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Application of a dual-channel solid state spectrometer to measure spectral surface radiation and atmospheric constituents

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Introduction

- Traditional instruments (Brewers and scanning double monochromators) disadvantages:
  - Cost
  - Susceptibility to movement
  - Speed of operation → limited sampling
- Solid state array instruments can overcome these, but have own drawbacks:
  - Stray light
  - Limited dynamic range
  - Temperature dependence

Aim to account for these issues in an atmospheric monitoring scenario measuring <u>direct and global spectral irradiance</u>, plus <u>ozone</u>

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Overview

- Instrument description
- Calibration procedure
- Some practical considerations
- DOAS procedure and preliminary results
- Conclusions

Instrument description (1)

- Two channel diode array instrument, 512 px, 280 to 700nm, 15-bit
- Common electronics and communications
- Channel A: cosine response, Schreder optics via 5m fibre optic
- Channel B: weatherproofed direct optics, ground quartz disc attenuator

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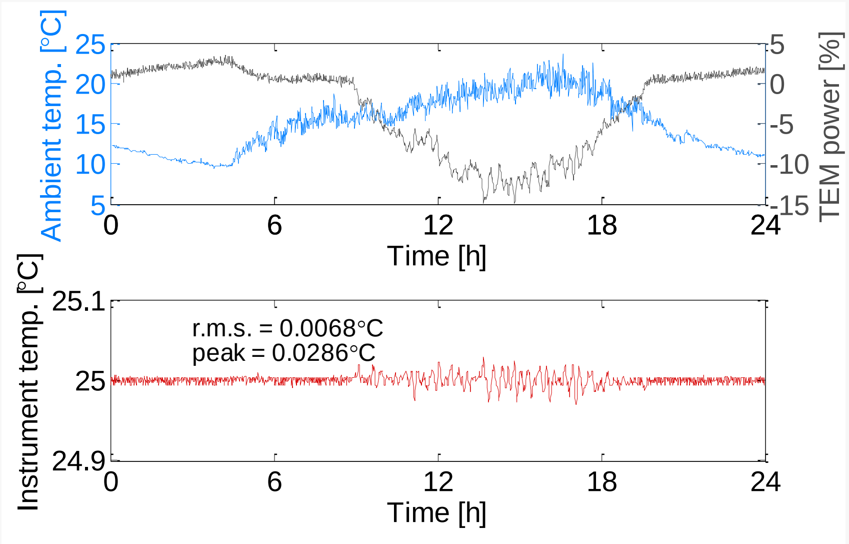
Instrument description (2)

- Spectroradiometer also requires weatherproofing – and temp stabilisation
- Weatherproofing via Al container and IP66 rated connectors
- Temperature control of entire system by PID controlled air-to-air TEM/Peltier system: $u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{d}{dt} e(t)$
- PID constants refined at set-point of 25ºC

— **Ziegler and Nichols, *Trans ASME* (1942)**



Calibration | Overview

1. Dark subtraction from raw counts
2. Scale to counts/s
3. **Apply wavelength calibration**
4. **Remove stray light**
5. Apply absolute calibration (responsivity) $\rightarrow$ $Wm^{-2}nm^{-1}$

