CIRRUS CLOUDS AND VERTICAL VELOCITY IN THE VICINITY OF TROPICAL TROPOPAUSE

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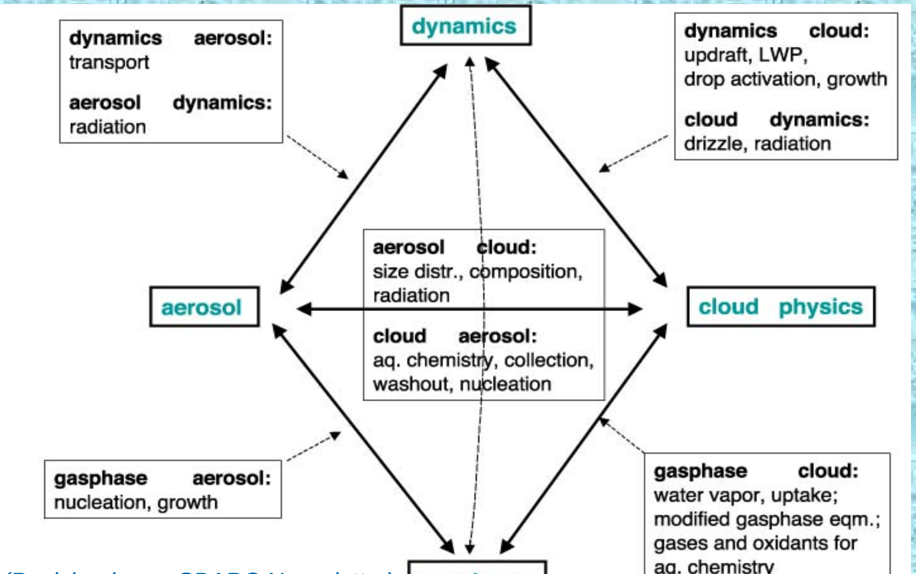
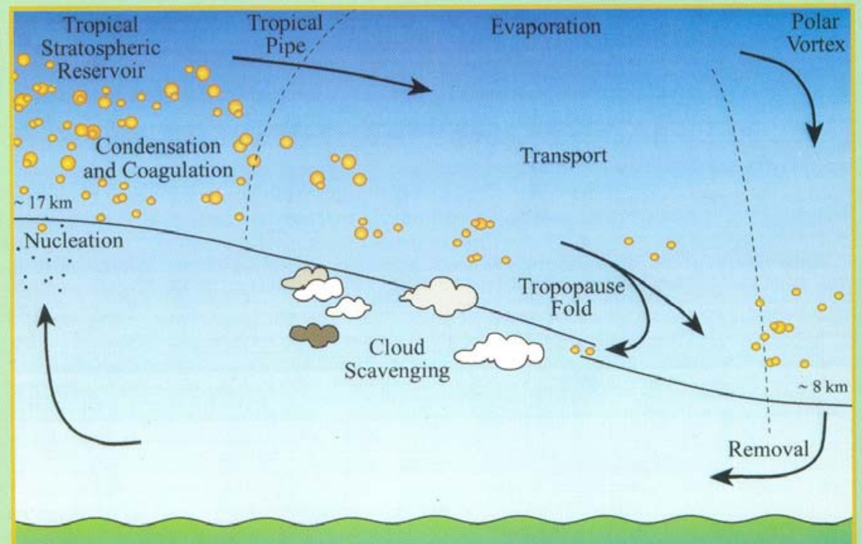
- Clouds and aerosol play key role in radiation budget of the Earth's atmosphere through their direct and indirect interaction with both solar and terrestrial radiations.

- The tropopause region is a region where Ozone, water vapor, cirrus clouds and aerosols have strong influence on the atmospheric radiation budget. *It is also a region where transport processes that couple the stratosphere and troposphere*. Thus, the tropopause region is of critical importance for understanding the long term changes of the Earth's climate.



(Ravishankara , SPARC News letter)



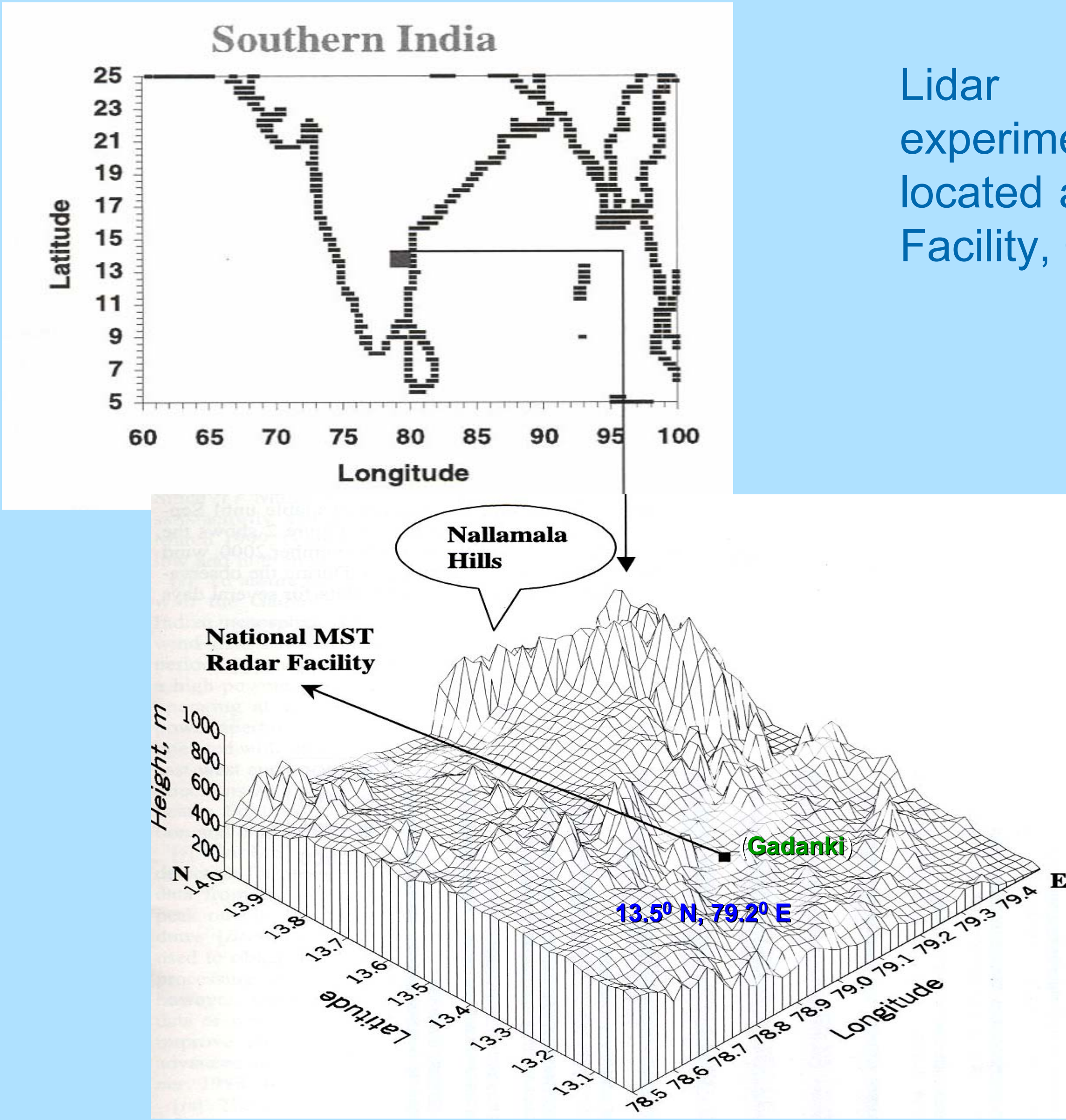
(Hamill et al 1997, Bulletin of American Meteorl. Soc)

- Lidar and MST radar are powerful tools to monitor dynamics of the tropopause region on near continuous basis.

- In the present study, attempts have been made to monitor cirrus clouds and vertical velocity in the vicinity of tropopause over Gadanki, a tropical station in INDIA, by making use of combined lidar and MST radar observations.

- **Lidar observations have been used to study height and temporal variations of cirrus clouds and also aerosols**
- **MST Radar observations have been used to monitor vertical velocity and stable layer structures in the vicinity of tropical tropopause.**
- **MST radar observed vertical velocities have been used to derive diabatic heating rates during different meteorological conditions.**

Location of Station



Lidar and VHF Radar experimental facilities are located at National MST radar Facility, Gadanki in India

- **Nd:YAG lidar (operating at 0.532 μm) has been used to monitor aerosols and cirrus clouds in upper troposphere and lower stratosphere. This lidar system is having capability to make co (‖) and cross (⊥) polarization measurements. Processing of lidar back-scattered signal (photons) provides two optical parameters**

  - **Scattering Ratio** $$SR = \frac{\beta_a + \beta_m}{\beta_m}$$

  - **Linear Depolarization Ratio** $$LDR = \frac{S_\perp}{P_{||}} \delta_{air}$$

Specifications of the Lidar System

Transmitter

(Solid state class PL8020 modal Laser source from Continum, USA)

Laser source	Nd: YAG (Visible)
Operating wavelength	532 nm
Average energy per pulse	550 mJ
Average output power	11 W
Pulse width	7 nsec
Pulse Repetition Rate	20 Hz
Beam Divergence	<0.1 mRad

Receiver

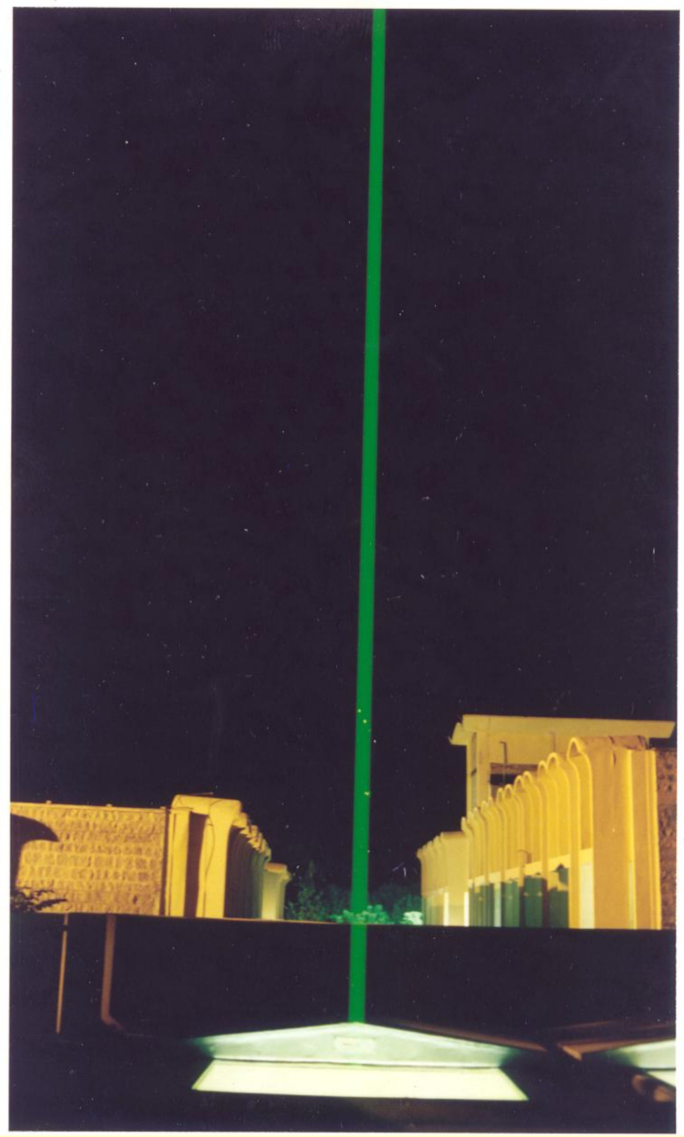
	Mie	Rayleigh
Telescope type	Schmidt-Cassegranin	Newtonian
Diameter	350 mm	750 mm
Field of View	1 mRad	1 mRad
Interference filter Bandwidth	1.13 nm	1.07 nm

Signal Processing *(4 channels PC based data acquisition system operating with EG & G ORTEC MCS software)*

Bin Width 2 µsec – 1800 sec settable (2 µsec present setting)

Scan Length 4 – 8192 channel settable (1024 channel present setting)

Integration Time 16,77,251 laser shots per channel
(At present 5000 laser shots in 250 sec)

