Retrieval of time-sequences of particle parameters from multiwavelength lidar measurements

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Information Available from Aerosol Lidar

Backscatter Lidar

Multiwavelength Lidar

- Aerosol layer heights
- Attenuated backscatter
- Extinction profile derived from backscatter
- Backscattering and extinction profiles at multiple wavelengths
- Particle size distribution at different heights
- Volume, surface, number densities, effective radius
- Complex refractive index and SSA

- Joint use of α and β - key for successful retrieval.
- The Raman lidar is based on tripled Nd:YAG laser:

  Three elastic channels and two nitrogen Raman (3+2)

  Backscattering β – 355, 532, 1064 nm

  Extinction α – 355, 532 nm

We need to treat underdetermined problem

For every set Rmin, Rmax, m_R, m_I - the problem is well-determined: number of optical data = number of equations

↓

Rmin, Rmax, m_R, m_I are varied and several thousands of solutions are found

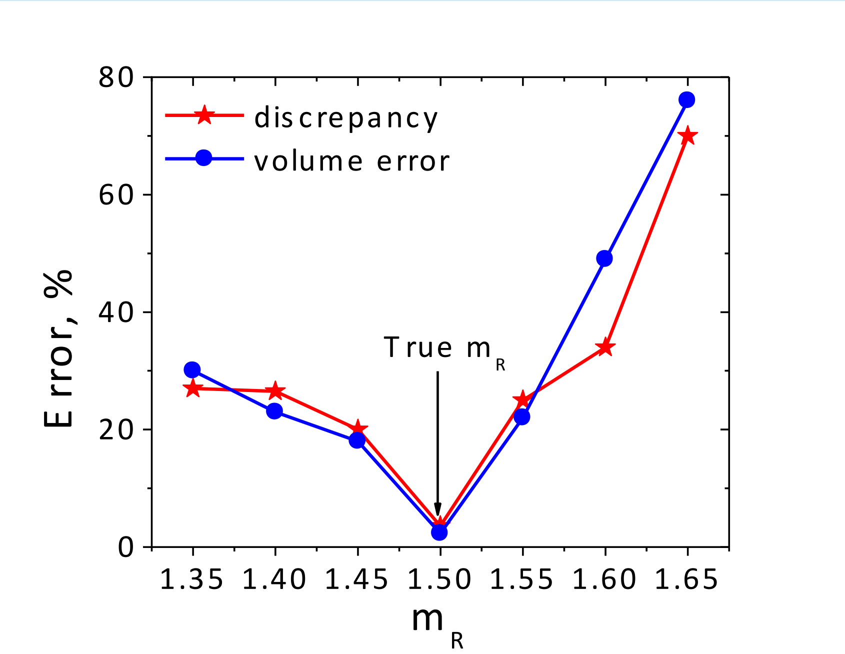
↓

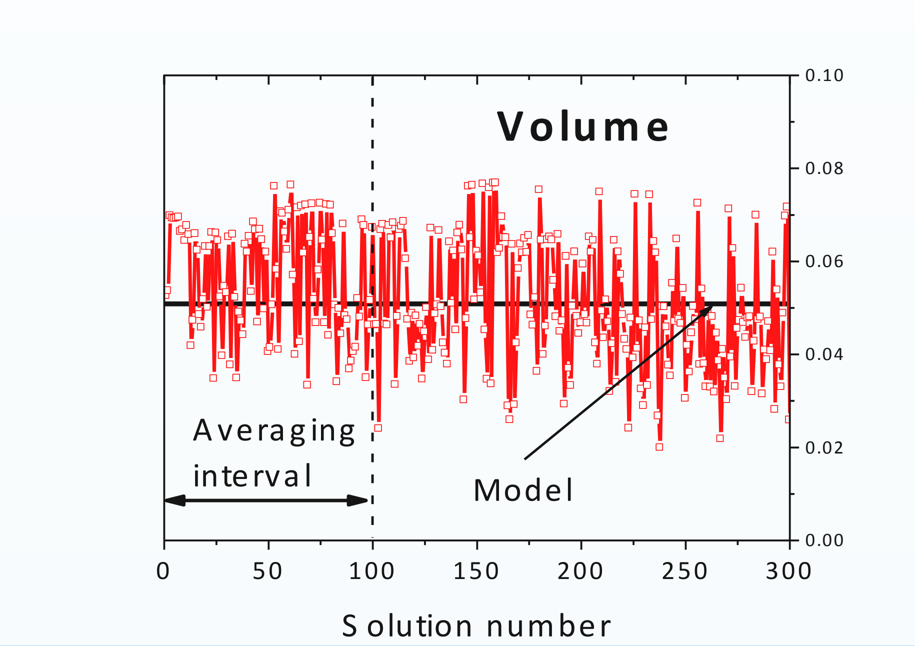
Every solution is characterized by discrepancy (difference between experimental data and data calculated from solution)

↓

Solutions are ranged and averaged

This is how it works

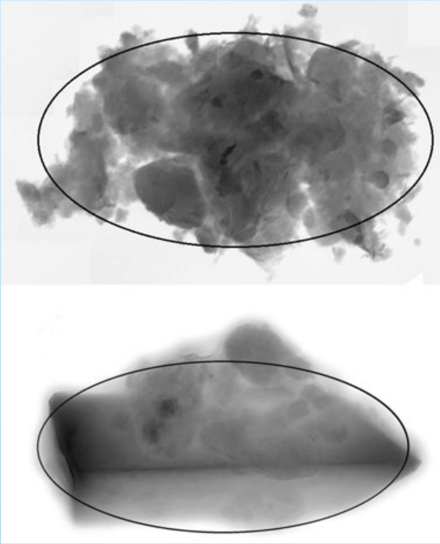




Particles parameters are retrieved from synthetic optical data; ~1% of solutions are averaged.

Treatment of Dust Particles

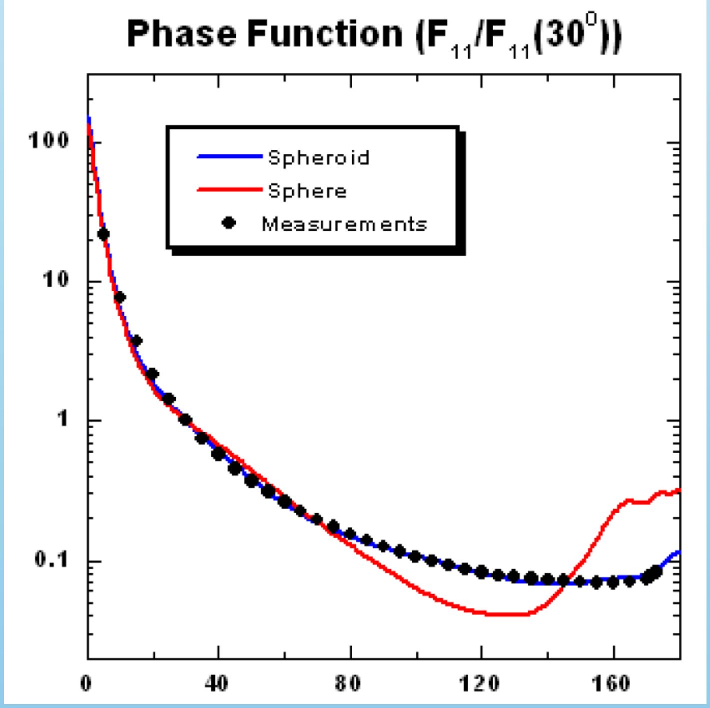
from M.Wiegner



Main Idea: **generalizing aerosol modeling by using randomly oriented spheroids instead of spheres (*Mishchenko et al. 1997*)**

