Using Principal Component Analysis in Radiative Transfer Calculations

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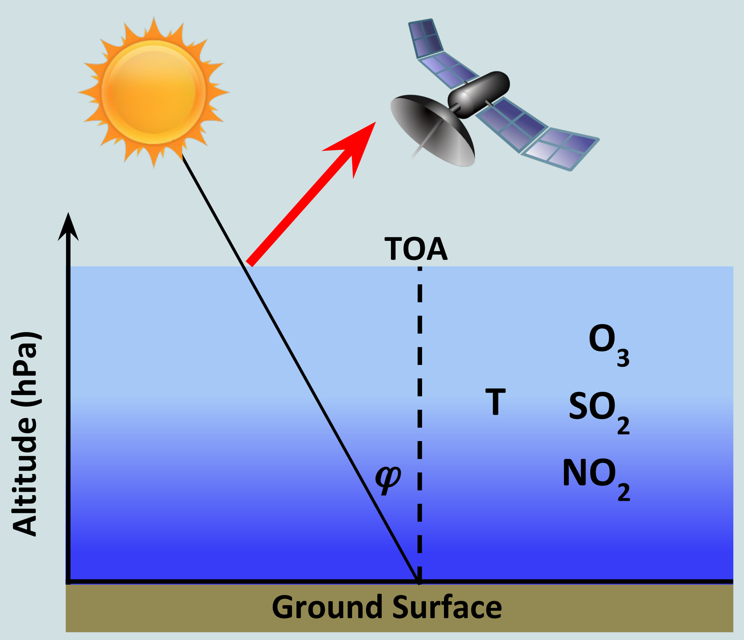
INTRODUCTION

Satellite remote sensing involves using measurements of electromagnetic radiation to understand atmospheric composition. The retrieval of useful information (like temperature and gas concentration) from the observed radiation depends on radiative transfer computation (**RTC**) which can be very slow.



To accelerate RTC, *Natraj et. al.* [2005] proposed to characterize atmospheric optical properties (**AOP**) using principal component analysis (**PCA**). For a near-infrared case, they reproduced the top of the atmosphere (**TOA**) reflectance with accuracy of 0.3% and an order of magnitude speed improvement.

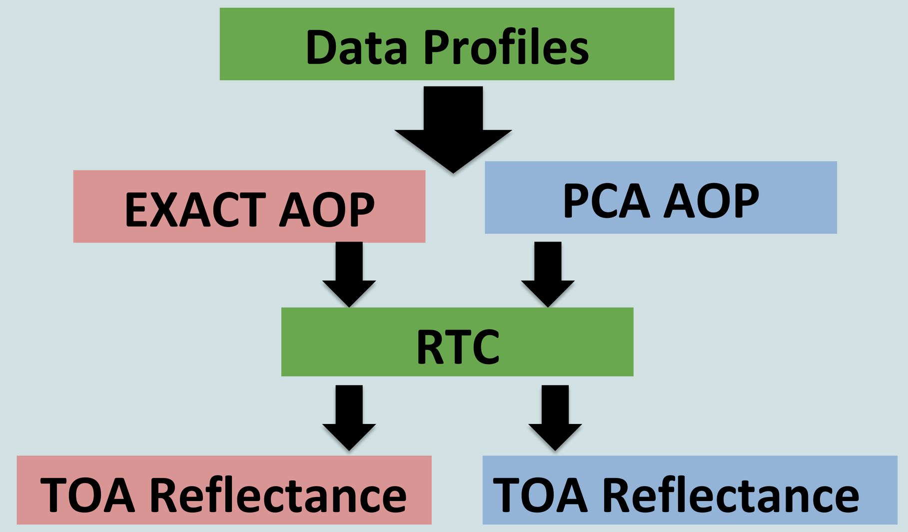
Here, we advance the work of *Natraj et al.* [2005] by evaluating the effectiveness of the PCA-based RTC for situations with more chemical species, more atmospheric layers, and a wider spectral range.