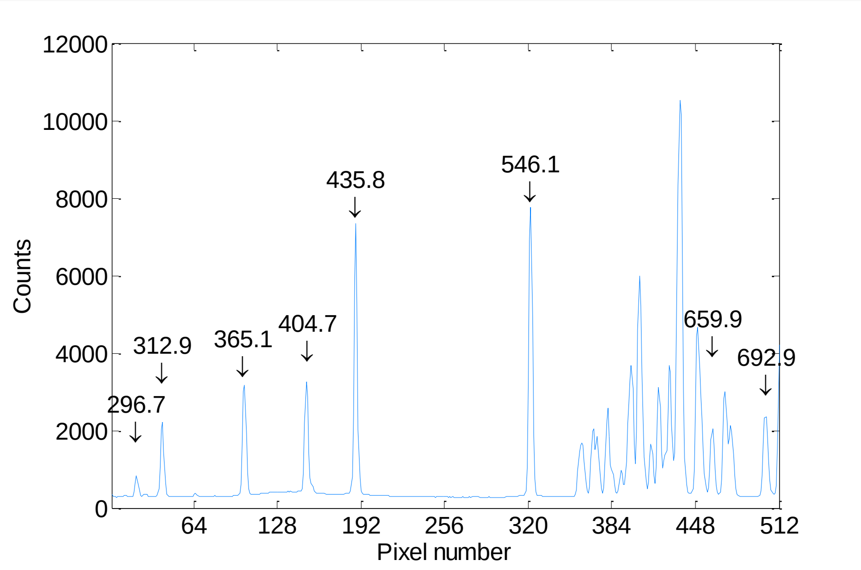
Calibration | Wavelength

- Centroid estimate: $p_{pk} = \frac{\sum p_i I_i}{\sum I_i}$

— **Shortis, Clarke and Short, *SPIE 2350* (1994)**

- Measure two emission pencil lamps <u>simultaneously</u>: Hg and Ne
- Additionally use doublets / triplets that fall within FWHM: $\bar{\lambda} = \frac{\sum \lambda_j I_j}{\sum I_j}$

— **NIST Atomic Spectra Database (2012)**



- Results in 8 (13) useable emission lines
- Third order polynomial fit with r.m.s. difference of 0.18 nm (0.08 nm)
- Additional improvements via shicRIVM algorithm

Calibration | Stray light correction (1)

- Characterised by the SDF matrix, $\mathbf{D}$, where:

$$\mathbf{Y}_{meas} = [\mathbf{I} + \mathbf{D}]\mathbf{Y}_{IB}$$

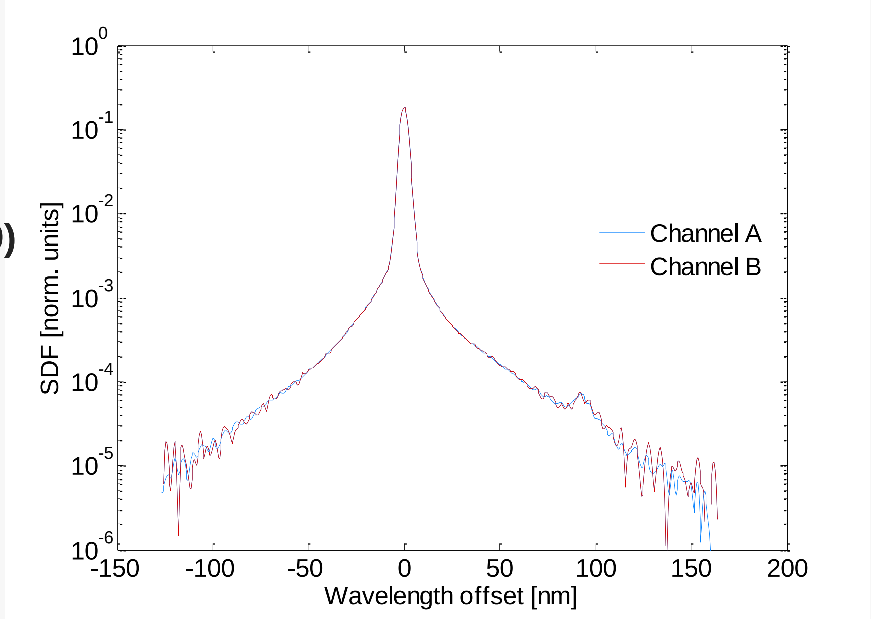
- Can be experimentally determined from LSF measured with tuneable laser across wavelength range

— Zong et al, Appl. Opt. (2006)

- For solar UV applications, can be simplified by measuring 405 nm laser and fitting power law

  — Kreuter and Blumthaler, Rev. Sci. Instr. (2009)

- But does not achieve good fit to our data



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Calibration | Stray light correction (2)

- Ideally want model-based parameterisation for stray light in diffraction grating monochromator:

$$\mathrm{LSF}(\lambda,\lambda_M) = \frac{\lambda_W}{\mathrm{sinc}^2\left[\pi\left(1-\frac{\lambda_B}{\lambda_M}\right)\right]}\left\{\left(4-\frac{\lambda^2}{d^2}\right)^2\left(\frac{a^2{\sigma_r}^2 q\pi^3}{df{\lambda_M}^4}\right.\right.$$

