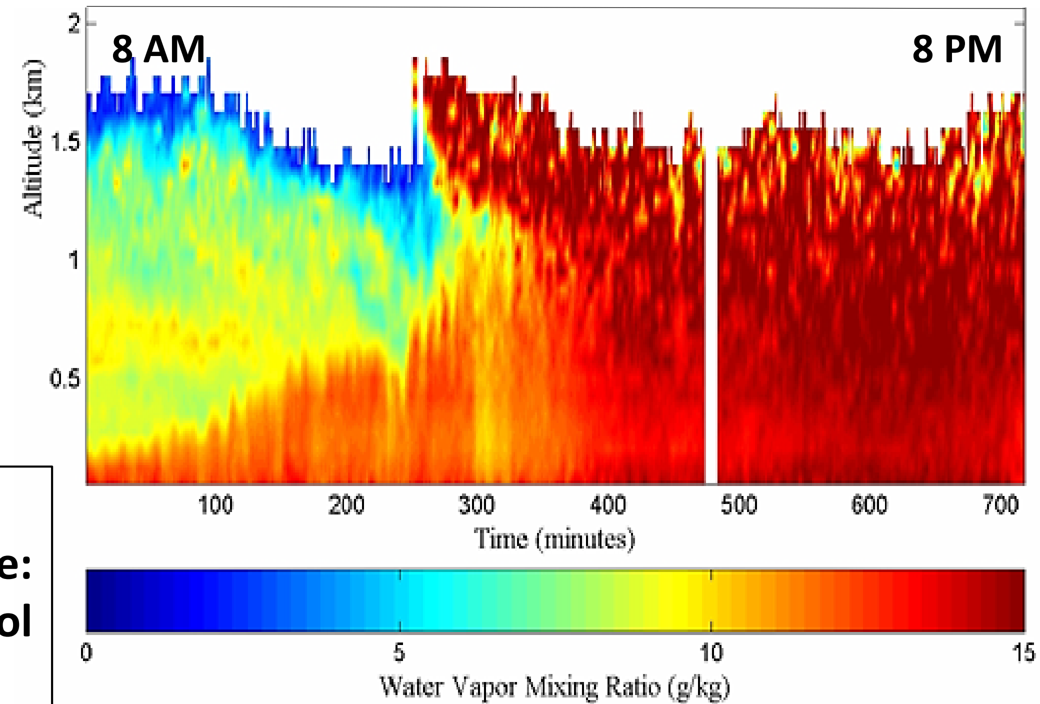
Atmospheric Measurements:
The Next Generation Laser Remote Sensor

Russell Philbrick and Hans Hallen
Physics Department and
MEAS Department,
NC State University,
Raleigh NC 27695-8202

08/22/1998 Philadelphia, PA NARSTO-NEOPS



Goals of this paper are to introduce:

(1) The set of measurements available: Water Vapor, Temperature, Aerosol Extinction, Particle Size, Ozone.

(2) Show examples: convection, pollution events, a bore wave, Brunt-Väisälä oscillations, and cloud micro-physics.

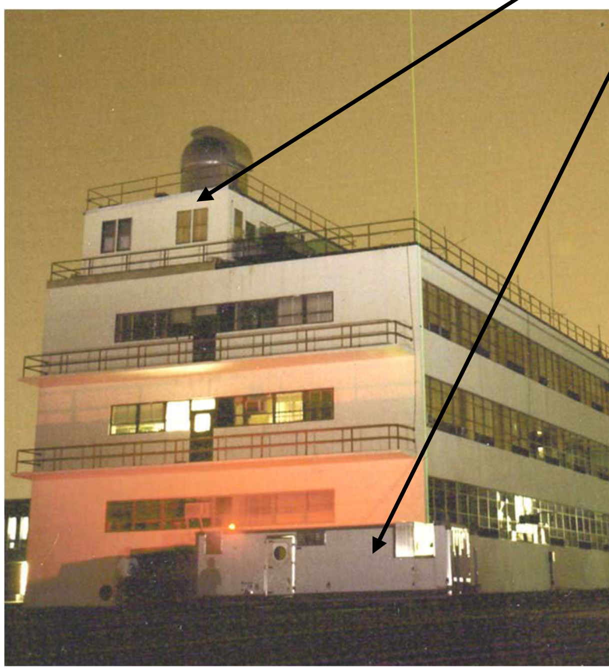
(3) A future continuous automated LIDAR instrument: meteorological data on H_2O, T (°K), extinction, aerosol size, and O_3.

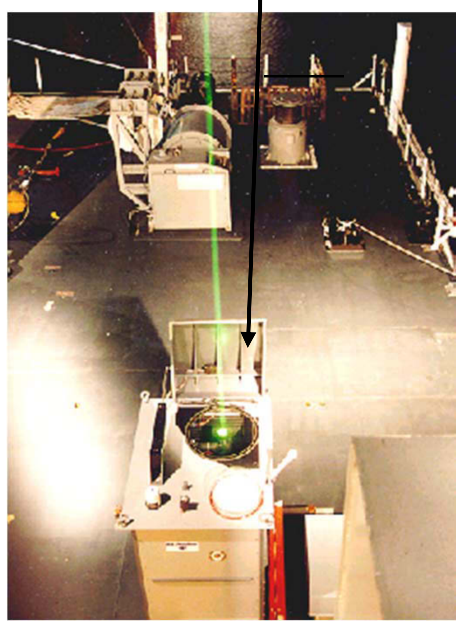
NASA Air Quality Applied Sciences Team (AQAST)
10th Semiannual Meeting at EPA,
Research Triangle Park, Jan 5-7, 2016

Raman Lidar Development

Five generations of Raman Lidars

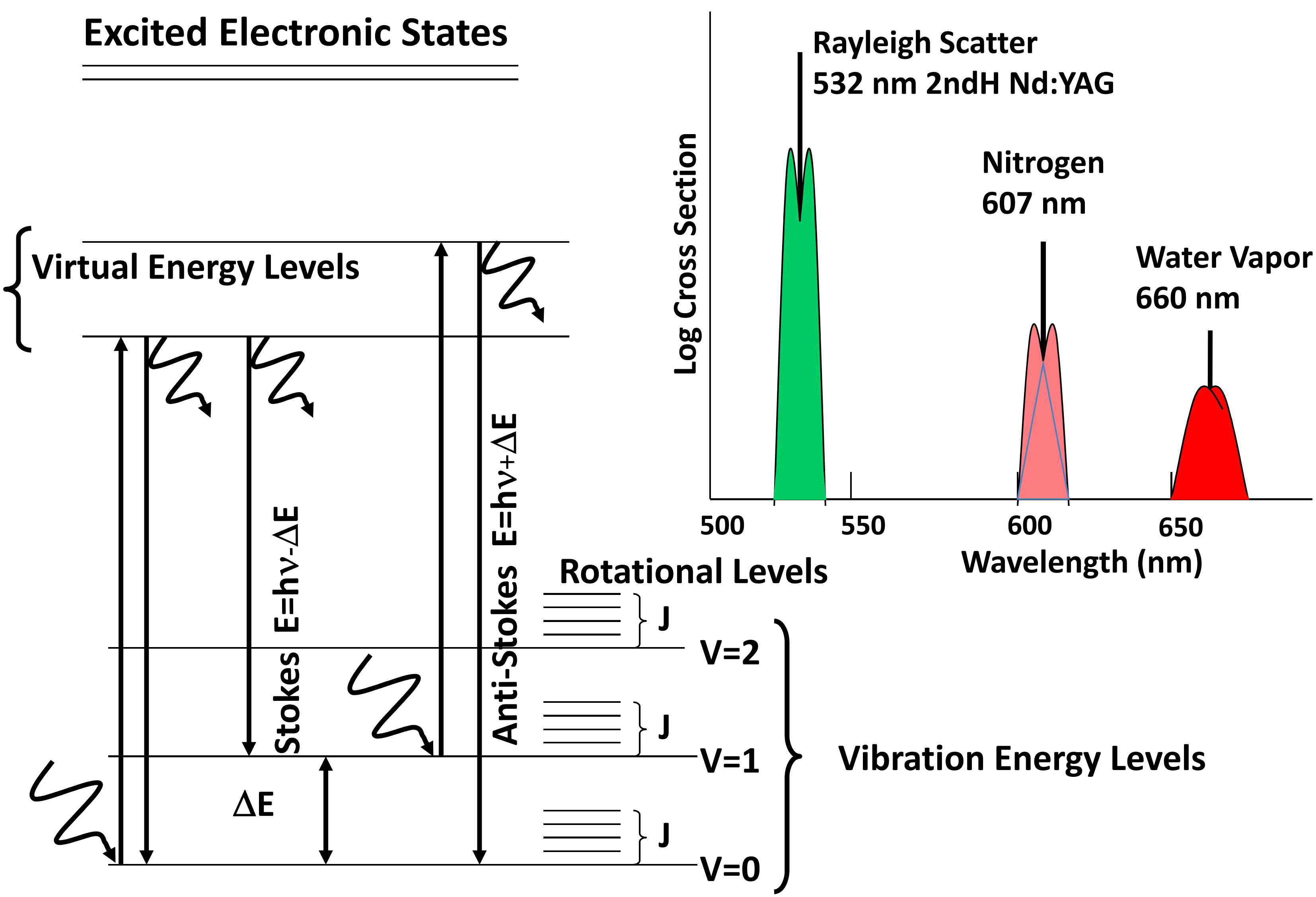
GLEAM (1978)
GLINT (1983)
LAMP (1990)
LARS (1994)
LAPS (1996)





