INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE: CENTRATOM TRIESTE

H4.SMR/645-10

SCHOOL ON PHYSICAL METHODS FOR THE STUDY OF THE UPPER AND LOWER ATMOSPHERE SYSTEM

26 October - 6 November 1992
Miramare - Trieste, Italy

Middle Atmosphere Measurements to Study Variability at Different Scales

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MIDDLE ATMOSPHERE MEASUREMENTS TO STUDY VARIBILITY AT DIFFERENT SCALES

Lecture 1: Ground based observations of the dynamics of the Middle Atmosphere.

Lecture 2: Long term trends in the Middle Atmospheric temperature.

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LECTURE 1

The study of dynamics at a variety of scales with periods ranging from minutes to hours, days and years requires continuous monitoring of the atmosphere. Sporadic measurements as the ones given by balloons and rockets are biased towards long periods, while continuous long term ground-based monitoring, whether it uses passive or active techniques, is able to provide locally access to a large range of periods. I will not cover the possibility offered by satellites, as the subject is covered by the lectures of Professor M. Geller. After a brief presentation of radars and passive techniques based on the observation of natural emissions, I will present the more recently developed lidar methods, with specific emphasis on their possibilities to study dynamics: planetary waves, tides, gravity waves, stratosphere-troposphere exchange.

LECTURE 2

The middle atmosphere is the place where the largest changes of anthropogenic origin have been observed in the last decades. The discovery of the Antarctic Ozone hole is the best known of such changes. This lecture will review the trends observed in the temperature, partly under the influence of the ozone depletion, and partly as a consequence of the increase of greenhouse gases, CO2 and H2O. The observations will be compared with what is expected from the measured changes in atmospheric composition, using different models. In both the stratosphere and the mesosphere, the temperature has decreased faster than predicted by any model, and the fact that while the temperature is expected to increase in the troposphere, the cooling observed just above the tropopause could be a major source of perturbation in the wave propagation between the two layers, change which could have an impact on the general circulation and therefore on the climate.

To conclude this lecture, I will mention the existence of a new project within the World Climate Research Programme, on " Stratospheric Processes and their Role in the Climate" and describe its content. The SPARC project was decided in March 1992; it will aim to a better understanding of how the stratospheric changes can influence the climate, using the coordinated effort of the worldwide atmospheric community.

Anyone who wishes to be on the mailist list to receive the SPARC Newsletter and all relevant informations, should give his (her) name to Dr M.L.CHANIN during the School.or later write to:
SPARC Project Office
B.P.3, 91370,Verrières-le-Buisson, FRANCE

LONG TERM TREND IN THE MIDDLE ATMOSPHERE TEMPERATURE

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I Model Predictions

II Temperature and O_3 trends in the low stratosphere.

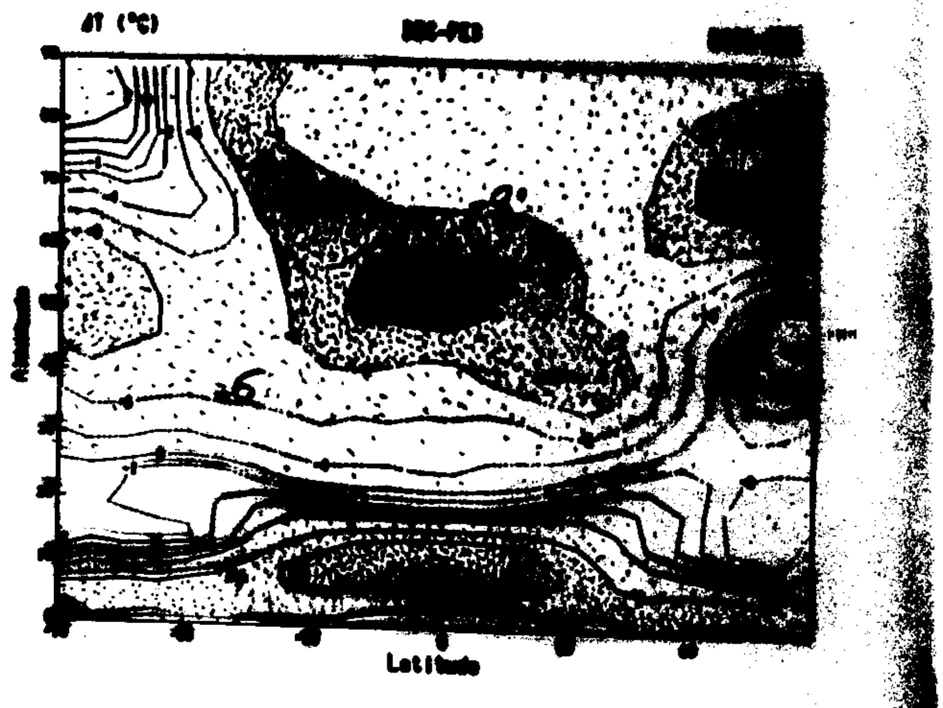
III Temperature trends in the mesosphere.

IV Comparison with Models.

V Conclusions

I

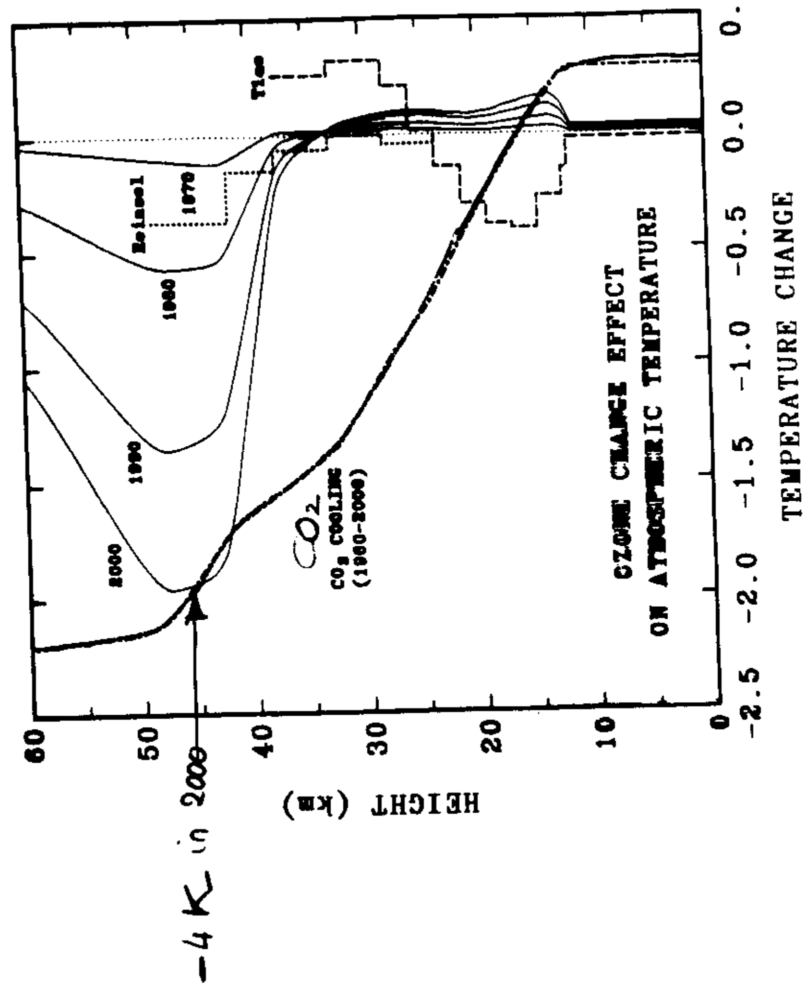
Resuets from the GISS model showing the warming of the troposphere (max : +8 K) and the cooling of the middle atmosphere (max : -10 K around 50 Km) for a doubling of CO_2 -



Recent results on temperature changes due to doubled CO_2 using the GISS model (Rind et al., [illegible])

From Rind and Lacis in " Survey in Geophysics " 1992

CO_2 and O_3 forcing of the temperature.

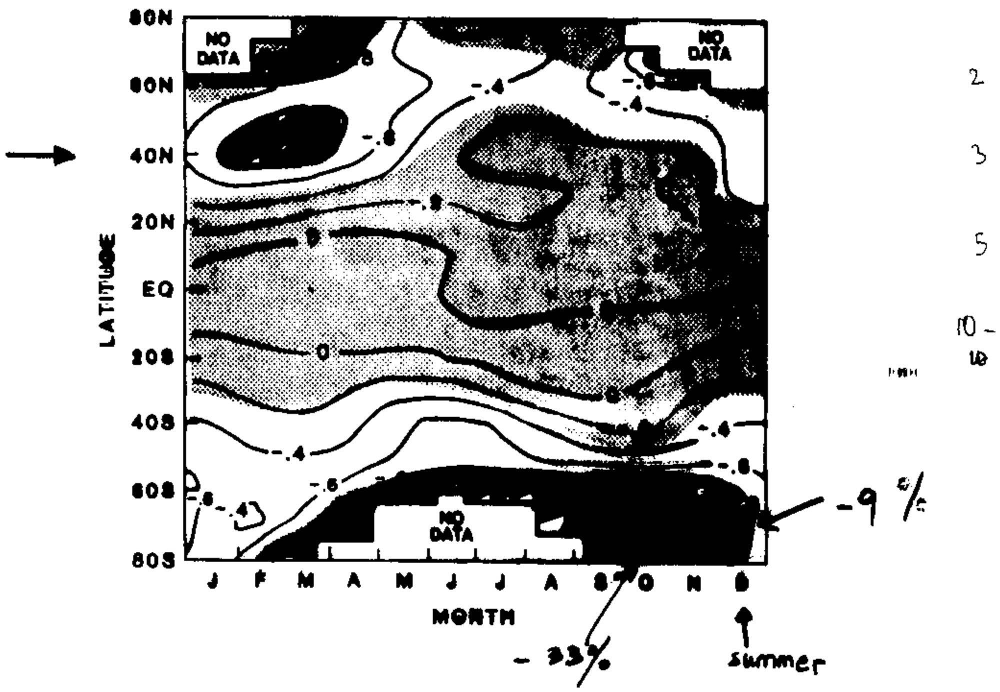


To model more realistically the temperature trends, one should know what has been happening in the Ozone in the last decade.

This is the change observed in Total Ozone for a 11 year period.

One should be aware that the Ozone is modulated by the 11 years solar cycle and therefore a full period of 11 years is a minimum to look at trends.

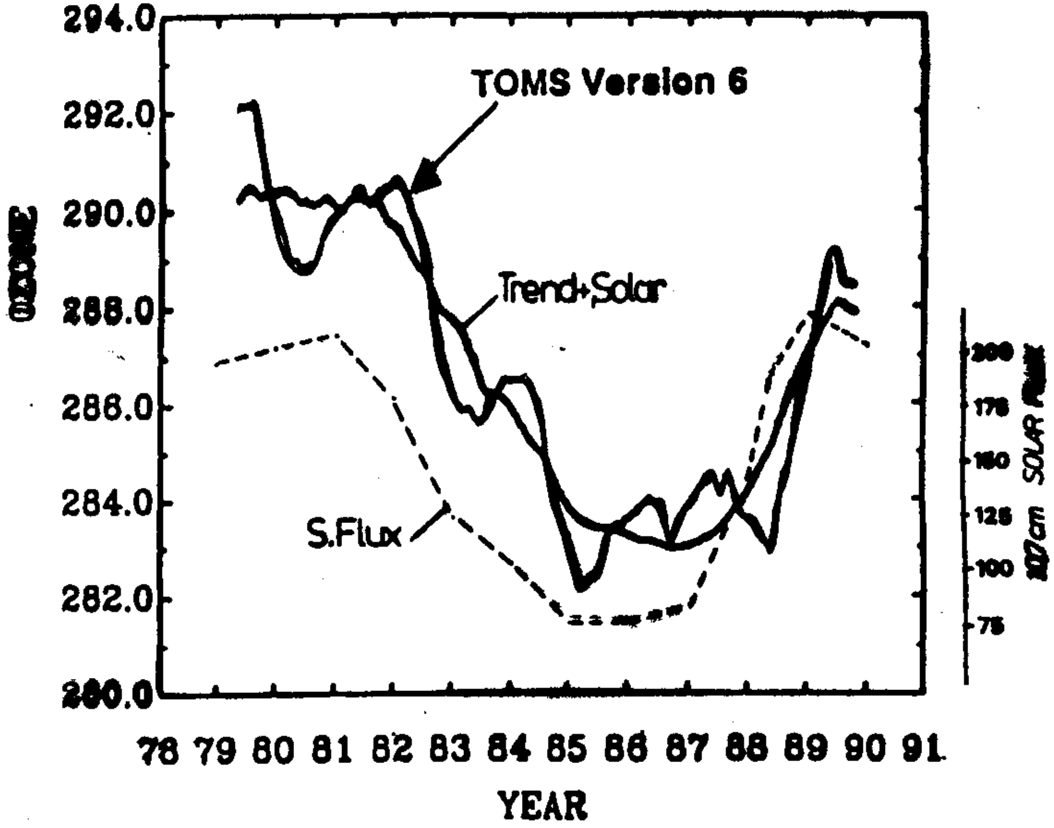
TOMS TOTAL OZONE TRENDS (%/YEAR)



