

Iterative approach to atmospheric temperature profiles using retrievals from the LAFE field campaign

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I. INTRODUCTION

Temperature is an important parameter when considering the state of the atmosphere and its processes. A method of atmospheric temperature retrieval discussed in Bosenberg [1] involves using differential absorption lidar (DIAL) as a means of finding the temperature sensitive absorption coefficient of a molecule with a known mixing ratio, such as oxygen. However the absorption coefficient has a non-linear dependence on temperature and therefore cannot be solved analytically; an iterative approach must then be used to complete the temperature retrieval. The accuracy of this retrieval method has been demonstrated using a modeled atmosphere [2]. This project will use this same retrieval method, but applying it to atmospheric data collected from the LAFE (Land Atmosphere Feedback Experiment) field campaign, which took place in August of 2017 at the Southern Great Plains atmospheric observatory in Oklahoma. The data from this experiment includes aerosol and molecular backscatter profiles as well as water vapor profiles, which are ancillary information necessary for finding the absorption coefficient and temperature profiles.

II. RETRIEVAL METHOD

The DIAL method of temperature profiling relies on the measurement of the temperature dependent absorption coefficient of a molecule with a known mixing ratio (number of molecules of gas divided by total number of molecules of air). The absorption lines of oxygen in the near-infrared around 770 nm are suitably temperature sensitive [1] and the mixing ratio of oxygen is reliably stable, known to be 20.95% [3]. The absorption coefficient is found by measuring the backscatter signal from two closely spaced wavelengths; one associated with the absorption feature (known as the online wavelength) and the other is unaffected by it (known as the offline wavelength). Comparing these two signals and accounting for the Doppler-broadened Rayleigh scattering, Mie scattering off of aerosols, and spectroscopic details of the absorption feature will allow for the retrieval of the absorption coefficient. The returns from an O₂ DIAL that will be used in this project are the same model used in a manuscript currently being prepared by Bunn et al. [2]

The DIAL equation used to calculate the absorption coefficient is given by [1]

$$\frac{\ln \left(\frac{N_1(r+\Delta R)N_2(r)}{N_1(r)N_2(r+\Delta R)} \right)}{\Delta R} = -\alpha_{u,eff,1}(r) + \alpha_{u,eff,2}(r) - \alpha_{d,eff,1}(r) + \alpha_{d,eff,2}(r) + G_1(r) - G_2(r) \quad (1)$$

where $N(r)$ is the return signal from range r and the subscripts 1 and 2 indicate online and offline wavelengths respectively. The differential range $\Delta R = \frac{c\tau}{2}$ is the bin size where c is the speed of

light and τ is the pulse duration. The effective absorption coefficients for outgoing and return signals (indicated by subscripts u and d respectively) for the online wavelength are given by

$$\alpha_{u,eff,1}(r) = \frac{\int h_1(v) \alpha_m(v, r) T_m(v, r) dv}{\int h_1(v) T_m(v, r) dv} \quad (2)$$

$$\alpha_{d,eff,1}(r) = \frac{\int g_1(v, r) E(v) \alpha_m(v, r) T_m(v, r) dv}{\int g_1(v, r) E(v) T_m(v, r) dv} \quad (3)$$

where $h_1(v)$ is the online laser line shape, $\alpha_m(v, r)$ is the molecular absorption coefficient, and $T_m(v, r) = \exp \left[- \int_0^r \alpha_m(v, r') dr' \right]$ is the one-way transmission due to molecular absorption. In Equation 3, the term

$$g_1(v, r) = \frac{\beta_A(r)}{\beta(r)} h_1(v) + \frac{\beta_m(r)}{\beta(r)} (h_1(v) * l(v, r)) \quad (4)$$

is the line shape of the backscattered light where $\beta_A(r)$, $\beta_m(r)$, and $\beta(r)$ are the aerosol, molecular, and total backscatter profiles respectively, $l(v, r)$ is the Doppler-broadened line shape, and $E(v)$ is the DIAL receiver spectral filter transmission function. The effective absorption coefficients for the offline wavelength, $\alpha_{u,eff,2}(r)$ and $\alpha_{d,eff,2}(r)$, have the same form as Equations 2 and 3.

The terms $G_1(r)$ and $G_2(r)$ are correction terms that help account for changes in the spectral distribution due to Doppler broadening of the scattered return signal, given by

$$G_1(r) = \frac{\int \frac{dg_1(v, r)}{dr} E(v) T_m(v, r) dv}{\int g_1(v, r) E(v) T_m(v, r) dv}. \quad (5)$$

The correction term $G_2(r)$ is written in the same form for the offline wavelength.

This project will rely on a perturbative solution to the DIAL equation (Equation 1) developed in a manuscript that is currently being prepared by Bunn et al. [2], which calculates the absorption coefficient while providing a means of accounting for the Doppler broadening of the elastically scattered light. This solution also relies on the aerosol and molecular backscatter profiles, which will be provided by HSRL measurements [4] taken at the LAFE field campaign.

With the absorption coefficient found from the perturbative method, we now use the following equation to retrieve the temperature profile:

$$\alpha(r) = q_{O_2} (1 - q_{H_2O}) \frac{P}{k_B T} S(T, \epsilon) \Lambda_V(v - v_0, P, T) \quad (6)$$

where q_{O_2} and q_{H_2O} are the mixing ratios of O_2 and H_2O (the latter of which is highly variable and will be provided by water vapor DIAL measurements [5] taken at the LAFE field campaign), P is the pressure, k_B is the Boltzmann constant, T is the temperature, $S(T, \epsilon)$ is the temperature dependent line strength of the absorption feature, ϵ is the ground state energy, and $\Lambda_V(v - v_0, P, T)$ is the normalized Voigt line shape function.

The temperature dependent line strength is given by [6]

$$S(T, \epsilon) = S_0 \frac{T_0}{T} \exp \left[- \frac{\epsilon}{k_B} \left(\frac{1}{T} - \frac{1}{T_0} \right) \right] \quad (7)$$

where S_0 is the line strength at temperature T_0 .

The perturbative solution relies on an initial guess at the temperature profile in order to complete the inversion. If this guess differs from the actual profile, errors in the retrieval of the absorption coefficient will occur, so an iterative approach must be used. The initial guess at the temperature profile will give an initial absorption coefficient, which is then used to retrieve the temperature profile. This new temperature profile is then used to complete the inversion again, providing an updated absorption coefficient and temperature profile. This process is repeated until the input temperature profile matches the retrieved profile. This iterative solution to Equation 6 is given here and has been shown to converge rapidly [6]:

$$T_{i+1} = \frac{\epsilon/k_B}{\ln[Cq_{O_2}(1 - q_{H_2O})\Lambda_V(T_i)] - \ln(\alpha T_i^2/P)} \quad (8)$$

where $C = \frac{T_0}{k_B} S_0 \exp\left(\frac{\epsilon}{k_B T_0}\right)$.

III. GOALS

One of my goals for this project is to see how many iterations are required for the temperature profile to converge given a certain departure from the actual profile. Another related matter I'd be interested in is how far from the actual temperature profile I can take the initial guess.

IV. REFERENCES

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