Raman Scatter Energy Levels

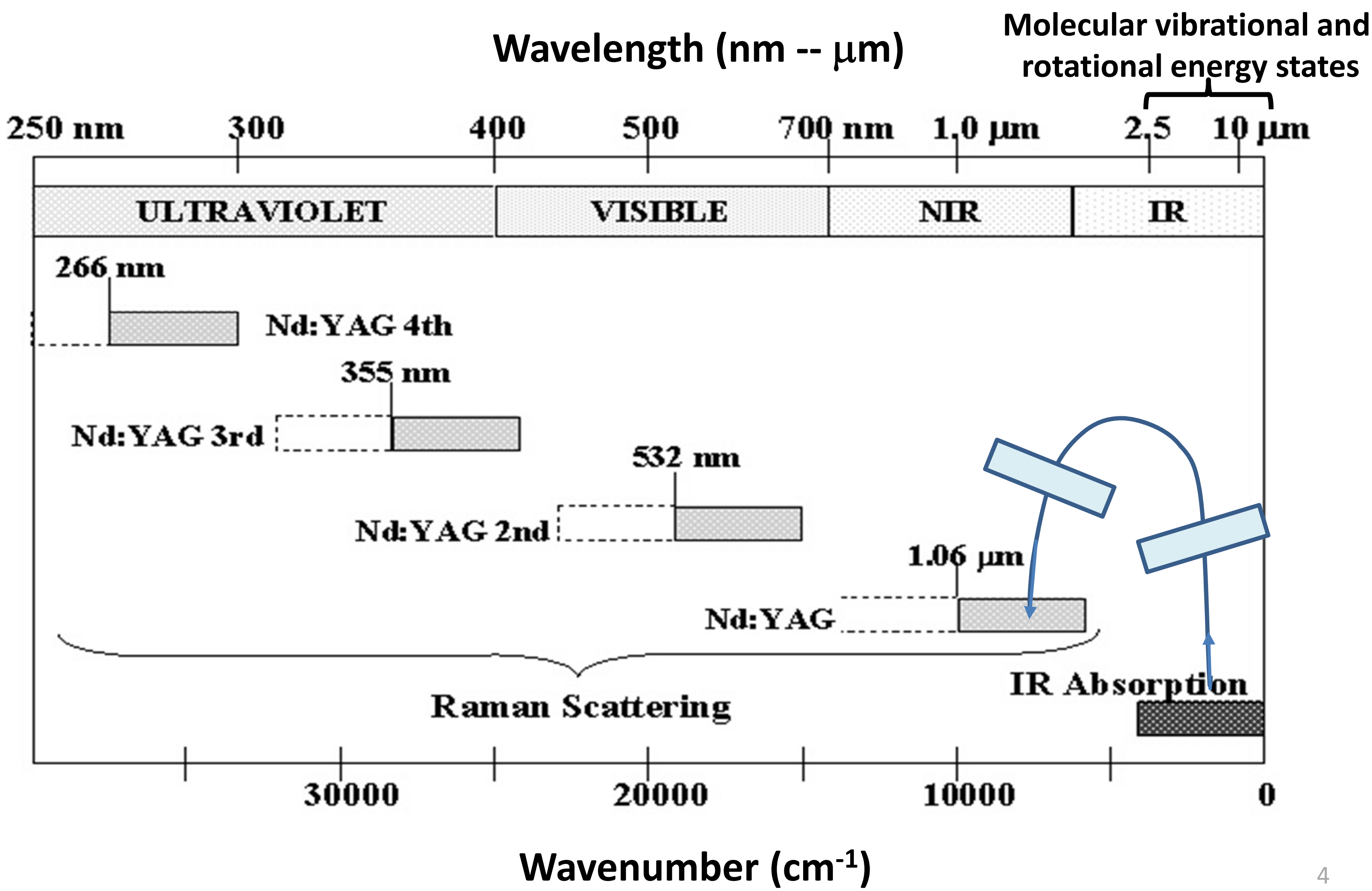
Raman Measurements Water Vapor and Aerosol Extinction



