Concept paper annotated outline
EC-68/Doc. 4.5 (1)

Executive Summary

In June 2015, the 17th World Meteorological Congress requested a plan for an Integrated Global Greenhouse Gas (GHG) Information System (IG^{3}IS). In December 2015, the UNFCCC nations forged the Paris Agreement, codifying the idea of nationally determined contributions (NDCs). These nationally appropriate pledges to reduce GHG emissions serve to unify all nations in an effort to slow and then stop global climate disruption. These pledges vary by nation, geographical region, and economic ability. Regardless of the strategies and mechanisms applied, the ability to implement long-term policies and manage them effectively will require consistent, reliable, and timely GHG emissions information. A framework capable of accepting and promoting a range of advanced GHG emission quantification capabilities could improve the quality of and confidence in GHG emission inventories. The IG^{3}IS will be such an information source and framework that will join atmospheric GHG composition and flux measurements and other observations (the "top-down") with spatially and temporally explicit socioeconomic emission inventory data (the "bottom-up"). The combination of these data sources will better inform emission reduction policies and measures.

A planning team was established to compile information and develop a plan to motivate action. It has developed the following vision and mission for IG^{3}IS.

> **Vision**: Nations, sub-national governments, businesses and individuals have additional data with which to inform strategies to reduce climate-disrupting greenhouse gas emissions while increasing wellbeing in society.
>
> **Mission**: Support the success of post-COP21 actions of nations, sub-national governments, and the private sector to reduce climate-disrupting GHG emissions through a sound scientific, measurement-based approach that improves the overall quality of national and subnational emission inventory reporting, and locates, quantifies, and potentially prioritizes previously unknown emission reduction opportunities.

This Concept Paper describes a strategic progression of confidence-building steps of near-, mid-, and long-term objectives and will be used to guide the next step of IG^{3}IS implementation planning. Near and mid-term objectives are focused on applying demonstrated capabilities to improve the quantification of GHG emissions and their changes over time. These objectives will be accomplished with existing and new measurements and modelling tools inside a framework of measurement standards and modelling metrics. Analogous to the development of numerical weather prediction and its architecture of observations and models, IG^{3}IS has a long-term vision for a GHG analyses and forecast system that will incorporate multiple coordinated satellites, aircraft, balloons, and ground observations, together with spatially and temporally explicit socioeconomic emission inventory data (the "bottom-up"), in a system of systems. The first step of implementation planning will be to identify relevant user communities and open dialogue with them to collect detailed user requirements, which will guide the formulation of the needed measurement, modelling, and data delivery infrastructure.

This Concept Paper provides background details for Executive Council document **EC-68/Doc. 4.5(1)** and requests Executive Council endorsement and support to proceed to the next steps of IG^{3}IS implementation planning, as well as support for execution of that plan from the Members and the Secretary-General.

1. Motivation for an IG³IS

Accurate and precise atmospheric measurements of greenhouse gas concentrations have revealed the rapid and unceasing rise of global GHG concentrations due to human socioeconomic activity. Accurate and precise long-term observations also show a resulting rise in global temperatures and evidence of negative impacts on society. In response to this mounting evidence, nations, sub-national governments, private enterprises and individuals are establishing and accelerating efforts to reduce GHG emissions while meeting the needs for global development and increasing energy access.

Now, with appropriate investments, the same evidence-based scientific approach that rang the climate change alarm bell stands ready to guide us along solution pathways and provide metrics for the success of the solutions. With this motivation, WMO and its partners have called for an Integrated Global GHG Information System[1] (IG^3IS). The IG^3IS will serve as an international coordinating mechanism to establish and propagate consistent methods and standards to help assess emission-reduction actions. For the IG^3IS initiative to succeed the end-users must understand, trust, and recognize the value of the information they will receive, and act more effectively in response. Over time, the IG^3IS framework will be capable of promoting and accepting advancing technical capabilities (e.g., new satellite observations) continually improving the quality of and confidence in such information.

Leading up to COP15 in Copenhagen December 2009, the climate change community developed a number of reports [e.g., Verifying Greenhouse Gas Emissions: Methods to Support International Climate Agreements (NAS 2010); GEO Carbon Strategy (GEO 2010); IPCC Task Force on National GHG Inventories: Expert Meeting Report on Uncertainty and Validation of Emission Inventories (IPCC 2010)] that reported on the state of carbon cycle and GHG research, and on the readiness of atmospheric GHG concentration measurements, combined with other forms of data and model analyses to independently evaluate and improve the accuracy of the traditional ”bottom-up” GHG emission inventories. In 2010, these studies concluded that with key research investments, increased density of well-calibrated atmospheric GHG measurements, and improvements in atmospheric transport modelling and data assimilation capabilities, a GHG information service framework could be achieved that would fill information gaps and serve the evolving needs of policies and actions to reduce GHG emissions.

