

Spectral direct solar UV measurements in Trondheim, retrieval of aerosol optical depth and aerosol size distribution in subarctic coastal region

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Outline

- AOD in Trondheim (coastal region), diurnal and seasonal variability, **aerosol effects on UV**.
- Method to retrieve aerosol size distribution.
- Comparison of spectral measurements and sun photometer measurements.

Instruments

- Bentham DM150
 - Spectral measurements
 - Global irradiance
 - Direct irradiance, field of view 1.5°
 - Radiance, diffuse
 - Range 250 to 600 nm, step 0.1nm, (1 nm step used)
 - *FWHM of about 0.86 nm*
 - Calibration, 1000 W NIST traceable standard lamp
- *Sun photometer, CIMEL CE318*
 - 9 spectral band measuring channels
 - Direct irradiance, field of view 1.2°
 - Radiance
 - *FWHM of about 2 – 10 nm*
 - Channels, 340, 380, 440, 500, 675, 870, 936, 1020 and 1640nm.
 - Calibration, Langley method

Calculation of AOD

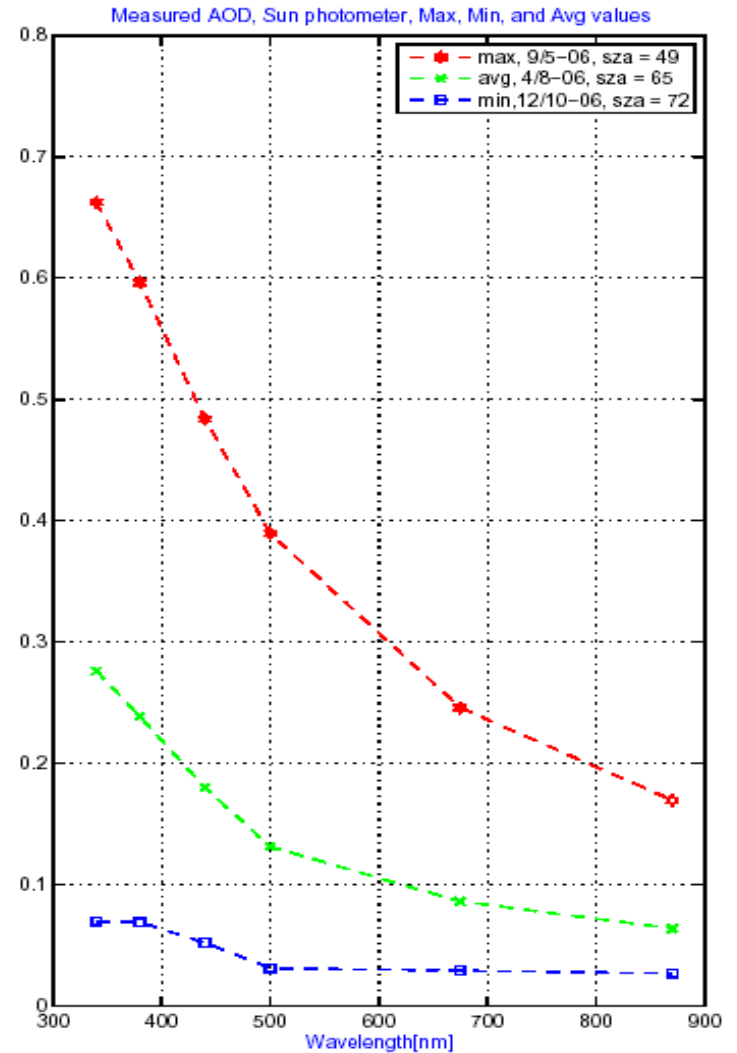
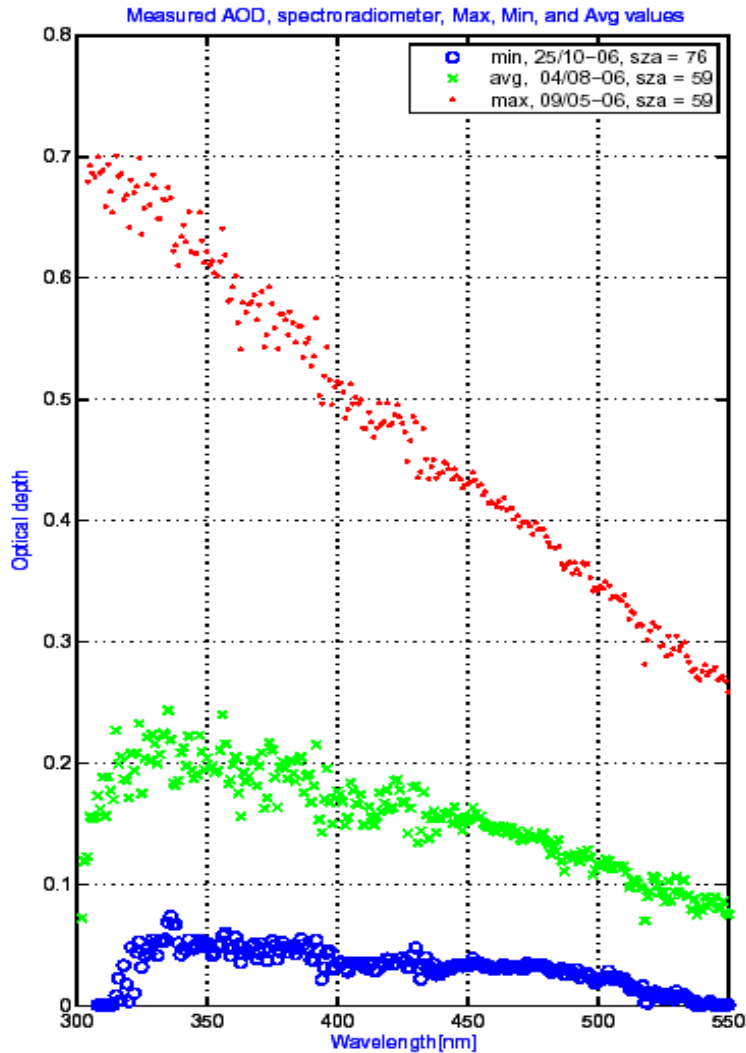
Following the Beer-Bouguer-Lambert law, AOD can be calculated from the following equation:

$$\tau_A(\lambda) = \frac{1}{m_A} \left[\ln \frac{I^*(\lambda)}{I(\lambda)} - m_R \frac{P}{P_0} \tau_R(\lambda) - m_{O_3} D_{O_3} k_{O_3}(\lambda) - m_{NO_2} C_{NO_2} k_{NO_2}(\lambda) \right],$$