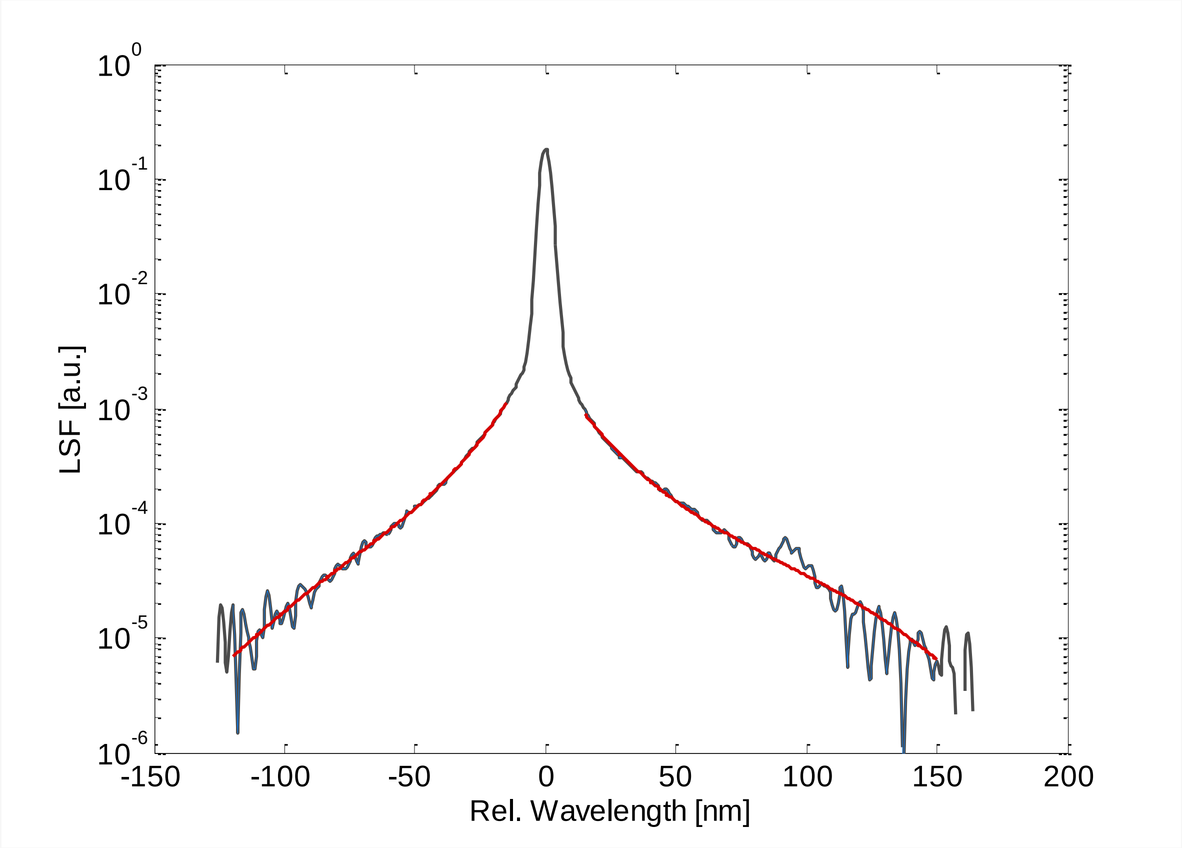
$$\left.+\frac{\pi^2{\sigma_d}^2}{{\lambda_M}^3}\mathrm{sinc}^2\left[\pi\left(\frac{\lambda-\lambda_B}{\lambda_M}\right)\right]\right)+\frac{1}{\lambda_M N}\cdot\frac{1+Nb(2\pi\lambda/\lambda_M)^2}{1-\cos(2\pi\lambda/\lambda_M)}$$

$$\left.\cdot\,\mathrm{sinc}^2\left[\pi\left(\frac{\lambda-\lambda_B}{\lambda_M}\right)\right]\right\}$$

— **Sharpe and Irish, Optica Acta (1978)**

$$\mathrm{LSF}(\lambda,\lambda_M) \approx \alpha_1\left(\frac{\lambda}{\lambda_M}\right)^4+\alpha_2\left(\frac{\lambda}{\lambda_M}\right)^2+\alpha_3+\alpha_4\left(\frac{\lambda}{\lambda_M}\right)^{-2}+\alpha_5\left(\frac{\lambda}{\lambda_M}\right)^{-4}$$

Calibration | Stray light correction (3)



- r.m.s. difference = 5.86 x 10^{-6}; c.f. r.m.s. for power law fit of 1.1 x 10^{-4}

