# Airborne Remote sensing of the OH tropospheric column with an Integrated Path Differential LIDAR.

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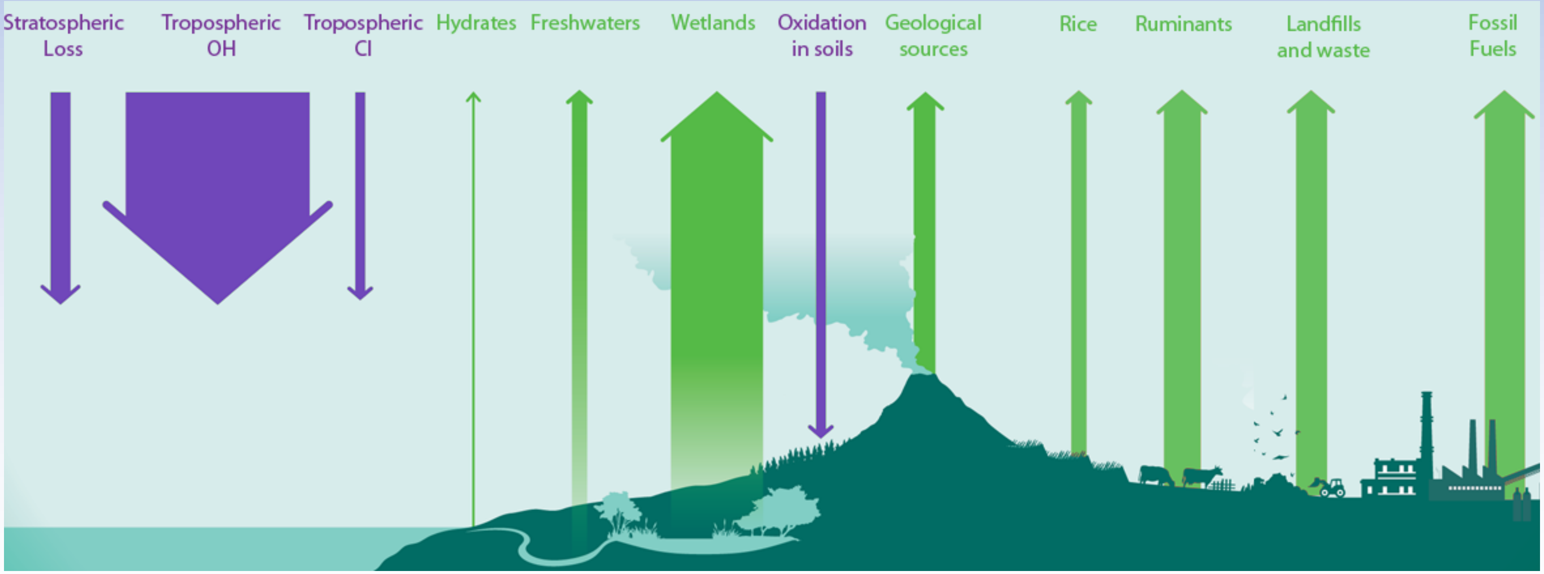
ESTO Fest
12 – June, 2018

# Motivation

The gas phase reaction of OH + $CH_4$ in the troposphere is responsible for 90% of the removal of methane.

The removal rate determines the lifetime of $CH_4$ and its global warming potential.

While the abundance of $CH_4$ depends on many sources, the removal rate depends mostly on OH, potentially simplifying model predictions.



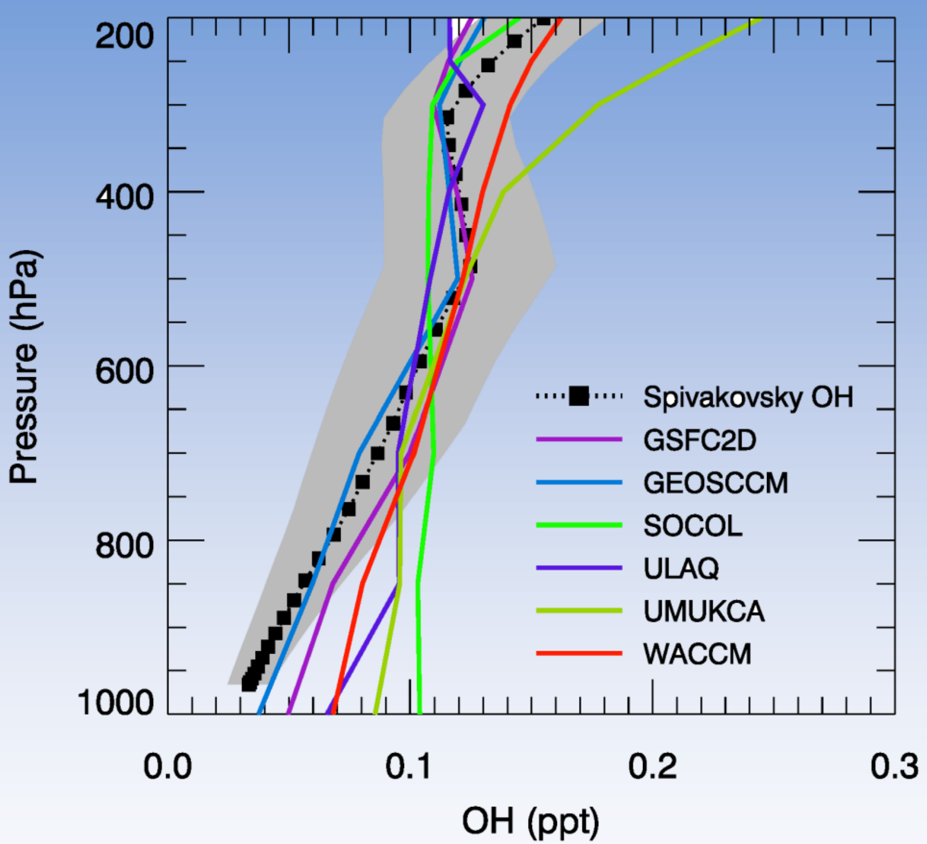
# State of the art

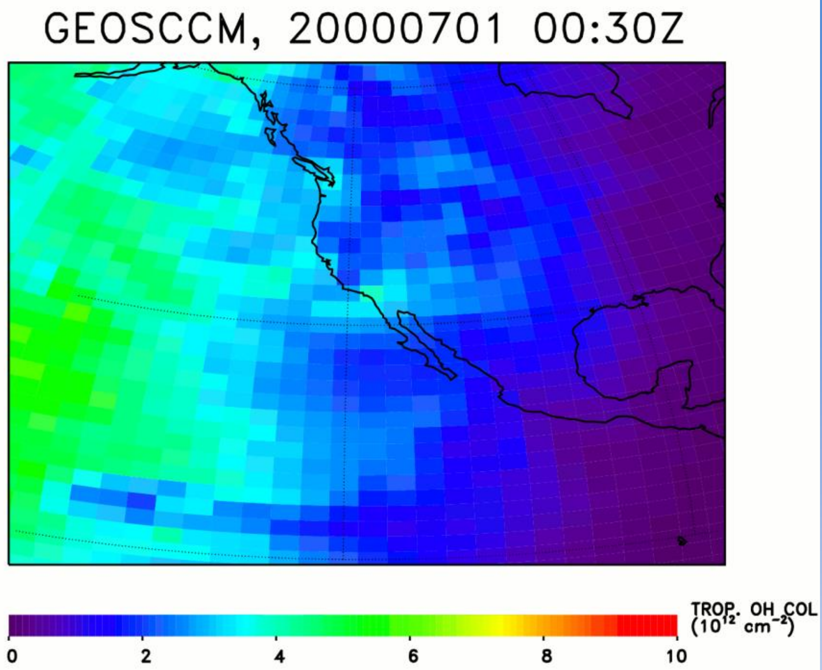
Methyl chloroform, $CH_3CCl_3$ is used to estimate OH. This estimate gives us a **singular value**:

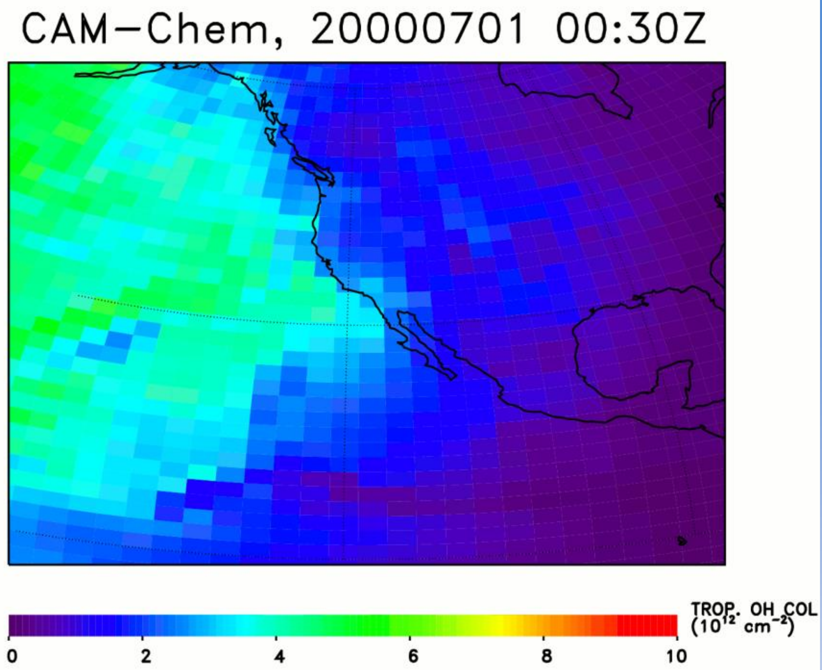
global annual average OH = $10^6$ /cm$^3$.

Our *predictive capability* with CCMs relies on being able to know how much, when, and where.

Models are not capable, yet, of meeting this challenge.

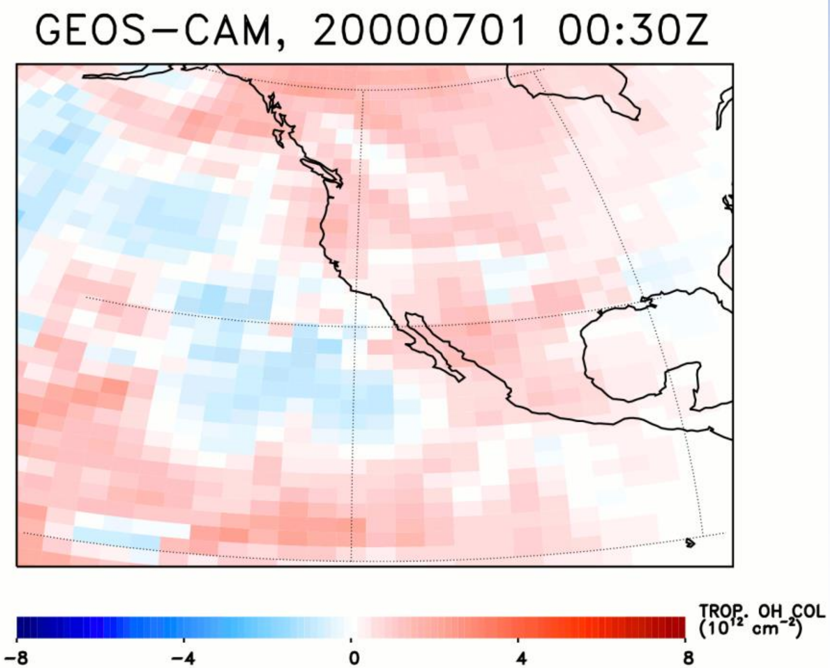




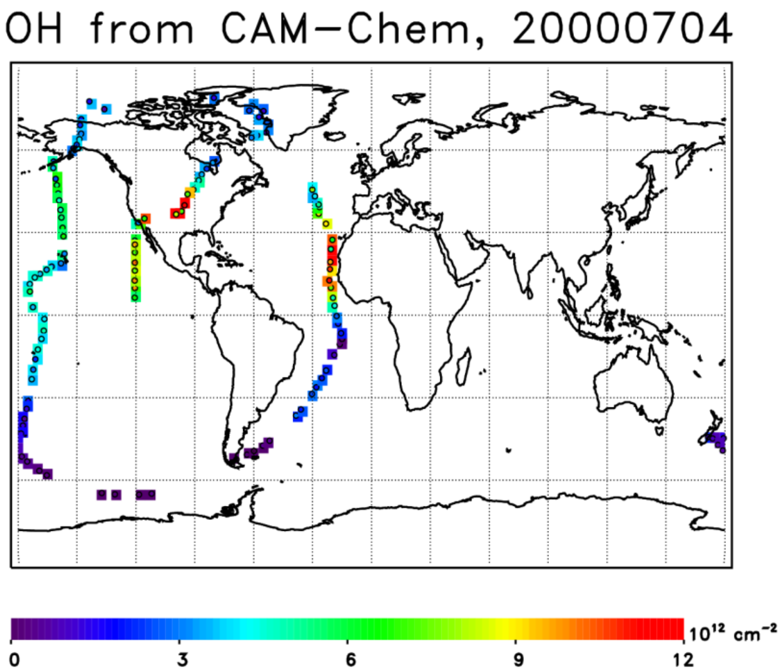



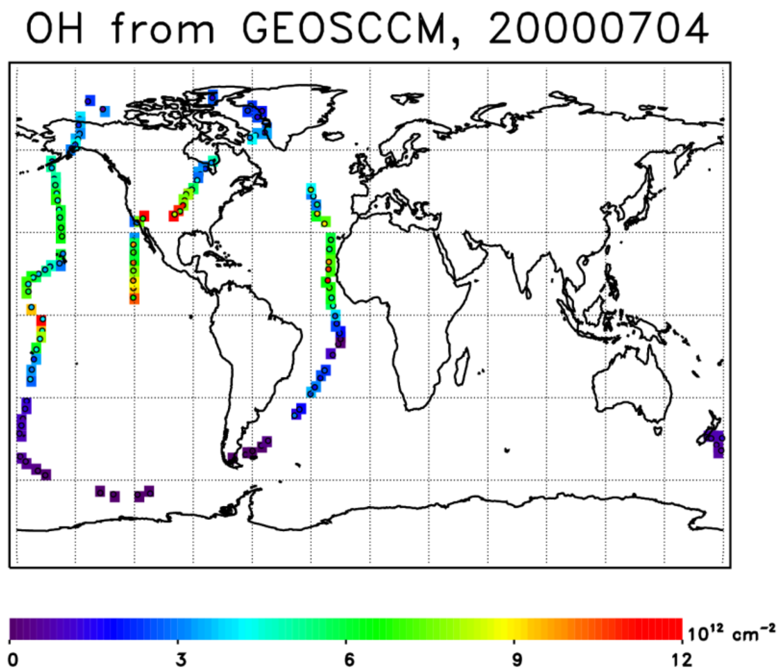

An illustration of the problem:

The difference between the two models is large



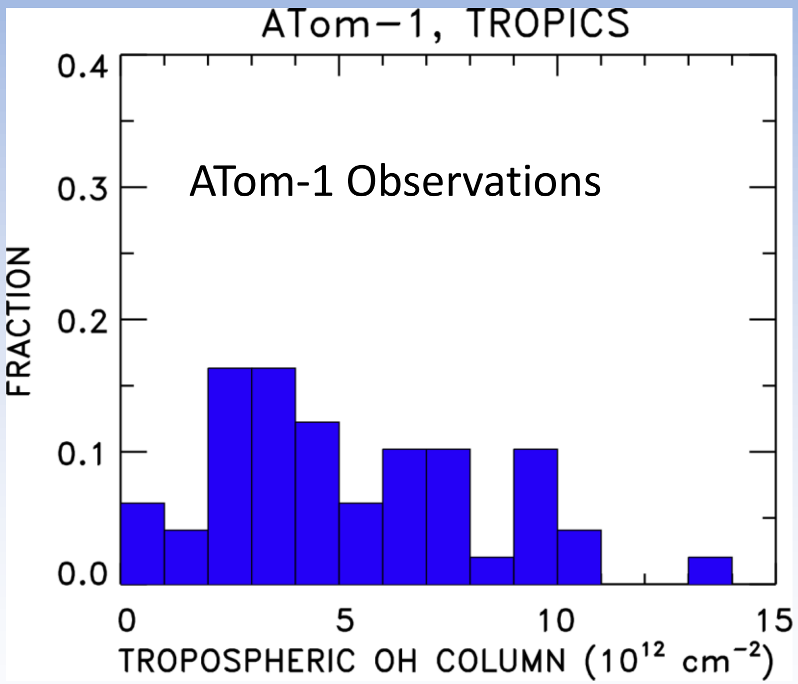
# *In Situ* measurements can be compared with global models, but the scales are mismatched and the process is inefficient.