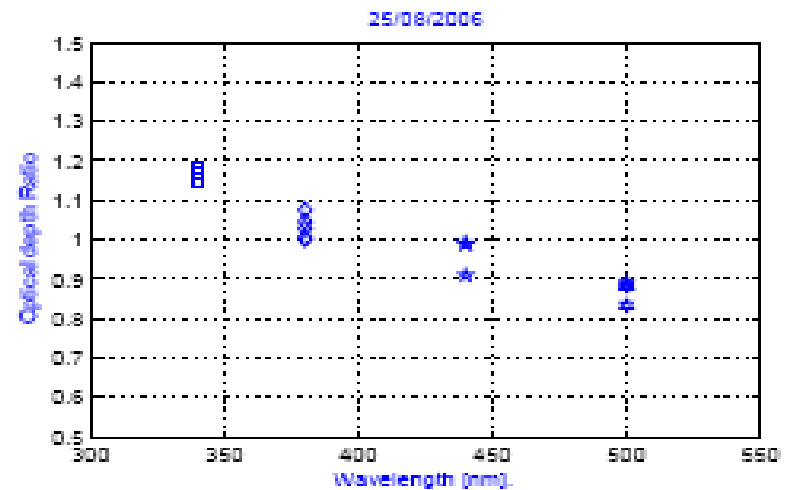
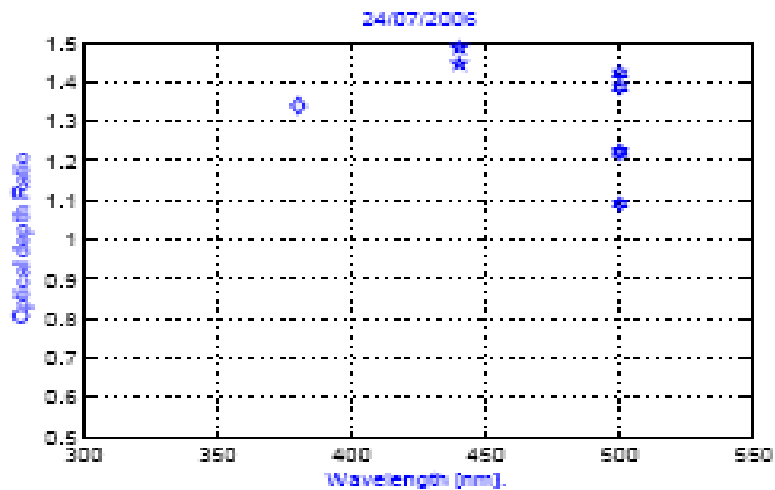
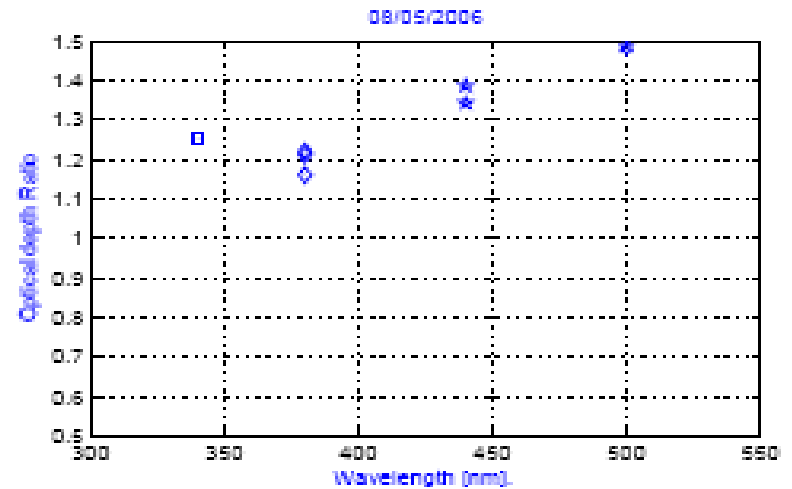
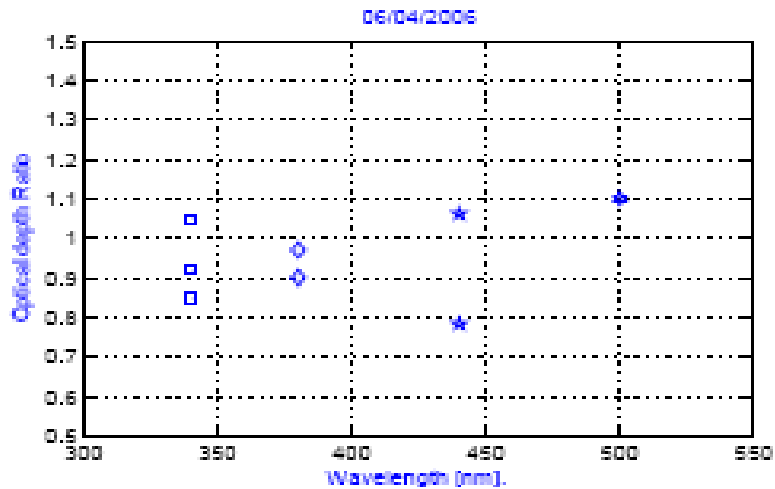
Experimental error in AOD:

$$(\Delta\tau_a)^2 = (\cos^2(\theta)) \left[\left(\frac{\Delta I_0}{I_0} \right)^2 + \left(\frac{\Delta I}{I} \right)^2 \right] + \left(\frac{\Delta D_{O_3}}{D_{O_3}} \tau_{O_3} \right)^2 + \left(\frac{\Delta C_{NO_2}}{C_{NO_2}} \tau_{NO_2} \right)^2.$$

