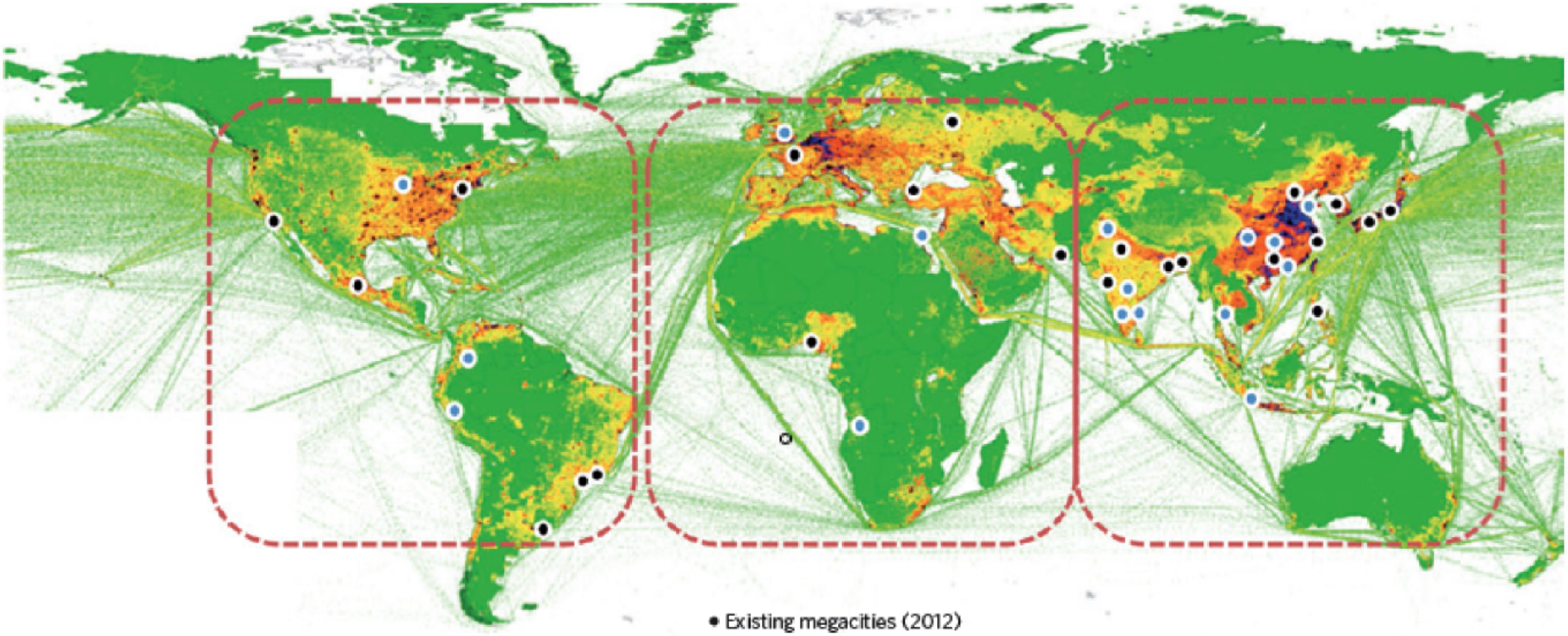


Figure 1 | A strategy for monitoring megacity carbon emissions. A 10-km-resolution gridded inventory of anthropogenic greenhouse-gas emissions in carbon dioxide equivalents indicates the distribution and intensity of emission sources, ranging from 0–55 Mg C per cell per year. Urban areas are indicated in orange, red and black. The darkest areas correspond to the emissions of urban and heavily industrialized areas. The black circles indicate proposed surface measurement networks concentrated within and around the 23 existing megacities. Blue circles indicate the 14 additional megacities projected to exist by 2025 (ref. 17). The dashed rectangles indicate the fields of regard of three remote-sensing instruments that if hosted on commercial communication satellites in geostationary orbit would offer sustained, wall-to-wall measurements of column-averaged carbon dioxide, methane and carbon monoxide mixing ratios several times per day for the vast majority of the Earth's populated areas. With such a system, a typical megacity would be sampled by over 2,500 measurements per day on average. An existing network of surface remote-sensing stations enables calibration of satellite data. Emission map taken from European Commission-Joint Research Council/Netherlands Environmental Assessment Agency (PBL). Emission Database for Global Atmospheric Research (EDGAR) version 4.0 (http://edgar.jrc.ec.europa.eu) 2009.

Duren, R.M and C.E.Miller (2012), Measuring the Carbon Emissions of Megacities, *Nature Climate Change* 2, 560–562 (2012) doi:10.1038/nclimate1629.

