The Challenges of Measuring Methane from Orbit

Haris Riris[1], Kenji Numata[1], Jianping Mao[2], Stewart Wu[1], Molly Fahey[1], Brayler Gonzalez[1], Michael Rodriguez[3], Stan Scott[1], and Xiaoli Sun[1]

[1]NASA Goddard Space Flight Center; [2]University of Maryland; [3]Sigma Space Inc., Greenbelt, MD 20771, USA

GSFC

ESTO Earth Science Technology Office

Methane and the 2017 Earth Science Decadal Survey

QUESTION W-8. What processes determine observed atmospheric methane (CH4) variations and trends and what are the subsequent impacts of these changes on atmospheric composition/chemistry and climate?

W-8a. Reduce uncertainty in tropospheric CH4 concentrations and in CH4 emissions, including regional anthropogenic sources and from a process level for natural sources.

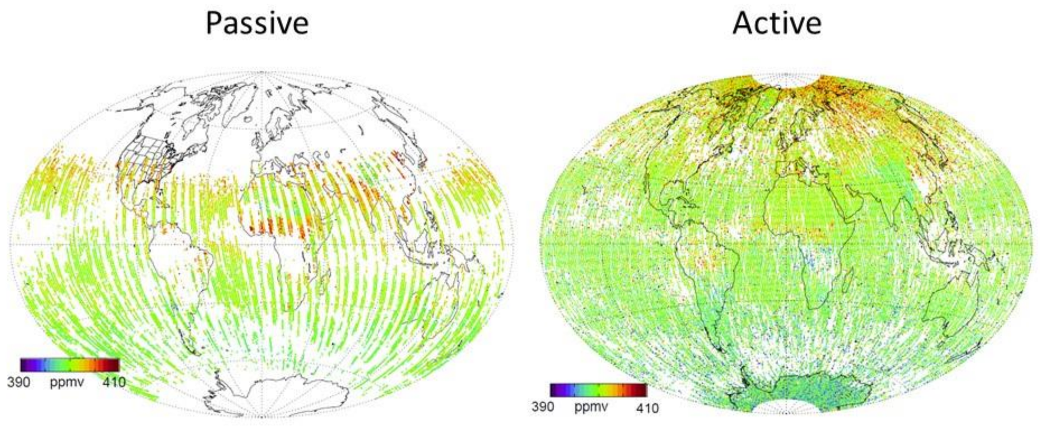
QUESTION C-8. What will be the consequences of amplified climate change already observed in the Arctic and projected for Antarctica on global trends of sea level rise, atmospheric circulation, extreme weather events, global ocean circulation, and carbon fluxes?

C-8f. Determine how permafrost-thaw driven land cover changes affect turbulent heat fluxes, above and below ground carbon pools, resulting greenhouse gas fluxes (carbon dioxide, methane) in the Arctic, as well as their impact on Arctic amplification.

TARGETED OBSERVABLE	SCIENCE/APPLICATIONS SUMMARY	CANDIDATE MEASUREMENT APPROACH	Designated	Explorer	Incubation
Greenhouse Gases	**CO_2 and methane fluxes and trends,** global and regional with quantification of point sources and identification of source types	Multispectral short wave IR and thermal IR sounders; or lidar**		x	
Ice Elevation	**Global ice characterization** including elevation change of land ice to assess sea level contributions and freeboard height of sea ice to assess sea ice/ocean/atmosphere interaction	Lidar**		x	
Ocean Surface Winds & Currents	**Coincident high-accuracy currents and vector winds** to assess air-sea momentum exchange and to infer upwelling, upper ocean mixing, and sea-ice drift.	Radar scatterometer		x	
Ozone & Trace Gases	**Vertical profiles of ozone and trace gases** (including water vapor, CO, NO_2, methane, and N_2O) globally and with high spatial resolution	UV/IR/microwave limb/nadir sounding and UV/IR solar/stellar occultation		x	
Snow Depth & Snow Water Equivalent	**Snow depth and snow water equivalent** including high spatial resolution in mountain areas	Radar (Ka/Ku band) altimeter; or lidar**		x	
Terrestrial Ecosystem Structure	**3D structure of terrestrial ecosystem** including forest canopy and above ground biomass and changes in above ground carbon stock from processes such as deforestation & forest degradation	Lidar**		x	

ESTO 1

Why use a laser?

