Comparison Between Ground-based Lidar Measurements from MPLCAN and Simulated Retrievals from the Aerosol Limb Imager

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Introduction

There is an increased demand for continuous measurements of the atmosphere as severe weather events become more frequent

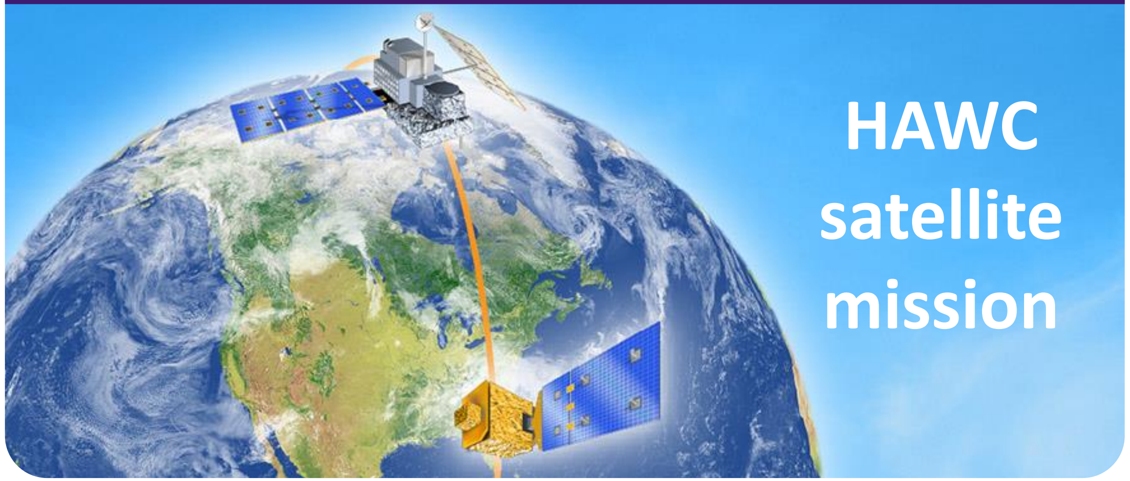
Hurricane Fiona [1]

Quebec Wildfires in 2023, the worst Canadian Wildfire season on record[2]

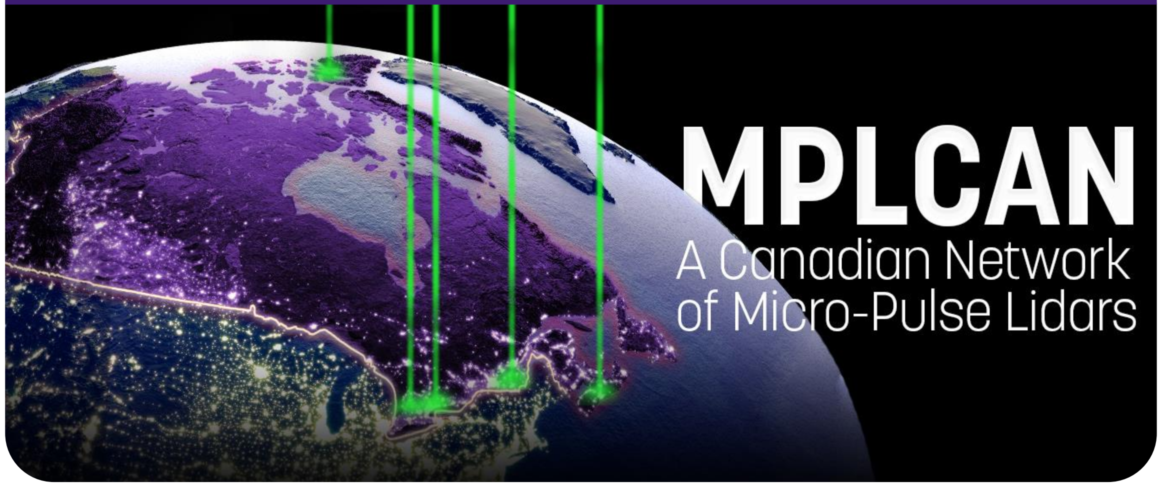
How do we measure our atmosphere?

