LIDAR ATMOSPHERIC MEASUREMENTS OF TROPOSPHERIC REFRACTIVITY DURING DEVELOPING SANTA ANA WINDS

D. W. Blood* and C. R. Philbrick
Applied Research Laboratory/Penn State University

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Sponsors: SPAWAR METOC Systems/PMW-175
NCCOSC/RDT&E Div. (NRad VOCAR Program)
NAWC/WPNS/Pt. Mugu ~~(Cooperating)~~
Penn State University ~~(Cooperating)~~

Mission: VOCAR Campaign
(Variability of Coastal Atmospheric Refractivity)

OUTLINE:

- Lidar measurements of lower atmosphere
- Santa Ana conditions, Pt. Mugu, CA/Oct.-Nov. 1993
- Interpretation of lidar measured results
- Impact of dynamic gradients on refractive effects
- Summary of observations during the Santa Ana

LIDAR ATMOSPHERIC MEASUREMENTS

Each 5 - 30 minutes Lidar yields atmospheric profile data at a resolution of 75 meters (15 m near-term goal)

BASIC TROPOSPHERIC MEASUREMENTS:

- Water Vapor Profile,
  r(z) = specific humidity, WVMR (g/kg)
- Temperature Profile, T(z)
- Surface Parameters, Po, To, & RH

DERIVED PROFILES:

- Pressure, P(z)
- Refractivity, N(z)
- Modified Refractivity, M(z)

Equations for Atmospheric Refractivity Profiling

Refractivity:

$$N(z) = 77.6 \frac{P(z)}{T(z)} + 3.73\times10^5 \frac{e(z)}{(T(z))^2}$$

Modified refractivity:

$$M(z) = N(z) + (0.157)\times z$$

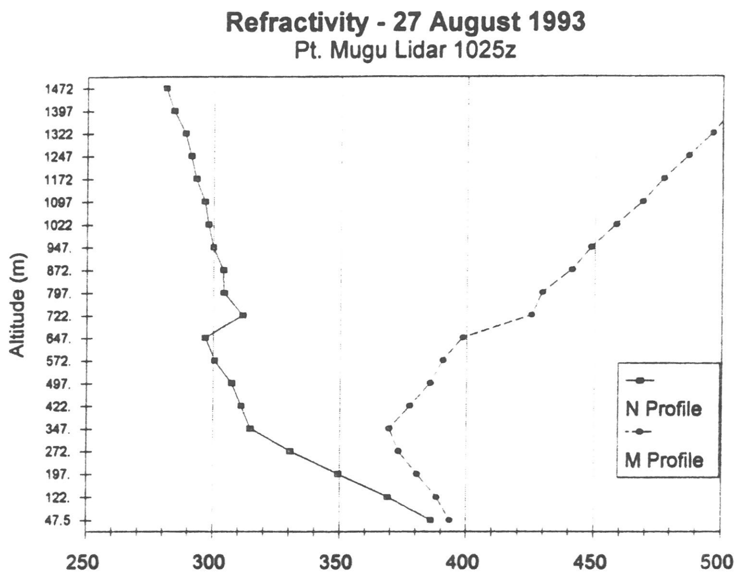
where:

$$N = (n-1)\times10^6$$

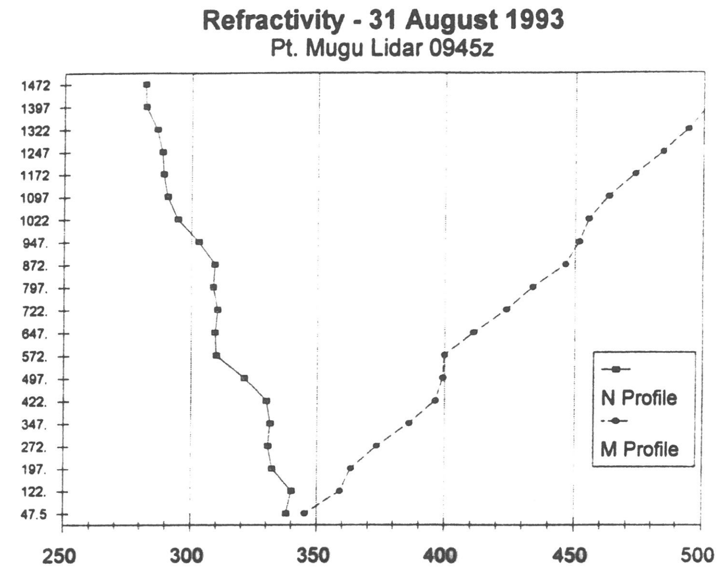
N = parts per million of refractive index of air
n = refractive index of air (nominally ~1.0003)
z = geometric height (m>m.s.l.)

e(z) = water vapor pressure (mb)
= r(z) x P(z)/[r(z)+621.97]

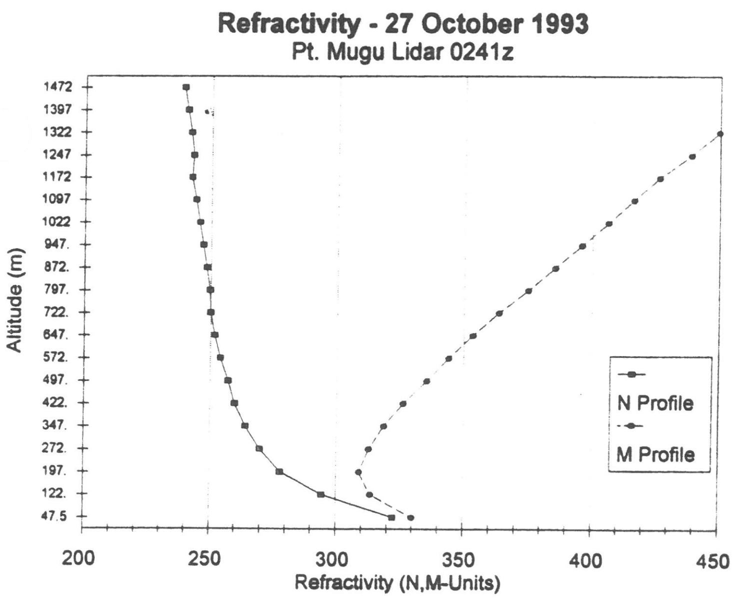
r(z) = water vapor mixing ratio (g/kg)
P(z) = absolute atmospheric pressure (mb)
T(z) = absolute atmospheric temperature (K)



