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Abstract: **Methane Emissions from the Marcellus Shale Based on Airborne Measurements**

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Natural gas production in the United States has increased rapidly over the past decade, along with concerns about methane (CH_4) leakage (total fugitive emissions) into the atmosphere and its climate impact. Quantification of CH_4 emissions from oil and natural gas (O&NG) operations is important for establishing scientifically sound and cost-effective policies for mitigating greenhouse gases. We use aircraft measurements to estimate CH_4 emissions from O&NG operations in the southwestern Marcellus Shale region. We used a mass balance approach for three flight experiments on three days in August and September 2015. The mean CH_4 emission is estimated to be 39.9±3.4 kg CH_4 s^{-1} (or 1.26±0.11 Tg CH_4 yr^{-1}, mean±1σ). A substantial source of CH_4 was found to contain little ethane (C_2H_6), likely due to coalbed CH_4 emitted either directly from coal mines or from wells drilled through coalbed layers. Of the total CH_4 flux, 23.5±3.4 kg CH_4 s^{-1} (or 0.74±0.11 Tg CH_4 yr^{-1}) is estimated to be emitted by O&NG operations. We estimate the average CH_4 leak rate from O&NG operations as 4.3±0.7% (3.6-5.0%). This leak rate is broadly consistent with the results from several recent top-down studies, but higher than the results from a few other observational studies as well as the leak rate specified in the US EPA CH_4 emission inventory. Our leak rate suggests that for a 20-year time scale,

energy derived from the combustion of natural gas extracted with current technologies from this region exerts a climate penalty compared to energy derived from coal.