Parameters: $dV(r)/d\ln r$, + $dn(\varepsilon)/d\ln\varepsilon$
r - radius of volume-equivalent sphere
ε - aspect ratio

from O.Dubovik



The positive experience of AERONET is used:

- **Aerosol is mixture of spheres and spheroids**

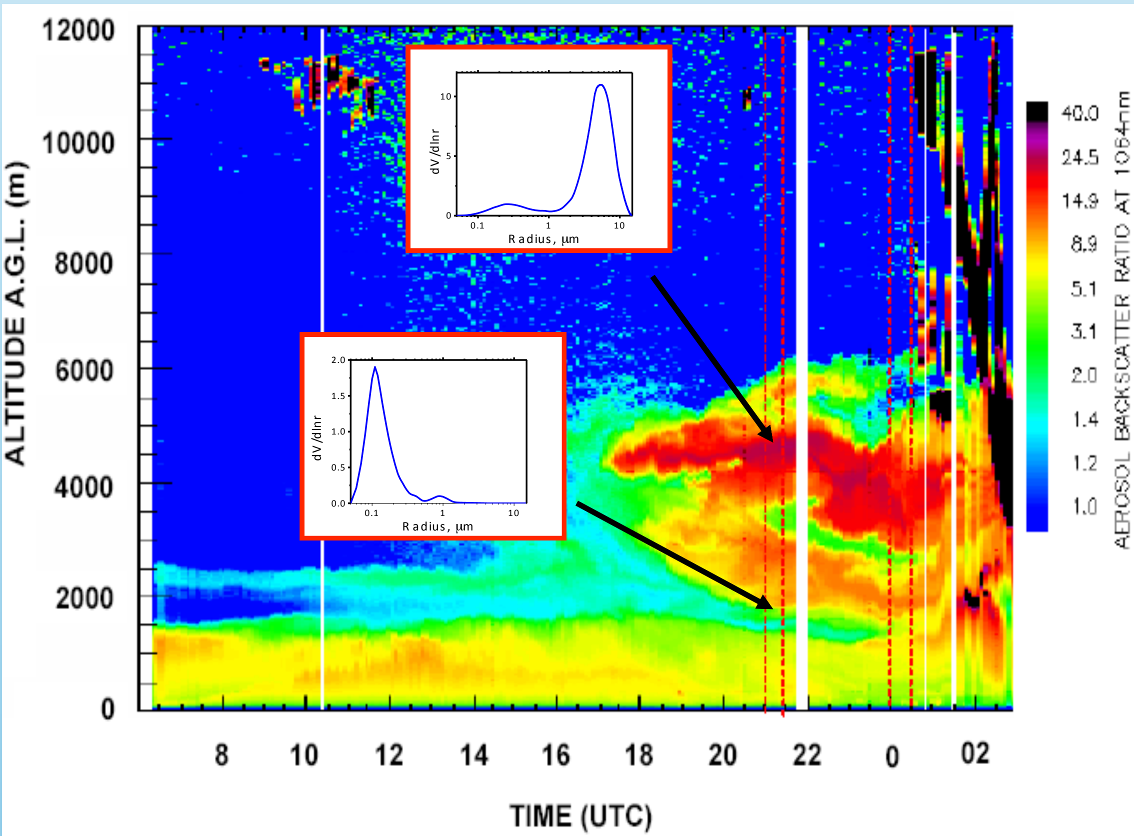
$$\frac{\partial V(r)}{\partial \ln r} = \frac{\partial V^{s}(r)}{\partial \ln r} + \frac{\partial V^{un}(r)}{\partial \ln r} \qquad \frac{\partial V^{un}(r)}{\partial \ln r} = \eta \frac{\partial V(r)}{\partial \ln r}$$

- **The spheroidal kernel functions are calculated with look-up tables provided by Dubovik et al.**

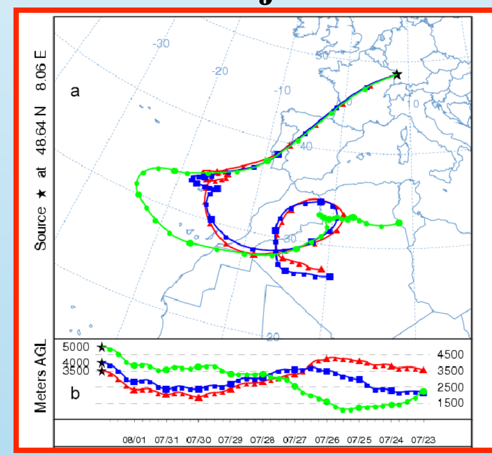
Saharan dust outbreak, Achern 2007

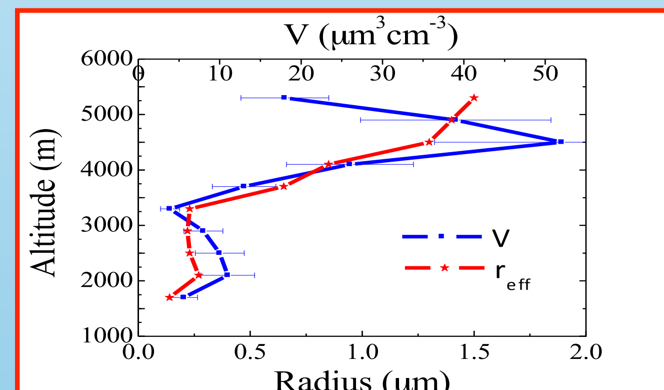
Data of Paolo Di Girolamo

Time evolution of the particle backscatter ratio at 1064 nm. Dust outbreak occurs on 1 August 2007 around 18:00. In the centre of plume the coarse mode dominates PSD.



Back trajectories





Profile of volume density and effective radius

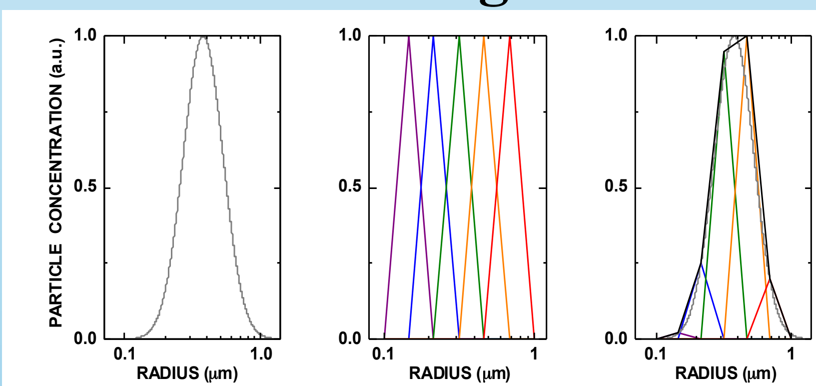
Two Approaches to Retrieval

Optical data (α or β) at different λ are calculated from equation:

$$g_i = \int_0^\infty K_i\,(m, r, \lambda)\,\frac{dV(r)}{dr}\,dr \quad\Rightarrow\quad \mathbf{K}^T\,\mathbf{v} = \mathbf{g}$$