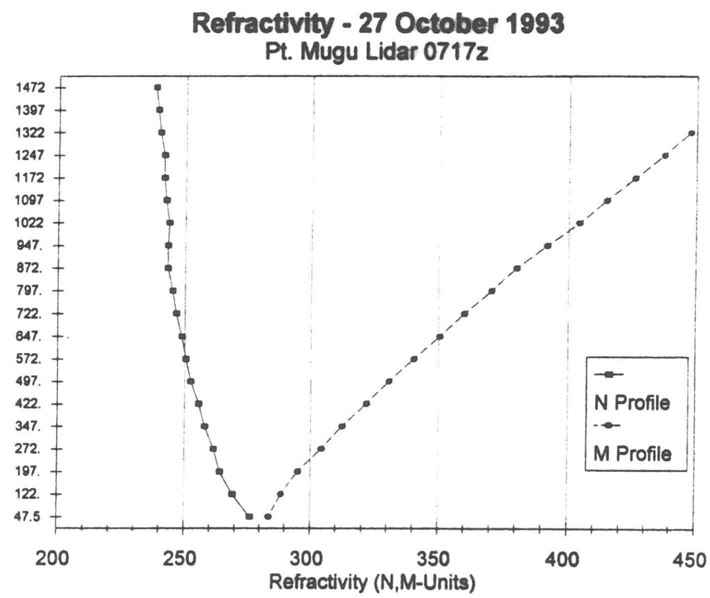
Refractivity - 27 August 1993
Pt. Mugu Lidar 1025z
Altitude (m)
N Profile
M Profile



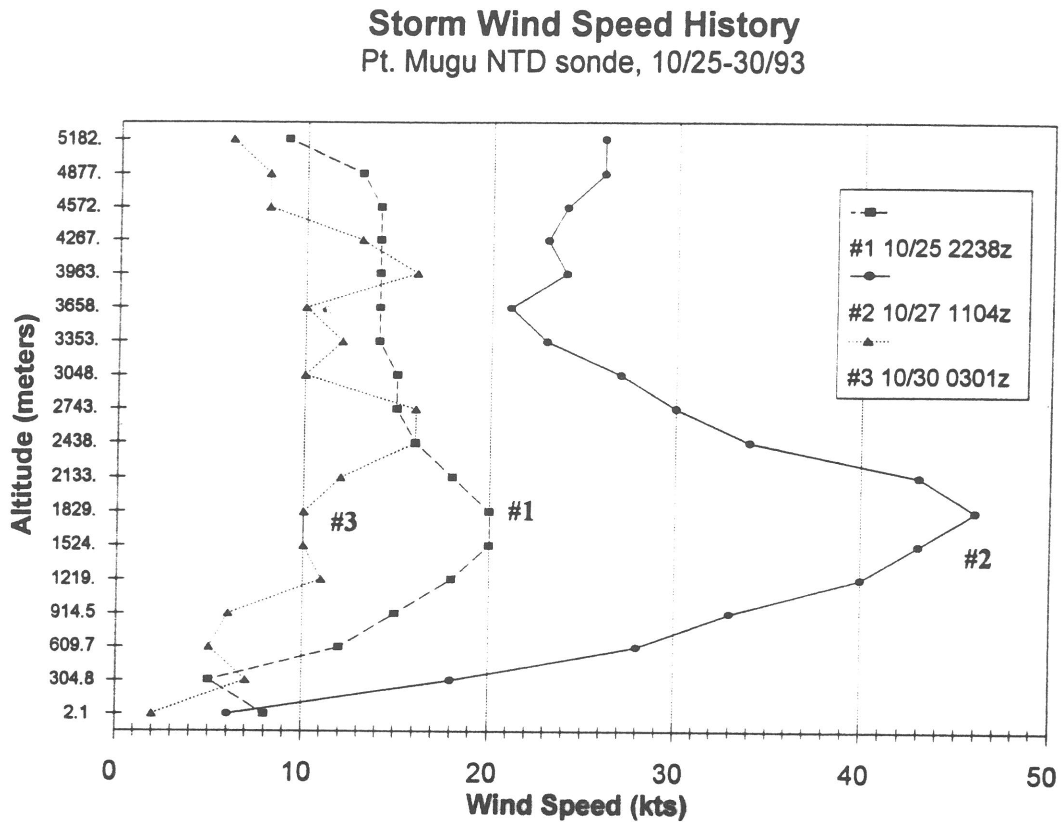
Refractivity - 31 August 1993
Pt. Mugu Lidar 0945z
N Profile
M Profile

