Inverse modeling to retrieve vertical profiles of aerosol extinction and trace gases

Sunil Baidar, Hilke Oetjen, Barbara Dix,
Rainer Volkamer
2011/11/01

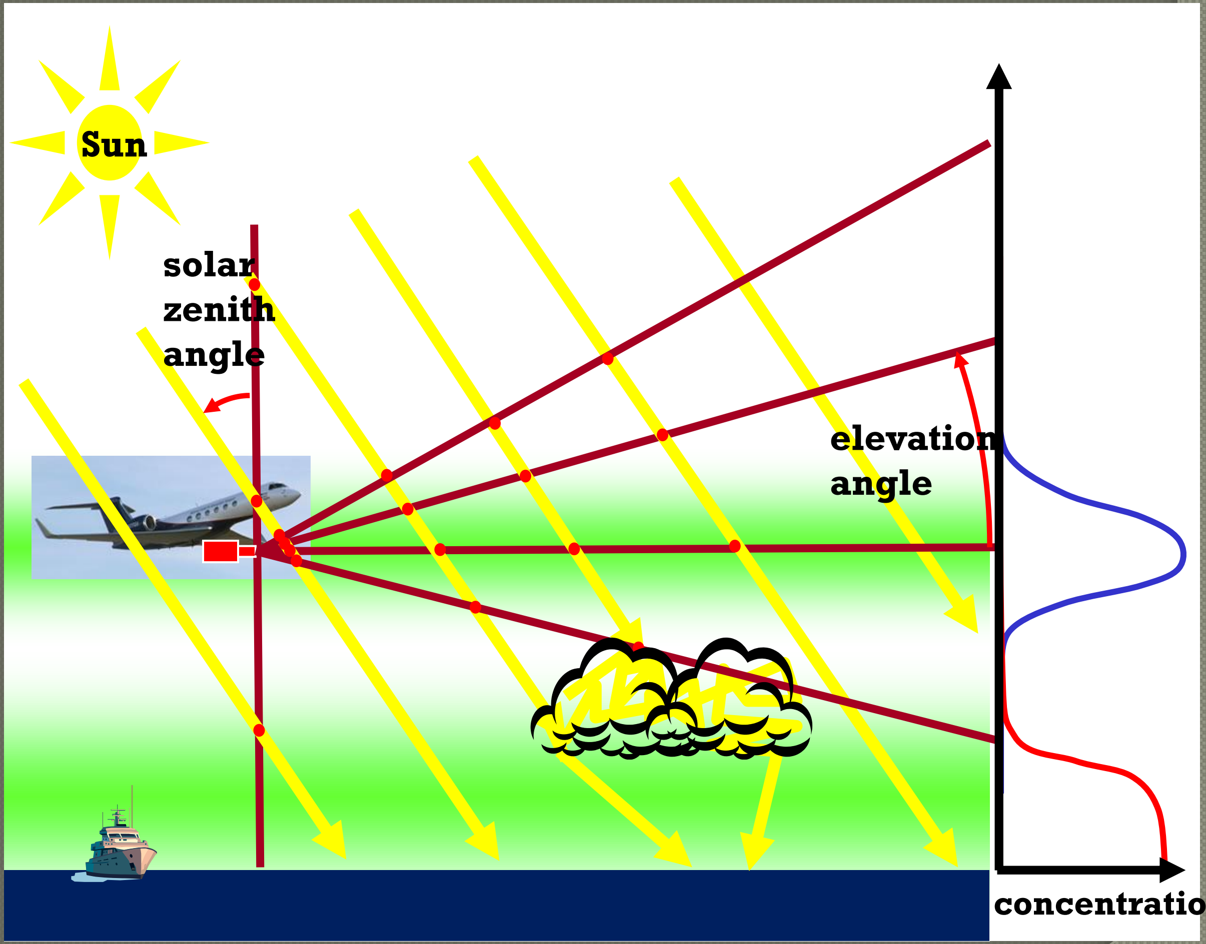
- Primary quantity measured by AMAX-DOAS is Slant Column Densities (SCDs).
- SCD- Integrated concentration of species along the light path.

- Difficult to interpret.