K – discrete kernels
v – discrete volume

Inversion with regularization

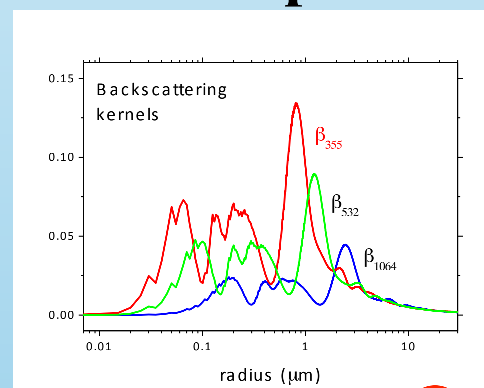


$$\mathbf{v} = \mathbf{B}\mathbf{x}$$

$$\mathbf{g} = \mathbf{K}^{\mathrm{T}}\mathbf{B}\mathbf{x} = \mathbf{A}\mathbf{x}$$

$$\mathbf{x} = \left(\mathbf{A}^{\mathrm{T}}\mathbf{A} + \gamma\mathbf{H}\right)^{-1}\mathbf{A}^T\mathbf{g}$$

Kernels expansion



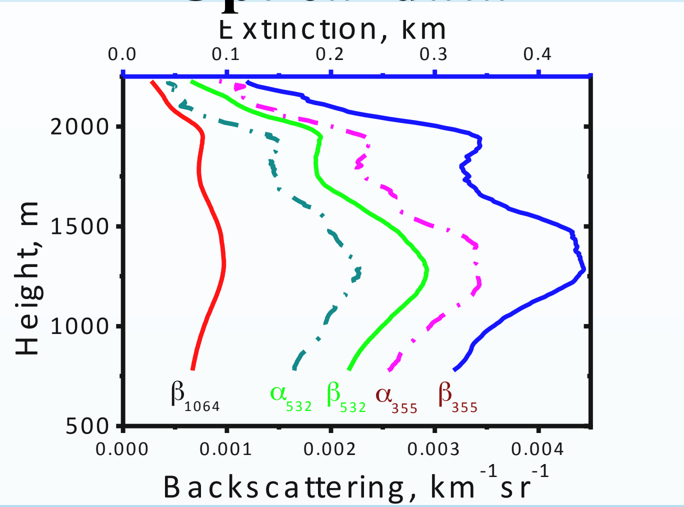
$$\mathbf{v} = \mathbf{K}\mathbf{x} + \mathbf{v}_\perp = \mathbf{v}_g + \mathbf{v}_\perp$$

$$\mathbf{g} = \mathbf{K}^{\mathrm{T}}\mathbf{K}\,\mathrm{x} + \mathbf{K}\,\mathbf{v}_\perp = \mathbf{K}^{\mathrm{T}}\mathbf{K}\,\mathrm{x}$$

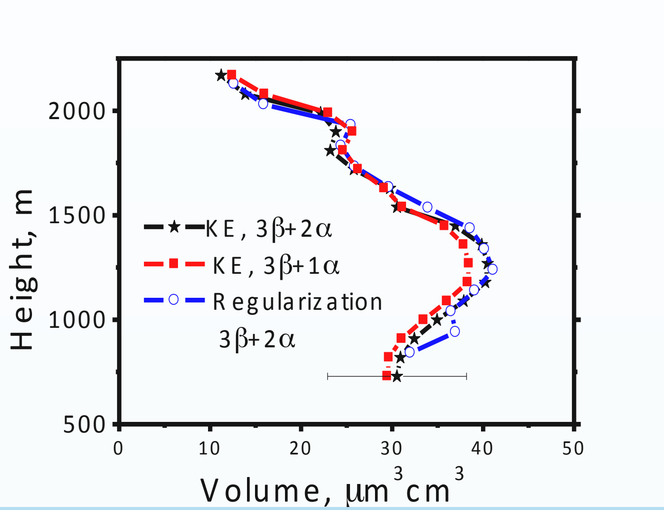
$$\mathbf{x} = \left(\mathbf{K}\mathbf{K}^{\mathrm{T}}\right)^{-1}\mathbf{g}$$

Comparison of regularization and KE (Measuremnts were performed in GSFC)

