

Lecture 23

Applications of lidars: Sensing of aerosols and clouds

Objectives:

1. Lidar sensing of aerosols
2. Lidar sensing of clouds
3. Lidars in space: LITE and CALIPSO

Required reading:

G: 8.4.3, 8.4.4

Additional/advanced reading:

Raman lidar

<http://www.arm.gov/docs/instruments/static/rl.html>

Clouds from lidars

<http://www.met.utah.edu/ksassen/cloud/principle.html>

1. Lidar sensing of aerosols

Main advantage: lidar sensing gives a vertical profile of an a particular aerosol optical characteristic (extinction, backscattering or the ratio of the extinction to backscattering).

Elastic Backscattering Lidars => extinction-to-backscatter ratio

NOTE: Eq.[22.7] which gives the solution for k_e for an assumed relationship between k_e and k_b

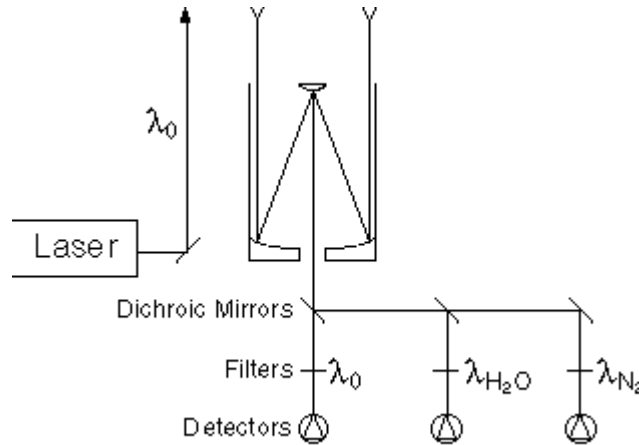
Example: MPL-Net is a worldwide network of micro-pulse lidar (MPL) systems operated

by NASA (<http://virl.gsfc.nasa.gov/mpl-net/>)

MPL operates at the wavelength **0.523 μm**

Raman (inelastic backscattering) Lidars => measures aerosol extinction and backscattering independently

Principles of Raman lidar: Raman lidar systems detect selected species by monitoring the wavelength-shifted molecular return produced by vibrational Raman scattering from the chosen molecule or molecules



- By taking the ratio of the signal at the water-vapor wavelength to the signal at the nitrogen wavelength, most of the range-dependent terms drop out, and one is left with a quantity that is almost directly proportional to the water-vapor mixing ratio (see Lecture 26).

The Raman lidar equation can be written as

$$P_r(R, \lambda_L, \lambda_R) = \frac{C}{R^2} \frac{h}{2} \frac{k_b(R, \lambda_L, \lambda_R)}{4\pi} \exp\left(-\int_0^R [k_e(r', \lambda_L) + k_e(r', \lambda_R)] dr'\right) \quad [23.1]$$

where λ_L and λ_R are the lidar and Raman wavelengths, respectively;

backscattering coefficient $k_b(R, \lambda_L, \lambda_R)$ is linked to the differential Raman backscatter cross section of a gas and molecule number density, $k_e(R, \lambda_L)$ and $k_e(R, \lambda_R)$ are due to molecular (Rayleigh) scattering and aerosol extinction



In Raman lidar, the inelastic Raman backscatter signal is affected by the aerosol attenuation but not by aerosol backscatter => aerosol extinction profile can be retrieved

Example: Raman lidar at DOE/ARM SGP site: Nd:YAG lidar (355 nm)

Receiving Wavelengths: Rayleigh/Aerosol (355 nm); Depolarization (355 nm) ,
Raman water vapor (408 nm), Raman nitrogen (387 nm)

Aerosol characteristics from SGP Raman lidar:

- Aerosol Scattering Ratio (also called lidar scattering ratio)

is defined as the ratio of the total (aerosol+molecular) scattering to molecular scattering