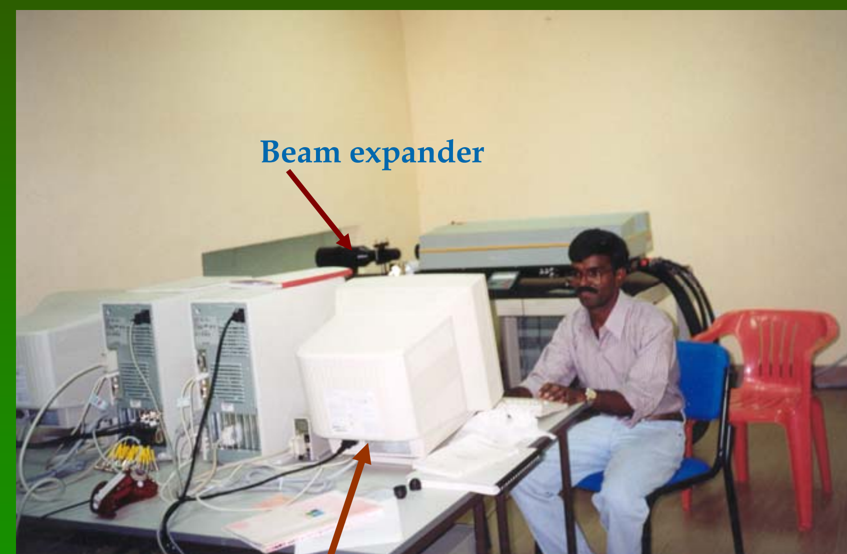


Nd:YAG Lidar system

Rayleigh and Mie Telescopes

Beam Directing
mirror

Transmitter



Signal Processing

Receiver

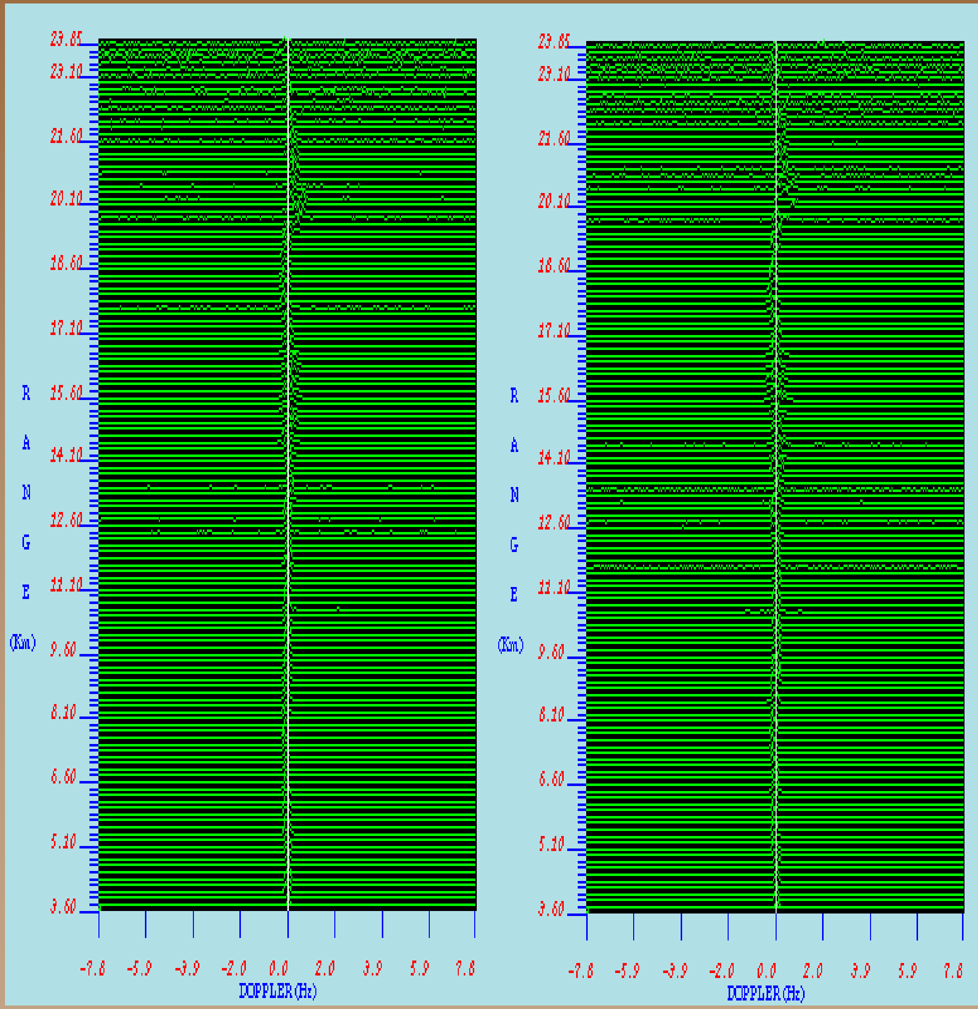
- **Mesosphere-Stratosphere-Troposphere (MST) radar is a high power highly sensitive Doppler radar operating at 53 MHz. The capabilities of MST radar include measurement of vertical velocity and also detection and monitoring of stable layer structures such as tropopause with high range and time resolutions, during all weather conditions.**

Specifications of MST Radar

Frequency	: 53 MHz in VHF Range
Effective Aperture Area	: 1.25×10^4 m^2
Peak Power	: 2.5 MW
Peak Power Aperture Product	: 3×10^{10} Wm^2
Duty Ratio	: Up to 2.5% depending on waveform
Antenna	: Phased array with 1024 crossed Yagi elements
Beam Width	: 3^0
Beam Directions	: 1^0 step in N-S and E-W planes (maxi. up to 20^0)
Pulse Width	: 1 – 64 μs
PRF	: 62.5 Hz – 8 kHz
Max. Range Resolution	: 150 m (for 1 μs pulse or baud length)
Max. Number of range bins	: 512
Max. Number of FFT points	: 1024
Typical Velocity Resolution	: 0.1 m/s
Typical Time Resolution	: 80 sec

32X32 Yagi Antenna Array of MST Radar

Typical height profiles of Doppler spectrum observed by Indian MST radar for E-W and N-S polarizations of antenna array



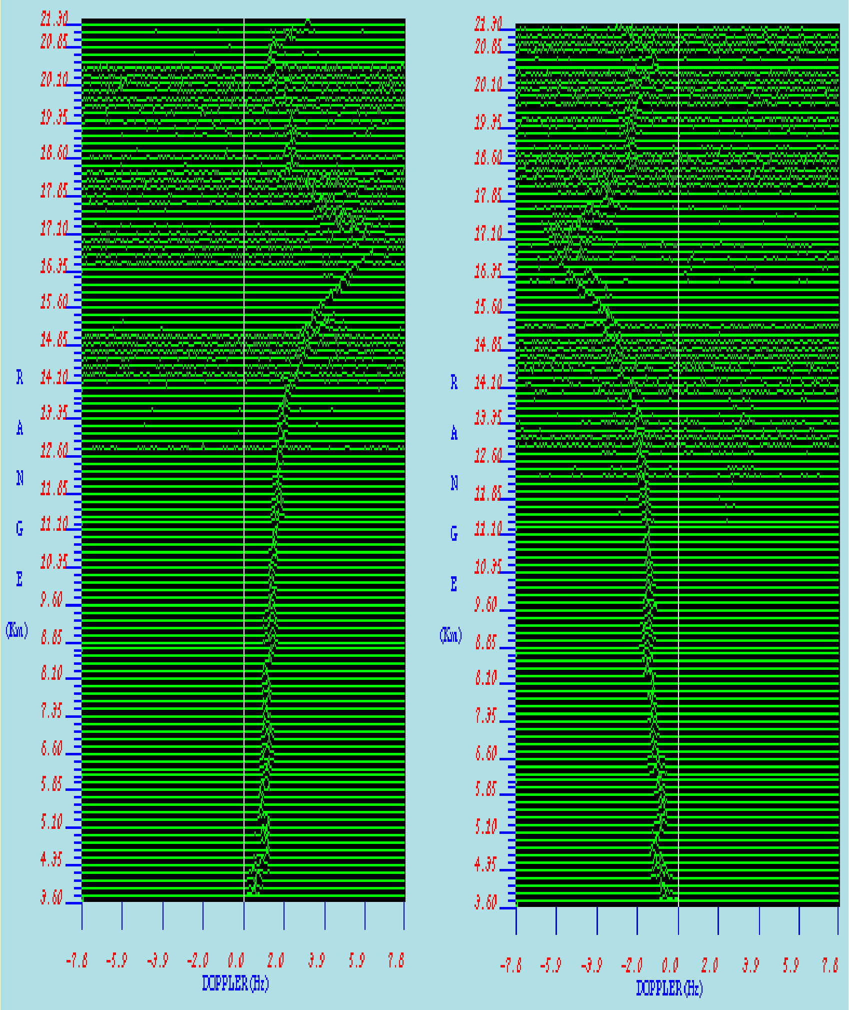
- MST Radar provides Doppler spectrum at each height level for different beam positions.
- Doppler shift (f_D) observed is proportional to the line of sight velocity

$$V = \frac{(c \times f_D)}{(2 \times f_C)} \quad or \quad \frac{f_D \times \lambda}{2}$$

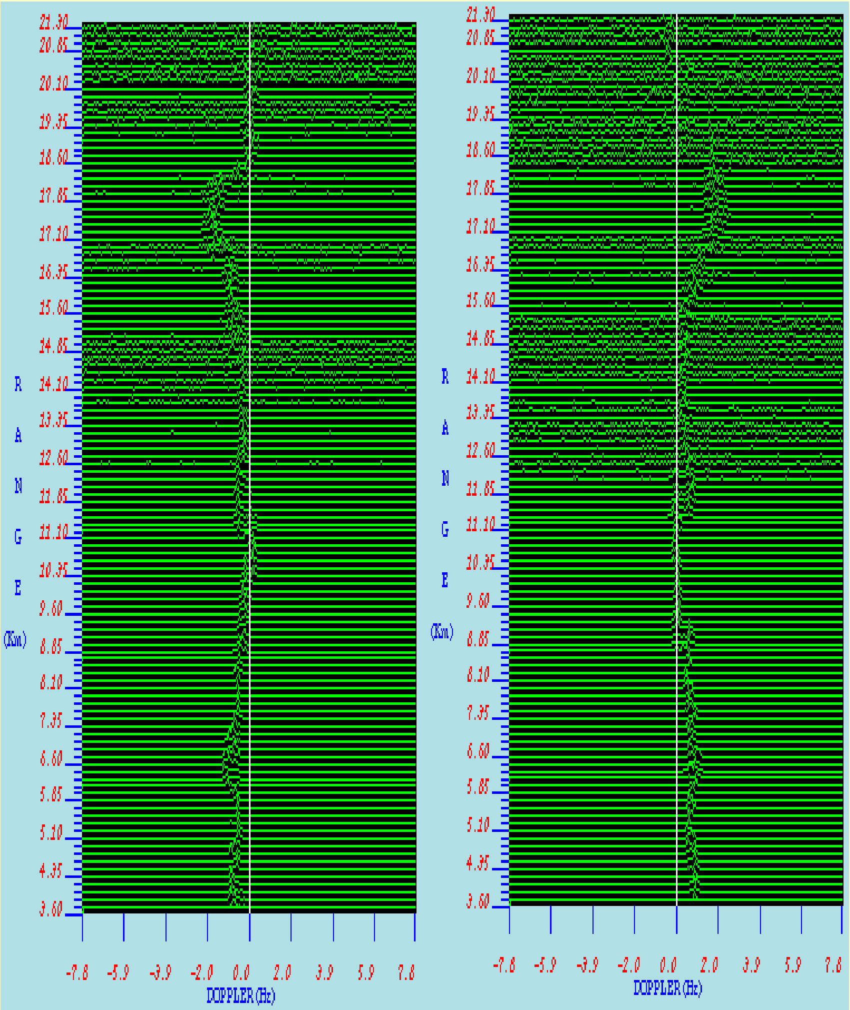
- Doppler shift observed for vertical beam is proportional to vertical velocity