Out of COP17 in Durban came a UN mandate to negotiate a new global agreement to reduce global GHG emissions recognizing that the unique needs and conditions of the member-states should drive definition of their pledges and goals. This was the rationale behind the Nationally Determined Contribution (NDC) approach approved at the COP20 in Lima and that contributed to the success at the COP21 in Paris.

The IG^3IS Planning Team is applying these lessons learned from the UNFCCC process. The IG^3IS plan will not be solely focused on the long-term vision for a comprehensive, totally independent integrated GHG information system. Instead, the IG^3IS plan begins with practical and focused near-term objectives. The IG^3IS Planning team defined a set of questions that must be answered with criteria for selecting these confidence-building, near-term objectives:

---

[1] The IG^3IS resolution approved by the 17th World Meteorological Congress in June 2015 refers to an “Integrated Global Greenhouse Gas Information System.” The IG^3IS Planning Team suggests substituting the word “Services” in place of the word “System” as a better representation of the IG^3IS initiative’s mission.

- What are the main improvements needed to strengthen the existing national inventory reporting system, and how can IG3IS contribute to these improvements?
- Are there research capabilities with demonstrated skill to meet these information needs in a quantitative and timely way?
- What valuable and additional outcomes will result?
- Will stakeholders see this value and be early and active partners in this effort?

The IG^{3}IS objectives are described in section 4. For the near-term objectives, both the policy applications and the technical skill are at hand and are well matched. The mid-term goals represent the opportunities for which the policy application requirements and the technical readiness to meet the information needs are both incipient. For example, the Paris Agreement aims to hold the increase in global average temperature to well below 2°C above pre-industrial levels, and pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels. . Several independent estimates highlight the fact that the current sum total of the emission reduction pledges from current NDCs does not put us on a least-cost pathway to achieve this goal. A foundation of the agreement is a "global stocktake" process every 5 years starting in 2023 with the intent, among other things, of tracking the global progress towards achieving the aforementioned goals. The IG^{3}IS methods (atmospheric measurements, remotely sensed and in situ activity data, and modelling systems) will be able to deliver additional information on greenhouse gas emissions as one possible input to the Global Stocktake process.

2. Goals of IG^{3}IS

Partnerships, such as the proposed IG^{3}IS partnership with UNEP, must be established that will help WMO to go beyond merely engaging in conversations with the "decision-making" communities. To have the best chance of meeting our ultimate IG^{3}IS success-criteria, we need the decision-makers to be part of the planning process. We need to transition from stakeholder engagement to stakeholder involvement, where they participate in specifying the requirements for the near- and mid-term IG^{3}IS objectives, and they are exposed to state-of-the-art techniques emerging from the scientific community that may open new opportunities and information needs. A present and on going example is the collaboration between the United Kingdom Department of Energy and Climate Change (DECC) and the UK Met Office. The DECC is responsible for reporting national emission inventories to the UNFCCC and the UK Met Office provides DECC with atmospheric model analyses of atmospheric concentration measurements to guide improvements to the DECC reported inventories. By combining accurate atmospheric measurements with enhanced socioeconomic activity data and model analyses we can meet the overarching goals of IG^{3}IS to:

- reduce uncertainty of emission inventory reporting,
- locate, quantify and prioritize previously unknown emission reduction opportunities, and
- provide national and sub-national governments with timely and quantified information to support their assessment of progress towards their mitigation goals.

An effective IG^{3}IS will provide on-going, observation-based information on the relative success of GHG management efforts on policy-relevant scales and the response of the global carbon cycle to a warming world.

3. IG³IS Principles

Implementation of an IG³IS requires that all elements of the system provide accurate, consistent and timely information useful for a broad range of policy uses, accommodate future policy changes, and take advantage of advances in emission inventory methods and information.