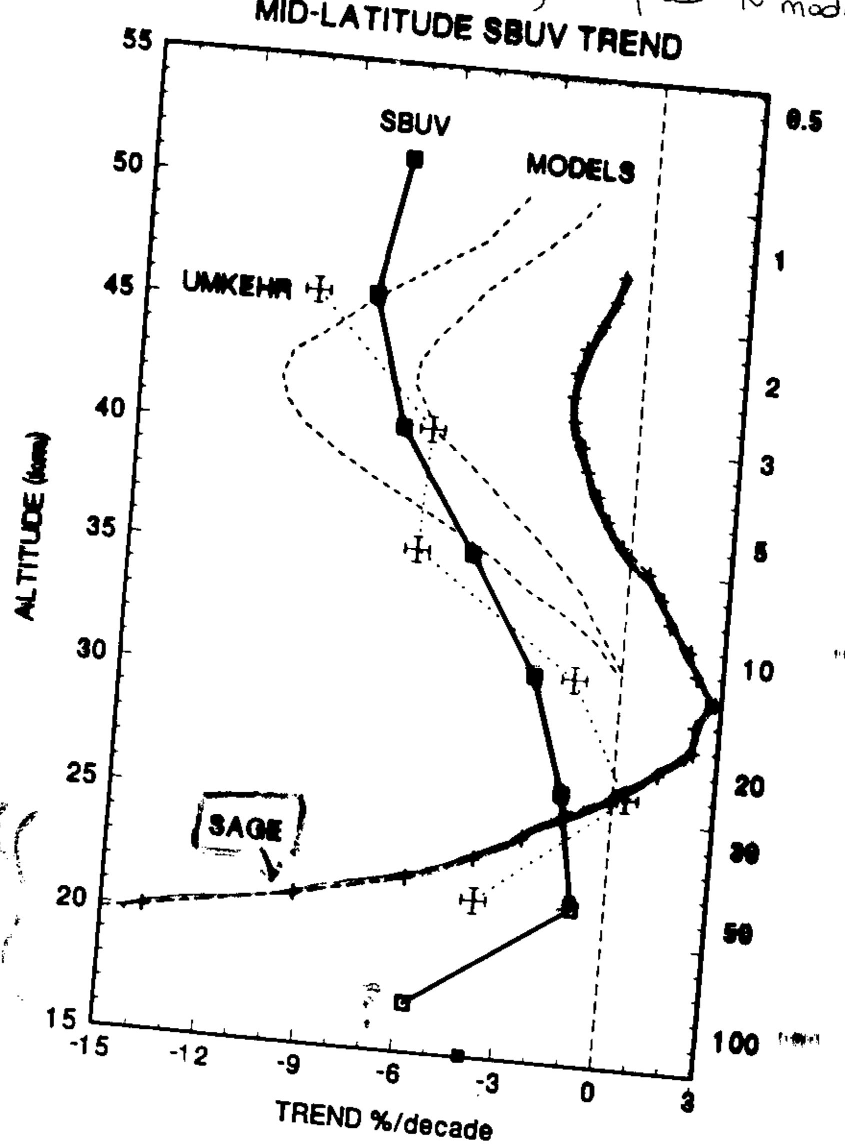
Stolarski et al GRL 1991

for 11 years of data

TIME SERIES OF TOMS OZONE COLUMN DENSITY
40S-40N USING 365-DAY RUNNING MEAN



Change in O_3 vertical profile from different satellites (SAGE, SBUV) and ground-based measurements (Umkehr) compared to models.



Other source of ozone profiles are Ozonosondes –

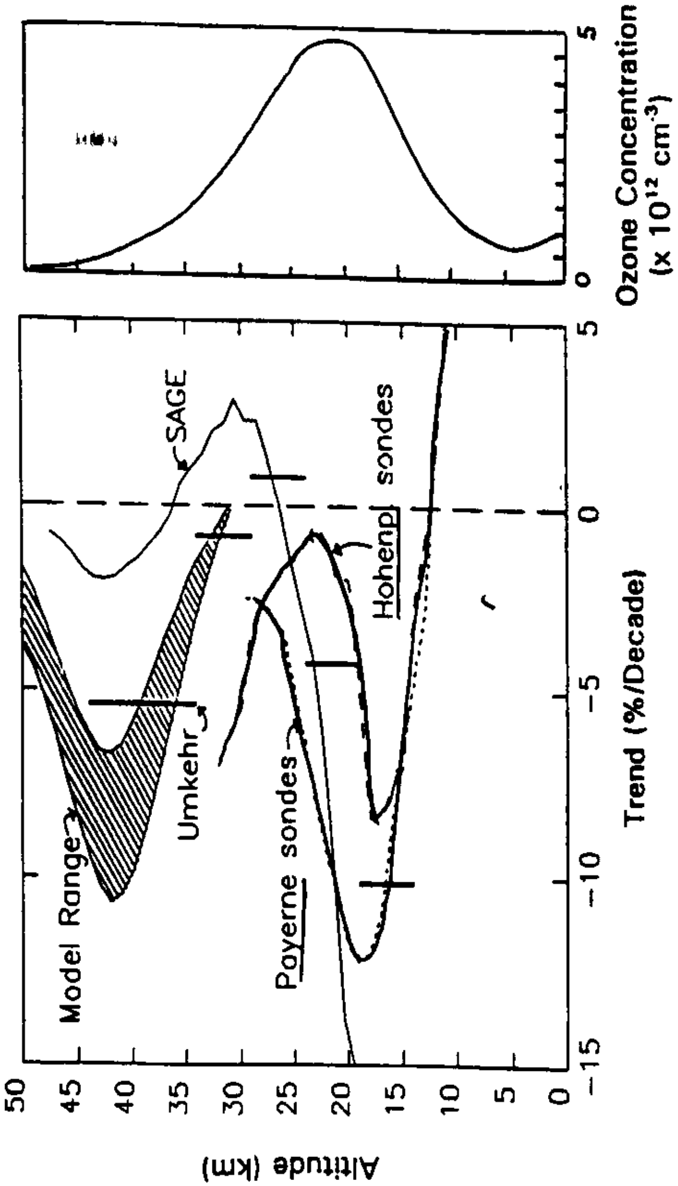


Figure 2-18: Comparison of ozone profile trend estimates from several measurement systems, SAGE, Umkehr, and two ozonesonde stations. SAGE data is an average over the latitude ranges 20-50°N and 20-50°S. The Umkehr is the average over 5 northern midlatitude stations. Shaded area shows the range of two model calculations at 50°N and 50°S. The panel on the right shows a typical ozone concentration versus altitude.

The conclusion of these measurements are that O_3 main decrease is around 15-20 Km, where it reaches 10% per decade at least. A smaller change is seen at 40 Km.

Model taking those O_3 changes into account

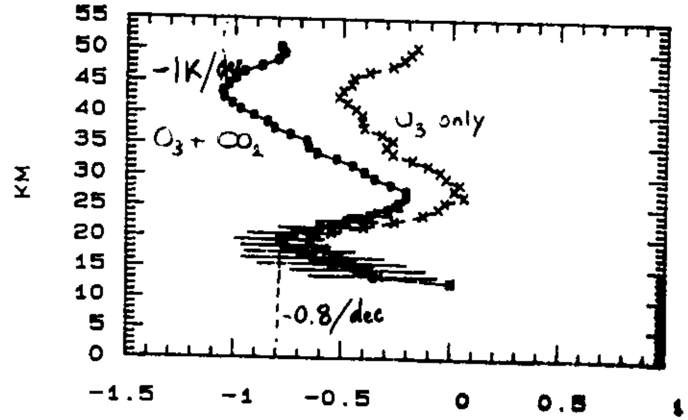


Fig. 2. Decadal temperature trend estimates derived from radiative transfer model using ozone change estimates of Figure 1. O's are estimates with CO_2 changing through the period and the horizontal lines represent the 95% confidence limits. The curve represented by X's is for the calculation with CO_2 fixed at the 1970 value.

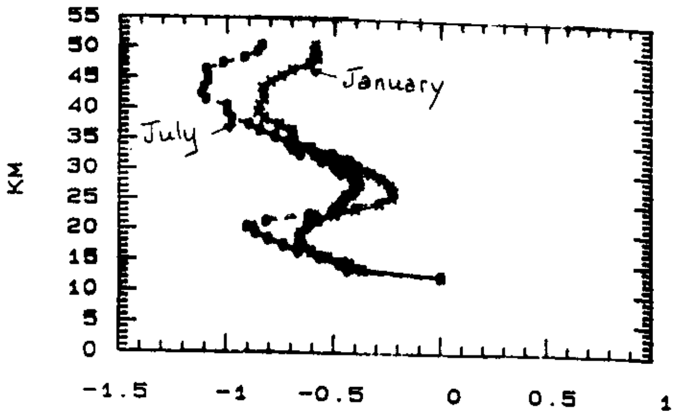


Fig. 3. Decadal temperature trend estimates as in Figure 2, but for January, X's, and July, O's. For description of model attributes, see text.

Results as for Angell (1988)

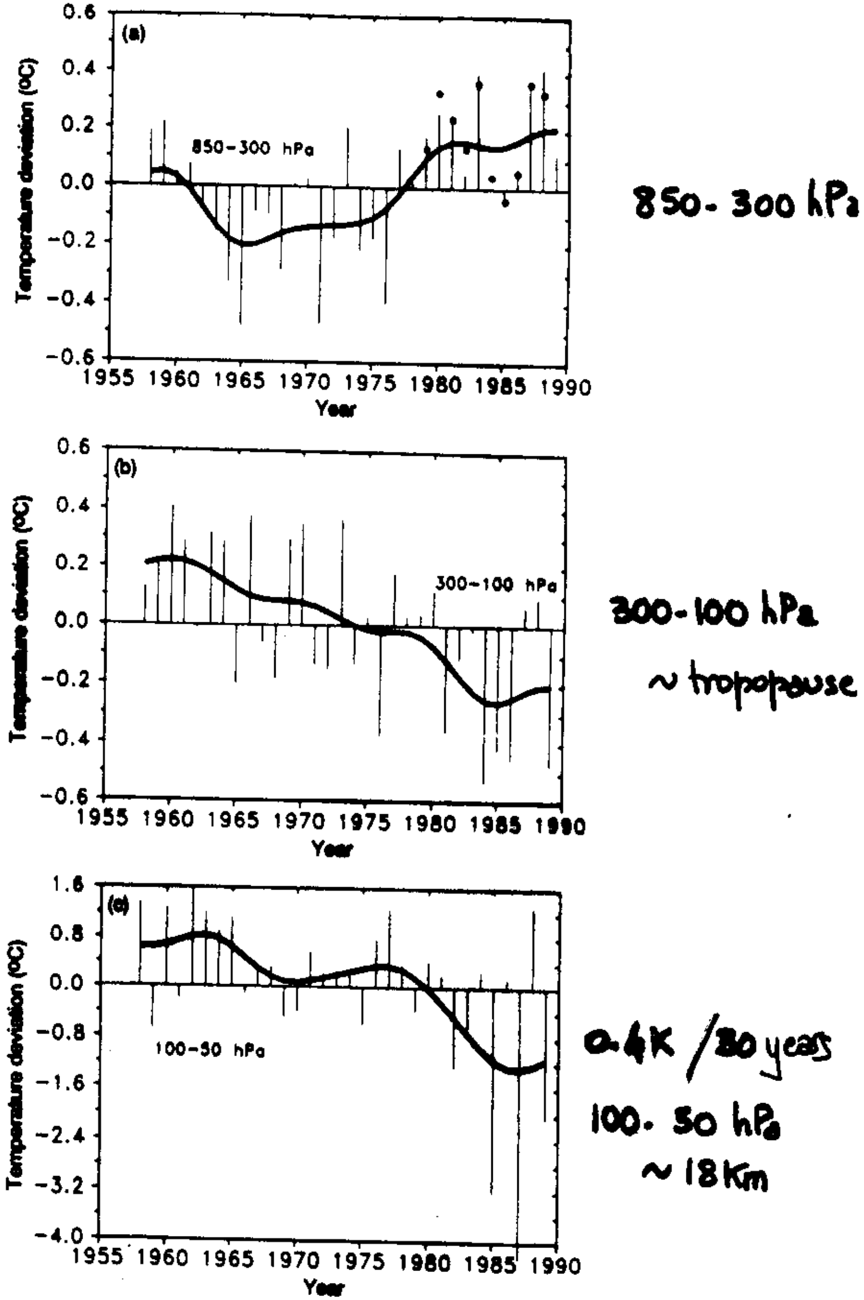


Figure 12.–Temperature anomalies in the troposphere and lower stratosphere for 1958-1989, based on Angell (1988). (a) Annual global values for 850-300 mb. Dots are values from satellite MSU; Spencer and Christy, 1990). (b) 300-100 mb. (c) Annual Antarctic (60°S-90°S) for 100-50 mb. Source: Houghton et al.,

Newly published analysis of the radiosonde data by Miller et al (1991) JGR, showing that the maximum cooling took place around 15-20 Km where O_3 decreased