TYPICAL DOPPLER SPECTRA OBSERVED BY INDIAN MST RADAR FOR OFF-VERTICAL RADAR BEAMS

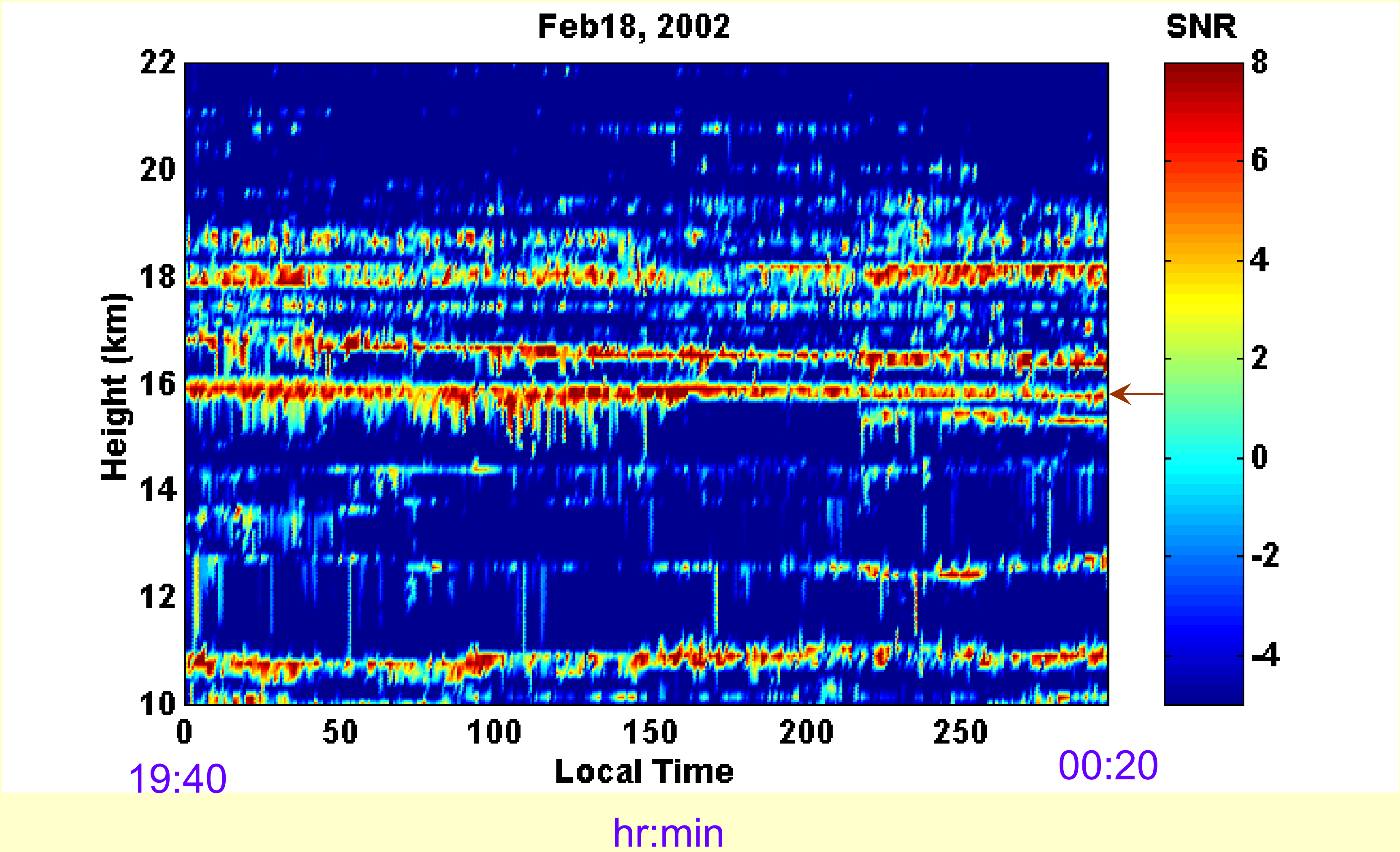
EAST AND WEST BEAMS



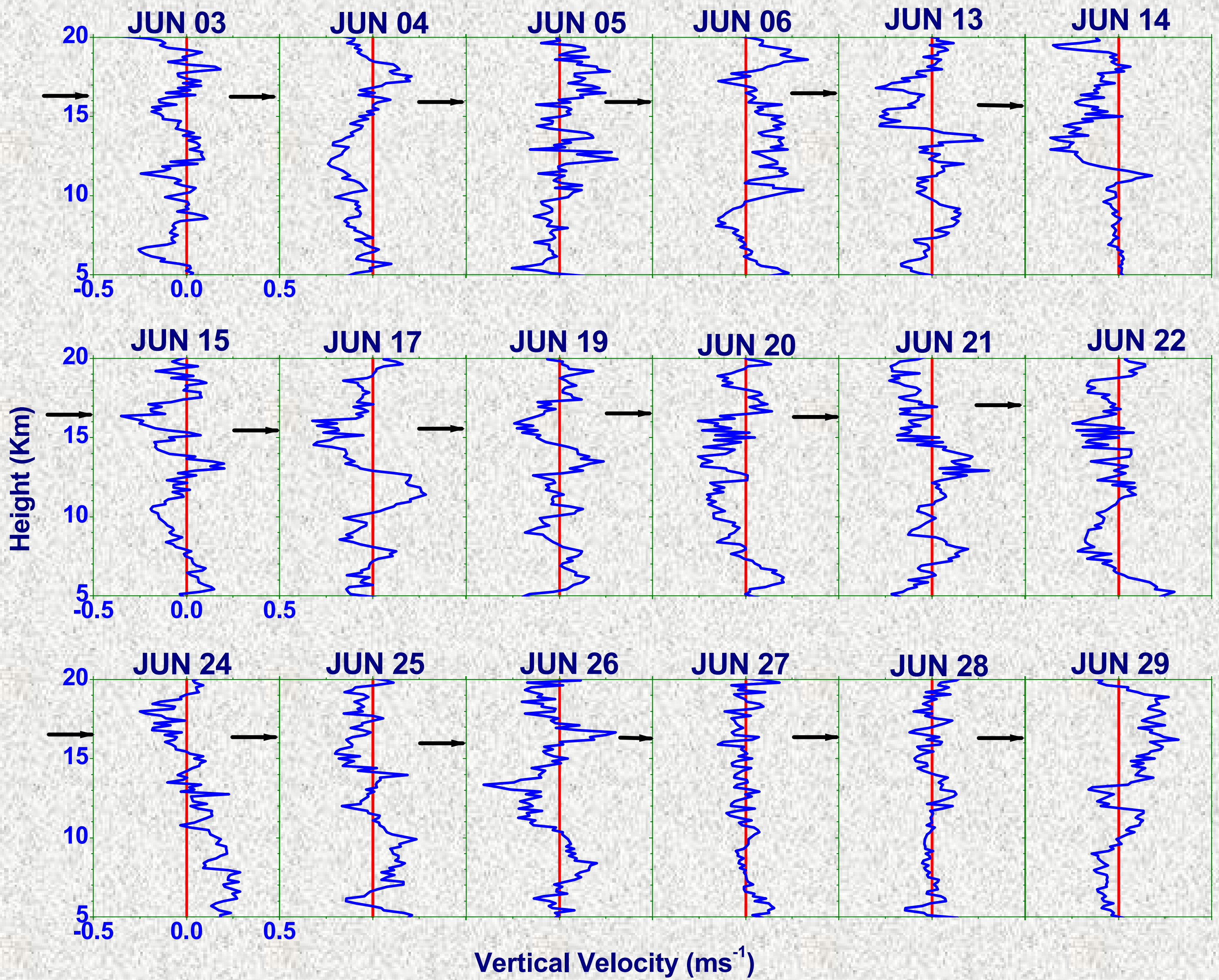
NORTH AND SOUTH BEAMS



MST Radar Observations of Stable Layer Structures



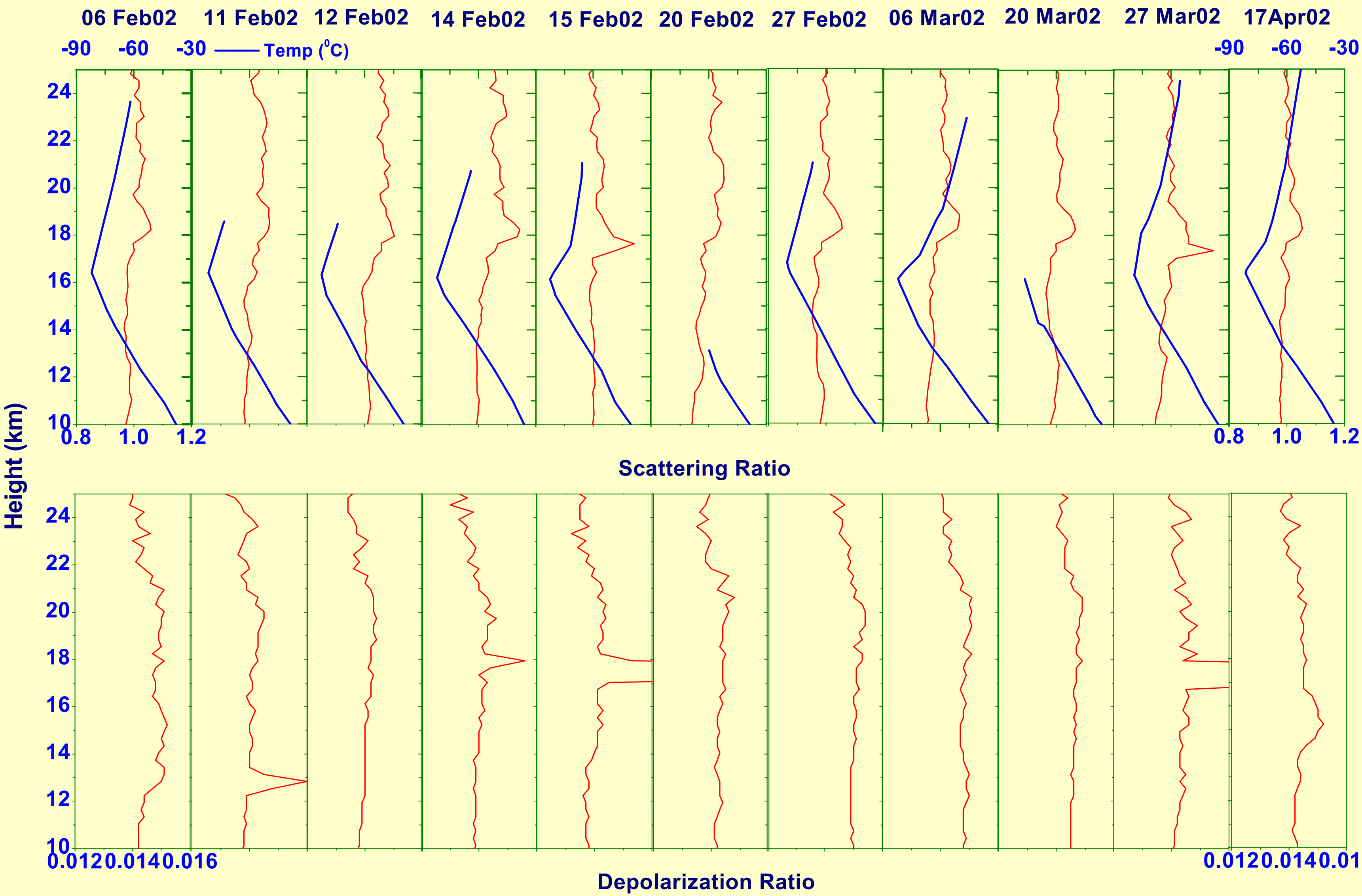
Daily Variation of Vertical Velocity during June 2002

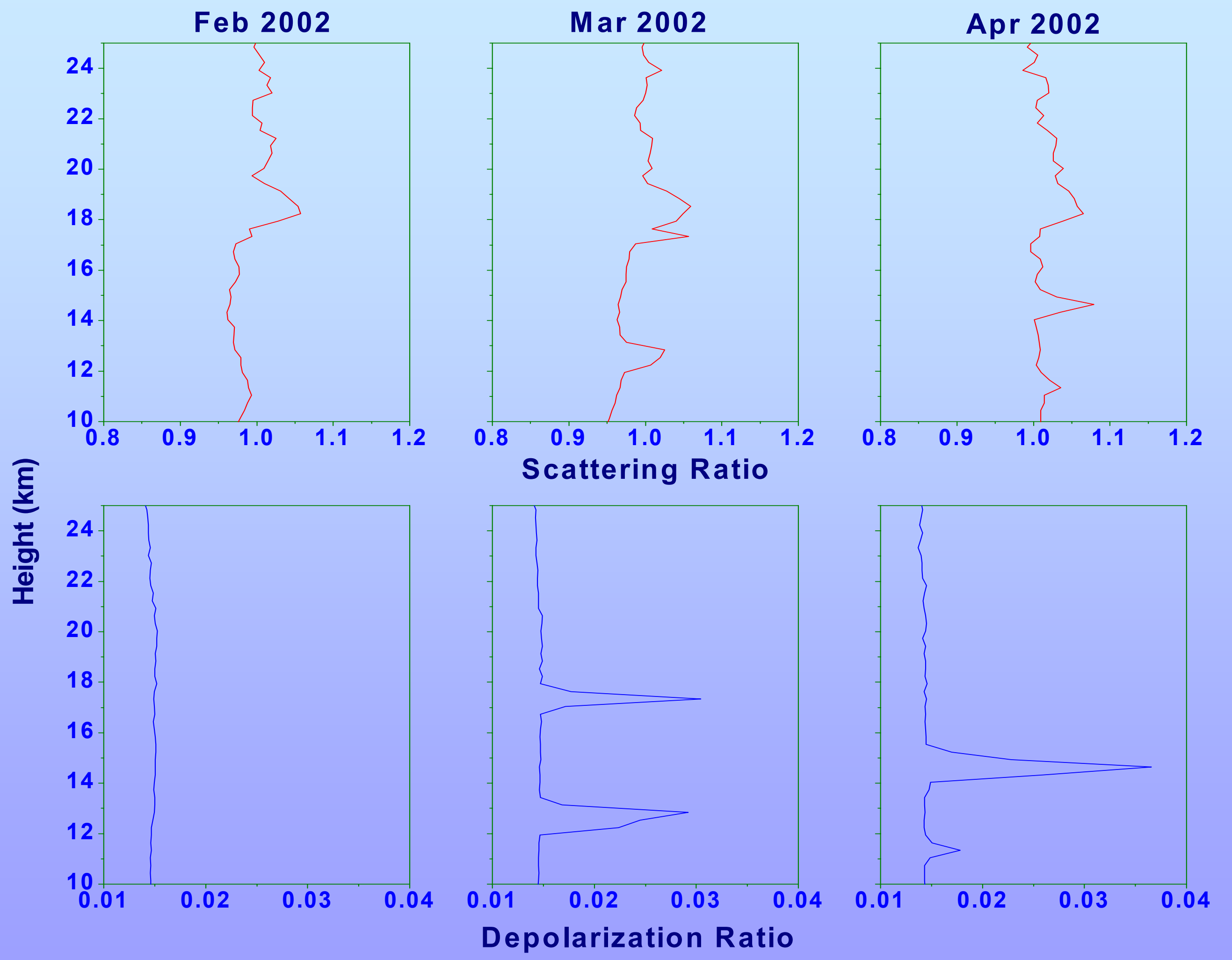


The arrow shows the height of the tropopause (Cold point)