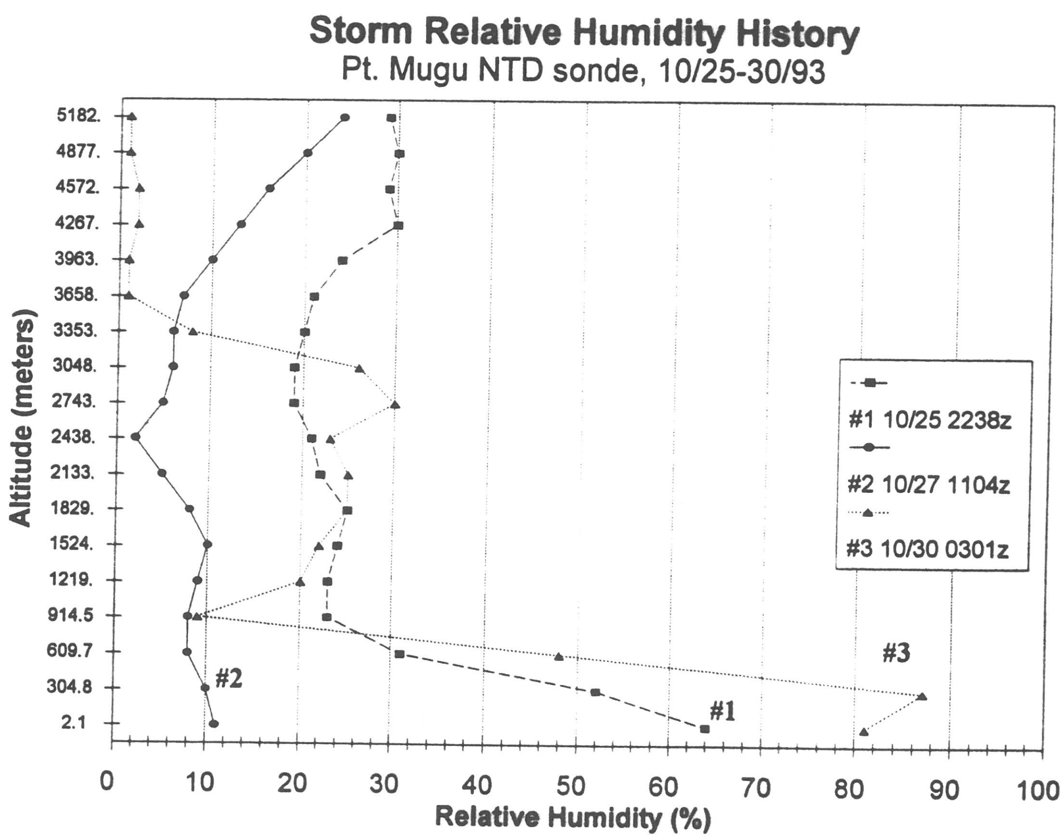


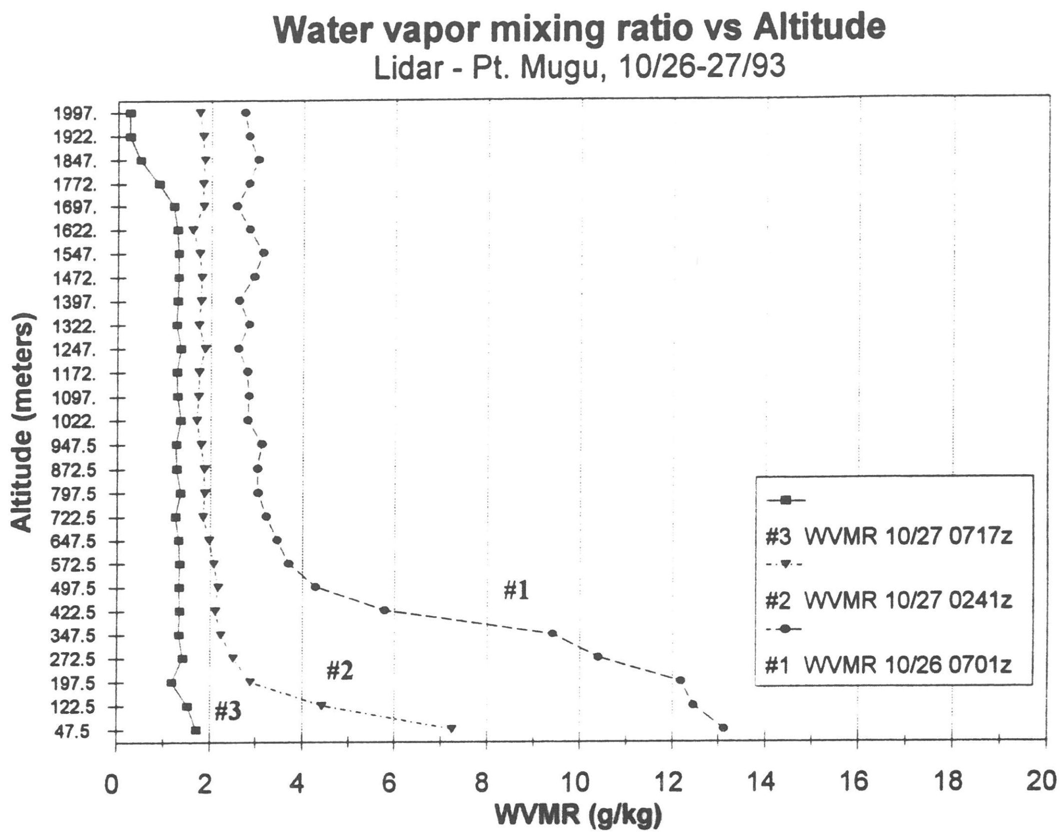
Refractivity - 27 October 1993
Pt. Mugu Lidar 0241z
Altitude (m)
N Profile
M Profile
Refractivity (N,M-Units)