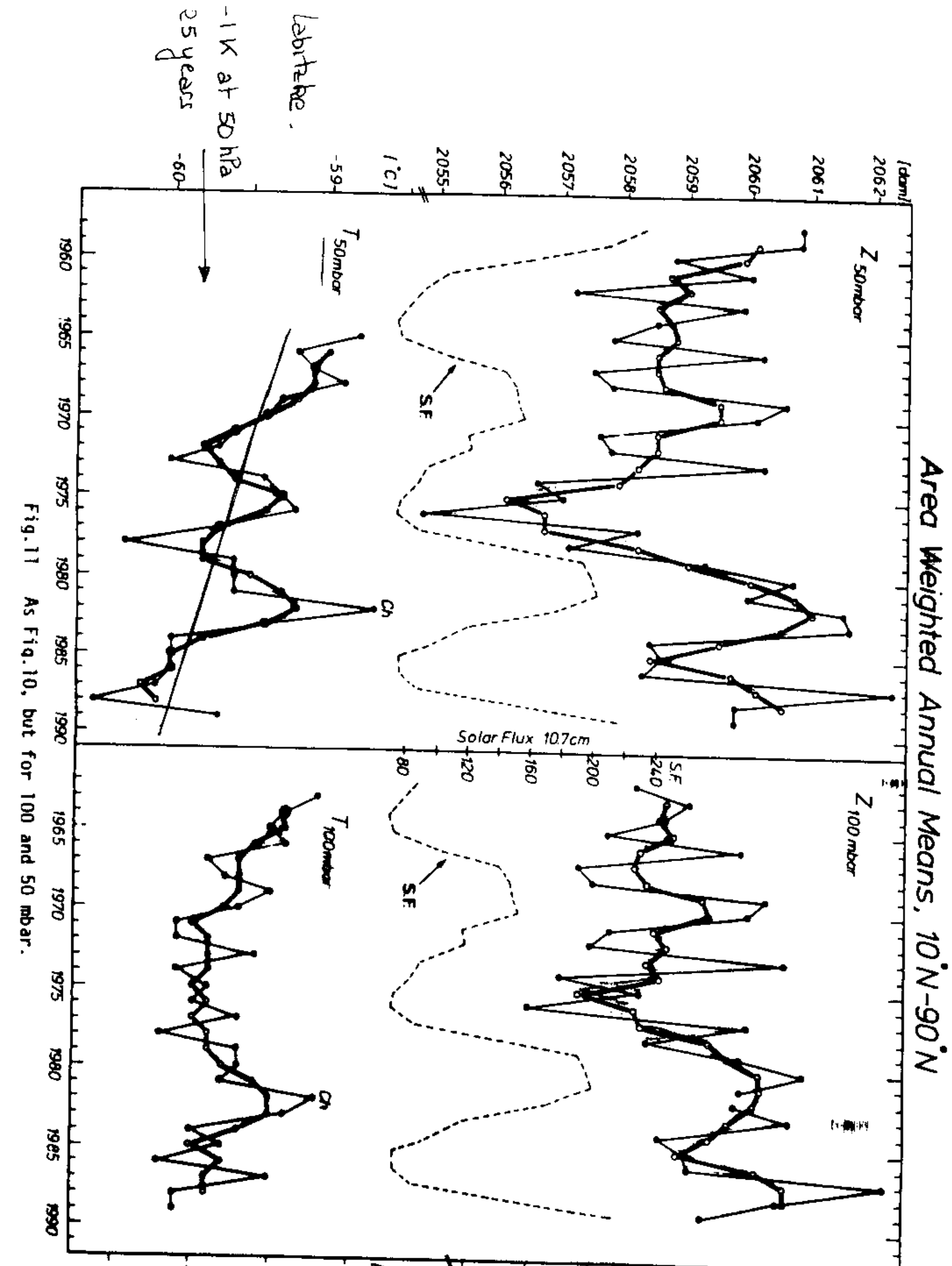


Fig.11 As Fig.10, but for 100 and 50 mbar.

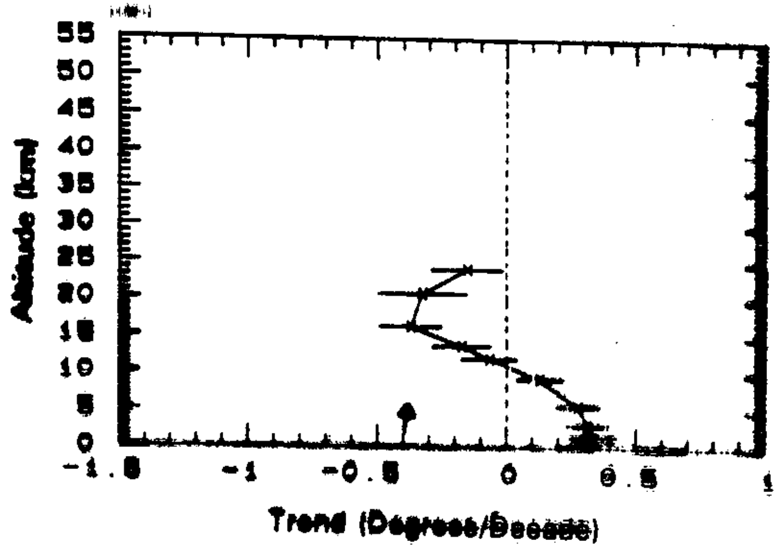
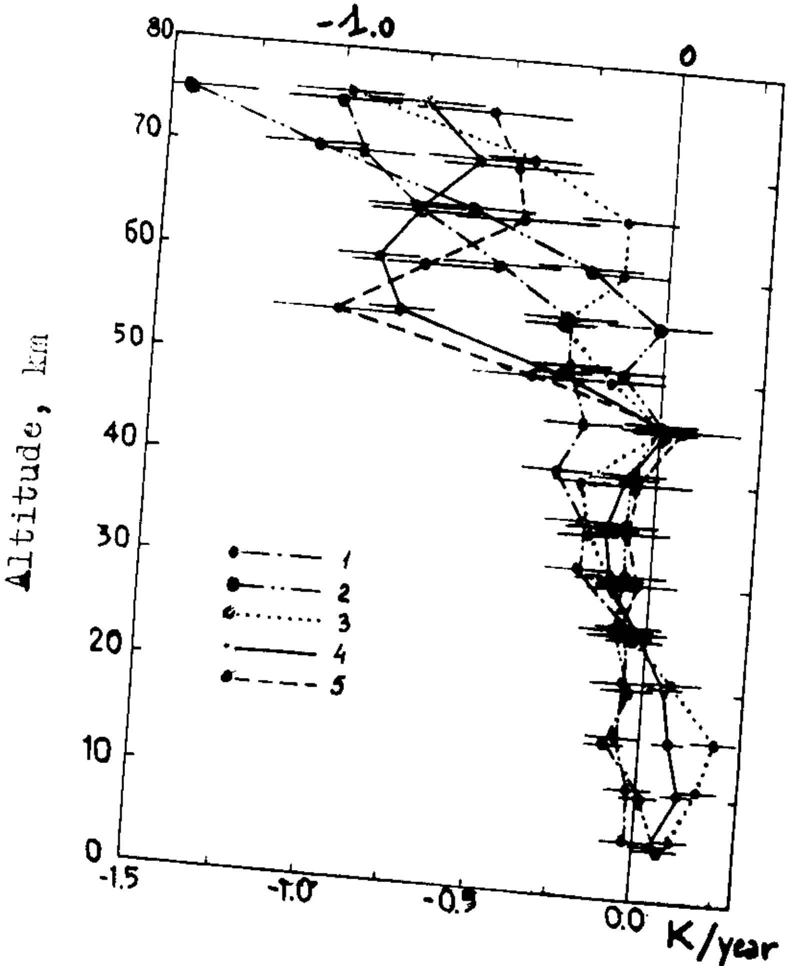


Figure 2-20: Rawinsonde temperature trend estimates in °C per decade as a function of altitude. Horizontal bars represent 95% confidence limits of estimated trends. (from Miller et al., 1991)

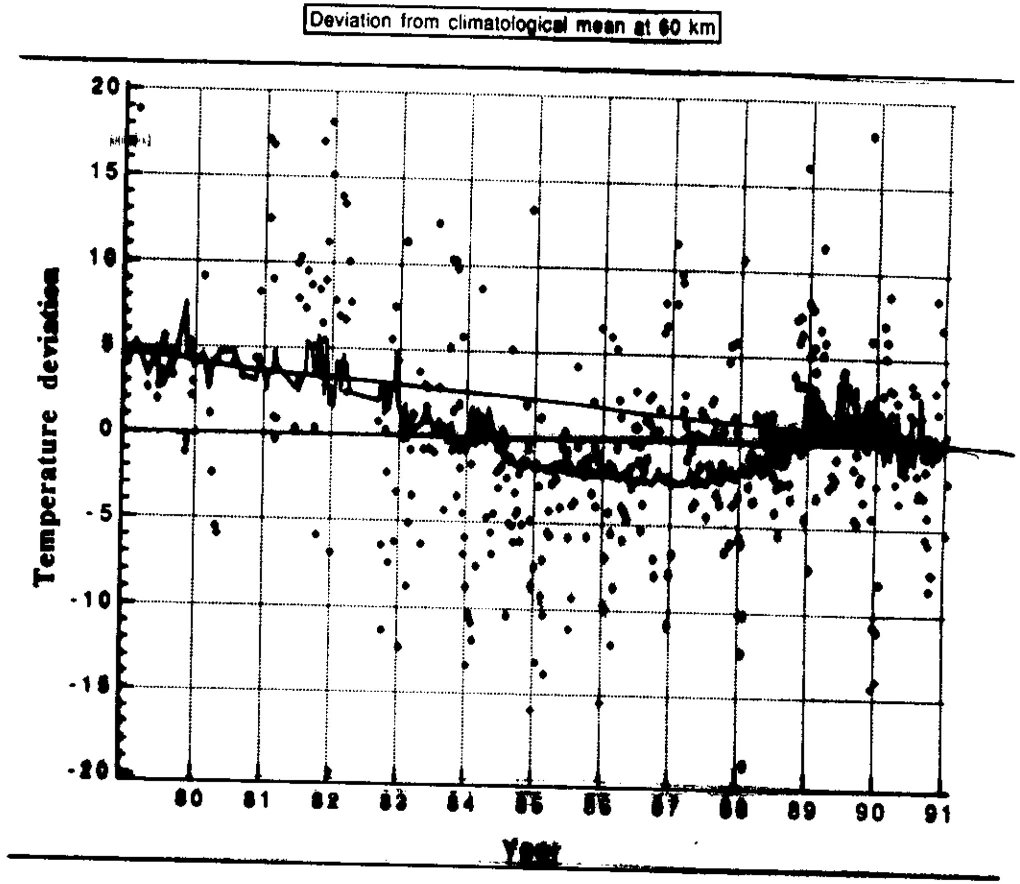
The upper middle atmosphere, as seen by rockets is shown to have cooled by 0.5 to 1K / year around 50-70 Km.



Temperature trends in K/year obtained from 5 rocket sites for the period 1964-1990, by KOKIN & LYSENKO (submitted to JATP, 1992)

- 1 HEYSS ISLAND (80.6°N, 58°E)
- 2 MOLODOZHNAYA (67.7°S, 45.8°E)
- 3 THUMBA (8.5°N, 76.8°E)
- 4 VOLGOGRAD (48.7°N,44.3°E)
- 5 BALKHASH 46.8°N, 74.6°E)

Rayleigh Lidar data also provide a data base to study the long term trend from 30 to 80 Km. This shows the raw weekly mean value of the deviation from the climatological mean at 60 Km



Rayleigh lidar data bank at OHP France

from Hauchecorne and Chanin.

DETERMINATION OF THE CONFIDENCE INTERVAL OF THE LEAST SQUARE FIT

Least square fit of the temperature:

$$T(z_i,t_j)=\overline{T(z_i)}+A_1(z_i)\cos[(2\Pi t_j-j_1(z_i))]+A_2(z_i)\cos[4\Pi(t_j-j_2(z_i))]$$
$$+B(z_i)(t_j-\bar{t})+C(z_i)\left[\frac{F(t_j)-\bar{F}}{100}\right]+T'(z_i,t_j)$$

Variance of the temperature :

$$\sigma_T^2(z_i)=\frac{1}{n-p}\Sigma_{j=1}^{n}T'^2(z_i,t_j)$$

Correlation between two successive measurements:

$$\phi(z_i)=\frac{\Sigma_{j=1}^{n-1}(T'(z_i,t_j)T'(z_i,t_{j+1}))}{\Sigma_{j=1}^{n-1}(T'^2(z_i,t_j)/2+T'^2(z_i,t_{j+1})/2)}$$

If the autocorrelation function decreases exponentially:

$$\phi(t,t+\Delta t)=\exp(-t/\Delta t)$$

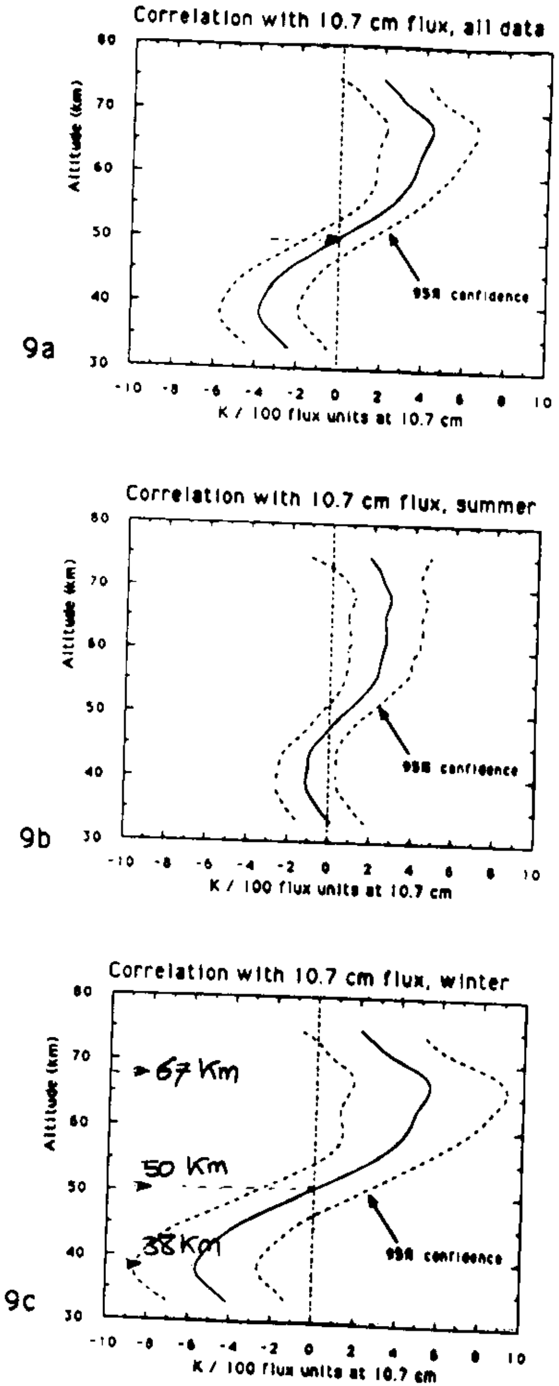
the least square estimator for the linear trend is:

$$\sigma^2(B(z_i))=\frac{(1-\phi^2(z_i))}{(1-\phi(z_i))^2}\,\frac{\sigma^2(T(z_i))}{\Sigma_{j=1}^{n}(t_j-\bar{t})^2}$$