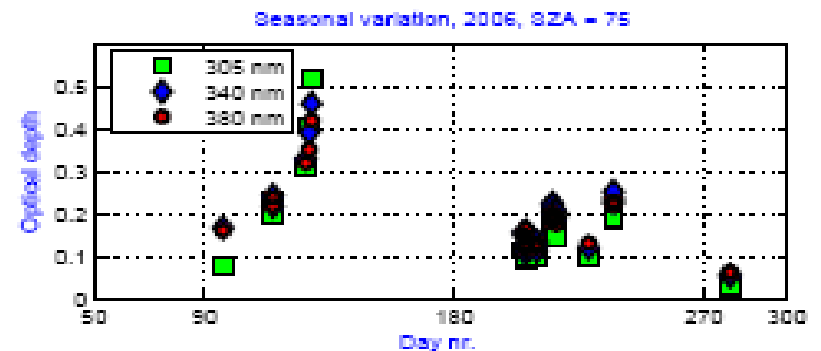
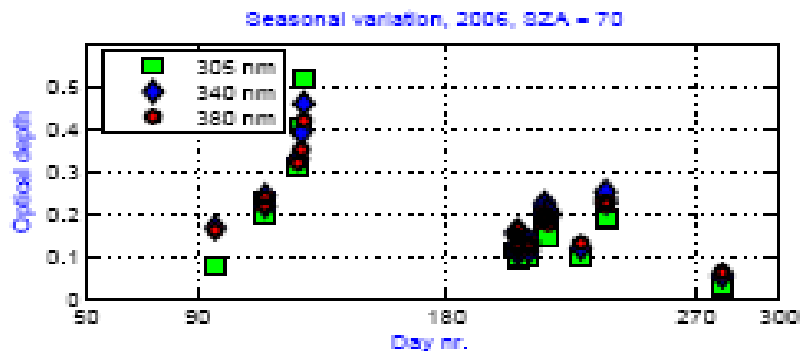
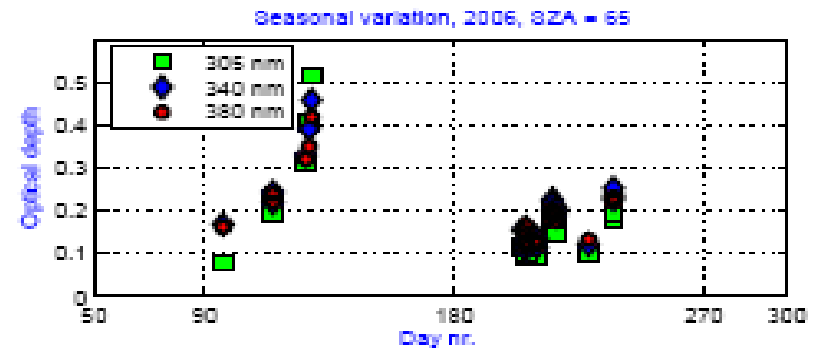
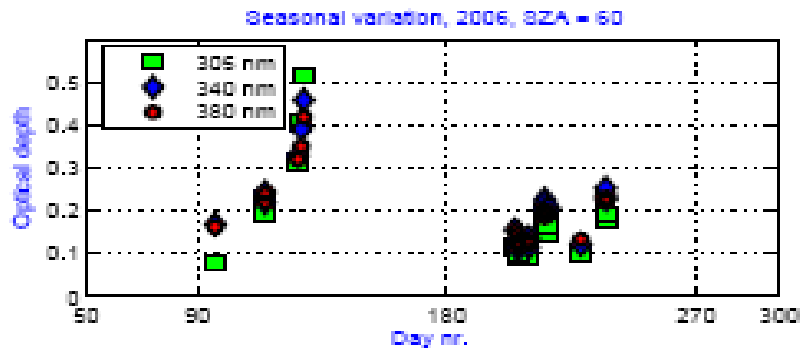
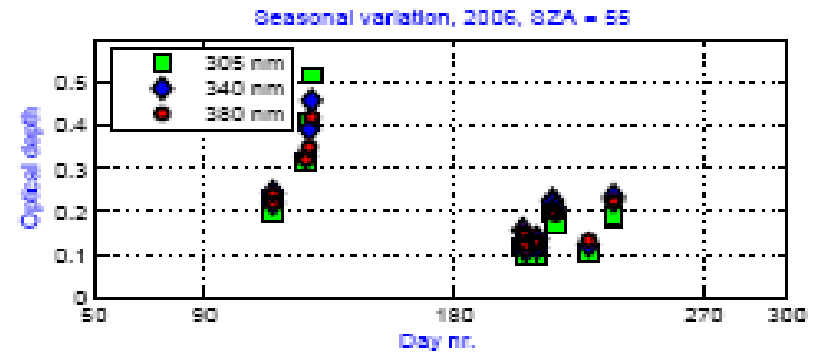
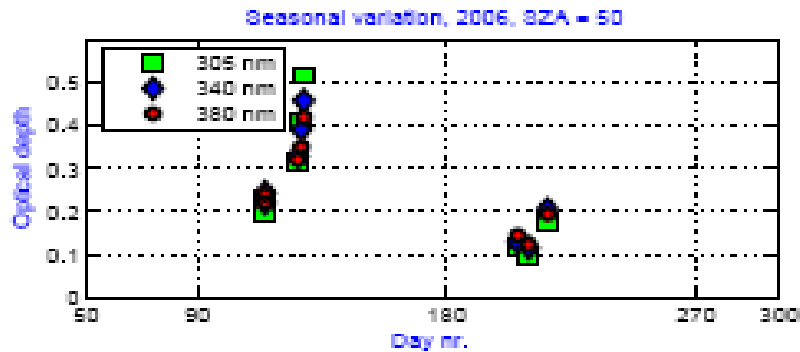
Spectral dependence, measured max., Min., avg AOD in 2006



