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Using Multi-Scale Measurements to Improve Methane Emission Estimates from Oil and Gas Operations in the Barnett Shale Region, Texas

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A growing body of work using varying analytical approaches is yielding estimates of methane emissions from the natural gas supply chain. For shorthand, the resulting emission estimates can be broadly described as top-down or bottom-up. Top-down estimates are determined from measured atmospheric methane enhancements at regional or larger scales. Bottom-up estimates rely on emissions measurements made directly from components or at the site level. (We note that bottom-up emission estimates (e.g., refs 4 and 13) may rely on data obtained with emission quantification methods sometimes labeled as top-down (e.g., refs 6, 7, and 9–12).) Both approaches have strengths and weaknesses. Top-down estimates cannot easily distinguish emissions from specific source types, limiting the development of informed mitigation strategies. Bottom-up estimates are resource intensive, and may not provide sufficient statistical characterization of each source type to accurately estimate total emissions.

Previously published large-scale top-down studies report higher methane emissions than estimated by bottom-up emission inventories. Recent reviews of this work[1,2] suggest that differences may result from (i) incorrect attribution of emissions among methane sources (e.g., fossil vs biogenic sources); (ii) obsolete or incomplete emission inventories, possibly based on emission factors developed using small or unrepresentative samples (including potential bias introduced by sampling only at cooperating facilities) and poor infrastructure activity data (e.g., site or event counts); (iii) failure to account for emissions from uncommon but anomalously high emitting sources (sometimes called superemitters); and (iv) the impact of intermittent, short-duration events. This issue contains 10 articles reporting results from a coordinated, two-week field campaign that examined methane emissions using a diversity of analytical approaches in an effort to address these issues.

The Barnett Shale Coordinated Campaign focused on a region of north Texas that includes the Barnett Shale oil and gas fields and the metropolitan area around Dallas and Fort Worth (population ~7 million). With about 30 000 active wells, the region produced ~2 trillion cubic feet of natural gas in 2013, or 7% of total U.S. production. As summarized below and in Figure 1, measurements from the campaign, supplemented with two recent national data sets,[9,15] were used to develop top-down and bottom-up estimates of oil and gas methane emissions in the Barnett Shale region.

CAMPAIGN INSIGHTS

Both top-down[3] and bottom-up[4] estimates of methane emissions from oil and gas operations in the Barnett Shale region were higher than the emissions expected from the U.S. Environmental Protection Agency Greenhouse Gas Inventory (GHGI). The bottom-up estimate for oil and gas is ~1.5 times higher than expected based on the GHGI.[4] The magnitude of the difference is consistent with the factor of 1.25–1.75 noted for all U.S. methane sources in Brandt et al.[1] The main reason the bottom-up inventory exceeds the GHGI-based estimate is the inclusion of many more gathering compressor stations, whose emissions are comparable to mainline transmission compressor stations. Future inventories need to carefully account for these facilities. A higher emission factor for oil and gas production sites was the second largest contributor to the difference.

TOP-DOWN EMISSION ESTIMATES

Karion et al.[3] and Smith et al.[5] quantify methane and ethane emissions from all contributing sources in the Barnett region using an aircraft-based mass balance technique. Karion et al. report total regional methane emissions, based on the average of eight flights, are 76 ± 13 Mg CH_4 hr^{-1}. Smith et al. provide ethane-to-methane correlations used to estimate that 71–85% of observed methane emissions in the region originated from