- Requires knowledge of effective light path

- Radiative transfer program

- Inversion technique



$$\mathbf{y} = \mathbf{F}(\mathbf{x}, \mathbf{b}) + \boldsymbol{\varepsilon}$$

$$\mathbf{y} \approx \mathbf{K}\mathbf{x} + \boldsymbol{\varepsilon}$$

$$\text{where } \mathrm{K} = \frac{\partial F(x)}{\partial x}$$

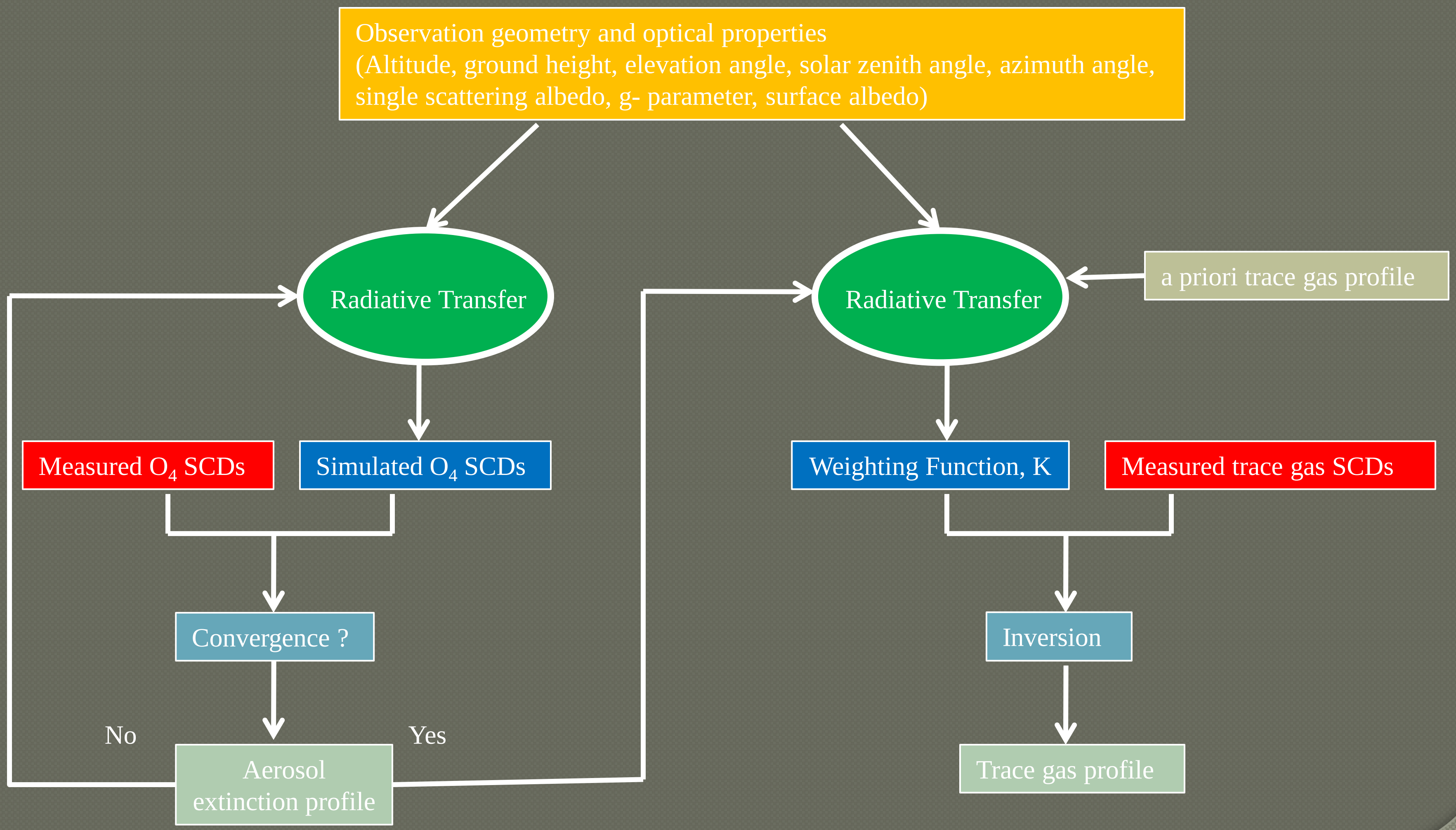
Optimal Estimation

- Uses apriori profile, x_a to constrain the problem.
- provides best solution out of all the possible solutions.