- Lidar Observations

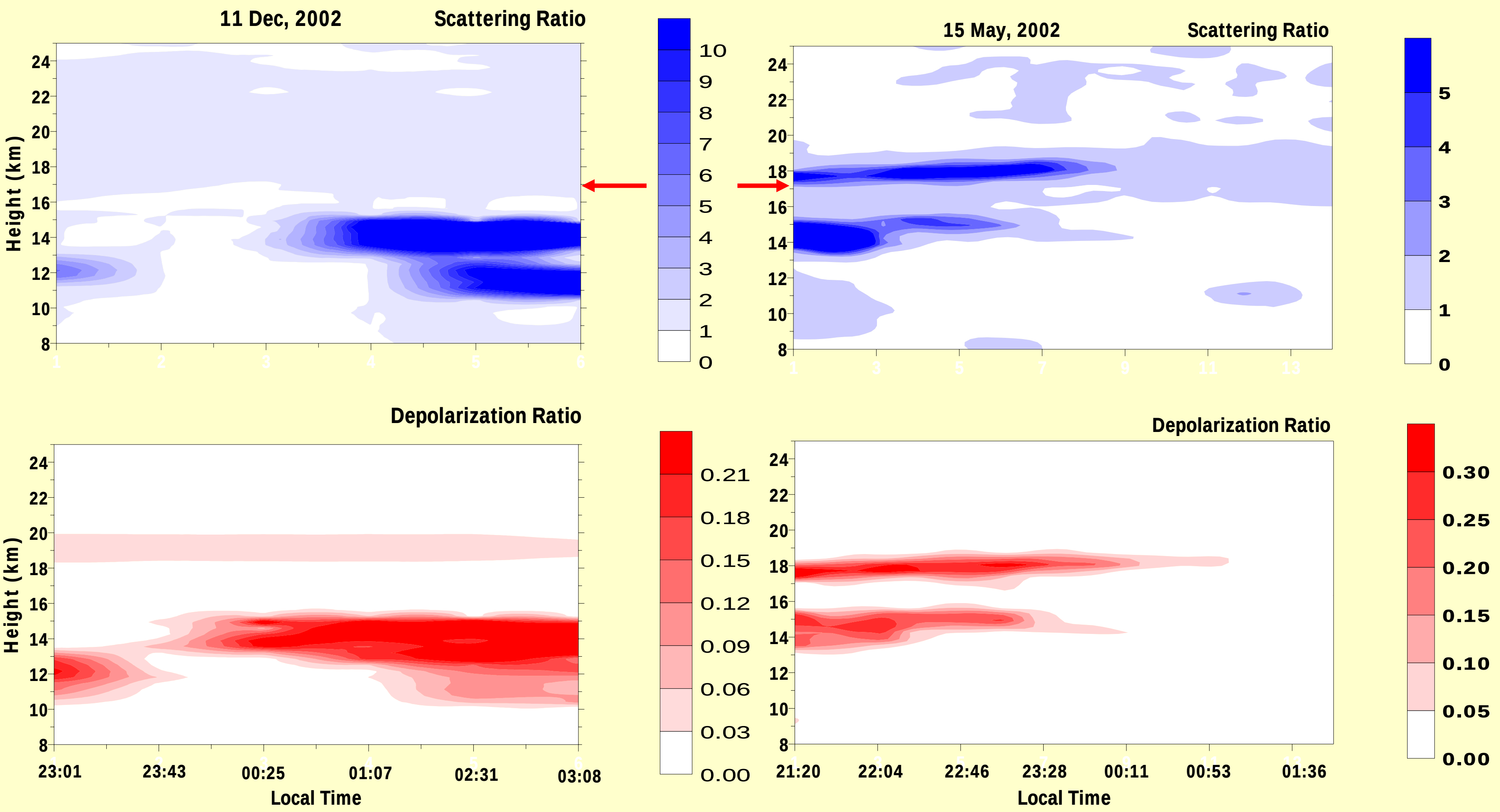
Day-to-Day variation of Scattering and Depolarization Ratios during clear sky

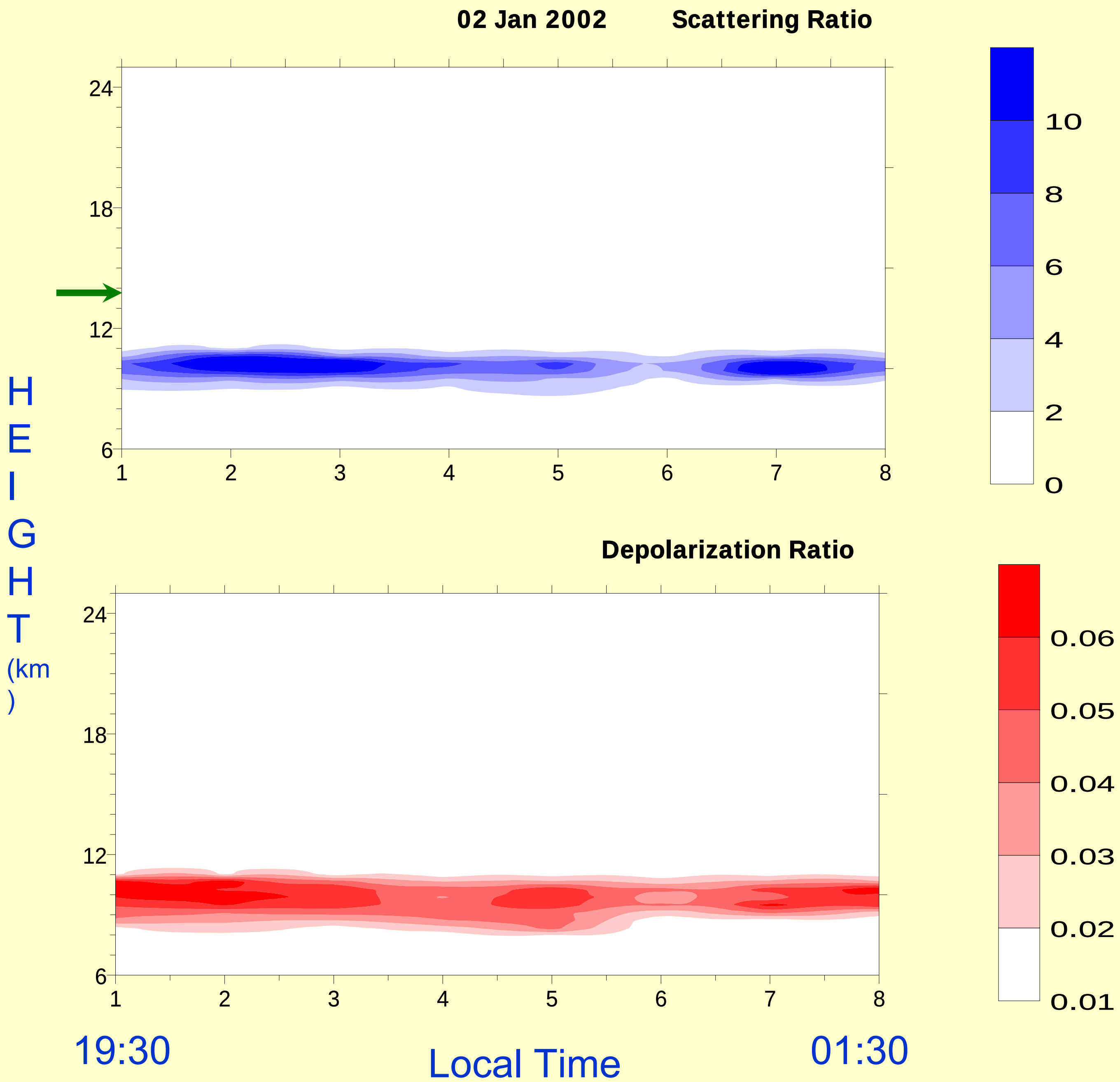




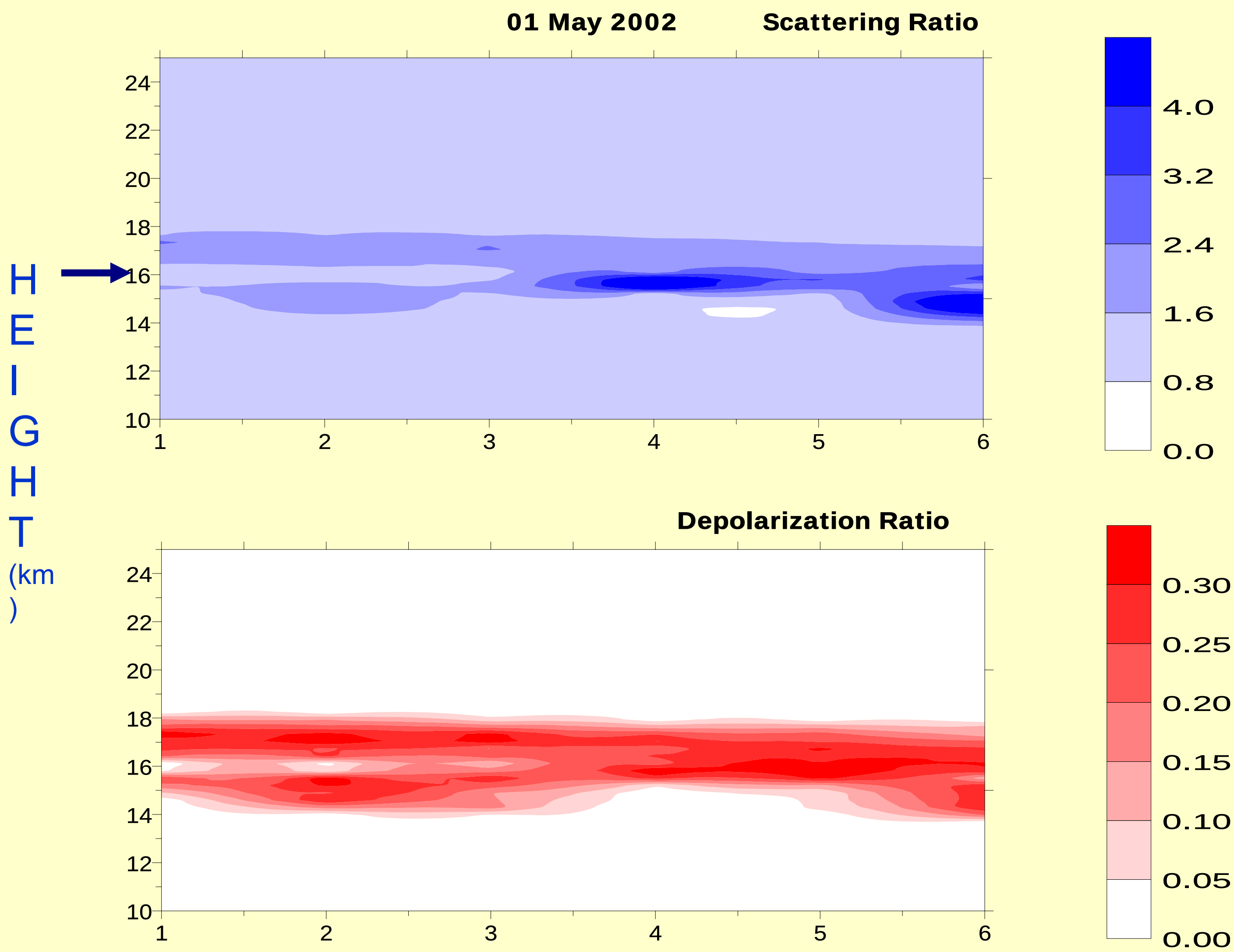
Monthly Variation of Scattering and Depolarization Ratios During Clear Sky

