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School on "Exploring the Atmosphere by Remote Sensing Techniques"
18 October - 5 November 1999

1151-24

"Limb Emission Spectroscopy"

H. Oelhaf
Institute of Meteorology & Climate Technology
Research Center - Karlsruhe
Germany

Please note: These are preliminary notes intended for internal distribution only.

LIMB EMISSION SPECTROSCOPY

Hermann Oelhaf

Institute of Meteorology and Climate Technol
Research Center - Karlsruhe
Germany

oelhaf@imk.fzk.de

www.fzk.de/imk/imk2/mipas-b/mipas-b.htm

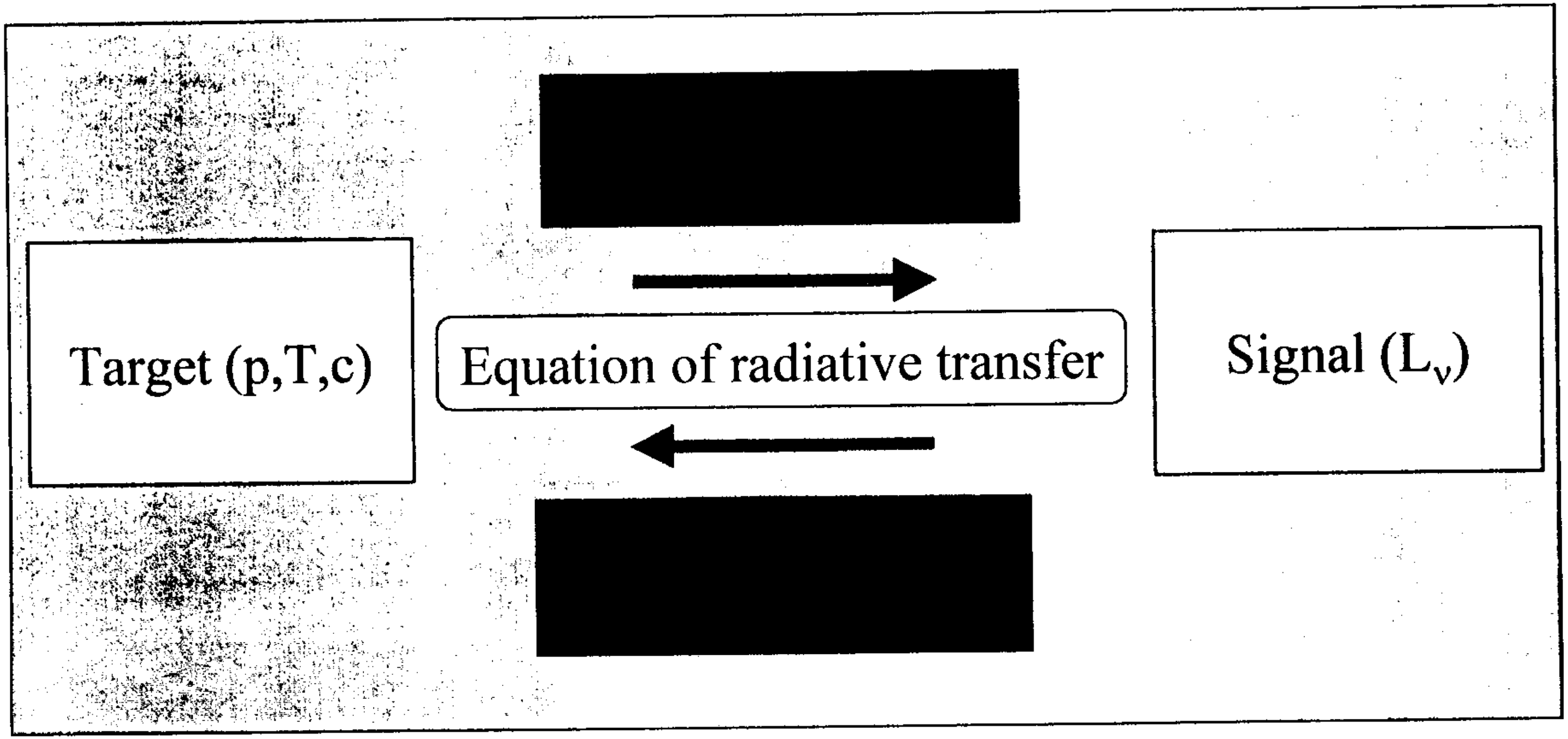
* LECTURE #1 : "Overview"

- Introductions
- Some basics
- Survey of sensors
- Research topics
- CLAES Results
- CHRISTA Results

* LECTURE #2 : "MIPAS-B" "MIPAS-S"

- Needs and requirements
- The MIPAS family
- MIPAS - B : instrument, data analysis, obs. strategy
- MIPAS - B : Scientific case studies
- MIPAS - ENVISAT

Principle of remote sensing



The equation of radiative transfer

A pencil of radiation traversing a medium will be

- weakened by absorption and scattering
- strengthened by emission plus multiple scattering:

$$d\,L_\nu = -k_{\epsilon,\nu}\rho L_\nu ds + k_{\epsilon,\nu}\rho J_\nu ds \Longleftrightarrow \frac{dL_\nu}{ds} = -\sigma_{\epsilon,\nu}(L_\nu - J_\nu) \quad (1)$$

With the assumptions

- local thermodynamic equilibrium
- nonscattering medium ($\sigma_{\epsilon,\nu} = \sigma_{a,\nu}$)
- $J_\nu = B_\nu(T)$

the integration of equation 1 leads to

$$L_\nu(s2) = L_\nu(s1)e^{-\int_{s1}^{s2}\sigma_{a,\nu}(s)ds} + \int_{s1}^{s2} B_\nu(T(s))e^{-\int_{s1}^{s2}\sigma_{a,\nu}(s)ds}\sigma_{a,\nu}(s)ds. \quad (2)$$

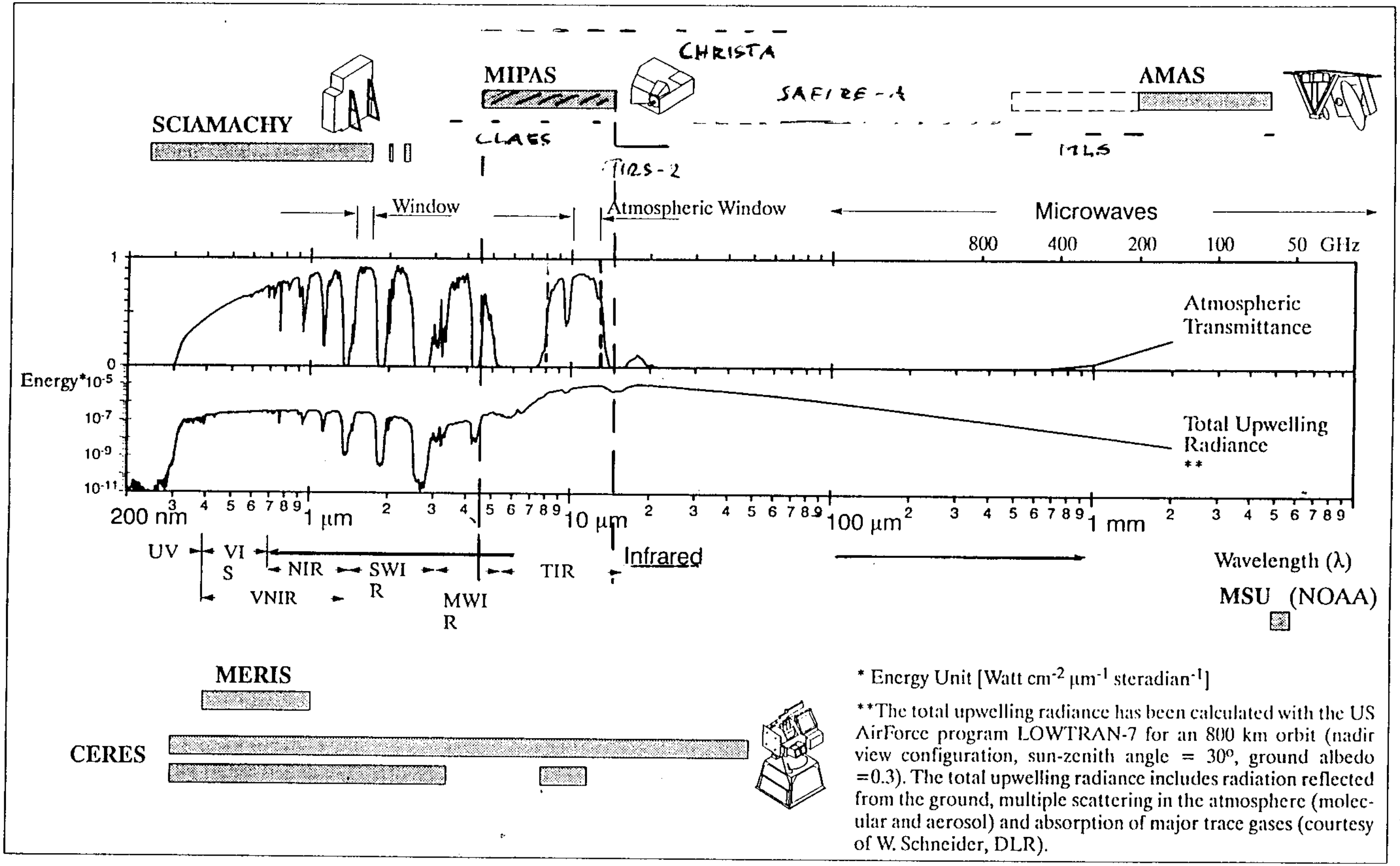
Introducing the transmission τ_ν

$$\tau_\nu = exp(-\int_{s1}^{s2}\sigma_{a,\nu}(s)ds) \quad (3)$$

and assuming balloon limb sounding geometry the equation of transfer can be rewritten

$$L_{\Delta\nu} = \int_{z_{min}}^{z_{obs}} B_{\Delta\nu}(T(z))\frac{\partial\tau_{\Delta\nu}(z)}{\partial z}\,dz - \int_{z_{min}}^{z_\infty} B_{\Delta\nu}(T(z))\frac{\partial\tau_{\Delta\nu}(z)}{\partial z}\,dz \quad (4)$$

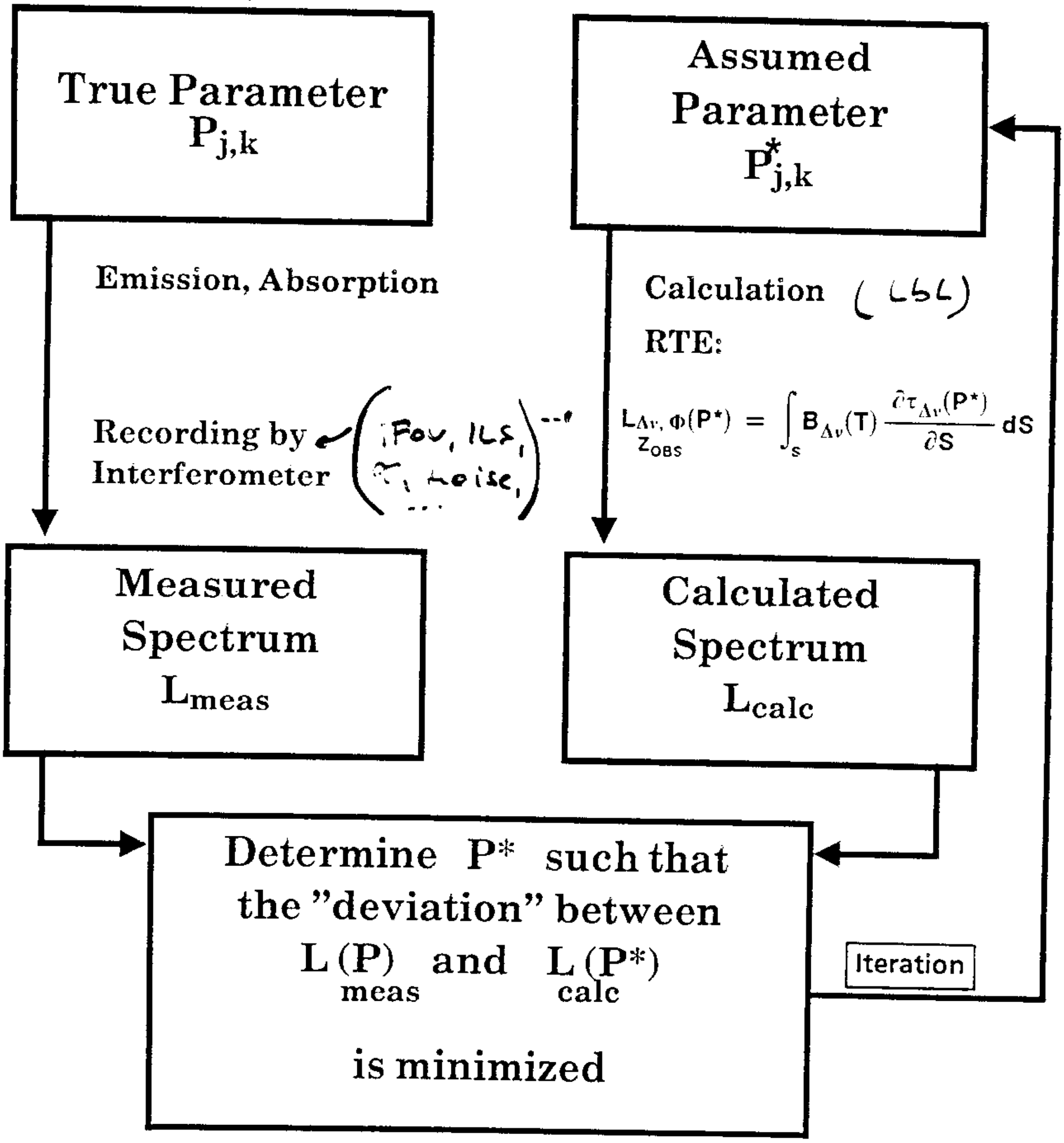
with $\partial\tau_{\Delta\nu}/\partial z$: weighting function



* Energy Unit [Watt cm^{-2} μm^{-1} $steradian^{-1}$]

**The total upwelling radiance has been calculated with the US AirForce program LOWTRAN-7 for an 800 km orbit (nadir view configuration, sun-zenith angle = 30°, ground albedo =0.3). The total upwelling radiance includes radiation reflected from the ground, multiple scattering in the atmosphere (molecular and aerosol) and absorption of major trace gases (courtesy of W. Schneider, DLR).