Remote sensing - acquire information about our atmosphere from the ground or from space by detecting reflected or emitted radiation

Space-based



Ground-based



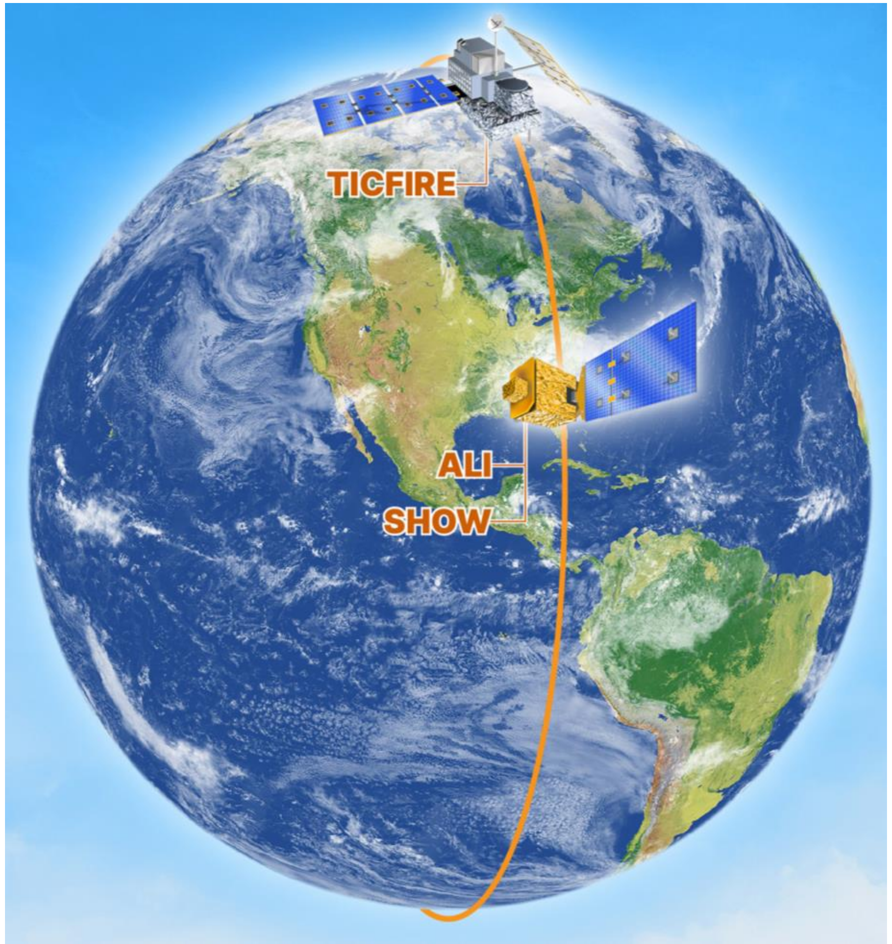
HAWC (High-altitude Aerosols, Water vapour and Clouds) Satellite Mission

HAWC consists of 3 Canadian instruments and a Canadian satellite that will be part of the international NASA-led Atmosphere Observing System (AOS).

The Canadian instruments:

1. **ALI (Aerosol Limb Imager)**
2. SHOW (Spatial Heterodyne Observations of Water)
3. TICFIRE (Thin Ice Cloud in Far InfraRed Emissions)

Set to fly in 2031



Instruments and satellites involved in HAWC [3]

ALI Instrument

Objective: characterize **aerosols** in the upper troposphere and stratosphere to reduce the large uncertainty in climate forcing due to aerosols