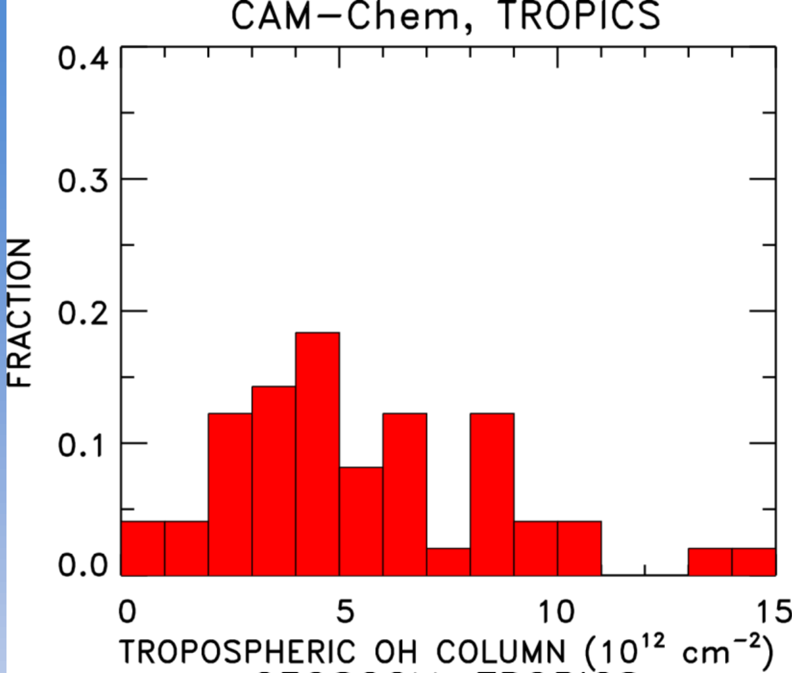


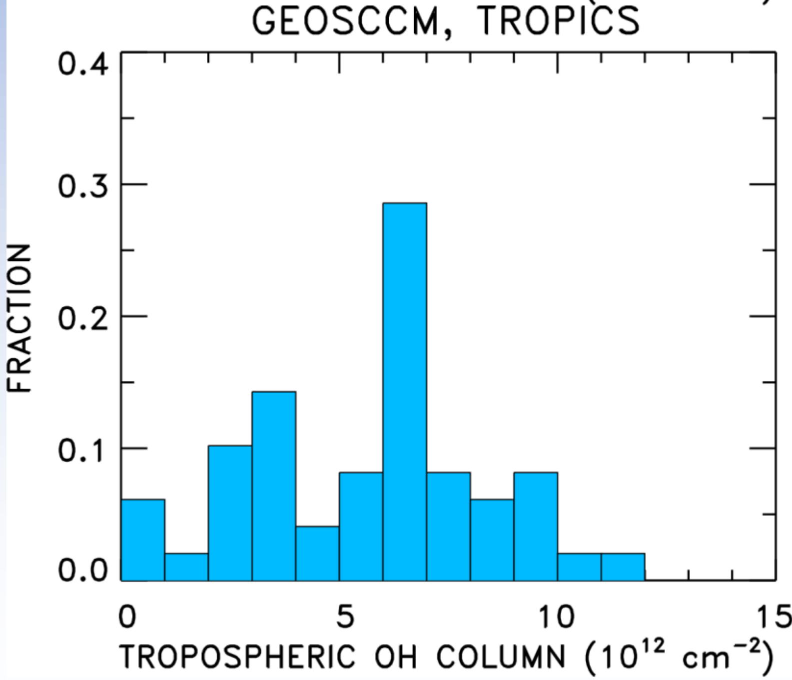




- ● circles Penn State *in situ* Column from Atom -1
- □ squares model output (x2 area)

Despite the mismatch in scale the value of these measurements is clear

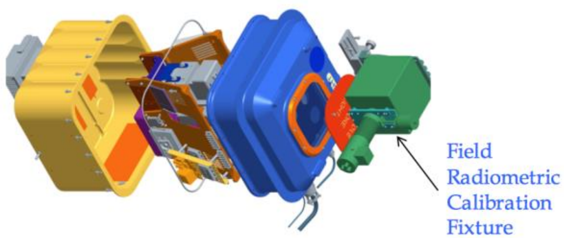


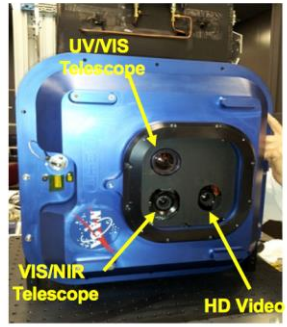



## Overview of GCAS (GEO-CAPE Airborne Simulator)

Exploded view




Telescopes map vertical slit extent to a 7.5 km cross-track FOV. Images captured at 2 Hz and co-added along track.

Spectral coverage and sampling
- 300-490 nm @0.2 nm/pixel
- 480-890 nm @0.4 nm/pixel

**Slant column product precision for $NO_2$**

•Minimum retrieved resolution 250 m x 500 m: 1.5e15 molecules $cm^{-2}$

•Typical retrieved resolution 1 km x 1.5 km: 0.4e14 molecules cm-2

**Retrievals for total O3 and HCHO have also been demonstrated**

Technology for remote sensing the tropospheric columns of $NO_2$, $O_3$ and HCHO exist and be paired with a remote sensing OH instrument.

## Overview of GeoTASO (TEMPO/GEMS Airborne Simulator)

Geostationary Trace gas and Aerosol Sensor Optimization

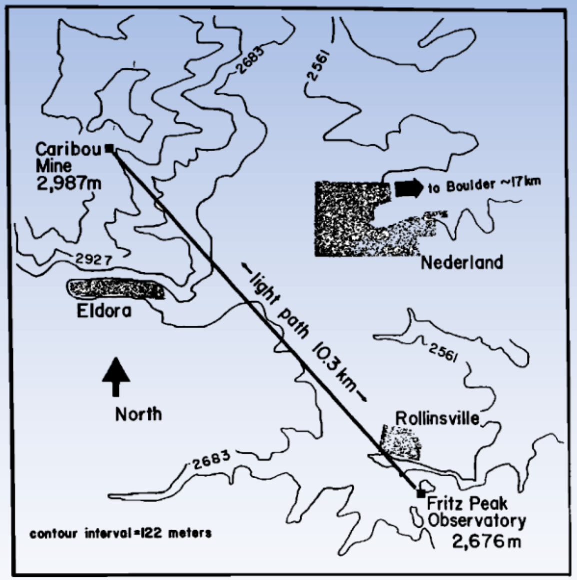
- NASA-funded airborne sensor and trace gas/aerosol retrieval project to advance mission readiness of sensor/algorithms for GEO-CAPE/TEMPO missions
  - UV-Vis spectrometer with 2 2-D detector arrays covering 290-390 nm ($O_3$, $SO_2$, HCHO) and 415-695 nm ($NO_2$, $O_3$, aerosol)
    - Imaging spectrometer covers ~8 km swath with 50 m x 80 m ground patch resolution
    - Spectral passbands of ~ 0.4 nm in UV, ~0.8 nm in Vis with 3x oversampling spectrally
    - Signal to noise of ~ 50 for individual samples

# Our concept: Long Path OH Absorption Spectroscopy

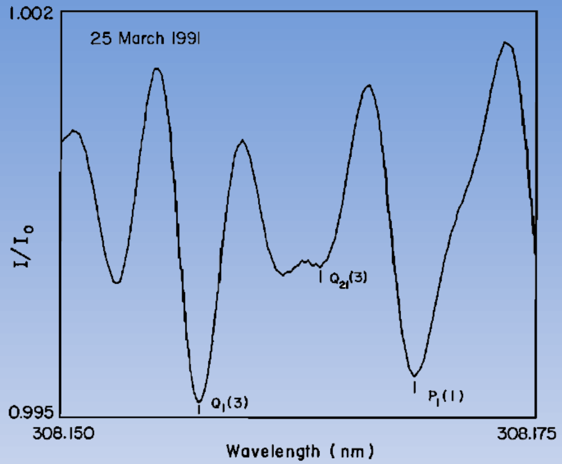
George Mount, J. Geophys. Res., 1992

Use Beer's Law, $I/I_0 = e^{-\sigma n l}$, to determine the abundance of OH in the laser path

