Policy/user needs for carbon monitoring systems

Riley Duren¹, Molly Macauley², Chip Miller¹

Riley.m.duren@jpl.nasa.gov

¹ Jet Propulsion Laboratory, California Institute of Technology
² Resources For the Future

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 $\rightarrow$ 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

“MRV&V”
Measurement, Reporting, Verification & Validation

Independent Review

Audit “books”, site inspections

Verification of Specific Actions

Computed & self-reported spatially aggregated emission Inventories

Emission = Activity * Emission Factor

Improved constraints on models (diagnostic & prognostic)

Observationally-driven, space-time resolved biogeophysical data

Validation of Impacts (& causes)

(observational focus)

Inter-comparison (consistency testing)

Informed by discussions with US State Dept, EPA, IPCC Task Force Inventories, World Bank, NIST
Example of transformational change: Natural gas and CH₄

Short-lived, fast moving sources!

US today; China, Europe, Australia, & S. Africa tomorrow?
How representative was the survey? (cooperating large companies vs random sample); How will things change over time?

Need more spatially complete, sustained monitoring!
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

**Policy analysis**
- Which stakeholders, policies?
- What do they need to know?
- When do they need to know it?
- How good is good enough?

**Use-Case Scenario**
- Completeness
- Time-scales
- Acceptable uncertainty

**Requirements for Flux Data**
- Spatial coverage
- Temporal coverage
- Trend detection
- Flux sensitivity

**Requirements for Monitoring System**
- Atmo mixing ratios
- Biosphere fluxes
- Meteorology

**Anthropogenic emissions analysis**
- Expected emissions distributions and variability $F(x,y,t)$
- Characteristics of the quantity of interest

**Biogeophysical analysis**
- Characteristics of the environment that is measured

**Capability & gap Analysis**
- What can be done?
- When?
- Needed improvements?

Workshops, Expert meetings, ongoing discussions with stakeholders

(practical guidelines for iteration)
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

California-ETS: $8B/yr*

EU-ETS: $176B/yr*

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

Can market confidence be grounded in a monitoring system that Validates reported FFCO₂ emissions (independent check on sub-national MRV systems)?
### Fast changing sub-national emitters: stabilization & growth

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

_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 CO2 emissions into sub-national areas: cities and heavily industrialized provinces/states 2008, EDGAR; 10 km flux thresholds 1000 (top) and 20 gCm⁻² yr⁻¹ (bottom).

Monitoring System
70-80% solution: 2% of land surfaces

95% solution: >33% of land surfaces

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

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)

<table>
<thead>
<tr>
<th>Policy Scenario</th>
<th>FFCO$_2$ Data Requirements</th>
<th>Monitoring System Requirements</th>
</tr>
</thead>
</table>
| 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. | Capable of detecting a 10% trend in FFCO$_2$ emissions over 5 years at 95% confidence interval for 70% of emitters. | 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 $\leq$ 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 $25 \times 25$ km$^2$ for each city and power plant target: column-averaged mixing ratios $\leq$ 0.3 ppm/yr (CO$_2$), $\leq$ 1 ppb (CO)  

High-res modeling & data system:  
- 1km, hourly CO$_2$, CO emissions data  
- Mesoscale transport models  
- Transparent, traceable access to data  
- Latency $\leq$ 18 months |
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.

Figure 4. Observational concept for the majority (70-80%) of FFCO\textsubscript{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\textsubscript{2}, CO, and CH\textsubscript{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).

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 CO2 attribution (if appropriate calibrated with surface $^{14}$C observations)
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 international collaborators encouraged!

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)

## Potential stakeholders (partial list)
operational agencies supporting decision-makers in national, state, and local govts as well as NGOs, private industry and individual stakeholders

<table>
<thead>
<tr>
<th>ORGANIZATION</th>
<th>PRODUCTS</th>
<th>POLICIES/PROGRAMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPA*, CARB, CEQ</td>
<td>Area fluxes from US land sector/AFOLU (CO2, CH4, N2O)</td>
<td>US Clean Air Act, California AB32; UNFCC</td>
</tr>
<tr>
<td>US State Dept, DOE, EPA</td>
<td>Country-level &amp; point sources of CO2 fossil-fuel emissions; Land Cover Change</td>
<td>Multi-lateral treaty or bi-lateral agreement (Kyoto follow-on); carbon ETS</td>
</tr>
<tr>
<td>DOI-USGS</td>
<td>US Ecosystem carbon (forest &amp; soil biomass?)</td>
<td>US EISA</td>
</tr>
<tr>
<td>USAID</td>
<td>Global forest biomass (stocks &amp; disturbance)</td>
<td>REDD+/Silva Carbon</td>
</tr>
<tr>
<td>USDA-USFS, EPA &amp; state agencies</td>
<td>US &amp; Global Forest biomass (stocks &amp; disturbance)</td>
<td>REDD+ &amp; existing forest mandates</td>
</tr>
<tr>
<td>USDA ARS &amp; NRCS</td>
<td>Soil Organic Carbon</td>
<td>US Farm Bill</td>
</tr>
<tr>
<td>Cities (Mayors, C40), State/Regional regulators (CARB, AIRPARIF), WorldBank/PMR, RGGI</td>
<td>Sub-national CO2 &amp; CH4 fluxes</td>
<td>Sub-national programs: City level Climate Plans (LA, Paris, Sao Paulo, Beijing, C40, ICLEI), California AB32, sub-national carbon markets</td>
</tr>
<tr>
<td>EPA, DOI, ARPA-E, EDF</td>
<td>CH₄ emissions from gas/oil sector</td>
<td>TBD (still being formulated)</td>
</tr>
</tbody>
</table>

*International counterparts: IPCC TFI and member agencies
NG is cleaner than coal – but only if fugitive CH4 emissions are managed/regulated/monitored.
Global shale gas basins, top reserve holders

- **Canada**: 11.0 Trln cubic metres
- **U.S.**: 24.4 Trln cubic metres
- **Mexico**: 19.3 Trln cubic metres
- **Argentina**: 21.9 Trln cubic metres
- **Poland**: 5.3 Trln cubic metres
- **Libya**: 8.2 Trln cubic metres
- **Algeria**: 6.5 Trln cubic metres
- **Brazil**: 6.4 Trln cubic metres
- **Australia**: 11.2 Trln cubic metres
- **South Africa**: 13.7 Trln cubic metres
- **China**: 36.1 Trln cubic metres

**Assessed basins**

- With resource estimate
- Without resource estimate

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

Reuters graphic/Catherine Trevethan
Example: transformational change in fossil-fuel CO₂

- 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
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.

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

_Duren and Miller, Environ Sci Tech, 2013, in prep_
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 CH4 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 CH4 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?