Figure 256: Atmospheric parameters and spectral ranges of some sensors


True Parameter $P_{j,k}$
Assumed Parameter $P^*_{j,k}$
Emission, Absorption
Calculation (LbL)
RTE:
$L_{\Delta\nu,\Phi}(P^*)_{z_{OBS}} = \int_s B_{\Delta\nu}(T) \frac{\partial \tau_{\Delta\nu}(P^*)}{\partial s} ds$
Recording by Interferometer
(FOV, ILS, τ, noise, ...)
Measured Spectrum L_{meas}
Calculated Spectrum L_{calc}
Determine P* such that the "deviation" between $L_{meas}(P)$ and $L_{calc}(P^*)$ is minimized
Iteration

Retrieval

IR EMISSION SPECTROSCOPY

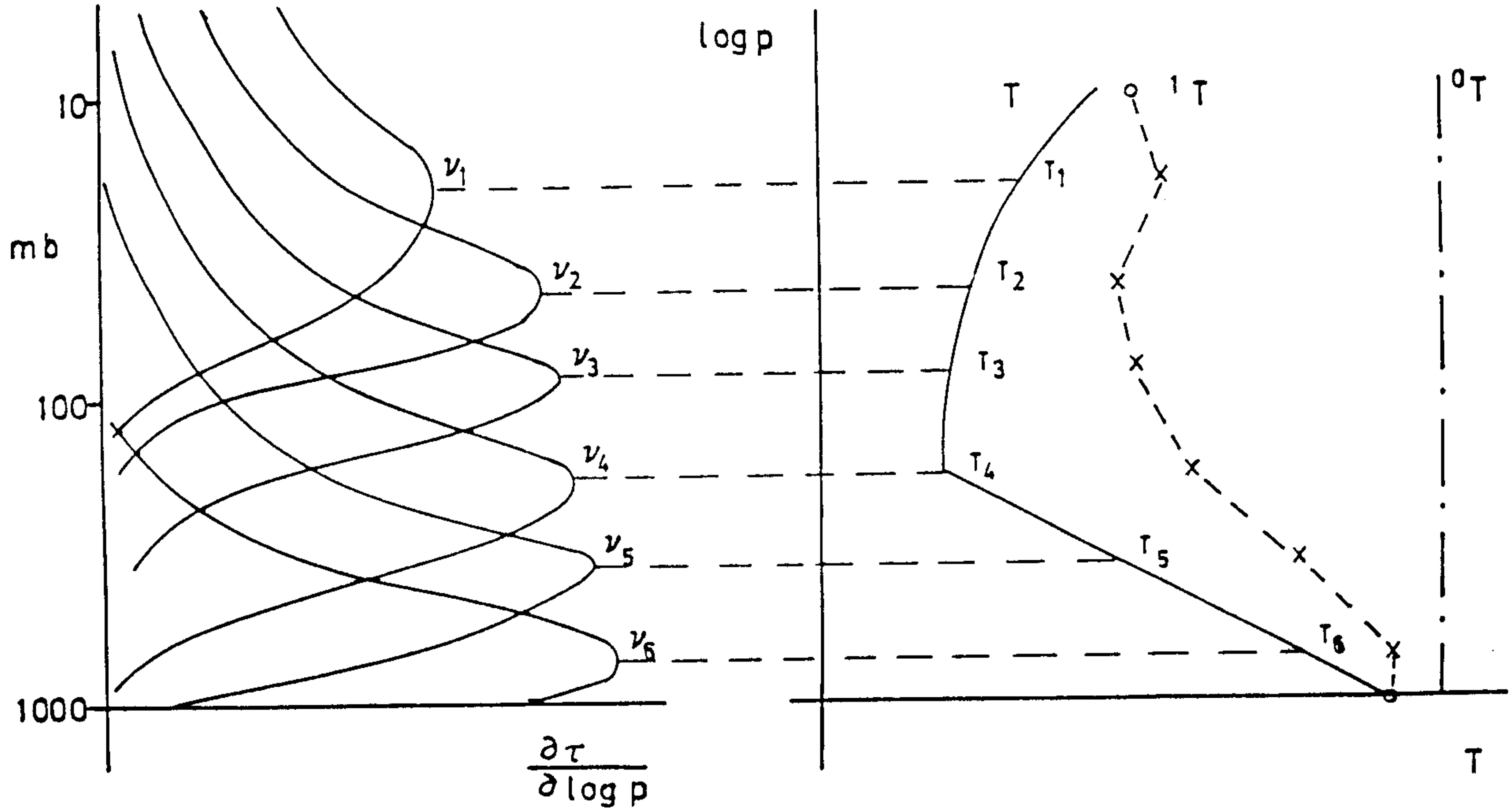
* ATMOSPH. APPLICATIONS *

- UPWARDS FROM GROUND
  - MW to sub-mm : vertical profiles of some gases
  - IR : lower atm. state parameters

- NADIR FROM SATELLITES ~~AND~~ AIRCRAFT
  - meteor. parameters
  - some gases
  - radiation budget

- LIMB FROM HIGH FLYING AC AND BALLOON
  - many gases, aerosol, good vertical precision and resolution, comprehensive → process studies

- LIMB FROM SPACE
  - surveys of chemistry and dynamics
  - non-LTE physics
  - global coverage



NONLINEAR RELAXATION METHODS

Abb.: 5.8

$$\alpha_L = \alpha_L(p, T) \sim \frac{p}{p_0}\left(\frac{T_0}{T}\right)^{n}$$

$$\alpha_D = \alpha_D(\nu, T) \sim \nu_0 \sqrt{T}$$

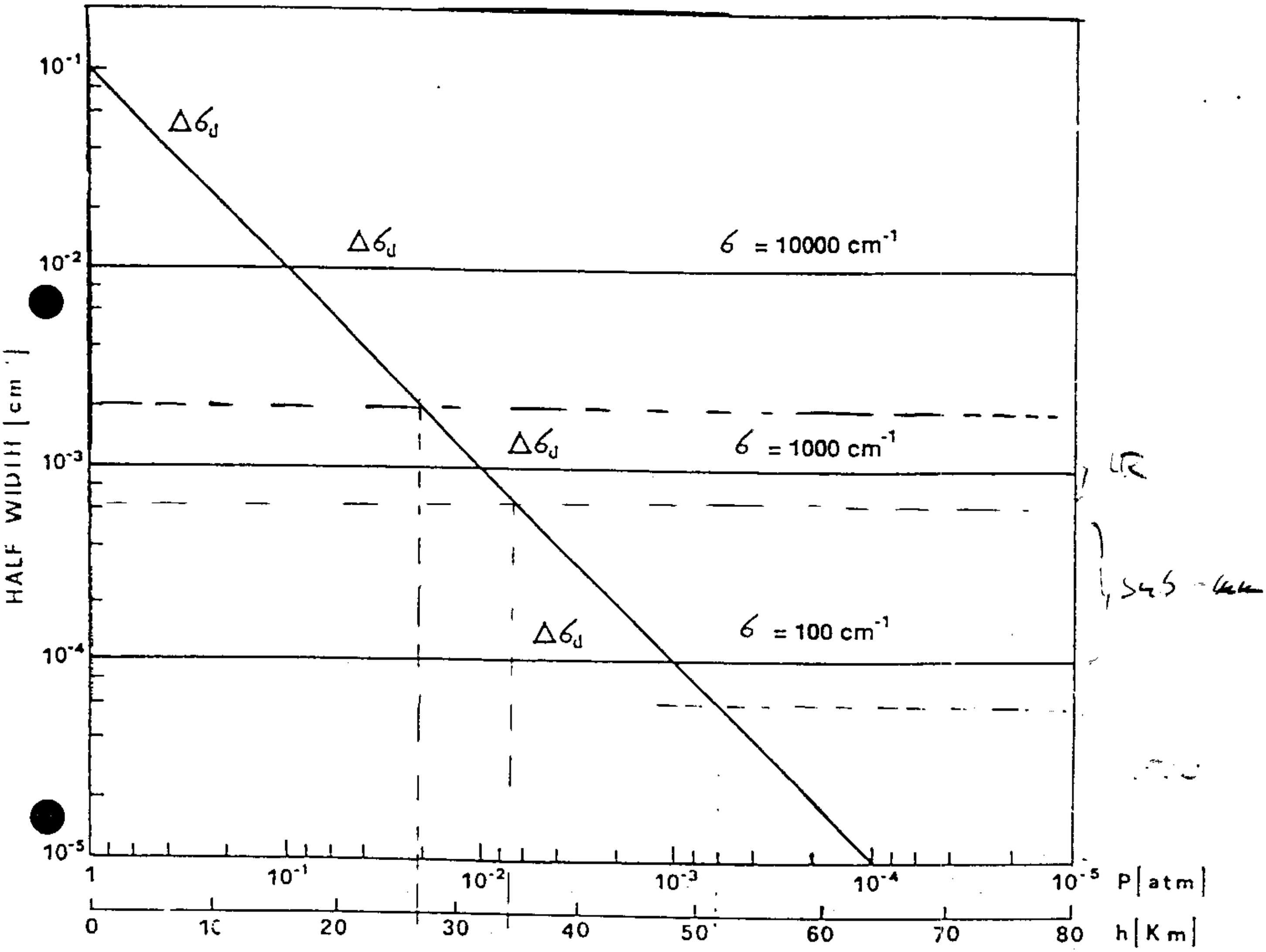
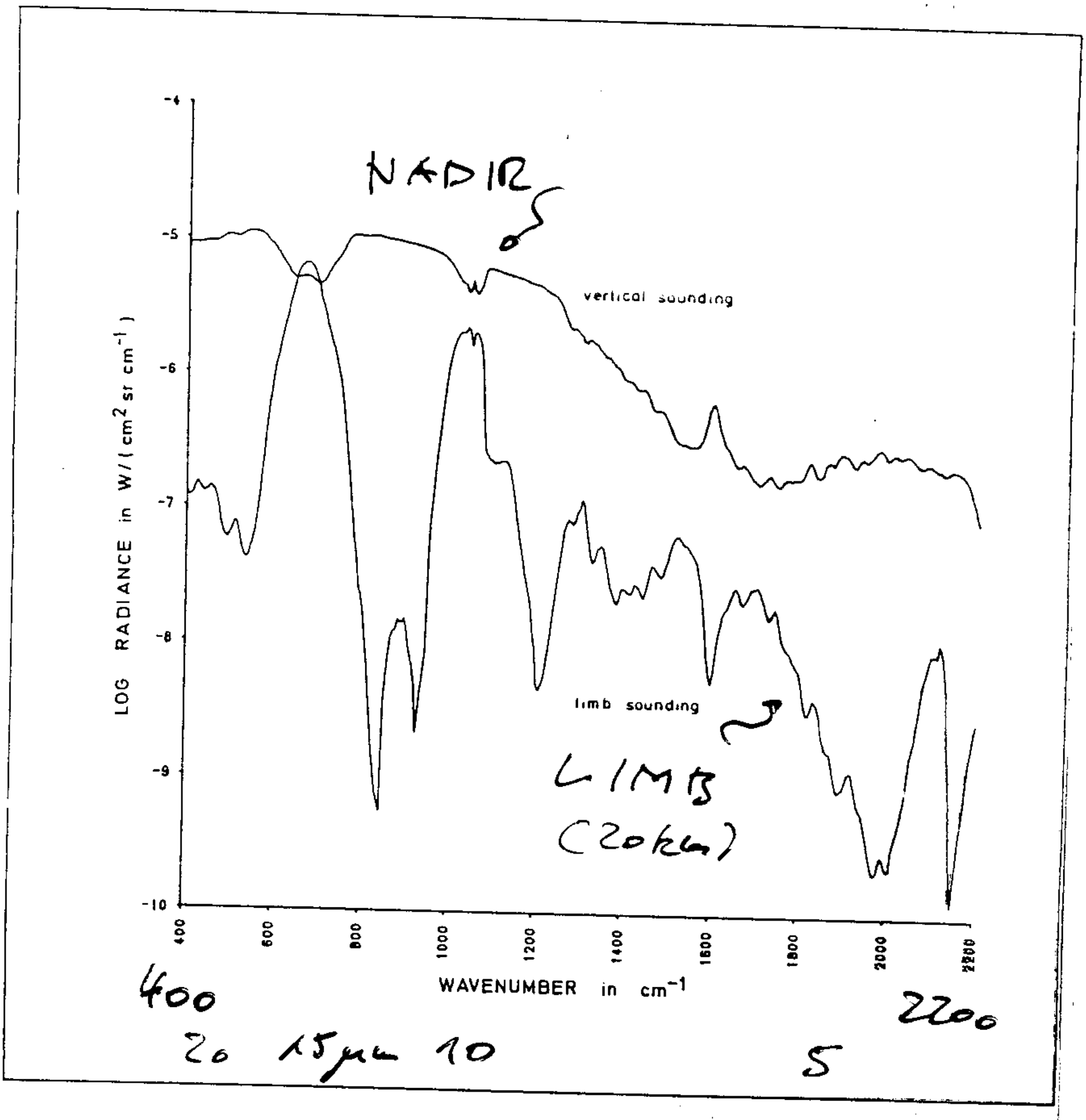
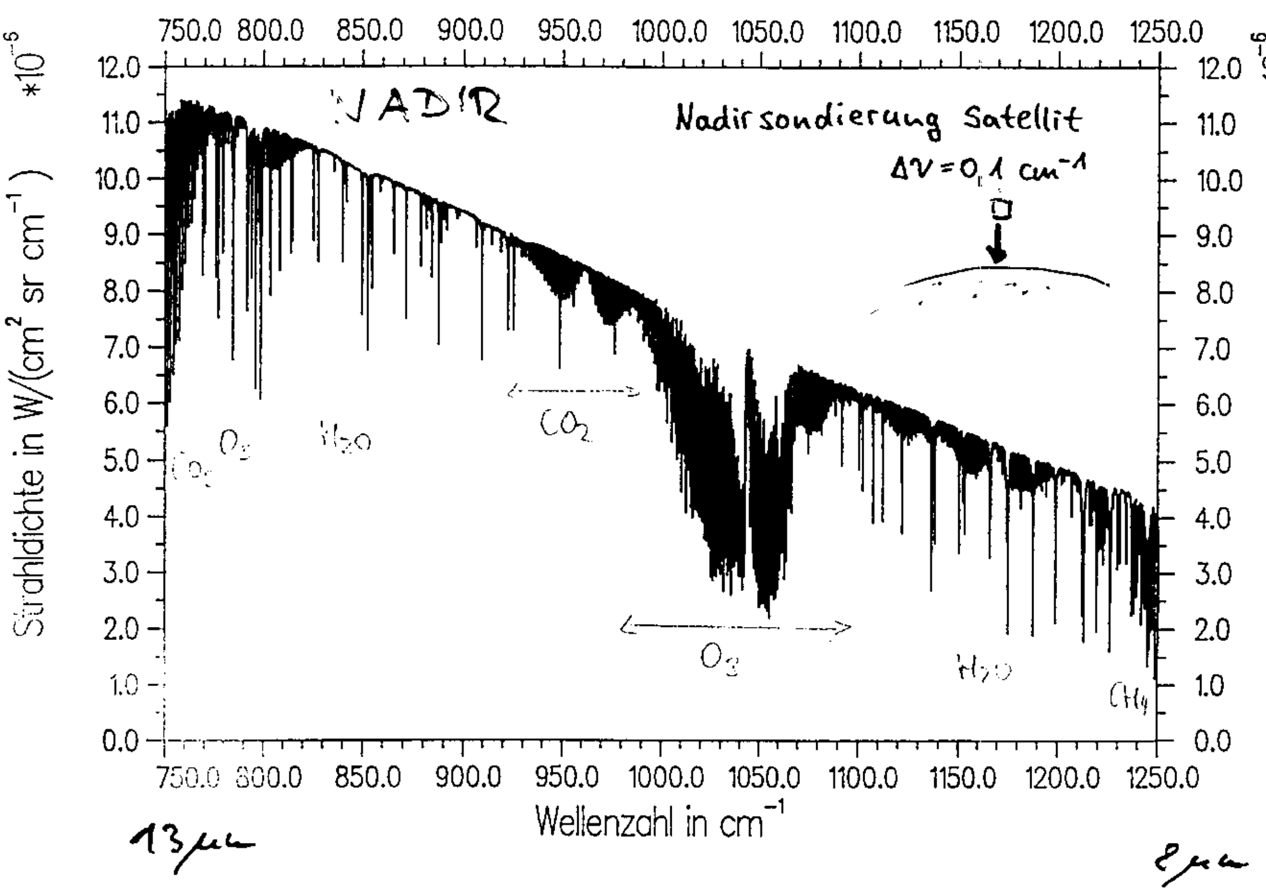
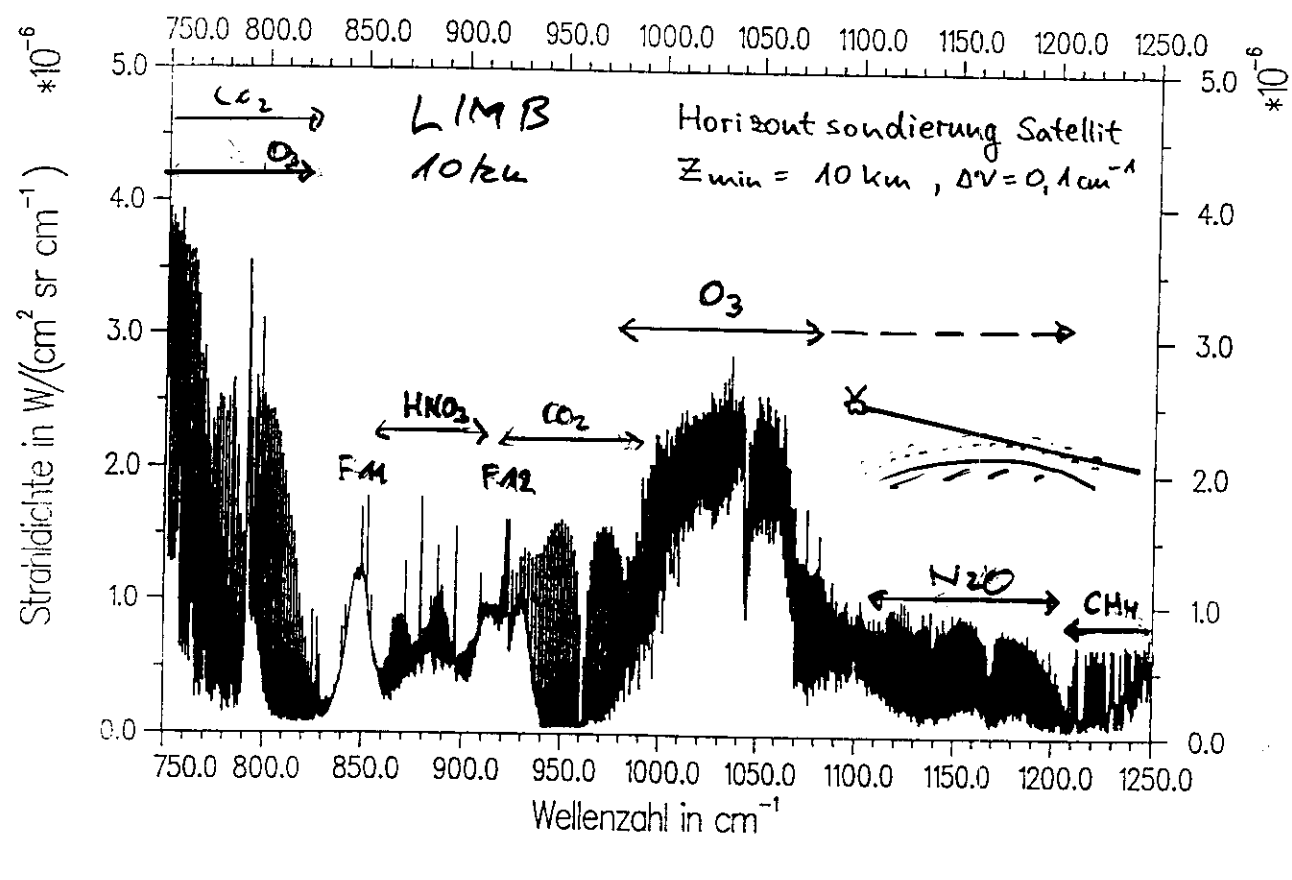