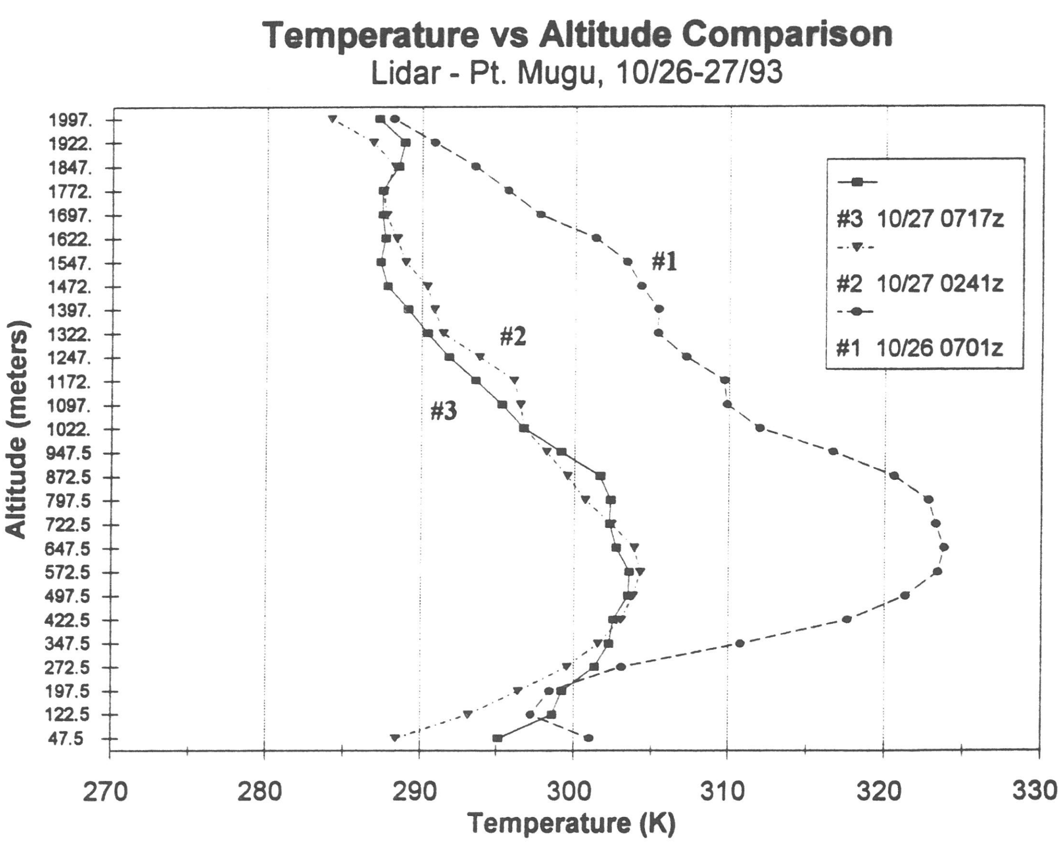


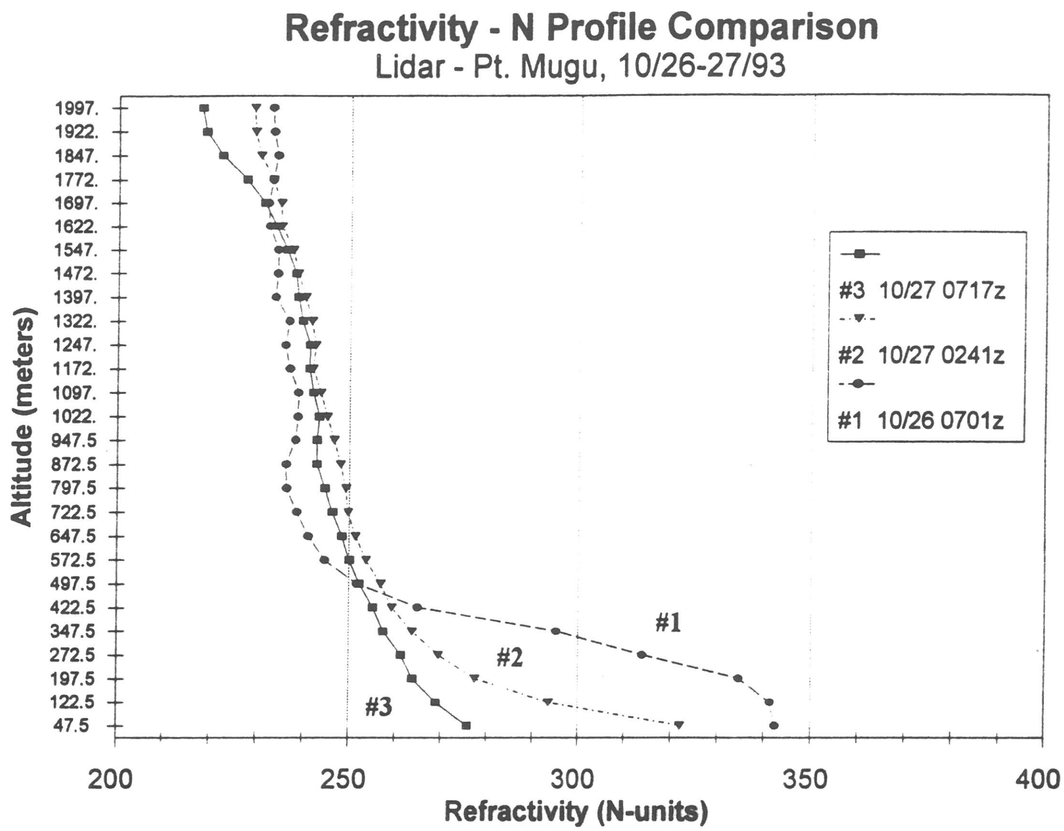
Refractivity - 27 October 1993
Pt. Mugu Lidar 0717z
N Profile
M Profile
Refractivity (N,M-Units)

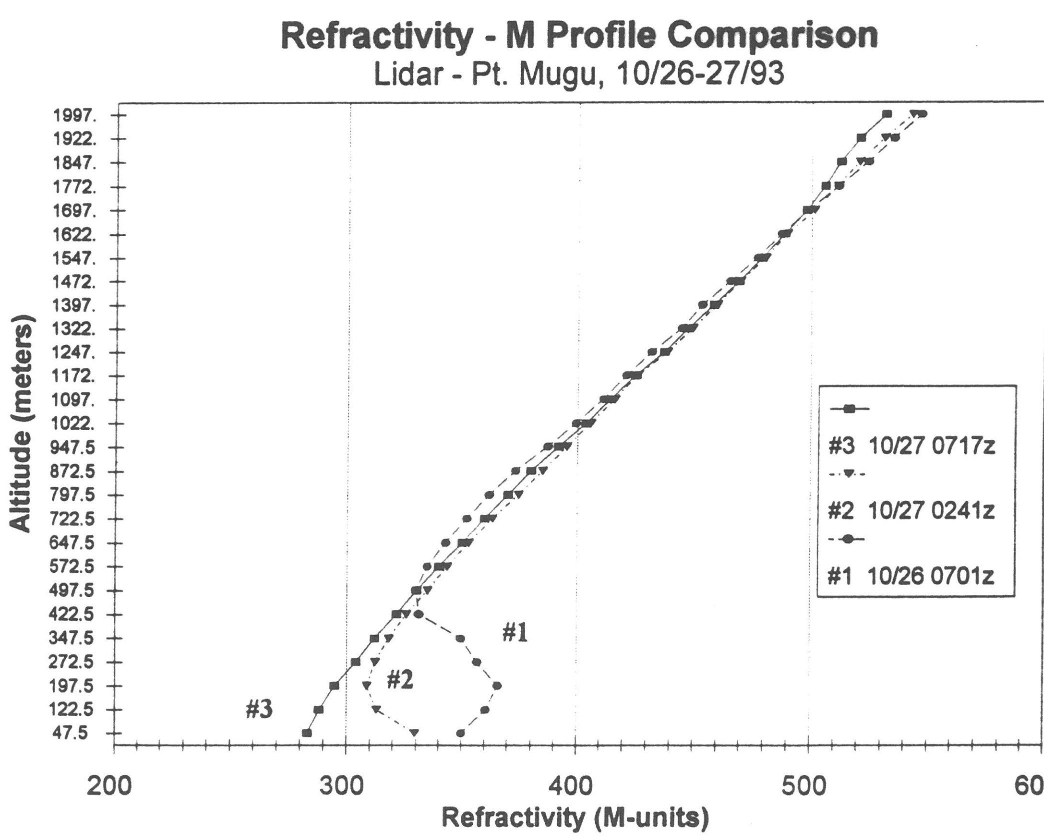

Storm Wind Speed History
Pt. Mugu NTD sonde, 10/25-30/93
Altitude (meters)
5182.
4877.
4572.
4267.
3963.
3658.
3353.
3048.
2743.
2438.
2133.
1829.
1524.
1219.
914.5
609.7
304.8
2.1
0
10
20
30
40
50
Wind Speed (kts)
#1 10/25 2238z
#2 10/27 1104z
#3 10/30 0301z
#1
#2
#3


Storm Relative Humidity History
Pt. Mugu NTD sonde, 10/25-30/93
Altitude (meters)
5182.
4877.
4572.
4267.
3963.
3658.
3353.
3048.
2743.
2438.
2133.
1829.
1524.
1219.
914.5
609.7
304.8
2.1
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (%)
#1 10/25 2238z
#2 10/27 1104z
#3 10/30 0301z
#1
#2
#3