$n = OH = \ln(I_0/I)/\sigma l$




The topography of the area between Fritz Peak Observatory and Caribou, Colorado, where t




MOUNT: TROPOSPHERIC OH 2

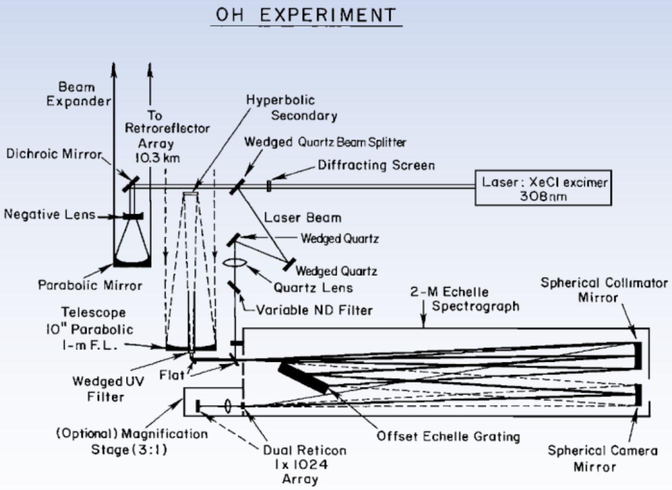
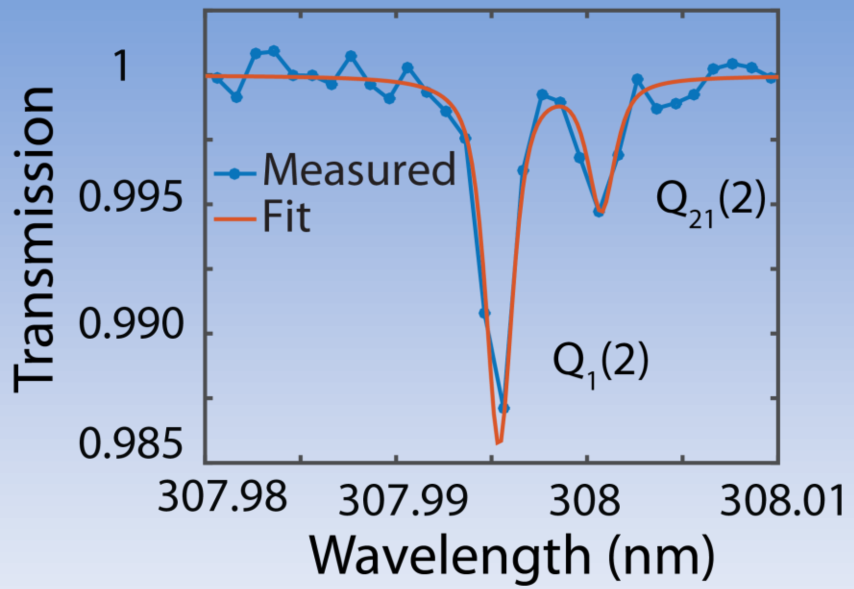
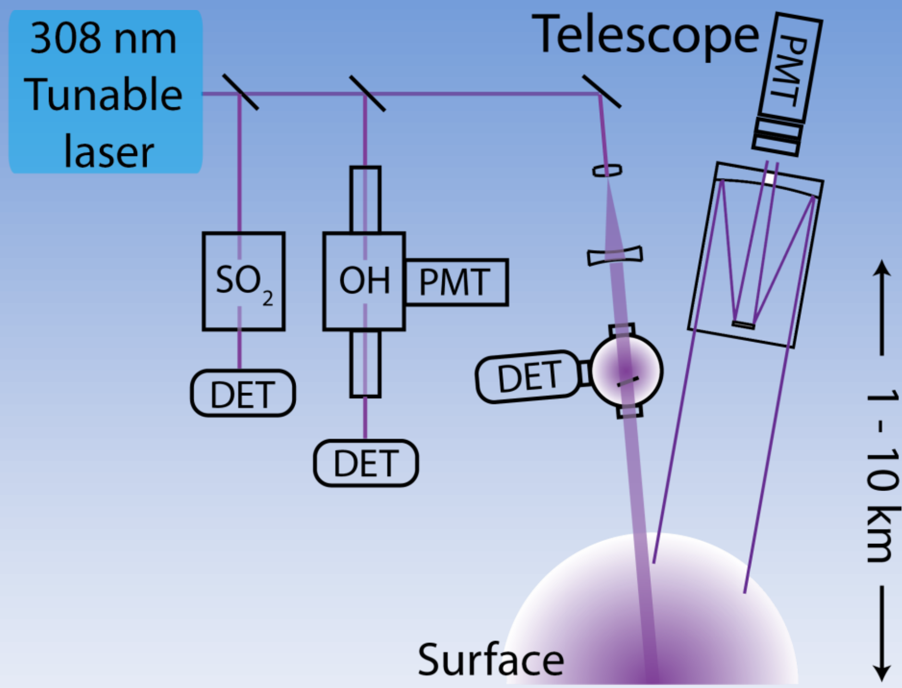



Fig. 1. A schematic drawing of the entire operational system for measurement of OH concentration in the troposphere.

# Our approach: Integrated Path Differential Absorption (IPDA) LIDAR




| Nominal performance parameters for the OH IPDA LIDAR | | | | | |
|---|---|---|---|---|---|
| **Laser wavelength** | 308 nm | Laser linewidth | <0.001 nm | Laser Power | 5 W |
| **Laser pulse width** | ~10 ns | Pulse energy | 50 uJ | Repetition rate | 100 kHz |
| **Beam divergence** | 1 mrad | Laser scan range | 0.05 nm | Laser scan rate | 250 Hz |
| **Receiver diameter** | 20 cm | Receiver FOV | 1 mrad | Receiver bandpass | 0.5 nm |
| **Altitude** | 10 km | Integration time | 30s | Signal To Noise/bin | 410 |
| **Precision (molec/cm²)** | $4 \times 10^{11}$ | | | Accuracy | 10% |