Linear Solution:

$$\hat{x} = (\mathbf{K}^T\mathbf{S}_\varepsilon^{-1}\mathbf{K} + \mathbf{S}_a^{-1})^{-1}(\mathbf{K}^T\mathbf{S}_\varepsilon^{-1}\mathbf{y} + \mathbf{S}_a^{-1}\mathbf{x}_a)$$

Profile retrieval Algorithm



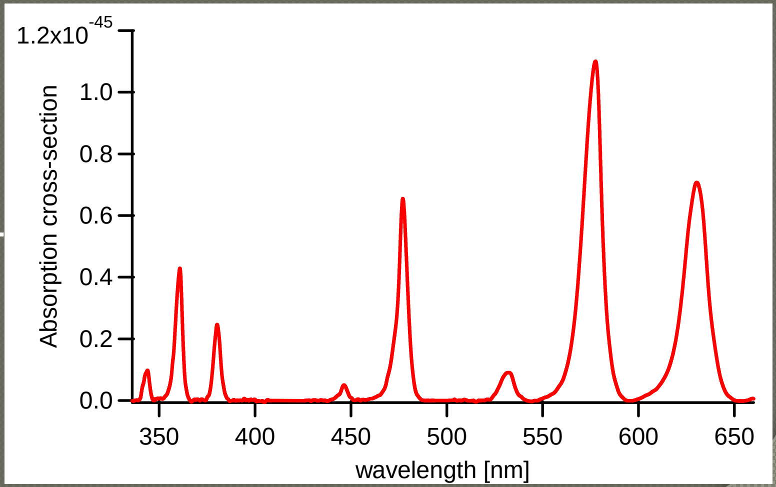
Aerosol Extinction Profile Retrieval

O_4

- O_2 dimer
- Concentration of O_4 is well known
  - depends only on temperature, pressure and O_2 concentration

- Any deviation in O_4 scds from the simulated O_4 scds for the Rayleigh atmosphere is due to the extinction of light by aerosols and clouds.

- O_4 measurement at 360, 477, 577 and 630 nm.