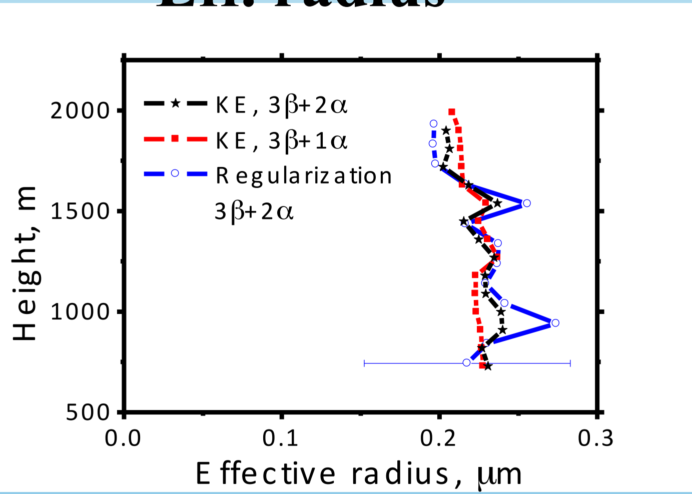
Optical data



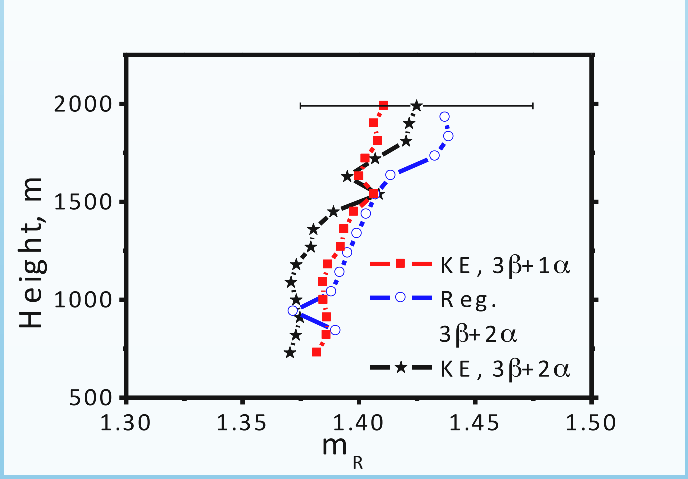
Volume



Eff. radius

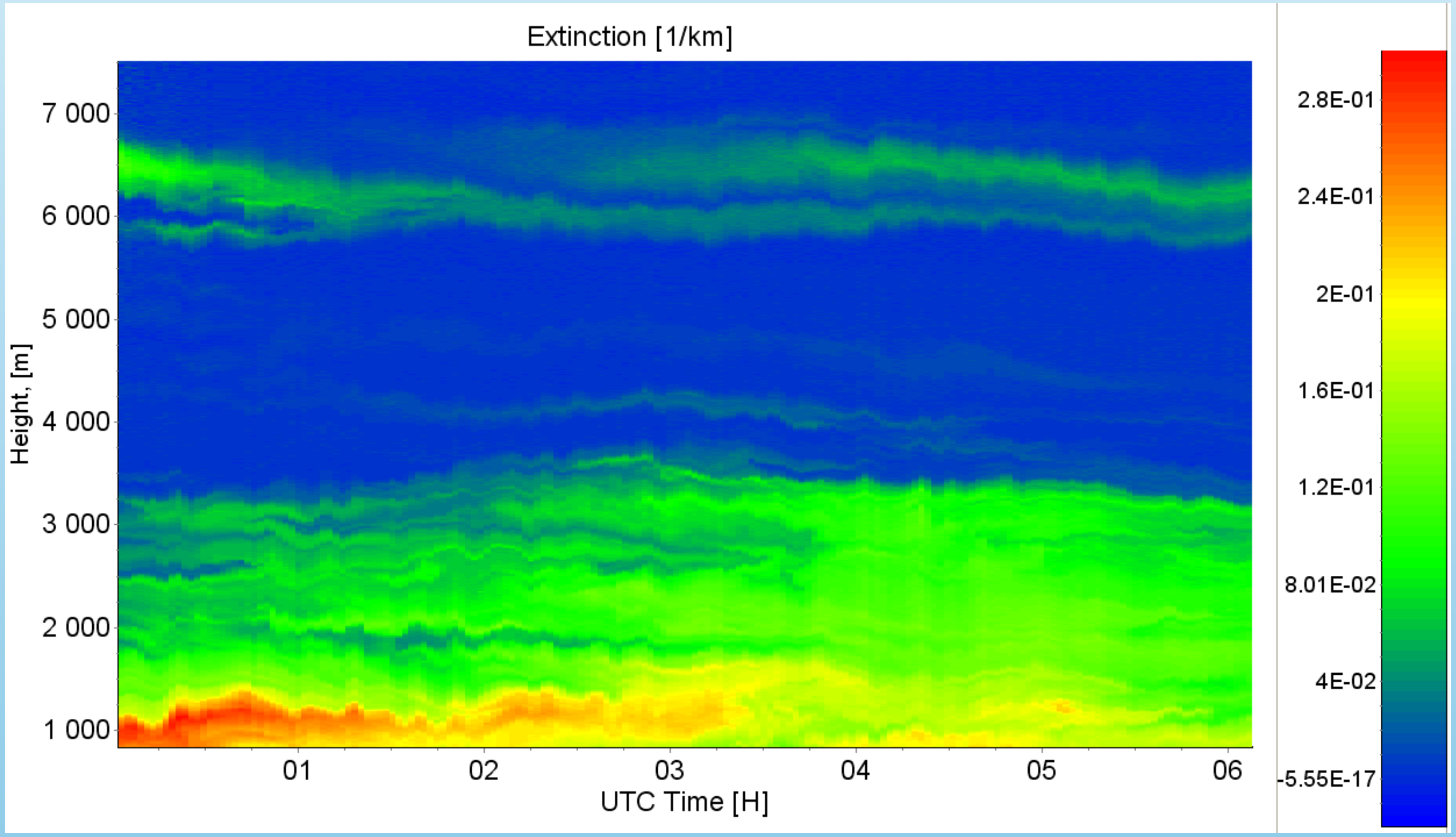


Real part



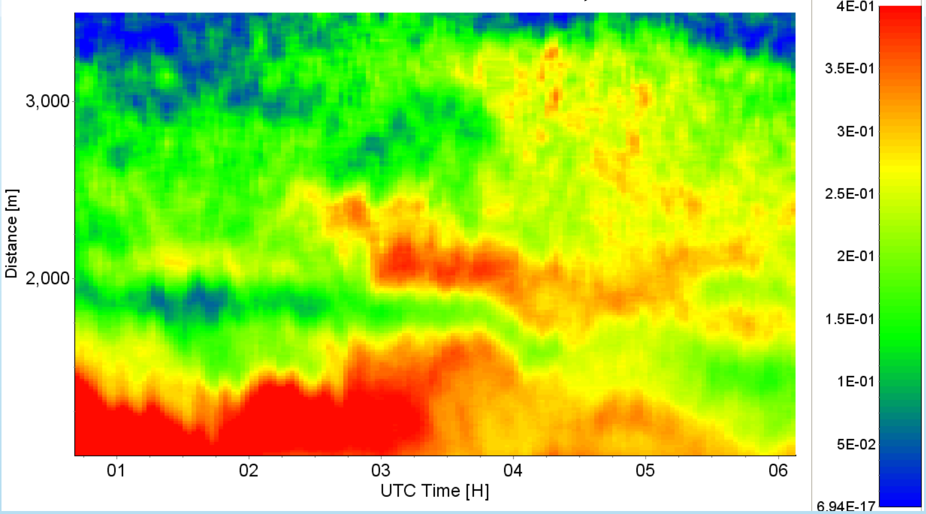
Results obtained in Summer 2011 in GSFC during DISCOVERY campaign

20 July. Extinction at 532 nm is calculated by Klett.
Height res. – 7.5 m, temporal res. – 2 min.
Laser: 300 mJ at 355 nm, 50 Hz, Telescope – 400 mm aperture

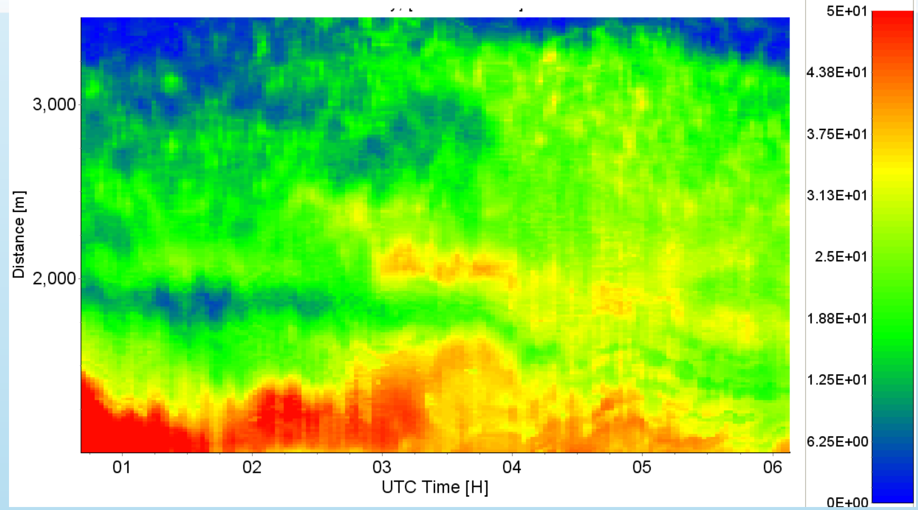


Retrieval particle parameters from 3β+1α set. Height res. ~100 m, temporal res. – 6 min