Water vapor mixing ratio vs Altitude
Lidar - Pt. Mugu, 10/26-27/93
Altitude (meters)
1997.
1922.
1847.
1772.
1697.
1622.
1547.
1472.
1397.
1322.
1247.
1172.
1097.
1022.
947.5
872.5
797.5
722.5
647.5
572.5
497.5
422.5
347.5
272.5
197.5
122.5
47.5
0
2
4
6
8
10
12
14
16
18
20
WVMR (g/kg)
#1
#2
#3
#3 WVMR 10/27 0717z
#2 WVMR 10/27 0241z
#1 WVMR 10/26 0701z

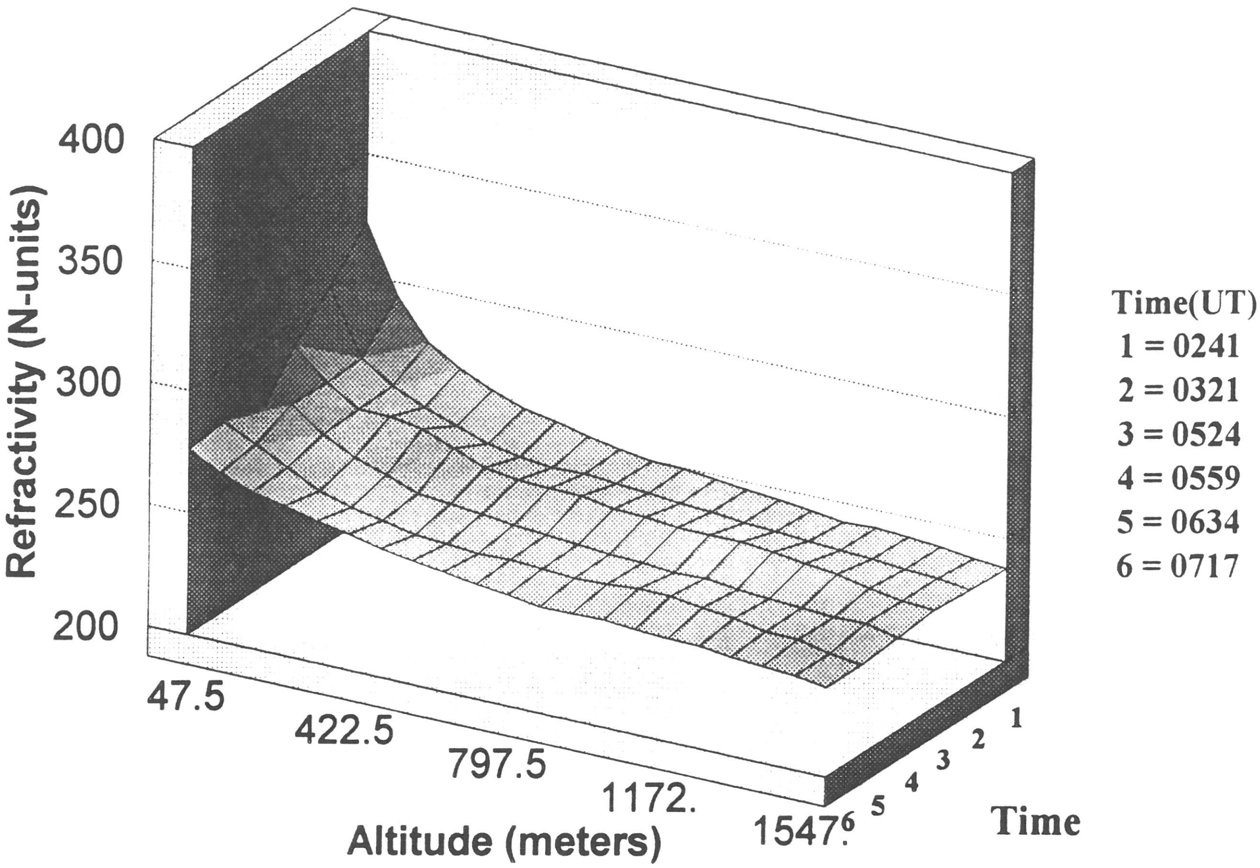

Temperature vs Altitude Comparison
Lidar - Pt. Mugu, 10/26-27/93
Altitude (meters)
1997.
1922.
1847.
1772.
1697.
1622.
1547.
1472.
1397.
1322.
1247.
1172.
1097.
1022.
947.5
872.5
797.5
722.5
647.5
572.5
497.5
422.5
347.5
272.5
197.5
122.5
47.5
270
280
290
300
310
320
330
Temperature (K)
#1
#2
#3
#3 10/27 0717z
#2 10/27 0241z
#1 10/26 0701z


Refractivity - N Profile Comparison
Lidar - Pt. Mugu, 10/26-27/93
Altitude (meters)
1997.
1922.
1847.
1772.
1697.
1622.
1547.
1472.
1397.
1322.
1247.
1172.
1097.
1022.
947.5
872.5
797.5
722.5
647.5
572.5
497.5
422.5
347.5
272.5
197.5
122.5
47.5
200
250
300
350
400
Refractivity (N-units)
#1
#2
#3
#3 10/27 0717z
#2 10/27 0241z
#1 10/26 0701z