Figure 3.5 Variation of line width with altitude for different wavenumbers.

HOW TO GET VERTICAL PROFILES FROM THE LINE SHAPES (uplooking observation).


NADIR
vertical sounding
limb sounding
LIMB
(20km)
LOG RADIANCE in W/(cm2 sr cm-1)
-4
-5
-6
-7
-8
-9
-10
400
600
800
1000
1200
1400
1600
1800
2000
2200
WAVENUMBER in cm-1
400
2200
20 15µm 10
5


NADIR
Nadirsondierung Satellit
Δν = 0,1 cm⁻¹
Strahldichte in W/(cm² sr cm⁻¹) *10⁻⁶
Wellenzahl in cm⁻¹
CO₂
O₃
H₂O
CO₂
O₃
H₂O
CH₄
13 µm
8 µm


LIMB
10 km
Horizontsondierung Satellit
Zmin = 10 km , Δν = 0,1 cm⁻¹
Strahldichte in W/(cm² sr cm⁻¹) *10⁻⁶
Wellenzahl in cm⁻¹
CO₂
O₃
O₃
HNO₃
CO₂
F11
F12
N₂O
CH₄

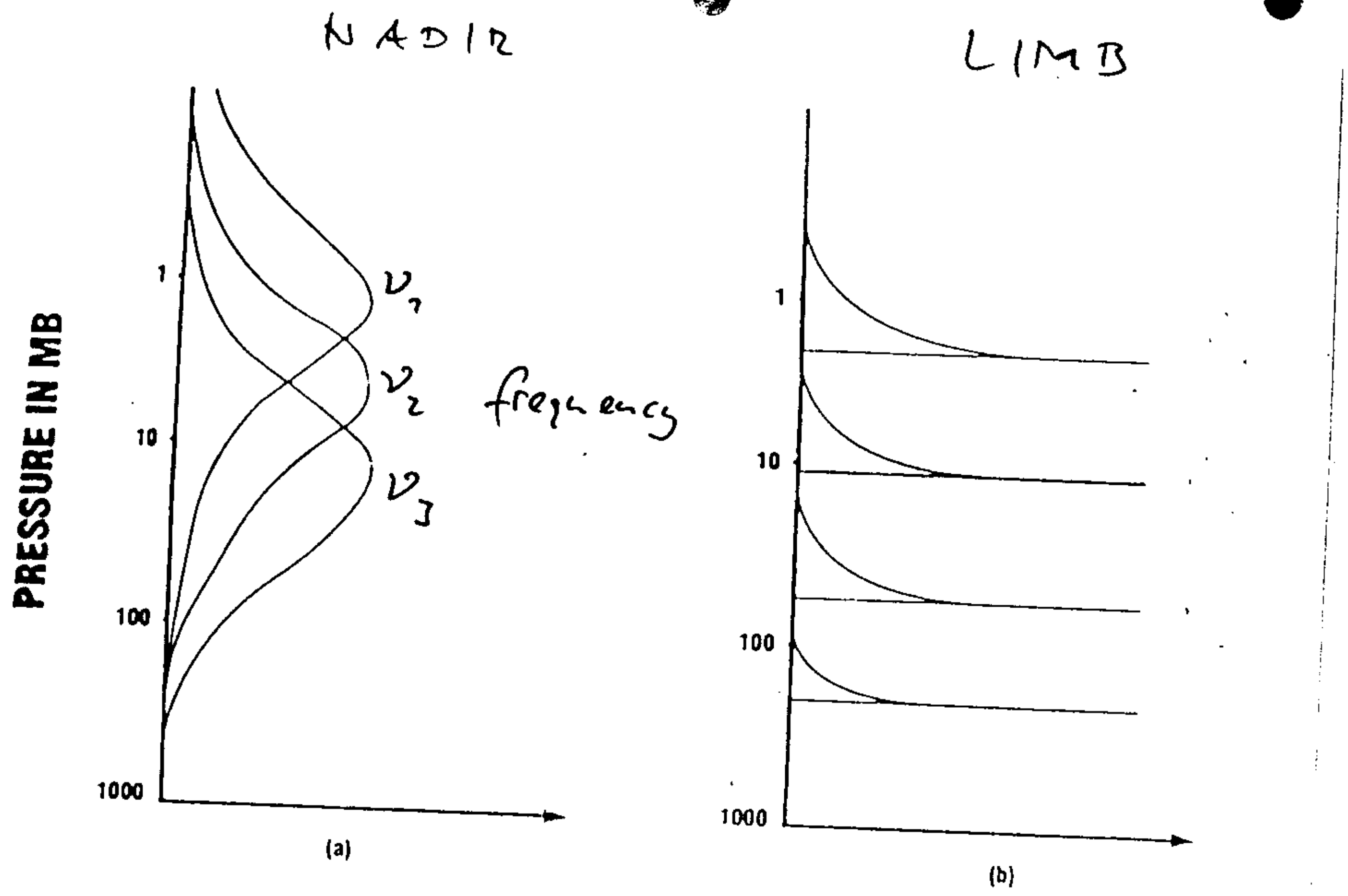


Figure 2.1 Typical weighting functions for the stratosphere. (a) Nadir sounding; (b) Limb sounding.

$$L_{\nu,i}(\ell_s) = L_{\nu,E}\, \tau_{\nu,i}(\ell_s)\Big|_{\ell_s,-\infty} + \int_{-\infty}^{\ell_s} B_\nu(T(\ell)) \frac{\partial \tau_{\nu,i}(\ell_s,\ell)}{\partial \ell}\, d\ell$$

LIMB EMISSION VS OCCULTATION SPECTROSC

[illegible]

[illegible]

[illegible]

[illegible]

→ [illegible]

→ [illegible]

→ [illegible]

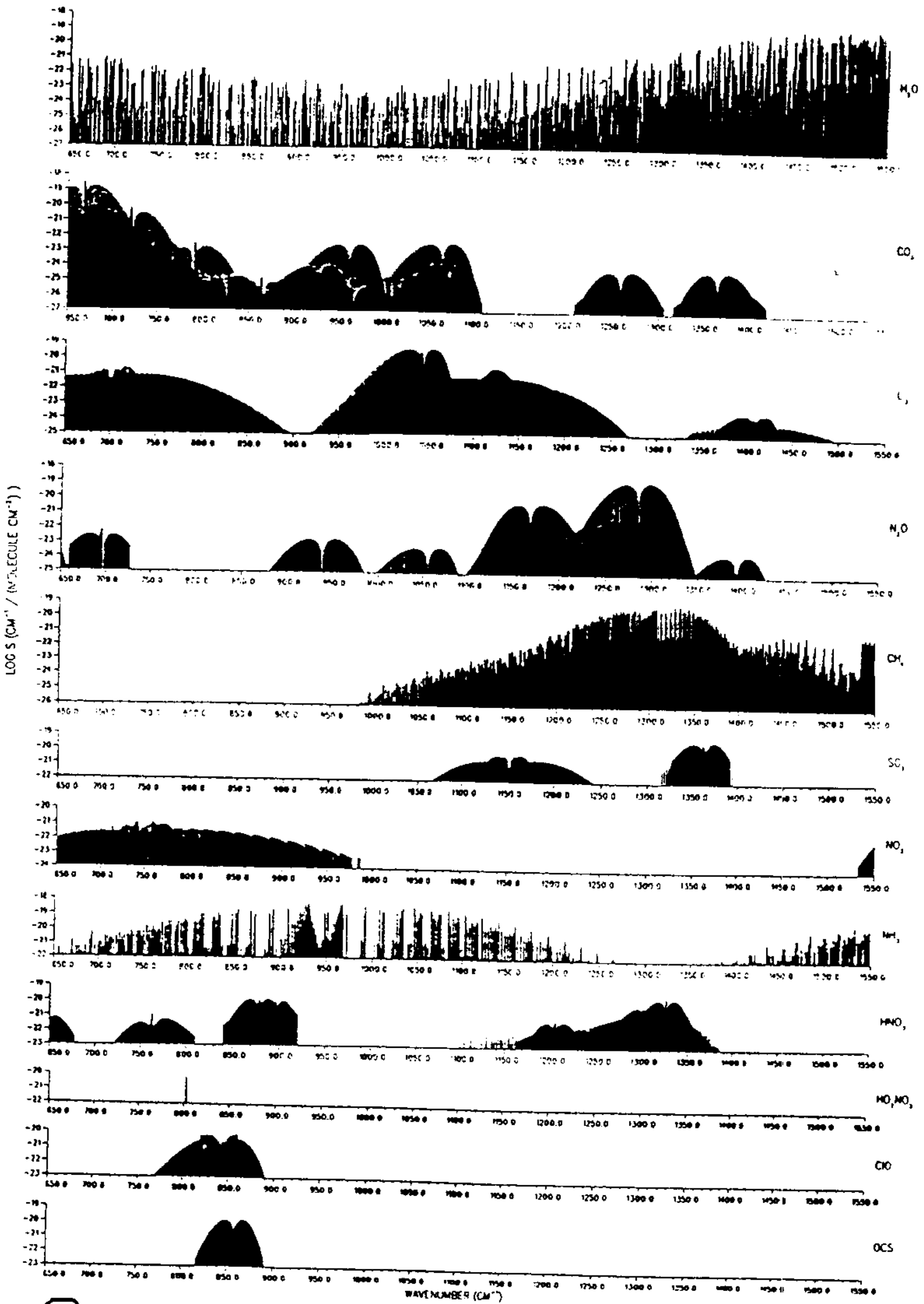
- technically more demanding
  → cooling of optics

- data evaluation more time consuming
  → absolute radiometric calibration
  → ...