AOD comparision

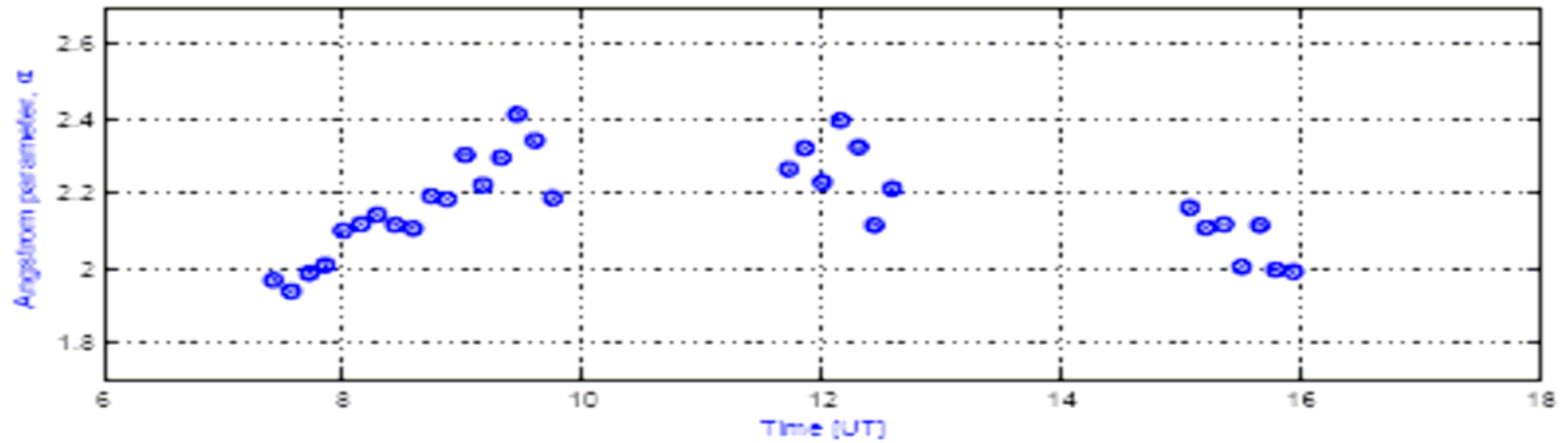


Seasonal variability in Trondheim

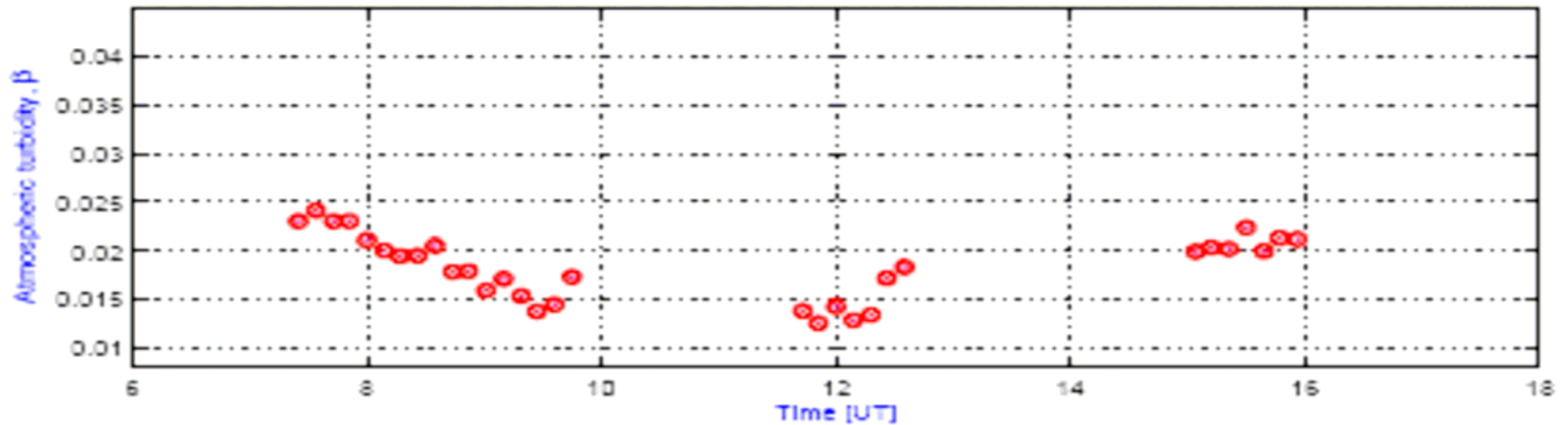


Diurnal variability

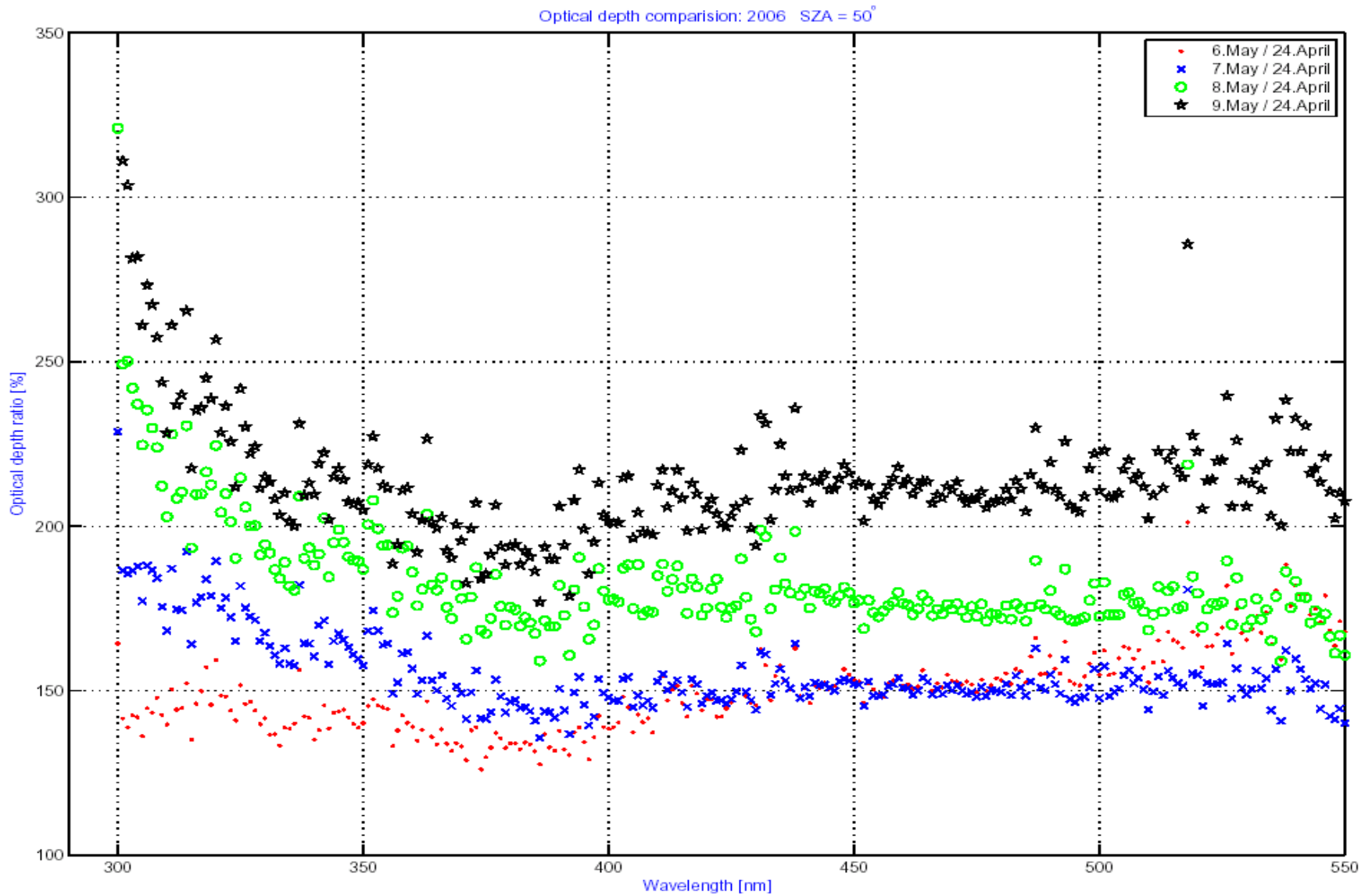
2006 4/8



2006 4/8



Large fire event in Baltic, AOD ratio, 2006, Trondheim



Aerosol size distribution

- Def. Of AOD in term of extinction coefficient [1/cm]:

$$\tau_A(\lambda) = \int_{z_0}^{z_{top}} \beta_e(\lambda, z) dz$$

And extinction coef. In term of extinction cross section [cm²] is given by:

$$\beta_e(\lambda, z) = \int_{r_0}^{r_{max}} \sigma_e(r, \lambda) n(r, z) dr$$

- Assuming Mie atmosphere, eq. of aerosol optical depth becomes:

$$\tau_A(\lambda) = \int_{z_0}^{z_{top}} \pi r^2 Q_{ext}(r, \lambda, m^*) n_c(r) dz$$

Assuming Junge distribution of aerosol, and limiting the integration over each coarse intervals in r , we get Fredholm integral equation:

$$\tau_A(\lambda) = \int_{r_j}^{r_{j+1}} \overbrace{\pi r^2 Q_{ext}(r, \lambda, m^*) r^{(-\nu^*+1)}} f(r) dr$$