Observational concept

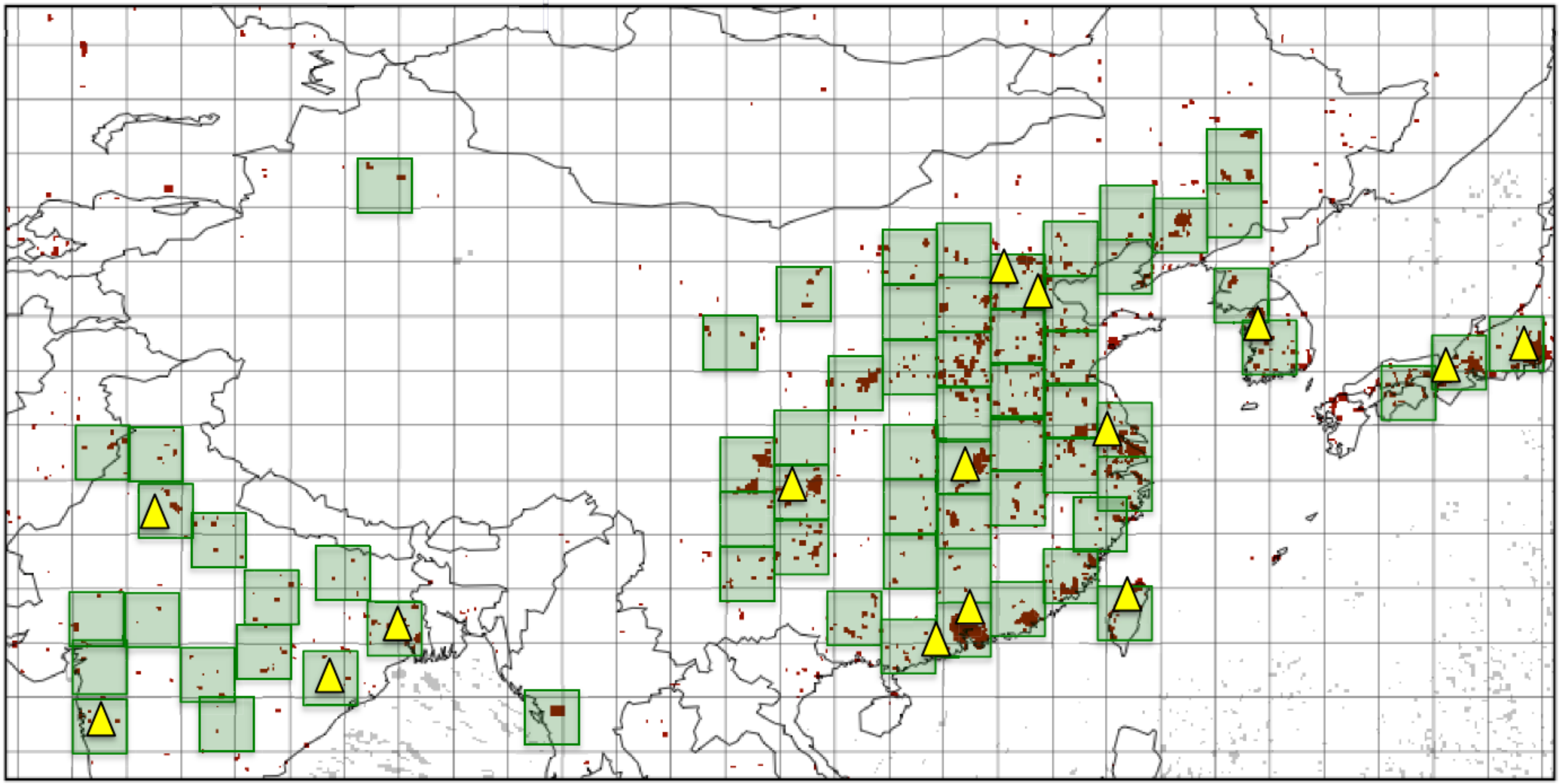


Figure 4. Observational concept for the majority (70-80%) of $FFCO_2$ emissions in Asia (top) and North America (bottom) overlaid on EDGAR v4.2 emissions (2008) with a threshold > 300 $gCm^{-2}yr^{-1}$. Yellow triangles indicate approximate locations of dense surface measurement networks in selected megacities (~30 total). Green squares indicate priority targeting for frequent (hourly) wall-to-wall mapping of column CO_2, CO, and CH_4 mixing ratios from hosted payloads on commercial communication satellites in geostationary orbit. Each green square is approximately 250 km x 250 km and composed of 64x64 pixels that each subtend 2.7 km at the equator (maximum of 4 km at high latitudes).

Duren and Miller, Environ Sci Tech, 2013, in prep.

Gap analysis: what can planned satellites do near-term?

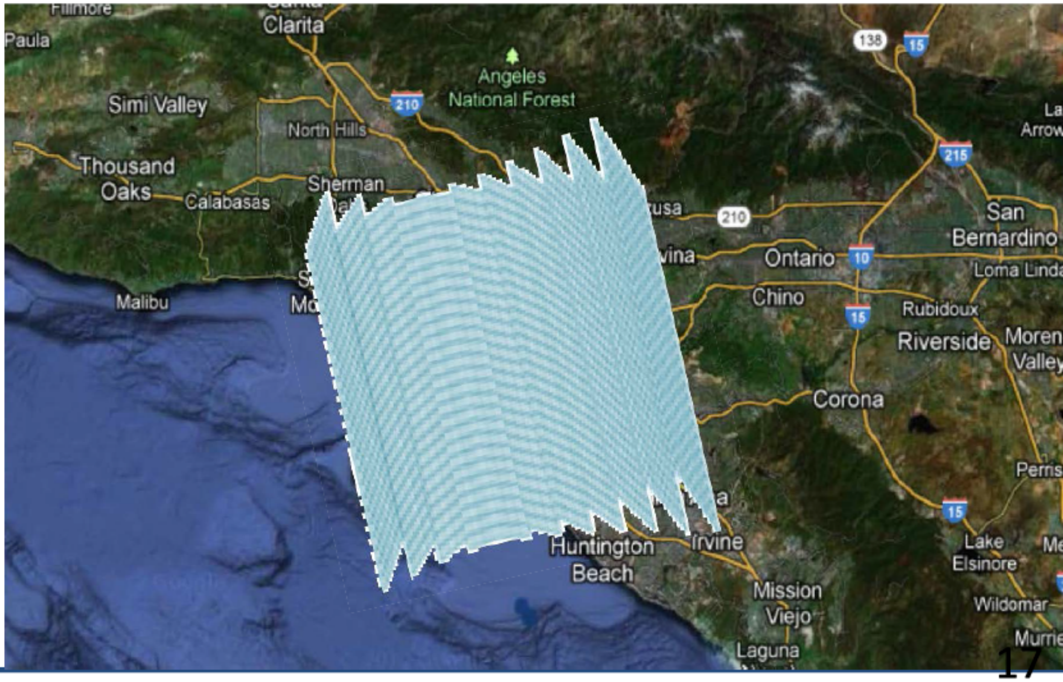
- Longer-term, we need to work towards *persistent, dense urban mapping* of CO2 (& CO, CH4) from Geostationary satellites and denser ground networks

