Carbon Dew Coordinated Response To: The Federal Strategy to Advance an Integrated US Greenhouse Gas Monitoring and Information System

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Respondents

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Introduction

The Carbon Dew Community of Practice compliments the draft plan for a US Greenhouse Gas Monitoring and Information System (GHGMIS), and appreciates the opportunity to provide input and feedback. Our community's vision is to anchor fair and equitable climate solutions in direct atmospheric measurements, and our mission is to facilitate technology transfer through providing a medium for public and private entities to work together towards common goals. We strive to translate surface-atmosphere science into real-world impacts and innovate industry practices with best-available science. To achieve this we support integration and coordination on existing capabilities and resources for enhancing measurement and quantification of GHG emissions and removals. With this in mind, we would like to use this opportunity to suggest potential areas of improvement for the GHGMIS. Carbon Dew is open and free for everyone to join, and additional information is available at www.carbondew.org.

Suggestions for Improvements

Complementing inference with direct measurements

The GHGMIS in its current form relies primarily on reconciling atmospheric-based and activity-based approaches. Both approaches **infer, i.e. model, GHG surface fluxes** from either a top-down, or a bottom-up perspective, respectively. One example is inverse modeling based on measurements of ambient GHG concentrations, at ground level and using satellites. We suggest that a third approach, in the following referred to as **ground-truth**, can complement and connect these two perspectives. The differentiator of ground-truth compared to inference is that **GHG surface fluxes are measured directly** at the surface-atmosphere interface by counting GHG molecules moving up or down.

Existing and future **eddy-covariance (EC) measurements** from masts, aircraft, vessels, and buoys offer a prime example for ground-truth. They can serve the GHGMIS for evaluating results against independent constraints and identifying areas for focused additional research. EC flux measurements possess a **unique combination of characteristics that make them ideally suited to serve as ground-truth** and to promote the connection between the atmospheric-based and activity-based approaches that the draft focuses on. EC counts gas molecules moving up or down at the surface-atmosphere interface, making it a **direct**, in-situ measurement of GHG emission and removal fluxes. Moreover, EC is **impartial** and equally applicable to abiotic and biotic sectors of carbon dioxide removal. This makes EC an ideal candidate to distinguish between GHG emissions and removals due to human-managed versus natural systems without disciplinary or sectorial bias. EC measurements are

multi-scale from facility to landscape, and consistently applicable to **multi-species** GHGs and air pollutants including CO_2, CH_4, N_2O, H_2O, VOCs, NO_y, and O_3. Finally, EC measurements offer **process attribution** and **temporal continuity**.

Several hundred quasi-continuous tower EC measurements exist in the US, and thousands globally, in established networks such as NEON, AmeriFlux and FLUXNET. These networks offer a unique opportunity to enhance the GHGMIS by increasing observations and fostering partnerships for multi-scale integration and synthesis. EC networks provide data post-processing, harmonization, and scalable data access including APIs with predictable formats. However, the current draft only mentions NEON and AmeriFlux in the appendix without specifying their integration within the GHGMIS. We believe that leveraging **networked EC measurements can provide a crucial link between the GHGMIS and actual surface emission and removal fluxes**. Therefore, we recommend explicit consideration of the utility of EC networks, and exploration of potential integrations within the GHGMIS.

Historical barriers have impeded the utilization of EC data in operational applications, including temporal continuity and latency, non-self-describing data formats, source attribution, and violation of mass and energy conservation. Fortunately, structural innovations are underway to increase automation and yield demonstrable progress, including **two-fold improvements in data availability and quality** (e.g., Sturtevant et al., 2022), and **sub-week data latency** reduction (e.g,, Papale, 2020; NCAR-NEON workshop). FLUXNET Committees work to overcome remaining EC challenges by providing **self-describing, cloud-compatible data formats**, contextual metadata, and data QA/QC based on artificial intelligence. An innovation of particular interest for GHGMIS integration is **high-resolution Flux Mapping**, which determines geolocated emission and removal fluxes [*at decameter and sub-hourly resolution*] across square-kilometer areas [*(Metzger, 2018)*]. Flux Mapping provides ultimate time, space, and process attribution for emission and removal fluxes, **increasing statistical power by 10-100 times per EC station**. It has also been shown to let EC **fulfill mass and energy conservation** [*(Xu et al., 2020)*], and can provide a powerful, independent constraint allowing GHGMIS to arbitrage inconsistencies among activity-based and atmosphere-based approaches.