The 95% confidence interval is:

$$\delta(B(z_i))=1.96\,\sigma(B(z_i))$$

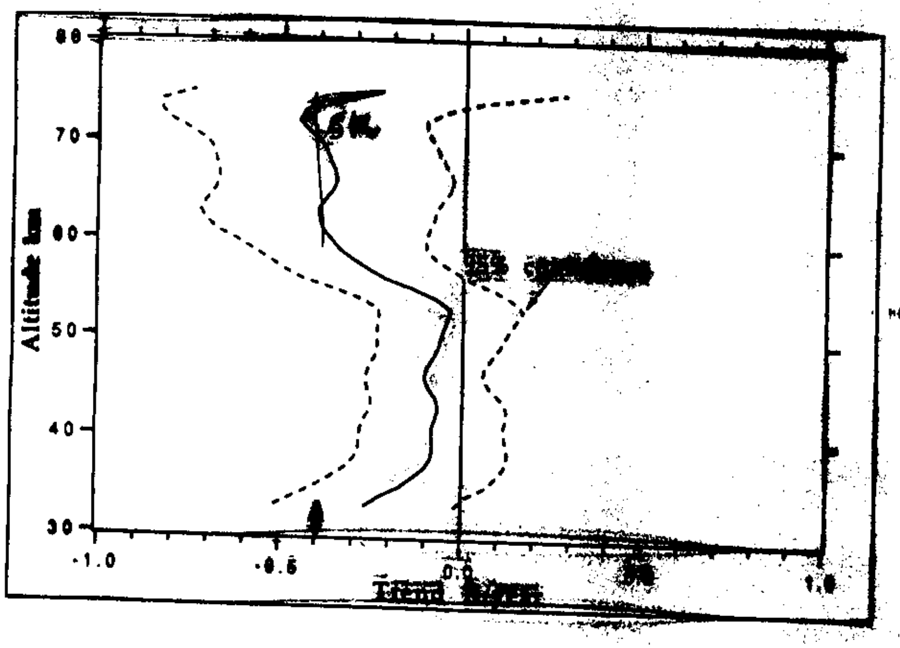
FIG. 9 Signature of the solar cycle from the lidar data bank



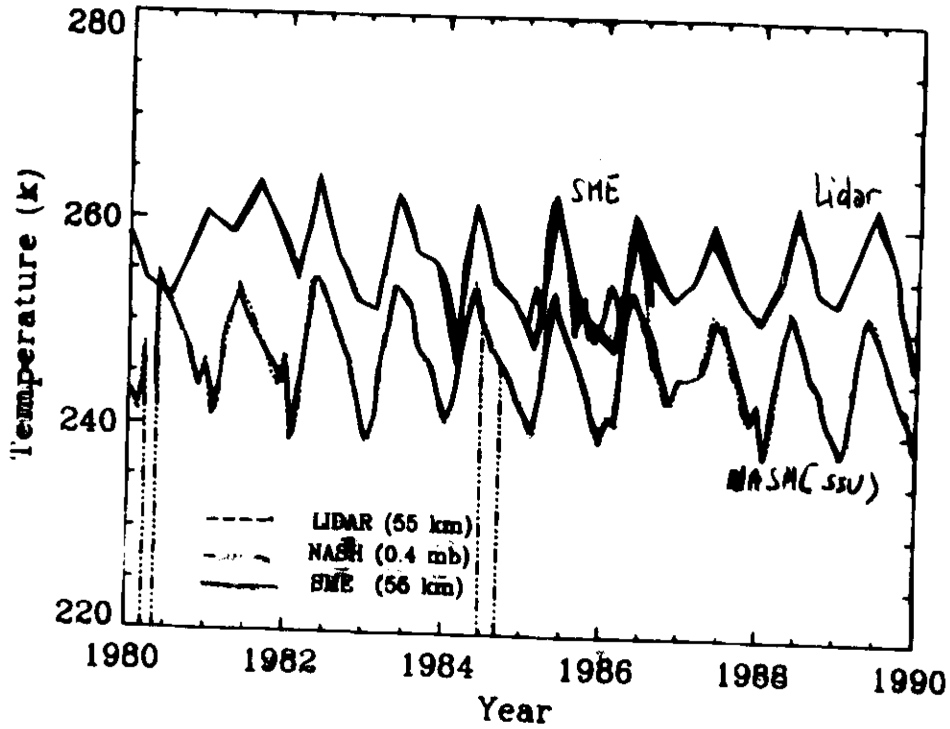
JGR - Hauchecorne et al 1991

Lidar gives only local information. Comparison with satellite data show that, even though there is a systematic difference in the absolute value of the temperature measured by SSU (47X) and by lidar, the trends are quite the same. (see next page)

Lidar temperature above south of France
Trend summer 1979-91

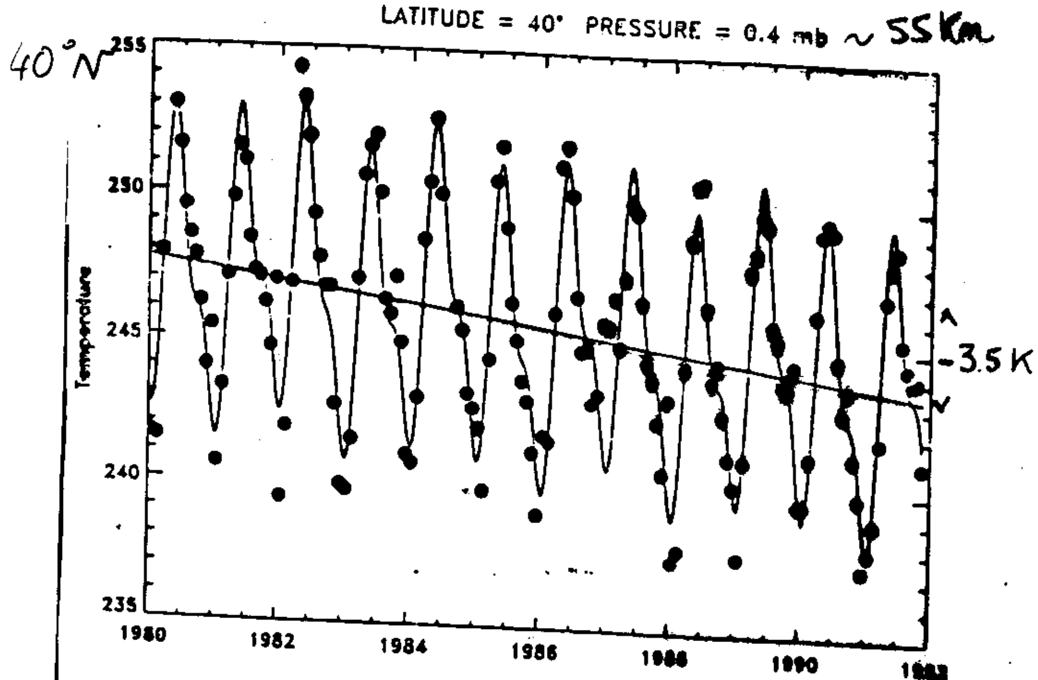


updated from Hauchecorne et al (1991)

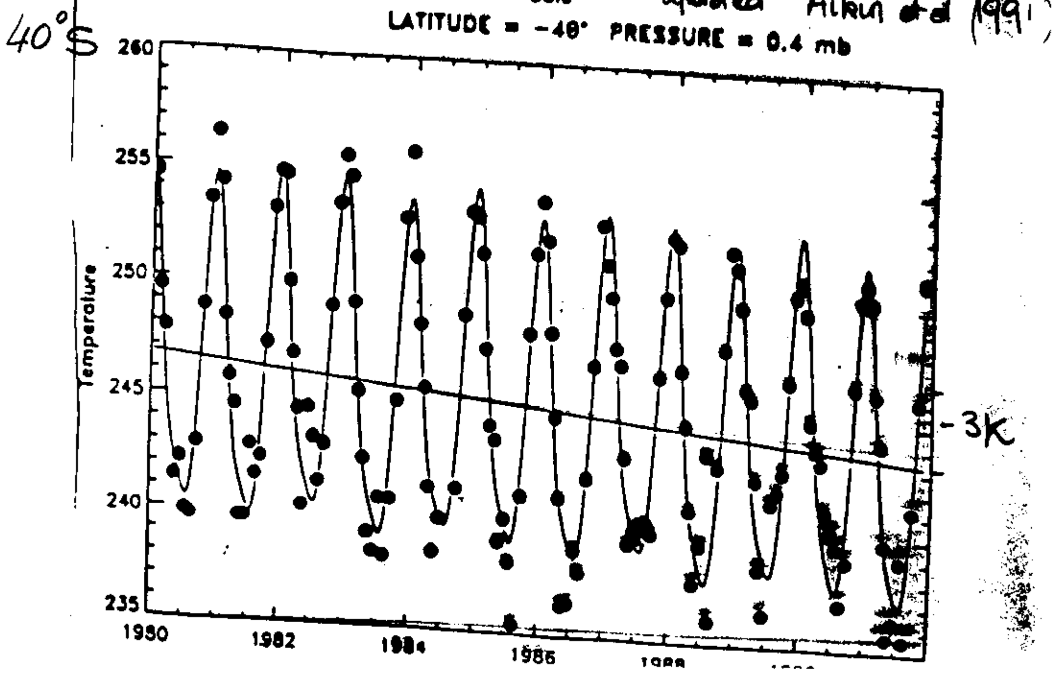


Aikin, Chanin and Nash (1991)

update from Aikin et al (1991)



updated Aikin et al (1991)



Latitudinal variation of the cooling trend.

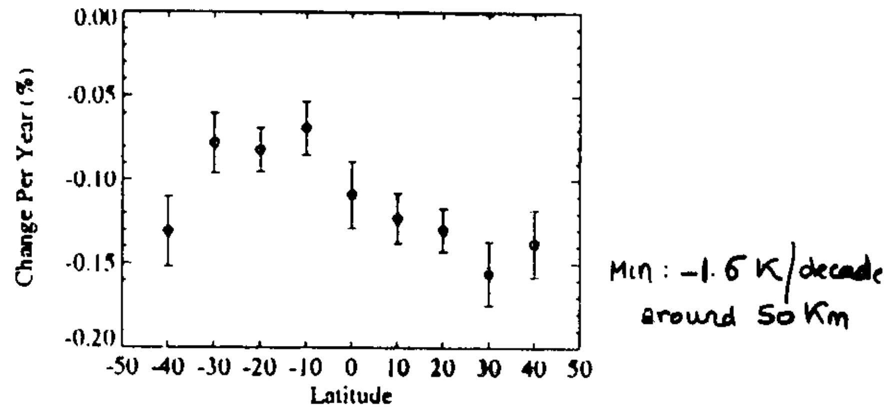


Fig. 3. Percentage change per year for the SSU 47X temperature data as a function of latitude. Error bars show $\pm 1\sigma$ uncertainties.