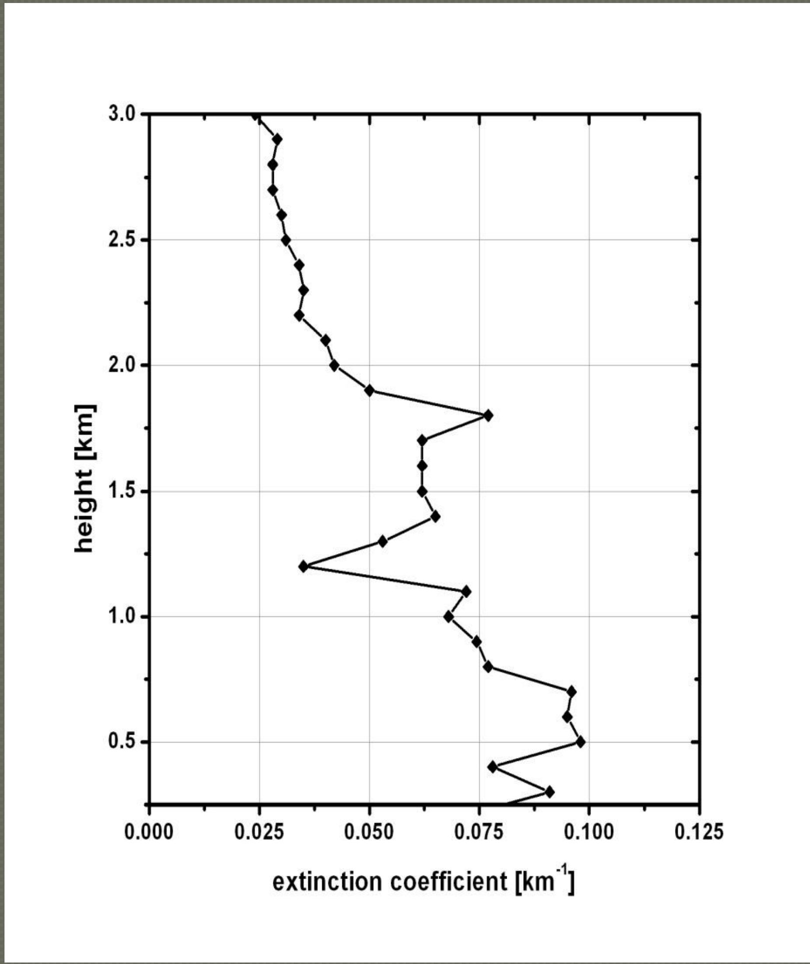
Radiances

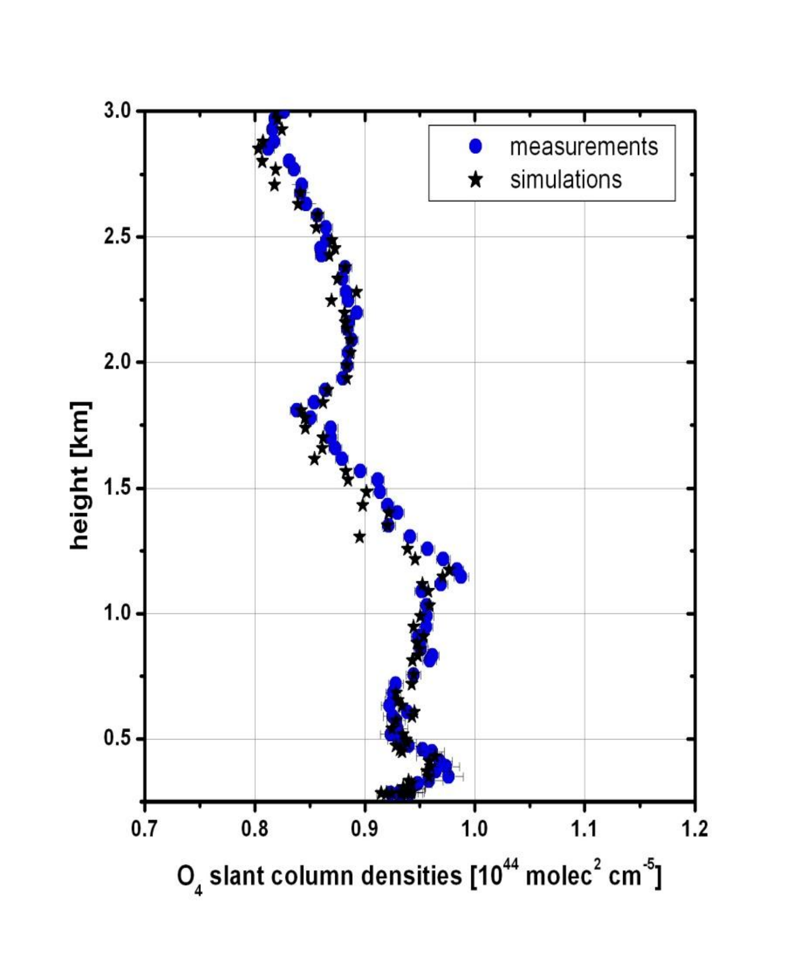
Relative radiance ratio of differen

retrieve aerosol extinction profiles.

Example Aerosol Extinction Profile

Only 0 degree elevation angle!