DATA

- **ECMWF** meteorological profiles for 27 & 30 June 2006
  - Altitude range: surface - 0.0001 hPa (115 levels)
  - 9 profile locations: between 29ºN - 41ºN & 120ºE - 77ºE
  - 5 local UTC times: 06, 09, 12, 15, 18 (for each location)
  - Species: O_3, NO_2, SO_2, H_2O, NO, CH_4, CO_2, etc
- **HITRAN** spectroscopic data over the wavelength (λ) range of 290 nm - 3030 nm [*Rothman et. al.*, 2013]

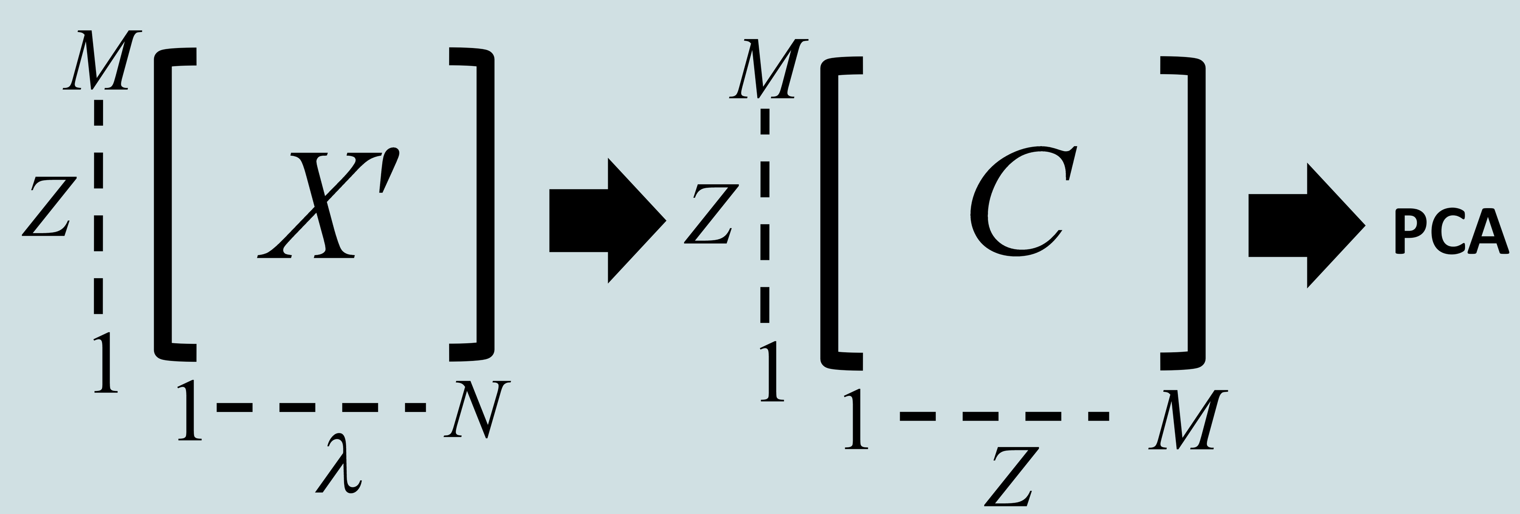
METHODS

- Based on **optical depth** ($d\tau$) and **single scattering albedo** (ω), two AOP sets are generated from data profiles.
  - **EXACT**: AOP for each wavelength
  - **PCA**: AOP reconstructed from 1-4 empirical orthogonal functions in 33 separate spectral bins



METHODS (CONT.)

$$X \equiv \text{Optical Properties} = \begin{bmatrix} \omega \\ \tau \end{bmatrix} \qquad X' \equiv X - \bar{X}$$



- AOP sets are used in RTC code → TOA reflectance
- VLIDORT (discrete-ordinates, multi-stream, line-by-line multiple scattering RTC) [*Spurr*, 2006]
- Assume surface reflectance and scattering phase function are wavelength independent.

RESULTS

Residual error is the difference between the radiances calculated using the exact data and that using the PCA method.

