Atmospheric temperature retrieval from Lidar data using techniques of non-linear mathematical inversion.

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Abstract

The conventional method to Lidar data processing to retrieve atmospheric temperature profiles has some limitations, which results in the abandonment of the temperatures retrieved at the uppermost range of the observational range. The limitations because of mathematical implementation of the conventional method requires one to choose a ‘seed pressure’ at the top of the atmospheric pressure profile, which is used to retrieve the temperatures. Hence, to minimise the bias in the retrieved temperatures, it is necessary to develop an alternative method where the mathematical implementation of the conventional method is replaced by using an equivalent technique. The Lidar data was processed using a novel technique, which minimises the bias in the retrieved temperatures.

1 Introduction

The conventional method (Chani and Hancecoren, 1984) of temperature retrieval from Lidar data makes use of the ideal gas law, law of hydrostatic balance and the Lidar equation for data processing. This results in the following relation between the observables (pressure P or counts N) and the observed (temperature T)

\[ T = \frac{B}{\ln(P) - \ln(A) - \frac{B}{C}} \]

where, T is the altitude, B is the universal gas constant, g is the acceleration due to gravity and M is the mean molecular mass of air.

The purpose of this work:

1. To develop a scheme, using mathematical inversion, to reduce the effect of a wrong choice of seed pressure and hence minimise the bias in the retrieved temperatures.

2 Methodology

The grid search method of global optimisation (Bevington and Robinson, 1992, Menke, 1989) is used to process Lidar data.

2.1 Application of Grid Search Technique

Forward model used:

\[ N(z) = \frac{N_{\text{count}} M}{CRF \Gamma(z)} \int \left[ \frac{P(z)}{T(z)} \right] \text{d}z \]

where C is a normalisation constant and \( N_{\text{count}} \) is the seed pressure value chosen at the lower altitude limit.

Integration is performed from the bottom of the observational range so as to improve the chances of making an accurate estimate of the seed pressure value. This is because there are many good experimental and theoretical sources available which give a good estimate of atmospheric pressure values at lower altitudes, which is not the case with measurements at higher altitudes.

• A guess of the seed pressure values and initial temperature profile is made by borrowing them from USMA (1976) and CIRA (Roes et al., 1990) models.

• The Mahalanobis distance (a general \( x^2 \) with scaling factors being the inverses of the covariance matrix terms (Mahalanobis, 1936)) between the modelled and real Lidar counts is minimised to reach an optimum temperature profile.

2.2 Error Analysis

Error Analysis of the results is done using a Monte Carlo approach on synthetic data (ICGM, 2008). The standard error in the retrieved temperatures is represented by the standard deviation of the Probability Distribution Function (PDF) of the retrieved temperature profiles. A sample of size 250 of retrieved temperatures is generated by processing 250 synthetically generated Lidar data and storing only the amount of uncertainty added to each of the input parameters on table 1. The uncertainty values of these input parameters are obtained by randomly choosing their values from their respective PDFs with mean and standard deviation listed in table 1.

Table 1. A list of the different sources of error in the retrieval process. The mean and standard deviation of the PDFs of each of these input parameters is also listed.

3 Results

Figure 1. Temperatures retrieved, using conventional method, at 5 seed pressure values for (a) synthetic data and (b) real data. Second panel shows the differences between retrieved profiles and the expected profile.

The algorithm of the retrieval process is initiated by guessing a seed pressure value at the top of the observational range. An error in this guessed value introduces a bias in the retrieved temperatures as shown in figure 1.

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Figure 2. Temperatures retrieved, using grid search technique, at 5 seed pressure values for (a) synthetic data and (b) real data. Second panel shows the differences between retrieved profiles and the expected profile.

Comparison with the conventional technique: A comparison between figure 1 and figure 2 (obtained by the application of grid search technique to the same data) shows improvement in terms of susceptibility to a wrong choice of seed pressure.

Comparison between standard errors: The standard errors in the temperatures, retrieved from conventional method and from the grid search technique, are comparable as shown in figure 3.

Temperature retrieved from real Lidar data: Temperature profiles were retrieved from real Lidar data for many nights of data collected using the Purple Crow Lidar. The result from processing of one such night is presented in figure 4. The standard error, obtained following a Monte Carlo approach, is also plotted. Temperatures retrieved from the conventional technique are also plotted for the purpose of comparison.

4 Conclusions and future work

• We observe that the application of a global optimisation technique reduces the susceptibility of retrieved temperature profiles to errors in the seed pressure \( P_{\text{seed}} \) value.

• Moreover, the accuracy of the result is increased because choosing a good value of \( P_{\text{seed}} \) is more likely at lower altitudes.

• The standard errors of the retrieved temperatures are comparable to their conventional counterparts.

• Better techniques of mathematical inversion (or global optimisation) must be implemented in the place of grid search to improve efficiency and stability of the convergence process.

• A systematic validation of the obtained results must be done by comparing them with data from other theoretical or observational sources.

References


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