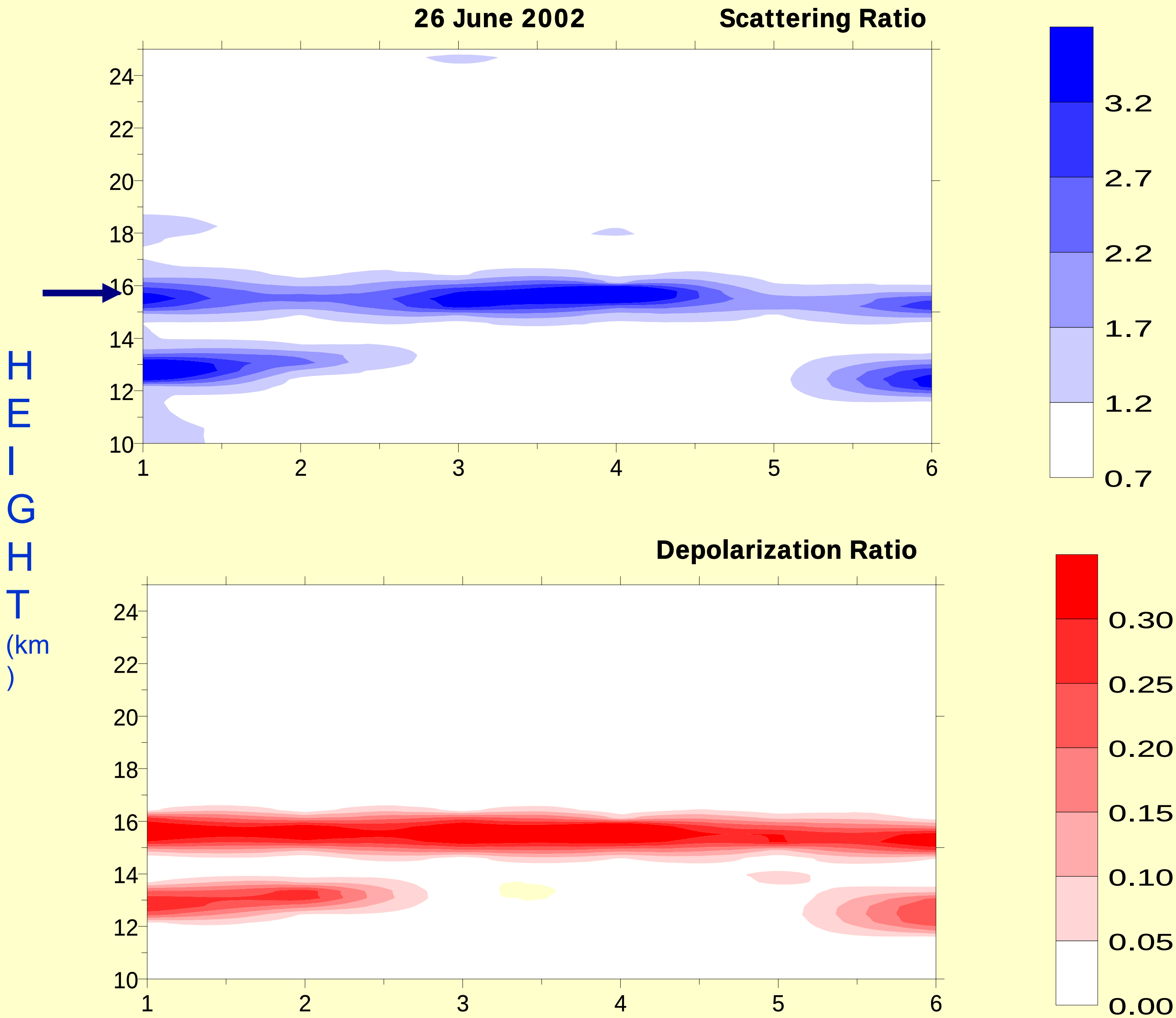
Temporal variation of lidar observed optical parameters in the presence of cirrus clouds

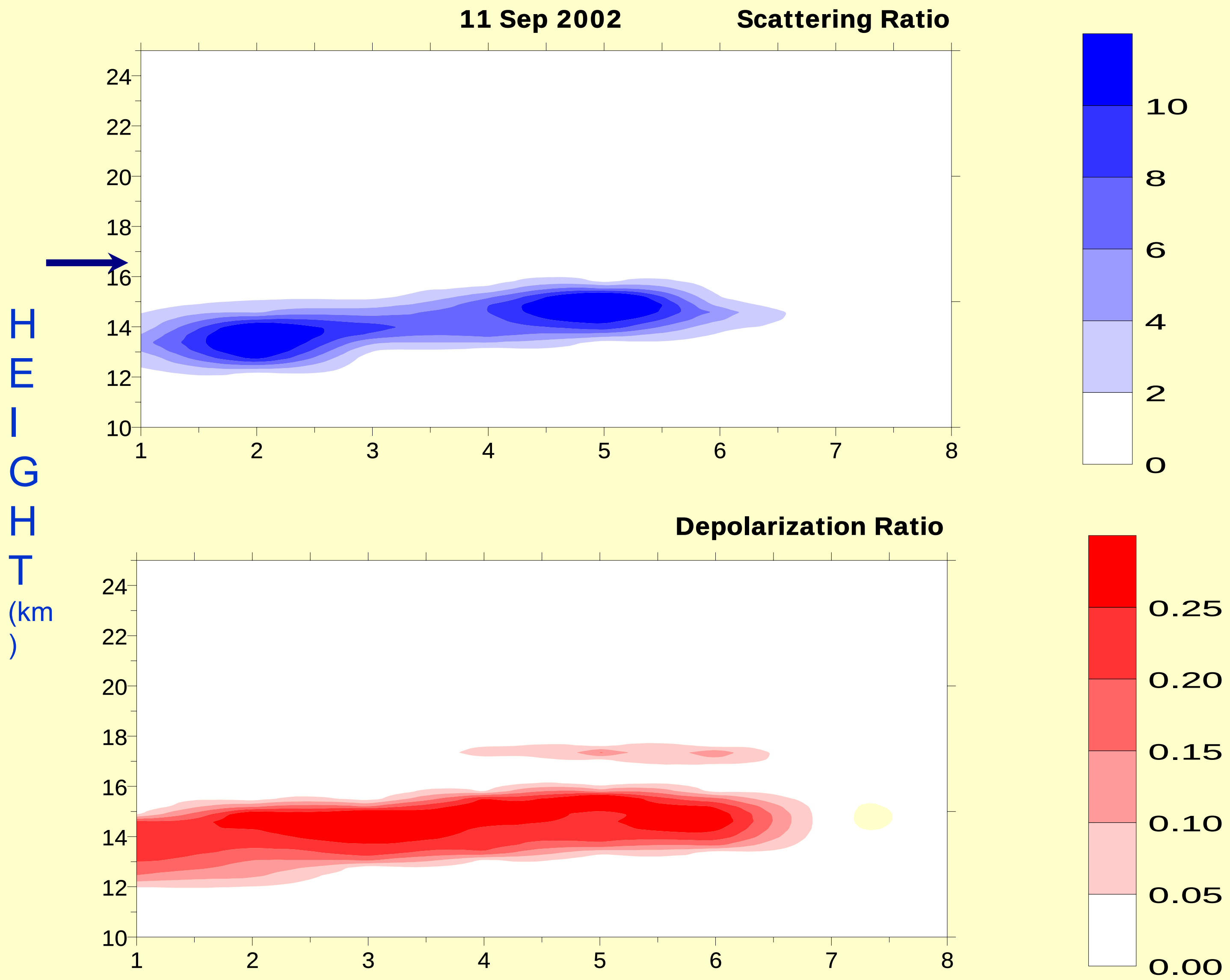




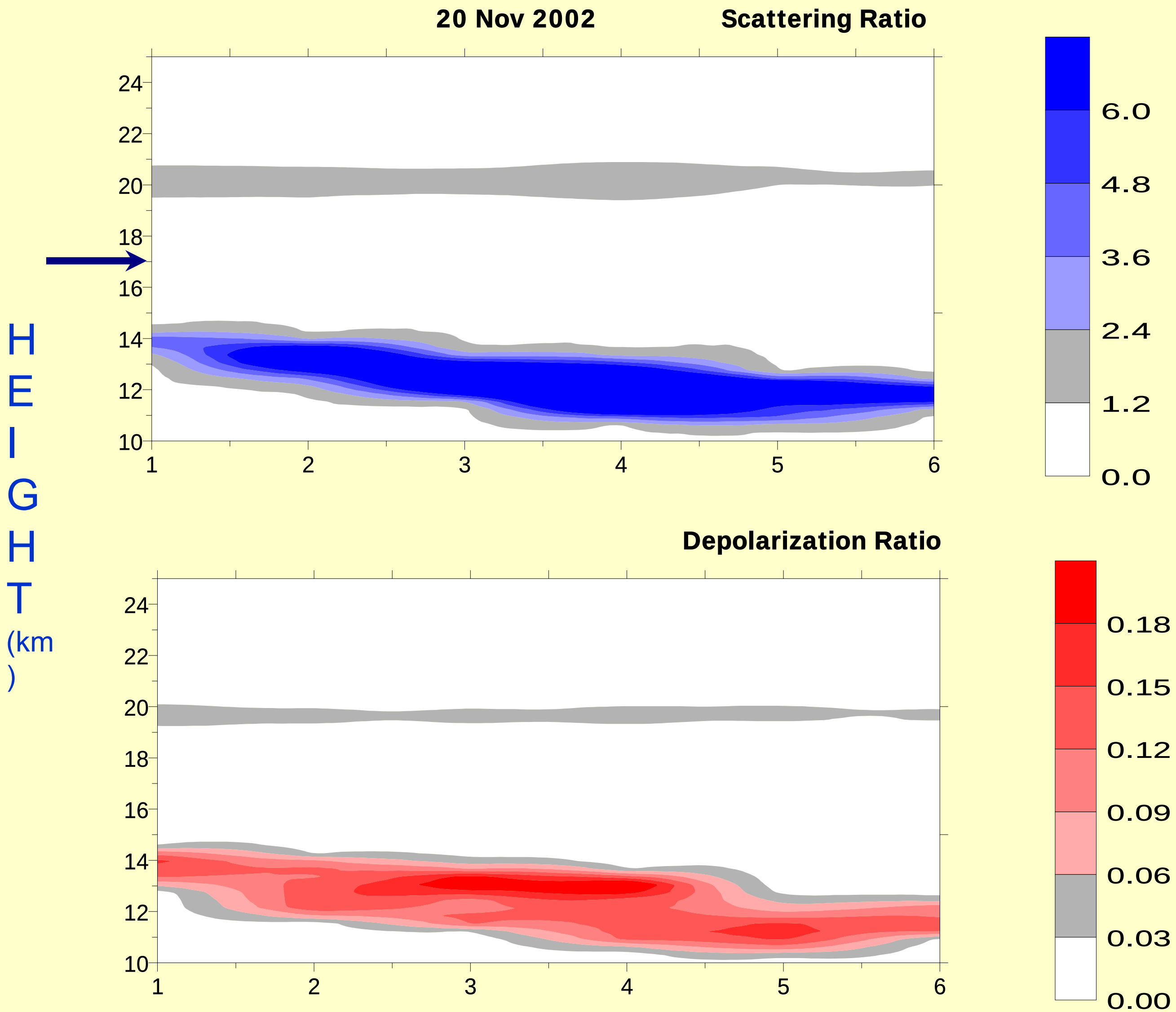
02 Jan 2002
Scattering Ratio
Depolarization Ratio
HEIGHT (km)
24
18
12
6
1
2
3
4
5
6
7
8
10
8
6
4
2
0
0.06
0.05
0.04
0.03
0.02
0.01
19:30
Local Time
01:30