- Nearer-term, there's much that OCO-2, OCO-3, Tansat, GOSAT-2, MERLIN, Micro-Carb, CarbonSat, etc ***could*** do, if focus on cities; example: if 7% of OCO-3 observations targeted 50 largest cities we could revisit most of them every 36-72 hours (no clouds) with *thousands of observation per visit* (city-mode); aggregation might yield < 0.5 ppm XCO2 **integrated error** per city (> 20 km)

- Urban CO obs by MOPITT and some of the above satellites could also help fossil-fuel CO_2 attribution (if appropriate calibrated with surface ^{14}C observations)

City	Country	center coords (lat/lon)	OCO-2 nadir pass available? (yes/no)	OCO-2 glint pass available? (yes/no)	OCO-3 city mode available? (yes/no)	OCO-3 revisit interval? (days)
Beijing	China	39.922878°, 116.400999°	NO	YES	YES	1.5 - 3
Tianjin	China	39.080563°, 117.201034°	YES	NO	YES	1.5 - 3
Shanghai	China	31.210791°, 121.468314°	NO	NO	YES	1.5 - 3
Guangzhou (Canton)	China		NO	YES	TBD	
Shenzen/Hong Kong	China	22.535498°, 114.049037°	YES	YES	YES	1.5 - 3
Wuhan	China		NO	YES	TBD	
Chongqing	China	29.563010°, 106.551557°	NO	NO	YES	1.5 - 3
Seoul	South Korea	37.566438°, 126.977960°	YES	YES	YES	1.5 - 3
Tokyo	Japan	35.686416°, 139.769594°	YES	YES	YES	1.5 - 3
Osaka	Japan		YES	YES	TBD	
Sydney	Australia	-33.863707°,151.210795°	BARELY	YES	YES	1.5 - 3
Bangkok	Thailand	13.676715°, 100.496622°	YES	YES	YES	1.5 - 3
Manila	Phillipines		NO	YES	TBD	
Jakarta	Indonesia	-6.211543°, 106.845173°	NO	NO	YES	1.5 - 3
Mumbai	India	19.080905°, 72.873432°	YES	YES	YES	1.5 - 3
Delhi	India		NO	YES	TBD	
Hyderabad	India		NO	YES	TBD	
Chennai (Madras)	India		NO	BARELY	TBD	
Bangalore	India	12.969209°, 77.590675°	NO	NO	YES	1.5 - 3
Kolkata	India		NO	NO	TBD	
Dhaka	Bangladesh		YES	YES	TBD	

Analysis by Duren, Bennnett et al 2013

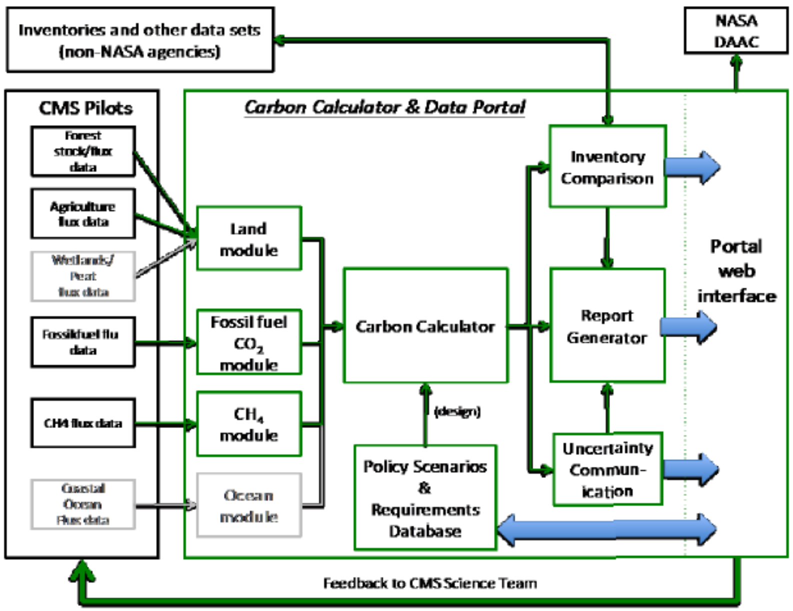


Looking ahead: CMS User Needs project

- Part of NASA's Carbon Monitoring System (CMS) phase 2
- Sept 2013 start, 3 year duration
- Team: policy experts, scientists, engineers
- Coordinate with other CMS teams and cross-section of user-community
- Currently US centric but inter-national collaborators encouraged!