Practical considerations

- Choice of integration time during unattended monitoring
  - Would normally take two-stage approach, but more complex in monitoring dual channel system, especially so when different optics have v. different throughputs
  - Due to single data acquisition request to instrument have to choose IT such that neither channel is saturated
  - For changeable conditions and unattended operation, select IT so that never saturated (ETSS):

$$t_{A,B} = \min\left(\frac{C_{\max} c_{A,B}(\lambda)}{I_0(\lambda)}\right)$$

  - **Benefit**: can measure quasi-continuously, so little information lost, and averaging on 1 min basis reduces SNR.
  - Methodology results in: **NEI of 0.1 $mWm^{-2}nm^{-1}$**, data capture of ~16%, c.f. scanning instruments of 0.2%

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DOAS retrieval

- Beer's law:

$$I(\lambda) = I_0(\lambda)\exp\left(-\alpha(\lambda)X\mu - \beta(\lambda)\frac{p_s}{p_0}m_R - \delta(\lambda)m_a\right)$$

  - I_0 from ATLAS dataset, convolved with instr. slit fn.
  - $\alpha(\lambda)$, O_3 cross-section, **— Molina and Molina (1996)**
  - assume λ^{-4} for Rayleigh scattering
  - assume Angstrom relation for aerosol with exponent of 1.3
  - multilinear regression to extract total ozone column

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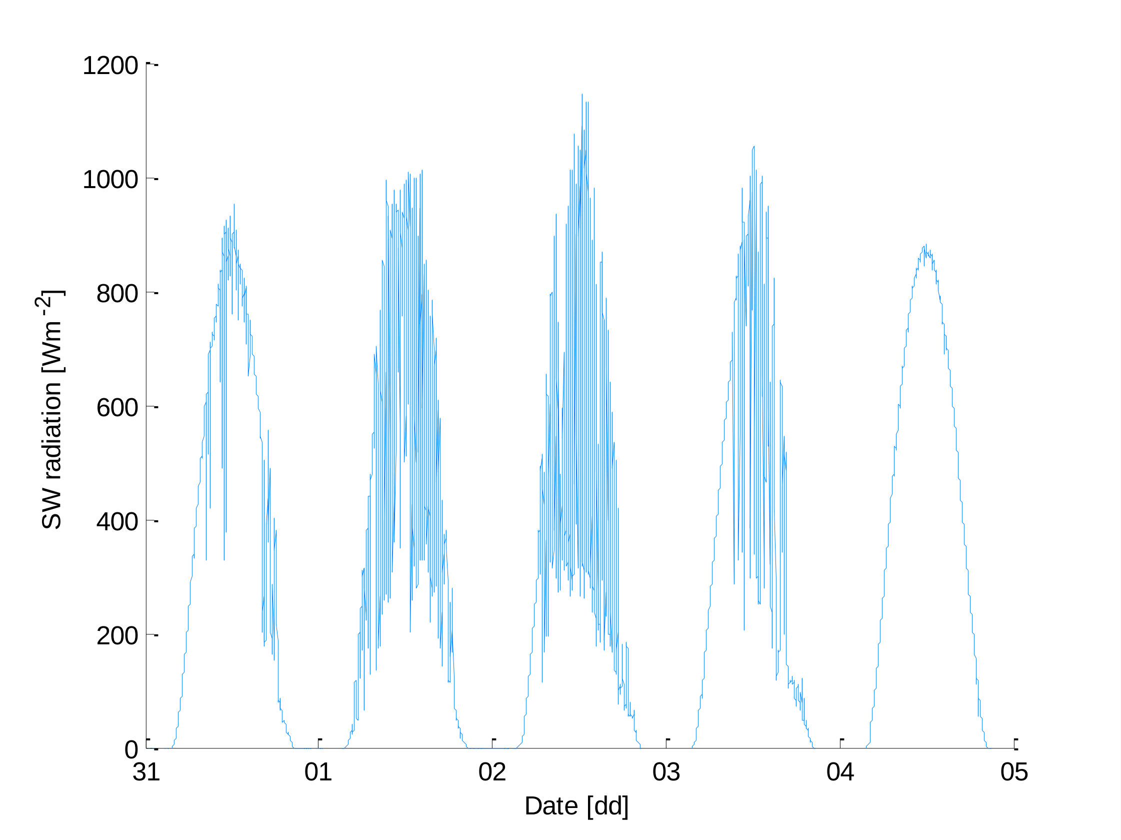
DOAS preliminary results



