Accelerating the combined use of policy-relevant data and advanced atmospheric models to support air quality and climate decision making

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What are the key challenges or questions for Earth System Science across the spectrum of basic research, applied research, applications, and/or operations in the coming decade?

Since the initial Earth Science and Application Decadal Survey (2007 DS), the Earth science community has made progress toward integrating measurements and models in frameworks that begin to address policy relevant questions in environmental management. A key challenge for Earth system science in the coming decade is to provide policy-relevant observations, integrated with modeling frameworks that feature sufficient fidelity, to **support environmental decision making for the future habitability of the Earth.**

The 2007 DS identified a "GEO-CAPE" mission with atmospheric composition objectives that strongly reflect those of an earlier open community meeting held at NCAR (Edwards et al. 2006). These objectives were built upon the concept of an integrated observing strategy (based on surface, airborne and space-based observations of atmospheric composition) that had been established in 2004 through international coordination by the intergovernmental group Integrated Global Observing Strategy (IGOS) in their Integrated Global Atmospheric Chemistry Observations (IGACO) report (Barrie et al. 2004). The integration of diverse observations is accomplished through modeling frameworks with data assimilation with products that can provide science based policy relevant information (e.g., Scovronick, et al., 2015).

The 2007 DS GEO-CAPE mission added methane observations to its mandate (Fishman, et. al., 2012) in recognition of the changes in methane emissions over North America (Miller et al., 2013; Petron et al., 2014) and co-benefits of reducing methane to both air quality and climate (West, et al., 2006; West, et al., 2013). Over a 20-year policy-relevant time frame, methane has a global warming potential of 86 compared to a reference of 1 for CO_2 (IPCC 2013). Lack of confidence in the available CH_4 emissions inventories (e.g., Miller et al. 2013) remains a problematic limitation to the design of efficient environmental policies and to accomplishing the objectives set forth in the U.S. Strategy to Reduce Methane Emissions (2014) and international policies.

From a larger climate perspective including plant damage, Avnery et al. (2015) examined potential benefits of a tropospheric ozone (O_3) mitigation strategy of gradual methane emission reductions since methane is also a tropospheric O_3 precursor that has not yet been targeted for O_3 pollution abatement. Climate and carbon cycle are tightly coupled on many timescales. The IPCC states with high confidence that climate driven changes of emissions from wetlands are the main drivers of the global inter-annual variability of CH_4 emissions. These emissions are highly sensitive to climate change and variability, as shown, for instance, from the high CH_4 growth rate in 2007–2008 that coincides with positive precipitation and temperature anomalies (Dlugokencky et al., 2009).

Dense satellite observations of CH_4 (multiple times per day at < 10 km spatial resolution) with attendant tracers of atmospheric transport such as carbon monoxide (CO) (e.g., Wecht et al., 2014, Locatelli et al., 2015) would **support** CH_4 **emissions estimates that are comprehensive, consistently measured, accurate, and spatially attributed**.

Why are these challenges/questions timely to address now especially with respect to readiness?

Existing NASA plans do not provide space-based observations of CH_4 or necessary tracers in the coming decade. However, the requirements for future CH_4 observations that build upon proven capability and provide the required improved spatial and temporal sampling needed for decision support are well documented (Fishman et al., 2012). Analysis of in situ CH_4 measurements from NASA's DISCOVER-AQ suborbital mission demonstrated that real-world CH_4 variability can be captured at spatial resolutions of a few kilometers as evaluated for the 2007 DS GEO-CAPE. In addition, analysis using the NCAR community WRF-CHEM modeling framework shows that discrimination between clean and polluted profiles (3-5% enhancement in total column CH_4) can be determined from such observations with 1% precision for total column CH_4 (Figure 1).