- more critical to temperature

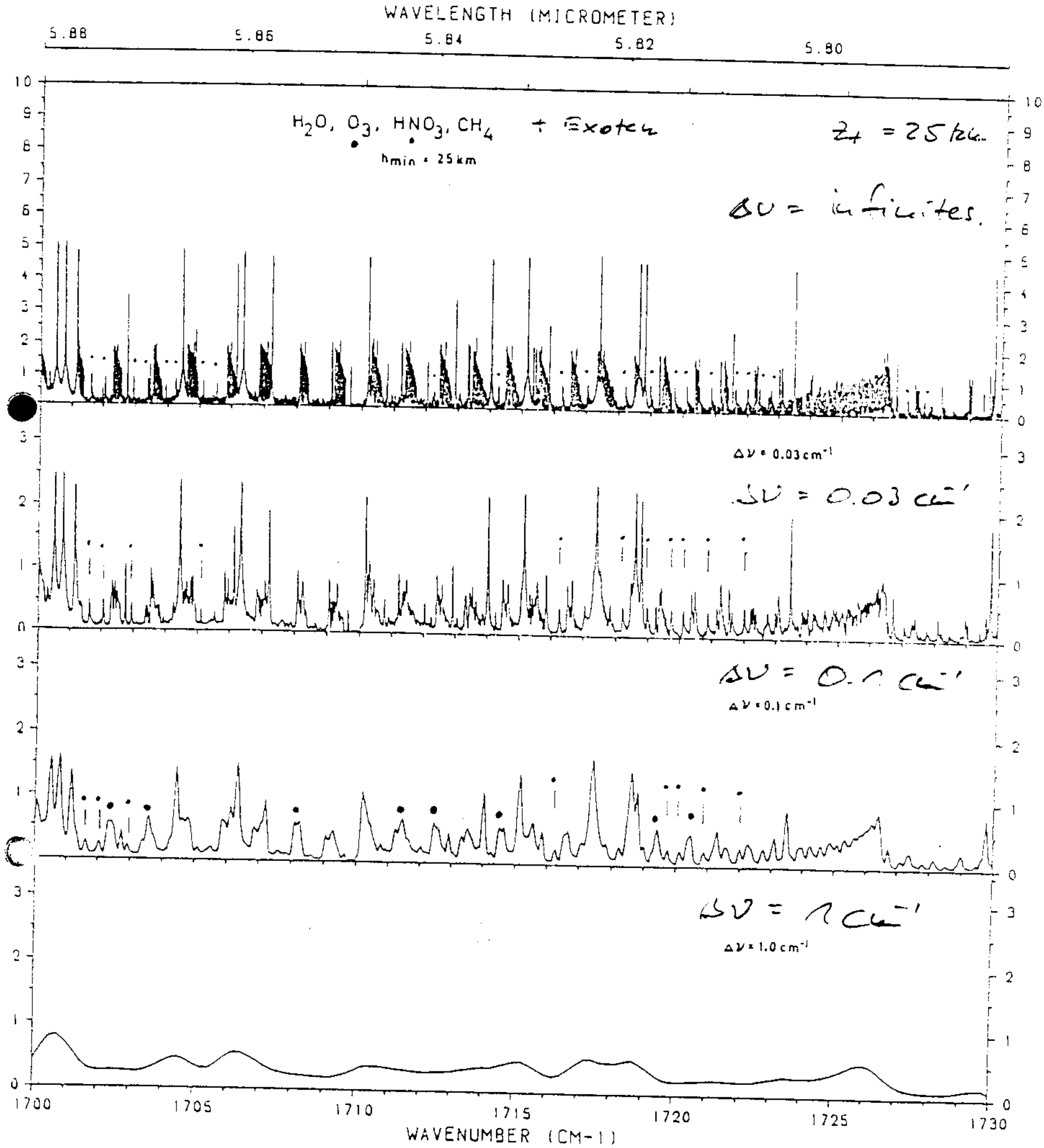
- non - LTE

- sensitivity
- spectral resolution
- spectral coverage
- weight, volume, complexity

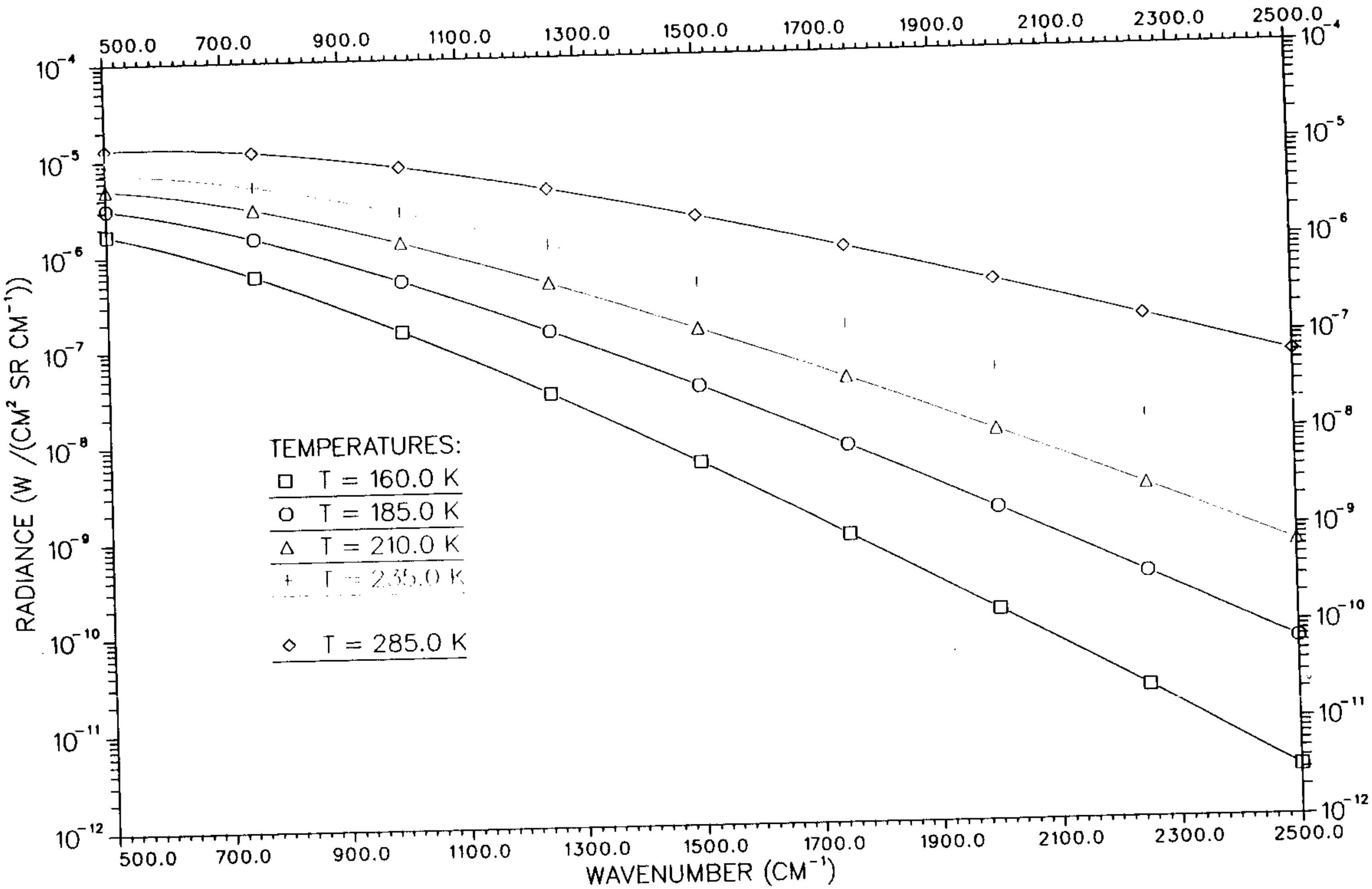


650 1550 cm⁻¹

Figure 1a: Line strengths for all species with absorption bands in the spectral region 650 - 1550 cm^{-1} (Part 1; for details see text).


WAVELENGTH (MICROMETER)
5.88
5.86
5.84
5.82
5.80
H2O, O3, HNO3, CH4 + Exoten
hmin = 25km
Zt = 25 km
Δν = infinites.
Δν = 0.03cm-1
Δν = 0.03 cm-1
Δν = 0.1 cm-1
Δν = 0.1cm-1
Δν = 1 cm-1
Δν = 1.0cm-1
1700
1705
1710
1715
1720
1725
1730
WAVENUMBER (CM-1)

PLANCK – FUNCTION



11 MAY 1992 2:29 PM BY IMK710

H. J. Kramer

Observation of the Earth and Its Environment

Survey of Missions and Sensors

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With 272 Figures and 441 Tables

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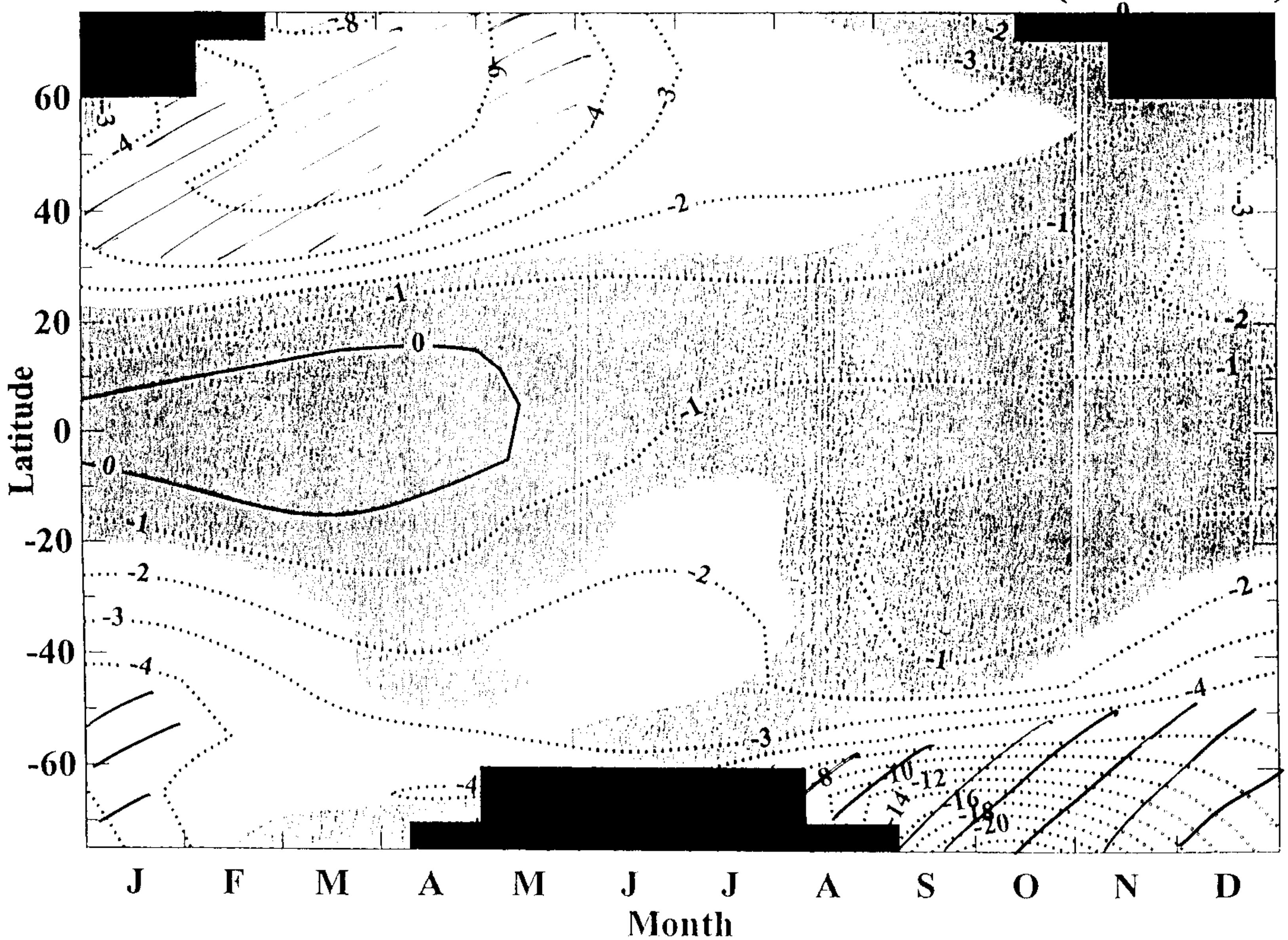
Sensor	S/C or Platform	Spectral Range	Observation Direction	Start of Operation Comments
ATMOS (JPL)	Spacelab-2,-3, ATLAS-1,-2,-3	2.2-16.0 µm	Limb viewing	1985, (2) 92, 93, 94
IASI (CNES/ASI)	METOP-1	3.62-15.5 µm	Nadir viewing	2002
IMG (JAROS)	ADEOS	3.3-14.0 µm	Nadir viewing	1996
MIPAS (KfK)	ENVISAT-1	4.15-14.6 µm	Limb viewing rear-wards and sideways	1999
MIRIAM (Free U. of Berlin)	MIR/Priroda	2.5-20 µm	Limb viewing	1996
SI-GDR	Meteor-P-2,-3,-4	6.25-25 µm	Nadir viewing	1976
SPIRIT-III (Utah State U.)	MSX	2.5-28 µm	Limb viewing	1996, FTS + scanning radiometer
TES (JPL)	CHEM-1,-2, -3 of EOS	2.3-15.4 µm	Limb or nadir viewing	2002