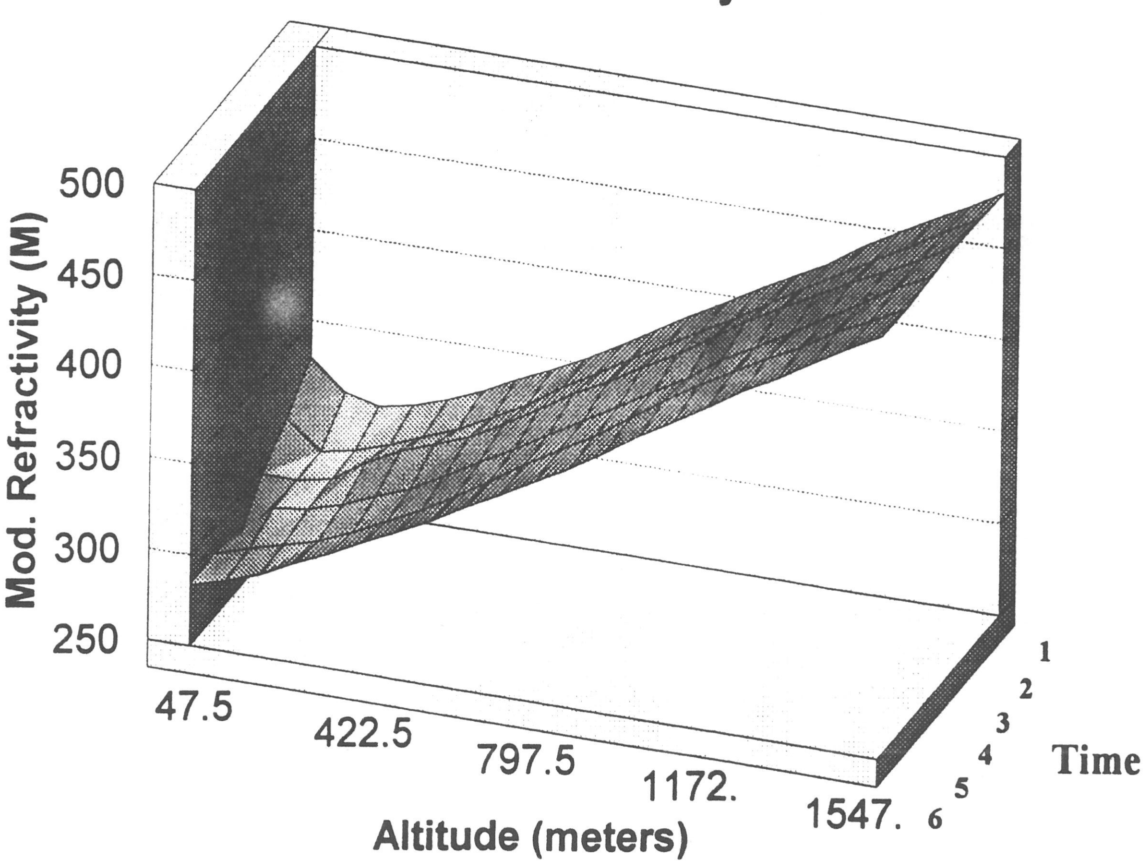

Refractivity - M Profile Comparison
Lidar - Pt. Mugu, 10/26-27/93
Altitude (meters)
1997.
1922.
1847.
1772.
1697.
1622.
1547.
1472.
1397.
1322.
1247.
1172.
1097.
1022.
947.5
872.5
797.5
722.5
647.5
572.5
497.5
422.5
347.5
272.5
197.5
122.5
47.5
200
300
400
500
600
Refractivity (M-units)
#1
#2
#3
#3 10/27 0717z
#2 10/27 0241z
#1 10/26 0701z