Assuming $f(r)$ is constant within each coarse interval, a system of linear equations can be written as:

$$g = Af + \varepsilon$$

Where:

$$g_i = \tau_A(\lambda_i) \quad i=1,2,\dots,p$$

$$A_{ij} = \int_{r_j}^{r_{j+1}} \pi r^2 Q_{ext}(r, \lambda_i, m^*) r^{(-\nu^*+1)} dr \quad j=1,2,\dots,q$$

$$f_j = f(r_j)$$

And ε is the deviation between measurement (g) and theory (Af) which arise from measurements errors and uncertainties to the exact form of kernel function.

Constrained Linear Inversion [King and LIOU]

- Following the method suggested by Twomey and Phillips, the solution vector f is obtained by minimizing

$$\frac{\partial}{\partial f} \left[\sum_{i=1}^p \left(\sum_{j=1}^q A_{ij} f_j - g_j \right)^2 C_{ij}^{-1} + \gamma \sum_{j=2}^{q-1} (f_{j-1} - 2f_j + f_{j+1})^2 \right] = 0$$

- Which leads to:

$$\sum_{i=1}^p \left(\sum_{j=1}^q A_{ij} f_j - g_j \right) C_{ij}^{-1} A_{ij} + \gamma \sum_{j=2}^q H_{jj} f_j = 0$$