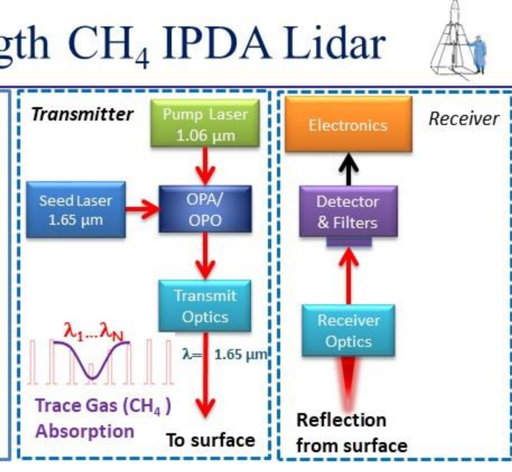


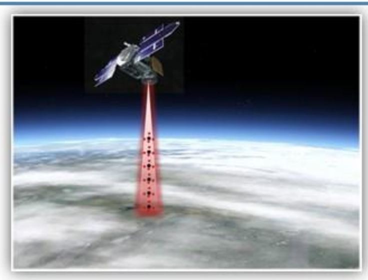
Comparison of actual OCO-2 coverage (left) vs. simulated ASCENDS coverage for December 16-31, 2015. The sparse sampling OCO-2 coverage at high latitudes is a major drawback of passive remote sensing missions.

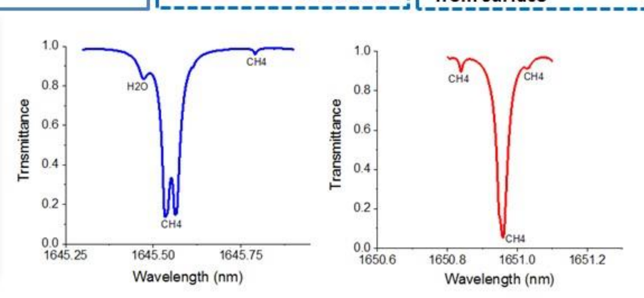
ESTO 2

GSFC Multi-wavelength CH_4 IPDA Lidar

- ***Transmitter (Laser) technology***
  - **Current (optimum) Wavelength for CH_4 Earth Detection: ~1.64-1.66 µm**
  - **Optical Parametric Oscillators (OPO) and Optical Parametric Amplifiers (OPA) are the "baseline" solutions for the transmitter.**
  - **Other options (Er:YAG and Er:YGG) now possible.**
- ✓ ***Receiver (Detector) Technology***
  - ✓ **DRS e-APD**

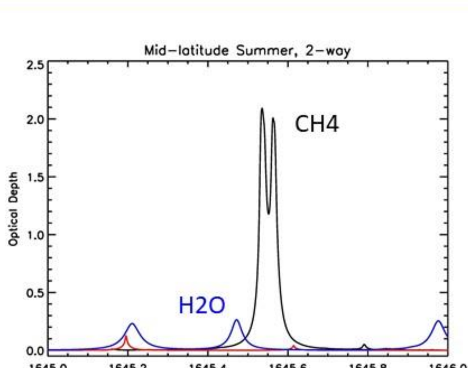




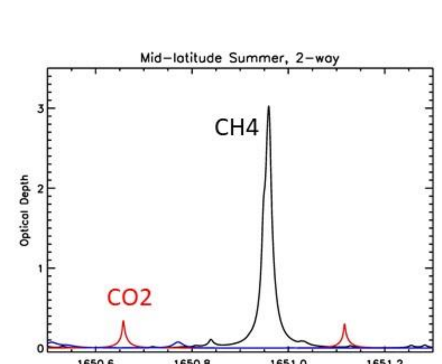


ESTO 3

Line Selection



Interferences



ESTO 4

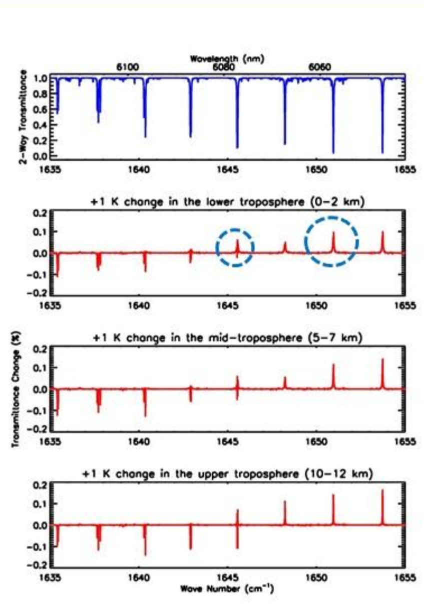
Sensitivity to Uncertainty in Temperature Data