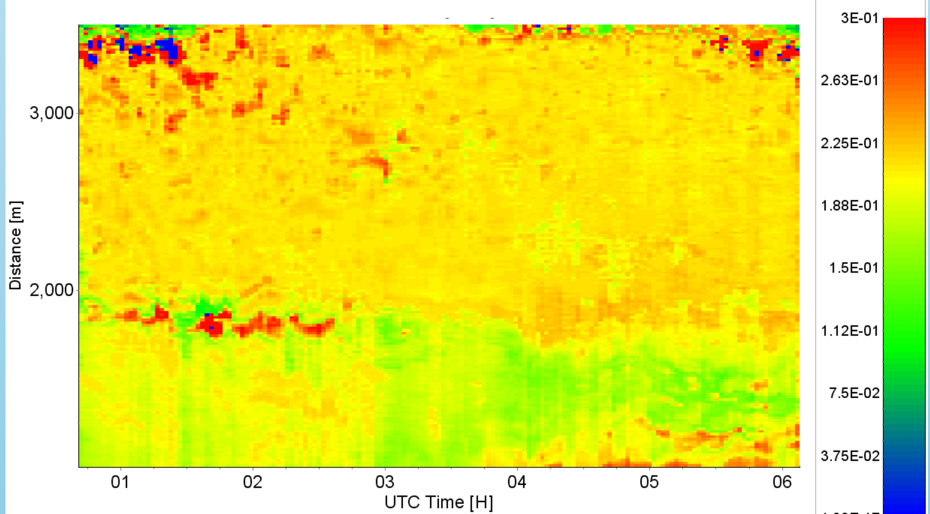
Extinction at 355 nm, km^{-1}



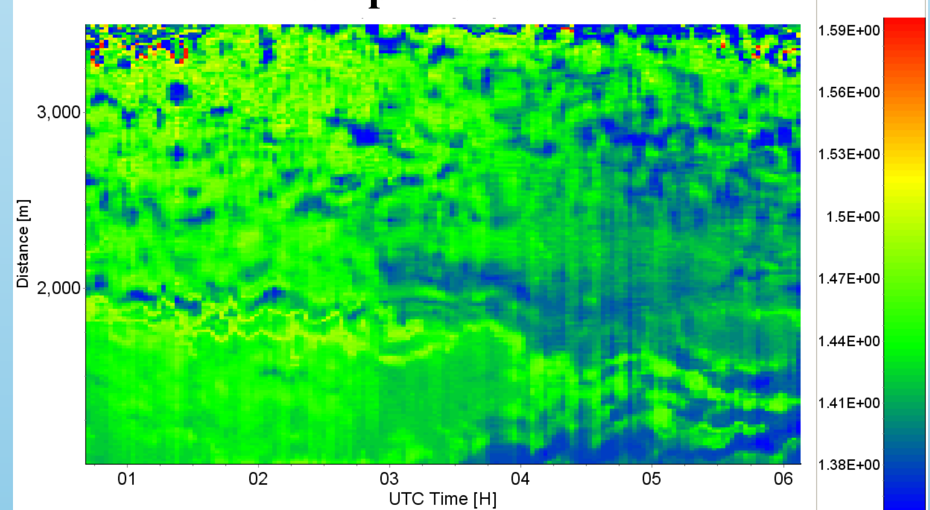
Volume, μm^3/cm^3



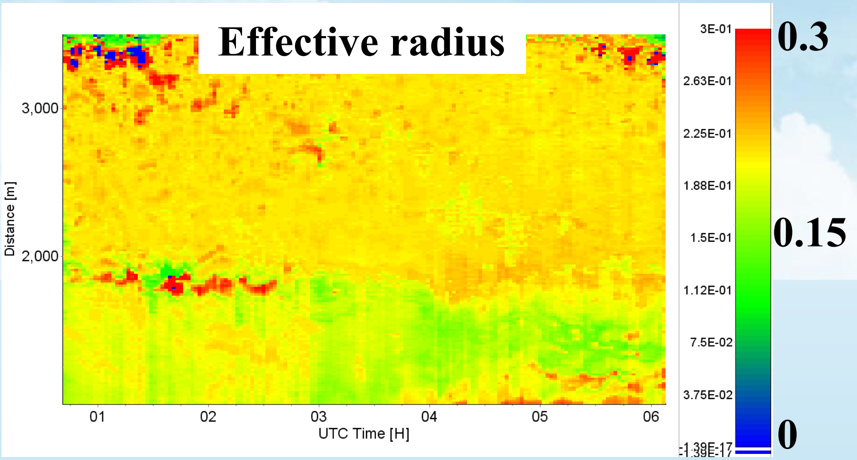
Effective radius

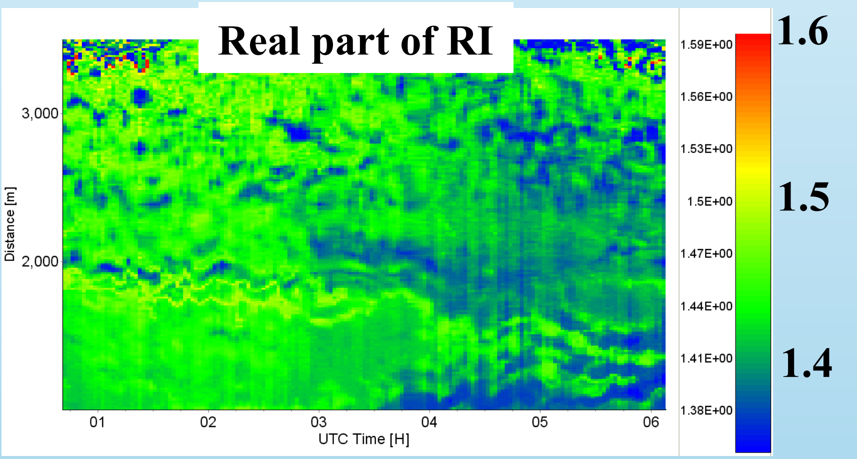


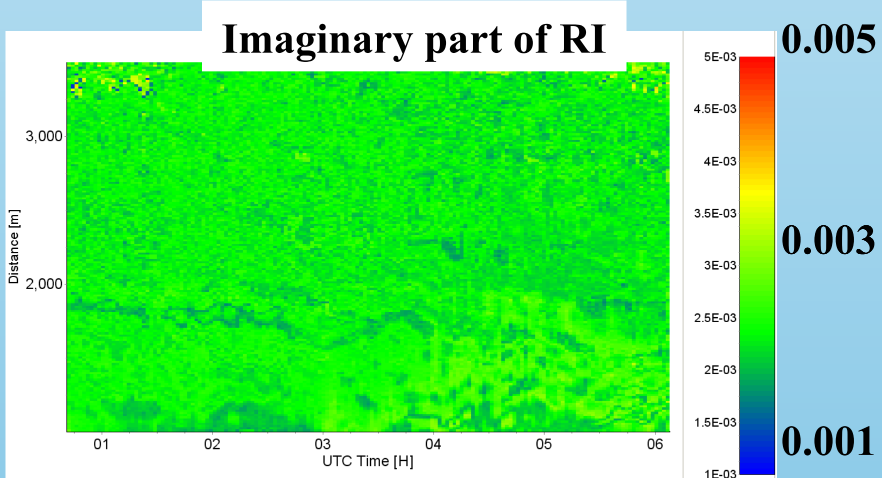
Real part of RI