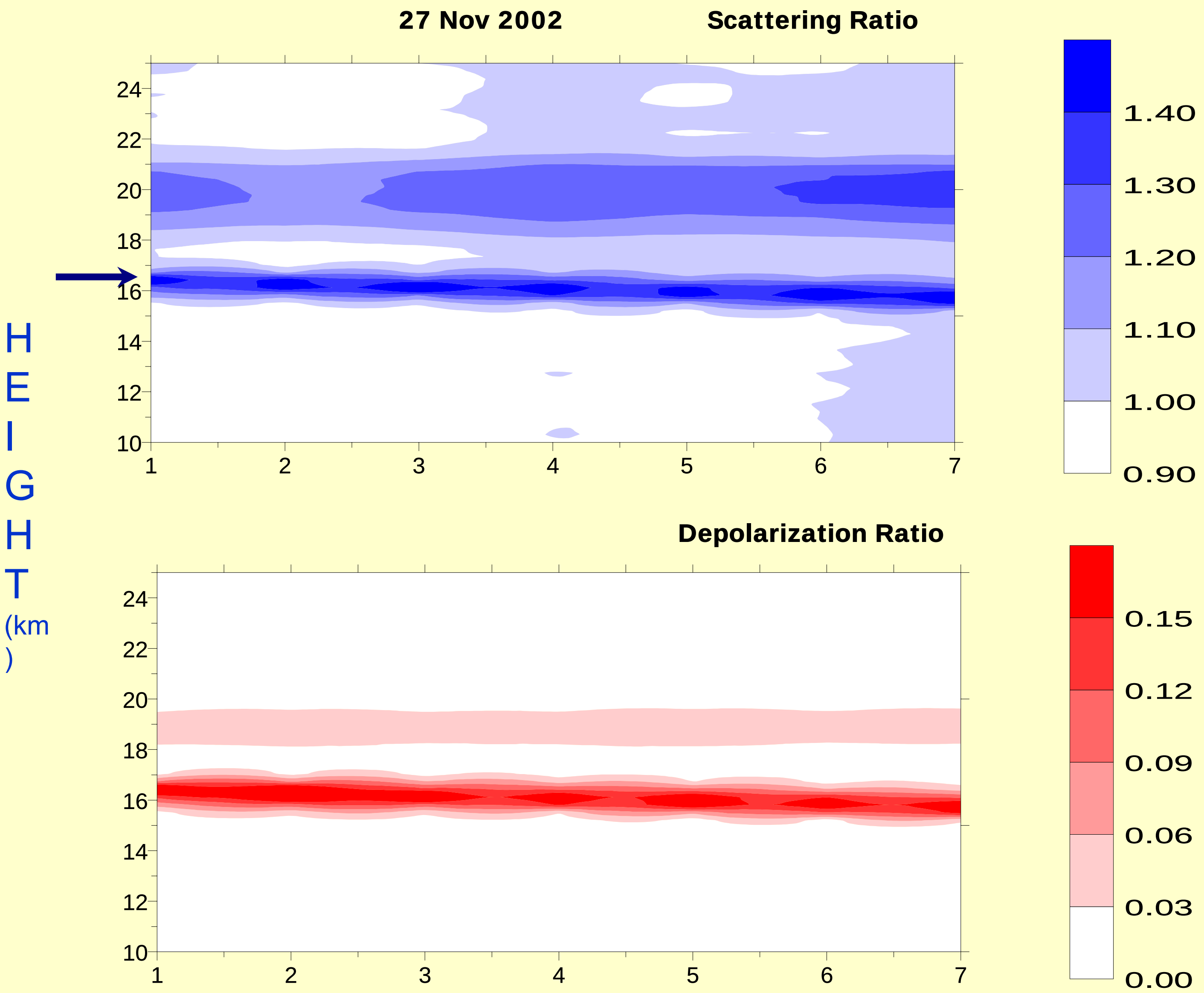

01 May 2002
Scattering Ratio
Depolarization Ratio
HEIGHT
(km
)
24
22
20
18
16
14
12
10
1
2
3
4
5
6
4.0
3.2
2.4
1.6
0.8
0.0
0.30
0.25
0.20
0.15
0.10
0.05
0.00


26 June 2002
Scattering Ratio
Depolarization Ratio
HEIGHT (km)
24
22
20
18
16
14
12
10
1
2
3
4
5
6
3.2
2.7
2.2
1.7
1.2
0.7
0.30
0.25
0.20
0.15
0.10
0.05
0.00



11 Sep 2002
Scattering Ratio
Depolarization Ratio
HEIGHT (km)
24
22
20
18
16
14
12
10
1
2
3
4
5
6
7
8
10
8
6
4
2
0
0.25
0.20
0.15
0.10
0.05
0.00

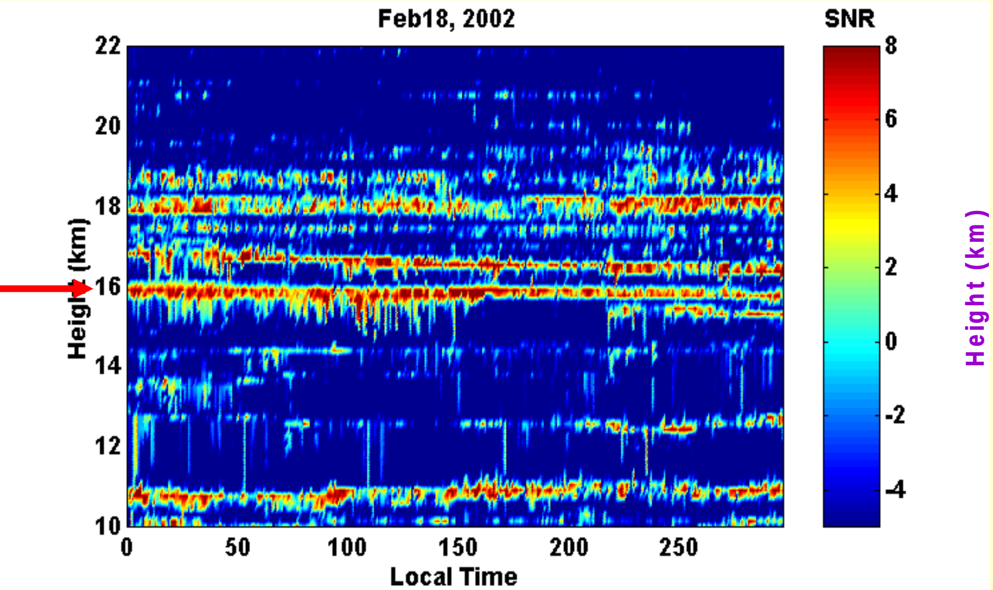

20 Nov 2002
Scattering Ratio
Depolarization Ratio
H E I G H T (km)
24
22
20
18
16
14
12
10
1
2
3
4
5
6
6.0
4.8
3.6
2.4
1.2
0.0
0.18
0.15
0.12
0.09
0.06
0.03
0.00

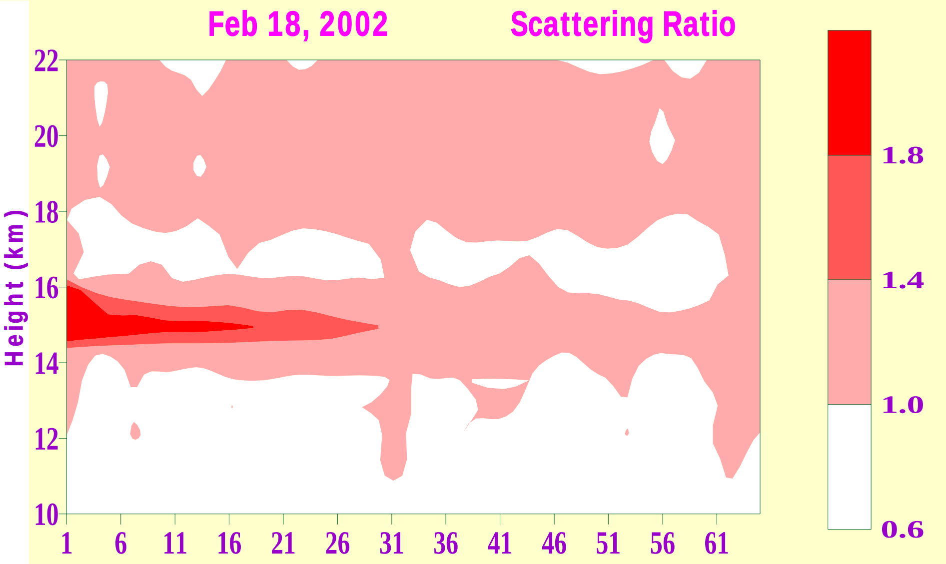


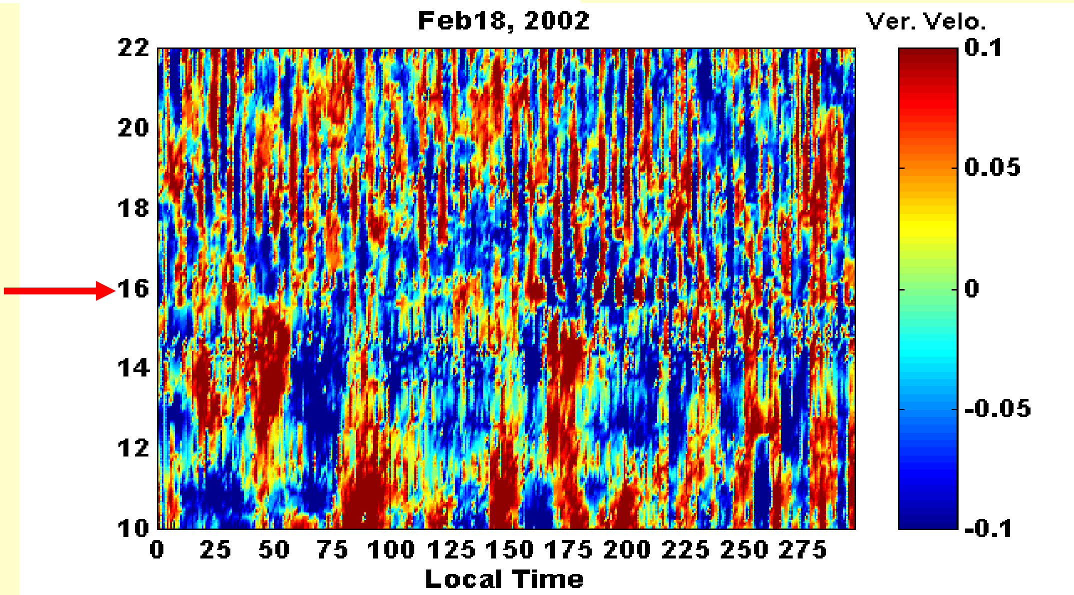
27 Nov 2002
Scattering Ratio
Depolarization Ratio
HEIGHT (km)
24
22
20
18
16
14
12
10
1
2
3
4
5
6
7
1.40
1.30
1.20
1.10
1.00
0.90
0.15
0.12
0.09
0.06
0.03
0.00

COMBAINED
LIDAR AND MST RADAR
OBSERVATIONS

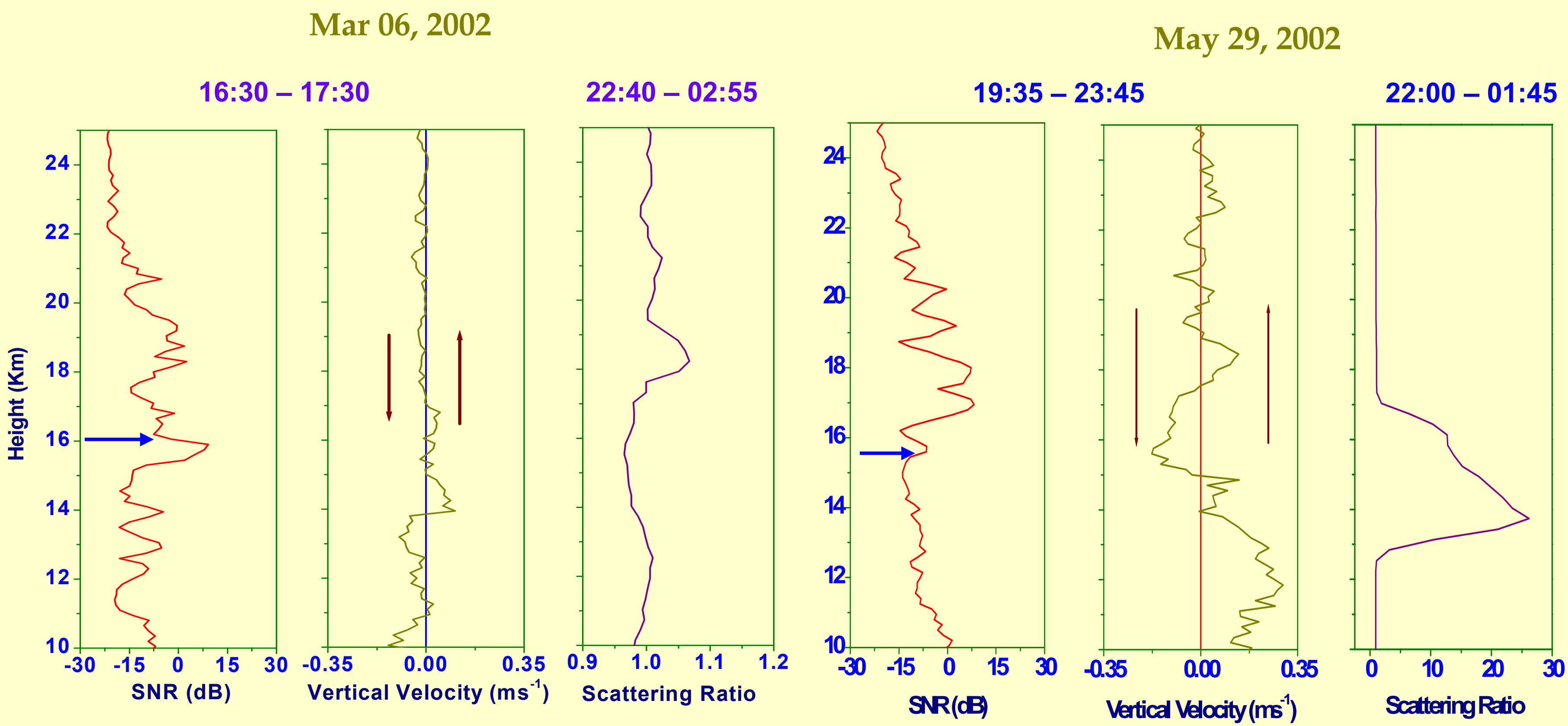
MST Radar observed SNR (Vertical Beam) and Vertical Velocity & Lidar Measured Scattering Ratio