Spectroscopic changes

2-way vertical path, ground-to-space
fixed total column CH4 # of molecules

Temp Perturbation: +1K at
a) 0, 1 and 2-km level;
b) 5, 6 and 7-km level;
c) 10, 11 and 12-km level

Change = Pert. – cont. Run



ESTO 5

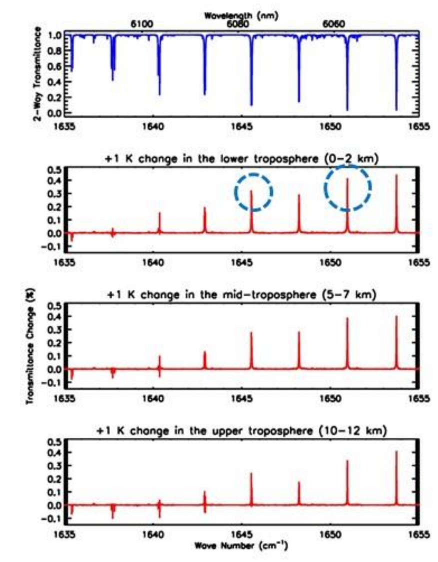
Sensitivity to Uncertainty in Temperature Data

including air density change

2-way vertical path, ground-to-space
fixed column-averaged CH4 mixing ratio

Temp Perturbation: +1K at
a) 0, 1 and 2-km level;
b) 5, 6 and 7-km level;
c) 10, 11 and 12-km level

Change = Pert. – cont. Run



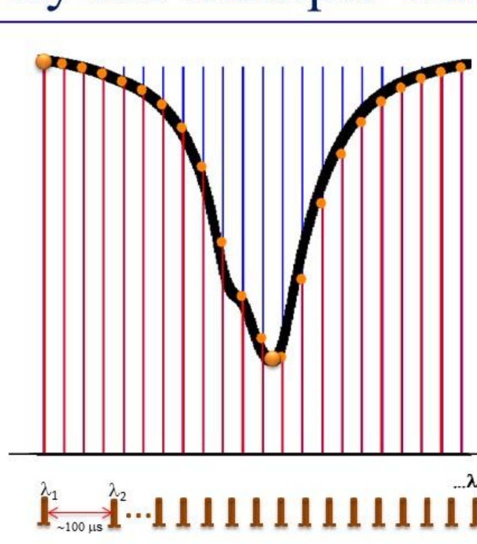
ESTO 6

CH_4 Laser Transmitter "Requirements"

- Emission wavelength must coincide with suitable CH_4 absorption lines (1645.5 nm and 1651 nm)
- Must have high pulse energy (~600 µJ) and high pulse repetition rate. Depending on the receiver size and other instrument parameters we calculate that approximately 600 µJ is needed to make a measurement with a 0.5% precision.
- Must be tunable (~300-500 pm) and scan rapidly (0.5-1 KHz) over the CH_4 absorption line
- Must have narrow linewidth (~100 MHz).

ESTO 7

Why use multiple wavelengths?



"***Ideal***" Instrument – has only random noise which can be averaged indefinitely.
Two wavelengths can adequately sample the lineshape. Averaging always helps.
Real Instrument – has random and non-random noise which can NOT always be averaged.
Two wavelengths can NOT adequately sample the lineshape and reduce biases.

