Geophysical Research Abstracts
Vol. 19, EGU2017-5336-2, 2017
EGU General Assembly 2017

A Compact, Low Resource Instrument to Measure Atmospheric Methane and Carbon Dioxide From Orbit

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Methane is the second most important radiatively active trace gas forcing anthropogenic climate change. Methane has ∼28 times more warming potential than carbon dioxide on a 100-year time horizon, and the background atmospheric concentration of methane has increased by more than 150% compared to pre-industrial levels. The increase in methane abundance is driven by a combination of direct human activity, such as fossil fuel extraction and agriculture, and natural feedback processes that respond to human-induced climate change, such as increased wetland production. Accurate accounting of the exchange between the atmosphere and the natural and anthropogenic methane reservoirs is necessary to predict how methane concentration will increase going forward, how that increase will modulate the natural methane cycle, and how effective policy decisions might be at mitigating methane-induced climate change. Monitoring and quantifying methane source intensity and spatial-temporal variability has proven challenging; there are unresolved and scientifically significant discrepancies between flux estimates based on limited surface measurements (the so-called “bottom-up” method) and the values derived from limited, remotely-sensed estimates from orbit and modeling (the so-called “top-down” method).

A major source of the discrepancy between bottom-up and top-down estimates is likely a result of insufficient accuracy and resolution of space-based instrumentation. Methane releases, especially anthropogenic sources, are often at kilometer-scale (or less), whereas past remote sensing instruments have at least an order of magnitude greater footprint areas. Natural sources may be larger in areal extent, but the enhancement over background levels can be just a few percent, which demands high spectral resolution and signal-to-noise ratios from monitoring instrumentation.

In response to the need for higher performance space-based methane monitoring, we have developed a novel, compact, low-resource instrument that meets the accuracy and spatial resolution challenges demanded by methane exchange processes. The baseline instrument uses reflected sunlight 0.7591-0.7646 μm and 1.6058-1.6761 μm, permitting individual spectral identification of CH4, O_2, CO_2 and H_2O. By combining spectral information, the complicating effects of aerosol and clouds can be reduced. A spectral resolving power of R∼20,000 is achieved by utilizing a novel matching off-axis parabolic (OAP) mirror system to send a collimated beam to an Echelle grating, which then picks off the high orders of interest and sends them back to one of the OAPs for final focus. A beamsplitter before the focus separates the near-visible O_2 signal from the ∼1.6 μm CH4, CO_2, and H_2O signals, creating two separate imaging channels. A high-heritage H1RG detector is used in both channels. The instrument images a $0.03° \times 5°$ field-of-view, with a point-source resolution of 0.03°. These specifications produce a 33 km wide instantaneous image at the nominal altitude of 380 km, with 200 m point-source resolution. Higher altitudes yield increased instantaneous coverage at the cost of wider point-source resolution. The 200 m pixels can be averaged to produce higher signal-to-noise while still maintaining km-scale resolution.

The entire instrument consumes 55 W with a mass of 20 kg and total volume of 0.07 m^3. Thus, the instrument provides performance similar to or better than existing hardware in a much smaller package. The small resource footprint provides the opportunity to fly as payload on one or multiple small satellite payloads or on the International Space Station.