Name	Institution	Role
Riley Duren	Jet Propulsion Laboratory	PI; coordination, policy scenarios and requirements analysis
Sassan Saatchi	Jet Propulsion Laboratory	Co-I; carbon calculator, LULCUF carbon stock and flux analysis and product eval
Kevin Gurney	Arizona State University	Co-I; carbon calculator, CO_2/CH_4 flux analysis and product eval
Dan Crichton	Jet Propulsion Laboratory	Co-I; data portal infrastructure
Molly Macauley	Resources For the Future	Co-I; user engagement
Roger Cooke	Resources For the Future	Co-I; uncertainty quantification
Leif Hockstad	US EPA	Collaborator; GHG emission inventories
David Reidmiller	US State Department	Collaborator; US/international climate policy
Kate Larsen	White House Council on Environmental Quality	Collaborator; US/international climate policy
Christopher Woodall	US Forest Service	Co-I; forest carbon accounting and policy
Bart Croes	California Air Resources Board	Collaborator: California GHG policy

- Objectives:
  - Engage users and identify stakeholder requirements
  - Evaluate CMS data products for decision making value
  - Explore visualization/sharing of carbon information
  - Explore uncertainty quantification/communication
  - Particular emphasis on remote-sensing for MRV
  - Explore potentially broader needs for carbon data for policy support beyond MRV (i.e., Validation)



Recommendations for decision makers

1. Recognize the need for both capability-driven (today) and requirements-driven (future) approaches to carbon monitoring

2. *Validation* (of ultimate policy efficacy and diagnosis/attribution of issues) should receive same priority as *Verification* (MRV-ing compliance with commitments)

3. Embrace the concept of a *suite* of monitoring *systems* to address divergent stakeholder questions (no one-size-fits-all)

4. Critically consider *"good enough"* monitoring systems: balance acceptable levels of completeness and uncertainty with affordability and timeliness

5. Need *sustained, working-level policy/science teams* to apply a *systematic and iterative process* to define & refine (evolving) policy/user requirements

6. Recognize need to build capacity in human resources (science community)

7. (Intentionally provocative) Be prepared to address looming policy wild-cards such as geoengineering (air-capture sequestration/CDR)

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backup

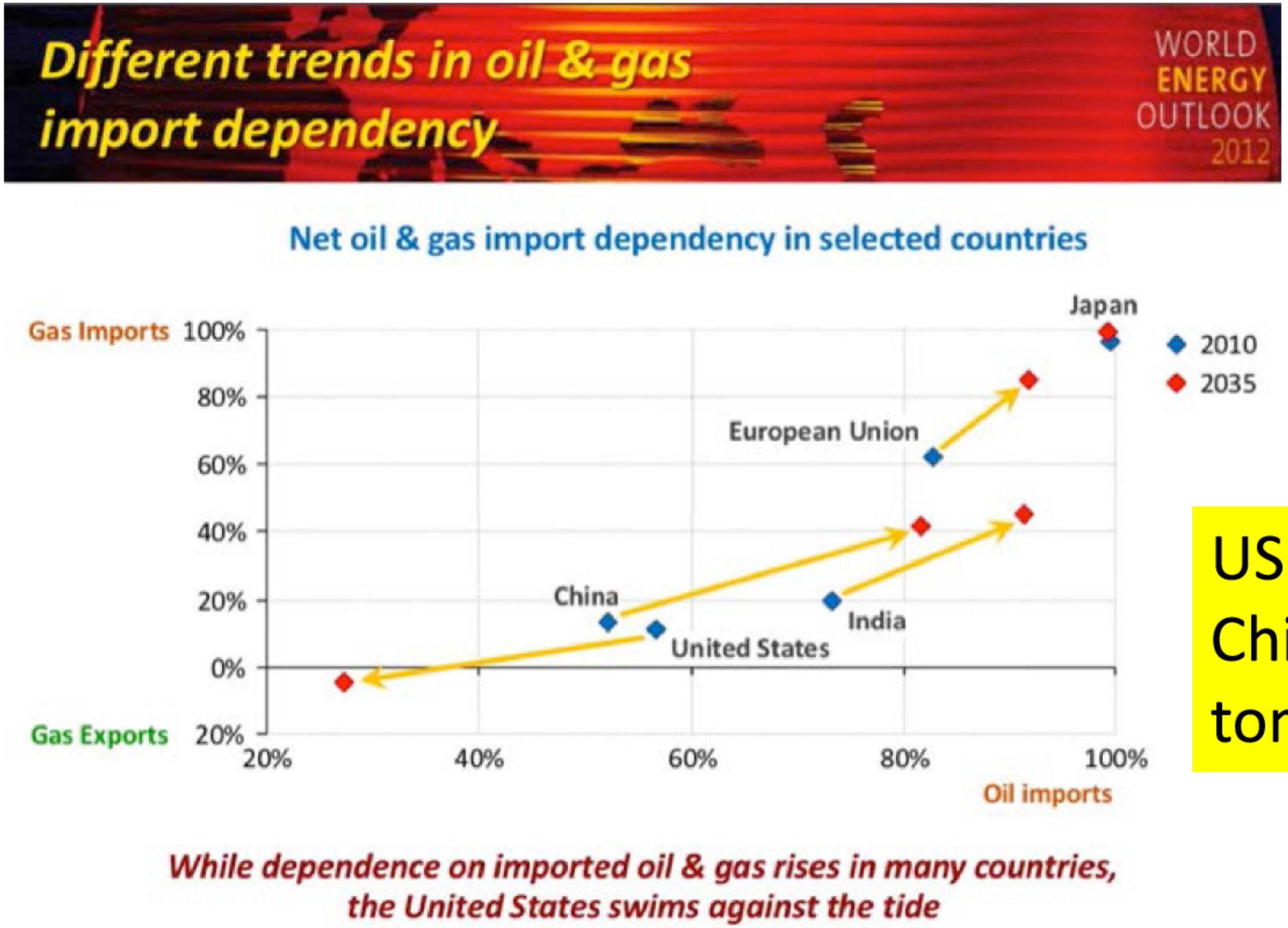
Potential stakeholders (partial list)