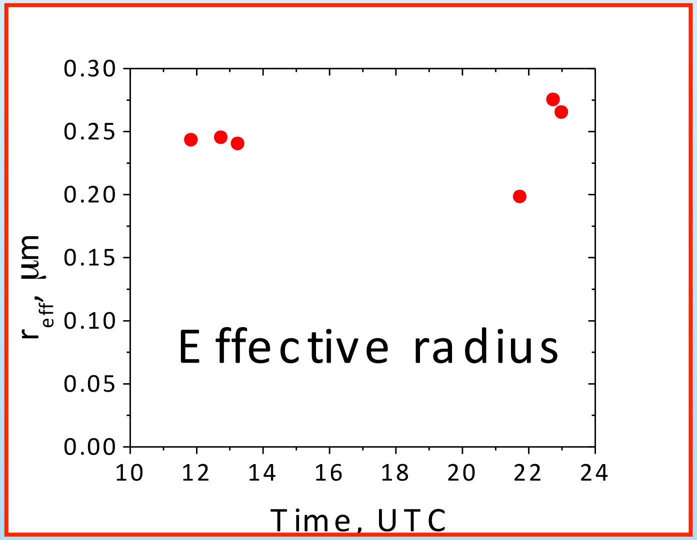


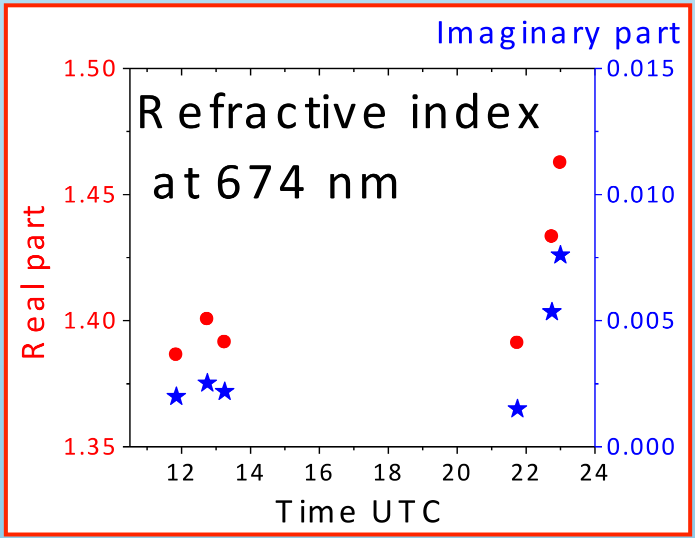
Comparison with AERONET





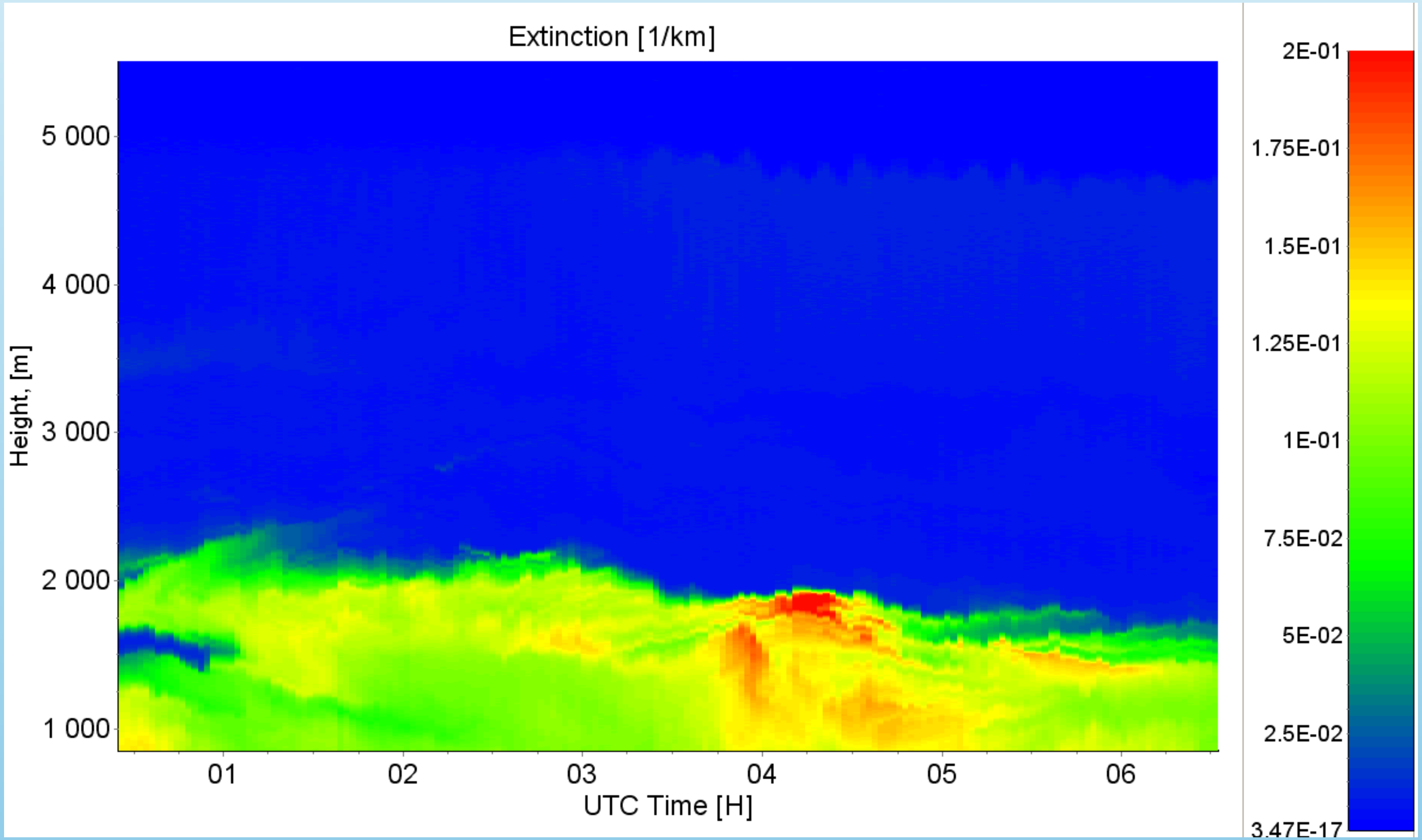




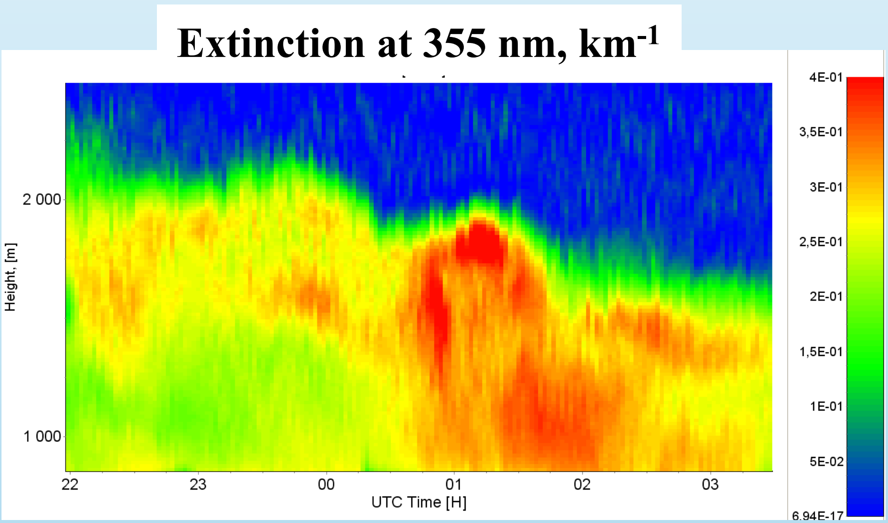


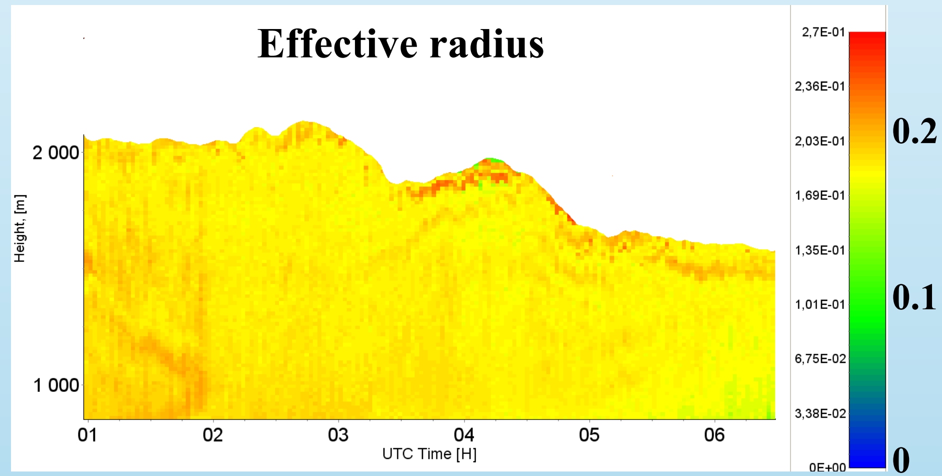
21 July 2011, GSFC

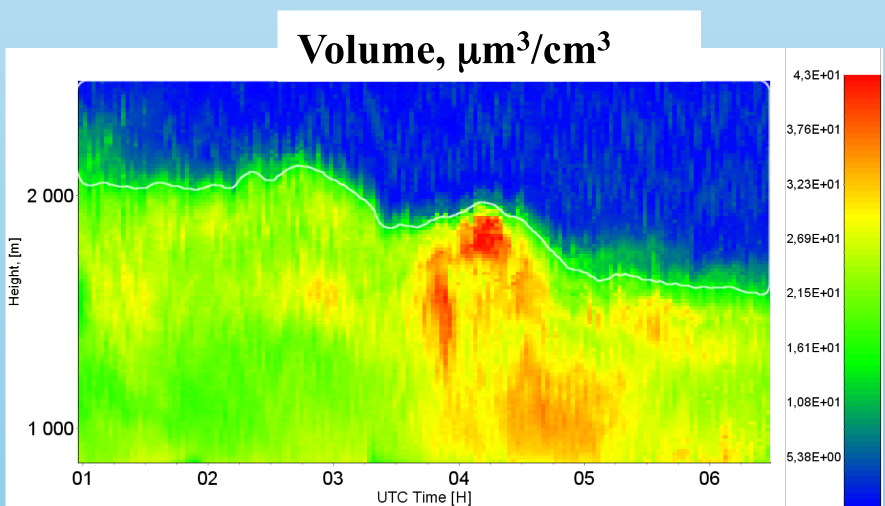
Extinction at 532 nm calculated by Klett.