Aikin et al., GRL, 1991

Comparison between NMP and lidar data

Fig 9d

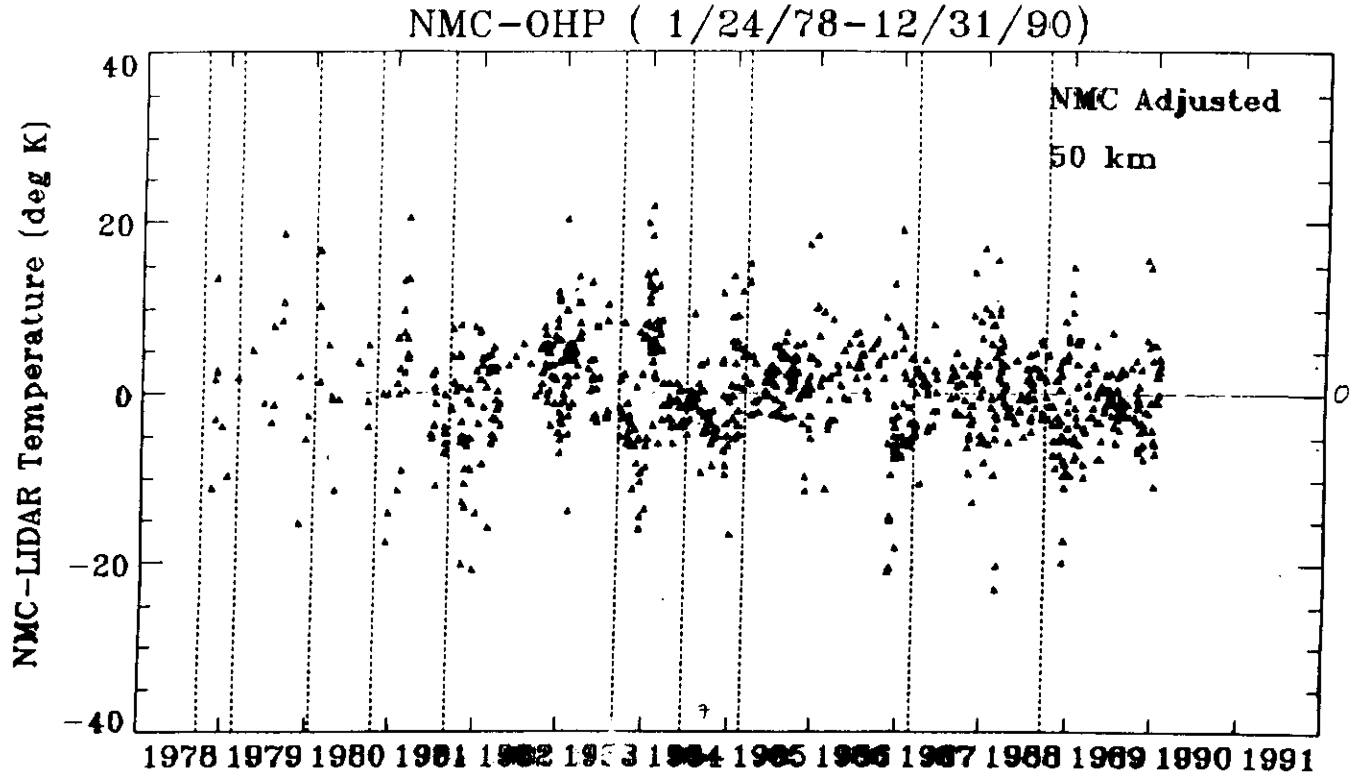
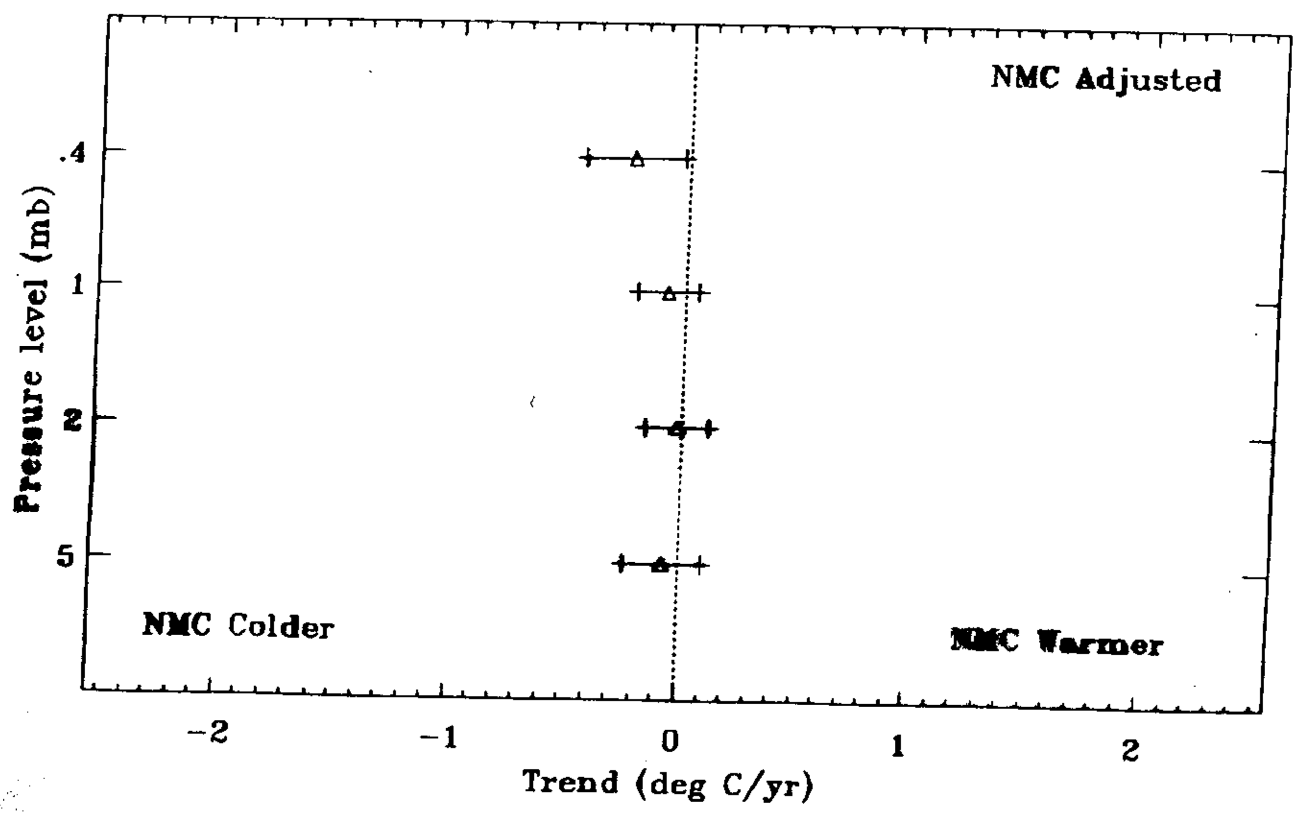


Fig 9d Adjusted temperature differences NMC-OHP

Note OHP will be interpolated to pressure level 48 km 1 mb

Difference in trends observed by Lidar and NMC.

Gellman et al (1992)



SUMMARY

- SMALL STRATOSPHERIC COOLING AROUND 15-20 KM.

- UNCERTAINTY ABOUT THE COOLING AROUND 40 KM WHERE CO_2, H_2O AND O_3 SHOULD ADD THEIR EFFECTS.

- DIRECT AND INDIRECT EVIDENCE OF LARGE MESOSPHERIC COOLING.

- MORE WORK NEEDS TO BE DONE TO ASSESS THE TEMPERATURE TRENDS.

GROUND OBSERVATIONS OF THE DYNAMICS OF THE MIDDLE ATMOSPHERE

__1) Methods of observation__

- Actives methods :
  . Radars
  . Lidars

- Passives methods:
  . Natural emissions

__2) Observational studies__

- General circulation
- Planetary waves
- Tides
- Gravity waves
- Turbulence

RADARS

1) MF / HF radars:

- Frequency : 2-6 MHz
- Process : partial reflection from ionized structures
- Altitude : 60-100 km (vertical profiles)
- Measured parameter : Doppler wind

2) UHF / VHF radars :

- Frequency : 40-50 MHz (VHF) and 440 MHZ (UHF)
- Process : scattering by ionized structures (60-110 km)
  and neutral structures (10-30 km)
  + meteor echoes (VHF)
- Altitude : 10-30 km and 60-110 km (vertical profiles)
- Measured parameters : Doppler wind
  Turbulence

NATURAL EMISSIONS

- Process Natural emissions of
  OH Meinel bands (700-800 nm)
  Oxygen green line (557.7 nm)
- Altitude OH : 85 km (horizontal structures)
  557.7 nm : 95 km (horizontal structures)
- Measured parameters :
  Airglow intensities
  Rotational temperature (OH)
  Doppler wind

LIDARS

1) Rayleigh lidars :

- Process : Rayleigh scattering by molecules
- Laser Wavelength : 532 nm (Nd-YAG)
  351-353 nm (XeF)
- Altitude : 30-90 km (vertical profiles)
- Measured parameter : air density
- Hydrostatic equilibrium : temperature

2) Sodium lidars :

- Process : resonant scattering by Na atoms
- Laser wavelength : 589-596 nm
- Altitude : 80-110 km (vertical profiles)
- Measured parameters: sodium concentration
  temperature (Doppler width)

3) Raman lidars :

- Process : Rotationnal or vibrationnal Raman scattering by molecules, mostly N_2, O_2
- Laser wavelenght : 532 (Nd. Yag)
- Altitude: 2-35 Km (vertical profile)
- Measured parameter : air density
- Calculated parameter : temperature

4) Mie Lidars :

- Process : Mie backscattering by aerosols or clouds
- laser wavelength : 1,06 µm 532, 352 nm (Nd-Yag)
- Altitude: 5-25 Km
- Measured parameter : concentration of aerosols → dynami
  Doppler shift → winds

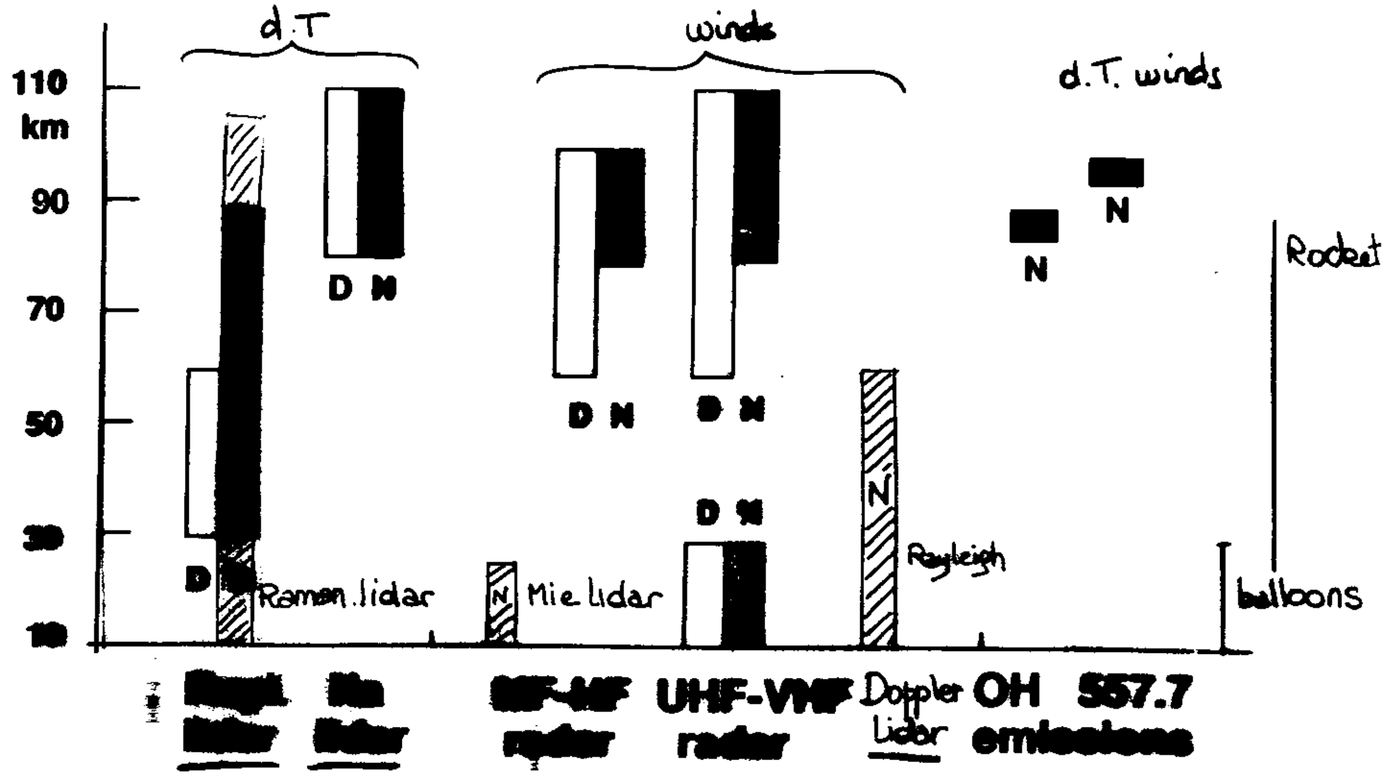
5) Doppler Rayleigh Lidar

- Process : Rayleigh backscattering by molecules
- laser wavelength : 532 nm
- altitude: 5 - 65 Km (in presence or not of aerosols)
- Measured parameter : horizontal components of the wind

6) DIAL Lidar

- Process : Differential absorption at different wavelength
  O_3, H_2O ... → Stratosphere - Troposphere exchange

DAY / NIGHT AND ALTITUDE COVERAGE



Lidar equation and principle

$$P(z, z+dz) = P_0 \times G(z) \times \tau_s(z, z+dz) \times e^{-2\tau_a(0, z+dz)}$$

Signal return — laser Power — efficiency of system — optical thickness of the scatterer — Integrated absorption in atmosphere

2 cases:

1. $\tau_s \rightarrow$ density of scatterer (using Rayleigh, Mie or Resonance scattering) if $\tau_s > \tau$ of other constituents between $z, z+dz$
2. $\tau_a \rightarrow$ density of the absorbers and of a specific absorber (using Rayleigh Scattering) by adequate choice of 2 different λ D.I.A.L

Scattering processus used for Lidar studies

—

Elastic Scattering

			σ
Rayleigh	$\lambda_r = \lambda_e$	$\sim$	10^{-28} cm^2
Mie	$\lambda_r = \lambda_e$	$\sim$	10^{-10} cm^2

Inelastic scattering

Resonance	$\lambda_r = \lambda_e$	$\sim$	[illegible] (atoms) 10^{-17} (mol.)
Fluorescence	$\lambda_r \neq \lambda_e$	$\sim$	10^{-18} cm^2
Raman	$\lambda_r \neq \lambda_e$	$\sim$	10^{-30} cm^2
Resonant Raman	$\lambda_r \neq \lambda_e$	$\sim$	10^{-25} cm^2