Table 419: Survey of spaceborne Fourier Transform Spectrometer (FTS) instruments

+ non - FTS e.g. : CLAES, CRISTA

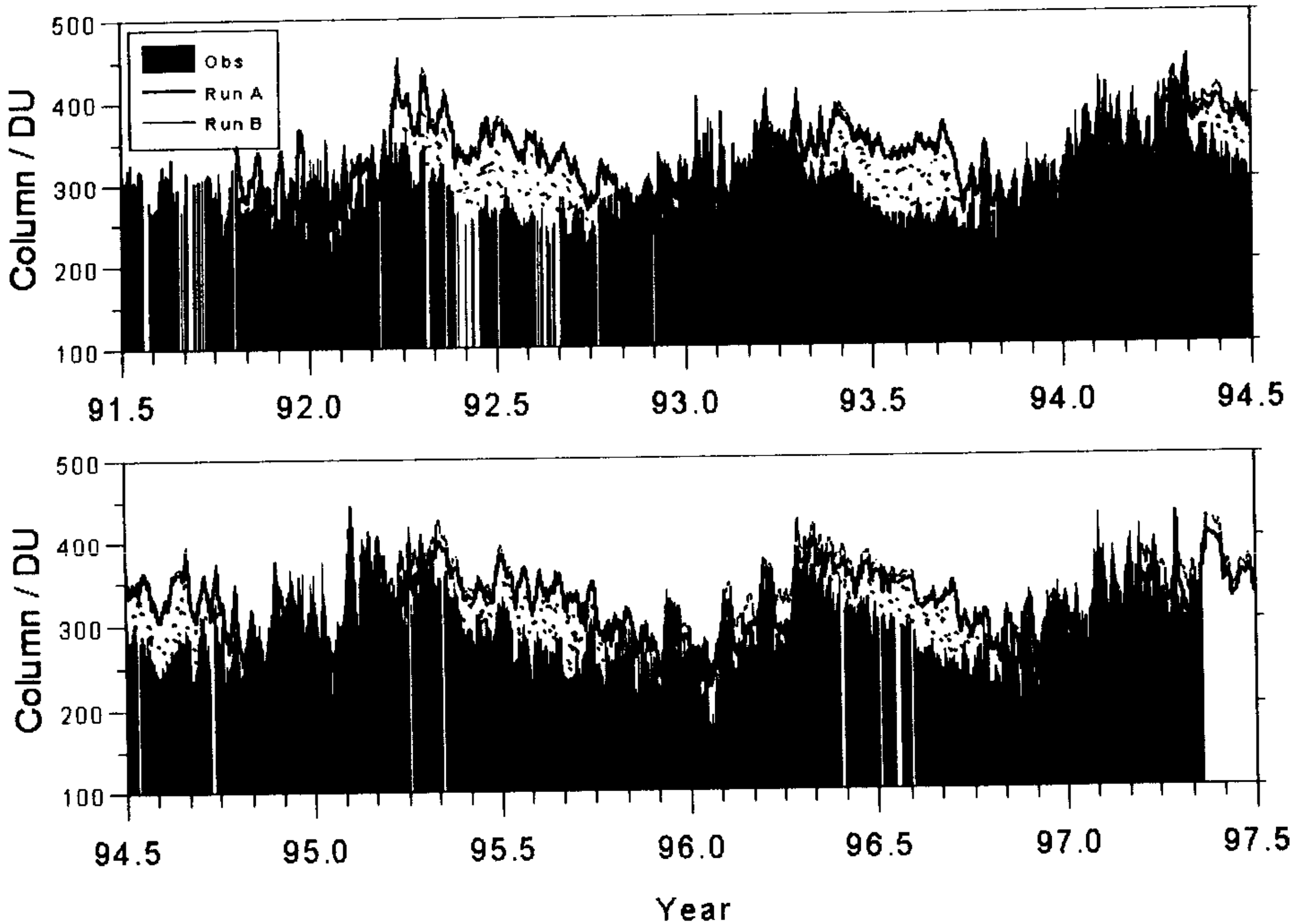
N7/M3 TOMS V7 Total Ozone Trend 11/78-10/94 (%/Decade)



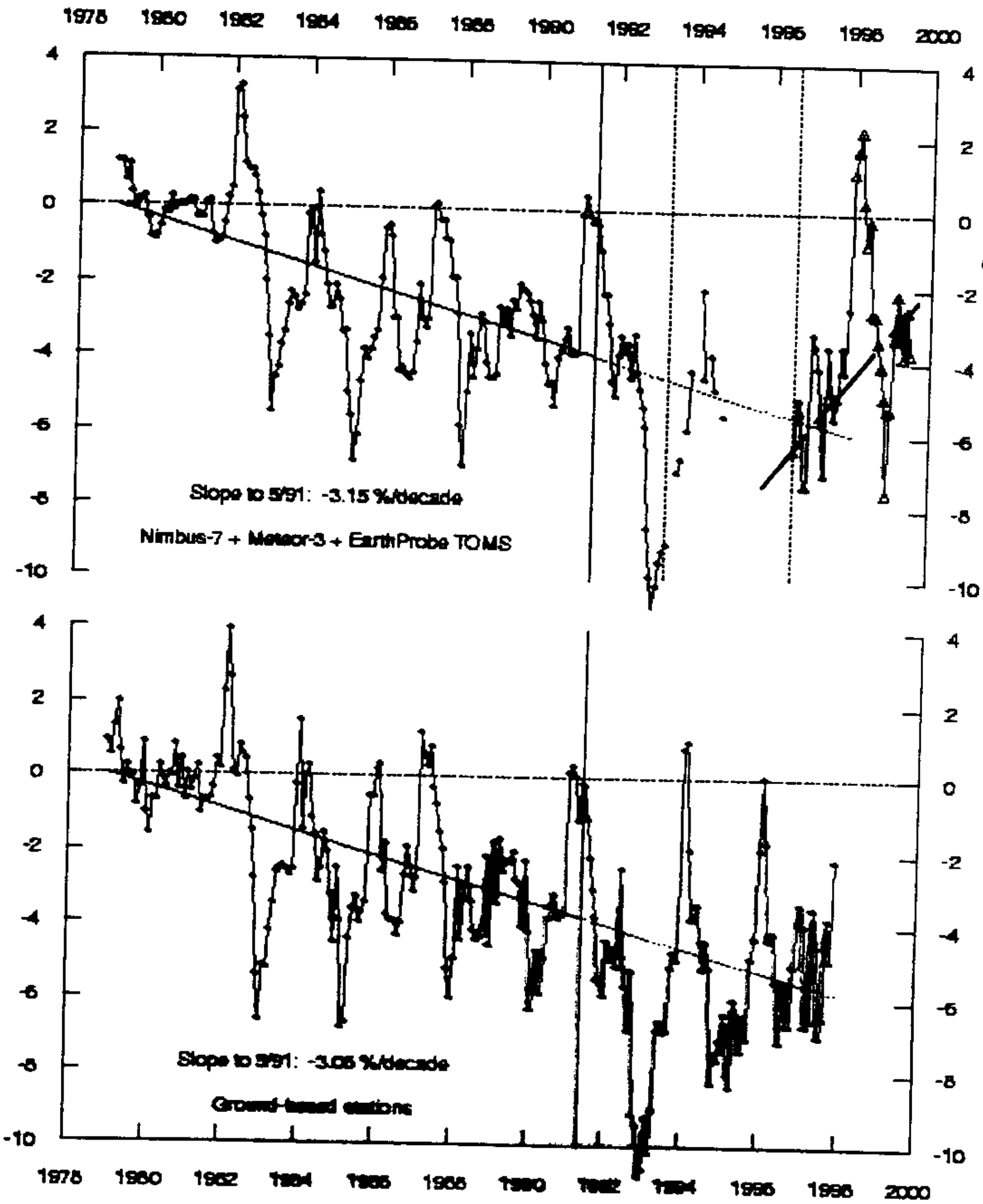
S. M. Hollandsworth

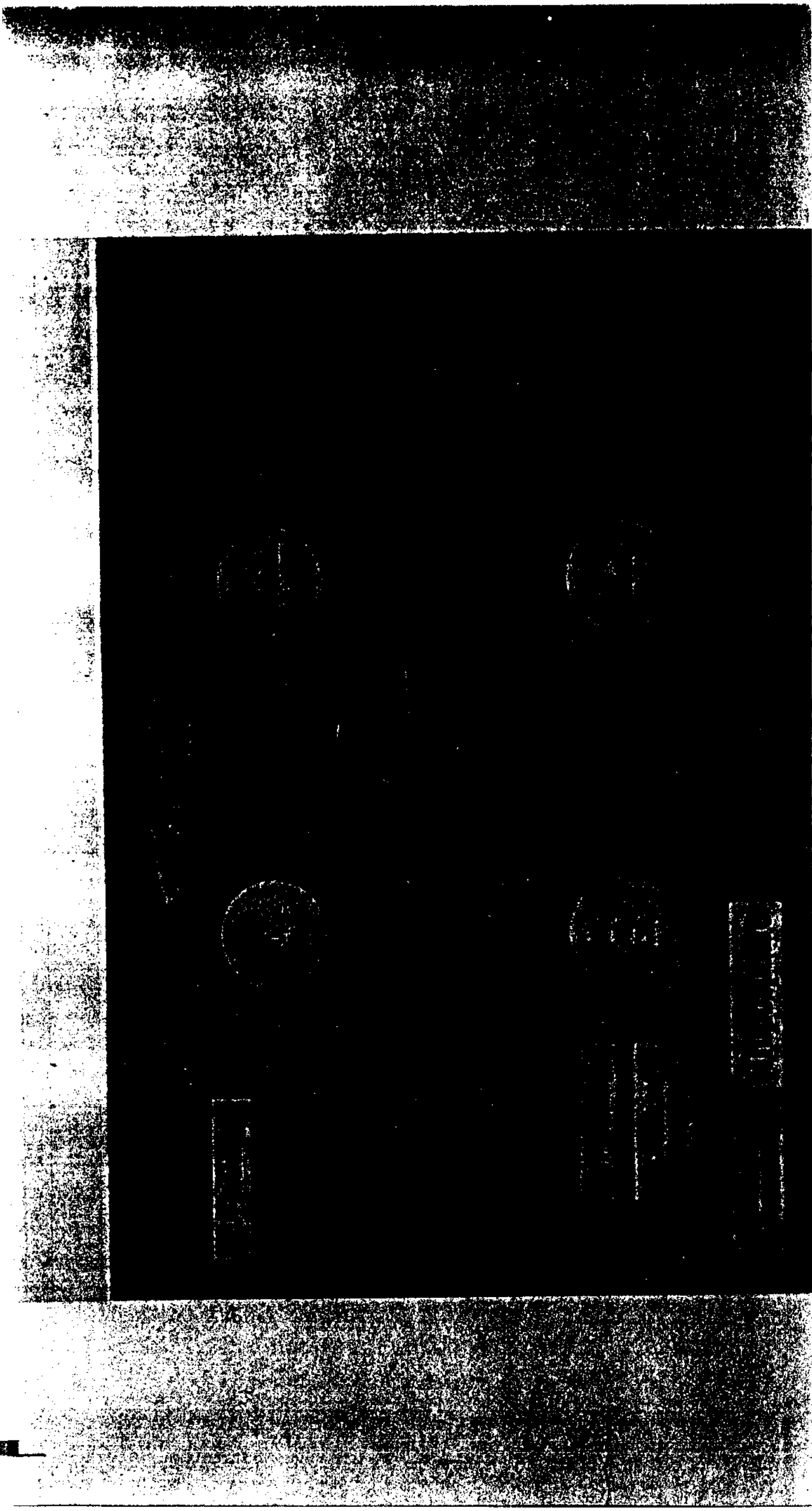
Geophys. Res. Lett., **23**, 3699-3702, 1996

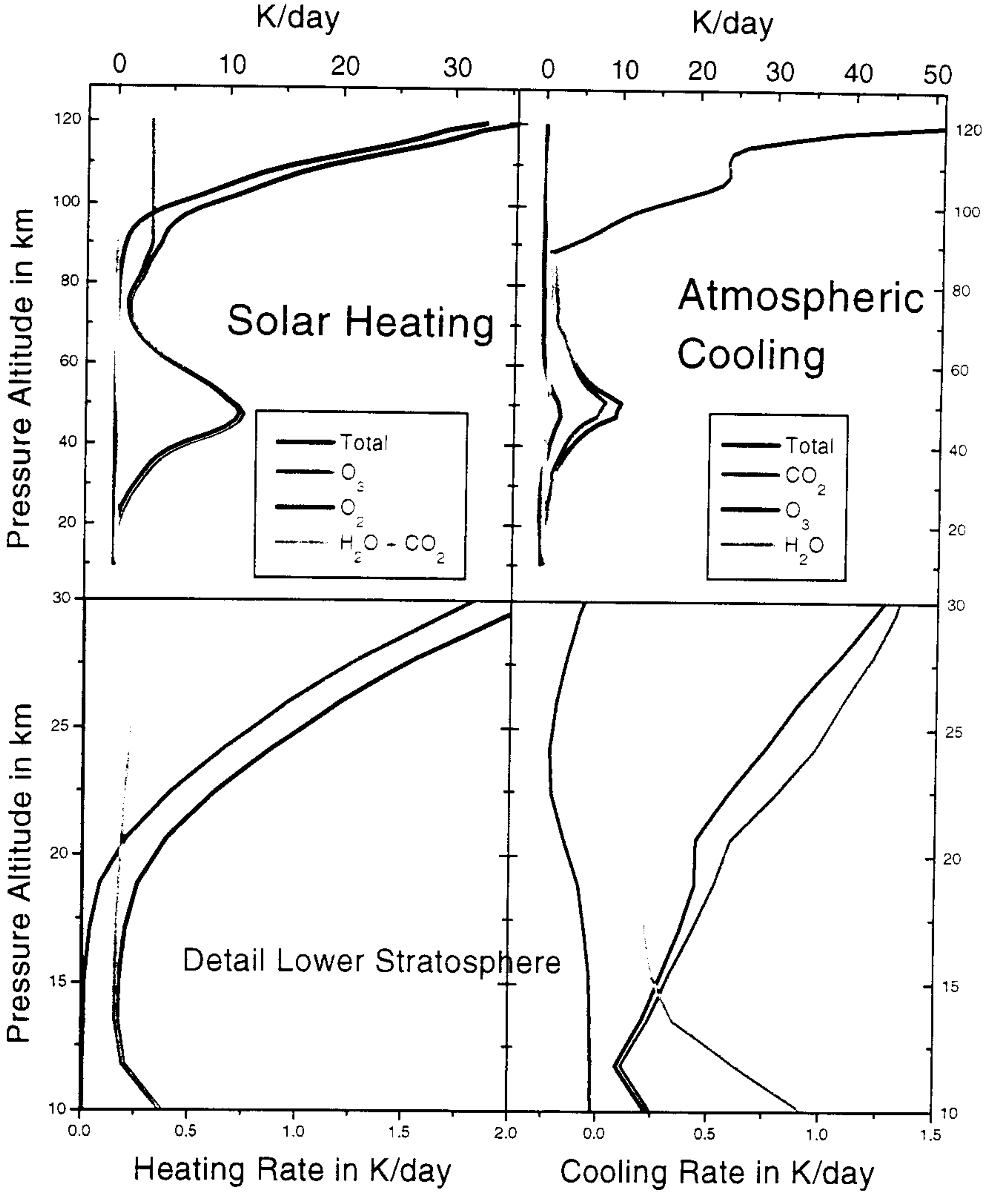
Sodankyla (67N, 26E)