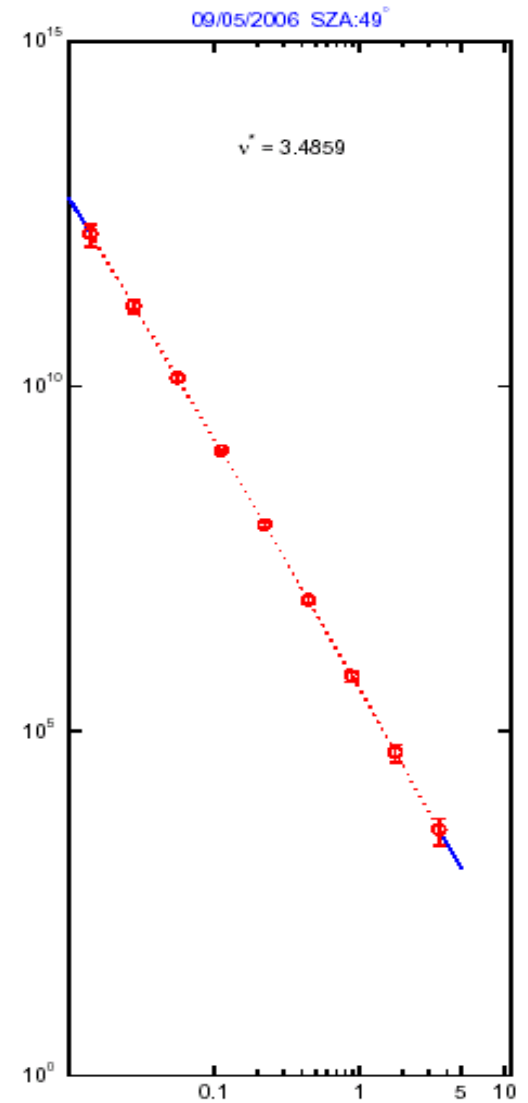
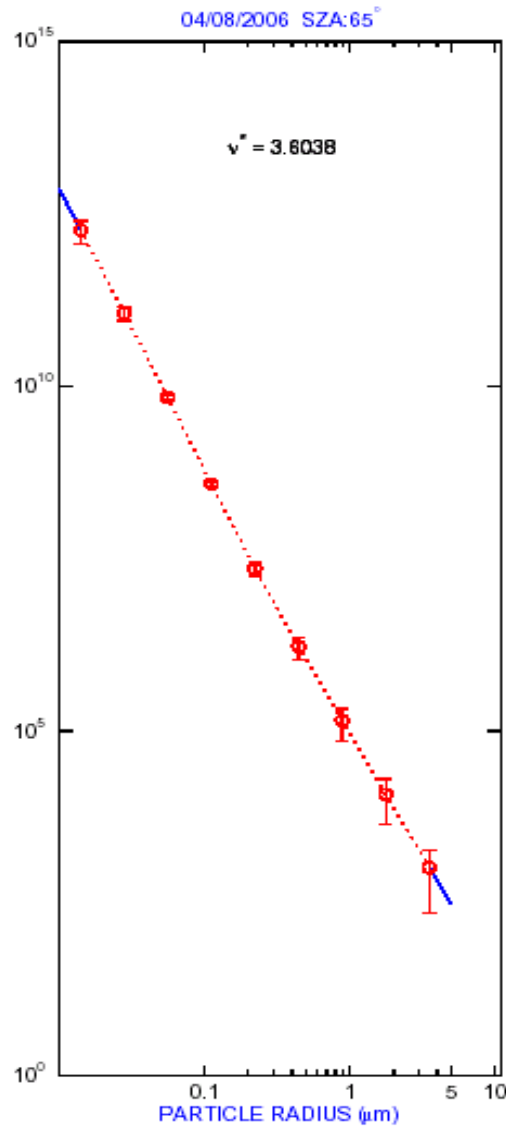
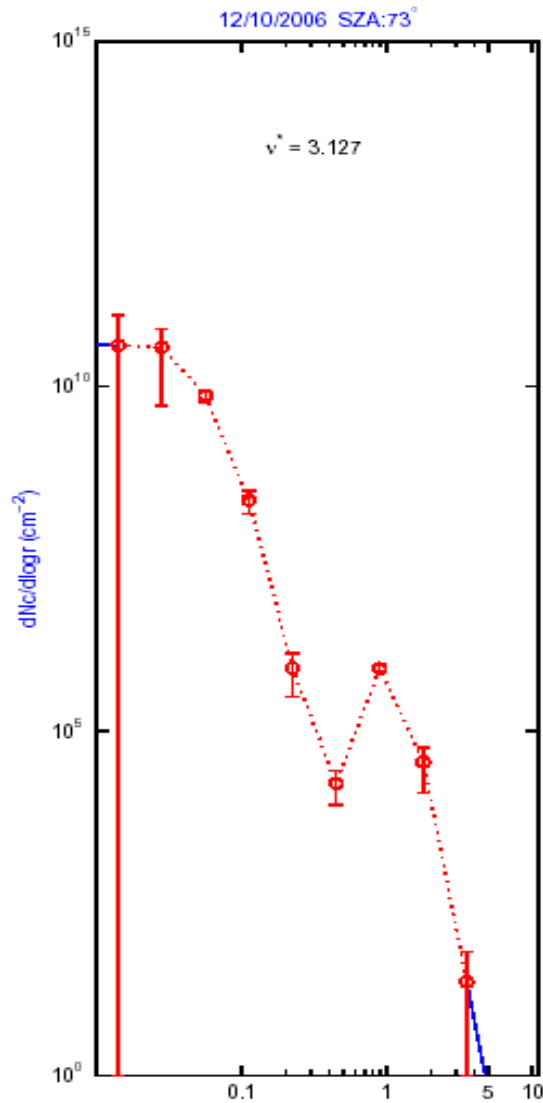
- In matrix form:

$$A^T A f - A^T g + \gamma H f = 0$$

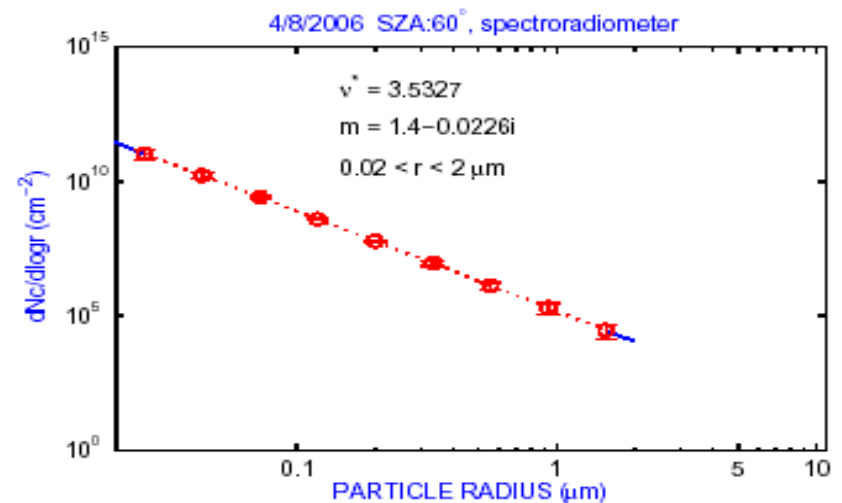
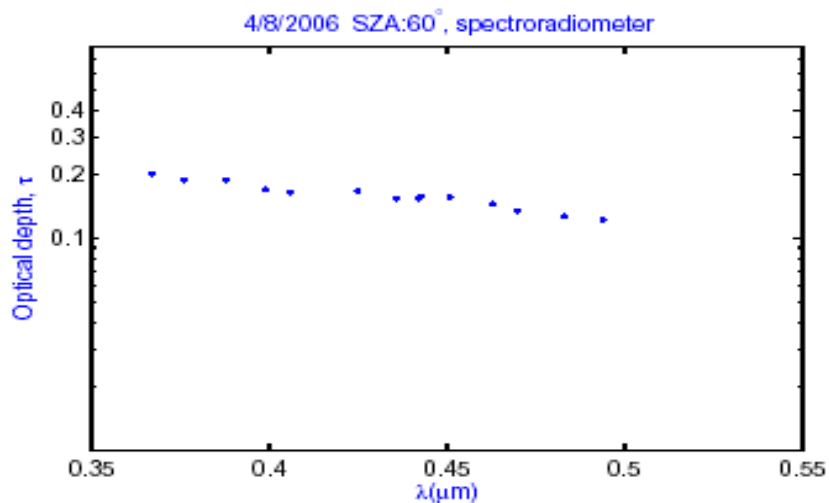
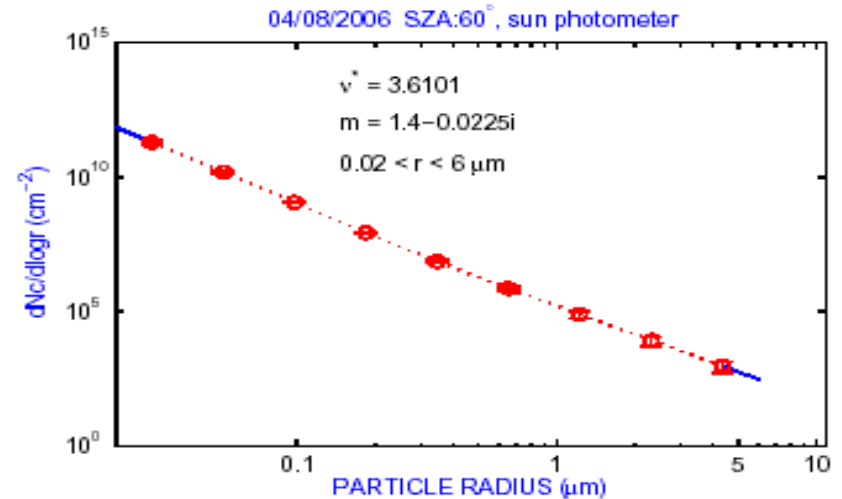
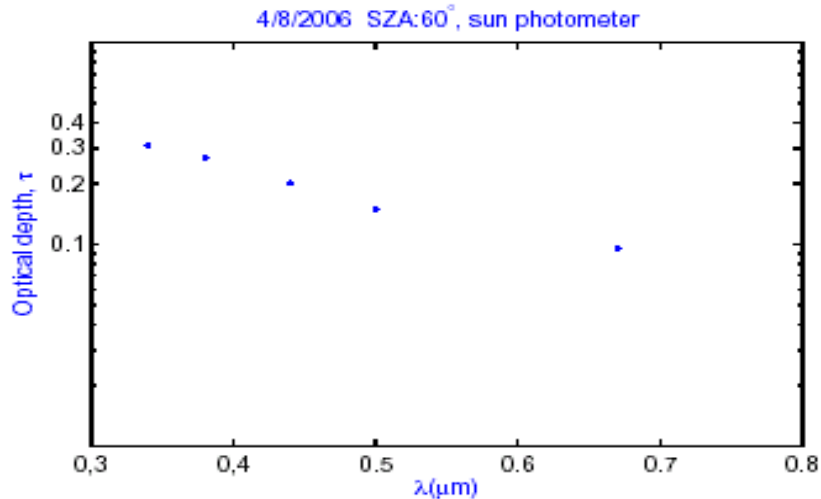
- The solution is given by:

$$f = (A^T A + \gamma H)^{-1} A^T g$$

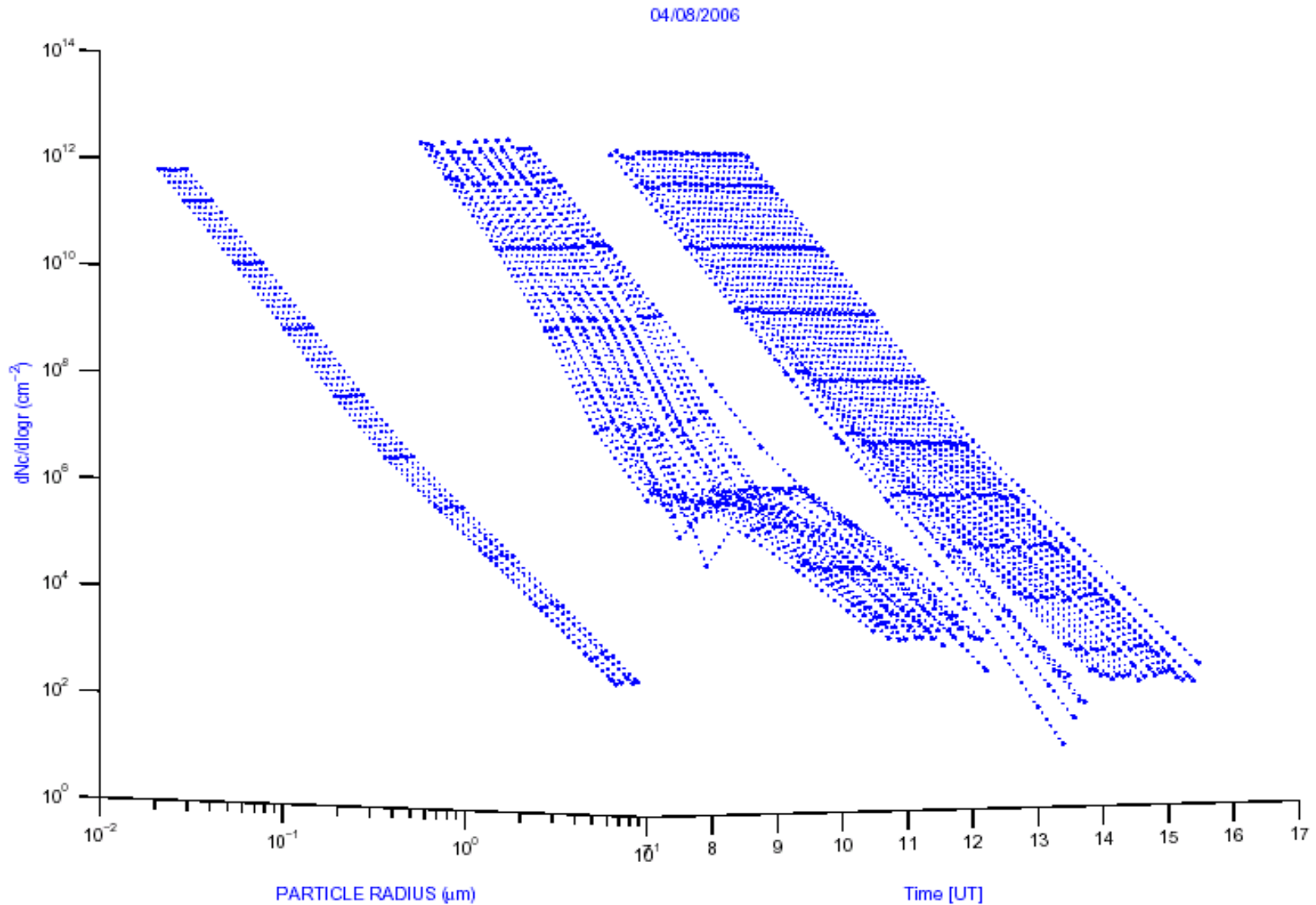
Size distribution results, sun photometer, max. Min. avg. data, 2006 Trondheim