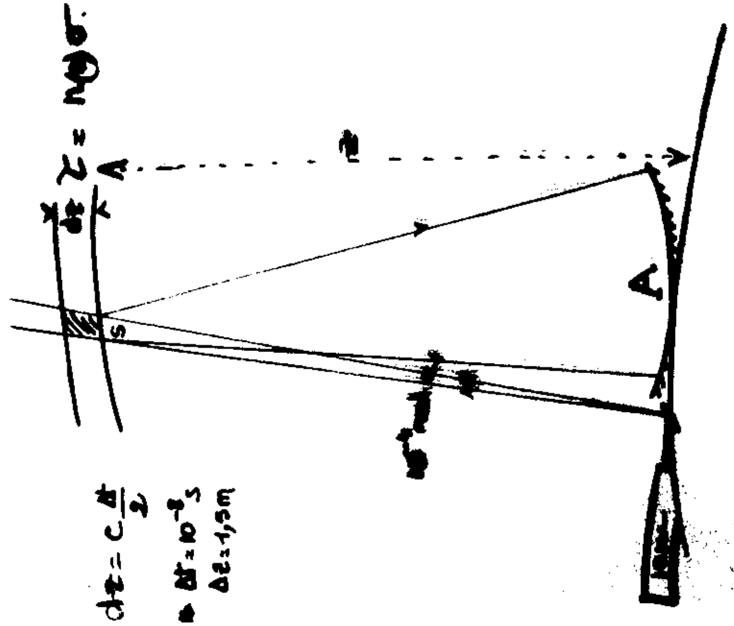
Lidar equation for Rayleigh scattering

$$N = \frac{N_0}{s} \cdot \frac{A}{4\pi z^2} \cdot \underline{n}\,\sigma\, s\, dz \;.\; K\, T^2$$

$$\int^{t}_{0} N \propto n(z)\; dz\; dt$$

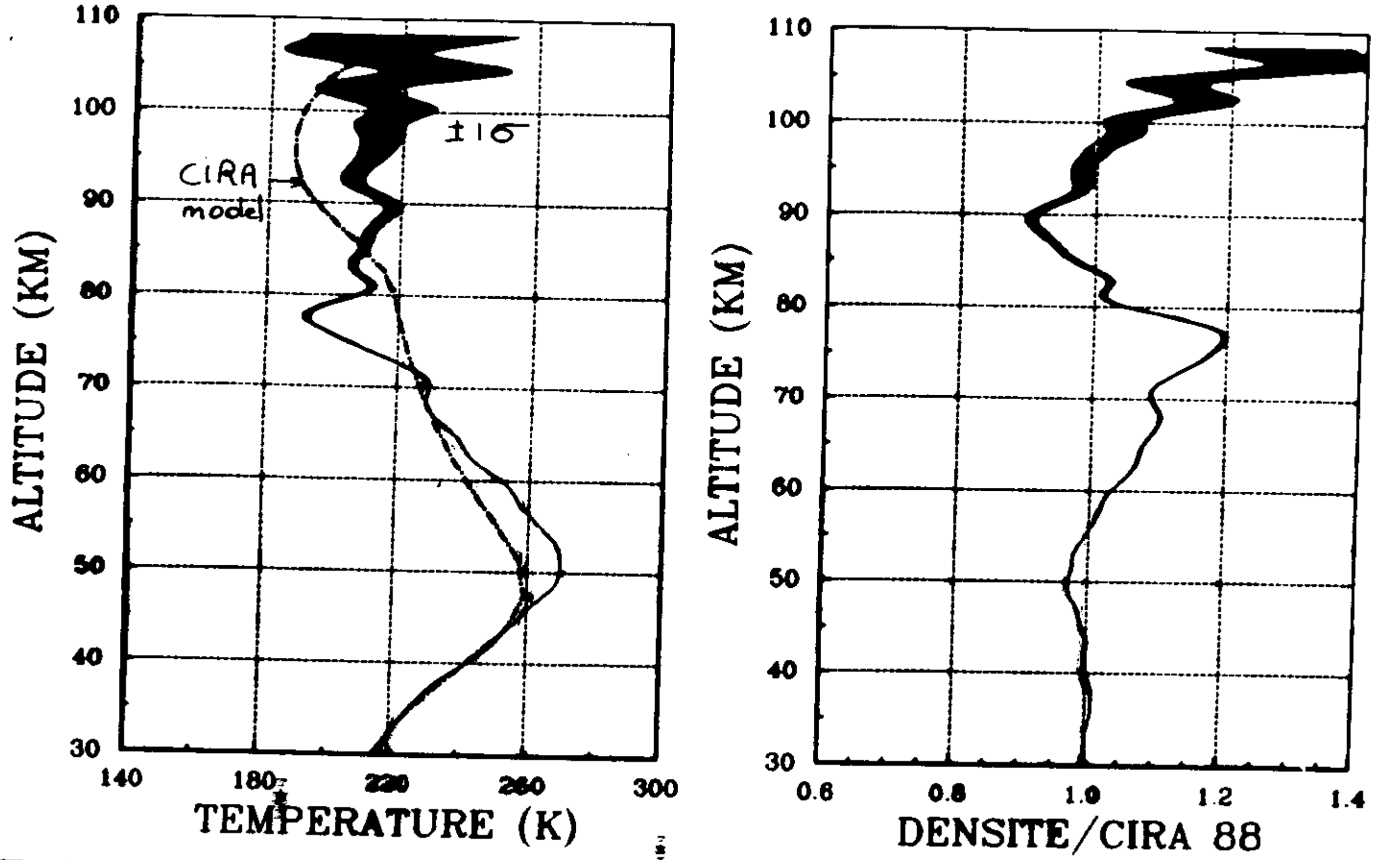
Accuracy $\quad \frac{\Delta n(z)}{n(z)} = \frac{\sqrt{N}}{N} \propto (dz\ dt)^{-1/2}$

Resolution
dz = 150 m (defined by sampling rate)
[illegible]
dt = [illegible] minutes (minimum integration time)