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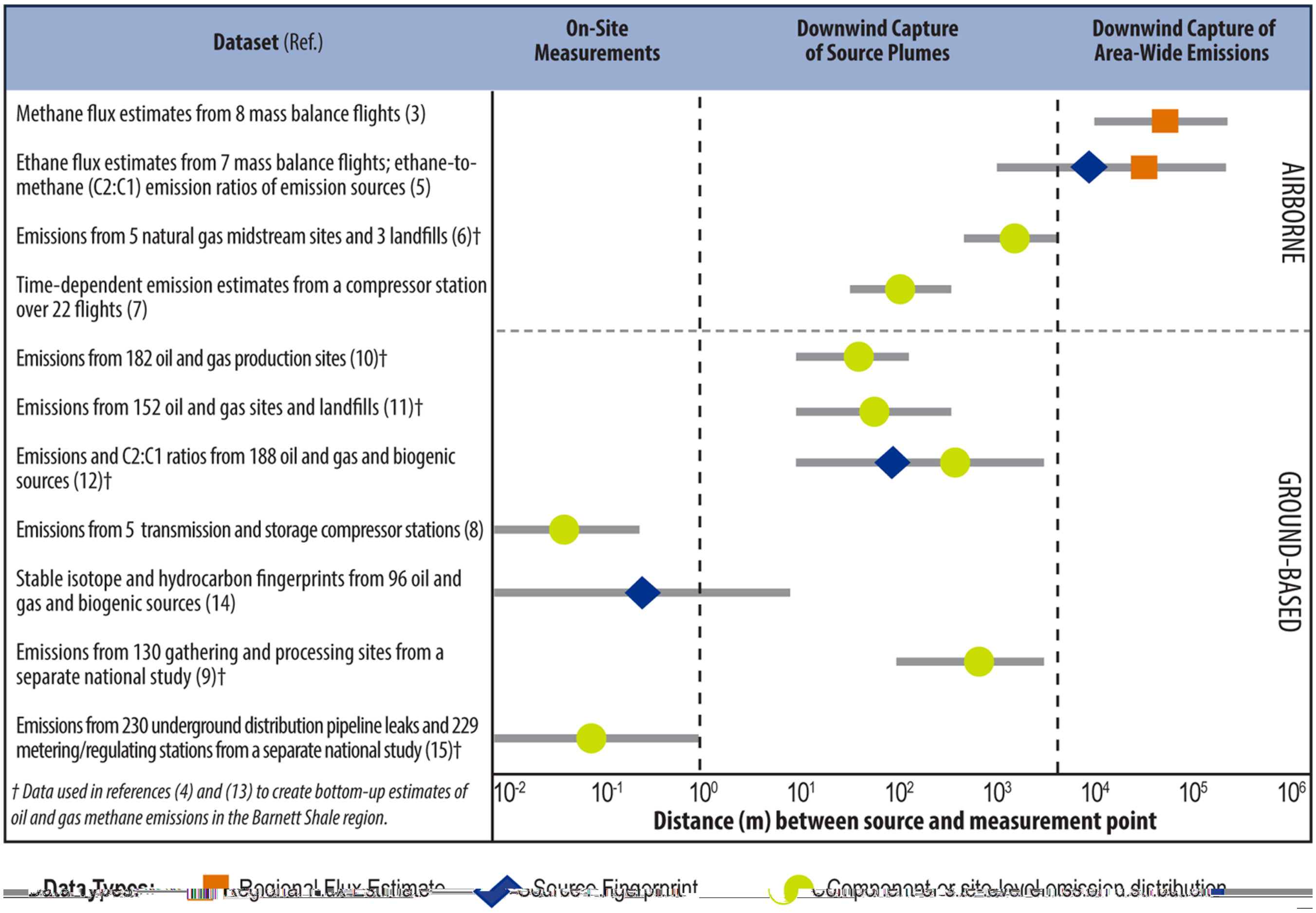

Figure 1. Multiscale measurements used to characterize methane emissions from oil and gas sources in the Barnett Shale.

fossil-based sources (primarily natural gas and oil operations) with the balance coming from biogenic sources (e.g., landfills).

FACILITY-SPECIFIC MEASUREMENTS

Additional airborne and ground-based studies quantify methane emissions from individual sources, generating data sets relating to emission distributions across the regional natural gas supply chain and the prevalence of large but relatively rare super-emitters. Lavoie et al.[6] use an airborne mass balance method to estimate emissions from eight high-emitting landfills and natural gas facilities; they highlight the contribution of large, rare sources characteristic of the fat-tail of emission distributions in the Barnett region (combined emissions from these eight sources were 10% of Karion et al.'s total methane estimate). Using a laser-based methane sensor mounted on a model aircraft, Nathan et al.[7] report that temporal variability (on time scales of hours to days) in one compressor station's emissions approached 2 orders of magnitude.

Several ground-based teams quantify emissions using measurements made with varying proximity to sources, ranging from direct on-site measurements of individual oil and gas components to downwind sampling at scales ranging from 25–5000 m. Johnson et al.[8] report emissions from five natural gas compressor stations and storage facilities based on comprehensive facility audits using direct source detection and quantification methods. Their average results are similar to the median of national data sets of compressor station emissions,[9] but 65% lower than the mean value; underscoring the importance of large samples to characterize skewed distributions. Rella et al.[10] quantify methane emissions from 182 natural gas and oil production sites using a mobile flux plane measurement technique. Lan et al.[11] and Yacovitch et al.[12] determine emission rates from a variety of natural gas and oil sites using Gaussian plume modeling. Rella et al., Lan et al., and Yacovitch et al. all report skewed emission distributions.

BOTTOM-UP EMISSION ESTIMATES

Zavala-Araiza et al.[13] integrate the measurements reported in Rella et al.,[10] Lan et al.,[11] and Yacovitch et al.[12] to estimate total emissions from natural gas production sites using a classification system based on sites' proportional loss rates. Zavala-Araiza et al. define "functional super-emitters" to be those sites with the highest loss rates and hypothesize that excess emissions at these sites are due to avoidable operating conditions such as malfunctioning equipment, which raises the prospect that these emissions can be mitigated. Lyon et al.[4] construct a comprehensive, spatially resolved methane inventory using Monte Carlo simulations that account for high-emission natural gas sites (typified by the highest observations in Lavoie et al., Yacovitch et al. and Lan et al.). Total estimated methane emissions for the 25-county Barnett Shale region were 72 (−9/+10) Mg hr^{-1} (95% CI); oil and gas operations were estimated to emit 46 (−6/+8) Mg hr^{-1}. Townsend-Small et al.[14] report stable isotopic and hydrocarbon fingerprints of emissions from individual sources; they estimate

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regional ethane emissions by integrating source-specific ethane:methane ratios into the Lyon et al. methane inventory.

By combining measurements made at multiple spatial scales, the Barnett Shale field campaign contributes to a more robust understanding of methane emissions from an active oil and gas production area. Region-wide emission estimates can be efficiently obtained using airborne top-down methods, while source-specific measurements can provide insights about the contribution of specific source types. Similar efforts are underway in other U.S. production areas.[16−18]

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Notes

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