These are the principles by which IG³IS will achieve its objectives:

- IG³IS will serve as an international coordinating mechanism and establish and propagate consistent methods and standards for the use of atmospheric measurements and models in support of improving GHG emission inventory,
- The IG³IS credibility rests upon the undisputed and high-quality atmospheric concentration measurement standards disseminated by the WMO GAW with very active participation by the international metrology community, and the relevance of these measurements toward assessing anthropogenic GHG emissions.
- IG³IS will provide a common framework for development of the good practices utilizing diverse measurement and analysis approaches inside a framework of standards.
- Stakeholders are significantly involved in planning and implementation from the beginning to ensure that information products meet user priorities and deliver the foreseen value.
- The system must be practical and focused on where the scientific and technical skill is proven, the use-case exists and the decision-maker recognizes value.
- Success-criteria are that the information provided guides additional and valuable emission-reduction actions.
- IG³IS must mature in concert with the evolution of user-needs, policy and technical skill.

4. Near- and Mid-term Objectives

The near- and mid-term objectives are designed to demonstrate early success. Current efforts have already partially demonstrated relevancy to improving GHG emissions information in some areas (e.g., national emission inventories improvements, methane leakage from the oil and gas sector, urban emissions). The initial focus of the work is development of high-level recommendations to establish the scope of the system in a systematic stepwise manner. These objectives will address the need to reduce global greenhouse gas emissions, while IG³IS evolves with increasing technical skill, scientific knowledge, and policy demands.

Table 1. Near-, mid-, and long-term IG³IS objectives in support of greenhouse gas emission reduction efforts

Near-term (1-3 years)	**Mid-term (3-10 years)**	**Long-term (>10 years)**
Provide guidance for nations applying atmospheric measurement and inverse methods to improve national inventory reporting (e.g., UK and Swiss examples)	Provide high-frequency, timely trend information for GHG emissions; radiocarbon and other tracer measurements to distinguish biogenic from fossil fuel emissions	Multi-gas atmospheric inversion analyses for sector specific attribution of emissions
Generate user interface and propagate existing urban GHG estimation information to	Demonstrate capacity sharing with local urban partners at a constellation of flagship cities.	Integration across scales, multi-species; global scale independent integration

global cities[2], and pioneer new techniques using remote-sensing derived activity data. Initial sensor deployment	Operationalize prognostic capability within urban planning. Mature sensor deployment	
Propagate to other global facilities the methods and standards developed in the USA for detection and attribution of CH_4 emissions from the oil & gas supply chain	Apply these methods and standards to methane emissions from the agricultural sector	Ability to provide complete attribution to sectors

[2] Sub-national and urban commitments are not formally a part of the Paris agreement because only nation states are Parties, however policies at the sub-national level are important for meeting the overall goals of Paris, and they pose particular inventory challenges that may be particularly amenable to solutions provided by IG3IS.

The IG^{3}IS will benefit from the continued evolution of research successes and will depend on a tiered observing system architecture employing surface-based, airborne, and satellite-borne sensors appropriate for the given application and analyses. In addition, the ability of IG^{3}IS to meet a number of its objectives will require investment in the latest techniques for building temporally and spatially disaggregated inventories from advanced data mining from non-traditional sources of socioeconomic activity. These will be used as prior information for some analyses and applications, but at other times model analyses of atmospheric measurements to independently evaluate these bottom-up inventories.

A brief description of each objective is provided here.

4.1 Atmospheric Concentration Measurements and Analyses Assisting National-Scale Greenhouse Gas Inventory Reporting

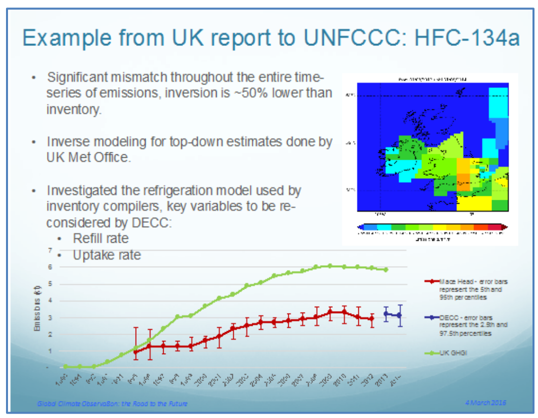

Fig. 1: UK country showing the value of top down inversions for reporting of HFC-134a to the UNFCCC.

Through Article 4 of the UNFCCC, Parties to UNFCCC have the responsibility to report anthropogenic greenhouse gas emissions and sinks. Data are estimated and reported according to guidelines developed by the IPCC Task Force on National GHG Inventories (IPCC TFI), and usually involve combining source-specific emission factors with activity data, a process often called “bottom-up”. Emissions from the use of homogenous fuels and predictable processes (e.g., pipeline natural gas or clinker production) can be estimated accurately where well-developed statistical systems are present. Other more heterogeneous and dispersed sources are more difficult, but inventories can be improved with more sophisticated methods and models, and improved inputs such as activity data collection and emission factor development for specific types of equipment.