operational agencies supporting decision-makers in national, state, and local govts as well as NGOs, private industry and individual stakeholders

ORGANIZATION	PRODUCTS	POLICIES/PROGRAMS
EPA*, CARB, CEQ	Area fluxes from US land sector/AFOLU (CO_2, CH_4, N_2O)	US Clean Air Act, California AB32; UNFCC
US State Dept, DOE, EPA	Country-level & point sources of CO_2 fossil-fuel emissions; Land Cover Change	Multi-lateral treaty or bi-lateral agreement (Kyoto follow-on); carbon ETS
DOI-USGS	US Ecosystem carbon (forest & soil biomass?)	US EISA
USAID	Global forest biomass (stocks & disturbance)	REDD+/Silva Carbon
USDA-USFS, EPA & state agencies	US & Global Forest biomass (stocks & disturbance)	REDD+ & existing forest mandates
USDA ARS & NRCS	Soil Organic Carbon	US Farm Bill
Cities (Mayors, C40), State/Regional regulators (CARB, AIRPARIF), WorldBank/PMR, RGGI	Sub-national CO_2 & CH_4 fluxes	Sub-national programs: City level Climate Plans (LA, Paris, Sao Paulo, Beijing, C40, ICLEI), California AB32, sub-national carbon markets
EPA, DOI, ARPA-E, EDF	CH_4 emissions from gas/oil sector	TBD (still being formulated)

*International counterparts: IPCC TFI and member agencies

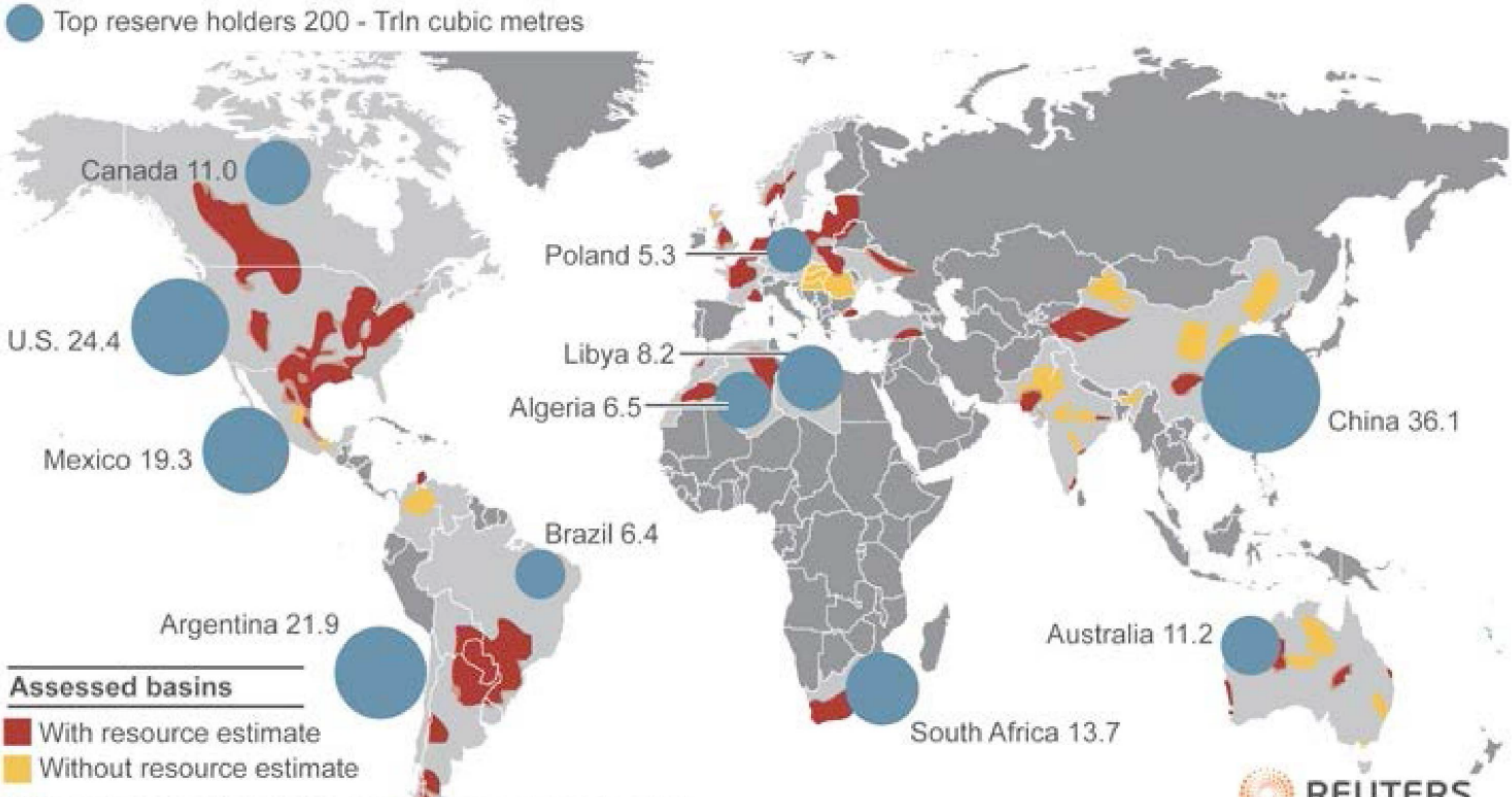
Example: Transformational change (fossil fuel CH_4)