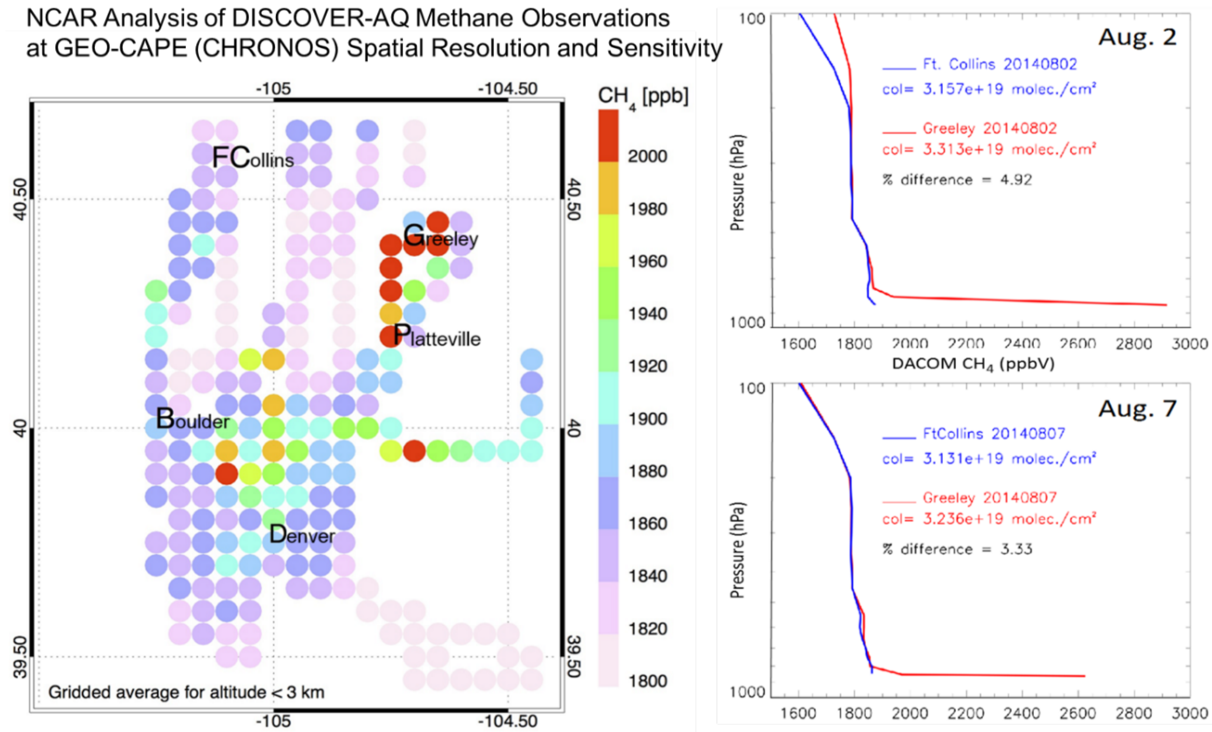

Figure 1. Hourly space-based methane observations at better than 10 km spatial resolution can capture the methane spatial variability and boundary layer enhancements observed during FRAPPE/DISCOVER–AQ in Colorado in 2014. Left panel shows simulated space based observations; right panel provides detailed in situ observations.

A broad atmospheric science community is engaged with the hypothetical GEO-CAPE observations and has initiated development of new modeling capabilities that could support air quality and climate policy needs for actionable information. The modeling framework assembled through these studies includes analytical tools for advanced chemical data simulation and assimilation, data analysis, and assessment (see report at http://geo-cape.larc.nasa.gov/pdf/GEO-CAPE_2009-2015_SummativeWhitePaper.pdf). This framework is the basis for integrating future space-based observations with existing surface and airborne observations. Timmermans et al. (2015) describe Observing System Simulation Experiments to quantify the value of new satellite observations of atmospheric constituents such as CH_4. The maturity of both CH_4 observation specifications and modeling frameworks to address air quality and climate policy needs suggests that Decadal Survey investments in both models and measurements can pay dividends for informed public decision making.

In addition to NASA's modeling activities, the National Science Foundation and U.S. Department of Energy sponsor chemistry-climate modeling work (e.g, Marsh et al., 2013; Amnuaylojaroen et al., 2014, Saide et al., 2014). The Community Earth System Model is a fully-coupled, community, global climate model. The Weather Research and Forecasting (WRF) model coupled with chemistry simulates the emission, transport, mixing, and chemical transformation of trace gases and aerosols simultaneously with the meteorology. The synthesis of observations with atmospheric chemistry models is central to progress, with a focus on understanding and modeling fundamental processes.

Why are space-based observations fundamental to addressing these challenges / questions?

The use of inverse models to estimate emissions relies fundamentally on dense data (e.g., Wecht et al., 2014). Existing and planned ground based networks remain extremely sparse globally, and poorly represent changing conditions in non-urban areas. Without spatially and temporally dense data, the modeling frameworks cannot produce products to support public decision making.

Quantitative estimates of air pollution emissions have been demonstrated using space based pollution observations (e.g., Streets et al., 2013). Alexe et al. (2015) demonstrated the value of existing space-based methane observations from SCIAMACHY and GOSAT to constrain methane emissions on a spatial scale of hundreds of km and an annual temporal scale. However, such spatial and temporal scales are inadequate to understand the relevant processes. There is considerable spatial overlap at hundreds of kilometers between different CH_4 source types (such as oil and gas, livestock, landfills); finer spatial resolution is needed to separate individual sources. Methane emissions can also have very large temporal variability, including “super-emitters” from oil/gas production and distribution systems that are thought to contribute a large share of total emissions. Thus, policy-relevant CH_4 observations would require substantial spatial and temporal resolution improvements over existing observing systems where the sampling representation error greatly exceeds measurement errors. The ESA TROPOMI mission (expected launch 2016) offers approximately daily (but not hourly) methane observations with 7 km x 7 km spatial resolution. There are no planned NASA space-based CH_4 observations in the coming decade.

Recent work by Bocquet et al. (2014) concluded the correction of emission biases may be an important area of development and applications for coupled chemistry and meteorology models, in particular for emission terms that carry large uncertainties. Barré et al. 2015 conducted Observing System Simulation Experiments (OSSEs) for time resolved observations of CO over USA, Europe and Asia using a computationally economic scene-dependent observation simulator that accurately represented vertical sensitivity (Worden et al., 2013). This work captured near-surface pollution emissions in each region around the globe and the importance of long-range transport between the regions that can be revealed with vertically resolved CO. (Note that that TEMPO will not provide vertically resolved CO.) NASA’s investments in GEO-CAPE studies for over seven years have substantially advanced the necessary analytical capabilities that could provide decision support when used with well-studied but not currently planned space based observations of CH_4 and related tracers.

In addition to spatially/temporally dense data from space, data-driven policy decisions require atmospheric chemistry and transport models to provide products on relevant spatial scales, often urban. Global models with a typical resolution of a few hundreds of kilometers and regional chemical-transport models used at resolutions of a few tens of kilometers, and their parameterization of physical and chemical processes, make them inadequate for modeling air-quality at urban scale (Cohen et al., 2006). Schaap et al. (2015) demonstrate that improving the model resolution from 50 km between 10 and 20 km is computationally practical and worthwhile.

A challenge for the decade ahead is to accelerate the combined use of policy-relevant data and advanced atmospheric models to support air quality and climate decision making. Community model development on finer scales would follow if decision support was prioritized. Current and planned space based assets do not meet the observation needs for methane and related tracer data, but the requirements could be met with mature observation capabilities that exist now.

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