- SW total irradiance from CM5 pyranometer
- Study period: 31 May – 04 June 2013

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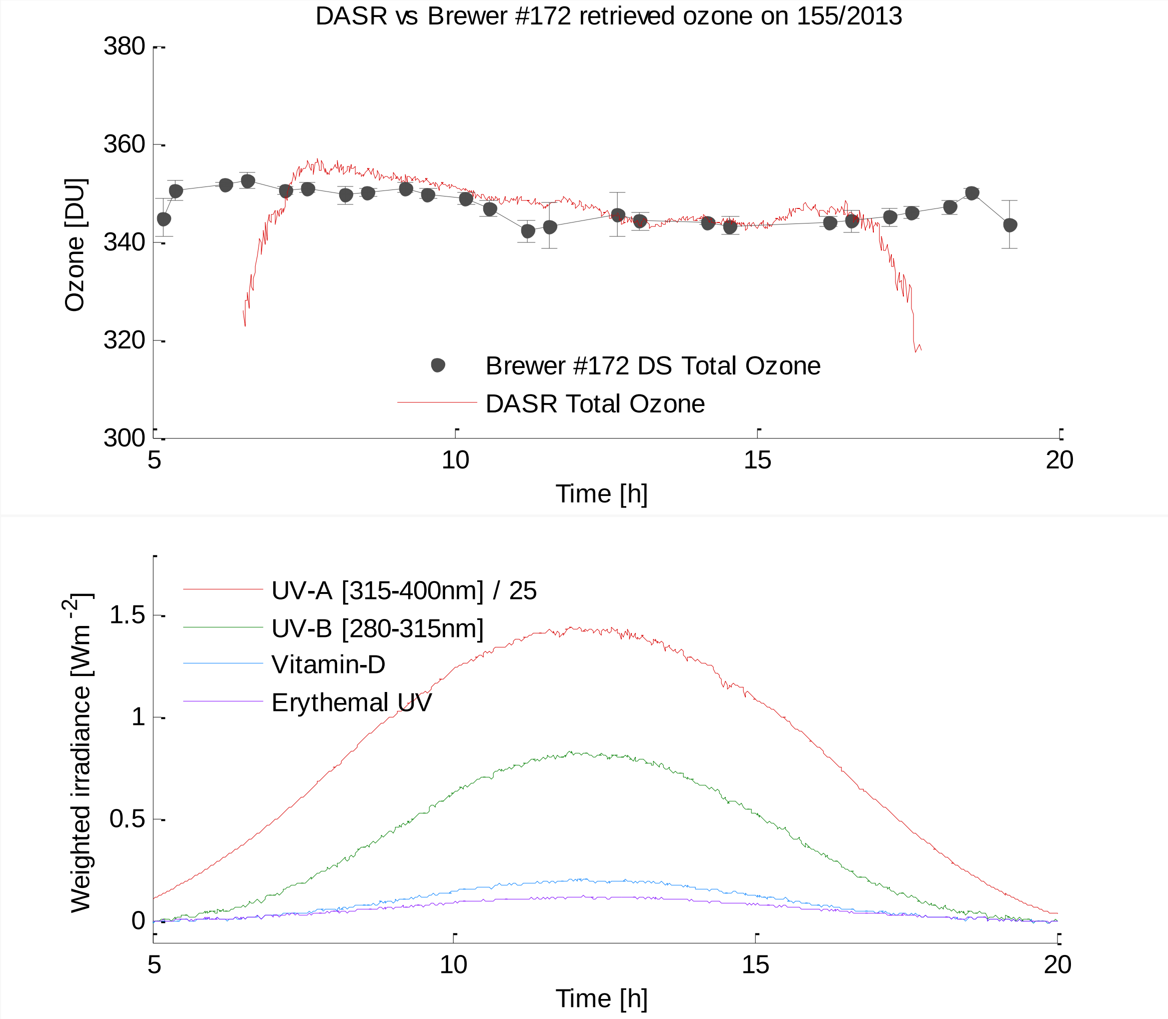
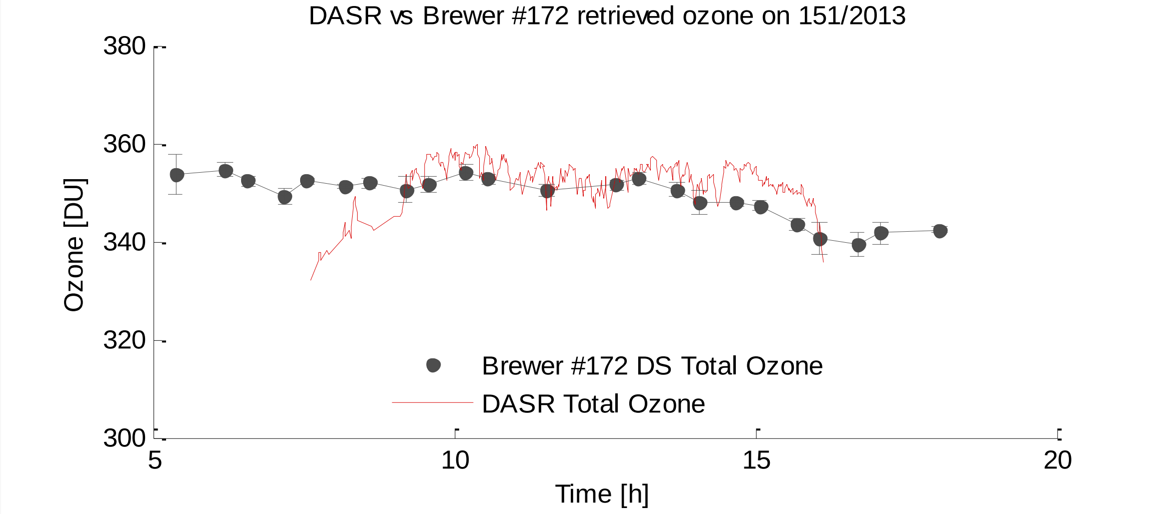
DOAS preliminary results