US today, China tomorrow?

NG is cleaner than coal – but only ***if*** fugitive CH4 emissions are managed/regulated/monitored

Global shale gas basins, top reserve holders



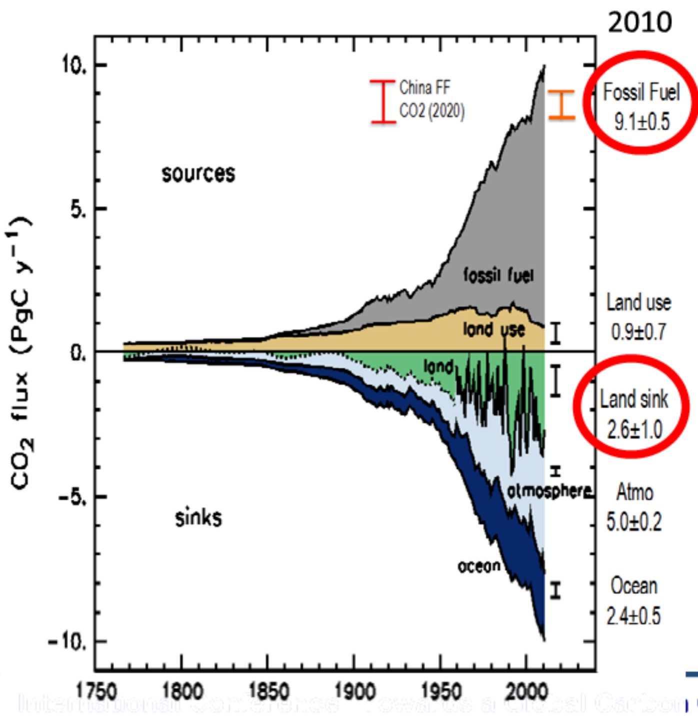
Source: EIA based on Advanced Resources International Inc data, BP

Reuters graphic/Catherine Trevethan

Example: transformational change in fossil-fuel CO_2

- Explosive growth will likely continue through 2025
- Major shift in demographics, players, and policy options
  - Developed → Developing world; National → Sub-national regimes
- Uncertainties remain large
  - >20% uncertainty for developing countries
  - 100% uncertainty (or not available) for sub-national entities (cites) – even in US/EU
  - Uncertainty in emission inventories *likely exceeds multi-year trends* in many cases