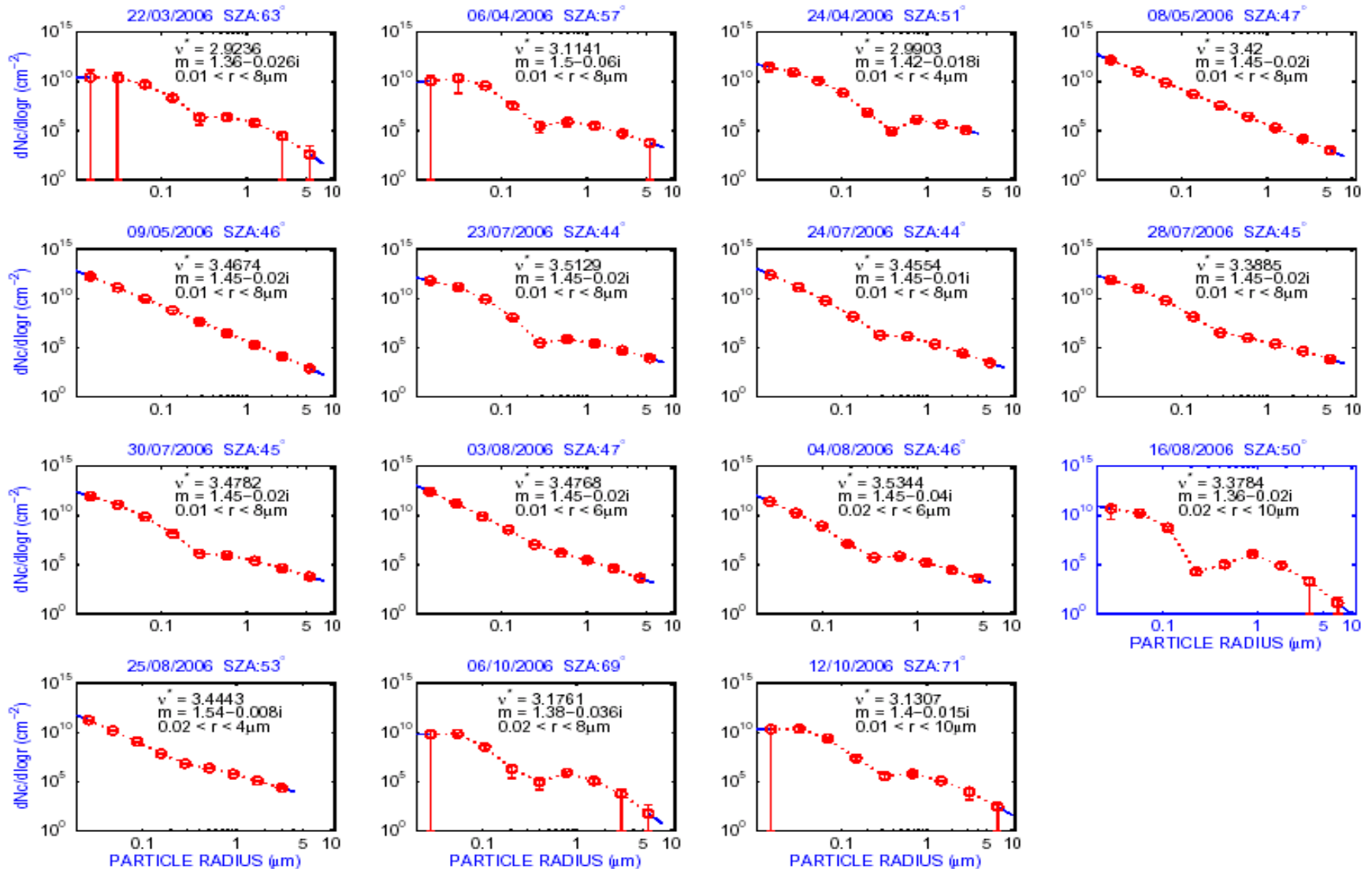
Observed radius range, Cimel and Bentham comparision



Diurnal variation



Yearly variation



Conclusions

- AOD retrieval;
 - The results show that, AOD in 2006 at this the site range from 0.03 to 0.38 for 500 nm (visible) and in the UVA region (380 nm) variation are from 0.06 to 0.59
 - The average value of *alpha* is about 2.2, showing that the measured optical depth is highly wavelength dependent, also very low average beta values (0.02) , showing a very clean atmosphere in Trondheim
 - Bias from diffuse into direct beam and field of view is the problem for spectral measurement in UVB
 - Good agreement in UVA-VIS for both instruments
- Size distribution;
 - At the measurement site we have variable aerosol type, they are absorber type aerosol, biomass aerosol type detected in May are clearly indicated
 - Comparison of the retrieved refractive index with aerosol model indicate that aerosol are changing from pure oceanic type to absorbing industrial type
 - The results also indicate that the radiation in UV are "seeing" aerosols which are smaller than about 2 μm
 - Results show that stratospheric aerosols are of bimodal type with the second maxima at about 1 μm