A METHANE IPDA LIDAR USING OPTICAL PARAMETRIC LASER TECHNOLOGY

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Outline

- Need for Methane Measurements
- Current Efforts
- GSFC Approach
  - Initial Results
  - Power scaling
  - Current Status
- Summary
CH$_4$ has strong radiative forcing (~x23 stronger than CO$_2$ on a per molecule basis). Carbon Budget needs accurate CH$_4$/CO$_2$ sinks and sources.

Large amounts of organic carbon are stored as CH$_4$ and CO$_2$ in the Arctic permafrost. Thawing Arctic permafrost soil, is a cause for concern as a rapid, positive greenhouse gas/climate feedback. In addition, large but uncertain amounts of CH$_4$ are sequestered as gas hydrates in shallow oceans and permafrost soils, which are also subject to potential rapid release.

NASA Earth Science Decadal Survey: “Ideally, to close the carbon budget, methane should also be addressed, but the required technology is not now obvious. If appropriate and cost-effective methane technology becomes available, methane capability should be added.”

Methane is also an important biogenic trace gas (“life marker”) for planetary science.
Rising Methane

Methane Measurements
NOAA ESRL Carbon Cycle

GLOBAL AVERAGE

CH₄ (ppb)

GLOBAL GROWTH RATE

CH₄ (ppb yr⁻¹)

84 86 88 90 92 94 96 98 00 02 04 06 08 10

Dec. 2011

Source: UNEP
MERLIN (MEthane Remote Sensing LIDAR Mission) mission

\[ \lambda_{on} : 1645.552 \text{ nm} \]
\[ \lambda_{off} : 1645.846 \text{ nm} \]
GSFC Approach - Integrated Path
Differential Absorption Lidar-same as CO$_2$
IPDA lidar
GSFC IPDA Lidar

Precision Goal: 10 ppb

Parameter | Value
---|---
Repetition Rate | 10 KHz
Pulsewidth | 6 nsec
Orbit altitude | 400 km
Ground Speed | 5 km/s
Laser Spot Diameter | 48 m
Detector Quantum Eff. | 70%
Telescope Diameter | 0.5 m
Receiver Field of View | 200 µrad
Surface reflectivity | 0.31
Receiver Optical Bandwidth | 0.8 nm
Averaging Time | 1 sec
Energy | 250-300 µJ
Ground Testing with two IPDA lidars using OPA - 3.29 μm and 1.65 μm
Airborne Tests in 2011 with an OPA and a PMT

“Airborne measurements of atmospheric methane column abundance using a pulsed integrated-path differential absorption lidar”, APPLIED OPTICS / Vol. 51, No. 34 / 1 December 2012
**Laser Transmitter Components**

**Pump**: a high power, single frequency, narrow linewidth fiber or solid state laser at 1064 nm

**Seed**: a low power, single frequency diode laser at 1651 nm.

Optical Parametric Oscillator (OPO) or Optical Parametric Amplifier (OPA). A non-linear crystal that amplifies the seed laser to the energy needed for space (250-300 μJ) **without** degrading the spectral characteristics.
Need ~300 µJ and narrow linewidth to achieve 10 ppb (~0.5%) random error.

OPA: Easy to align, easy to tune, power scaling hard to achieve while maintaining narrow linewidth. OPA samples the CH₄ line at several wavelengths using a single, continuously tuned seed laser.

OPO samples the CH₄ line at several discrete wavelengths using multiple seed lasers. Complicated to align and tune; power scaling easier to achieve while maintaining narrow linewidth.
Output signal energy: \( \sim 140 \ \mu \text{J} \) after \( \sim 70 \% \) transmission filter = \( 200 \ \mu \text{J} \)

BUT linewidth is \( \sim \) several GHz
Current Status of OPO using custom pump laser

>210 µJ @ 5kHz
<300MHz linewidth

Current Status of OPO using custom pump laser – open path measurements

Long term measurement of CH4 by OPO lidar
- CH4 by Picarro (left axis)
- DOD measured by OPO (1-min average, right axis)

Time [hours] (from May 1, 2013 0:00 EDT)
Why is the linewidth important?

The graph shows the transmission of CH4 at 370 Torr and 8 cm, comparing DFB laser only (CW), seeded OPO + injection-seeded pump, and seeded OPO + pump without injection seeding. The linewidths tested include 1 GHz, 3 GHz, 10 GHz, and an ideal case, with the US standard atmosphere (400 km) also indicated.
Detector Development

HgCdTe e-APD 4x4 Array Test Results at GSFC

- First 4x4 HgCdTe e-APD array for the CO2 lidar received in April 2013 and met requirements
CH$_4$ and CO$_2$ are the two most important greenhouse gases.

Active (laser) measurements of CH$_4$ are needed to improve coverage of important regions of the Earth, such as the Arctic permafrost.

The laser transmitter is currently the most challenging technological hurdle.

At GSFC we hope to achieve high precision CH$_4$ measurements using a 4-wavelength OPO and a sensitive detector.