Refractivity - N vs Altitude and Time

27 October 1993 - LIDAR PSU/ARL

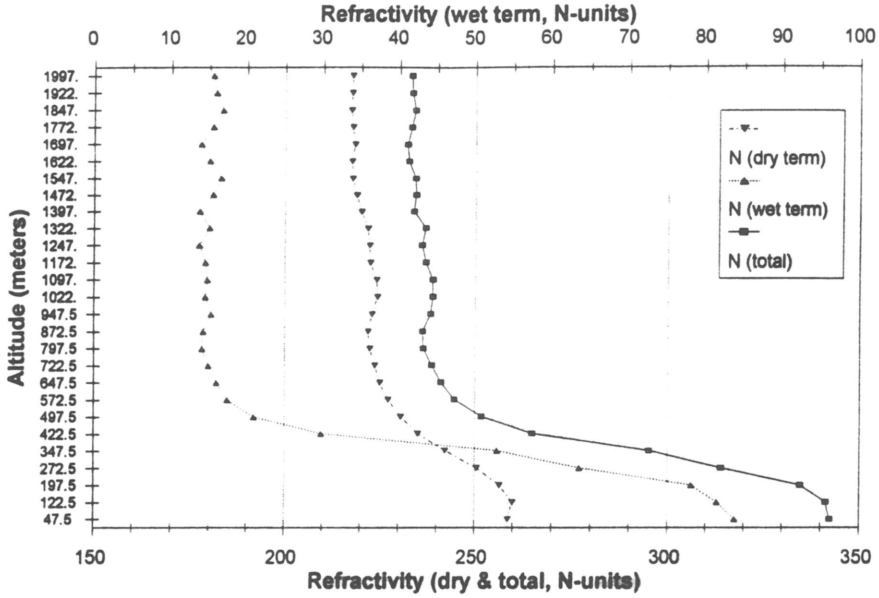


Mod. Refractivity - M

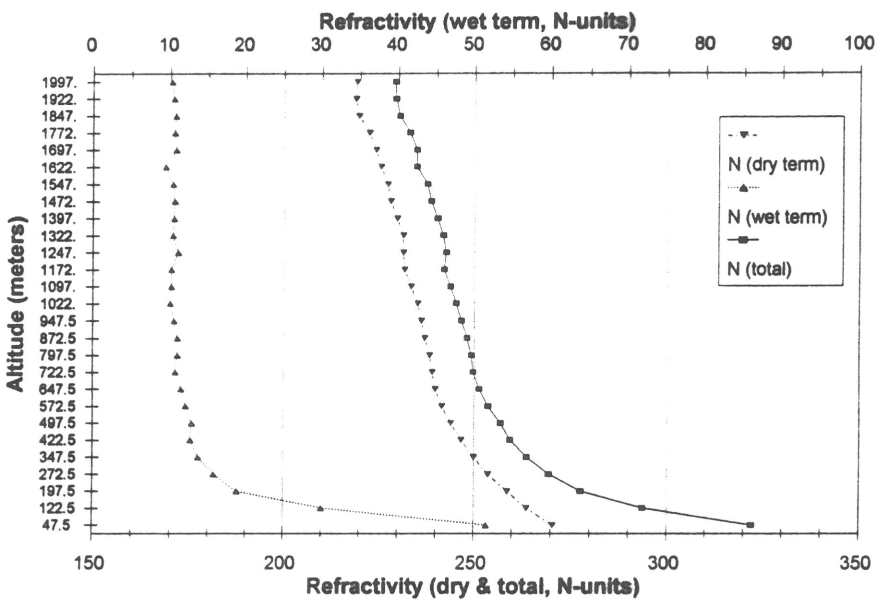


Refractivity & Components vs Altitude

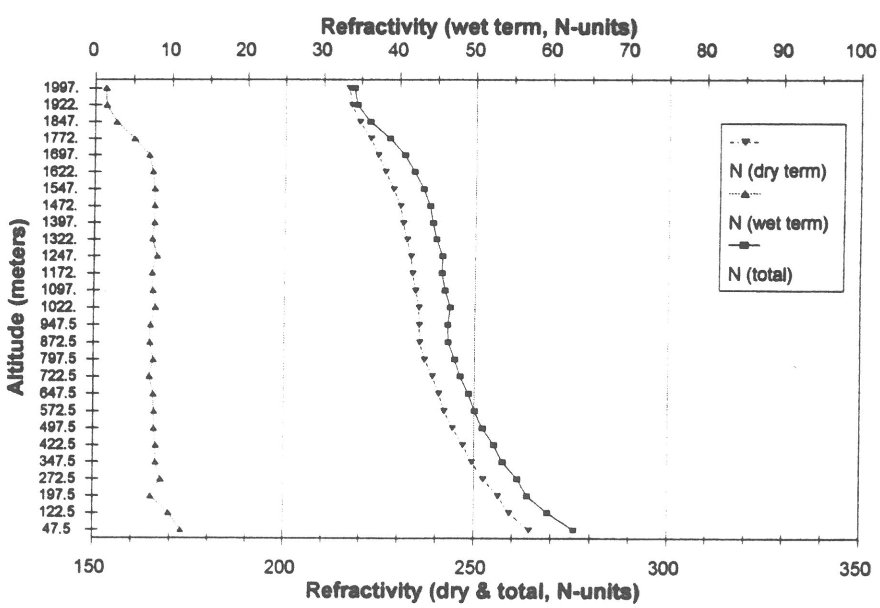
Lidar - Pt. Mugu, 10/26/93 0701z

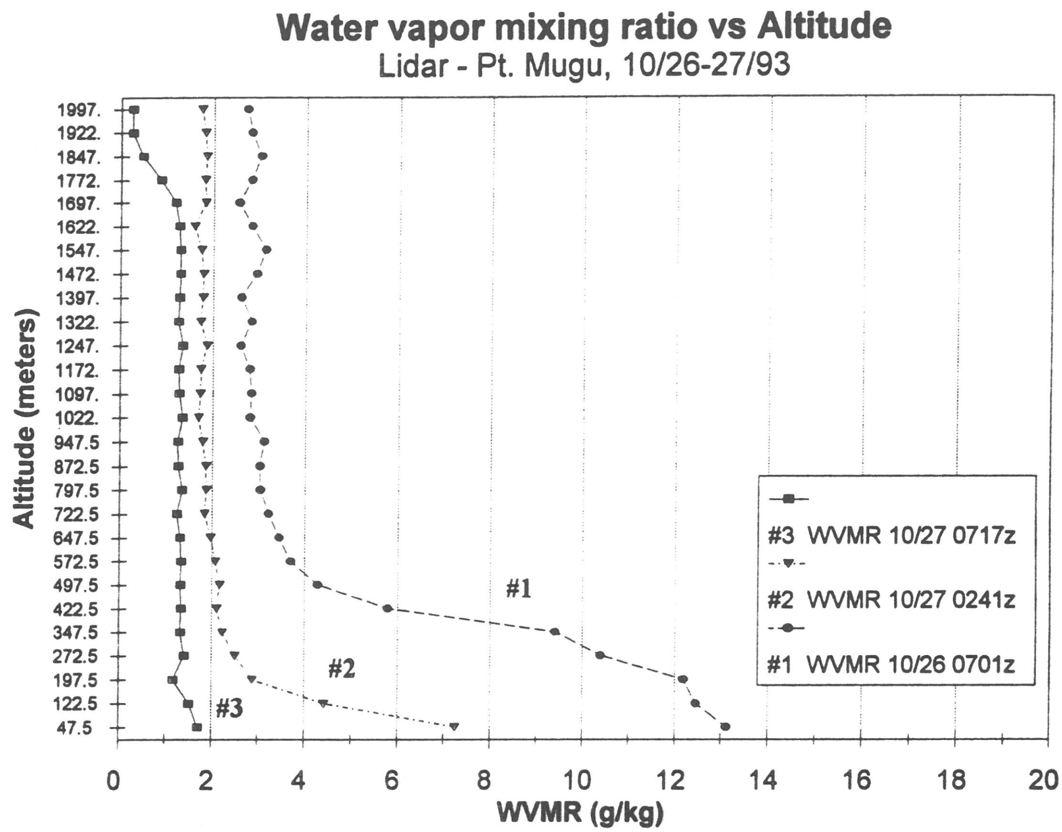


10/27/93 0241z

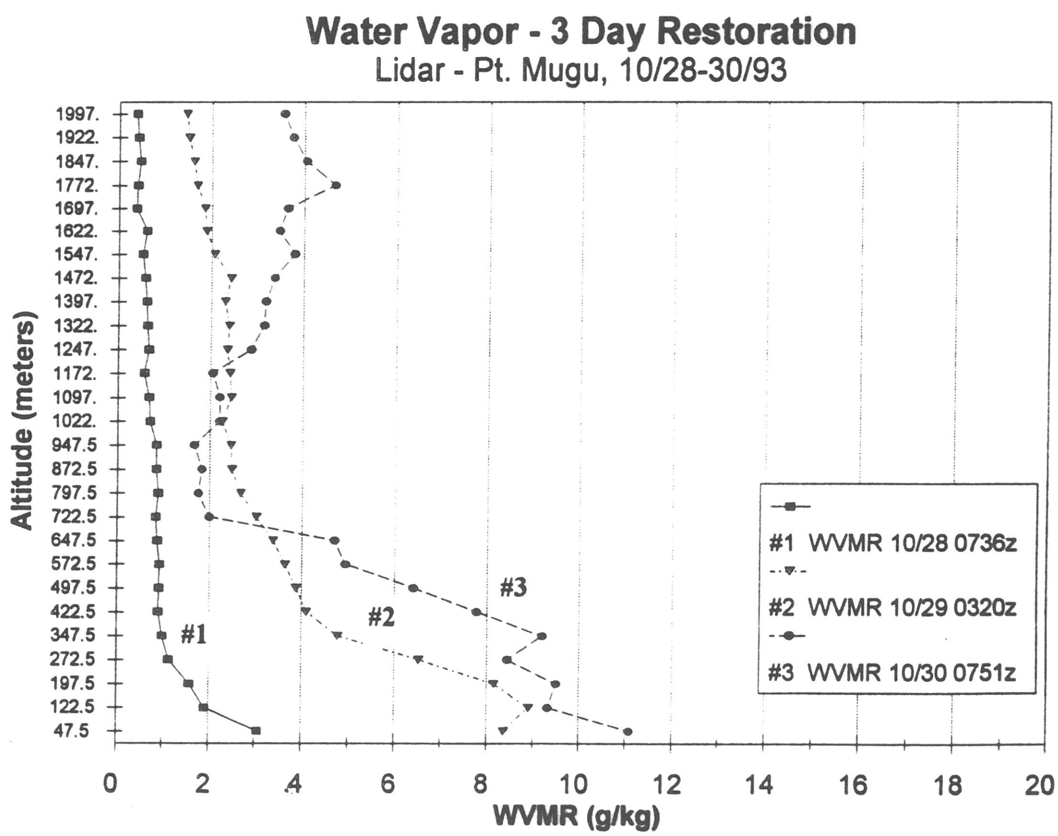


10/27/93 0717z





Water vapor mixing ratio vs Altitude
Lidar - Pt. Mugu, 10/26-27/93
Altitude (meters)
1997.
1922.
1847.
1772.
1697.
1622.
1547.
1472.
1397.
1322.
1247.
1172.
1097.
1022.
947.5
872.5
797.5
722.5
647.5
572.5
497.5
422.5
347.5
272.5
197.5
122.5
47.5
0
2
4
6
8
10
12
14
16
18
20
WVMR (g/kg)
#1
#2
#3
#3 WVMR 10/27 0717z
#2 WVMR 10/27 0241z
#1 WVMR 10/26 0701z



Water Vapor - 3 Day Restoration
Lidar - Pt. Mugu, 10/28-30/93
Altitude (meters)
1997.
1922.
1847.
1772.
1697.
1622.
1547.
1472.
1397.
1322.
1247.
1172.
1097.
1022.
947.5
872.5
797.5
722.5
647.5
572.5
497.5
422.5
347.5
272.5
197.5
122.5
47.5
0
2
.4
6
8
10
12
14
16
18
20
WVMR (g/kg)
#1
#2
#3
#1 WVMR 10/28 0736z
#2 WVMR 10/29 0320z
#3 WVMR 10/30 0751z

SUMMARY OF OBSERVATIONS

- Very high upper level winds (exceeding 40 kts) from NNE at Pt. Mugu caused a drying out of the maritime moist air near the surface from the top at ~500 m downward with time.

- Sharp water vapor gradients (-4 to -6 g/kg/100m), combined with extreme temperature gradients (inverted, +5 to +10 deg C/100m), produced first elevated, and then surface refractive ducting gradients in N (illustrated by M).

- Initially, the N gradients are supported and dominated by the humid surface layer affecting the "wet" term of the refractivity equation.

- When the moist air is driven out, the dominant contributor to the N profile shape is the "dry air" term.

- Relative humidities diminished below 5% near and at the surface as the Santa Ana winds reached the surface.

- A somewhat reverse process occurrs as the winds subsided and the moist air returns to the lower air boundary layer, however, the extreme gradients in water vapor and temperature do not occur to produce strong ducting conditions.

- Lidar provided an appropriate instrument to measure and map out these effects due to it's fixed spatial (true vertical) profiling and the ease of producing multiple rapid-sequence atmospheric profiles during the dynamic atmospheric changes.

IEEE/URSI
JUNE 20TH
(PRESENTATION ONLY)
OUTLINE

LIDAR ATMOSPHERIC MEASUREMENTS OF TROPOSPHERIC REFRACTIVITY DURING DEVELOPING SANTA ANA WINDS

D. W. Blood* and C. R. Philbrick
Applied Research Laboratory/Penn State University
P.O. Box 30, State College, PA 16804
(814) 863-7089, Fax (814) 863-8783

ABSTRACT

A multi-wavelength Raman lidar was used to measure profiles of water vapor, temperature and other atmospheric properties in the troposphere during the beginnings of the 1993 Los Angeles fire storm period with developing high velocity Santa Ana wind conditions. The PSU/LAMP lidar instrument was being is used to make measurements at Point Mugu, CA for an observational campaign called VOCAR (Variability of Coastal Atmospheric Refractivity). The Raman technique provides an accurate way to measure the