Atmospheric inverse modelling can support this process by providing an independent “top-down” quantification of emissions. The United Kingdom and Switzerland already successfully include “top-down” analyses to guide improvements to their reporting. An IG^{3}IS near-term objective is to propagate good practices and establish quality metrics for these top-down methods, how they can be compared to GHG inventories developed from bottom-up methodologies, and how the results can be used to target improvements in bottom-up inventory data inputs. The IG^{3}IS initiative has already made progress on this objective through participation in a recent IPCC TFI Expert Meeting. This near-term IG^{3}IS objective was presented to the IPCC TFI members who recommended that more information on top-down approaches such as IG^{3}IS be incorporated as part of targeted updates to the 2019 methodology report updating the IPCC Guidelines.

4.2 GHG emissions estimation in Large Urban Source Regions

Cities and their power plants are the largest sources of greenhouse gas emissions from human activity. As of 2010, urbanization has concentrated more than half of the world's population, at least 70% of fossil fuel carbon dioxide emissions, and a significant amount of anthropogenic methane into a small fraction of the Earth's land surface. If the top 50 emitting cities were counted as one country, that 'nation' would rank third in emissions behind China and the United States. Once urban form and infrastructure are established, they are difficult to alter. Hence, the window of opportunity for shaping low-carbon urban futures may be closing. In order to provide a diagnosis of urban emissions at scales relevant to urban decision-making and enable identification of low-carbon or carbon mitigation opportunities, cities need better information about their emitting landscape; information that not only reflects scientifically accurate methods, but places emissions at space and time scales relevant to urban decision-making and identifies key functional characteristics (sector, sub-sector, fuel).

A number of research projects around the world have developed and tested methods for independent estimation of greenhouse gas emissions (e.g., Indianapolis INFLUX study, Los Angeles/Paris Megacity Project). This work has established an urban greenhouse gas information system that combines atmospheric monitoring, data mining and model algorithms. IG^{3}IS will re-design this information system to be deployable to different parts of the world, particularly in the low- and middle-income countries where GHG information needs are greatest and capacity is limited.

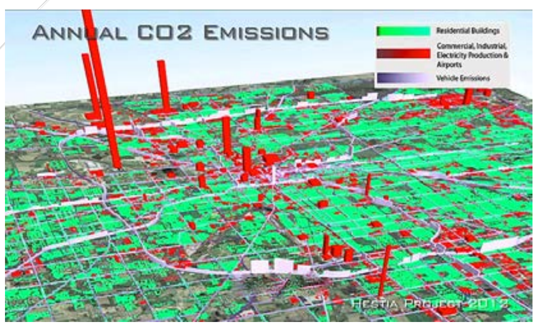

Fig. 2: High spatial and temporally resolved urban data developed through the Hestia Project.

Our near-term objective is to build an information delivery portal for the existing global, high-resolution emissions information data product. This will offer global cities with little existing information, a starting point for CO_2 emissions estimation. We follow this by more active partnerships with interested cities to build-out more resolved and process-based information systems to actively track progress and enable efficient, optimal GHG mitigation choices based on more detailed and accurate emissions diagnostics.

4.3 Detecting and Attributing Methane Super Emissions from the Oil and Gas Supply Chain

While atmospheric carbon dioxide is 200 times more abundant than methane, methane has 80 times more global warming potential than CO_2 (ton for ton on a 20 year time scale). Also unlike

CO_2, the amount of "fugitive" methane emissions from some processes, equipment and activities in the fossil fuel supply chain are not well understood, with higher uncertainties. Additionally, for some activities, processes and equipment, there is a challenge posed by the skewed distribution of emission sources and regionally specific data. This skewed or fat-tail distribution of particular emission sources (super emissions resulting from low probability, high consequence events) offers the potential for effectively locating and then controlling a significant fraction of methane emissions through a tiered suite of atmospheric observations: aircraft-based, ground-based in-situ or on vehicles, towers, and models. This IG^{3}IS objective intends to extend the significant successes in detecting methane super-emitters in North America to the world's oil and gas supply chain has excellent potential to inform oil and gas operators. If acted upon, significant methane emissions reductions are achievable. Exploring these solutions and applying them to new types of sites or emissions profiles, for example offshore platforms or coal bed methane, can potentially provide further reductions. IG^{3}IS also intends to extend these approaches to other methane emitting sectors such as flooded lands, agriculture, waste and wastewater and develop sector-appropriate methodologies in the medium term. These sectors have close links with urban emissions as they are much more likely to be located in or close to cities than oil and gas extraction sites.