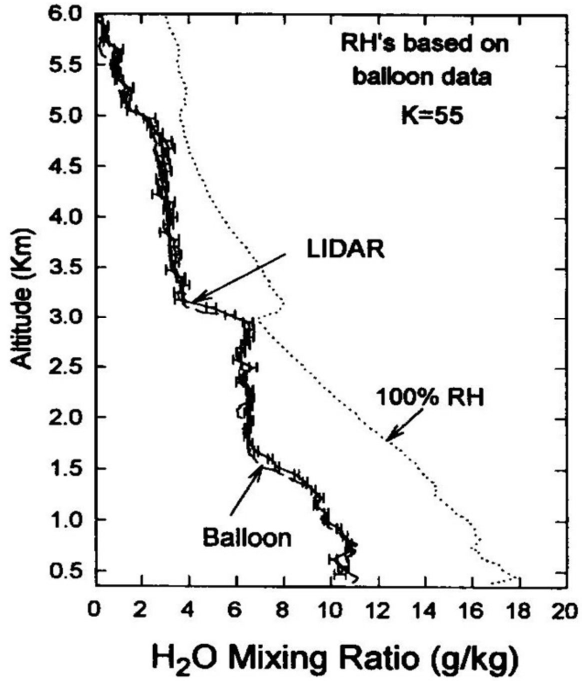
Multiple Wavelength Laser Transmitter

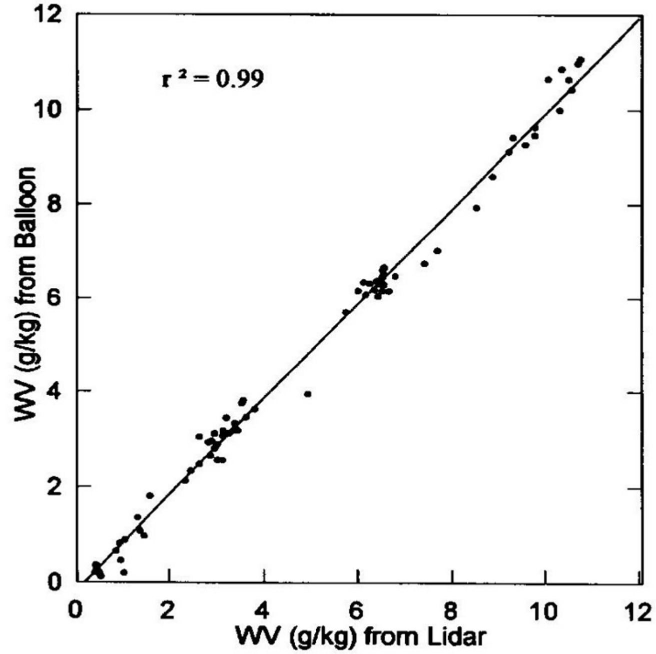
Fundamental Nd:YAG Laser at 1064 nm

With 2nd, 3rd, 4th Harmonics – 532, 355, 266 nm



75 meter resolution

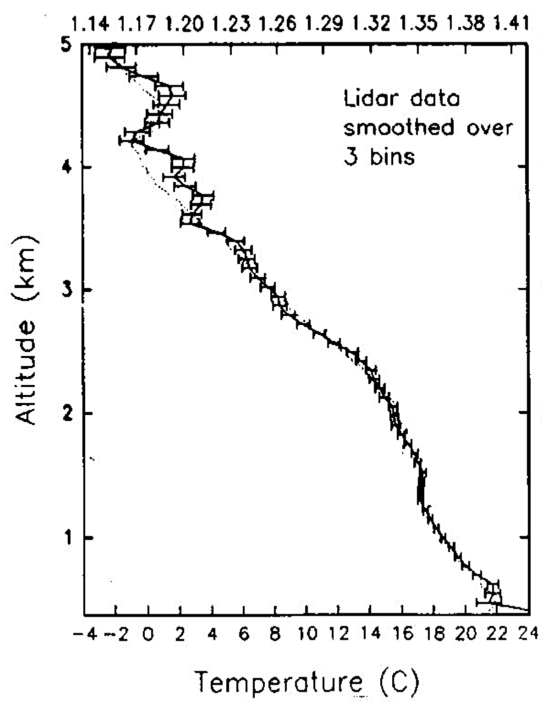


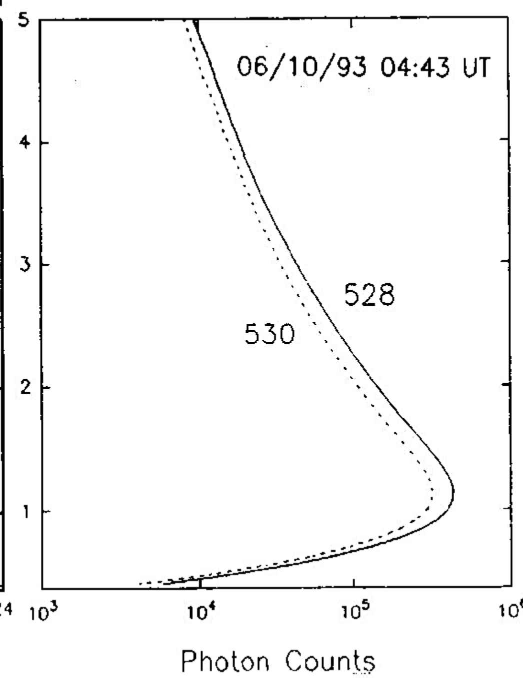


Water Vapor

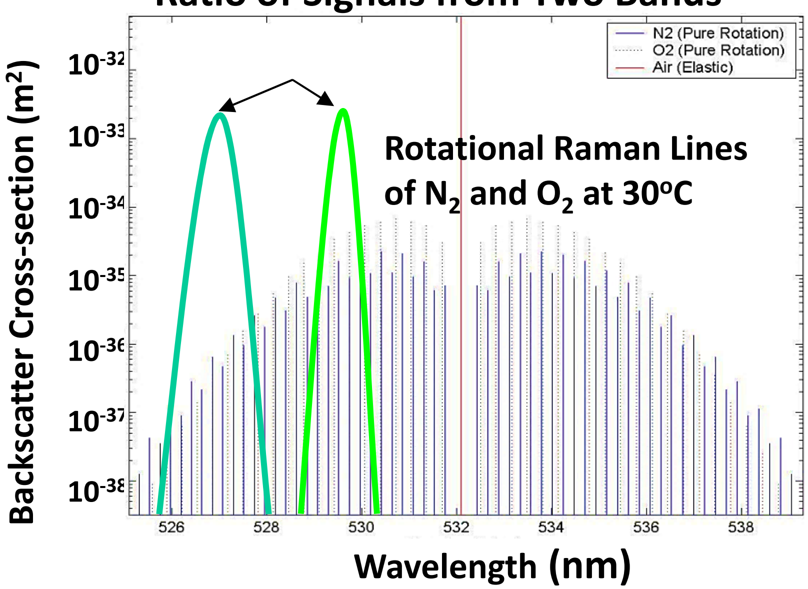
Compare Lidar and Balloon and water vapor if 100% RH

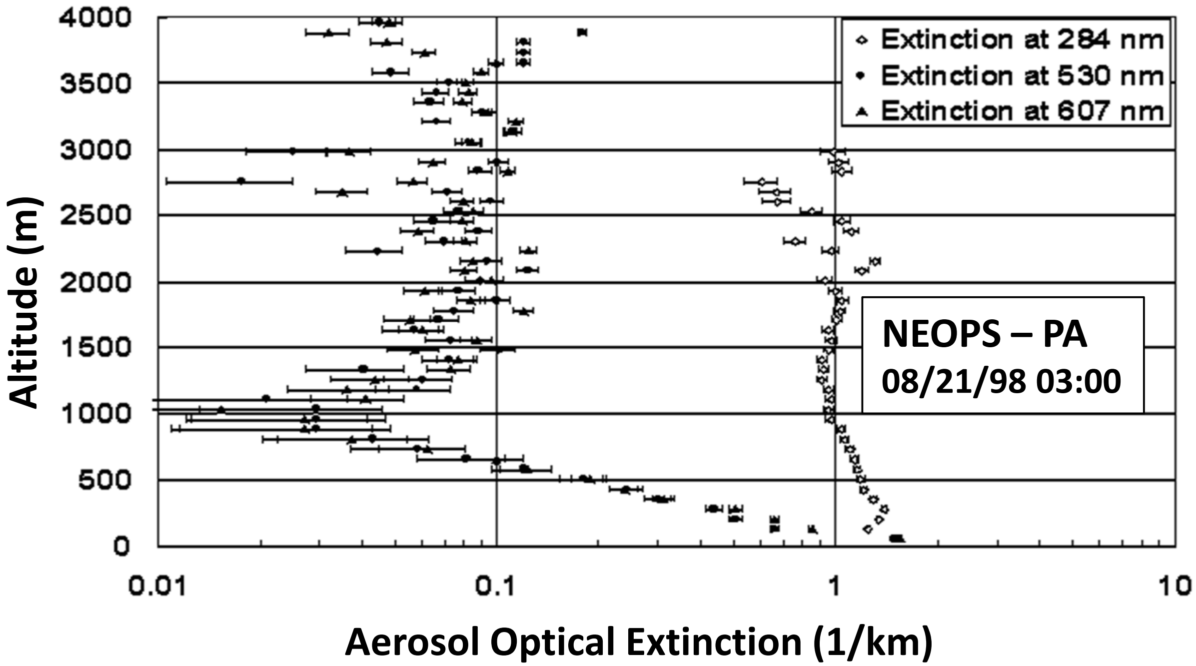
Temperature





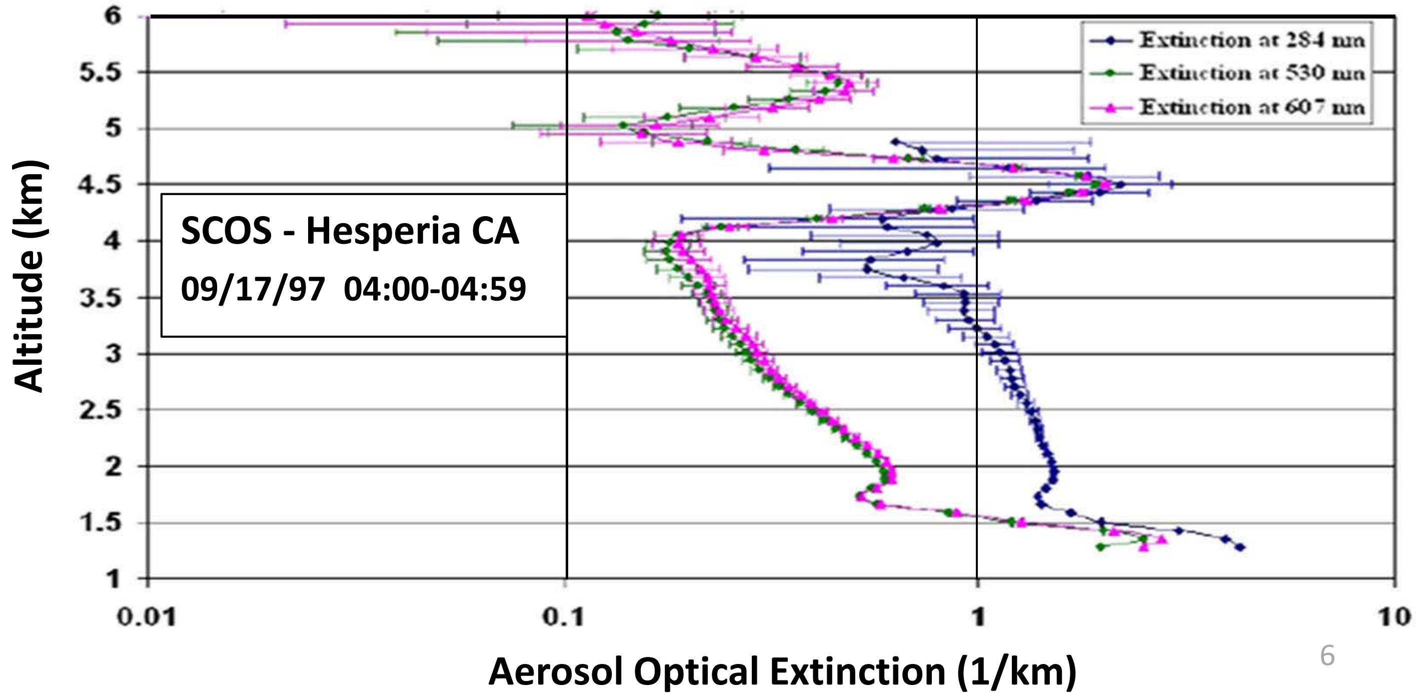
Temperature Proportional to Ratio of Signals from Two Bands