$$[k_{s,m}(\lambda,z) + k_{s,a}(\lambda,z)] / k_{s,m}(\lambda,z)$$

- Aerosol Backscattering Coefficient

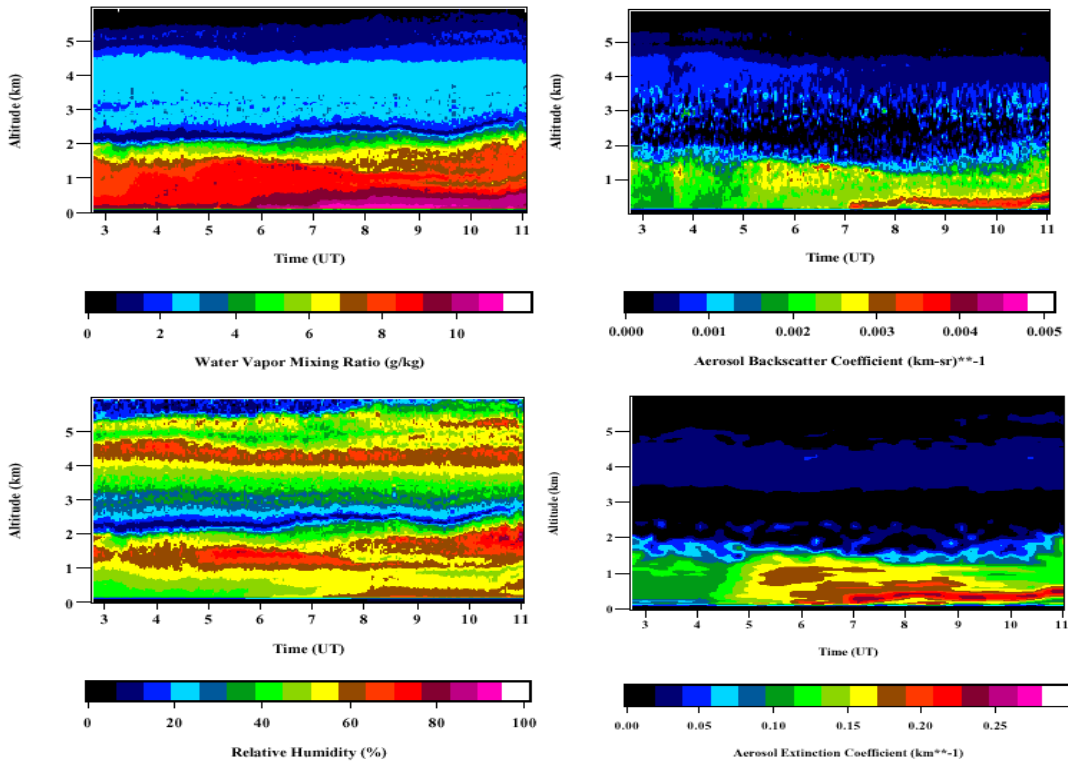
Profiles of the aerosol volume backscattering coefficient $k_b(\lambda=355 \text{ nm}, z)$ are computed using the aerosol scattering ratio profiles derived from the SGP Raman Lidar data and profiles of the molecular backscattering coefficient. The molecular backscattering coefficient is obtained from the molecular density profile which is computed using radiosonde profiles of pressure and temperature from the balloon-borne sounding system (BBSS) and/or the Atmospheric Emitted Radiance Interferometer (AERI). No additional data and/or assumptions are required.

- Aerosol Extinction/Backscatter Ratio

Profiles of the aerosol extinction/backscatter ratio are derived by dividing the aerosol extinction profiles by the aerosol backscattering profiles.

