Long-Term, Calibrated In Situ Observations are an Essential Component of a Carbon Emission Monitoring System

Lori M. Bruhwiler, NOAA Global Monitoring Laboratory

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The NOAA Global Greenhouse Gas Reference Network (GGGRN):

Foundational Measurements of CO$_2$ and CH$_4$
Global, Multi-Decadal Observations of Atmospheric CO$_2$ and CH$_4$

NOAA Global Greenhouse Gas Reference Network Sites (blue symbols)
- Calibrated measurements of 55 different gases
- A solid foundation for atmospheric GHG measurements.
In Situ Analyzers Provide Continuous Data

Information about the CO$_2$ diurnal cycle and how it’s propagated vertically.

Information about CH$_4$ emissions from local wetlands.
Profile Data from Aircraft, Balloons and Tall Towers

Uganda, 2020-12-30

CO₂

CH₄

CO

km

ppm

ppb

ppb
A Challenge for Detecting Changes in Fossil Fuel Emissions from Space: the Signal of Interest is at the Surface

Satellite sensors retrieve total column CO$_2$.

Column average source/sink signals are weak.

Biases/errors could be large compared to key signals.

Fossil fuel emissions dominate long-term CO$_2$ growth, but variability is dominated by the biosphere.
Long-Term Atmospheric Observations Help us to Understand the Earth’s Changing Energy Budget

Radiative Forcing calculated using NOAA’s long-term global network observations (GGGRN).

The CO$_2$ contribution is rapidly increasing
(2x emission time ~ 30 yrs.!)  

The GWP-100 of CH$_4$ is 28-36, but there is less of it in the atmosphere.

* Radiative Forcing = human impact on Earth’s energy budget since pre-industrial times. Units are Watts/meter$^2$.

www.esrl.noaa.gov/gmd/aggi, (fig: Bruhwiler et al., 2021)
High Quality, Long-Term Data are Needed to Evaluate and Improve Climate Models

Model Spread:

**CO₂** – Climate sensitivity differences including feedbacks (clouds, carbon cycle)

**CH₄** – Effects on other radiative forcers (ozone, stratospheric water vapor, aerosols).

![Graph showing observed warming and contributions to warming based on two complementary approaches.](image)
We Should Not Ignore Terrestrial and Ocean Carbon Fluxes

Land and Oceans Take up ~ ½ of the CO₂ emitted, the rest accumulates in the atmosphere.

Will this continue?

If not, do we need to adjust our emission mitigation strategies?

How can carbon dioxide removal and other mitigation efforts succeed when fundamental understanding of “natural” carbon sinks is lacking?
High Quality, Long-Term Measurements are Essential For Detecting Carbon-Climate Feedbacks

The amount of carbon in Arctic permafrost Soils is ~4x what humans have already emitted.

Arctic CH\textsubscript{4} emissions could double over this century with accelerating increases next century.

Will the Tropics take-up or emit more carbon in the future?
In Situ Observations are Complementary to Satellite Data

Large differences between in situ observations and satellite retrievals in the Tropics where we don’t have many in situ obs.

These areas should be priorities for in situ observations.
Atmospheric Carbon Data Assimilation/ Flux Inversion: NOAA’s CarbonTracker

Carbon Flux Models (inventories, wetland models)

Remotely-Sensed Column Data

In Situ Surface Network Data

Atmospheric Transport Model+ DA/Inversion Techniques (FV3 Development!)

Carbon Analyses

Estimated Fluxes

Profiles

www.esrl.noaa.gov/gmd/ccgg/carbontracker/
www.esrl.noaa.gov/gmd/ccgg/carbontracker-ch4/
Federal Research Agencies Have a Lot of Infrastructure for Understanding the Carbon Cycle

Ocean Surveys

Satellite Datasets

Chlorophyll

Biomass

Inventories

Flux Measurements

Vegetation Indices

Carbon Flux Models and Inventories

Fossil Fuels

Fires

Oceans

Land-use change

Vegetation
What Would Help: Increased International Coordination
Could we do this for CO$_2$ and CH$_4$?

What could we learn about the carbon cycle if we could fly GHG analyzers on commercial aircraft?

What we have for weather forecasting

NOAA RESEARCH NEWS

NOAA, Boeing team up to test greenhouse gas-measuring technology

Scientists with NOAA’s Global Monitoring Laboratory will evaluate the optimal placement of greenhouse-gas sampling inlets on a Boeing 737 flying testbed owned by Alaska Air during Boeing’s 2021 ecoDemonstrator technology development...
• **Long-Term, high quality in situ datasets are essential for:**

  • Improving climate projections to support mitigation and adaptation efforts
  • Fully exploiting data from satellite missions

• **Greenhouse gas emissions are a global issue that requires international commitments to long-term observations and infrastructure for timely data sharing.**

  • Establishing and maintaining monitoring sites in developing nations should be a high priority.
  • International sharing of data should be facilitated.

• **US Federal agencies have developed many new capabilities that are still rapidly evolving.**

  • We need a plan to transition to sustained operations and to develop next generation data products and services to support mitigation and adaptation efforts.