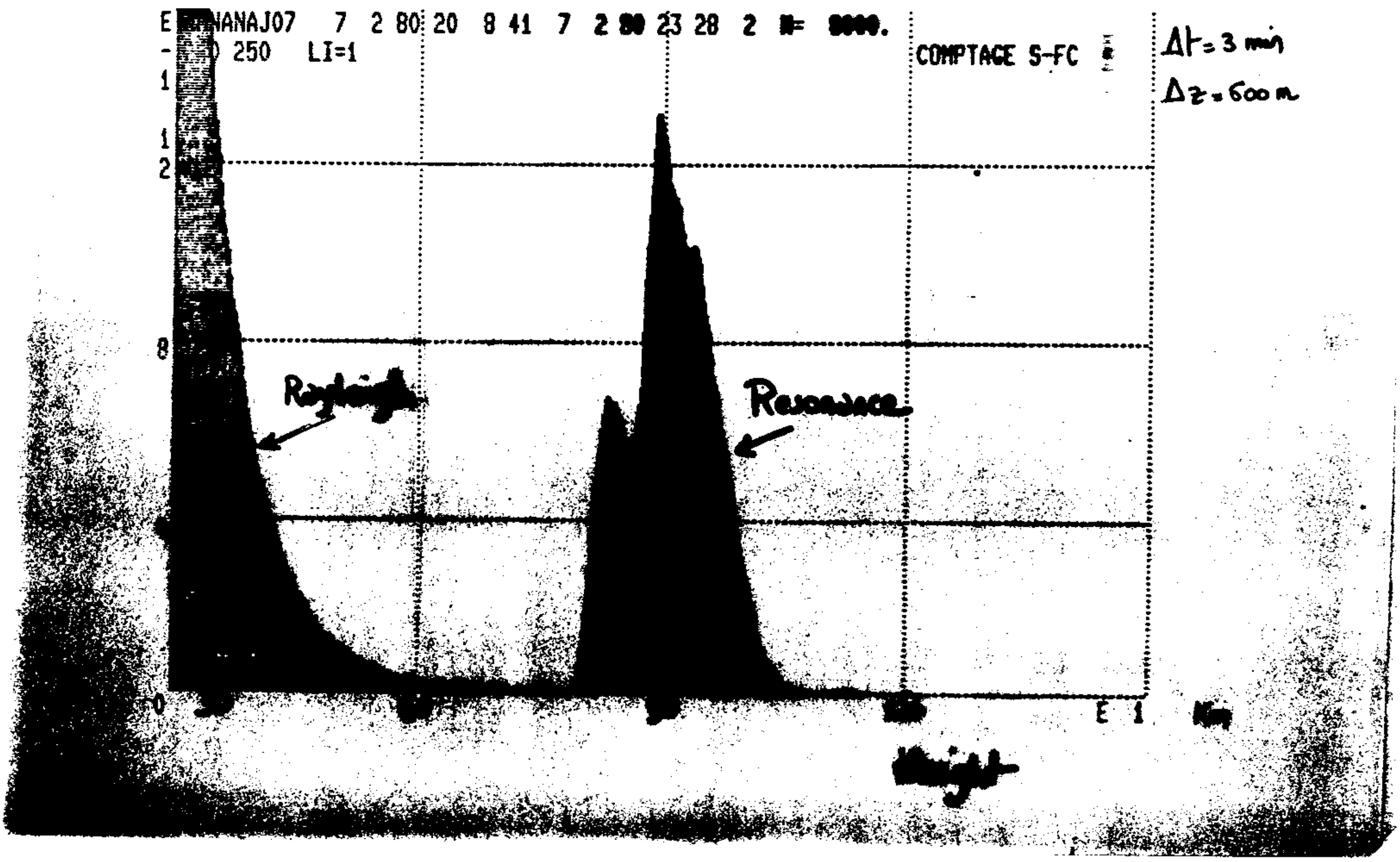


Exemple of Rayleigh lidar Temperature and density profiles

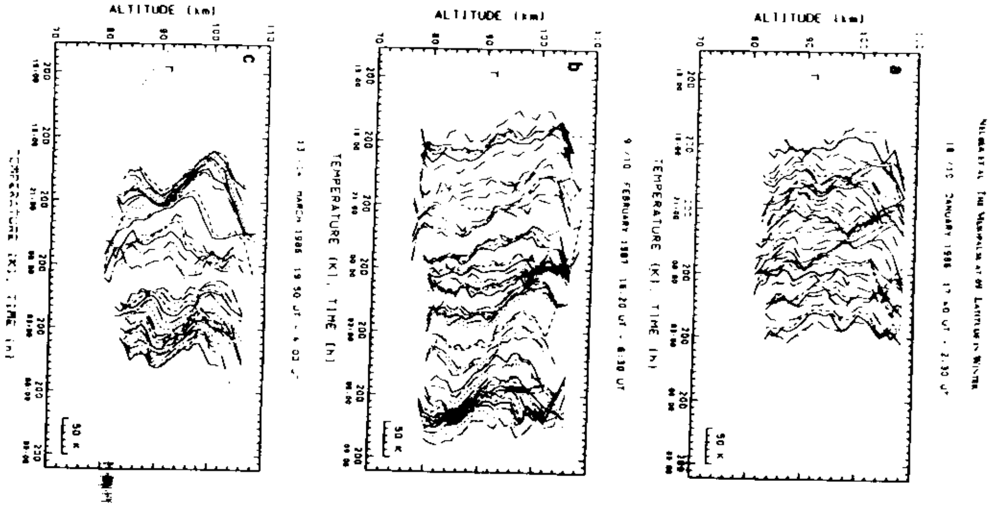
SITE : LIM DATE 21/11/89 19h16 04h06 REFERENCE : CIRA NOV 36.0 OUEST 43.0 NORD



FILTRAGE = 17
NB DE TIRS = 1202400 FOND DE CIEL = 0.40 PENTE = 0.0000 SQL = 261

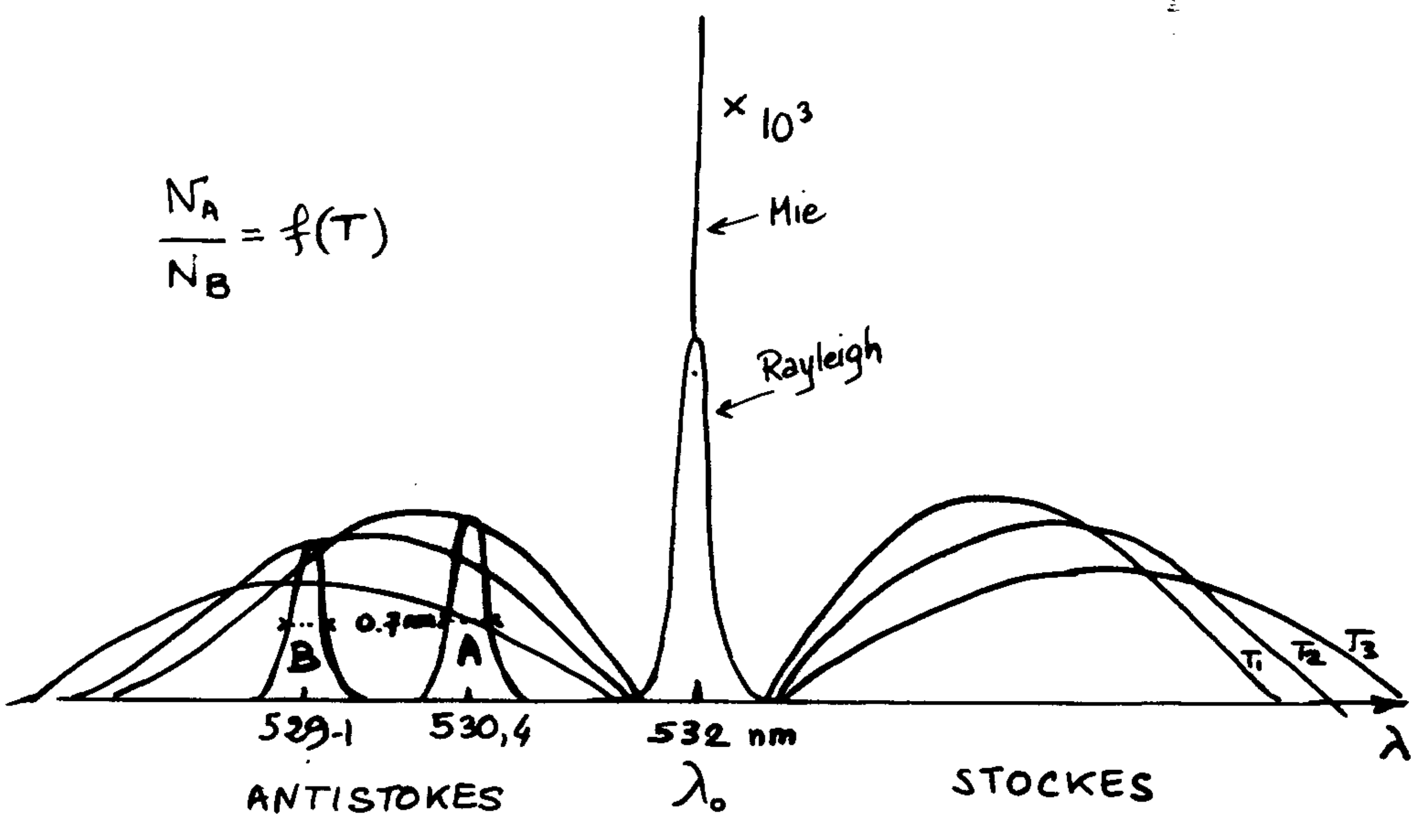


Neuber et al., 1988



ROTATIONAL RAMAN LIDAR

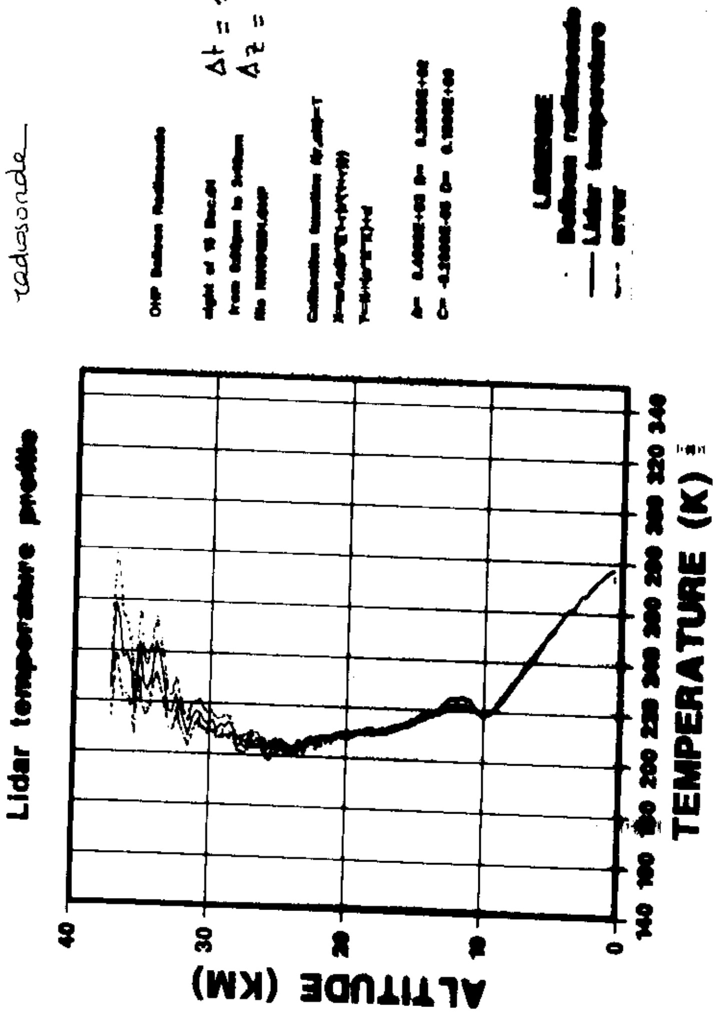
$$\frac{N_A}{N_B} = f(T)$$



Comparaison between Raman lidar and radiosonde

$\Delta t = 10\ h$ ± 1 K : 20 km

$\Delta z = 300\ m$ ± 4 K : 30 km



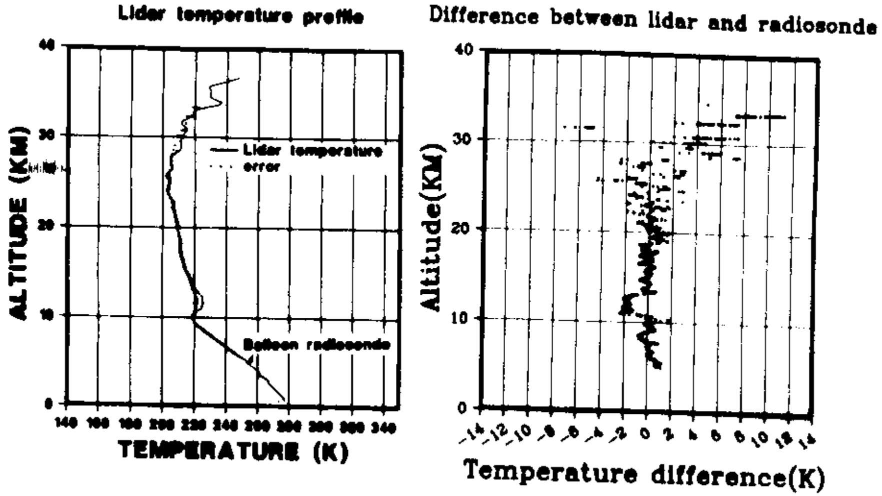


Figure 8: a) Profils de température obtenus par Lidar Raman et par radiosondage.
b) Différence entre les deux mesures

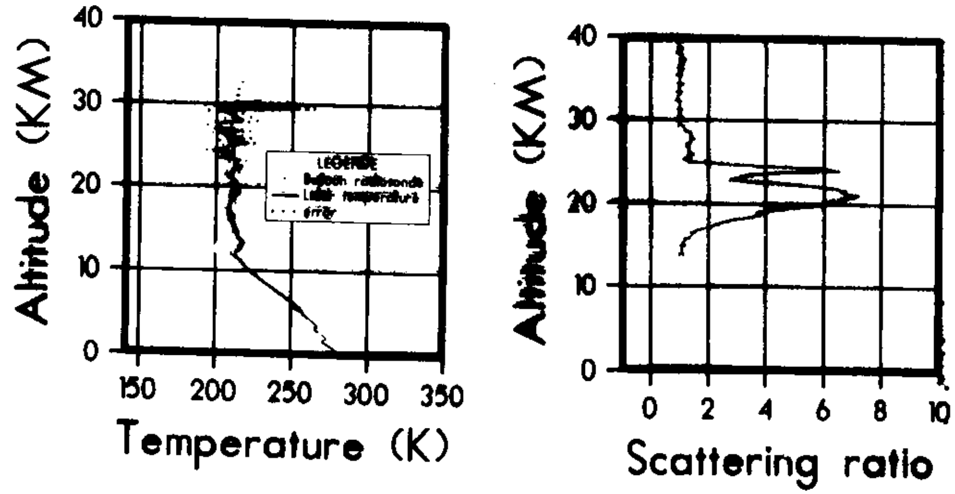
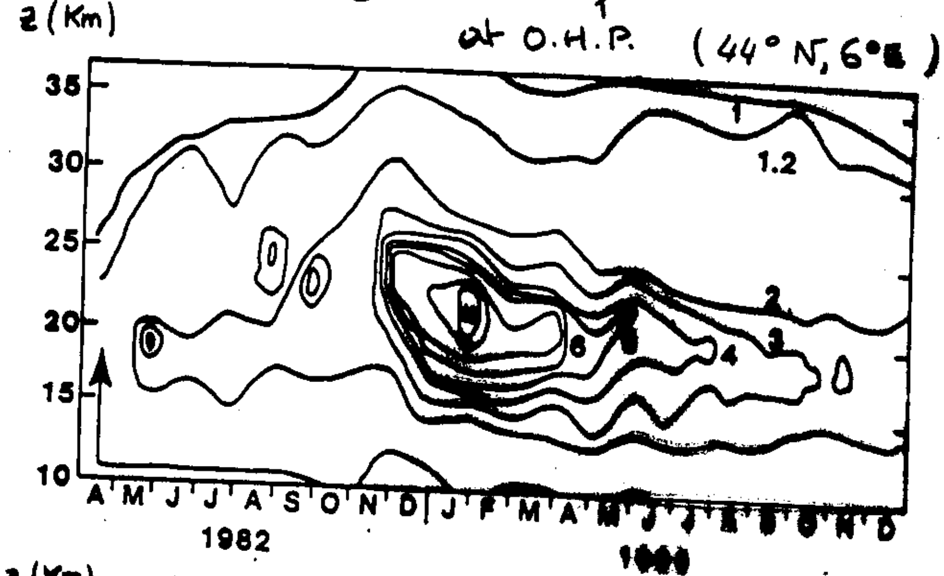
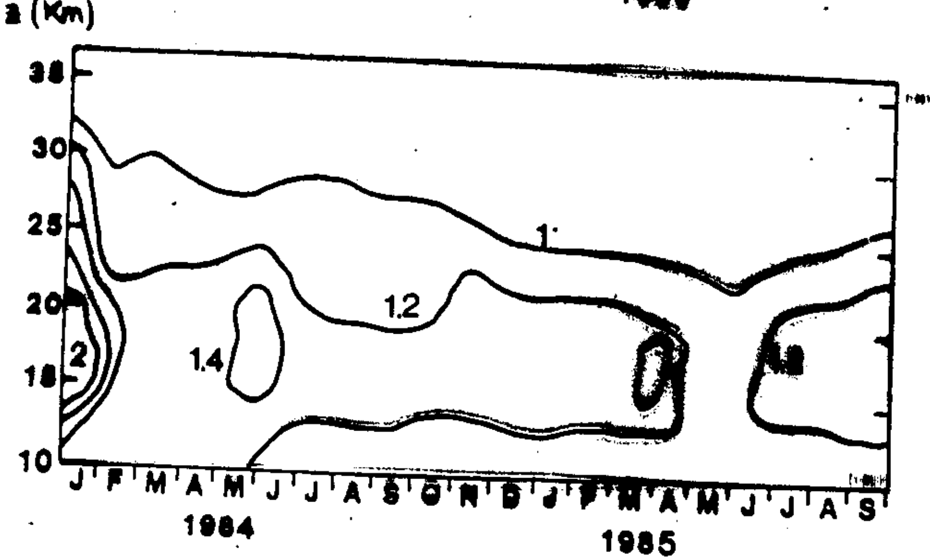


Figure 9 : a) Profil de température par Lidar Raman le 19/12/91 à l'OHP
b) profil d'aérosols obtenu simultanément le 19/12/91 à l'OHP.

Mie-Lidar

Scattering Ratio after El Chichon at O.H.P. (44° N, 6°E)

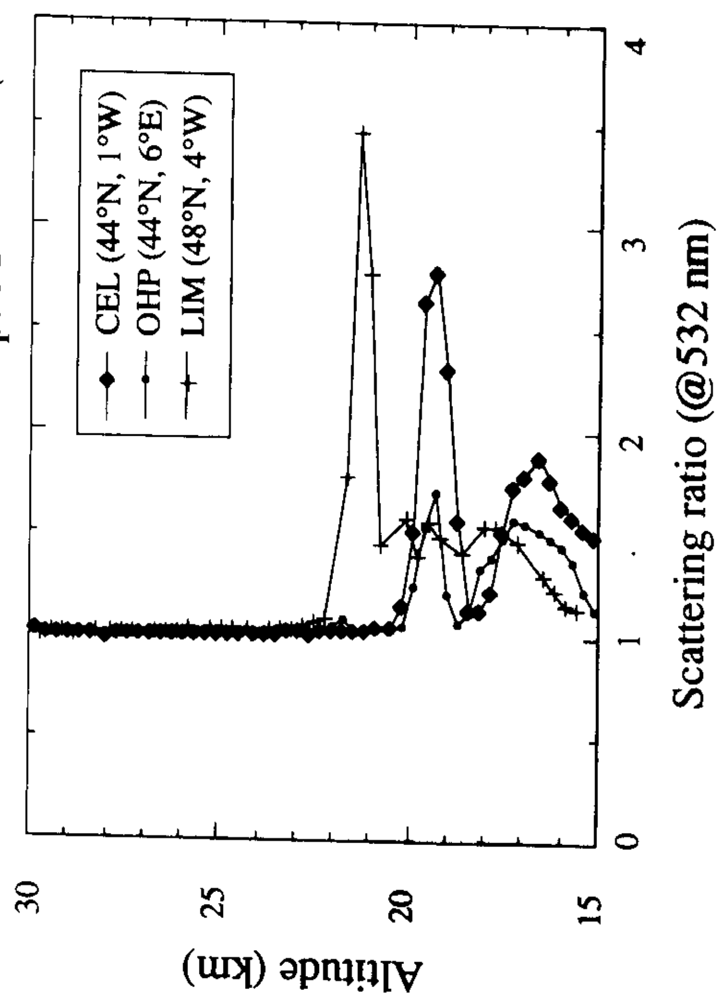




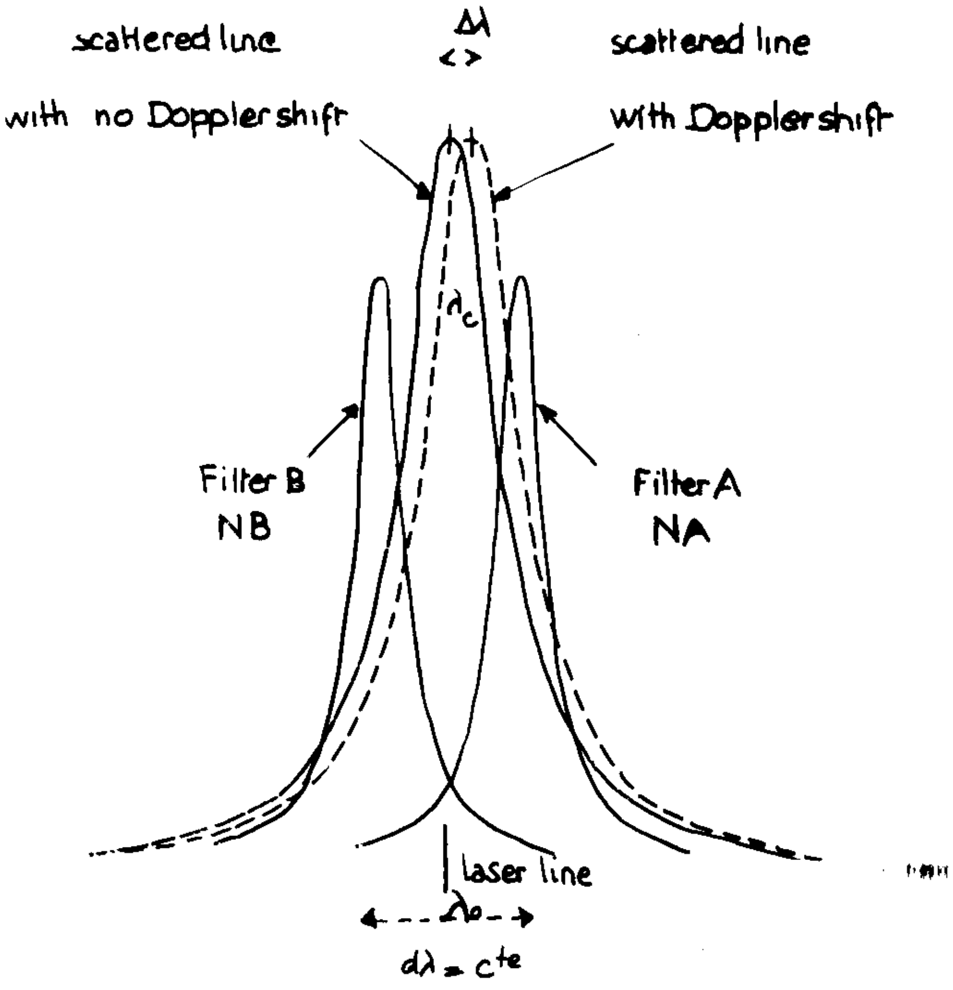
$$R(z_i) = \frac{n_r(z_i)\beta_r + n_a(z_i)\beta_m}{n_r(z_i)\beta_r}$$