Time 19:40 – 00:20



Height profiles of MST radar observed SNR (vertical beam), vertical velocity and lidar measured scattering ratio during clear sky and in the presence of Cirrus cloud

Estimation of Diabatic Heating Rate

The First Law of Thermodynamics:

$$\frac{dT}{dt} = \frac{\partial T}{\partial t} + V.\nabla_H T + W\frac{\partial T}{\partial t}$$

Thermodynamic energy equation

$$C_P \frac{dT}{dt} - \alpha \frac{dp}{dt} = Q$$

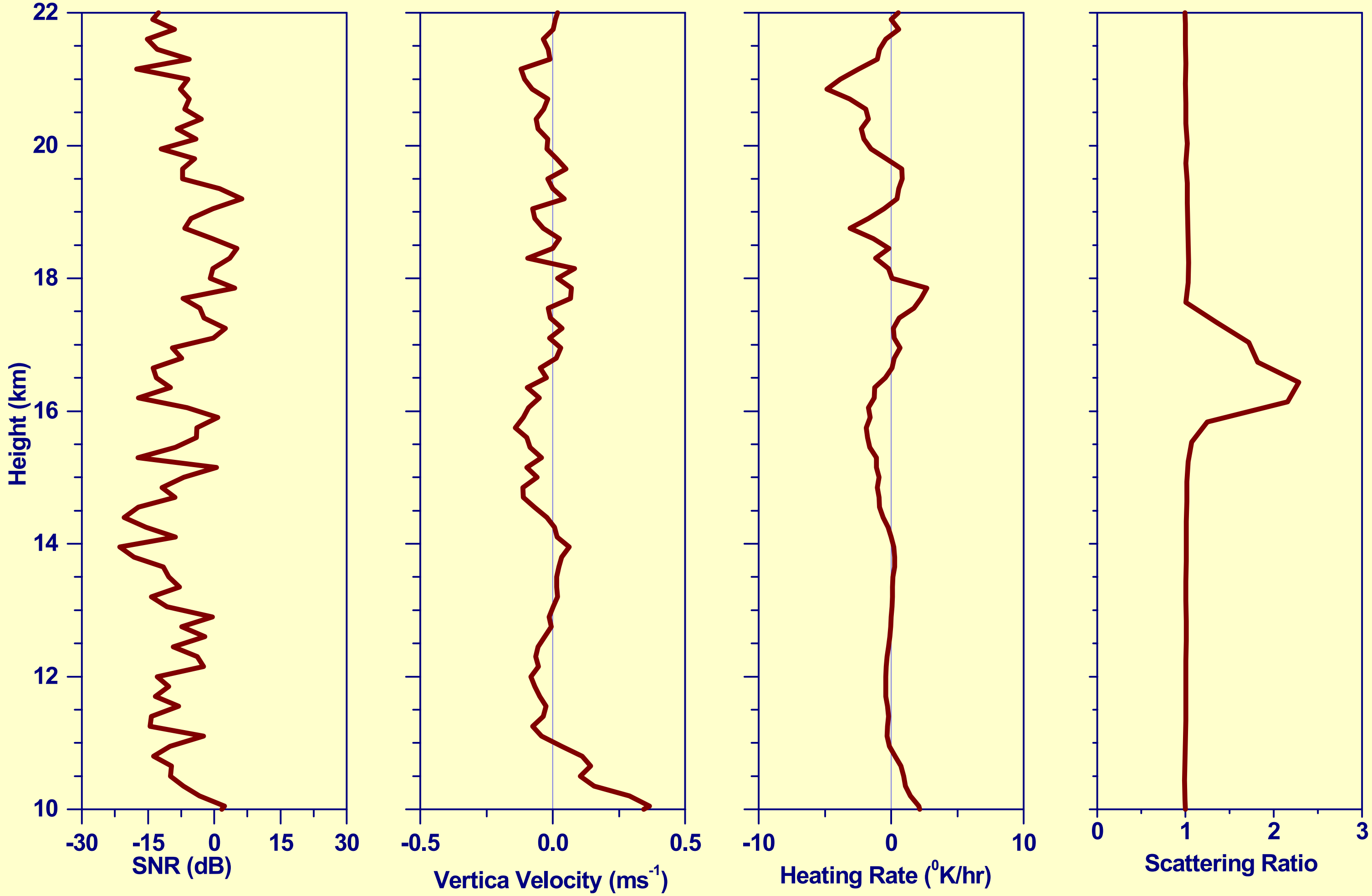
$$C_P \frac{dT}{dt} = Q + \alpha \frac{\partial p}{\partial t} + \alpha\left(\vec{V}.\nabla p\right) - gW$$

Scaling can be used to simplify this equation by noting that $\alpha \frac{\partial p}{\partial t}$ and $\alpha\left(\vec{V}.\nabla p\right)$ are very small

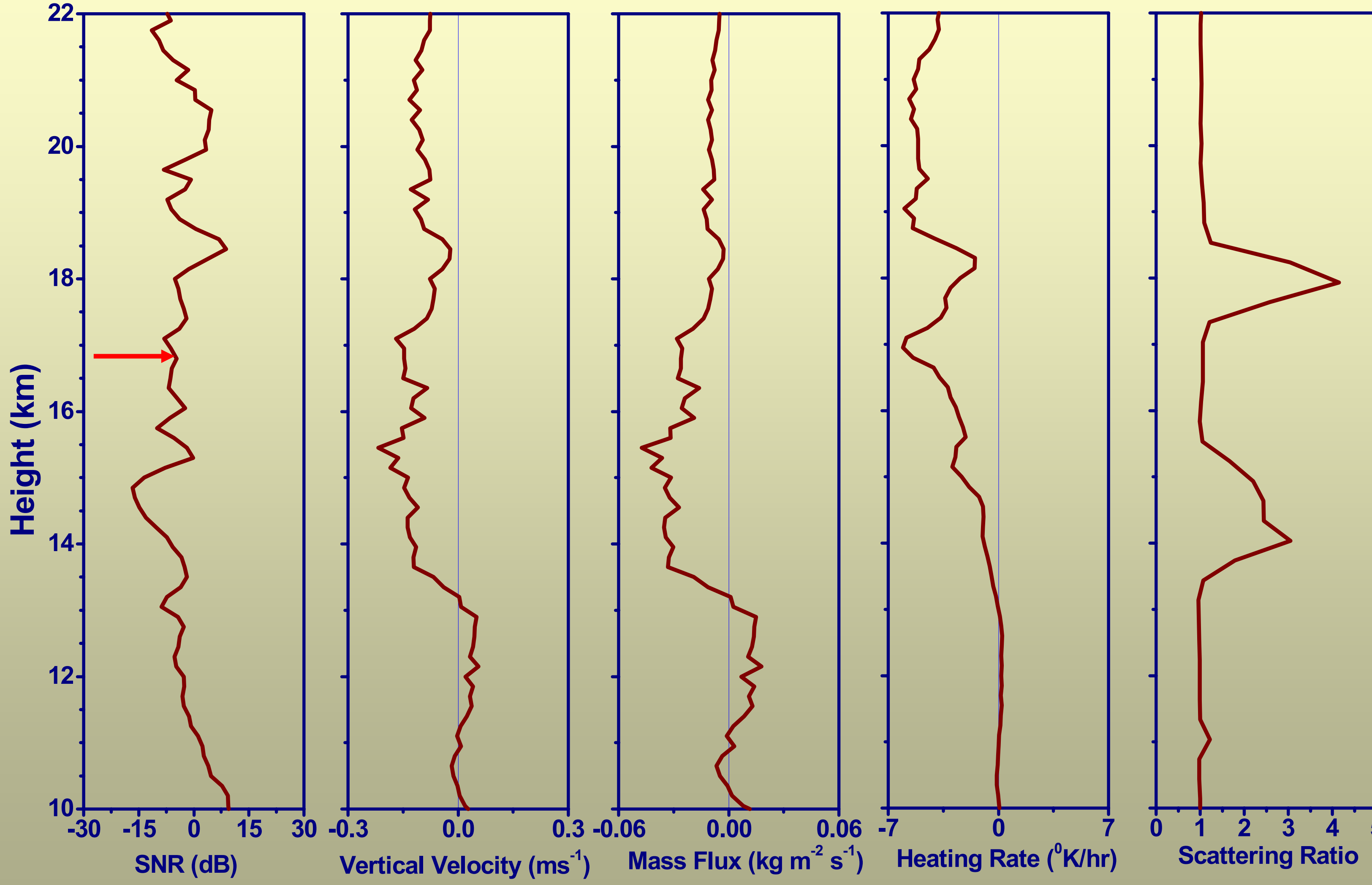
Thus diabatic heating rate can be expressed as

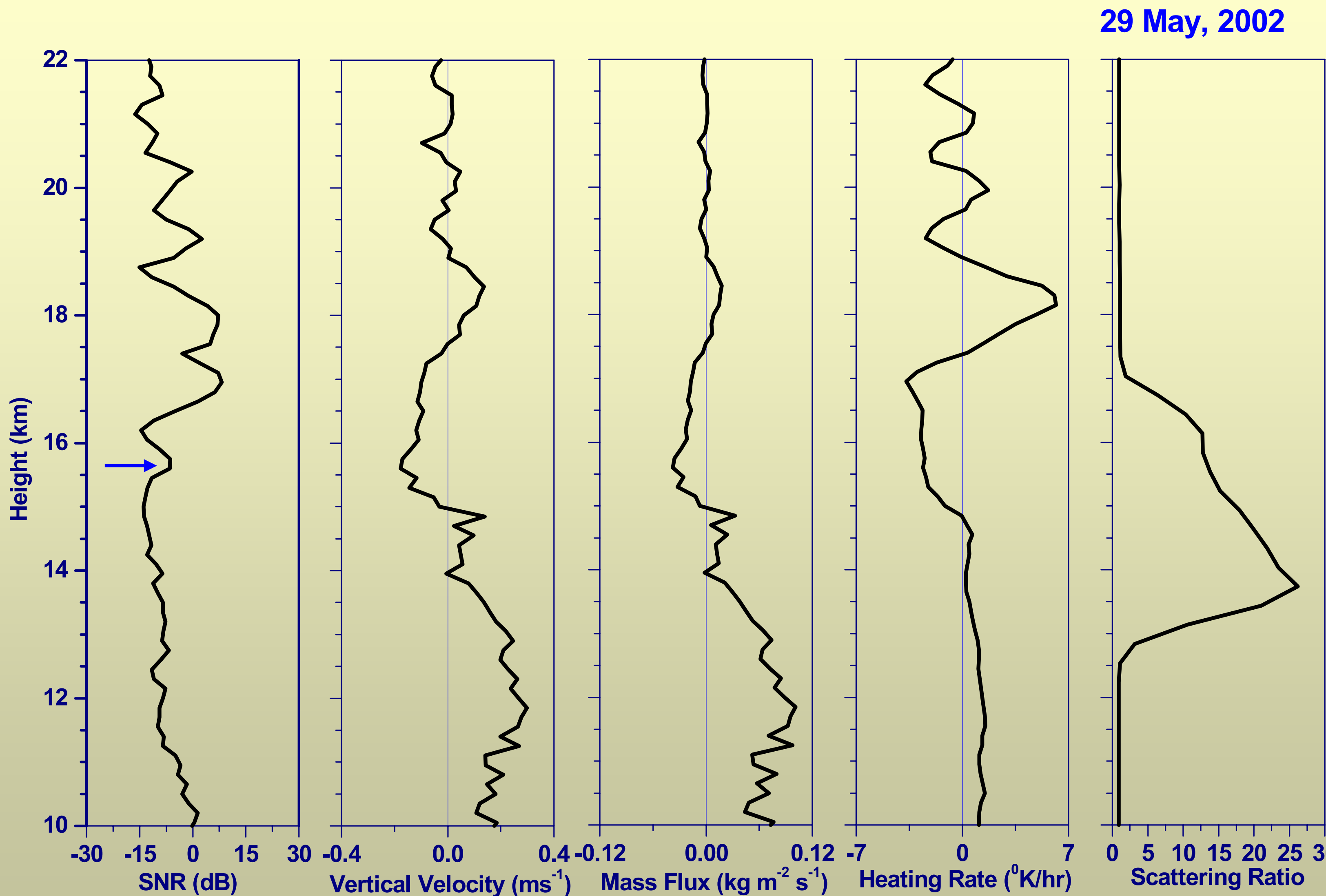
$$\frac{Q}{C_P} = \left(\frac{g}{C_P} + \frac{dT}{dz}\right)W$$