ESTO 8

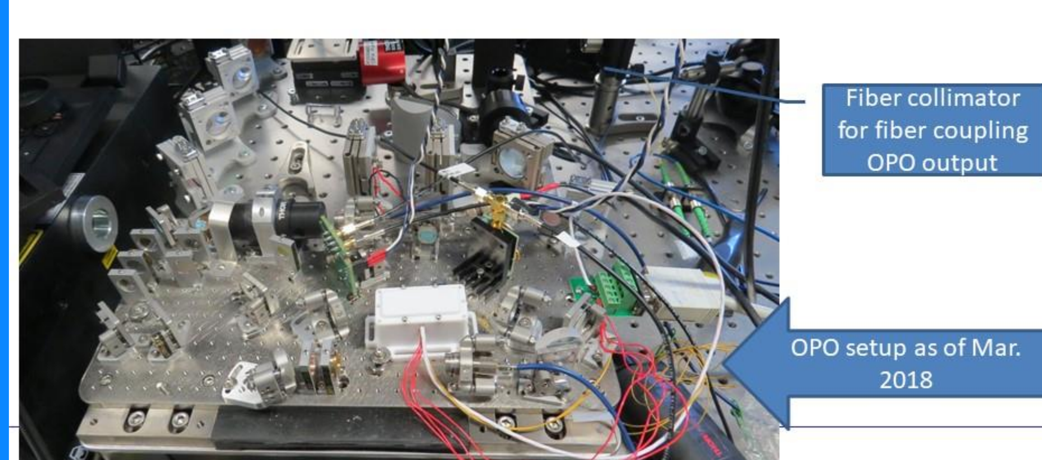
GSFC laser transmitter current status

- OPO
  - Successful seeding with step-tuned DBR laser
  - Open path measurements started.
- OPA
  - On hiatus – will be revisited when high power seed is delivered.
  - Power scaling and tunability need testing.
- Er:YGG/Er:YAG
  - Waiting for Er:YAG laser (~June 2018)
  - Testing Er:YAG NPRO crystal in CW mode
  - Setting up seeding for Er:YGG
- Fast-tuned seed laser
  - 16-wavelength locked seed laser now combined with the OPO
  - **Fast-tuned seed laser is applicable to <u>all</u> designs**

ESTO 9

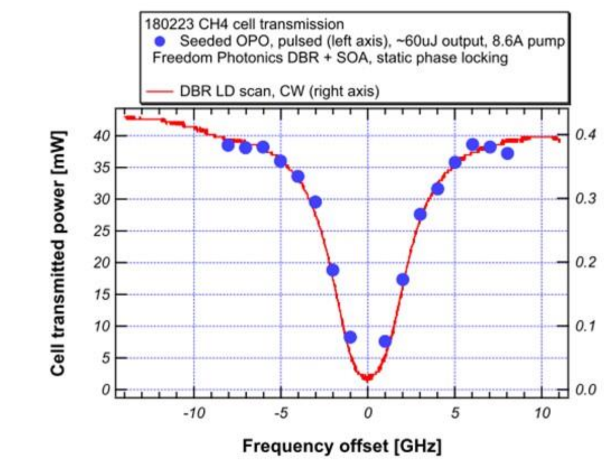
GSFC New multi-wavelength OPO

– Now combined with the fast tuning DBR seed laser
– Multi-wavelength OPO is becoming a reality.
– Starting open path measurements



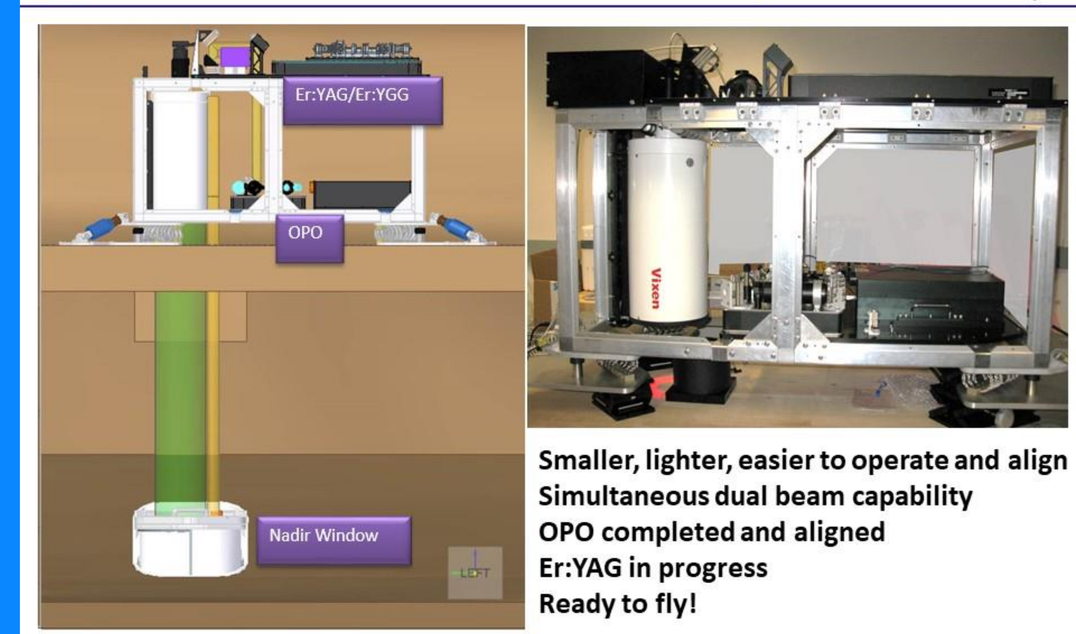
Seeded OPO with DBR laser

- CH_4 transmission using a Reference cell
  - Good agreement with CW laser scan
  - Seeding and cavity control working