Height res. – 7.5 m, temporal res. – 2 min.

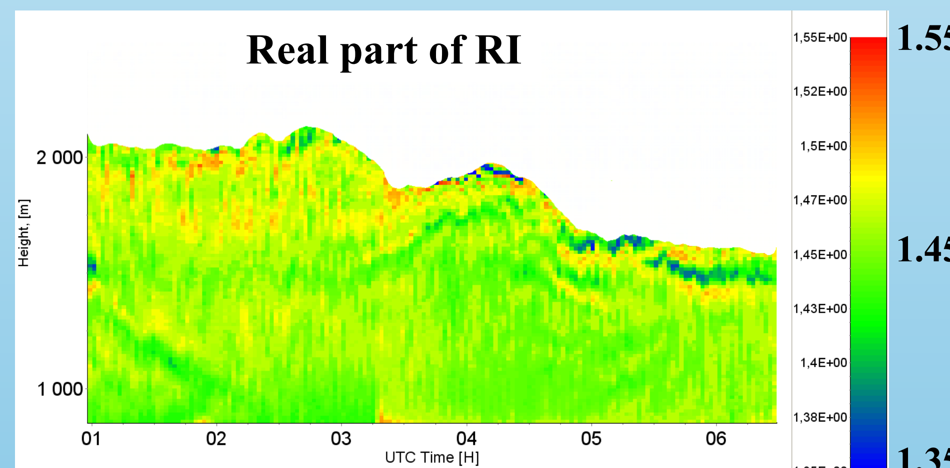


Retrievals for 21 July

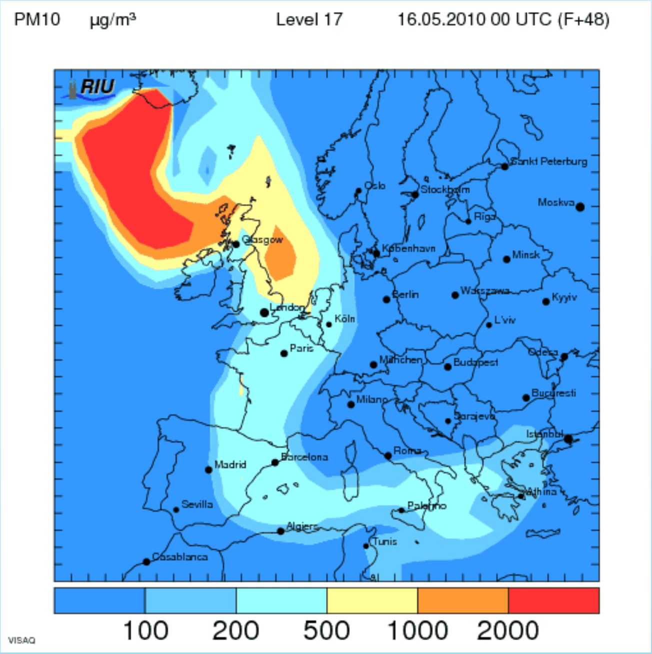




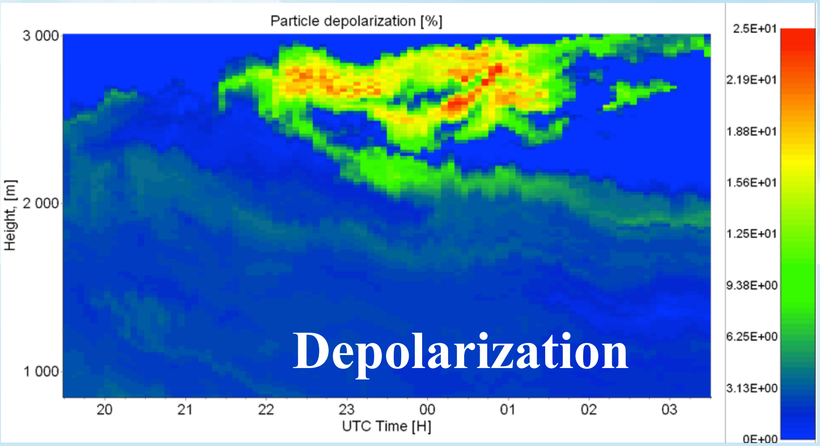




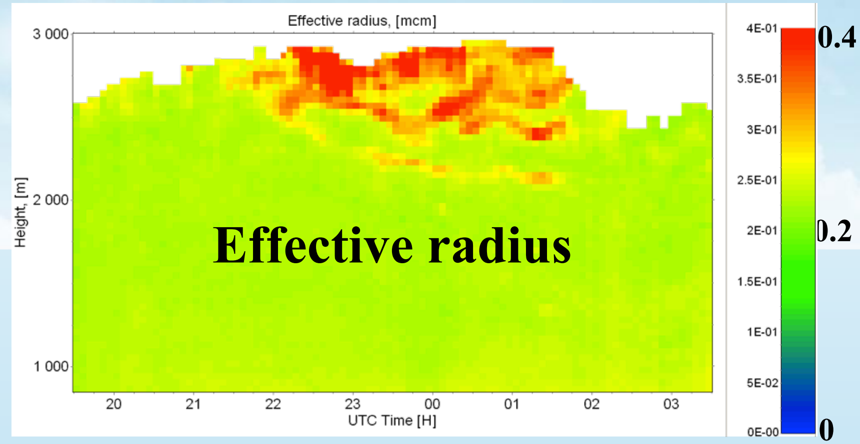
Episode of volcanic ash intrusion on 20-21 May 2010, Istanbul