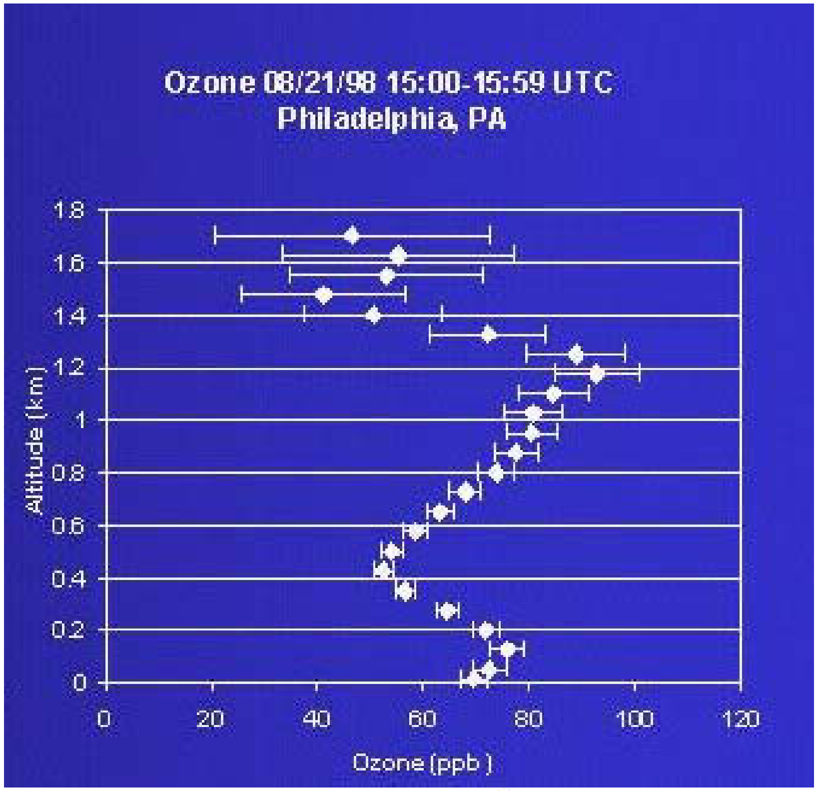
Aerosol Extinction at Three Wavelengths

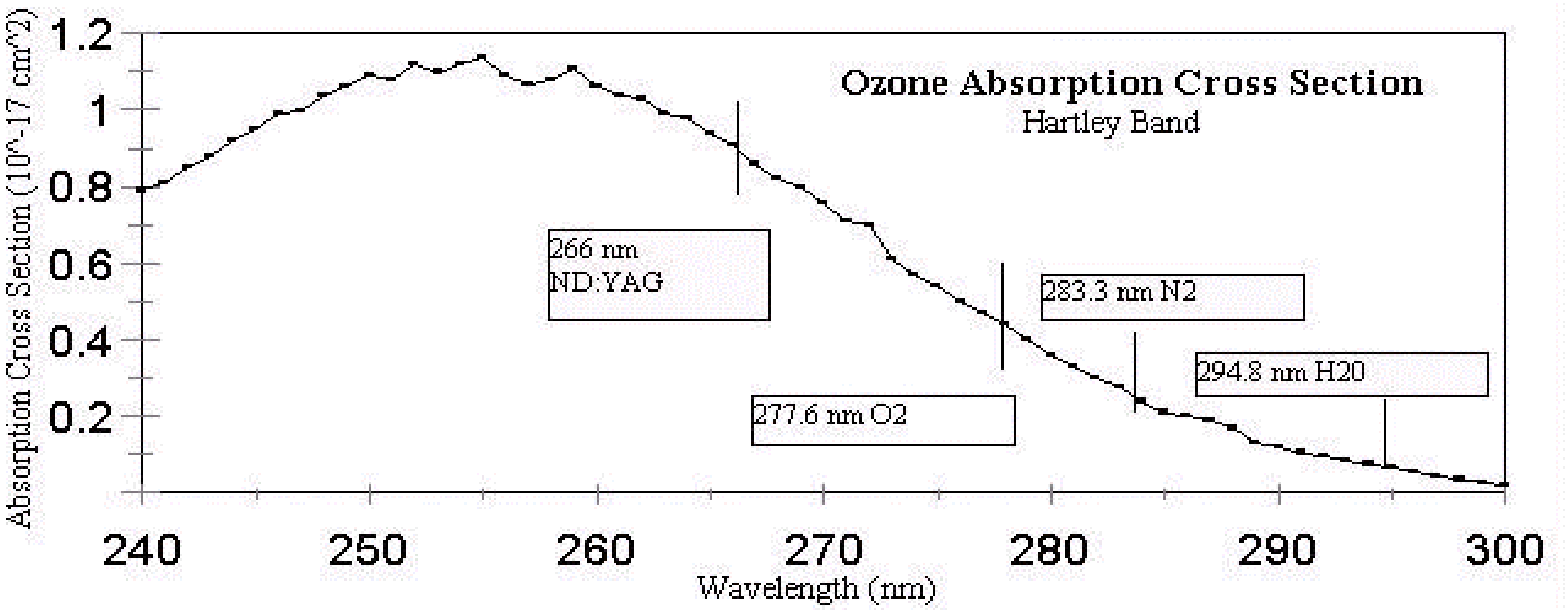
Scattering extinction depends on number density and particle size relative to wavelength.



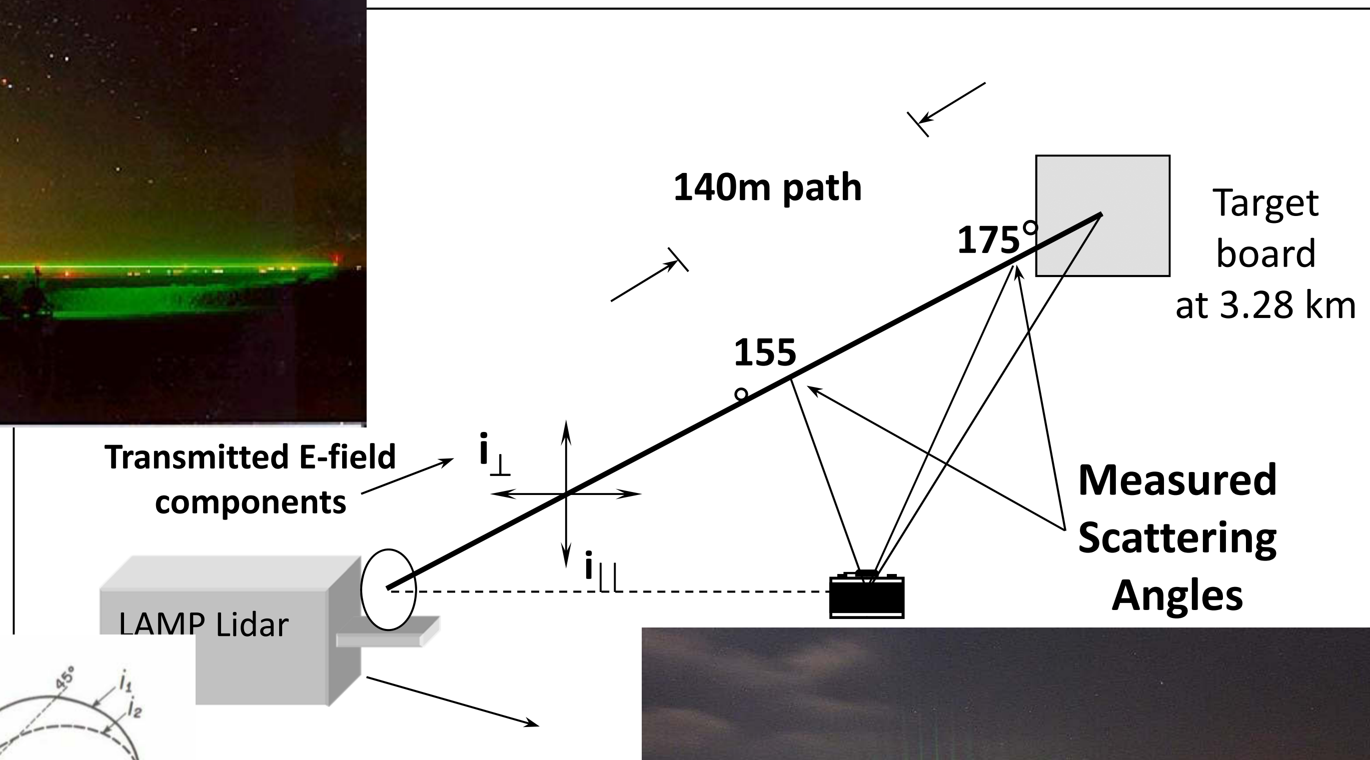
Raman/DIAL Ozone Lidar

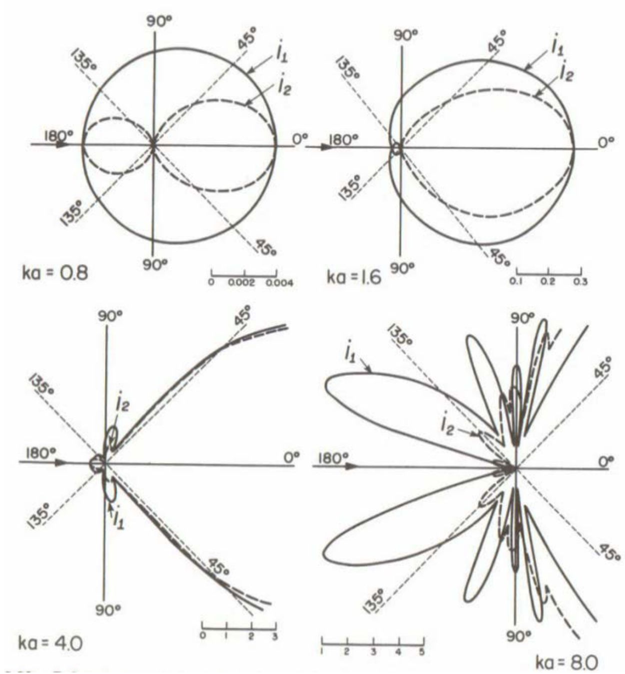
- Ratio of O_2/N_2 Raman signals from 4th harmonic of Nd:YAG
- Atmospheric ratio stable to 1:100000
- Result only depends on lab cross-sections