Global Carbon Project, 2011



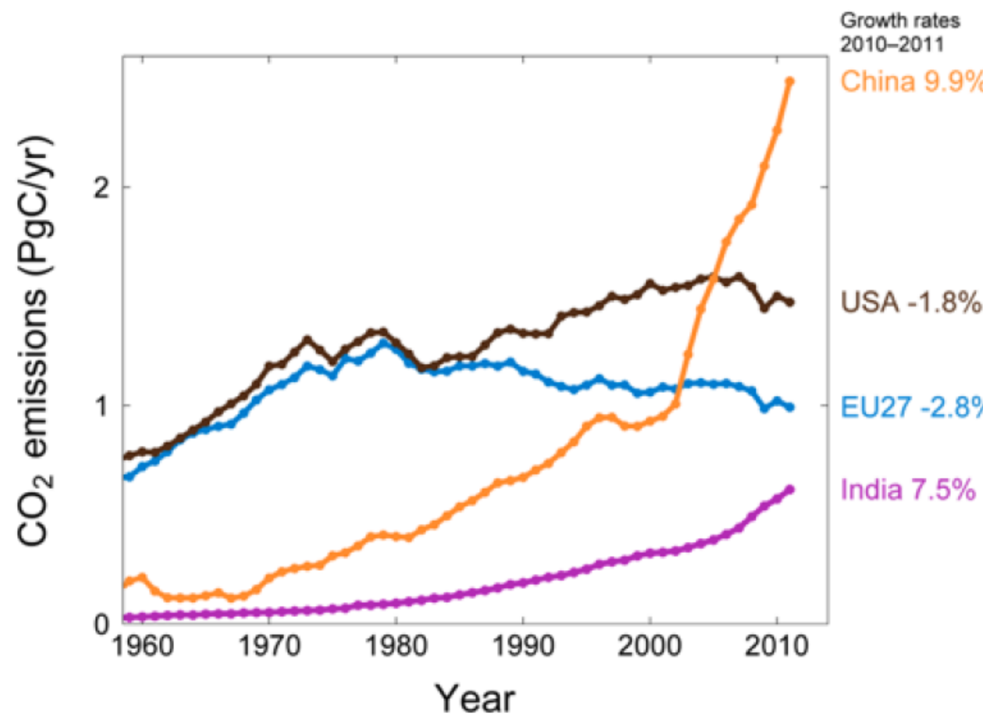
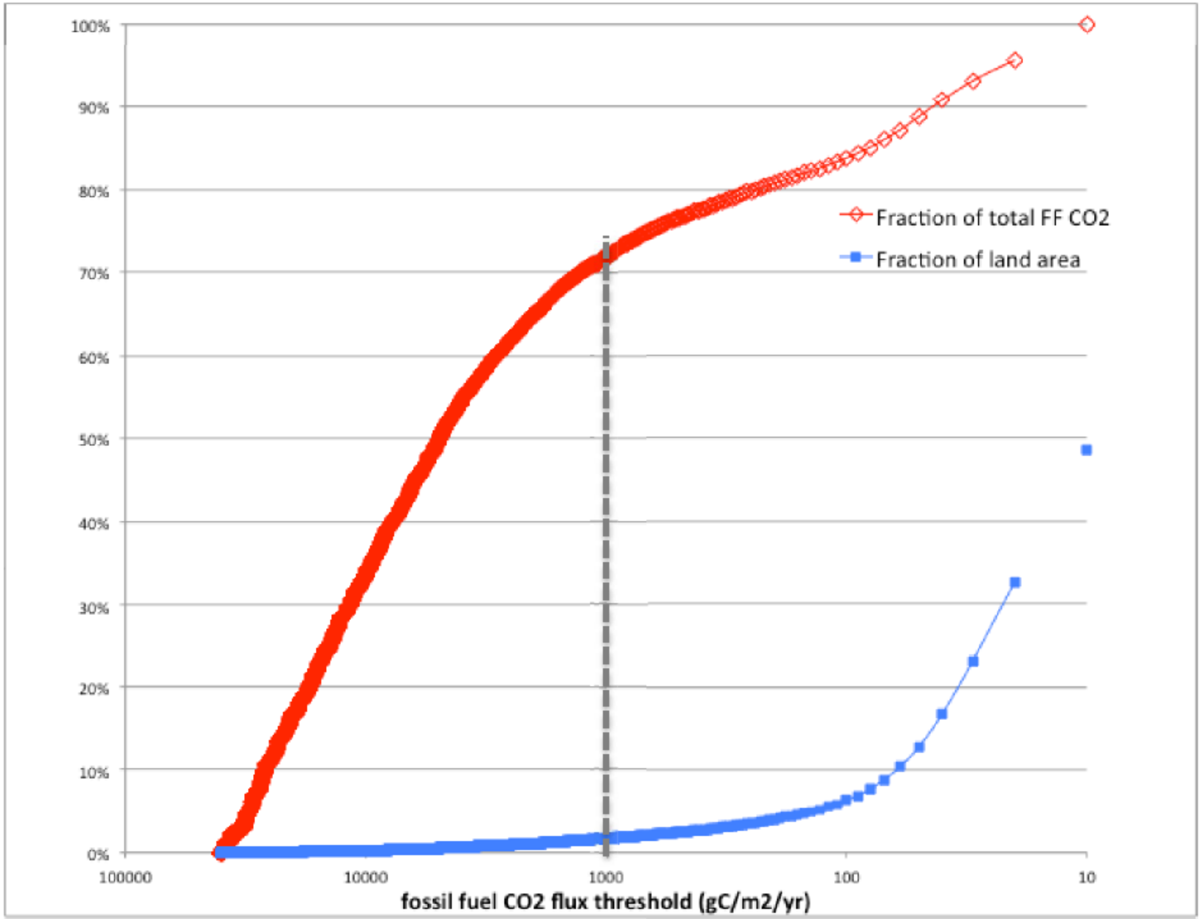


Figure 3. Plot for the coterminous US and China indicating the fraction of each country's total $FFCO_2$ emissions (red curve) and fraction of land area (blue curve) as a function of emission flux sensitivity in $gCm^{-2}yr^{-1}$. Based on EDGAR V4.2 10 km data for 2008. The optimal design point lies between 300 and 1000 $gCm^{-2}yr^{-1}$ – achieving 70-80% complete coverage of emissions while focusing on ~2% of the land area.



