Ozone absorption cross-section in ozone lidar algorithm

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Main ground-based instruments for ozone profile measurements

- **Ozone sondes (GAW, NDACC)**
  - Balloon borne in situ chemical sondes
  - 0 – 30 km, best 0 – 25 km – high resolution

- **Lidar (NDACC)**
  - Active remote sensing, DIAL method
  - Strato: 10 – 50 km, best: 15 – 45 km – high resolution in the low-middle stratosphere

- **Microwave (NDACC)**
  - Passive remote sensing of ozone emission line in the microwave frequency range
  - Range: 20 – 60 km - Low resolution

- **Umkehr: Dobson or Brewer spectrometers (GAW)**
  - Zenith sky observations at high solar zenith angle
  - Best range 20 – 45 km : Umkehr layers – Low resolution
Importance of monitoring ozone in the high stratosphere

Ozone evolution at 35-45 km altitude range from various lidar measurements time series

Steinbrecht et al., 2006; 2008
Intercomparisons within NDACC

Numerous campaigns involving several lidars, sondes, microwave spect., satellites (SAGE, HALOE, …)
Best agreement in 20 – 40 km range

NDACC strongly involved in satellite validation
Provides intercalibration of successive satellite missions

SOMORA microwave spectrometer (Switzerland)

Principle of lidar ozone measurement

DIAL Method: Differential Absorption Lidar

- Emission of 2 laser beams in the UV range ($\lambda_{on}$, $\lambda_{off}$)
- Different ozone absorption cross-section
- Pulsed laser sources: range resolved measurement
- Large dynamic of the lidar signals: several acquisition channels
- $N_2$ Raman wavelengths: volcanic aerosols
- Self calibrated measurement

Common wavelengths pairs used:
- Stratospheric systems: 308, 351-355 nm
- Tropospheric: 266, 289, 299, 316 nm

Retrieval of ozone number density

DIAL Method: \textbf{D}ifferential \textbf{A}bsorption \textbf{L}idar

\[ n_{O_3}(z) = -\frac{1}{2} \frac{d}{dz} \left( \Delta \sigma_{O_3}(z) \right) \left( \ln \left( \frac{S(\lambda_{on}, z) - S_b(\lambda_{on}, z)}{S(\lambda_{off}, z) - S_b(\lambda_{off}, z)} \right) \right) + \delta n_{O_3}(z) \]

\textit{Laser wavelengths chosen so that the correction term is less than 10\% of main term}

\[ \delta n_{O_3}(z) = \frac{1}{\Delta \sigma_{O_3}(z)} \left[ \frac{1}{2} \frac{d}{dz} \ln \left( \frac{\beta(\lambda_{on}, z)}{\beta(\lambda_{off}, z)} \right) - \Delta \alpha(z) - \sum_i \Delta \sigma_i n_i(z) \right] \]

\text{Extinction by other species}

\text{Rayleigh & Mie}

\text{Backscatter Rayleigh & Mie}

\text{Laser signal background correction term}
Example of DIAL ozone profile

- Ozone measurements performed during the night
- Temporal resolution 3 – 4 hours, depending on laser power and repetition rate
- Require clear skies
Ozone absorption cross-sections

- Evaluation of $\sigma_{o3}(\lambda)$ at emitted laser (308 nm & 355 nm) and 1\textsuperscript{st} Stokes N\textsubscript{2} Raman wavelengths (332 nm & 387 nm)

- Variation of $\sigma_{o3}(\lambda)$ with temperature T taken into account:
  $\sigma_{o3}(\lambda)$ varies with altitude
  
  $\sigma_{o3}(\lambda)$ variation with temperature (from Bass & Paur)
  $\sigma_{O_3}(\lambda, z) = (a + b.(T - 273.15) + c.(T - 273.15)^2)^{20}$ cm\textsuperscript{2}

Sensitivity at 308 nm~ 0.2%/K

Temperature data from
- off-wavelength lidar signal
- meteorological analyses
- climatological model
Accuracy of DIAL ozone profiles

Residual error after correction of $\delta \text{no3}$ (not including the photon noise)

- Atmospheric number density 5\% error
- 1.5 \% precision in ozone cross-section, Temperature : error of 5 K

Above $\sim$15-20km, residual error dominated by error on $\sigma_\text{o3}(\lambda, z)$
Conclusions

- DIAL ozone retrieval requires determination of ozone cross-sections in the range 266 nm – 332 nm, with accurate temperature dependence.

- Correct evaluation of ozone cross-section temperature dependence important for ozone trends evaluation, taking into account temperature trends in the stratosphere.

- At present, most lidar groups within NDACC use Bass & Paur ozone cross-sections but DIAL ozone measurements can easily be re-computed from archived raw data in case of change in recommended ozone cross-section.