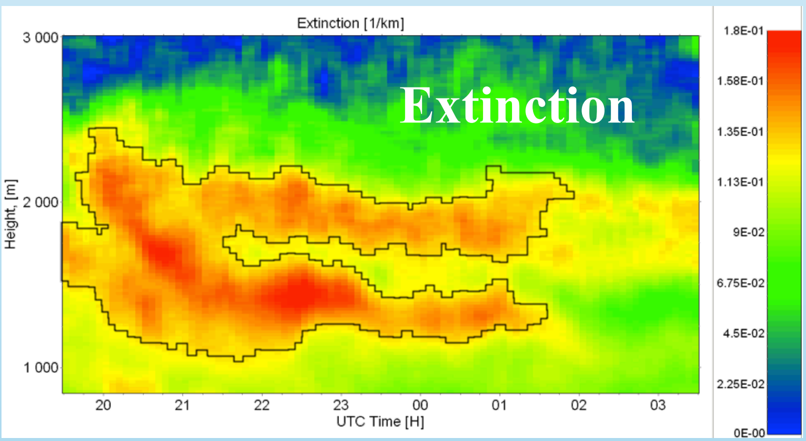
Multiwavelength Raman lidar was installed in the Spring 2009 in TÜBITAK (Turkey).



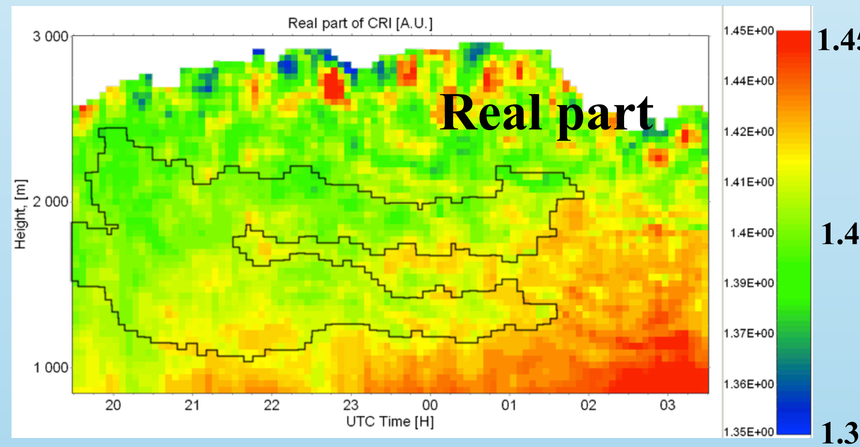
Particle depolarization [%]
Depolarization
Height, [m]
3 000
2 000
1 000
20 21 22 23 00 01 02 03
UTC Time [H]
2.5E+01
2.19E+01
1.88E+01
1.56E+01
1.25E+01
9.38E+00
6.25E+00
3.13E+00
0E+00



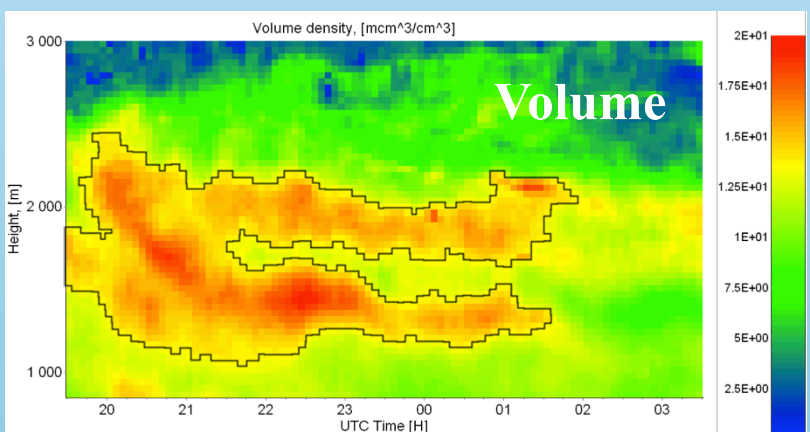
Effective radius, [mcm]
Effective radius
Height, [m]
3 000
2 000
1 000
20 21 22 23 00 01 02 03
UTC Time [H]
4E-01
3.5E-01
3E-01
2.5E-01
2E-01
1.5E-01
1E-01
5E-02
0E-00
0.4
0.2
0



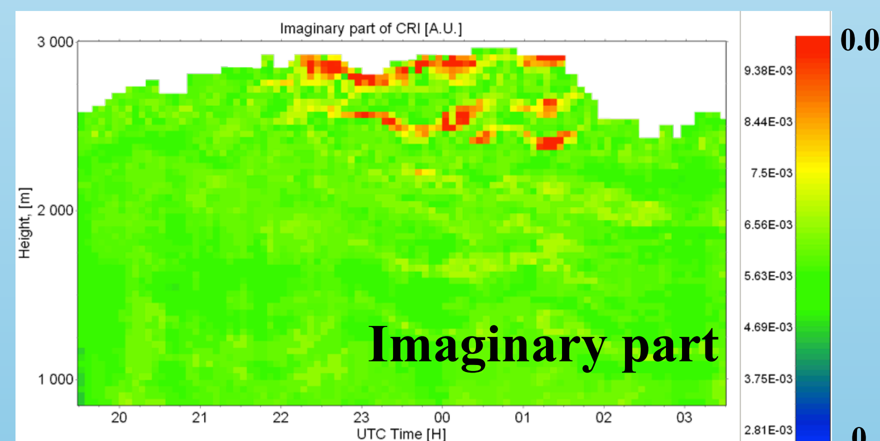
Extinction [1/km]
Extinction
Height, [m]
3 000
2 000
1 000
20 21 22 23 00 01 02 03
UTC Time [H]
1.8E-01
1.58E-01
1.35E-01
1.13E-01
9E-02
6.75E-02
4.5E-02
2.25E-02
0E-00



Real part of CRI [A.U.]
Real part
Height, [m]
3 000
2 000
1 000
20 21 22 23 00 01 02 03
UTC Time [H]
1.45E+00
1.44E+00
1.42E+00
1.41E+00
1.4E+00
1.39E+00
1.37E+00
1.36E+00
1.35E+00
1.45
1.40
1.35



Volume density, [mcm^3/cm^3]
Volume
Height, [m]
3 000
2 000
1 000
20 21 22 23 00 01 02 03
UTC Time [H]
2E+01
1.75E+01
1.5E+01
1.25E+01
1E+01
7.5E+00
5E+00
2.5E+00
0E-00



Imaginary part of CRI [A.U.]
Imaginary part
Height, [m]
3 000
2 000
1 000
20 21 22 23 00 01 02 03
UTC Time [H]
9.38E-03
8.44E-03
7.5E-03
6.56E-03
5.63E-03
4.69E-03
3.75E-03
2.81E-03
0.01
0

Summary

- Application of “kernels expansion” technique brings a significant increase in speed of computations. Time sequences of particle physical parameters can be obtained.
- Possibility to decrease number of input data is important for coming missions.