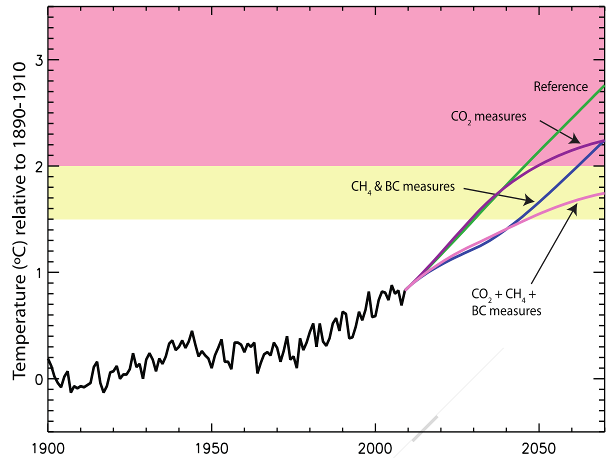

Fig. 3: The combination of CH_4 and black carbon measures along with substantial CO_2 emissions reductions [a 450 parts per million (ppm) scenario] has a high probability of limiting global mean warming to <2°C during the next 60 years, something that neither set of emissions reductions achieves on its own.

4.4 Timely and Quantitative Support for the Paris Agreement

A mid-term objective for the IG^{3}IS is to provide frequent, near-realtime estimates of fossil fuel carbon dioxide and other anthropogenic GHG emissions at national and sub-national scales to help inform policy-making and assess the efficacy of emission reduction strategies. For the case of the non-CO_2 GHGs from some source categories, the IG3IS approach offers the demonstrated ability for independent evaluation of inventory estimates with rigorously quantified uncertainties and the potential for high-frequency and rapid assessments of emissions, which could provide useful feedback to policy-makers.

There have been many proof of concept demonstrations of how the combination of atmospheric measurements, data mining, emissions modelling and inverse model analyses can provide useful information to policy makers such as the examples associated with non-CO2 GHGs [Lunt et al, 2015, and Henne et al, respectively]. For the case of fossil fuel-CO_2, measurements alone contain a significant biospheric signal and are therefore necessary but not sufficient to infer fossil fuel-CO_2 emissions [Shiga et al, 2014]. However, it has been demonstrated that fossil fuel-CO_2 emissions can be inferred by inverse model analyses of a combination of atmospheric CO_2, radiocarbon ($^{14}CO_2$) measurements, together with measurements of other co-varying atmospheric species [Basu et al, 2016]. A fundamental goal of IG^{3}IS is to disseminate these analyses and methods more broadly. The primary limits to greater dissemination of the IG^{3}IS approach is the number of high quality measurements of atmospheric greenhouse gases (e.g. CO_2, $14CO_2$, CH_4, CO, HFC-134a), access to high-resolution satellite imagery, and access to in-country socioeconomic/energy data. This translates into an immediate priority to expand atmospheric observations in low- and middle-income nations and combine this information with new emissions modelling approaches.

5. Long-Term IG^3IS Objectives

A long-term information system must have more dense and frequent observations, better transport modeling, and improved analysis and assimilation focused on policy-relevant scales. With these in mind, it is imperative that the system be designed and implemented in a way that supports current and emerging issues.

Earth's carbon-climate system is undergoing profound and unprecedented change. This change is driven globally by fossil fuel and land use change emissions that increase atmospheric concentrations of CO_2 and other greenhouse gases. During the last decades, the effect of emissions on the increase of atmospheric CO_2 has been strongly attenuated by the response of the natural carbon cycle, with ocean and land carbon sinks absorbing on average approximately half of the emissions. Future climate change is projected to weaken the capacity of natural sinks, i.e., a positive feedback on the increase of CO_2. The complex mix of accelerating and stabilizing processes in the coupled carbon climate system may also result in sudden, non-linear tipping points, such as shifts in natural sources/sinks magnitude (and/or polarity) or the appearance of new sources. Changes also occur in the socio-economic processes controlling emissions – from local-scale, such as sporadic leaks of CH_4 from natural gas use, to transitions in provincial and urban economies, and in energy and food production systems. This combination of complexity across many space-time scales and controlling processes has some parallels with well-established weather and other environmental extremes. However, unlike weather and extreme events, society currently has limited "situational awareness" of the coupled human-natural carbon system.