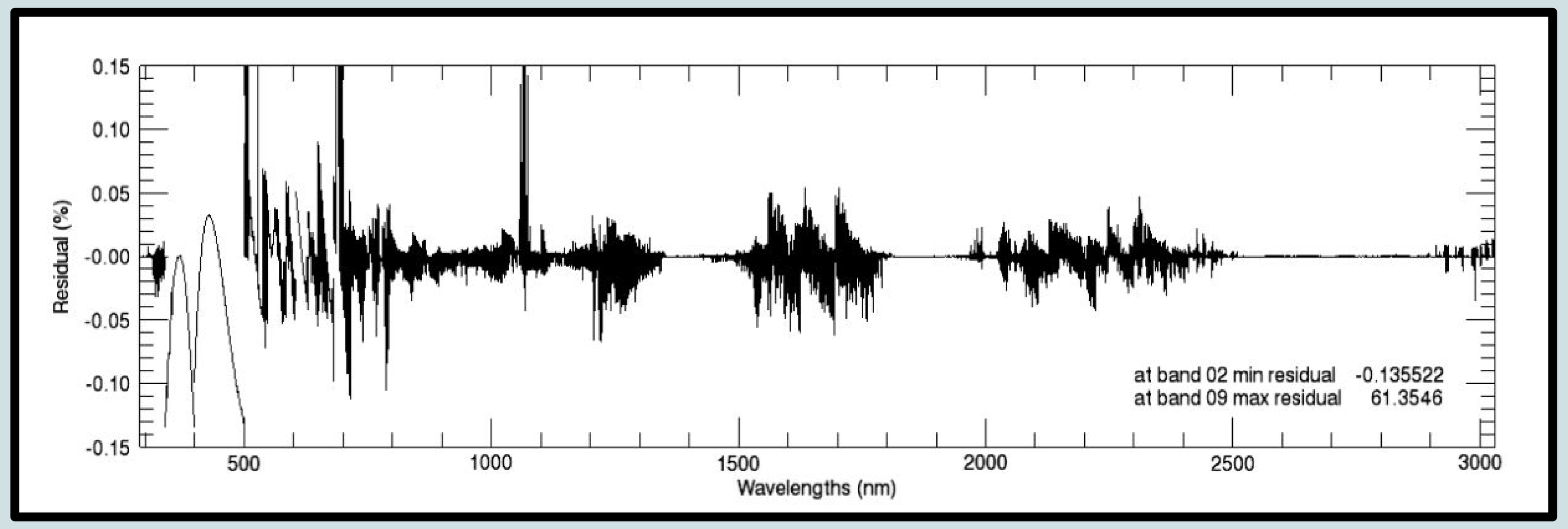


FIG 1: An example of TOA reflectance residual error between PCA and EXACT calculations.

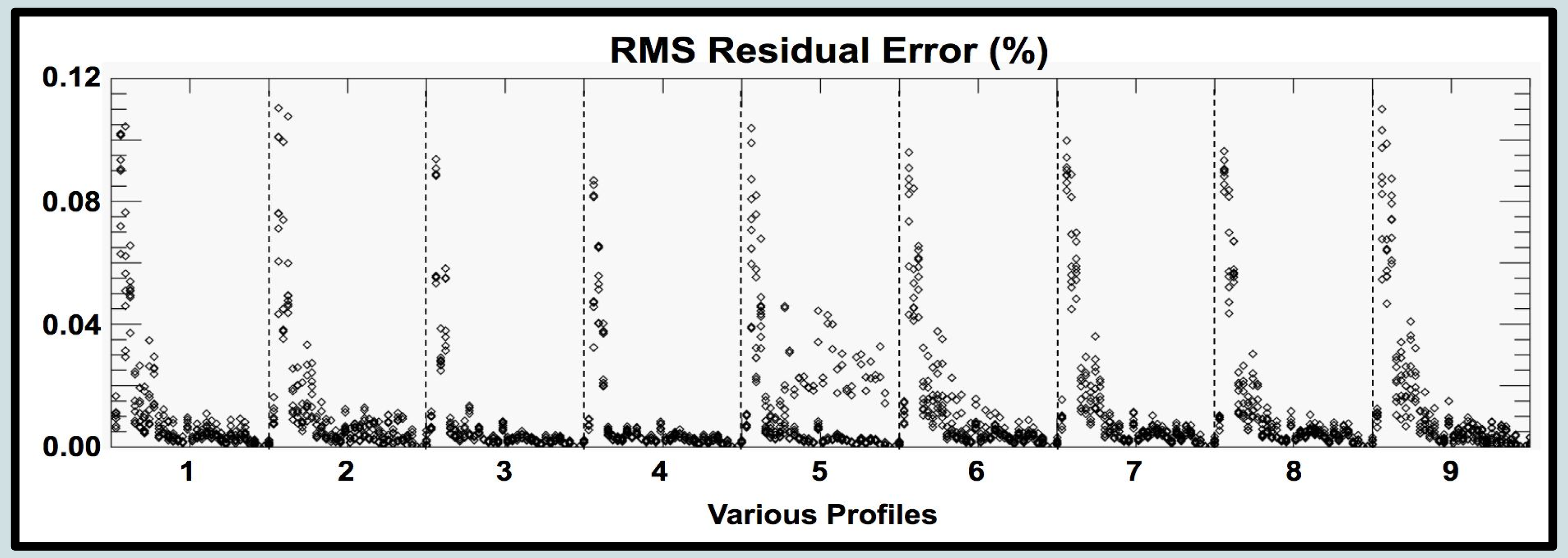


FIG 2: Averaged residual errors between PCA and EXACT calculations. Each profile box spans the wavelength range of 290 nm to 3030 nm from left to right.