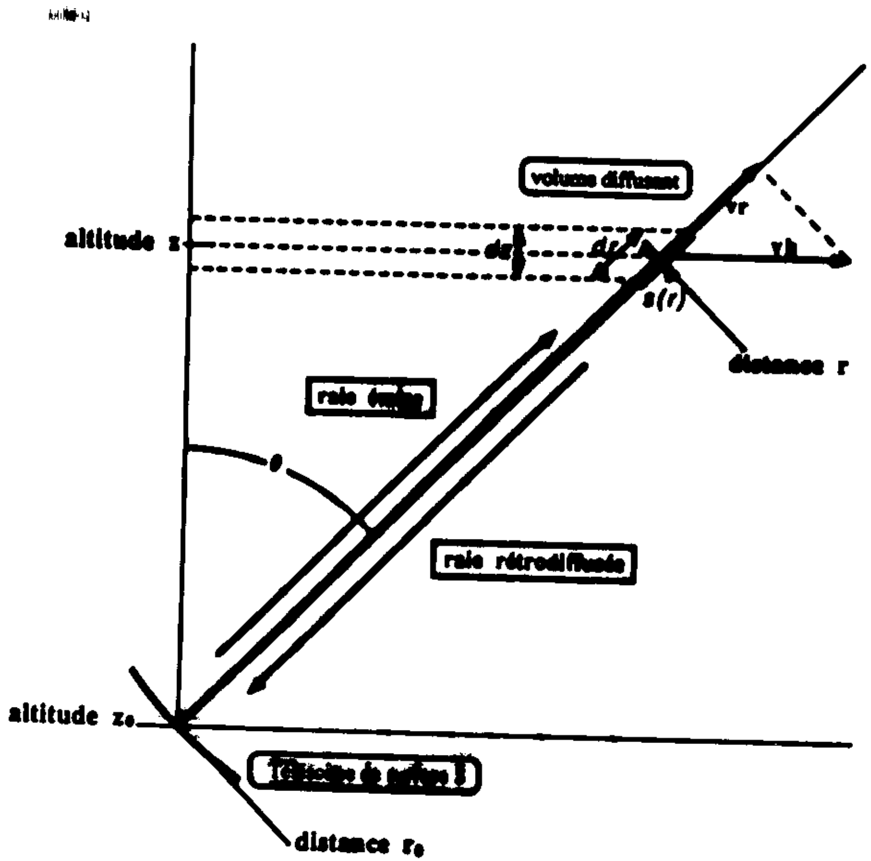
$\lambda = 532$ nm

CNRS Rayleigh Lidars → Aerosol layers due to Pinatubo from 3 different sites

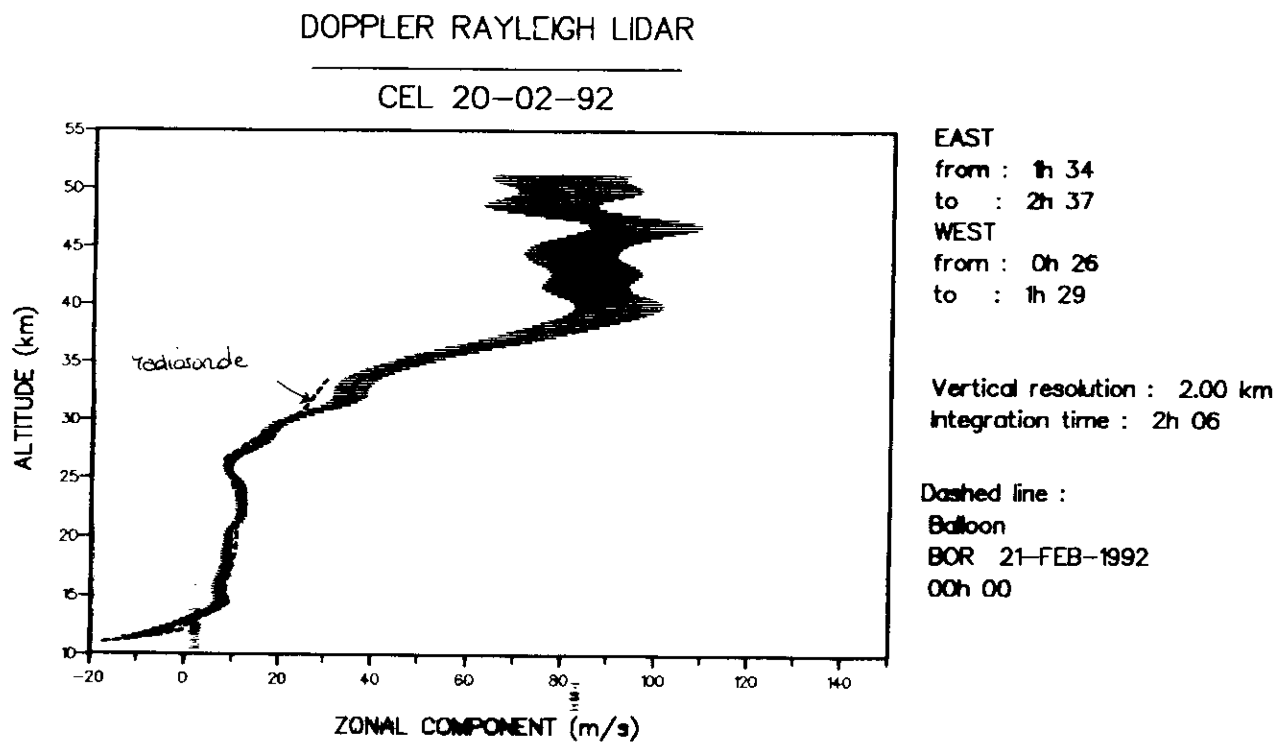


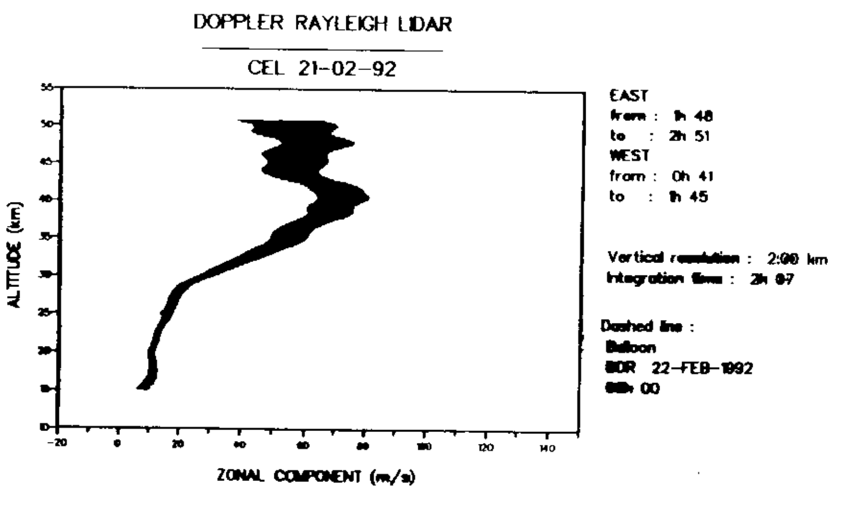
The Rayleigh Doppler Lidar principle

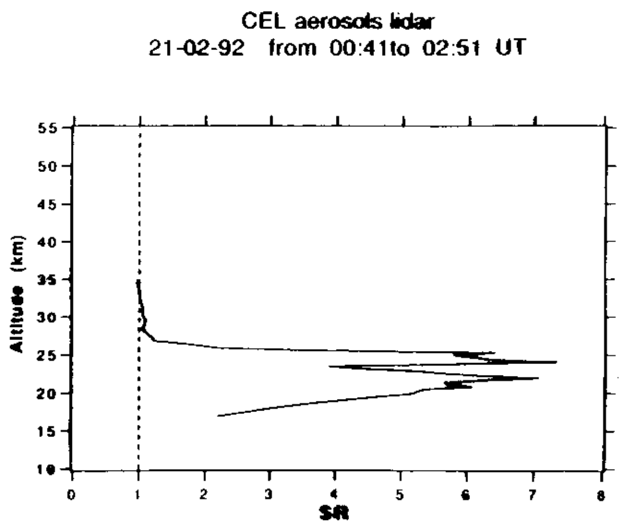




We measure the response R: $R = \dfrac{NA - NB}{NA + NB}$ successively for a tilted (45°) line of sight and for the vertical one







The wind profile is shown not to be disturbed by aerosols

STRATOSPHERIC PROCESSES AND THEIR ROLE IN CLIMATE

(SPARC)

A Project of the World Climate Research Programme

Chairmen: M-L. CHANIN & M. GELLER

FOCUS 1 : THE INFLUENCE OF THE STRATOSPHERE ON CLIMATE

FOCUS 2 : PROCESS STUDIES ASSOCIATED WITH STRATOSPHERIC OZONE DECREASE

FOCUS 3 : GLOBAL CHANGE OF THE STRATOSPHERE

FOCUS 4 : MONITORING AND MODELING OF UV IRRADIATION CHANGES IN THE BIOSPHERE AND THE TROPOSPHERE

STRATOSPHERIC PROCESSES AND THEIR ROLE IN CLIMATE

SPARC

A Project of the World Climate Research Programme

FOCUS 1 : THE INFLUENCE OF THE STRATOSPHERE ON CLIMATE

- Activity 1.1 Understand the Influence of the Stratosphere on Tropospheric Climate
- Activity 1.2 Assess the Potential Role of Stratosphere - Troposphere Interactions in climate change

FOCUS 2 : PROCESS STUDIES ASSOCIATED WITH STRATOSPHERIC OZONE DECREASE

- Activity 2.1 Chemical and Aerosol Processes
- Activity 2.2 Dynamical Transport of Chemical Constituents
- Activity 2.3 Radiative forcing of the stratosphere
- Activity 2.4 Radiative-Dynamical-Chemical Interactions

FOCUS 3 : GLOBAL CHANGE OF THE STRATOSPHERE

- Activity 3.1 Understanding the Variability and Long-Term Trends in the Stratosphere.

FOCUS 4 : MONITORING AND MODELING OF UV IRRADIATION CHANGES IN THE BIOSPHERE AND THE TROPOSPHERE

•Activity 4.1 Modeling and Experimental Validation of UV Penetration

•Activity 4.2 Global UV Climatology and Prediction

COMPLEMENTARY PROGRAMME

BIOSPHERIC EFFECTS AND FEEDBACKS RESULTING FROM SOLAR UV-B CHANGE

TO BE RUN BY IGBP AND SCOPE IN CLOSE COOPERATION WITH SPARC

Activity I.1 Aquatic Ecosystem Responses

Activity I.2 Terrestrial Vegetation Responses

Activity I.3 Assessments of Altered Animal and Human Health

Activity I.4 Biogenic Trace Gas Balances

HISTORY OF SPARC

1985-1986: W.G. on Solar-Terrestrial influence on the climate and the biosphere.

July 1987: First meeting of the SG-IGBP

August 1987: proposal of MARC by IAGA/IAMAP

1988-1989: presentation at SC-IGBP: MARC becomes STIB

Jan. 1990: STIB WG meeting at Abington UK.

June 1991: STIB Implementation Plan prepared during a meeting held at Stony-Brook, USA.

Aug. 1992: IGBP refuses to establish STIB as an IGBP Core Project.

Sept.1992:SPARC (STIB - The Biosphere) is proposed to WCRP

March 1992: The JSC/WCRP accepts SPARC as a WCRP project and appoints the SSG.

SPARC SCIENTIFIC STEERING GROUP

At this date the SPARC SSG composition is as follows.

- M.L. CHANIN (F)
- M. GELLER (USA)

co-chairmen

- J. MAHLMAN (USA)
- T. MATSUNO (J)

members of the JSC

- J. PYLE (U.K.) chairman of WGATC
- I. ISAKSEN (N)
- V. KHATTATOV (R)

members of the ex-STIB CPPC

- H. TANAKA (J)
- R. TURCO (USA)
- D. EHHALT (G)

One member (a chemist) is still to be named by the JSC

+ ex officio members representing IGBP (GCTE, JGOFS, LOICZ), SCOSTEP, GAW, SCOPE, COSPAR.

SPARC MEETINGS

in the very near future

September 1992: NATO ASI " The role of the stratosphere in Global Change"
Carqueiranne, France

May 1993: SPARC session at the EGS meeting, Wiesbaden, Germany.

July 1993: SPARC Symposium at the IAMAP meeting, Yokohama, Japan

1993: NATO ARW on Stratosphere-Troposphere exchange, Directors J.Holton, P. Haynes, Cambridge ?

1994; NATO ARW : The Effect of Pinatubo, Director: G. Fiocco, Italy ?

June 1994: STEP Symposium in Sendai (Japan)