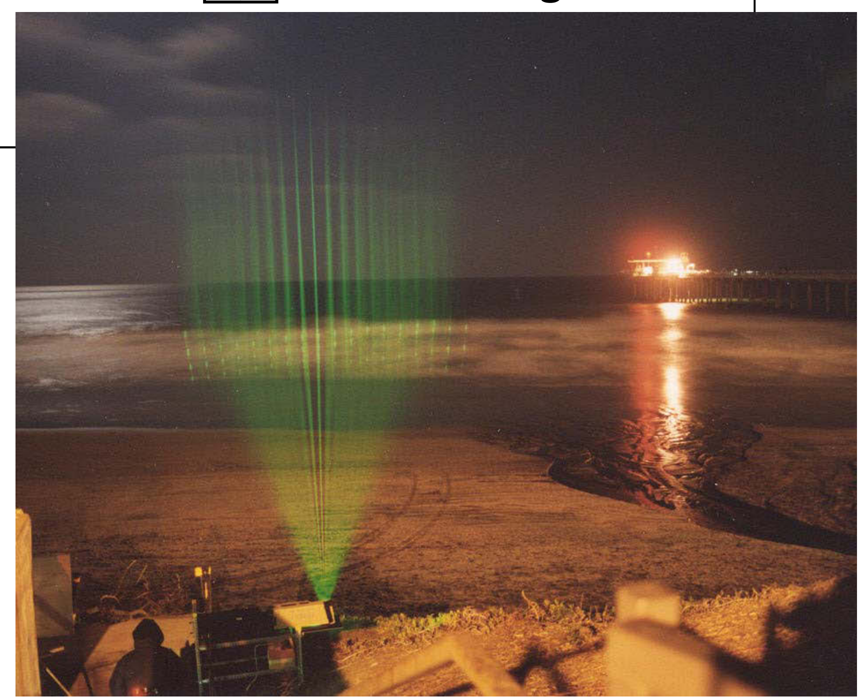
Bistatic Methodology to Determine Particle Size



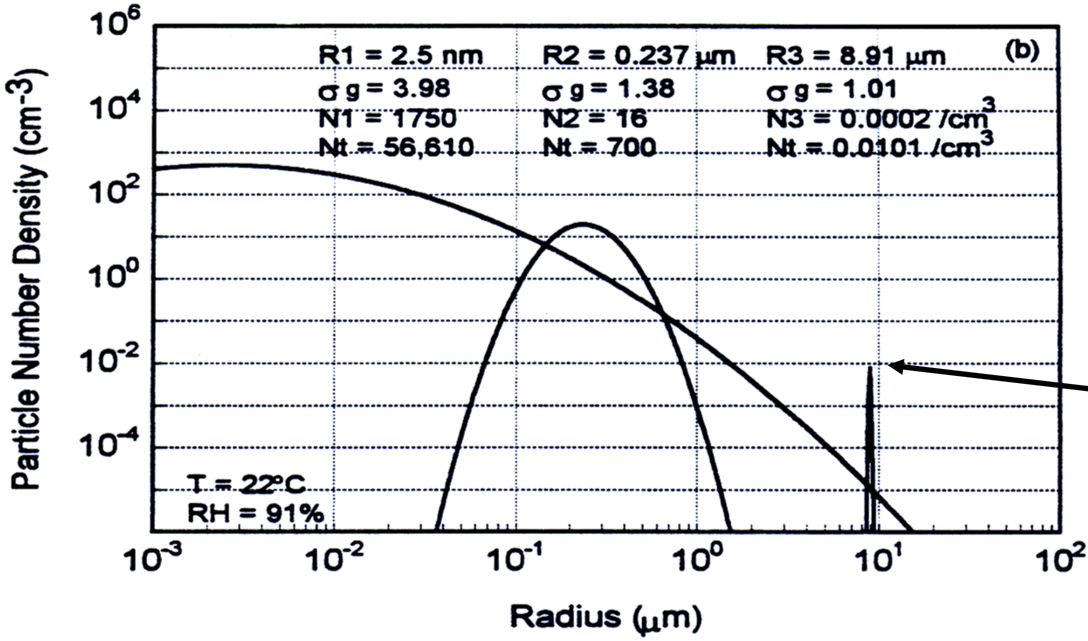


Scattering Phase Function

(Born and Wolf, 1964)



Polarization Ratio

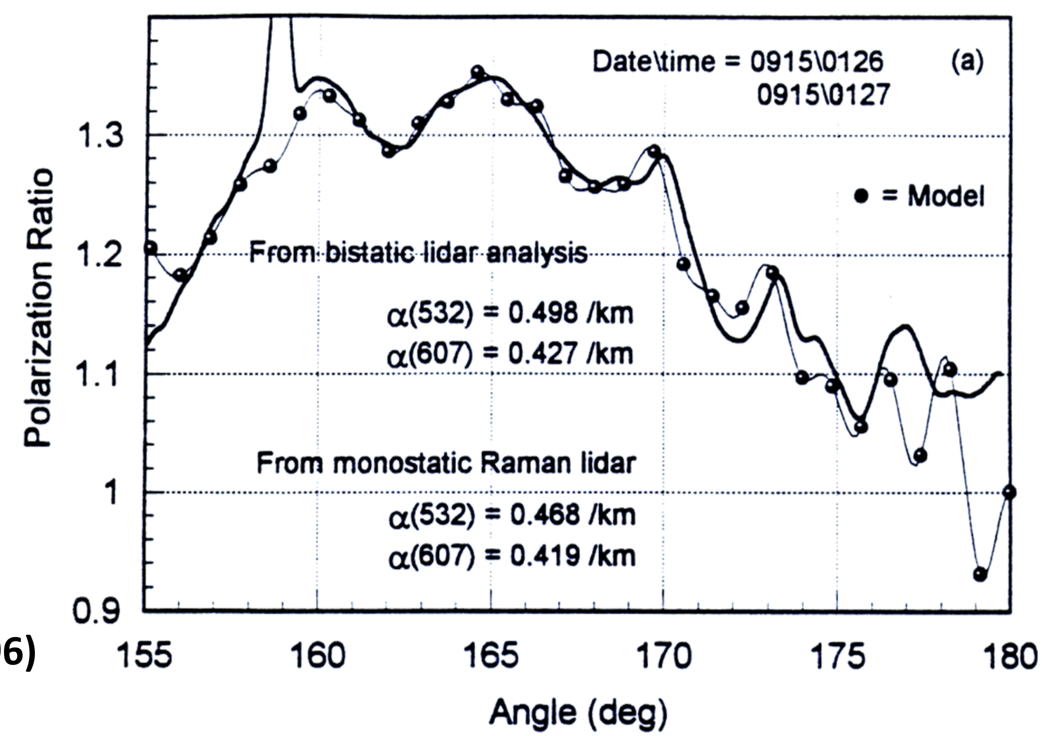


Narrow 3rd Mode Dominates Total Scattering

Best Fit Lognormal Distribution

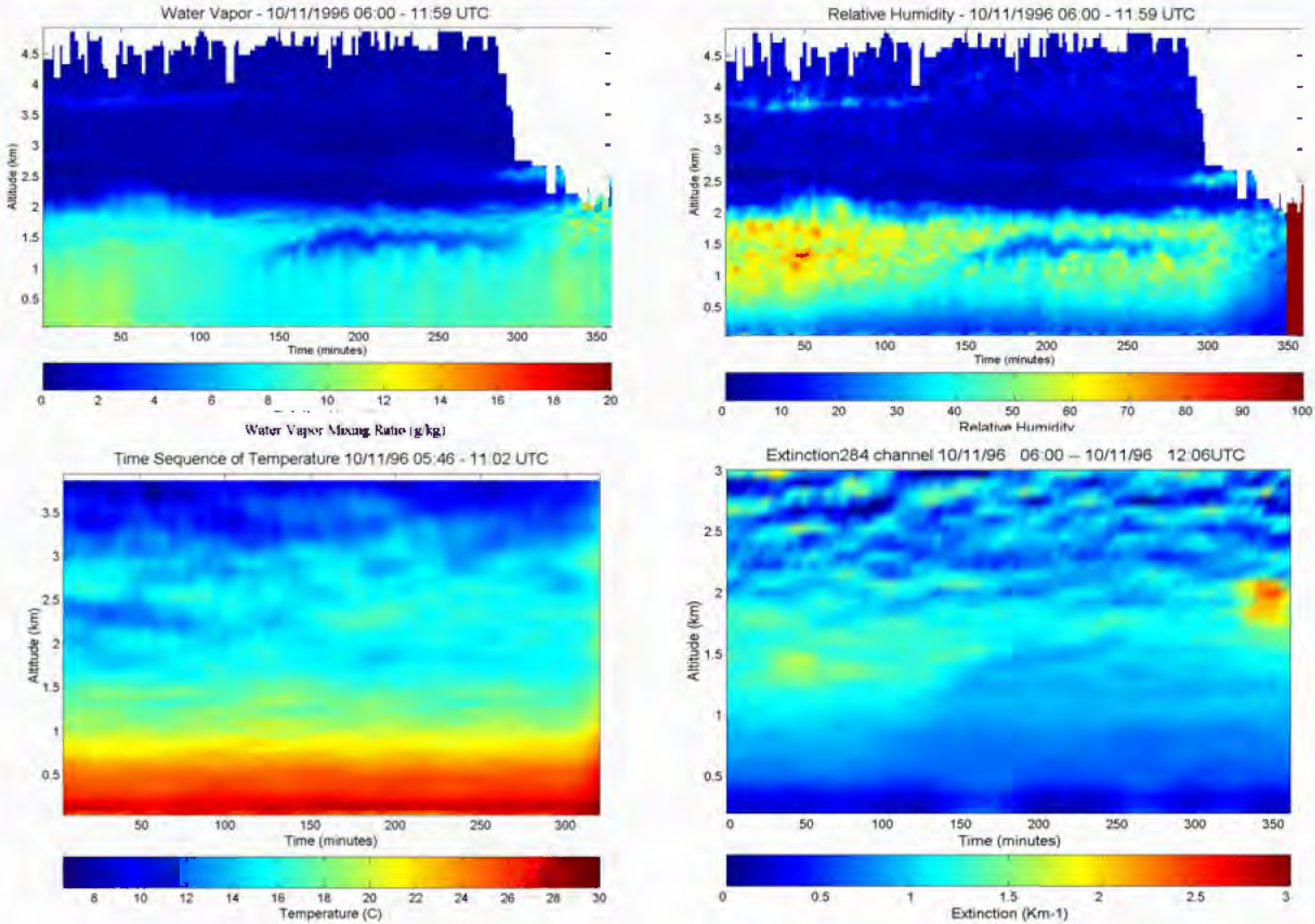
Changes measured during the development of radiation fog