profiles of water vapor from the ratio of the Raman vibrational backscatter signal from water vapor to that of nitrogen. The lidar has been used both to obtain water vapor profiles from molecular Raman vibrational scattering at several wavelengths, and temperature profiles from Raman rotational scattering at 528 and 530 nm. The water vapor measurements have been made using the vibrational Raman backscatter intensity from the 660/607 ratio from the 532 nm, 407/387 ratio from 355 nm, or the 294/285 ratio from 266 nm laser radiation.

The measurements of the atmospheric refractive environment on October 26 and 27th, 1993 at Point Mugu, CA during the developing wind storm, produced an intense temperature inversion and gradient further producing an RF ducting condition in the lower troposphere. The lidar temperature and water vapor data were used to compute profiles of refractivity, N, and modified refractivity, M, at 75 m height intervals in the lower tropospheric region (surface to 5000 m). The lidar data, stored at one minute intervals, is examined with integration times of several minutes. The time history of these profiles shows a dramatic low altitude drying effect in the maritime boundary layer. This changes the atmospheric refractive condition from a strong refractive surface based duct to the complete absence of any ducting over a 5 hour period. Atmospheric variability decreases as the moisture is driven entirely out of the surface air layer. This anomalous type of refractive ducting is entirely different from the usual ducting conditions produced during more quiescent conditions, where an elevated or surface duct is frequently formed by a significant drop in water vapor near a temperature inversion. The time history of this rare developing atmospheric condition is shown and the corresponding physical parameters contributing to the refractivity effects are analyzed.

OUTLINE of Presentation:

1. Introduction: (1 vugraph)
   - Mission of Pt. Mugu operations, Sponsor, Organizations, etc.
   - Coverage of talk and focus of investigation

2. Lidar and Measurement capability: (2 VGs)
   - Lidar measurement technique (brief)
   - WV, T, Po ---> N(z), M(z) --->(mention system propagation loss/coverages)
   - Refractivity variability by lidar under changing environmental conditions (standard and ducting), Examples from other VOCAR periods?

3. Santa Ana condition observations - development - Oct. 26, 27th, '93: (8 VGs)
   - General conditions before, during and after first wind storm period from lidar and radiosonde profiles, (1 VG)
   - Wind magnitude and direction from sondes, (1 VG)
   - Lidar measurements in detail during atmospheric drying-out period, (2 VGs)
   - Contributions to N, M refractivity equation calc, due to wet, and dry terms and influence of WV and T gradients on profiles (2 VGs)
   - Time evolution of refractivity on 10/27th (strong surface ducting transitions to a total absence of duct as WV is driven out of lower atmosphere by the upper level winds), Ducting height and depth data vs time (2 Vgs)

4. Summary of Observations: (1 VG)
   - Characterize the effects
   - Quantitative data on WV gradients, RH(%), T gradients, ducting