- Aerosol Optical Thickness

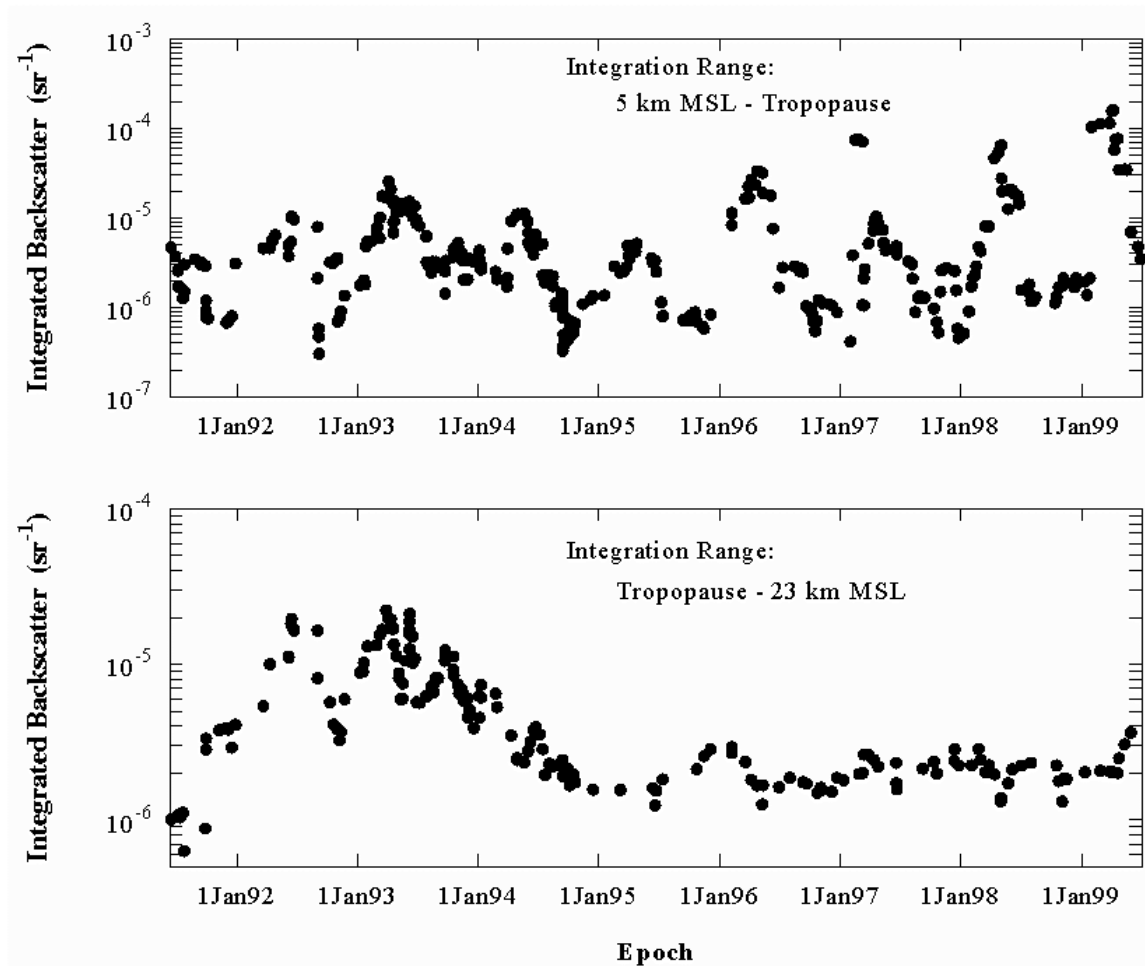
Aerosol optical thickness is derived by integrating the aerosol extinction profiles with altitude.



High Spectral Resolution Lidar (HSRL): see G 8.4.3

CO₂ lidar at 9.25 μm and 10.6 μm: backscattering coefficient

Example: Jet Propulsion Lab (JPL) CO₂ lidar (almost continuous operation since 1984):
vertical resolution is about 200 m throughout the troposphere and lower stratosphere (up to about 30km)



Integrated backscatter from the free troposphere (upper panel) and the lower stratosphere (lower panel) column above the JPL Pasadena site since the eruption of the Philippine volcano Mt. Pinatubo in June of 1991 (Tratt et al.)