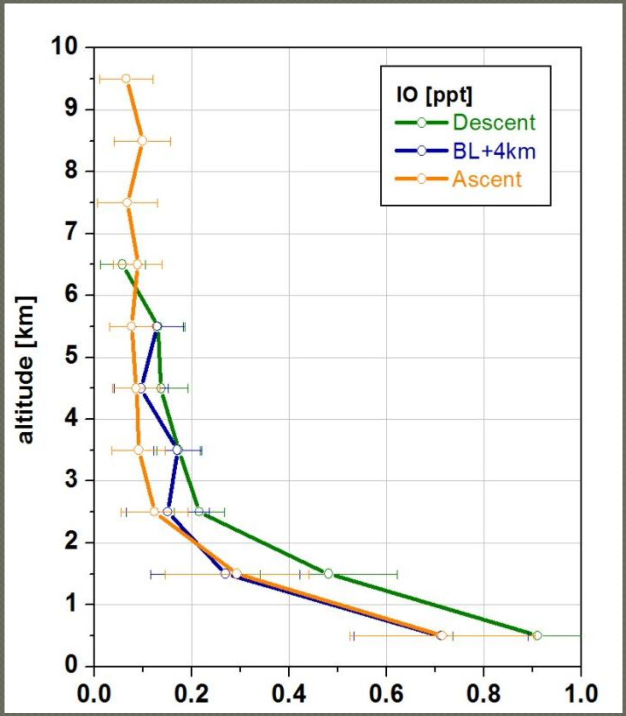


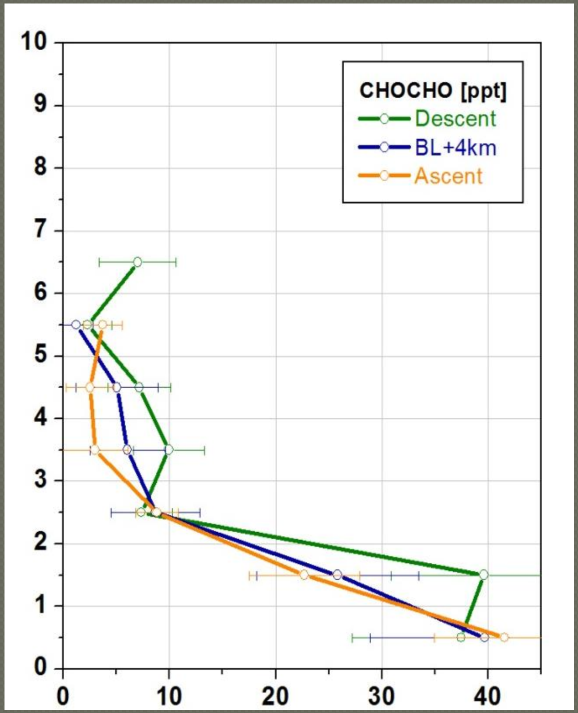
Example Trace Gas Profiles

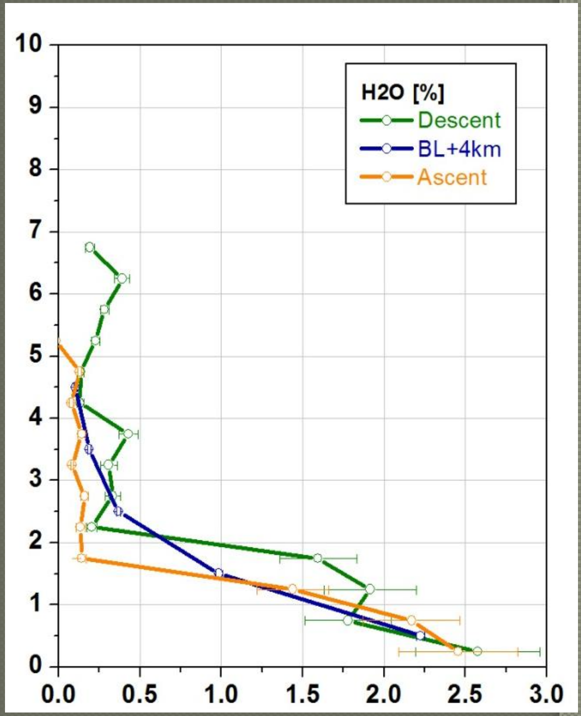
IO

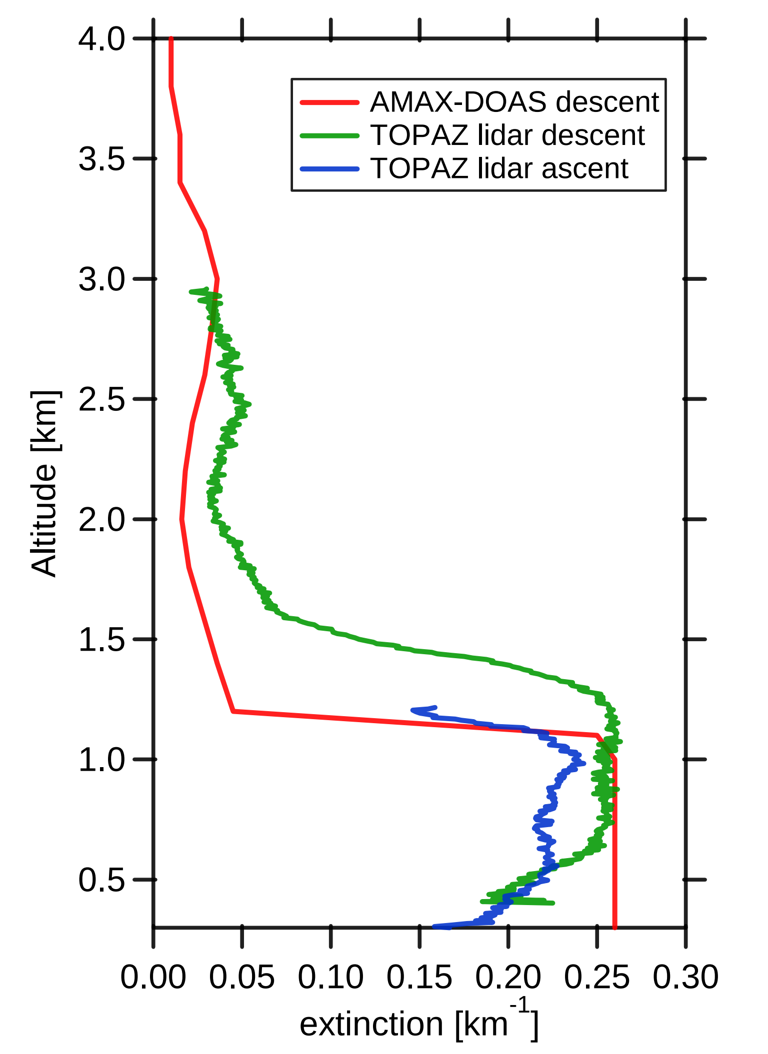
CHOCHO

H_2O









- Aerosol extinction profile from NOAA TOPAZ lidar and AMAX-DOAS.
- Different air masses being probed by AMAX-DOAS and TOPAZ at a given segment.
- How do we maximize the overlap between different instruments?

Instrument	Species / Parameters	Detection limit / Accuracy / Comment	Time / Space resolution	PI / Institution
CU AMAX-DOAS	IO BrO OClO NO_2 HCHO CHOCHO	0.1 ppt 1 ppt 0.7 ppt 10 ppt 120 ppt 3 ppt	Acquisition: 2-30 sec Profile scan: 1-5 mins Vertical resolution: ~ few 100 m– few km	Rainer Volkamer (CU Boulder)
HARP	Photon actinic flux: J_{O3}, J_{NO2}, J_{OVOC}, J_{RX}, J_{IxOy}, etc. Hyper spectral irradiance Surface albedo Cloud optical depth + Percent cloud cover Cloud/Aerosol eff. radius Single scattering albedo Asymmetry parameter	~ 9 % (280–680 nm) < 5 % (260–2217 nm) < 3 % ~ 3 % ~ 5 % ± 0.03 ~ 0.1	0.1 – 3 sec 1 sec inferred by difference from hyper spectral irradiance data	Sam Hall (NCAR/ACD) Sebastian Schmidt (CU Boulder)
GV-HSRL	Aerosol Backscatter, Depolarization, Extinction altitude profiles	$1x10^{-9}$ m^{-1} sr^{-1} ~ 1% $2x10^{-8}$ cm^{-1}	Acquisition: 0.5 sec Profile time: 3-5 mins Vertical res.: 7.5 m Range: 30 km	Ed Eloranta (U Wisconsin)