24 April, 2002

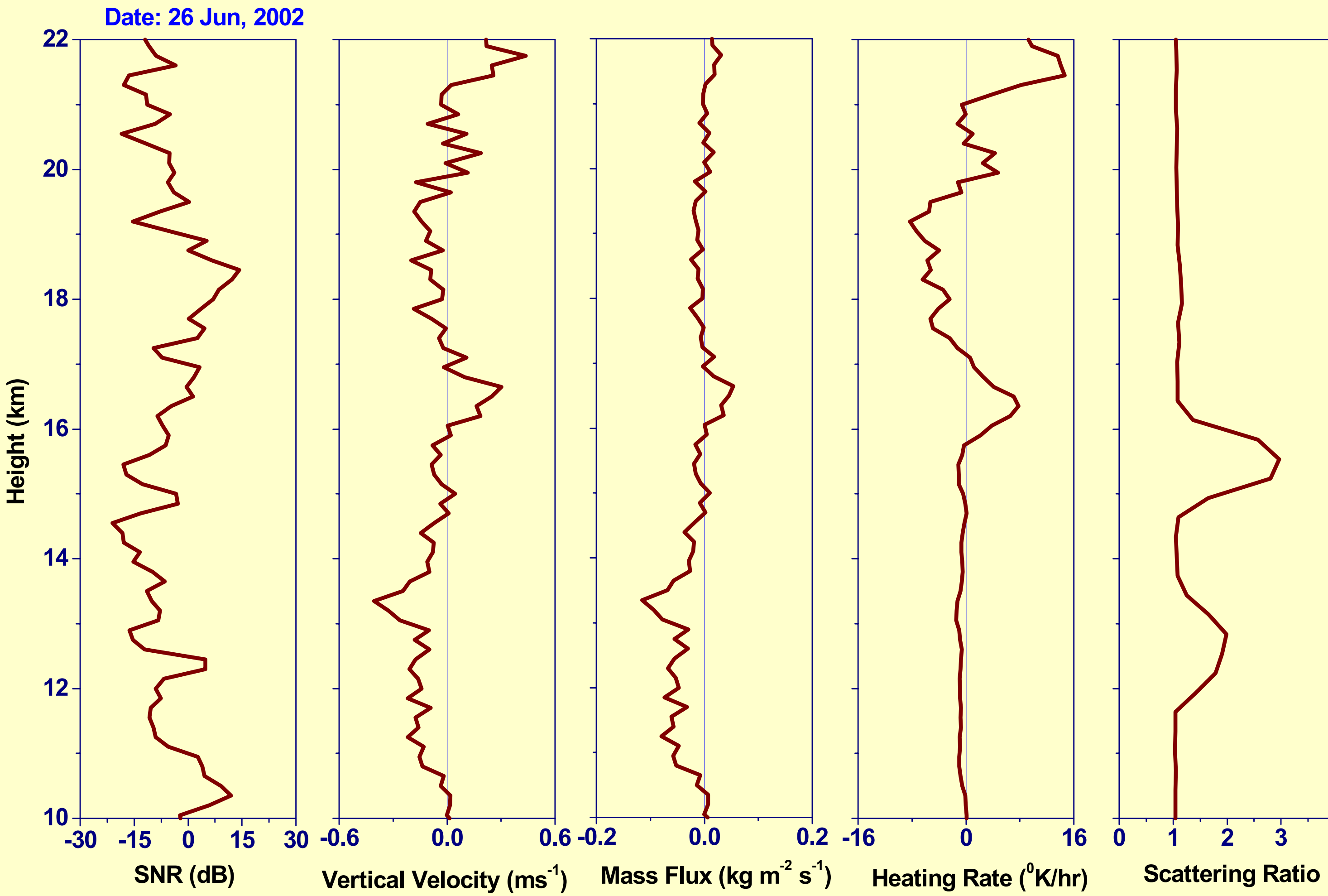


Date: 15 May, 2002

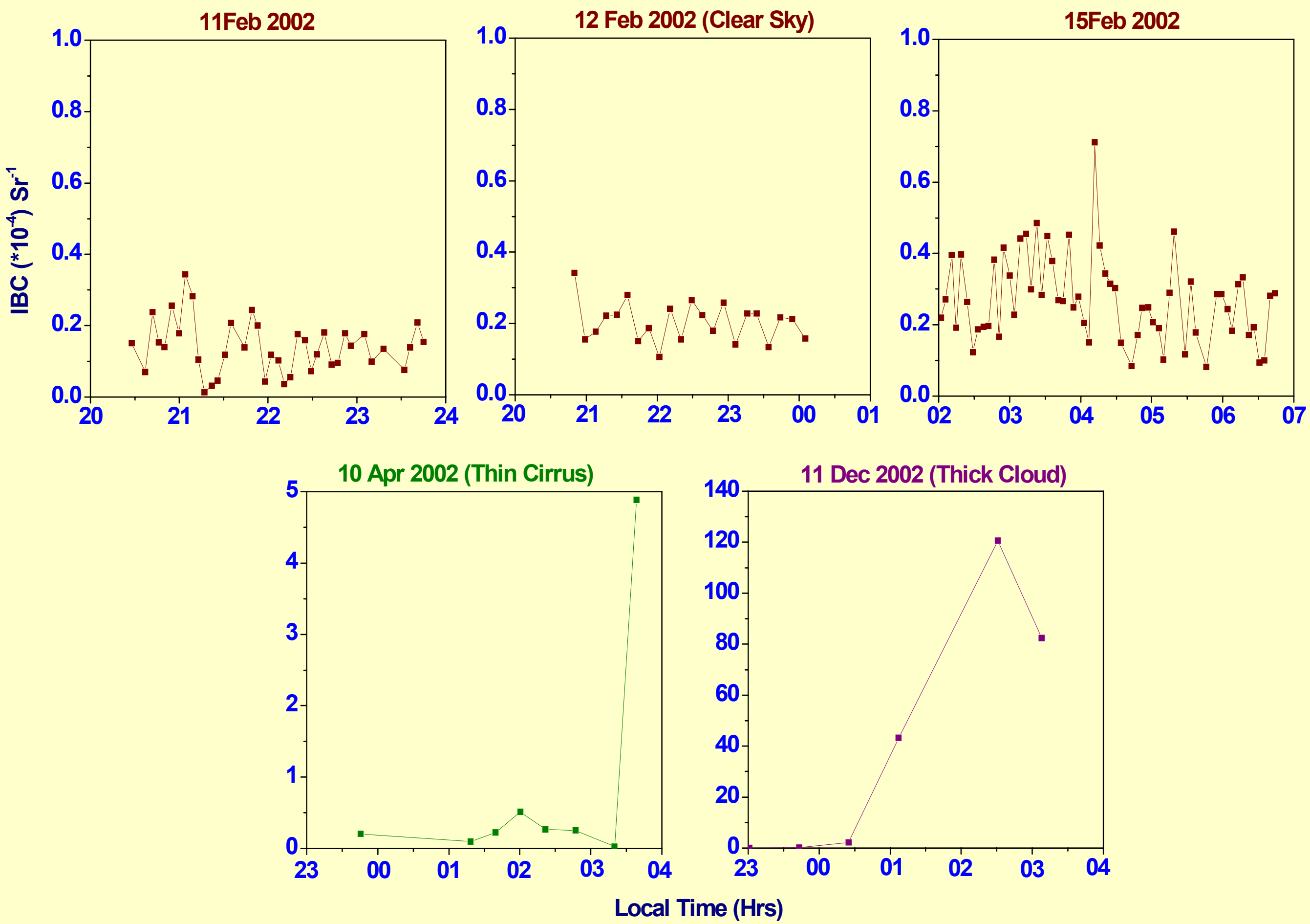


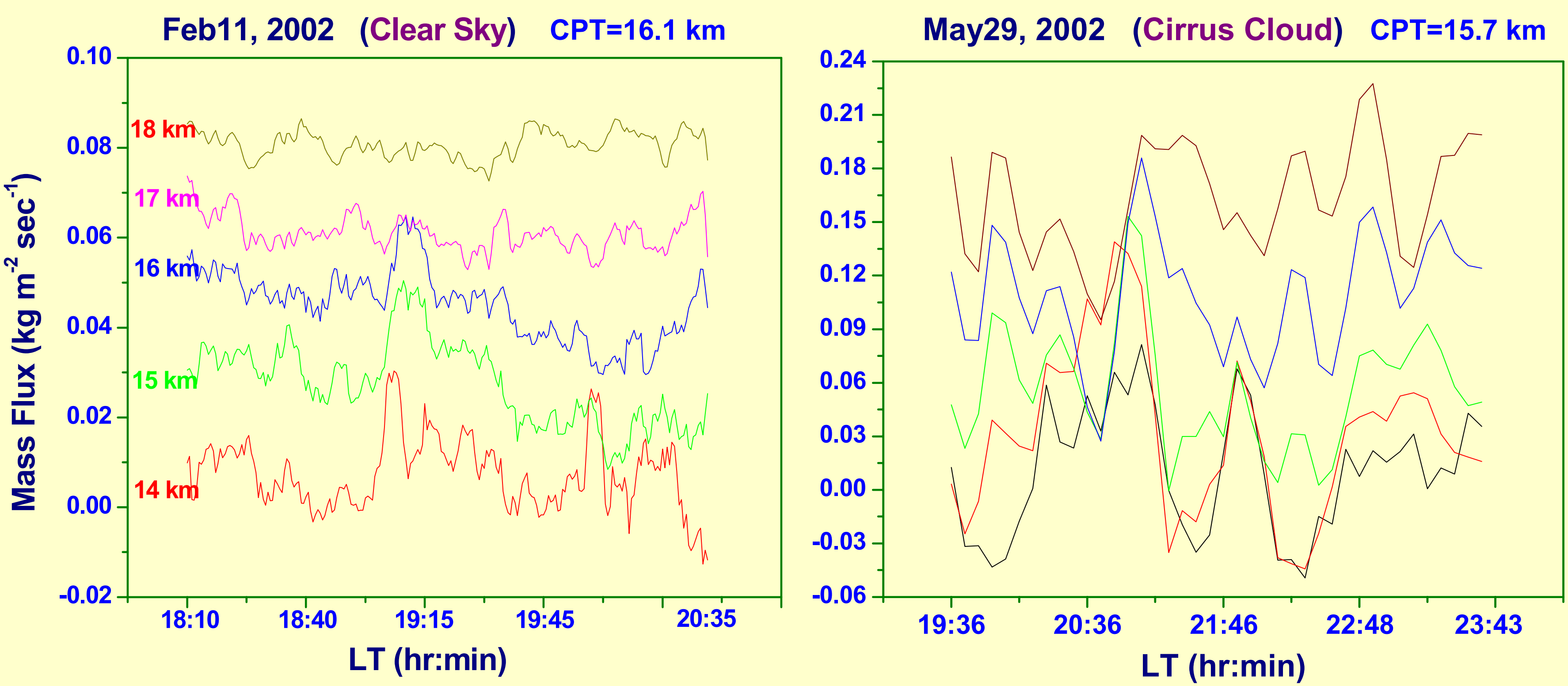


29 May, 2002
Height (km)
22
20
18
16
14
12
10
-30 -15 0 15 30
SNR (dB)
-0.4 0.0 0.4
Vertical Velocity (ms-1)
-0.12 0.00 0.12
Mass Flux (kg m-2 s-1)
-7 0 7
Heating Rate (0K/hr)
0 5 10 15 20 25 30
Scattering Ratio


Date: 26 Jun, 2002
Height (km)
SNR (dB)
Vertical Velocity (ms-1)
Mass Flux (kg m-2 s-1)
Heating Rate (0K/hr)
Scattering Ratio

Temporal Variation of Backscattering Coefficient (integrated within the height region of 14–18 km) in presence of aerosol and cirrus cloud





Temporal variation of mass flux in the height region 14 -18 km

Conclusions

- Lidar observations show enhancement in scattering ratio in the height region 17 -19 km (peak around 18 km) during clear sky days, indicating the presence of aerosol layers. These layers are observed to occur above the tropopause and the variation in the height of these layers seems to be in association with the variation in height of the tropopause. Enhancement in Linear Depolarization Ratio(LDR), observed on few occasions, indicating the anisotropic nature of aerosol particles.

- Large magnitude of LDR during the presence of cirrus cloud indicates the presence of non-spherical ice crystals within the cloud.

- Temporal variation of lidar optical parameters during presence of cirrus clouds clearly shows the persistence and dissipation of layers associated with the cirrus clouds. Interaction between tropopause and cirrus clouds has also been observed on few occasions.

- Vertical wind variability has been observed in the vicinity of tropopause. Vertical wind variation has also been observed, some times, in the vicinity of aerosol layers observed by lidar in the lower stratosphere. Enhanced magnitude and also reversal of vertical velocity have been observed in the vicinity of tropopause during presence of thick cirrus cloud.

- Mass flux across the tropopause has been observed during different sky conditions. Enhanced mass flux across the tropopause, observed in presence of thick cirrus cloud, could be due to decreased stability of the tropopause/ "weakening of tropopause" (vertical beam SNR, in the vicinity of tropopause is observed to be low in presence of thick cirrus cloud).

- Diabatic heating rates have been derived usning MST radar observed vertical velocity. Heating rates show enhancement just above the cirrus cloud.

Acknowledgements

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Thank You all