25°N - 60°N Total Ozone Adjusted for Seasonal Effects Only

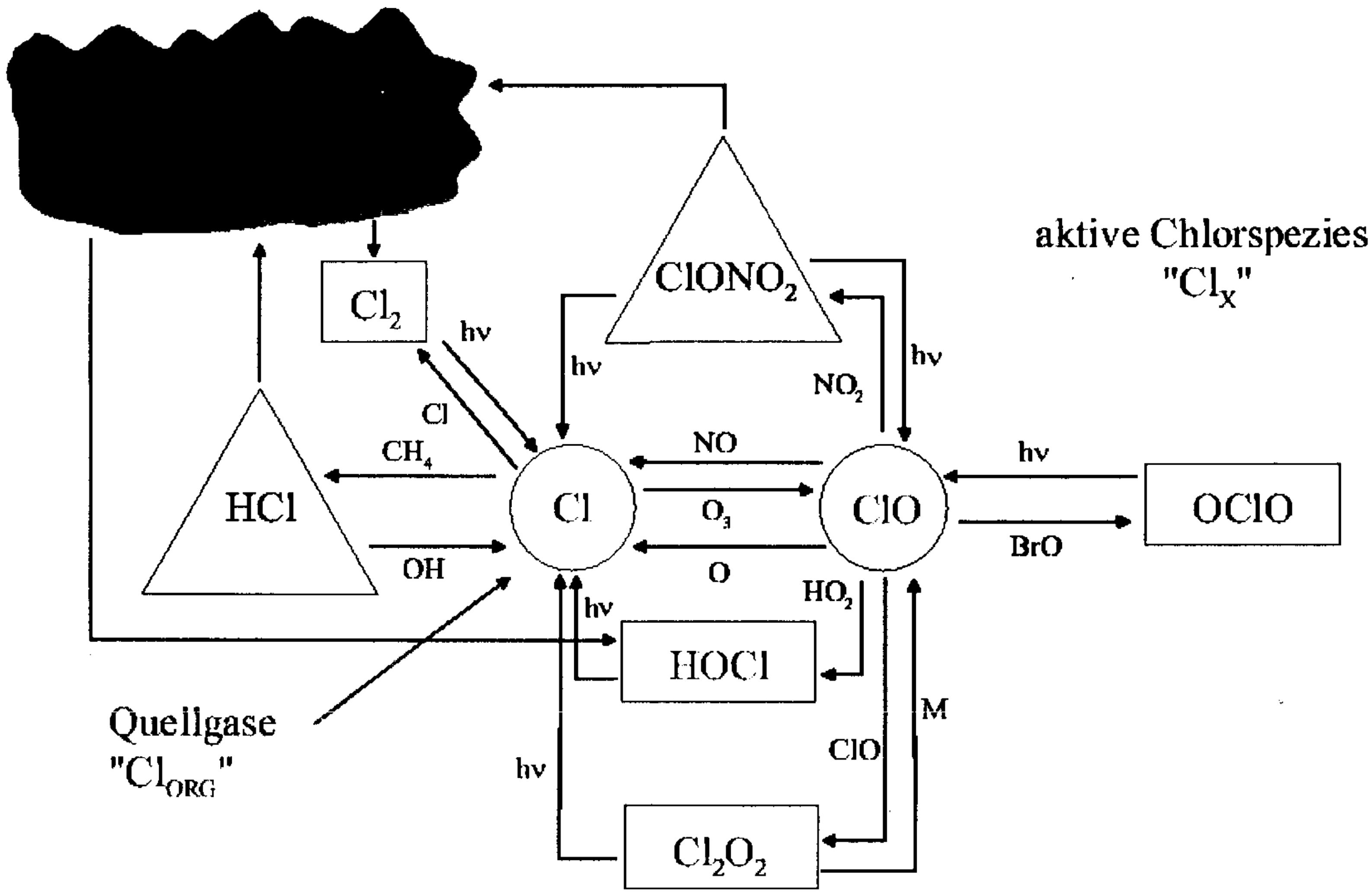






US-Std.-Temp.+ O_3, $\theta = 23°$. Solar heating daily mean.

Anorganische Chlorspezies, "Cly":



JMO'96

OZONABBAU DURCH NO_x-ZYKLUS

40° N background aerosol

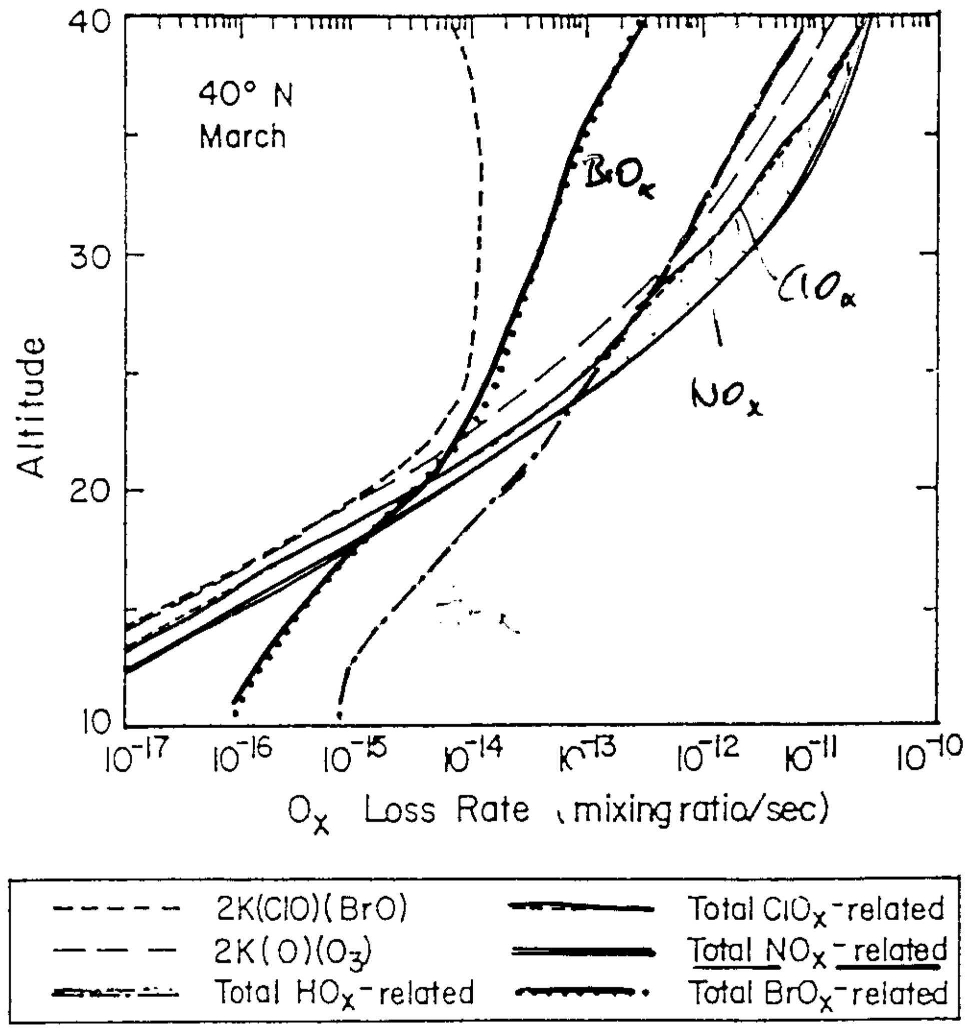
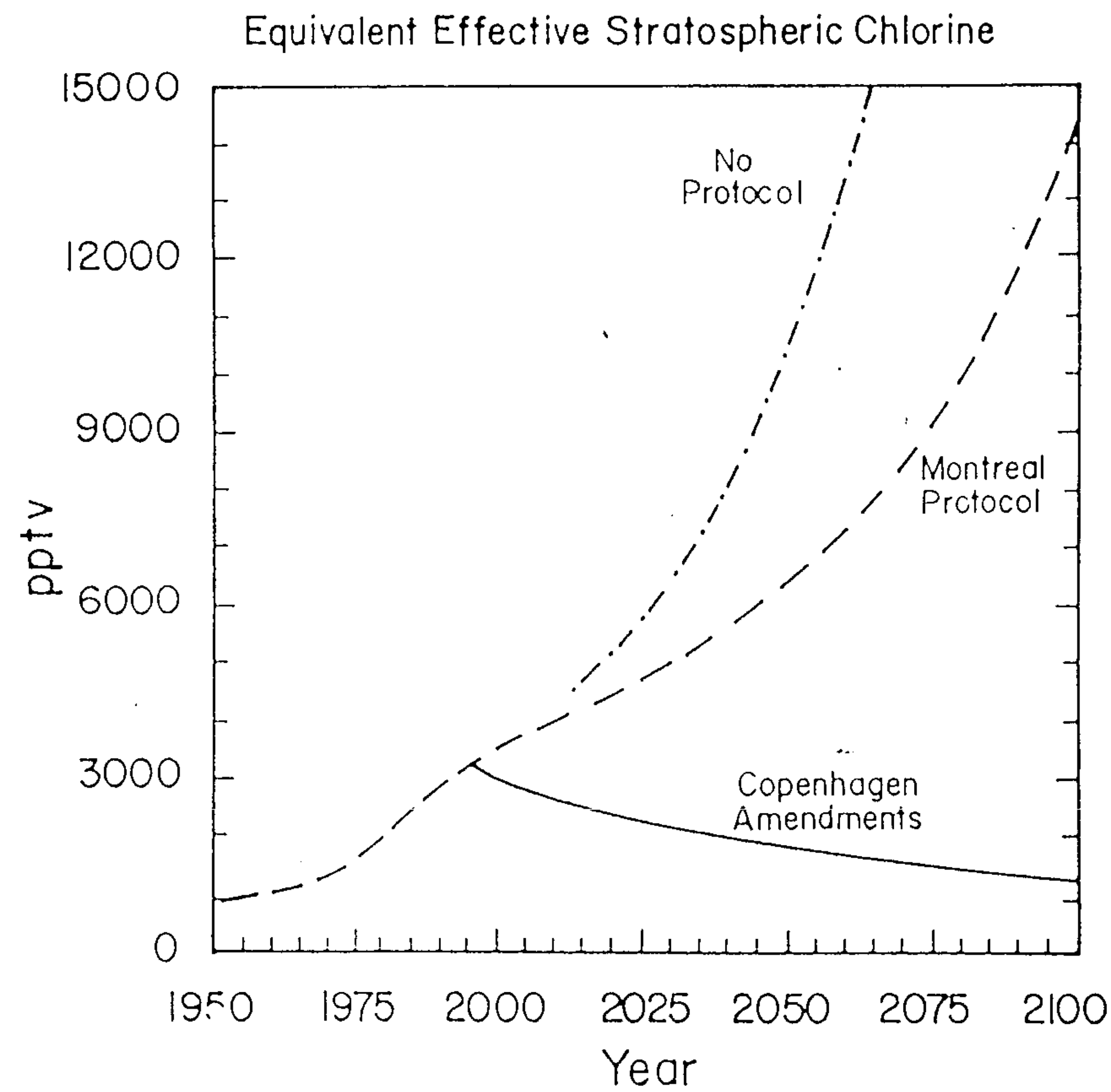
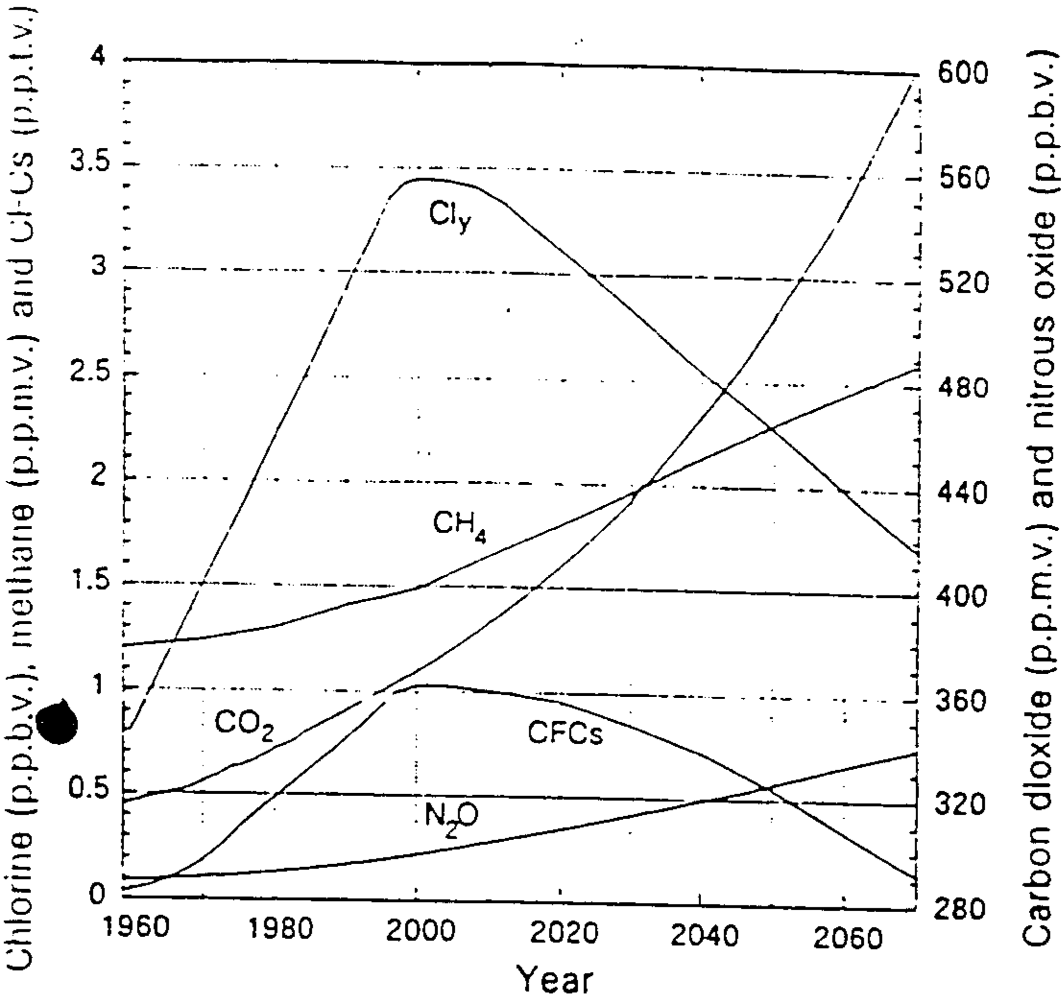