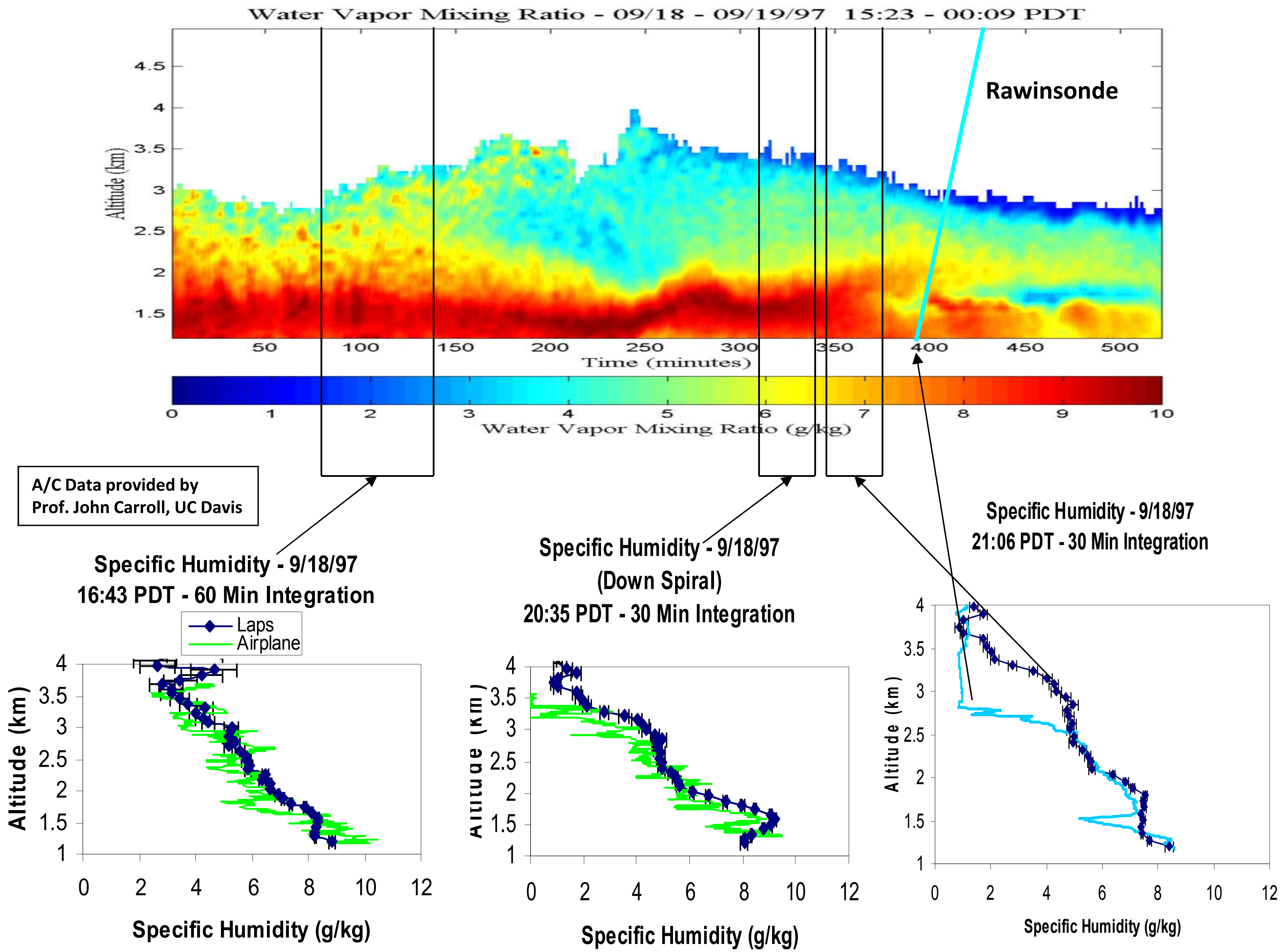
Comparisons with Raman lidar extinction on the same path



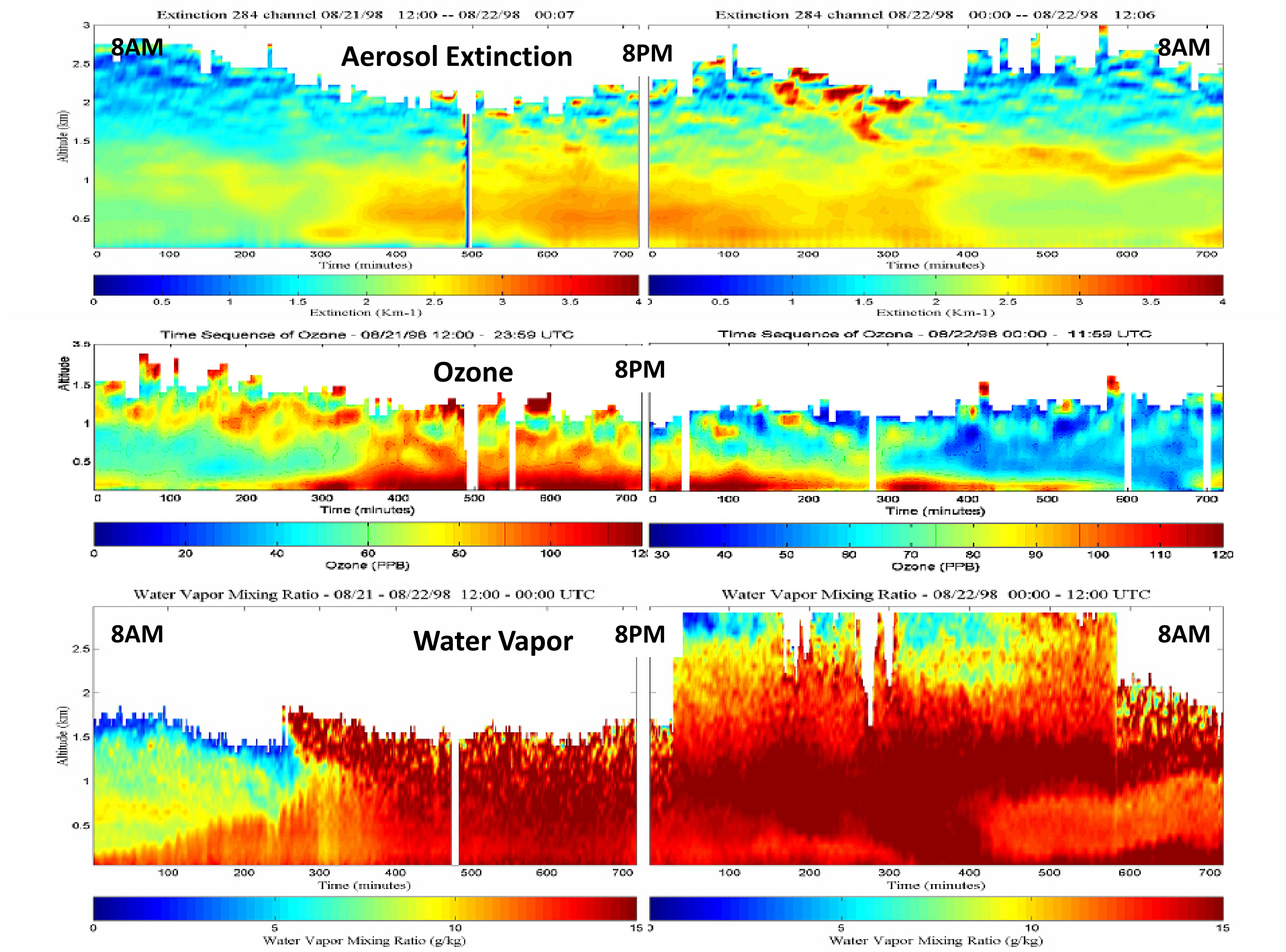
Stevens (PhD 1996)