ESTO

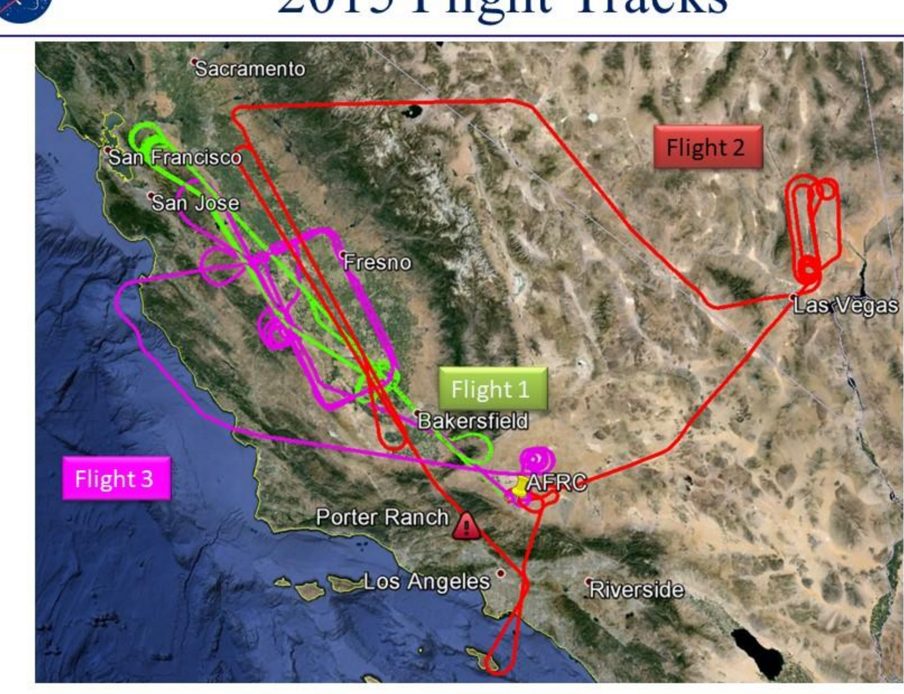
New 2018 airborne CH_4 lidar



Smaller, lighter, easier to operate and align
Simultaneous dual beam capability
OPO completed and aligned
Er:YAG in progress
Ready to fly!

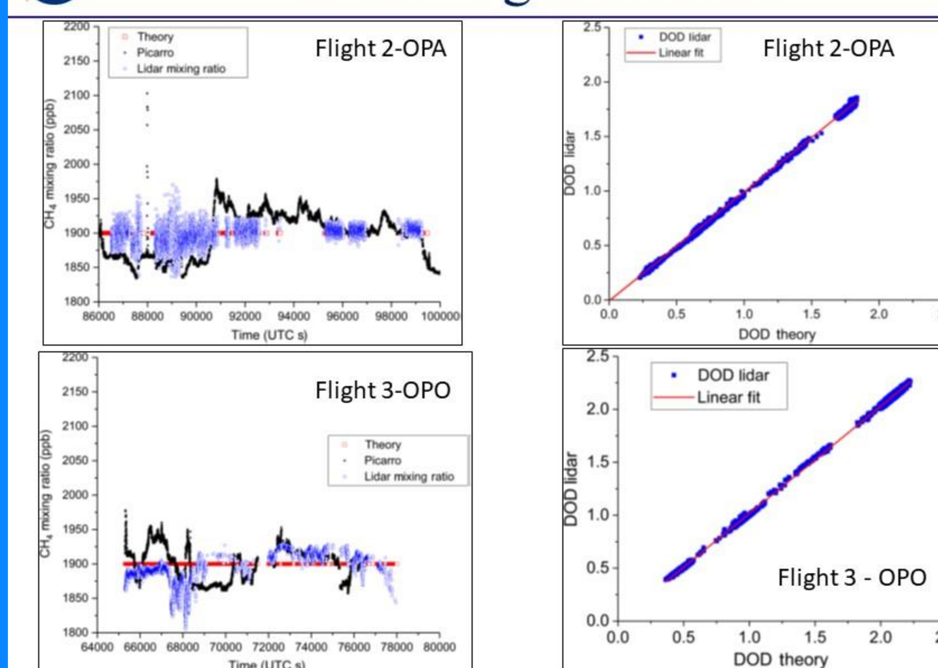
ESTO 12

2015 Flight Tracks



ESTO 13

2015 Flight Results



ESTO 14

Summary

- We have a prime candidate (OPO) for the laser transmitter for space (and airborne).
- A backup candidate (Er:Yxx) is also possible.
- Engineering issues remain but laser transmitter architecture has converged.
- All approaches are benefitting from step-tuned and locked DBR seed laser.
- ***New CH_4 lidar ready for airborne campaigns.***

ESTO 15