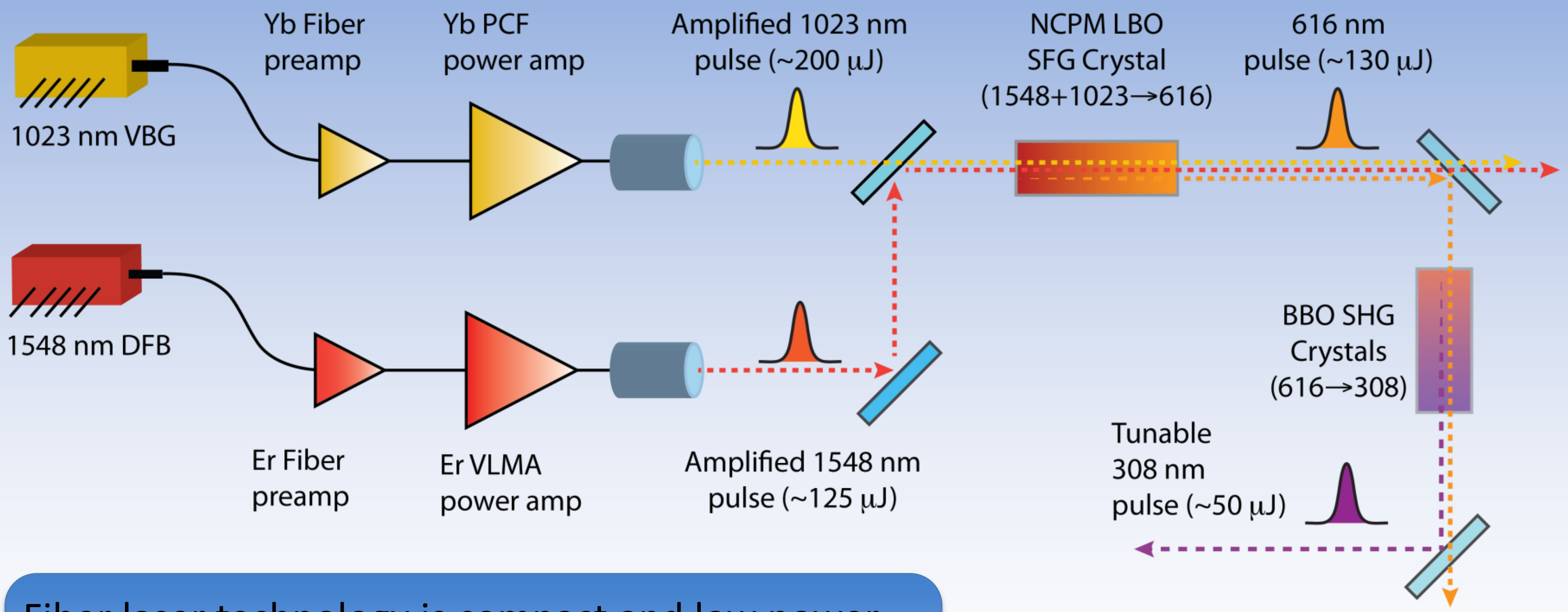
# Measurement perpective

- **Why measuring OH is hard:**
  - OH abundance is sub parts per trillion ($10^6$ times lower than $CO_2$)
  - Rayleigh removes 90% of UV light.  Need powerful laser
- **Why measuring OH is possible:**
  - *A-X* transition at 308 nm is super sensitive:  $\sigma = 5\text{x}10^{-16}/\text{cm}^2$
  - Science goals are 10% not 0.1%
  - $CO_2$ folks and others have developed half of our laser already

# Tunable fiber laser for OH IPDA

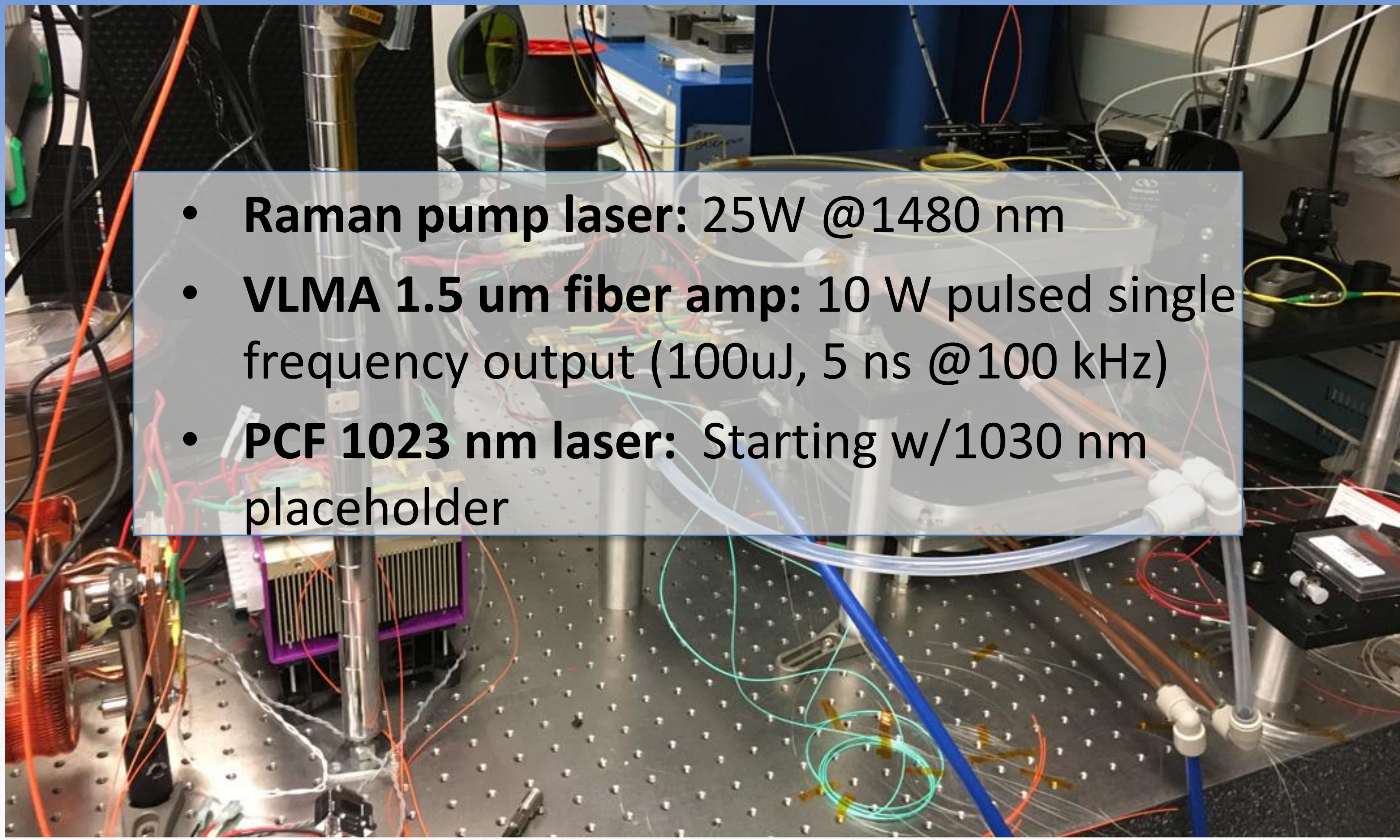
**NASA IIP and GSFC IRAD**

Demetrios Poulios, Paul Stysley, Steve Bailey, Jason St. Clair, George Mount

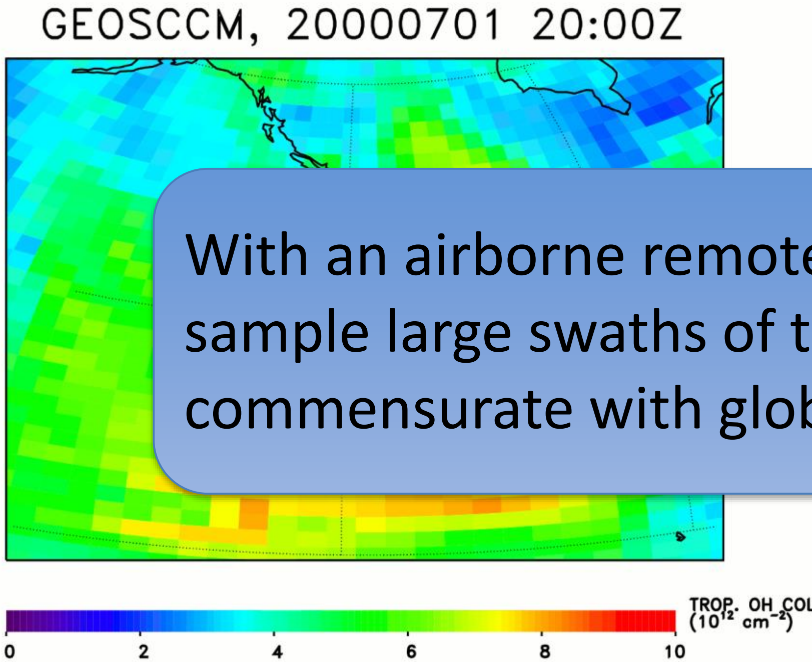


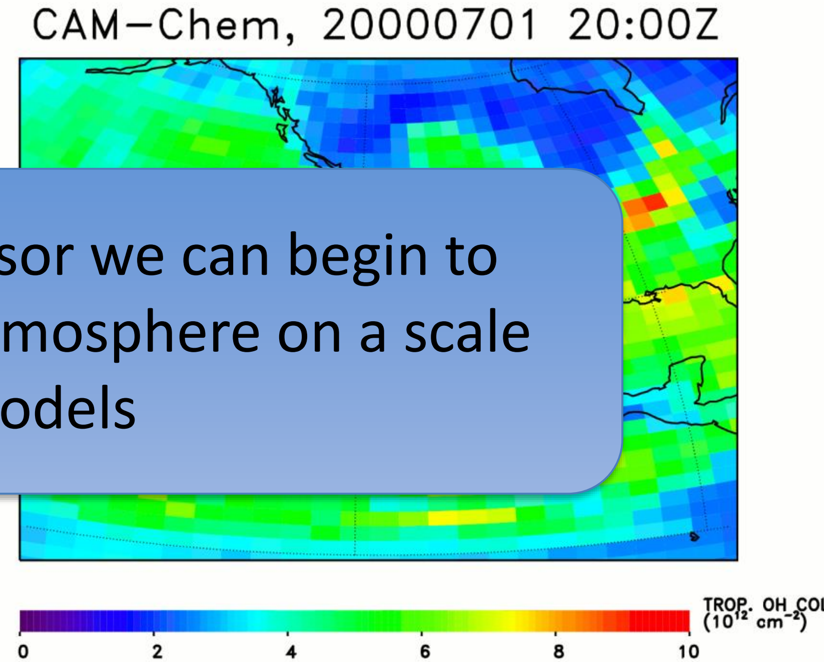

Fiber laser technology is compact and low power, ideal for airborne operation.
SWAP: 20x30x35 cm, ~15 kg, 180W