2. Lidar sensing of clouds.

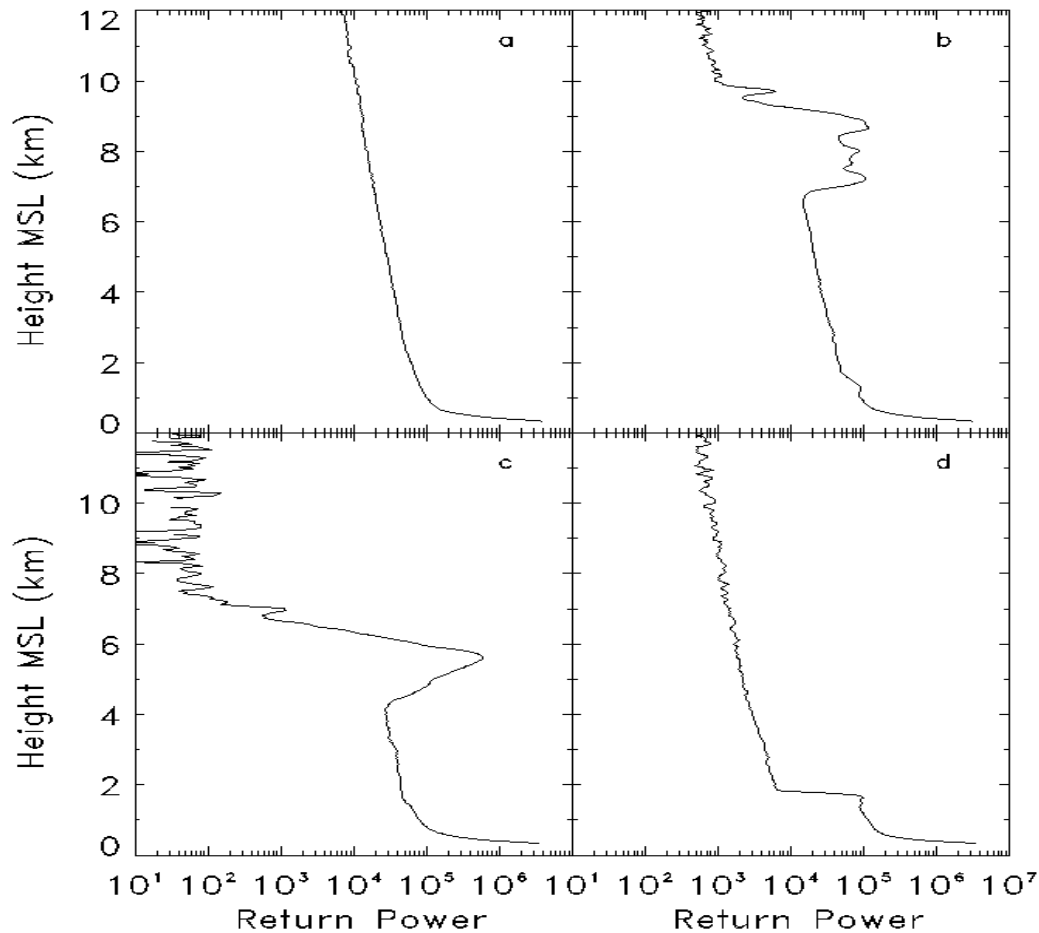


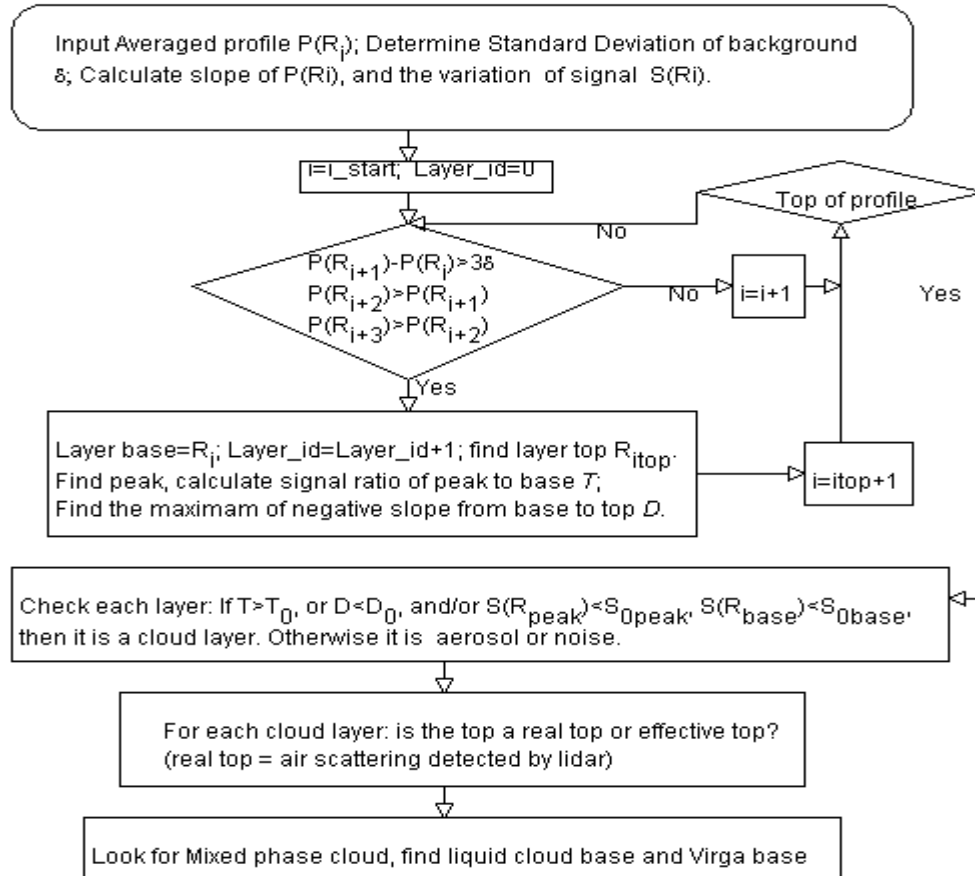
Figure 23.1. Four typical examples of range corrected lidar backscatter versus altitude (ARM Raman lidar, 10 min average, Sassen et al.). Fig. 23.1a illustrates a clear sky backscatter, which decrease with altitude due to the decrease in molecular density. Fig. 23.1b shows a backscatter from cirrus, which has a strong increase in backscatter above cloud base, and air return above cloud top. Backscatter, which is totally attenuated in clouds, is shown in Fig. 1c. Compare with clear sky case (Fig. 23.1a), we can find a very strong increase in lidar backscatter form clouds (Fig. 23.1b-c), but it is not always observable (Fig. 23.1d). The other common feature for cloud signal is there is a fast decrease region in cloud backscatter due to strong attenuation of clouds or transition form cloud to clear region. So strong negative and strong positive slope in lidar backscatter signal are observable in the presence of clouds.