aerosol - particles or droplets suspended in the air. Ex: dust, pollen, smoke

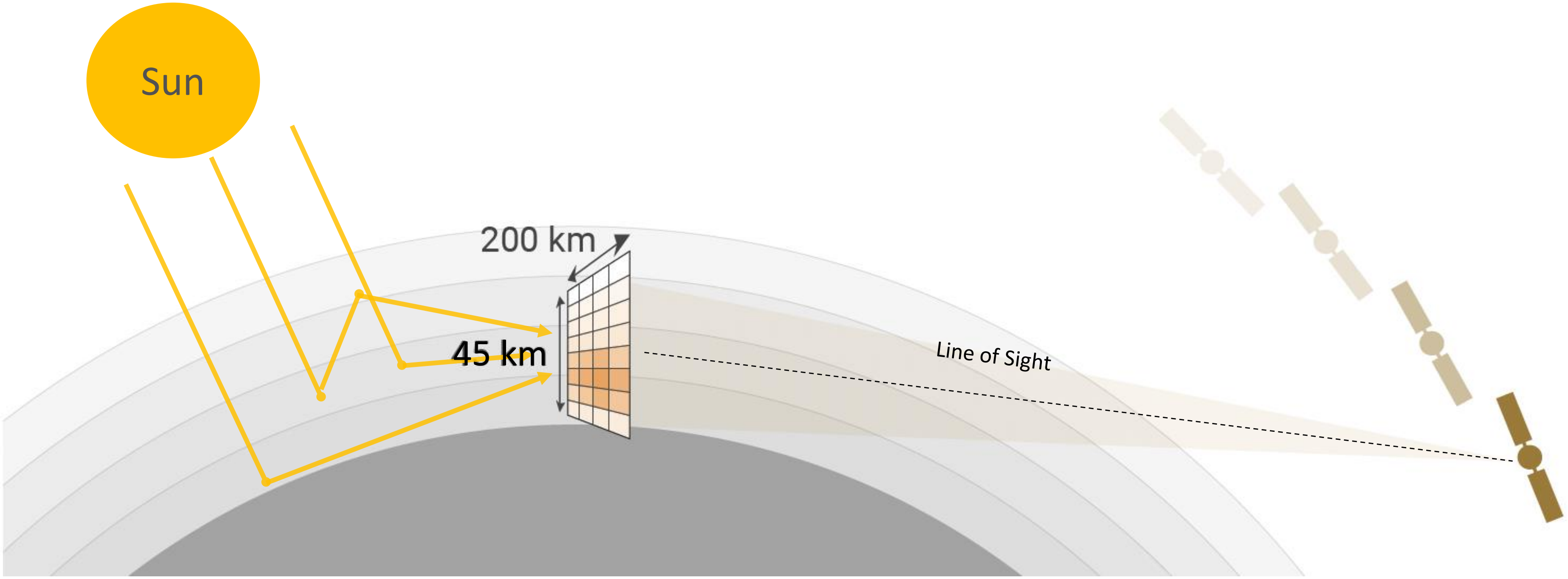


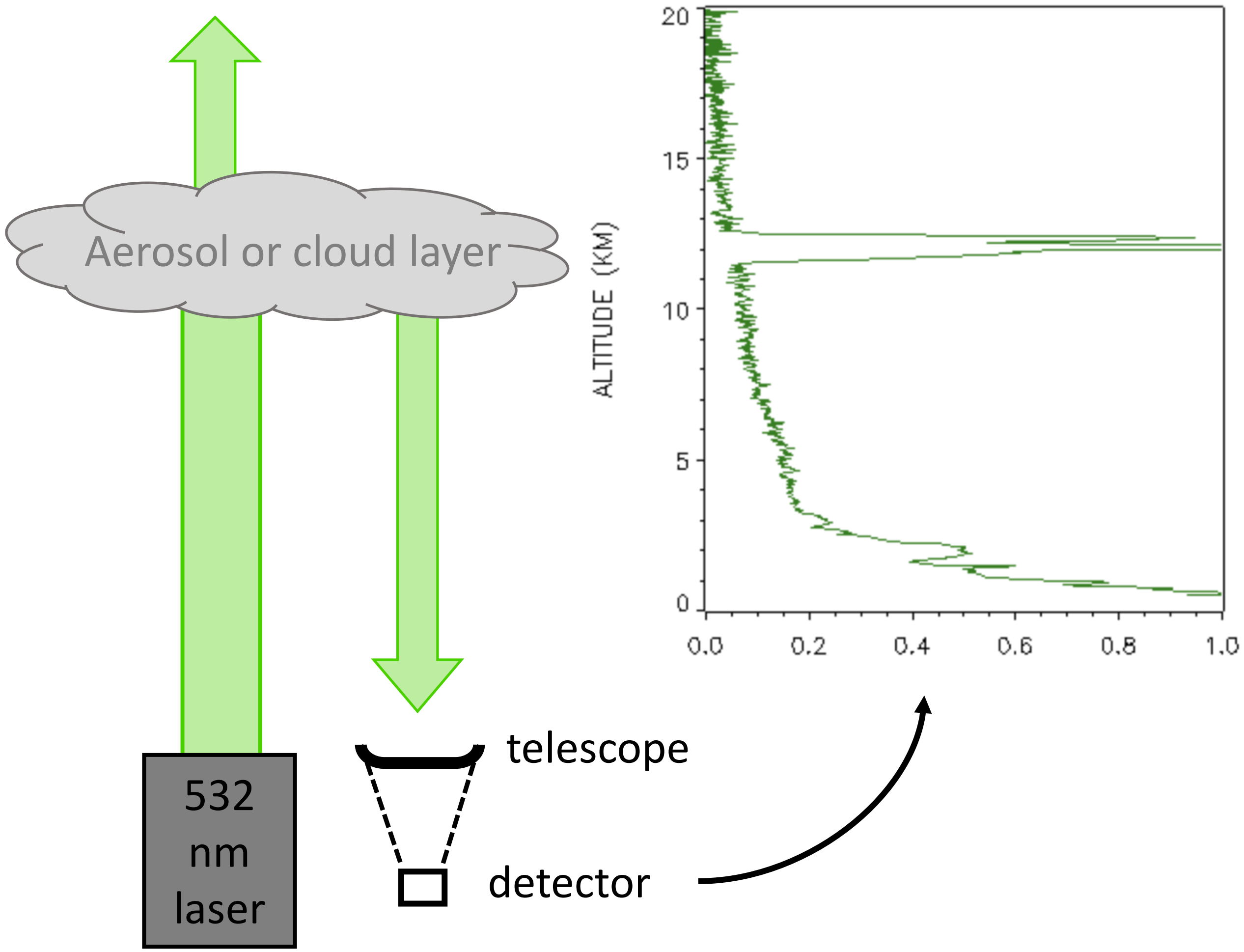
Illustration of ALI measurement geometry [4]