RESULTS (CONT.)

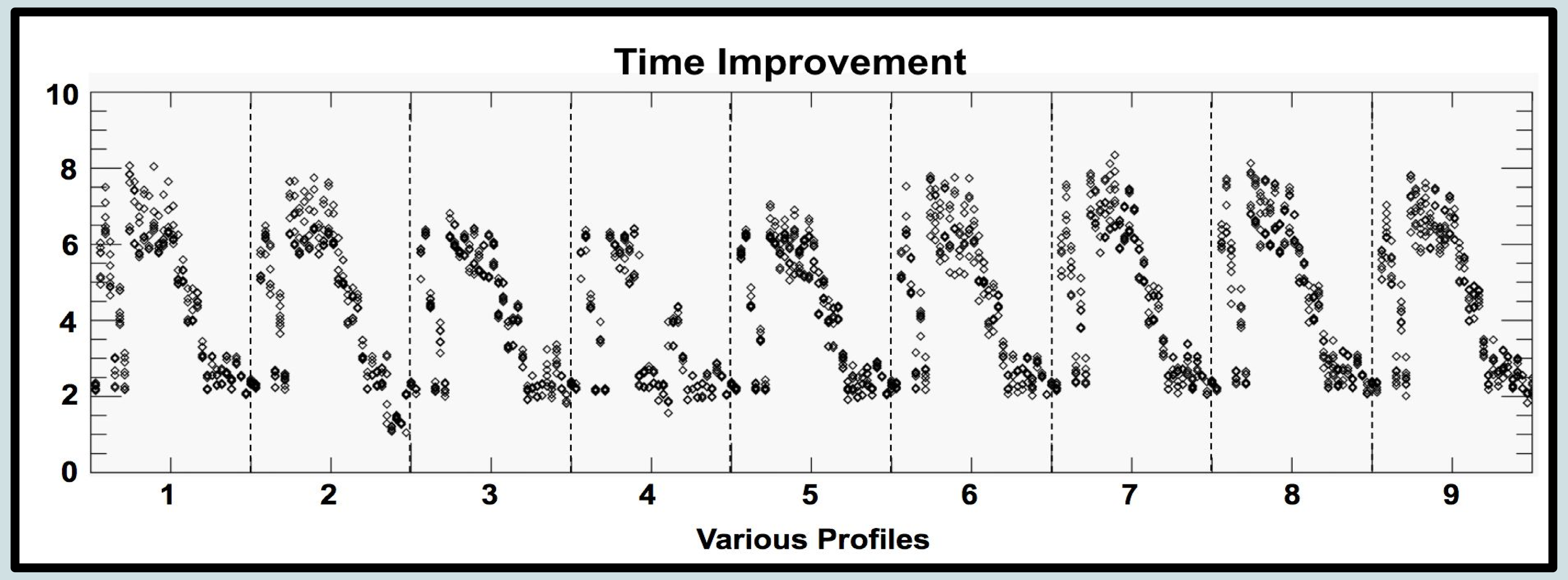


FIG 3: Ratio of execution time between EXACT and PCA calculations, using Intel Haswell CPU (GNU Compiler). Each profile box spans the wavelength range of 290 nm to 3030 nm from left to right. Time for EXACT case is typically >10 hours.

SUMMARY

Given the stated assumptions and tested profiles, the usage of PCA can significantly reduce computational time of TOA reflectance while maintaining acceptable residual errors.

- Average time improvement of about 5 times (λ dependent).
- Average errors hover around 0.02% (λ dependent).
- Shorter wavelengths typically seem to have a smaller speed improvement as well as an increased residual error. This might be the result of the spectral binning scheme for the PCA calculations.

Potential Problems and Future Developments:

- Code crashes for some profiles (related to different numbers of atmospheric levels in those profiles).
- Explore uniform versus variable layer pressure thicknesses.
- Explore the optimization of spectral binning.

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