Water Vapor and Temperature



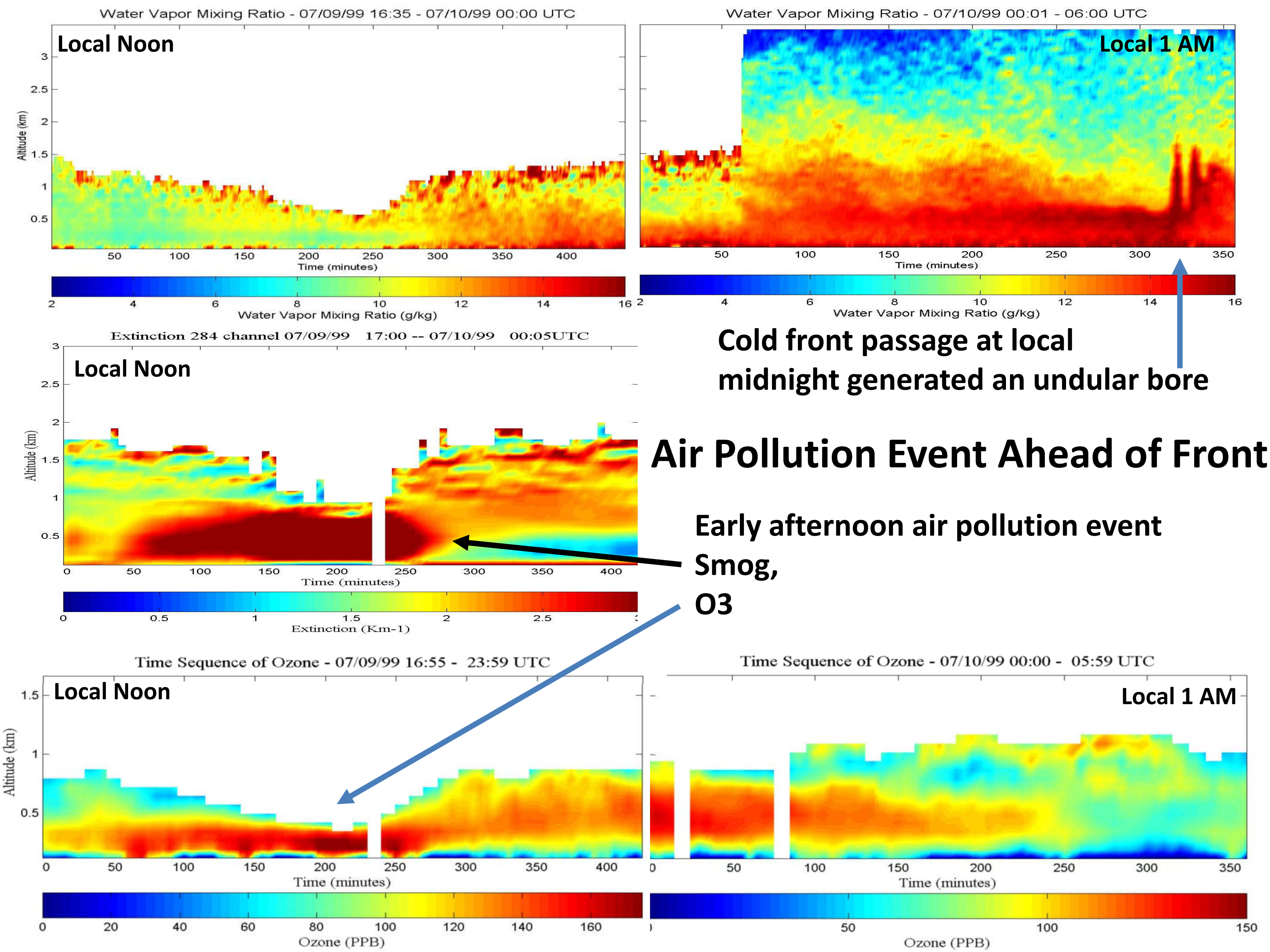


Water Vapor Mixing Ratio - 09/18 - 09/19/97 15:23 - 00:09 PDT
Altitude (km)
Time (minutes)
Rawinsonde
Water Vapor Mixing Ratio (g/kg)
A/C Data provided by
Prof. John Carroll, UC Davis
Specific Humidity - 9/18/97
16:43 PDT - 60 Min Integration
Laps
Airplane
Specific Humidity - 9/18/97
(Down Spiral)
20:35 PDT - 30 Min Integration
Specific Humidity - 9/18/97
21:06 PDT - 30 Min Integration
Altitude (km)
Specific Humidity (g/kg)

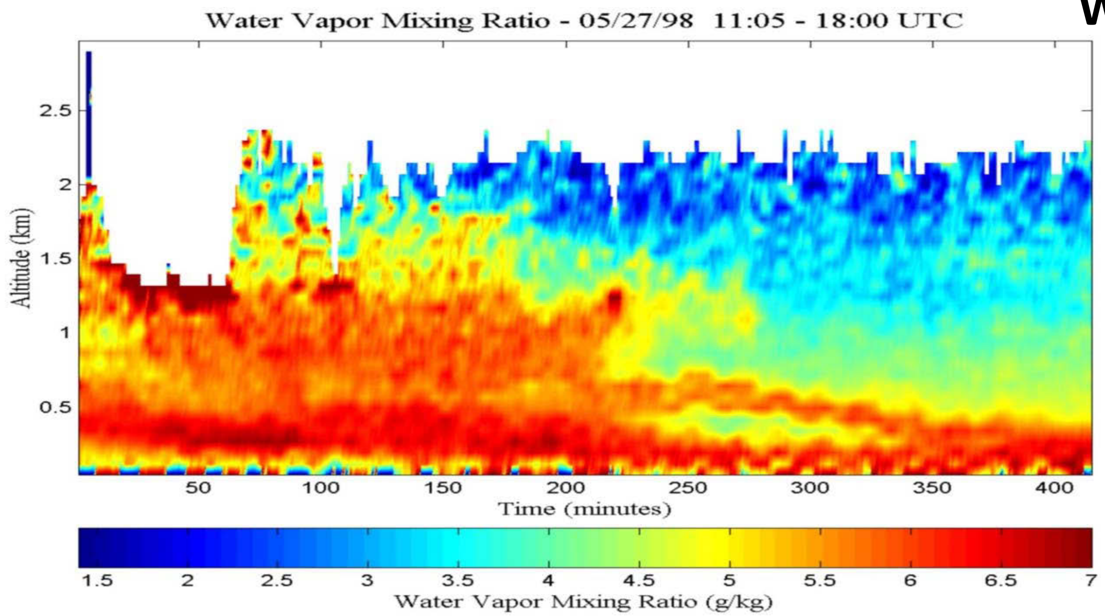


Extinction 284 channel 08/21/98 12:00 -- 08/22/98 00:07
Extinction 284 channel 08/22/98 00:00 -- 08/22/98 12:06
8AM
Aerosol Extinction
8PM
8AM
Altitude (km)
Time (minutes)
Extinction (Km-1)
Time Sequence of Ozone - 08/21/98 12:00 - 23:59 UTC
Time Sequence of Ozone - 08/22/98 00:00 - 11:59 UTC
Ozone
8PM
Altitude
Time (minutes)
Ozone (PPB)
Water Vapor Mixing Ratio - 08/21 - 08/22/98 12:00 - 00:00 UTC
Water Vapor Mixing Ratio - 08/22/98 00:00 - 12:00 UTC
8AM
Water Vapor
8PM
8AM
Altitude (km)
Time (minutes)
Water Vapor Mixing Ratio (g/kg)

Air Pollution Event Ahead of Front



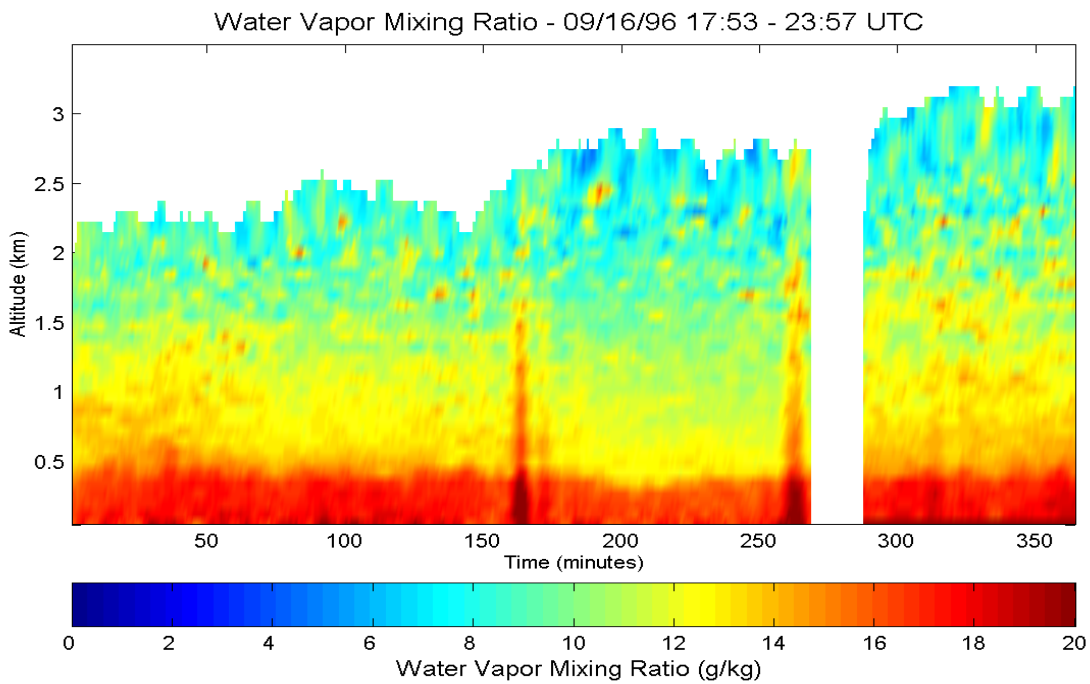
Atmosphere Resonant Oscillation



Water Vapor as a Tracer of Dynamics

Buoyant oscillation forced by pressure wave at the Brunt-Väisälä frequency observed at Point Barrow Alaska on 27 May 1998 , 4-10 AM during the arctic spring.