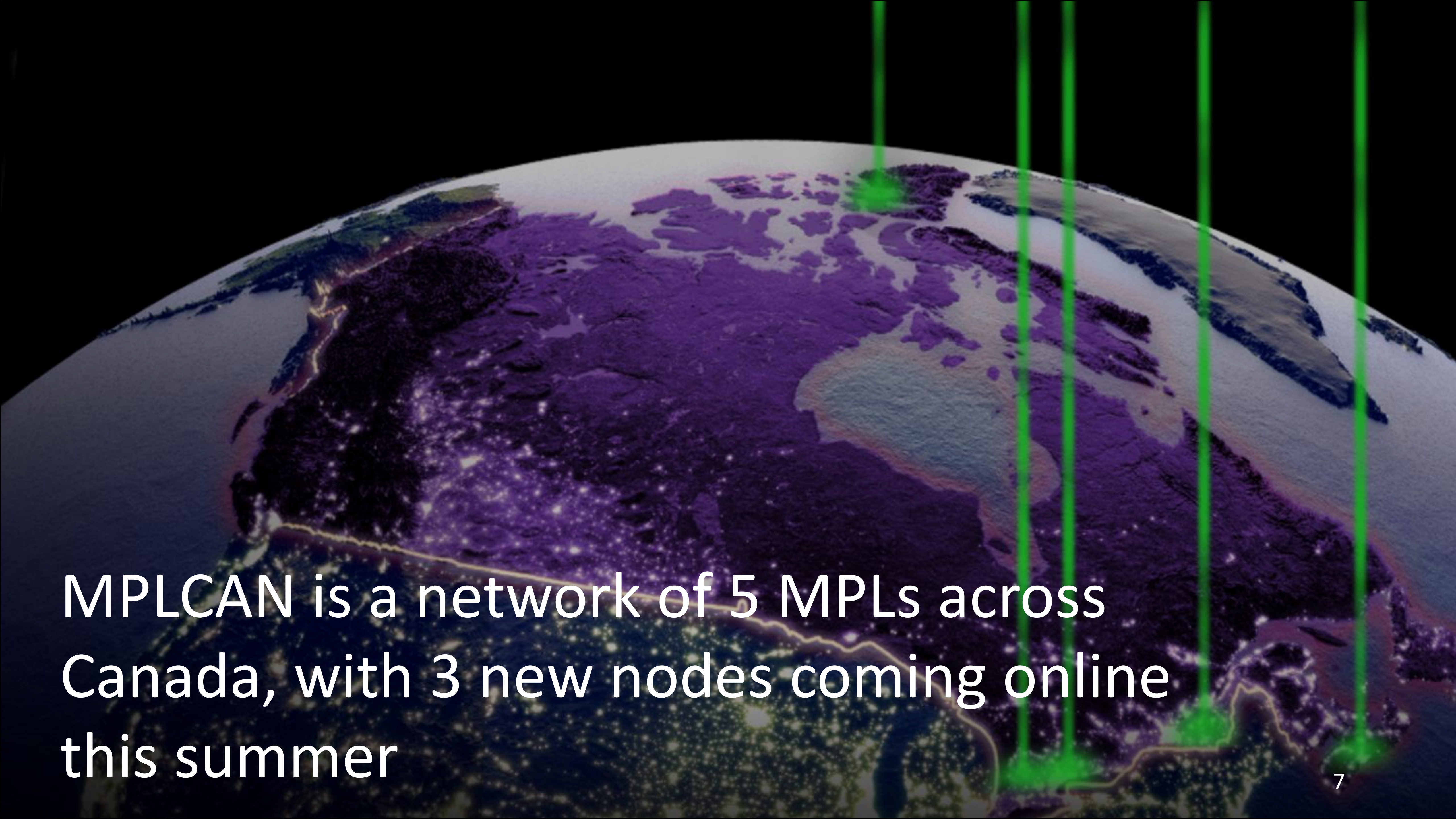
measures the visible and near infrared spectral region