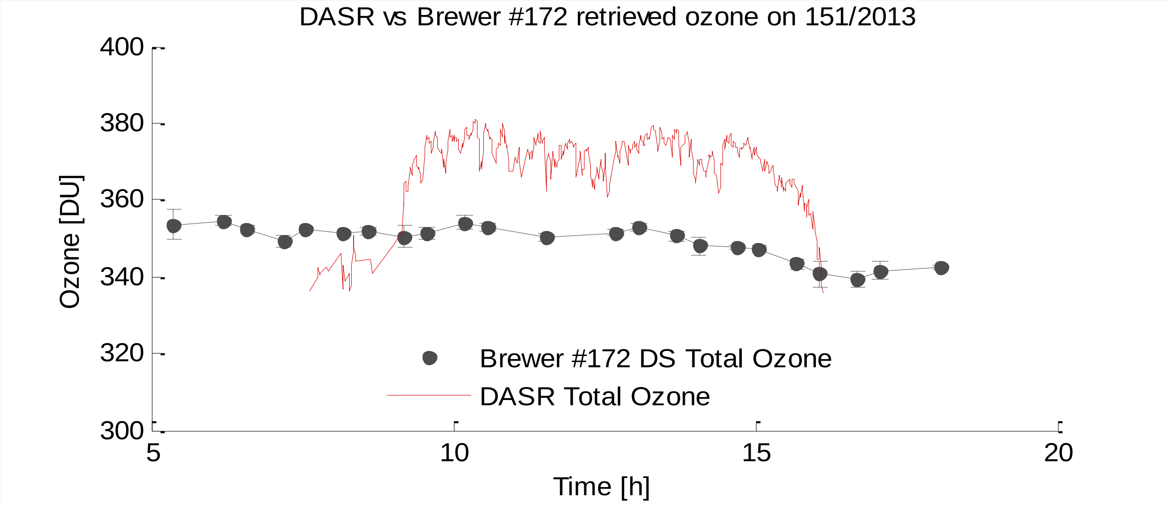


- r.m.s. diff = 0.83% for $\mu < 3$

DOAS preliminary results

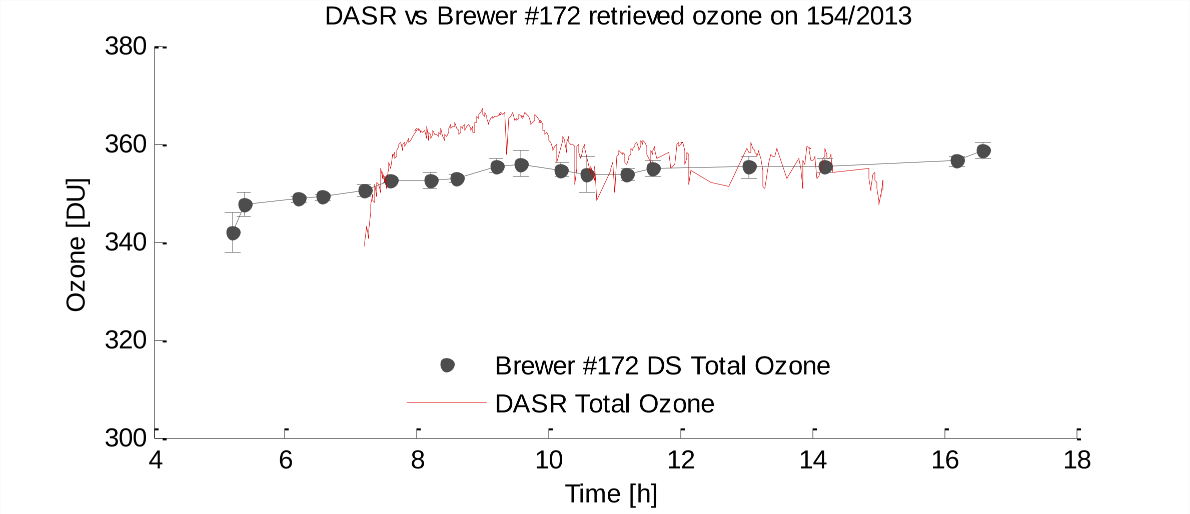


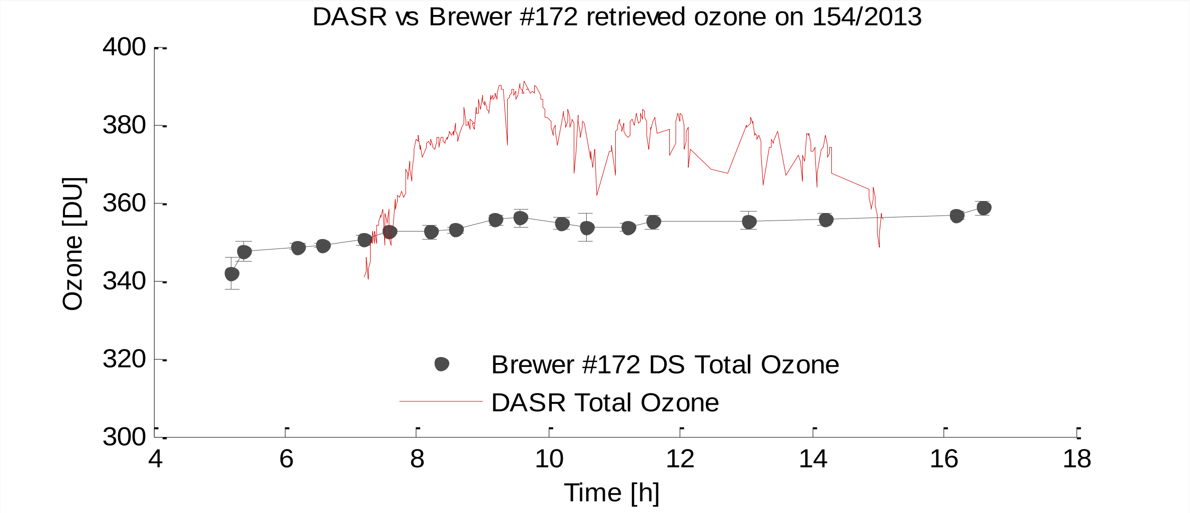
- r.m.s. diff = 1.41% for $\mu < 3$



- r.m.s. diff = 6.00% for $\mu < 3$ when lower wavelength limit = 306.5nm

DOAS preliminary results





- r.m.s. diff = 1.94% for $\mu < 3$

- r.m.s. diff = 7.3% for $\mu < 3$ when lower wavelength limit = 306.5nm

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Summary

- Initial results promising:
  - Two channel diode array spectrometer acquiring simultaneous direct and global spectra every 1 min; now running for several months
  - Retrieved ozone values agree with calibrated Brewer to ~1% for airmasses < 3
  - Fitting LSF with model-based function improves SLC
  - Need to pay close attention to stray light correction and associated issues to extend range of airmass validity

- Future work:
  - Improve regression procedure; extract AOD, other species
  - Analyse / compare new data over longer timescales
  - Improve data filtering for partially cloudy conditions
  - Inv. effect of different ozone cross-sections (Bass and Paur, Serdyuchenko etc)

Thanks for your attention.

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