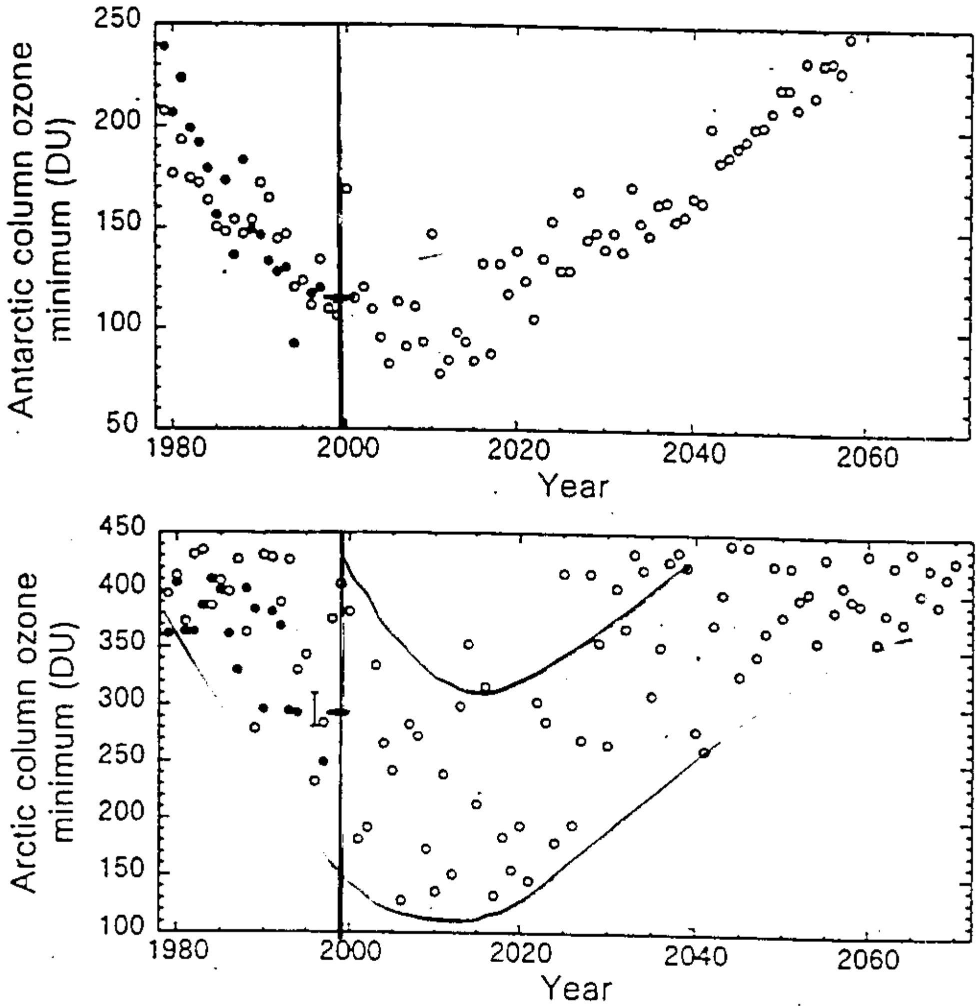
Figure 4-11. Calculated 24-hour averaged O_x loss rates (mixing ratio/sec) from various chemical cycles for 40°N in March for low (*i.e.,* non-volcanic) sulfate aerosol loa 'ing. In these circumstances the dominant ozone loss below 22 km is due to reactions involving OH and HO_2, with NO_x dominating between 23 and 40 km. Under higher aerosol loading conditions, coupled HO_x - halogen cycles become more significant. (From Garcia and Solomon, 1994.)


Equivalent Effective Stratospheric Chlorine
pptv
15000
12000
9000
6000
3000
0
1950
1975
2000
2025
2050
2075
2100
Year
No Protocol
Montreal Protocol
Copenhagen Amendments

27



-e 1 Emission trends for CO_2, N_2O, CH_4, CFCs and chlorine (Cl_y) used as to the model runs. Projected lower stratospheric chlorine loading (indepen- of height or latitude) is based on the trend derived from the 1992 Copenha- -evisions to the 1987 Montreal Protocol on Substances that Deplete the ie Layer[1], normalized slightly upwards and decreasing more slowly in the e to match recent observations[12,13,30]. Greenhouse-gas emissions are based oservations to the end of 1984, and subsequently are similar to, though for on dioxide slightly lower than, the 1992 International Panel on Climate ige (IPCC) preferred scenario IS92a[25]. The exception is CFCs, for which a dy reduction after 2000 has been assumed, consistent with their expected e-out and with the chlorine loading scenario.



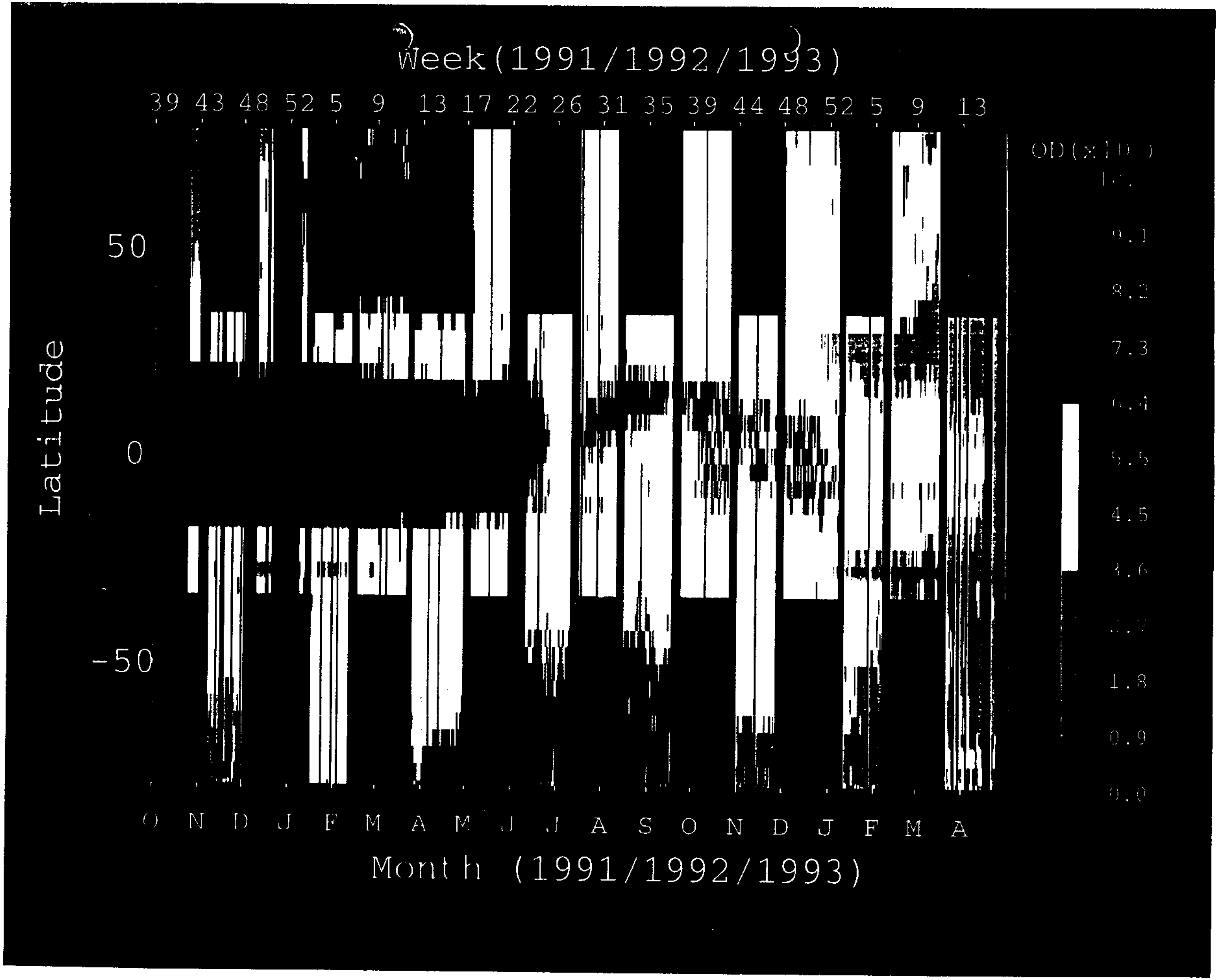
Arctic

Figure 4 Total column ozone minima in the polar regions during spring. The top panel shows minimum ozone (DU) south of 65° averaged over the last three days of September (except for 1993, for which 23–25 September was used), as seen in TOMS version 7 data (filled circles), and in the model (open circles). Similarly, the bottom panel shows minimum column ozone north of 65°, averaged over the last three days of March, as seen in TOMS data and in the model. Model values do not include intrusions of low-ozone air from lower latitudes into the Arctic, so they tend to be on the high side of observed values. The bar shown for 1996 is an estimate for that year derived from chemical column depletions of 120–160 DU with respect to a climatological mean of 435 DU, calculated based on Halogen Occultation Experiment observations[7].

aus Shindell et al. (1998)

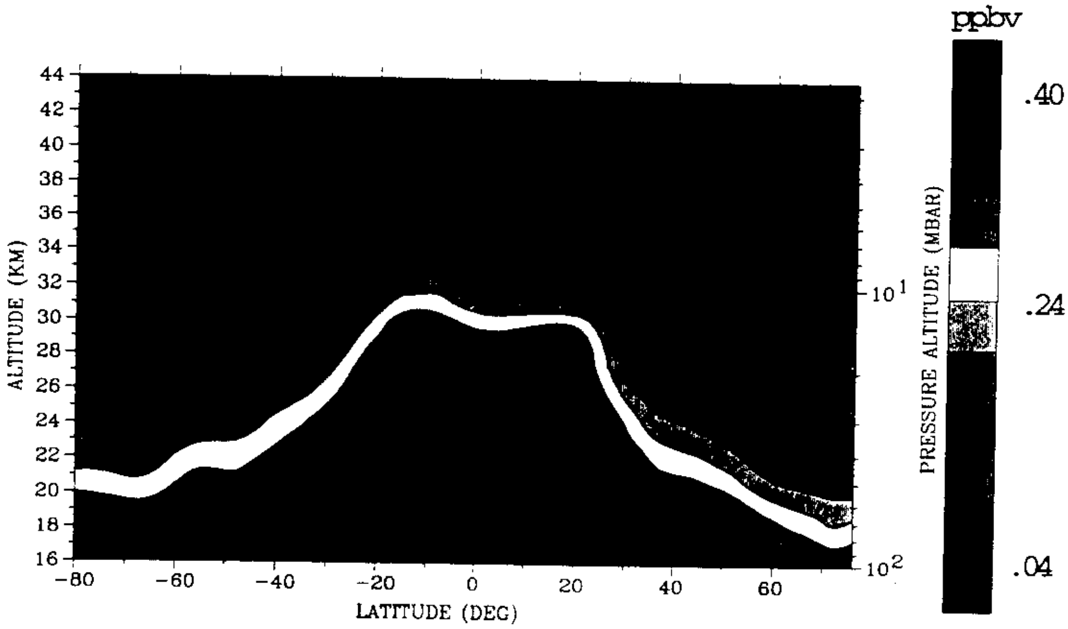
TABLE 1. Scientific Payload of the UARS

Instrument	*Technique*	*Measurement*	*Investigator*
SOLSTICE (Solar-Stellar Irradiance Comparison Experiment)	full-disk solar irradiance spectrometer incorporating stellar comparisons for onboard sensitivity tracking	solar UV spectral (1 nm) irradiance from 420 to 120 nm	G. J. Rottman, University of Colorado
SUSIM (Solar Ultraviolet Spectral Irradiance Monitor)	full-disk solar irradiance spectrometer incorporating onboard sensitivity tracking using D_2 lamps and redundant optical elements	solar UV spectral (1 nm) irradiance from 410 to 120 nm	G. E. Brueckner, Naval Research Laboratory
ACRIM (Active Cavity Radiometer Irradiance Monitor)	full-disk solar total irradiance cavity radiometers	solar total (spectrally integrated) irradiance	R. C. Willson, Columbia University
PEM (Particle Environment Monitor)	X ray, proton, and electron spectrometers	energetic particle flux, X ray flux, and magnetic field	J. D. Winningham, Southwest Research Institute
CLAES (Cryogenic Limb Array Etalon Spectrometer)	solid-cryogen cooled interferometer sensing atmospheric infrared emissions	T, O_3, $ClONO_2$, N_2O, CH_4, N_2O_5, HNO_3, H_2O, $CFCl_3$, CF_2Cl_2, aerosols	A. E. Roche, Lockheed Palo Alto Research Laboratory
ISAMS (Improved Stratospheric and Mesospheric Sounder)	mechanically cooled radiometer sensing atmospheric infrared emissions	T, O_3, CO, HNO_3, NO, NO_2, N_2O, H_2O, N_2O_5, HNO_3	F. W. Taylor, University of Oxford, England
HALOE (Halogen Occultation Experiment)	gas filter/radiometer sensing atmospheric absorption of sunlight	T, O_3, HCl, HF, NO, NO_2, CH_4, H_2O, aerosol	J. M. Russell III, Hampton University
MLS (Microwave Limb Sounder)	microwave radiometer	T, O_3, ClO, H_2O, SO_2, HNO_3	J. W. Waters, Jet Propulsion Laboratory
HRDI (High-Resolution Doppler Imager)	Fabry-Perot spectrometer sensing atmospheric emission scattering and absorption	mesospheric winds, O_3, T, and stratospheric winds	P. B. Hays, University of Michigan
WINDII (Wind Imaging	Michelson interferometer sensing atmospheric airglow emission	mesospheric winds	G. G. Shepherd, York University

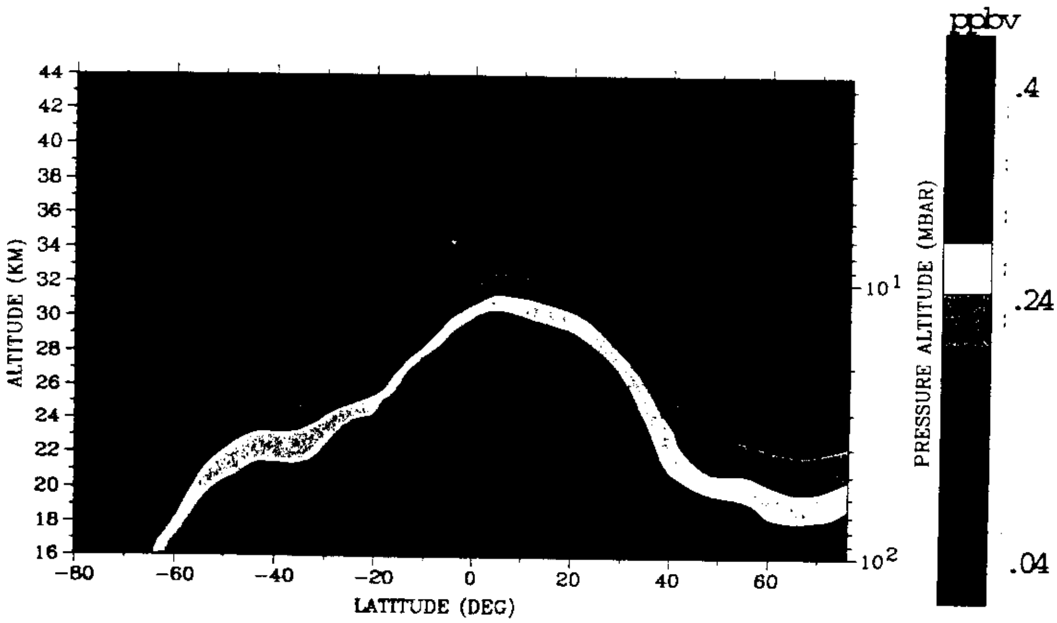

Week (1991/1992/1993)
39 43 48 52 5 9 13 17 22 26 31 35 39 44 48 52 5 9 13
Latitude
50
0
-50
O N D J F M A M J J A S O N D J F M A
Month (1991/1992/1993)
9.1
8.2
7.3
5.5
4.5
1.8
0.9
0.0