Microwave Temperature Profiler	Altitude temperature profile	1 K (near plane) < 2 K (within 6km from plane)	Profile scan: 18 sec Vertical resolution: ~150 m to few km	Julie Haggerty (NCAR/RAF)

Discussions

Radiative transfer calculation would be greatly improved by having independent measurement of

1. Temperature Profile (MTP)
2. Aerosol extinction profile (HSRL)
3. Cloud layer altitude (HSRL)
4. Surface albedo (HARP)
5. Aerosol optical depth (HARP)
6. Single scattering albedo, asymmetry parameter (HARP)

Optimal Estimation:

-formally described by Clive Rodgers (Rodgers, 1976).
- Uses apriori profile, x_a to constrain the problem.
- provides best solution out of all the possible solutions.

Linear Solution:

$$\hat{x} = (K^T S_\varepsilon^{-1} K + S_a^{-1})^{-1} (K^T S_\varepsilon^{-1} y + S_a^{-1} x_a)$$

$\hat{x}$ the retrieved state vector

$\mathbf{x}_a$ the a priori information of the state

$\mathbf{S}_a$ the a priori covariance. A square matrix with the uncertainty of the a priori as diagonal elements.

$\mathbf{S}_\varepsilon$ covariance of the uncertainty of the measurement.

$\mathbf{K}$ weighting function matrix.

$\mathbf{S}_a$ is also used as the tuning parameter to maximize the information content while avoiding oscillations.