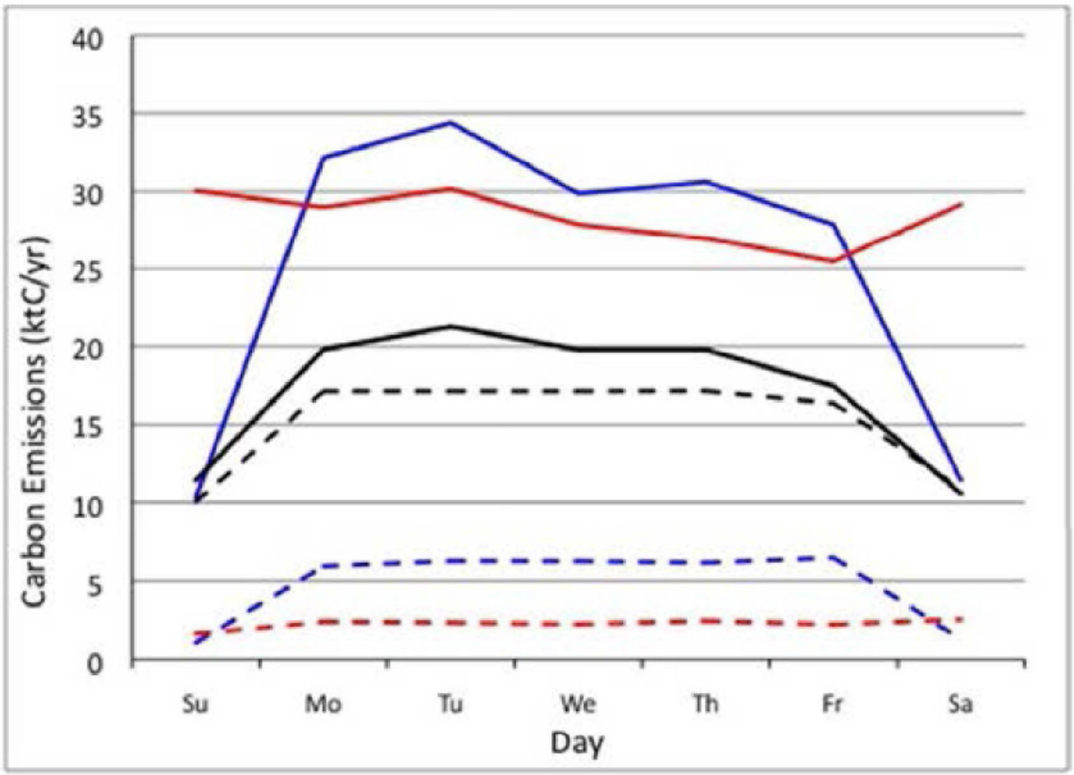
Duren and Miller, Environ Sci Tech, 2013, in prep

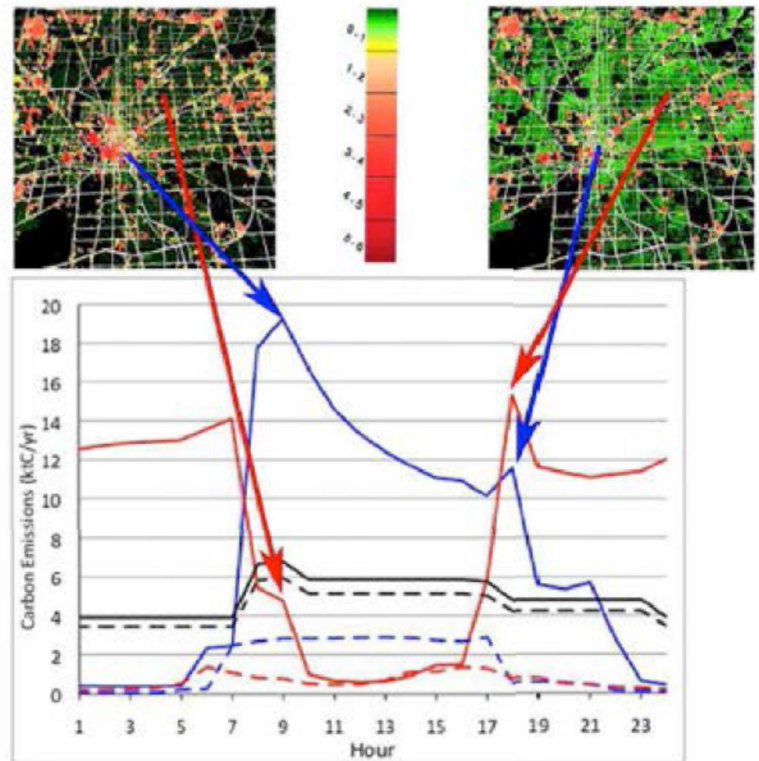
Suggests regional focus for carbon-monitoring system (concentrate surface networks and satellite observations on priority cities/provinces)

Attributing observed changes to specific sectors

Implication on temporal completeness and sample frequency requirements

Weekly and diurnal signatures for industrial (black), commercial (blue) and residential (red) emission sectors for Indianapolis, Hestia, Gurney et al, Env Sci Tech, 2012





Need to a) link observations with space-time resolved human energy system models; b) sampling intervals of hours to days - not weeks

Example questions from decision makers

- (State/province) Are the MRV systems of other sub-national carbon markets (states/provinces/megacities) sufficiently robust for us to link to our market?
- Should we use facility-level verification and/or basin-level validation to track fugitive CH_4 emission from natural gas production?
- How do we diagnoses and reconcile reported discrepancies between top-down and bottom-up emission estimates for sector X?
- Under the UNFCCC and carbon fund, what's a reasonable level of uncertainty at a national scale?
- What's the cost per level of uncertainty associated with monitoring systems?
- Is it possible to measure forest degradation at the national scale on with latencies < 5 years - and at what cost?
- What emission factors should we assign to biodiesel from palm oil? Coastal wetlands?
- Are fracking regulations having the intended impact on fugitive CH_4 emissions at the scale of major shale basins?
- Will Country-A's land sink remain a sink beyond 2020?
- Should we include LULUCF fluxes in our upcoming stabilization commitment given current uncertainties in the trend?
- How do I (mayor) convince my electorate that the city's climate plan (GHG stabilization) is worth the cost?
- What's the true magnitude of carbon losses from peatland draining in Indonesia and Malaysia?
- What's the potential for future inclusion of blue carbon in national GHG inventories?
- What are the carbon-cycle impacts (desired and unintended) of approved or rogue geoengineering field-experiments?