Utility of ground-truth and potential GHGMIS integrations

Ground truth data from networked EC measurements offers a significant opportunity to enhance the accuracy and consistency of GHG quantification. It can help **promote convergence between activity-based and atmospheric-based approaches** where estimates do not currently agree and minimize or resolve differences. Additionally, it can facilitate the convergence of (inter-)governmental accounting schemes such as GHGMIS with approaches that inform actionable applications, such as local-level decision-making and **market-based solutions**. Ultimately, it can support the development of a cohesive and integrated GHG monitoring and information system, as exemplified by Gurney and Shepson (2021).

For example, EC measurements can **improve the accuracy of activity-based emission factors**, and serve as an impartial benchmark across economic sectors to enhance the performance of GHG monitoring and information systems. **EC testbeds** can help identify sources of differences between activity-based and atmospheric-based approaches and promote the convergence of bottom-up and top-down approaches for GHG estimates, thus improving global consistency. Side-by-side demonstrations on **coal mines, oil and gas production, urban GHG emissions, landfill emissions, and natural systems** emissions and removals can showcase the benefits of impartial EC measurements and contribute to achieving **global consistency in GHG monitoring**.

In another example, ground-truthing with EC measurements has great potential for **satellite calibration and validation**, and in extension for informing atmospheric inversions. This approach has been proven to be exceedingly powerful for a global terrestrial monitoring network (Running et al., 1999) that informed the 4^{th} Assessment of the Intergovernmental Panel on Climate Change, which won the Nobel Peace Prize in 2007. By calibrating satellite data products, EC towers can provide independent validation or **priors for atmospheric inversion approaches**. Subsequent collaboration between inventory developers and the atmospheric science community can also be supported by EC's independent priors or validation data, thereby achieving convergence of results from both approaches.

In extension, GHGMIS could leverage the **template employed by national weather monitoring** to provide actionable local information in addition to a comprehensive national overview of GHG emissions. Multiple **EC ground-truth stations could tune GHG remote sensing products and GHG models in near-real time**, similar to how multiple automated weather stations tune remote sensing weather products and weather models. This system would be crucial for GHG management and decision-making at a local scale by US regulatory entities, businesses, and individual citizens (Jungmann et al., 2022). Utilizing the high-resolution Flux Mapping approach, this data would create a set of **high-quality information flows that will allow both regulatory and grassroot societal response**. Moreover, this approach would create the origin for an accurate, just, and equitable carbon market based on the best scientific methodology available to date. This will then create a new and balanced economic powerhouse that **aligns economic interests with climate interests**, providing optimal solutions over time. Such a GHGMIS would place the US in a leadership position in climate response, with the US's approach being adopted globally.

Federated information discovery enables efficient use of distributed GHGMIS data

To truly **enhance the utility of GHGMIS data**, we must not only improve the data products themselves, but also how they are accessed and used. While there have been advances in data sharing and open science, discovering and utilizing GHG data is still challenging due to the highly distributed nature of the data, inconsistent metadata, and the lack of discovery capabilities. To address this, we propose a **multi-cloud solution** that allows users to define a compute graph that is aware of the location of the data and compute across different platforms. By utilizing large-scale data processing solutions, we can optimize workflows for performance and resource utilization, making **distributed discovery and analytics** workflows possible. This will massively accelerate insight generation and decision making from GHGMIS, allowing for more efficient and effective climate action.

Partnership opportunities

In order to strengthen the draft, it would be helpful to make visible partnership opportunities with complementary US communities such as **NEON, AmeriFlux, Carbon Dew, FFAR, and NACP**, who serve as liaisons to both academic and non-academic groups in the US. Additionally, **State Mesonets and the National Mesonet Program** can be utilized as existing frameworks for implementing real-time network information. To further improve the draft, we recommend to look into and reference already existing emission monitoring systems, such as **CarbonWatchNz, ICOS, and FLUXCOM**, from both domestic and international sources. Furthermore, the GHGMIS could include partnerships with **airline, aircraft and drone companies/manufacturers**, including unmanned (marine) surface vehicles like Saildrone, to place sensor packages on commercial airplanes or towers, similar to **TAMDAR**. In terms of engagement and participation, educational institutions and structures should be involved, including **K12, universities, and adult education programs**, and a "climate extension" service should be established similar to agricultural extension programs. A new **"climate-grant" program** may also be created to complement existing land-, sea-, space-, and sun-grant universities.

Coordination mechanisms

It may be beneficial to consult with **ICOS RI** on the mechanisms they are already using with EU governmental agencies and other global bodies, such as **GAW and WMO**. Their experience may be informative for developing new mechanisms as well.

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