Cloud boundary detection: there is no universal algorithm

Common approach: analysis of dP/dR (i.e., returned power vs. the range)

Algorithm by Sassen et al.: <http://www.met.utah.edu/ksassen/cloud/principle.html>

Cloud Detection Algorithm



Other cloud properties from Raman lidar:

Warm clouds:

Liquid water, droplet radius, number density

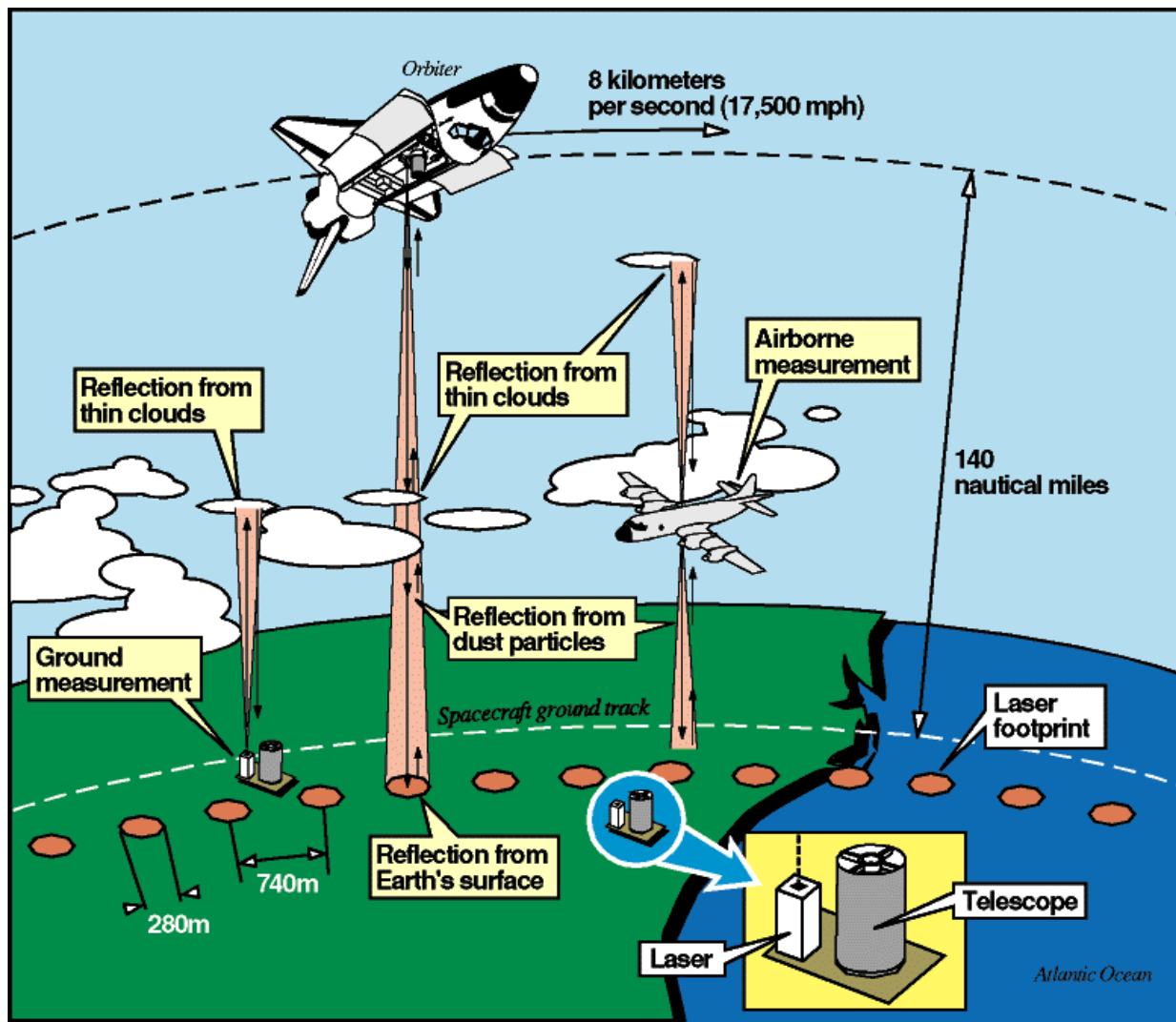
Melfi, S.H., K. Evans, J. Li, D. Whiteman, R. Ferrare, and G. Schwemmer, 1997: Observations of Raman scattering by cloud droplets in the atmosphere. *Appl. Opt.*, 36, No. 15, 3551-3559