(600-1500 nm)

Micro Pulse Lidars (MPLs)

- Transmitter is a 532 nm laser emitting pulses of 3-4 μJ
- A telescope collects photons that are backscattered from the atmosphere at the same wavelength (elastic scattering)
- It is a dual-polarized lidar allowing for total volume depolarization ratio measurements





MPLCAN is a network of 5 MPLs across Canada, with 3 new nodes coming online this summer

A Little Radiative Transfer

N(z): particle number density

σ : cross section

$\left(\frac{d\sigma_{sca}}{d\Omega}\right)_{\pi}$: differential scattering cross section

Extinction – fraction of light lost when transmitted through a medium due to scattering and absorption

extinction coefficient: $\alpha = N(z)\,\sigma_{tot}\,(\lambda)$

$$\alpha(z,\lambda) = \alpha_{mol}^{sca}(z,\lambda) + \alpha_{aer}^{sca}(z,\lambda) + \alpha^{abs}(z,\lambda)$$

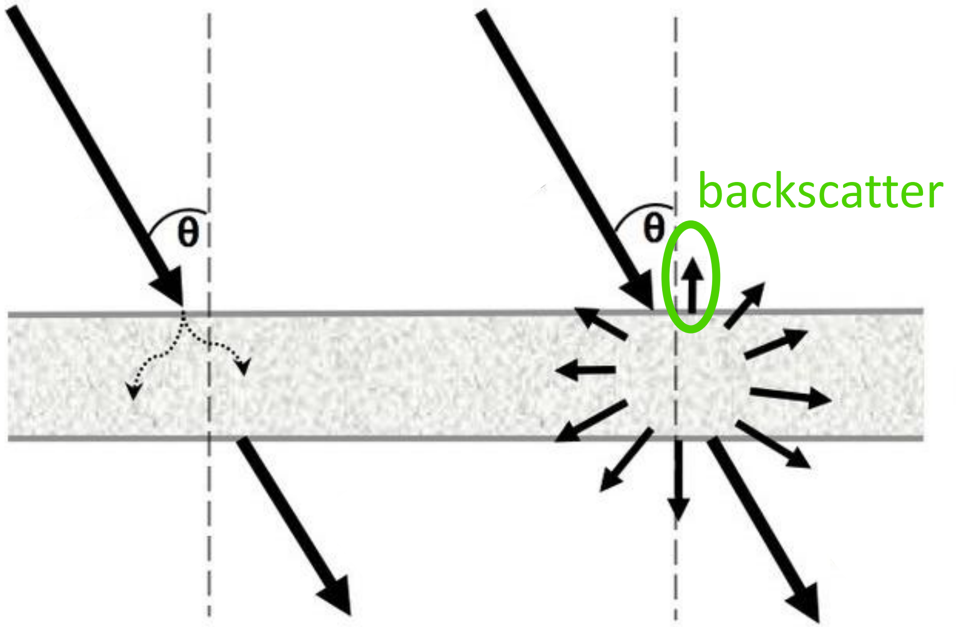
Backscatter – amount of light backscattered to the lidar receiver (180° for MPLs)

backscatter coefficient: $\beta(z,\lambda) = N(z)\left(\frac{d\sigma_{sca}(\lambda)}{d\Omega}\right)_{\pi}$

$$\beta(z,\lambda) = \beta_{mol}(z,\lambda) + \beta_{aer}(z,\lambda)$$

Absorption

Scattering



MPL measurements

Attenuated backscatter can be derived from photon counts detected by the MPL.