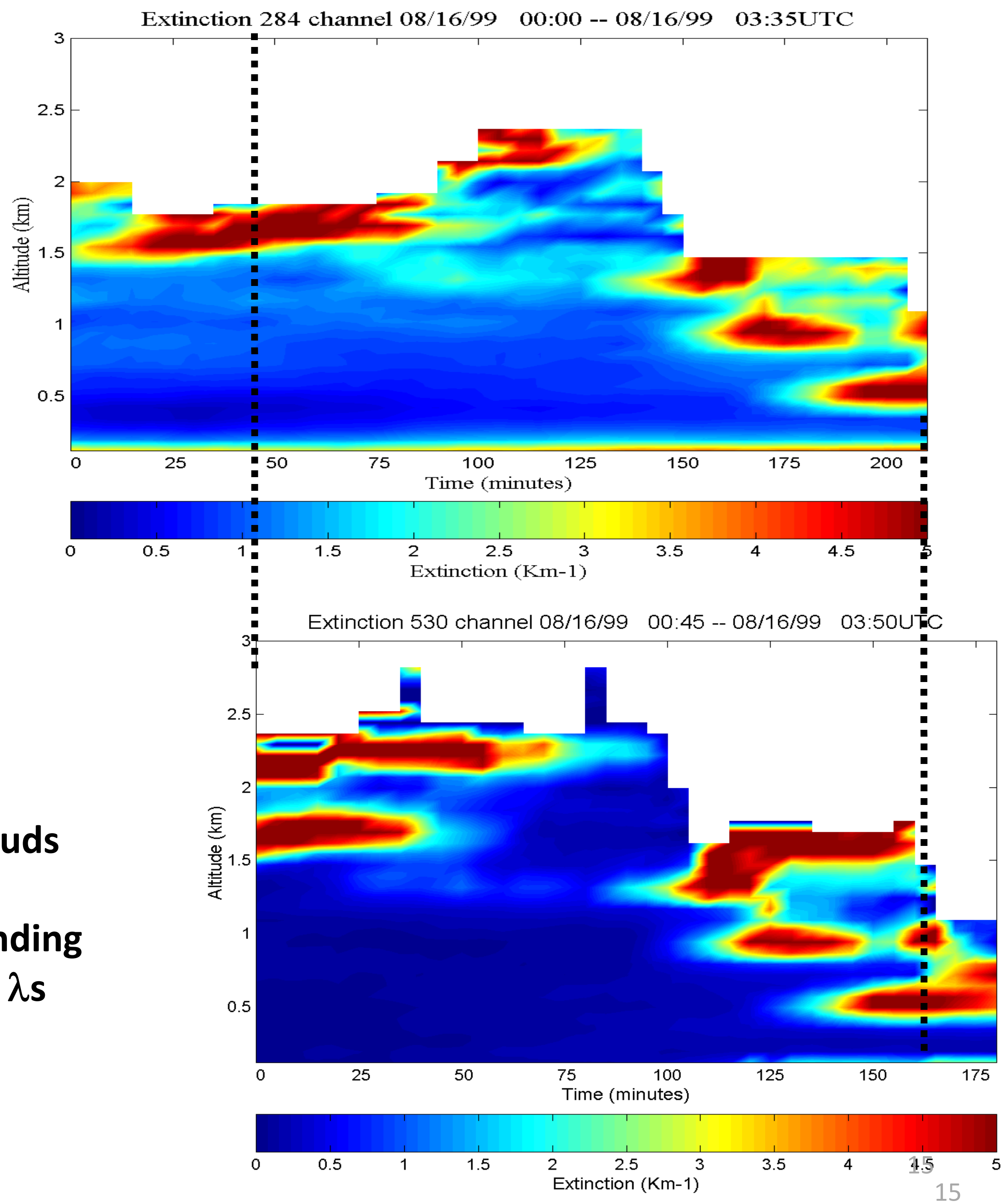
Water Transfer into Cloud Base



Water vapor feeds directly from the marine boundary layer into the base of growing convective clouds forming over the ocean. Data taken on USNS Sumner in the Gulf of Mexico and Atlantic.

Cloud Microphysics

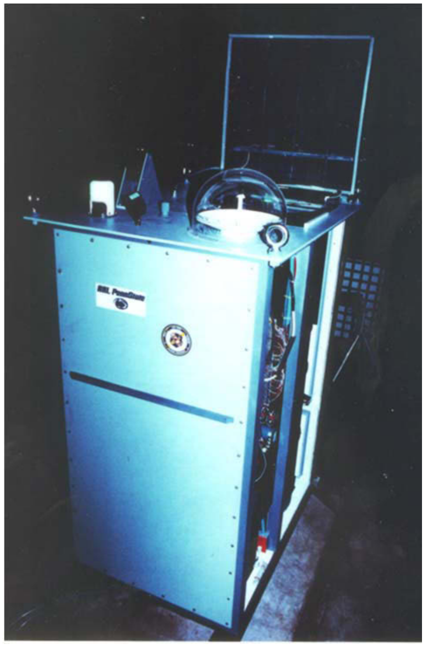
Two-wavelength Raman lidar extinction shows regions of cloud formation and dissipation



Items:

1. **Small aerosols outside of clouds**
2. **Multi-scatter in cloud center**
3. **Many small particles surrounding**
4. **Scales are the same for both λs**

Sachin Verghese, PhD 2008



Instrument Characteristics and Measurements

Property	Measurement	Altitude	Time - Resolution
Water Vapor	660/607 (H_2O/N_2) 294/283 (H_2O/N_2)	0-5 km 0-2 km	Night -1 min Day & Night -1 min
Temperature	528/530 Rotational Raman	0-5 km	Night 10 min
Extinction 530 nm	530 nm Rotational Raman	0-5 km	Night 10 min
Extinction 607 nm	607 nm N_2 1st Stokes	0-5 km	Night 10 min
Extinction 285 nm	283 nm $N_2$1st Stokes	0-3 km	Day & Night 10 min
Ozone	O_2/N_2 (278/283)Raman/DIAL	0-2 km	Day & Night - 30 min

	LAPS	New	LAPS	New
Transmitter E and PRF Expander	Flash Lamp 1.2 J at 30 Hz 5X Beam	Diode Pumped 40 W at 2 kHz	532 nm - 500 mj 15 W 266 nm – 60 mj 1.8W 20X Beam	532 nm - 8 mj 16 W 266 nm - 3 mj 6 W
Receiver	61 cm Telescope	50 cm Telescope	Fiber optic pickup	Fiber optic pickup
Detector	8 PMT Channels Photon Counting	8 PMT Channels Photon Counting New Generation of Detectors	528/530 nm – Night Temp 660/607 nm – H_2O/N_2 Night 294/283 nm – H_2O/N_2 D-N 278/283 nm – O_3 DIAL 283, 530, 660 nm – Aerosols	528/530 nm – Night Temp 263/265 nm – Day-Night Temp 660/607 nm – H_2O/N_2 Night 294/283 nm – H_2O/N_2 Day-Night 278/283 nm – O_3 DIAL 265, 283, 530, 532, 607 nm – Aer
Data	100 MHz	1 GHz	75 m bins	50 m bins
Safety	Marine X-Band	Eye-safe	Automatic cut-off	No protection needed (closed)

Summary

1. **Raman lidar water vapor and aerosol profiles provide good tracers dynamics in the troposphere.**
2. **Aerosol extinction profiles at multiple wavelengths can be used to describe the particle size distributions.**
3. **An additional way to determine the size distribution of aerosols is to image the path of a laser beam scattered at a few angles while the beam polarization is flipped. Polarization ratio of the scattering phase function describes the particle size distribution.**
4. **Dynamical processes can be studied: undular bore wave, low level jets, Brunt- Väisälä oscillations, and cloud microphysics.**

Our goal is to encourage the idea that continuous automated Raman lidar profiles would be an advantage for atmospheric investigations. They would provide a valuable supplement to the twice per day rawinsonde releases and this type of sensor could be made commercially available.