Cold clouds (cirrus): Optical depth, extinction /backscatter ratio, particle radius

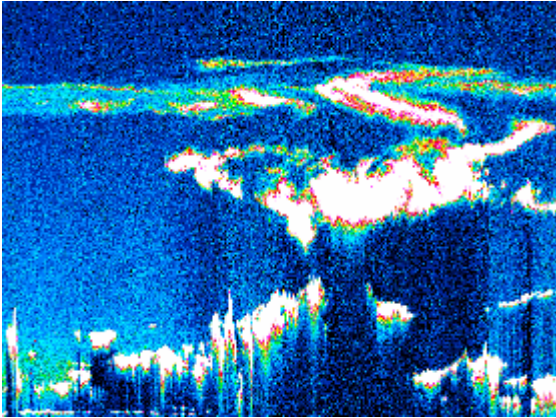
3. Lidars in space

LITE (Lidar In-space Technology Experiment) (<http://www-lite.larc.nasa.gov/>)

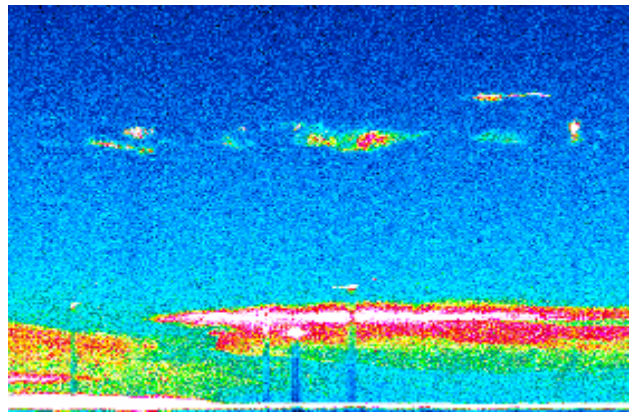
- LITE flew on Discovery in September 1994
- LITE was operated for 53 hours, resulting in over 40 GBytes of data covering 1.4 million kilometers of ground track;
- YAG lasers which emit simultaneously at the three harmonically related wavelengths of 1064 nm (infrared), 532 nm (visible green), and 355 nm (ultraviolet). The two-laser system provides redundancy in case one laser fails. Only one laser operates at a time.



LITE provided FIRST highly detailed global view of the vertical structure of cloud and aerosols



Multi-layer cloud system



Saharan dust

CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations)

<http://www-calipso.larc.nasa.gov/picasso.html>

- **CALIPSO** will fly a 3 channel lidar and passive instruments in formation with Aqua and CloudSat to obtain coincident observations of radiative fluxes and atmospheric state.
- **CALIPSO** will be launched in April 2004

Together, CALIPSO and Aqua provide

- A global measurement suite from which the first *observationally* -based estimates of aerosol direct radiative forcing of climate can be made.
- A dramatically improved empirical basis for assessing aerosol indirect radiative forcing of climate.
- A factor of 2 improvement in the accuracy of satellite estimates of longwave radiative fluxes at the Earth's surface and in the atmosphere.
- A new ability to assess cloud-radiation feedback in the climate system.