$$\beta_{att}(z, \lambda) = \beta(z, \lambda)\ e^{-2\int_0^z \alpha(z',\lambda)dz'}$$

We cannot separate extinction and backscatter in an elastic lidar measurement without assumption of the lidar ratio:

$$S = \frac{\alpha}{\beta}$$ units: sr

ALI measurements

ALI measures limb scattered radiance from the Sun and retrieves:

- **Aerosol extinction**
- **Aerosol particle size**

Relating MPL and ALI Measurements

MPL: $\beta_{att}(\alpha, \beta)$

ALI: α_{aer} & $n_{aer}(r)$

I convert the ALI retrievals into attenuated backscatter by calculating the aerosol backscatter coefficient for direct comparison with MPLs.

Method 1: assume lidar ratio and use retrieved extinction:

$$\beta_{aer} = \alpha_{aer}/S$$

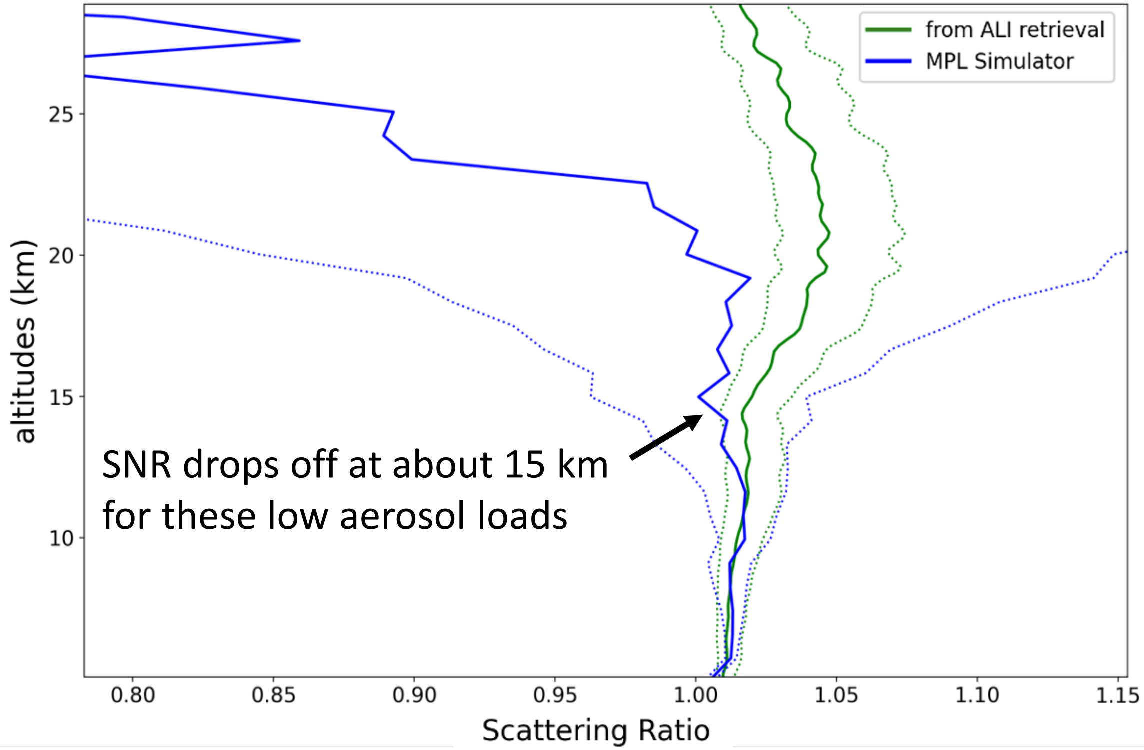
Method 2: Use retrieved aerosol size distribution and Mie theory:

$$\beta_{aer}(z,\lambda) = \underbrace{N_{aer}(z)}_{\text{Number density}} \left(\frac{d\sigma_{sca}(\lambda)}{d\Omega}\right)_{\pi}$$