# Status:

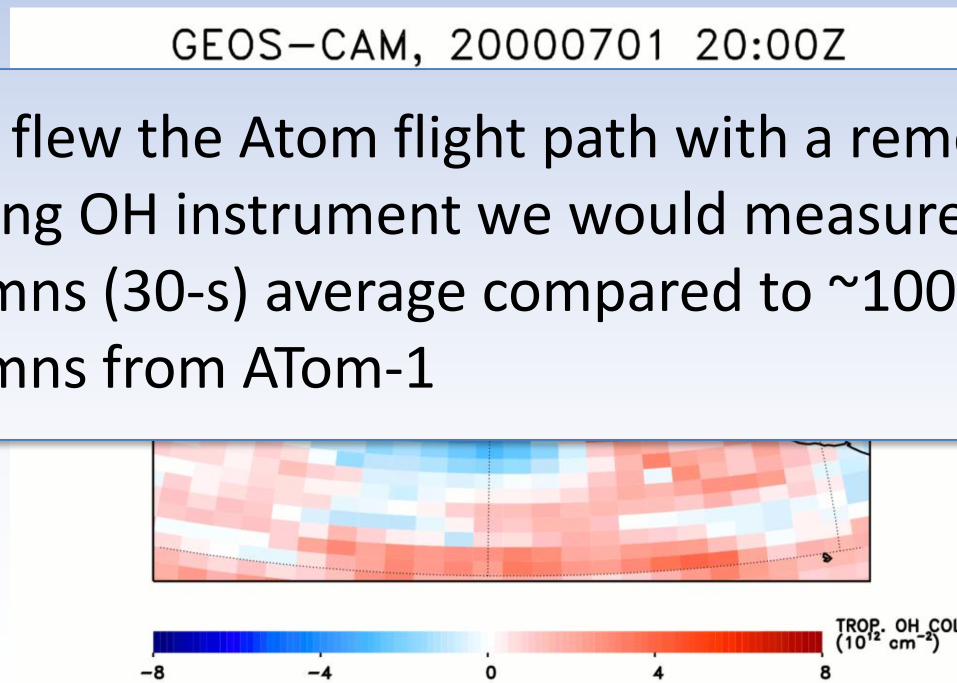


- **Raman pump laser:** 25W @1480 nm
- **VLMA 1.5 um fiber amp:** 10 W pulsed single frequency output (100uJ, 5 ns @100 kHz)
- **PCF 1023 nm laser:** Starting w/1030 nm placeholder

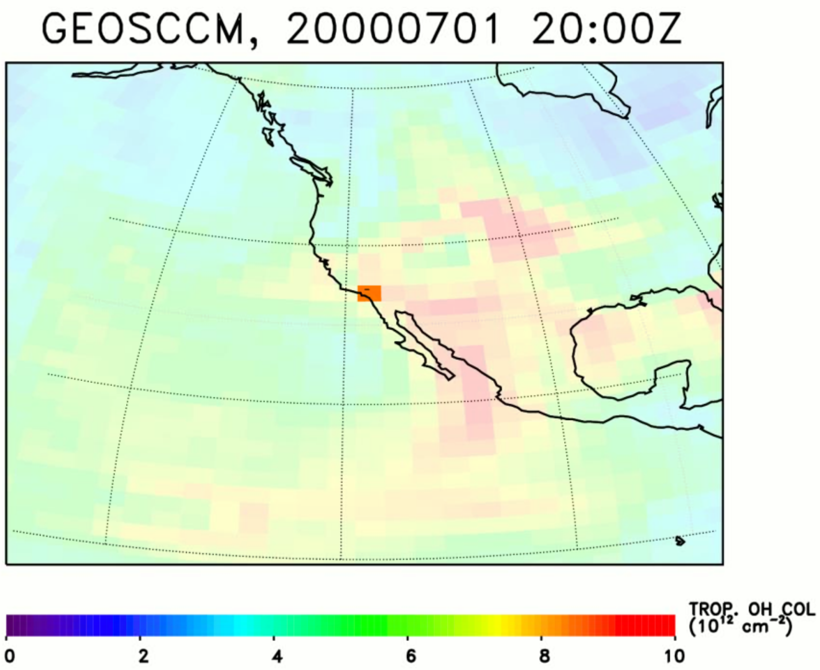



With an airborne remote sensor we can begin to sample large swaths of the atmosphere on a scale commensurate with global models