While IG^3IS has near-term deliverables that will guide improved knowledge on emissions and potentially inform new emission reduction opportunities, the long-term payoff is to enable the provision of decision-relevant carbon situational awareness through comprehensive, reliable, sustained, frequent assessments of greenhouse gas fluxes. IG^3IS can help to bridge the current gap between top down measurements and national greenhouse inventory programs. In the long-run, IG^3IS will provide both diagnostics and input data for improved inventories and timely inputs for mitigation guidance, and supporting long-term policy planning. IG^3IS capabilities will be similar in some respects to aspects of modern weather services – primarily the rapid delivery of current and recent carbon fluxes and controlling activity (on time-scales of weeks rather than years). Potentially, IG^3IS could also deliver short-term "carbon forecasts" for selected domains – if deemed valuable for decision-making (e.g., driven by recent observations rather than long-term integrated assessment models).

IG^3IS will build upon, integrate and improve existing and planned surface-based measurement networks, airborne and satellite observations, modeling frameworks and data assimilation systems and where necessary, fill key gaps in those systems. As with modern weather services, the transition between research-driven and operational GHG observing and information systems for successful long-term implementation of IG^3IS presents a number of challenges. Meeting current and future stakeholder needs will require:

- frequent definition of stakeholder requirements to successfully capture the evolving needs of GHG mitigation management,
- build partnerships with governmental and non-governmental organizations and the private sector,
- development of a system architecture that optimizes cost and performance while maintaining sufficient flexibility to accept new capabilities as these become available,
- a robust program plan and long-term funding strategy, and
- a road-mapping strategy that assesses gaps in both observational and informational system needs and identifies research having potential to fill these gaps through incremental deployment and prototyping, including pilot projects, that evaluates key component performance.

As the modern weather services enjoyed by most of the world today, WMO, its member institutions and partners have the experience and technical knowledge essential for building the IG^3IS through formulation, design, prototype, and sustaining it in its future construction, deployment and operational phases. By leveraging existing skills from weather services and ongoing carbon cycle research, WMO can provide the leadership and structure needed to support the stepwise building of the IG^3IS capable of meeting society's need for decision-relevant *carbon situational awareness*.

6. Next Phase of IG^3IS Planning

The next step for IG^3IS will be the implementation planning with the necessary details to build systems to deliver the near- and mid-term services described above. This planning by necessity will begin with the definition of a statement of work (SOW) and budget for these activities. Critical for the success of this step will be active entrainment of partners, users, and sponsors through all stages of development and close coordination with UNFCCC, IPCC, GCOS, GFCS, GEO Carbon Flagship, WCRP and their constituencies.

This activity will result in delivery of the IG^3IS Program Roadmap to the sponsors and key stakeholders culminating in a formal review in summer 2017. If approved, the Program Concept Plan will provide the foundation for design and implementation of IG^3IS in subsequent years.

Period of performance: July 2016-June 2017

Milestones and Deliverables:

- Fall 2016 – sponsor/stakeholder meeting – establish IG^3IS driving objectives and scope
- Spring 2017 – complete IG^3IS Program Roadmap (covering above tasks)
- Summer 2017 – IG^3IS Roadmap Review with stakeholders and sponsors

References:

Lunt, M. F., et al, Reconciling reported and unreported HFC emissions with atmospheric observations, www.pnas.org/cgi/doi/10.1073/pnas.1420247112

Henne, S, et al, Validation of the Swiss methane emission inventory by atmospheric observations and inverse modeling, Atmos. Chem. Phys., 16, 3683–3710, 2016 www.atmos-chem-phys.net/16/3683/2016/ doi:10.5194/acp-16-3683-2016

Shiga, Y. P., A. M. Michalak, S. M. Gourdji, K. L. Mueller, and V. Yadav (2014), Detecting fossil fuel emissions patterns from subcontinental regions using North American in situ CO2 measurements, *Geophys. Res. Lett.*, *41*(12), 4381-4388.

Basu, S., J. B. Miller, and S. Lehman (2016), Separation of biospheric and fossil fuel fluxes of CO2 by atmospheric inversion of CO2 and 14CO2 measurements: Observation System Simulations, *Atmos. Chem. Phys.*, *16*(9), 5665-5683.