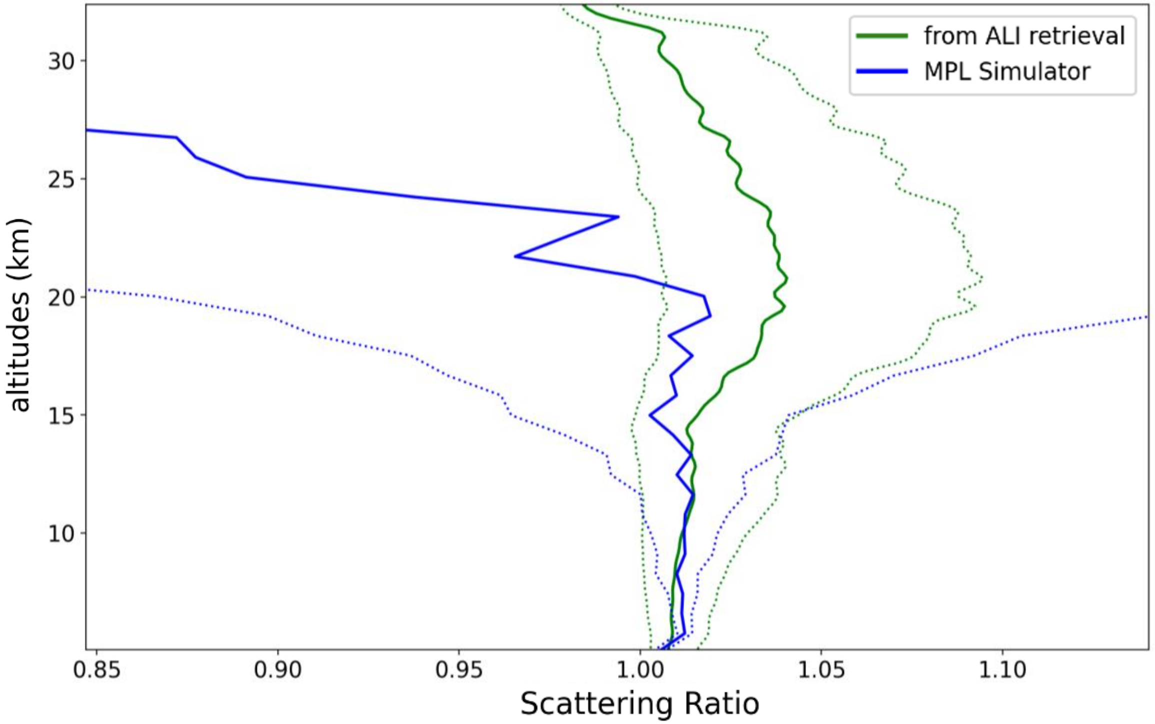
$$\left(\frac{d\sigma_{sca}(\lambda)}{d\Omega}\right)_{\pi} = \frac{1}{4\pi}\int_0^{\infty} \pi r^2 \underbrace{Q_{back}(r,m,\lambda)}_{\text{backscattering efficiency}} \overbrace{n_{aer}(r)}^{\text{Size distribution}} dr$$

Initial Result Comparing ALI and MPL Simulations

Method 1: Using lidar ratio



Method 2: Using particle size and Mie theory



Scattering ratio - ratio of total attenuated backscatter to molecular attenuated backscatter

Future Work

- Run several coincident measurements using various atmospheric models, including higher aerosol loadings that would be more easily detectable by MPLs
- Simulate the satellite passing over the MPLCAN during a wildfire smoke event where a pyrocumulonimbus cloud injects smoke into the stratosphere

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- Collaborator: Landon Rieger (University of Saskatchewan)

References

[1] https://earthobservatory.nasa.gov/images/150392/canada-braces-for-fiona

[2] https://montreal.ctvnews.ca/forest-fire-centre-declares-2023-already-worst-year-ever-for-canadian-wildfires-1.6456879

[2] Gobbi, G. P. (1995). Lidar estimation of stratospheric aerosol properties: Surface, volume, and extinction to backscatter ratio. *Journal of Geophysical Research: Atmospheres*, *100*(D6), 11219–11235. https://doi.org/10.1029/94jd03106

[3] https://www.asc-csa.gc.ca/eng/satellites/hawc/

[4] L. Rieger, Adam Bourassa, Alexis Bourassa, “ALI Instrument and Simulator Report,” Canadian Space Agency, June 21, 2022. [Online]