If we flew the Atom flight path with a remote sensing OH instrument we would measure 12K columns (30-s) average compared to ~100 total columns from ATom-1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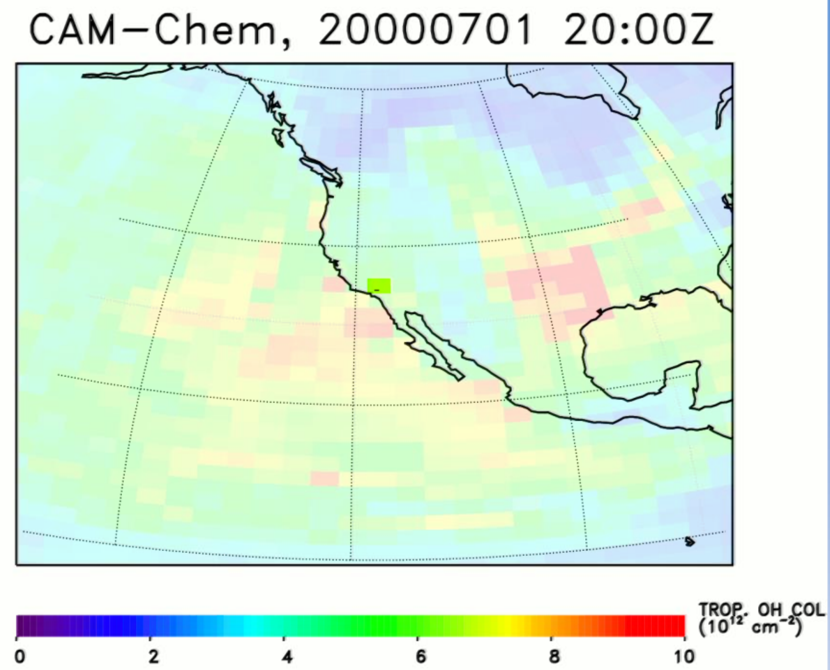
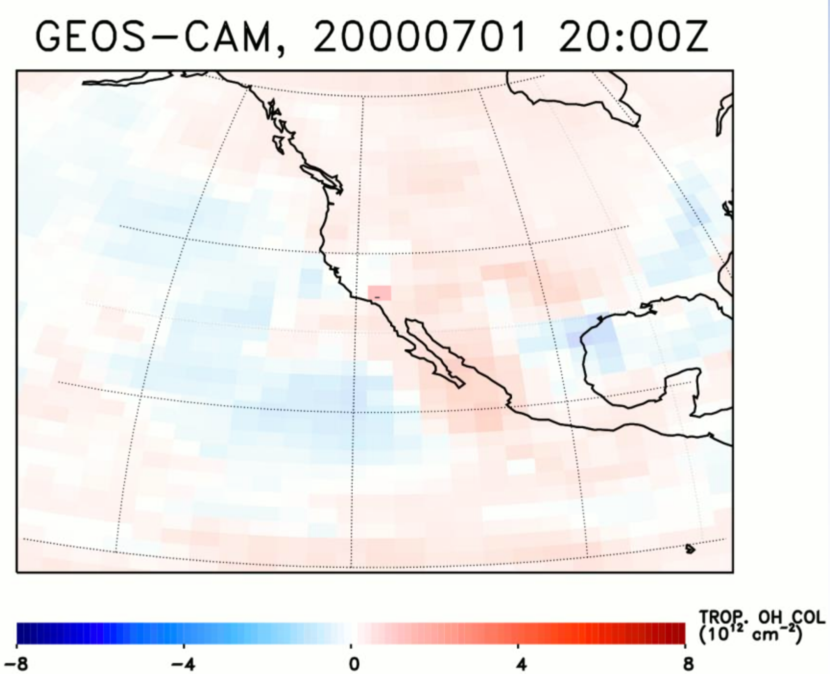
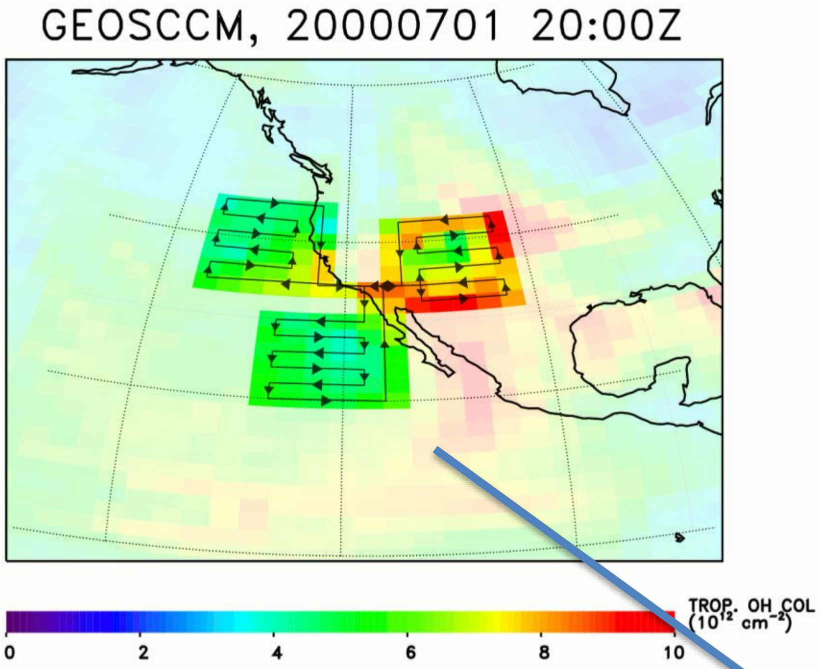
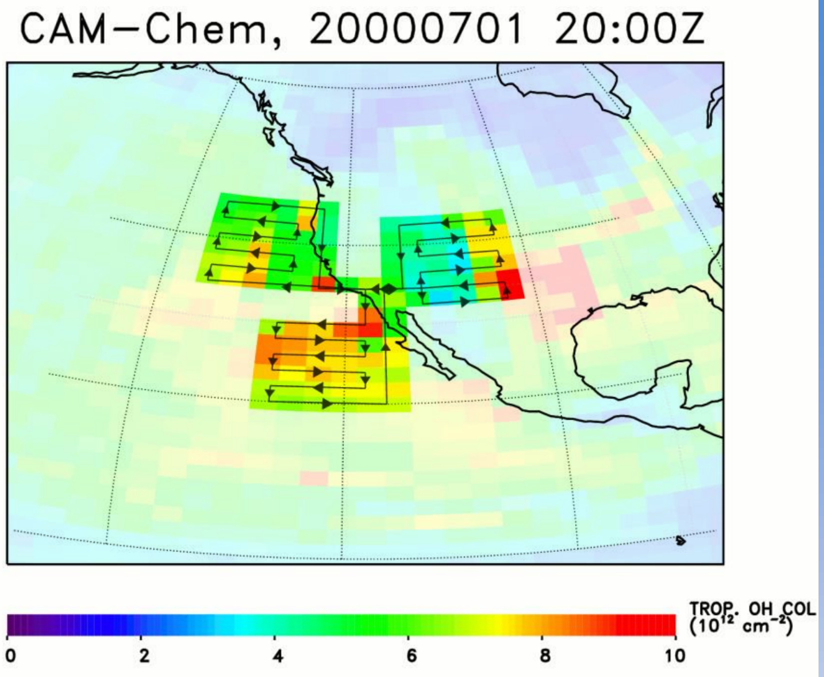
TROP. OH COL
(10^12 cm^-2)
0
2
4
6
8
10

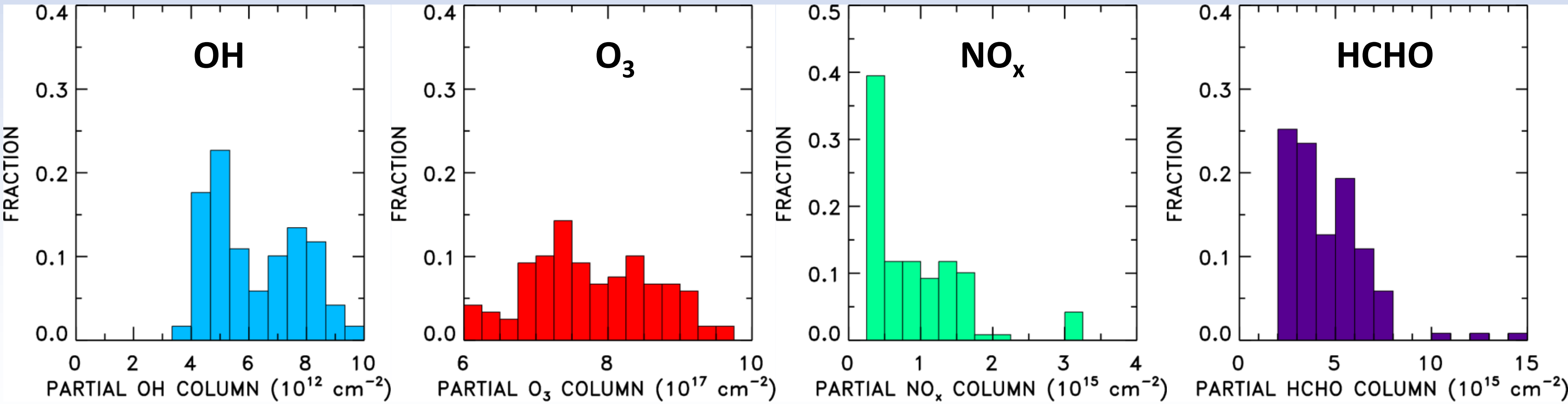

CAM−Chem, 20000701 20:00Z
TROP. OH COL
(10^12 cm^-2)
0
2
4
6
8
10

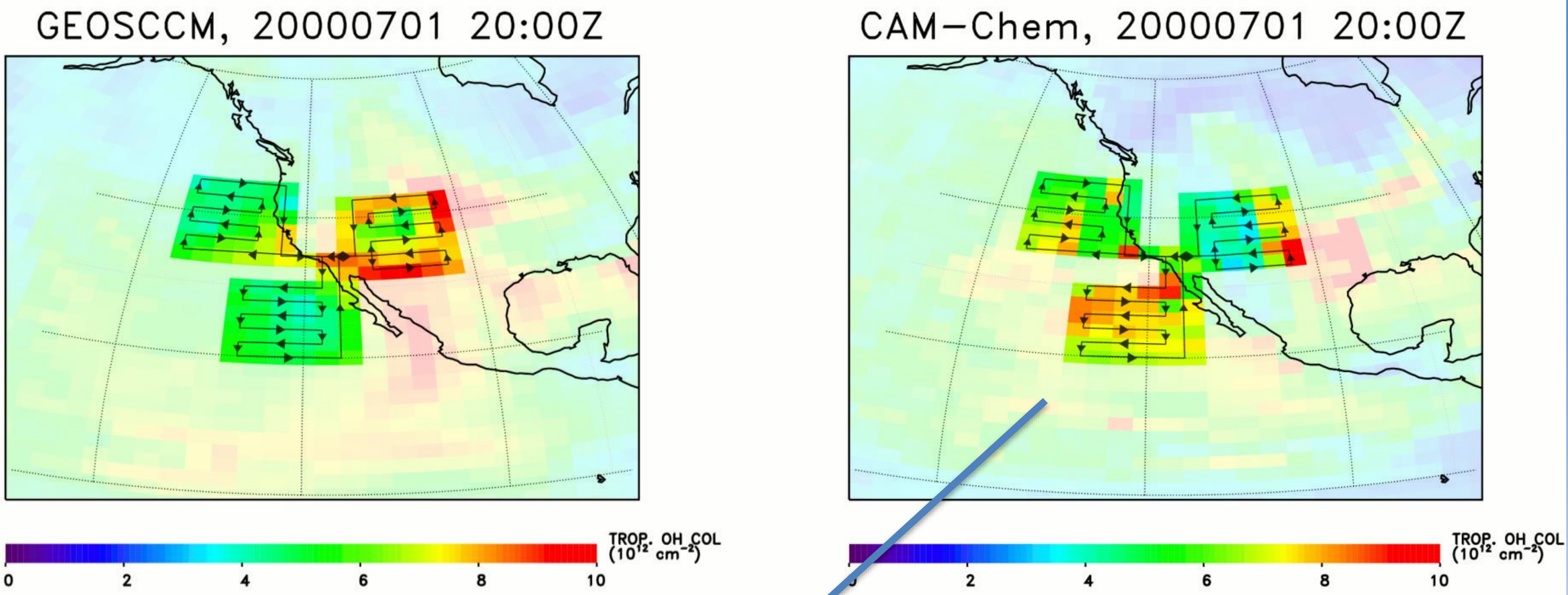

GEOS−CAM, 20000701 20:00Z
TROP. OH COL
(10^12 cm^-2)
−8
−4
0
4
8


GEOSCCM, 20000701 20:00Z
TROP. OH COL ($10^{12}$ cm$^{-2}$)
0 2 4 6 8 10

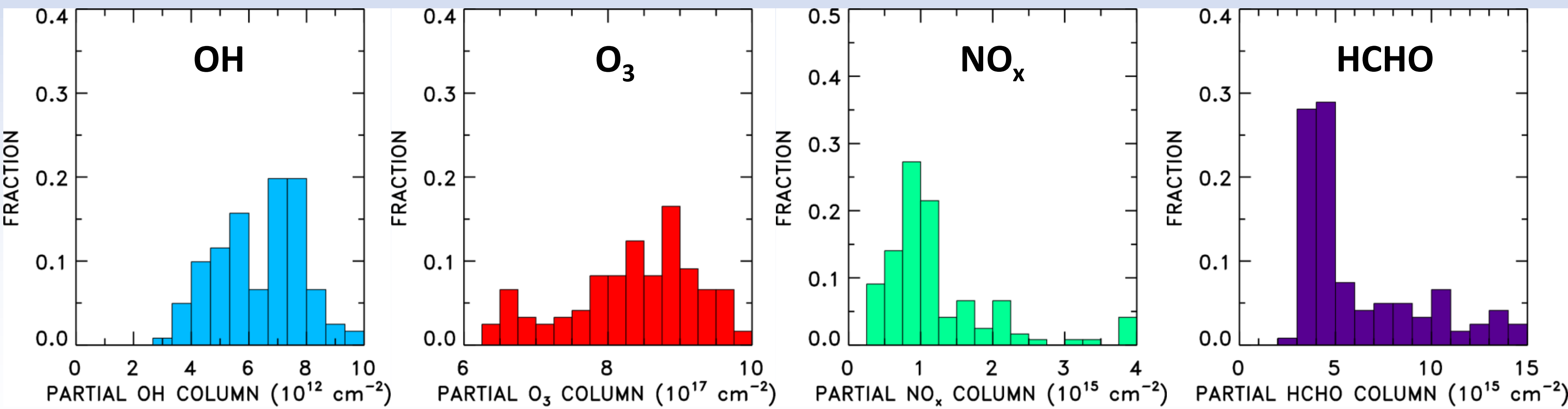

CAM−Chem, 20000701 20:00Z
TROP. OH COL ($10^{12}$ cm$^{-2}$)
0 2 4 6 8 10

## GEOSCCM


OH
FRACTION
PARTIAL OH COLUMN ($10^{12}$ cm$^{-2}$)
$O_3$
PARTIAL $O_3$ COLUMN ($10^{17}$ cm$^{-2}$)
$NO_x$
PARTIAL $NO_x$ COLUMN ($10^{15}$ cm$^{-2}$)
HCHO
PARTIAL HCHO COLUMN ($10^{15}$ cm$^{-2}$)

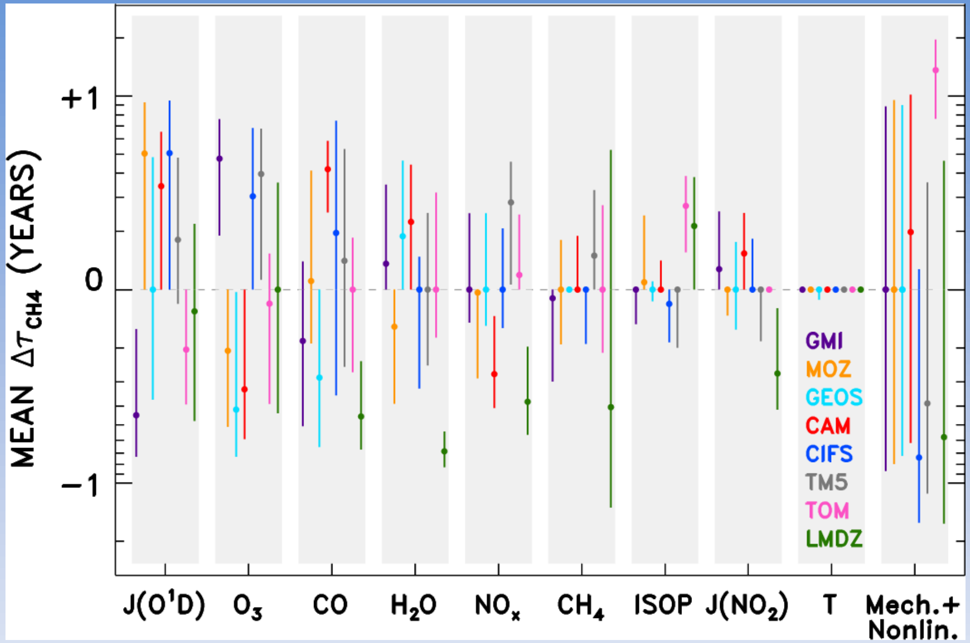

GEOSCCM, 20000701 20:00Z
CAM−Chem, 20000701 20:00Z
TROP. OH COL
($10^{12}$ cm$^{-2}$)
0 2 4 6 8 10

**CAM-Chem**


OH
$O_3$
$NO_x$
HCHO
FRACTION
PARTIAL OH COLUMN ($10^{12}$ cm$^{-2}$)
PARTIAL $O_3$ COLUMN ($10^{17}$ cm$^{-2}$)
PARTIAL $NO_x$ COLUMN ($10^{15}$ cm$^{-2}$)
PARTIAL HCHO COLUMN ($10^{15}$ cm$^{-2}$)

We have the framework to evaluate model differences.

With measurements of OH, combined with $NO_2$, $O_3$, HCHO, … we can provide the quantitative standard.




Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE
10.1002/2016JD026239

Quantifying the causes of differences in tropospheric OH within global models

Julie M. Nicely[1,2,3], Ross J. Salawitch[1,4,5], Timothy Canty[4], Daniel C. Anderson[4], Steve R. Arnold[6], Martyn P. Chipperfield[6,7], Louisa K. Emmons[8], Johannes Flemming[9], Vincent Huijnen[10], Douglas E. Kinnison[8], Jean-François Lamarque[8], Jingqiu Mao[11], Sarah A. Monks[12,13], Stephen D. Steenrod[2,3], Simone Tilmes[8], and Solene Turquety[14]

Key Points:

- Factors responsible for OH and $CH_4$ lifetime differences between eight models are quantified by using neural networks

# Summary:

- We have completed the design of an IPDA lidar for OH column measurements
- We have initiated construction of the laser transmitter breadboard (mid-2018 delivery)
- Next step is a ground demo, then an airborne prototype.