CLAES: Global Stratospheric CF2C12

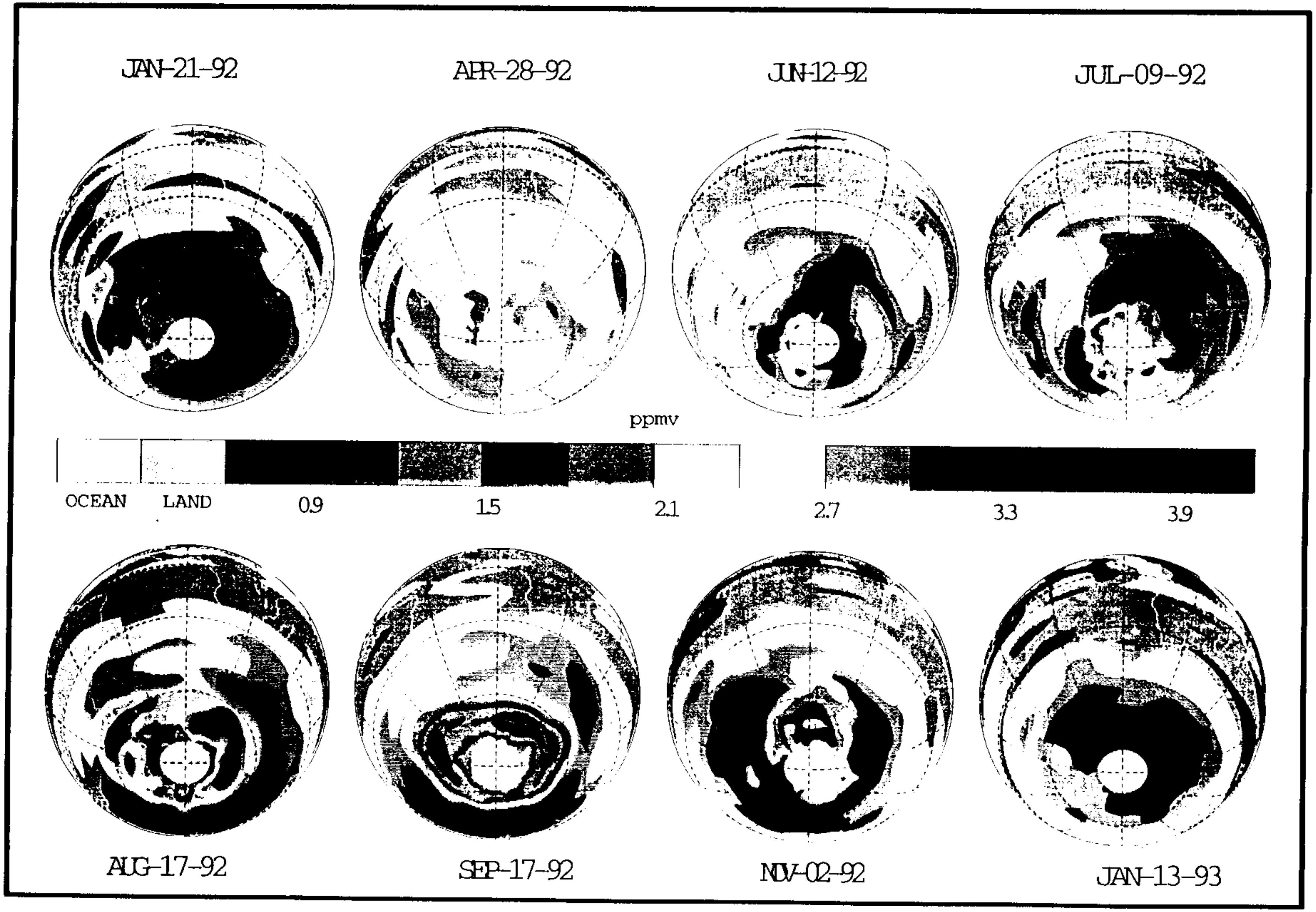
Combined Mar-20/27-1992



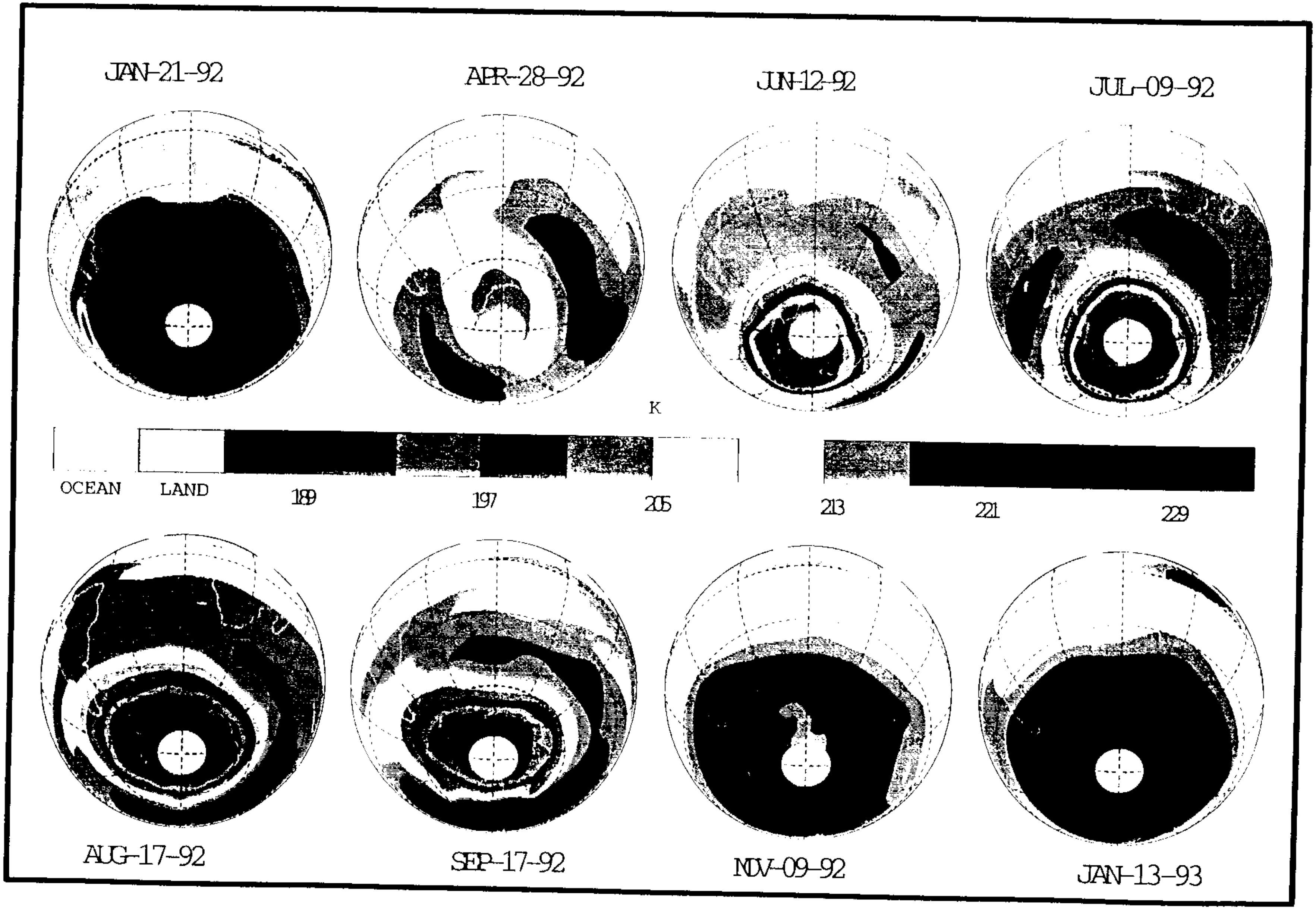
Combined Sep-17/25-1992

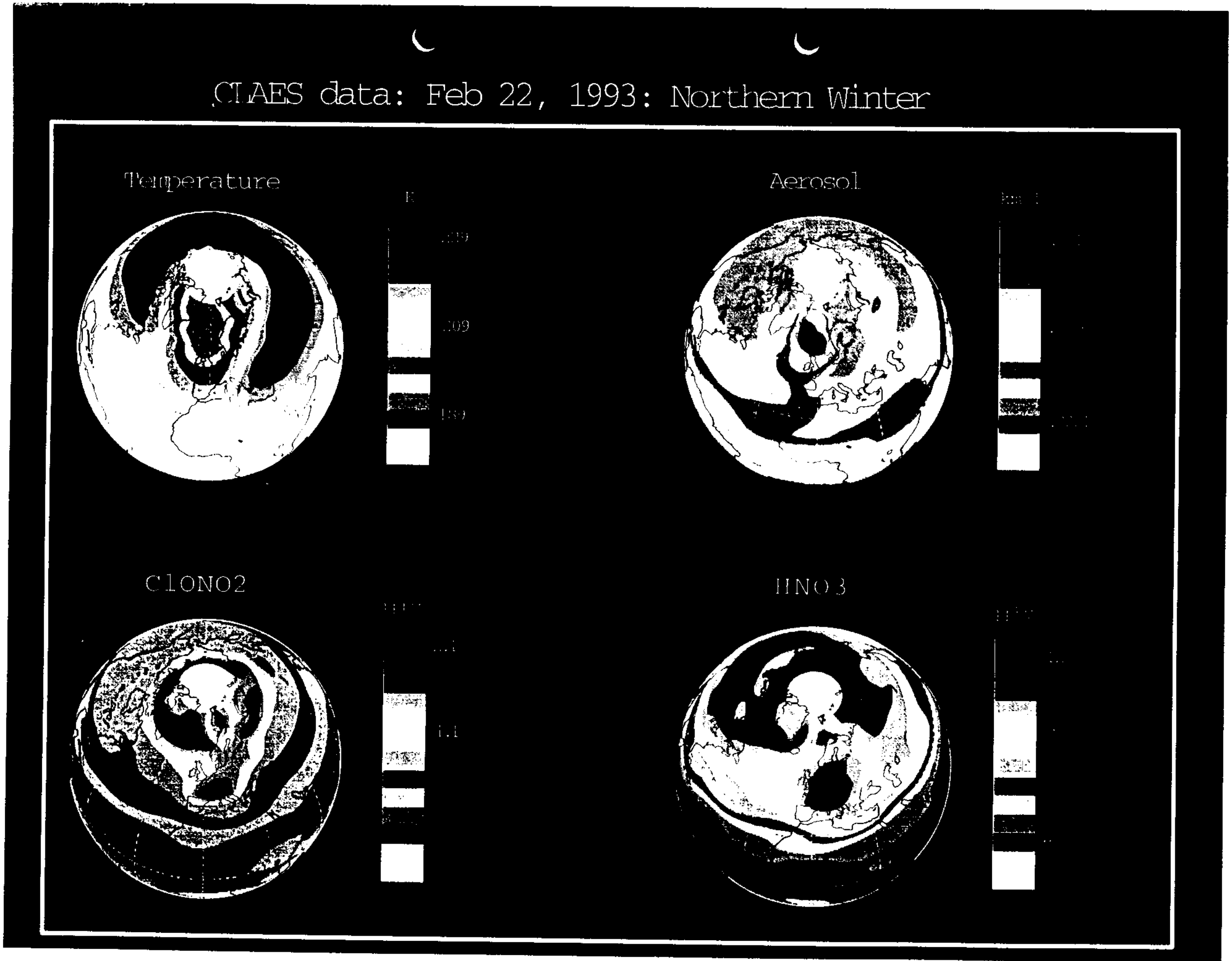


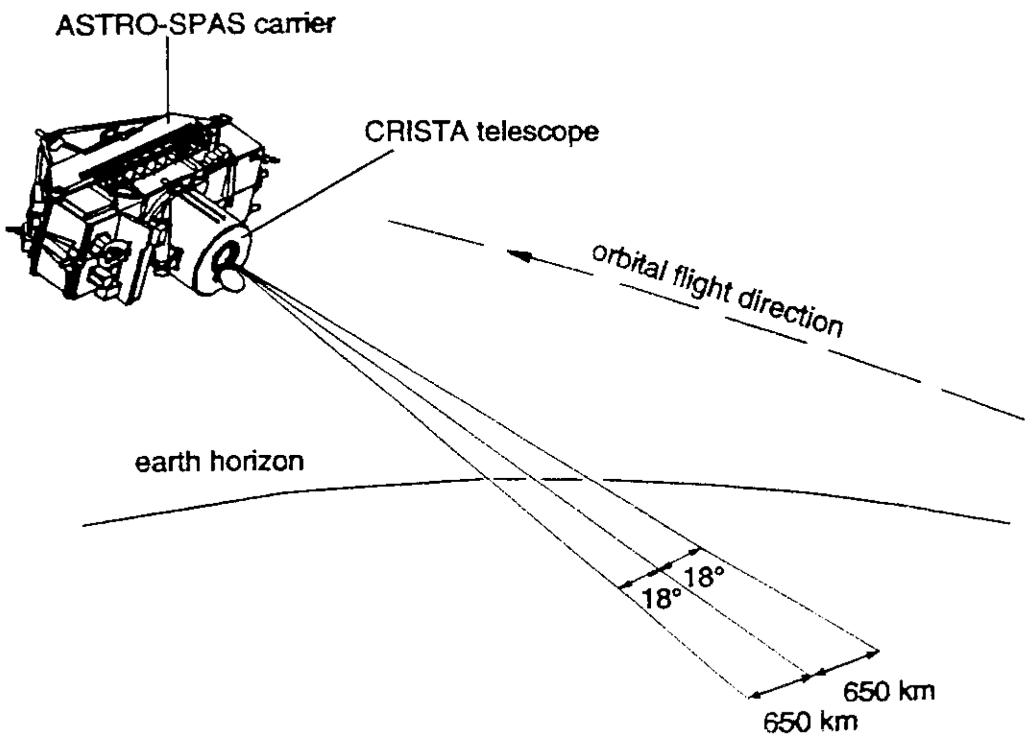
CLAES O3 at 21 km: SH

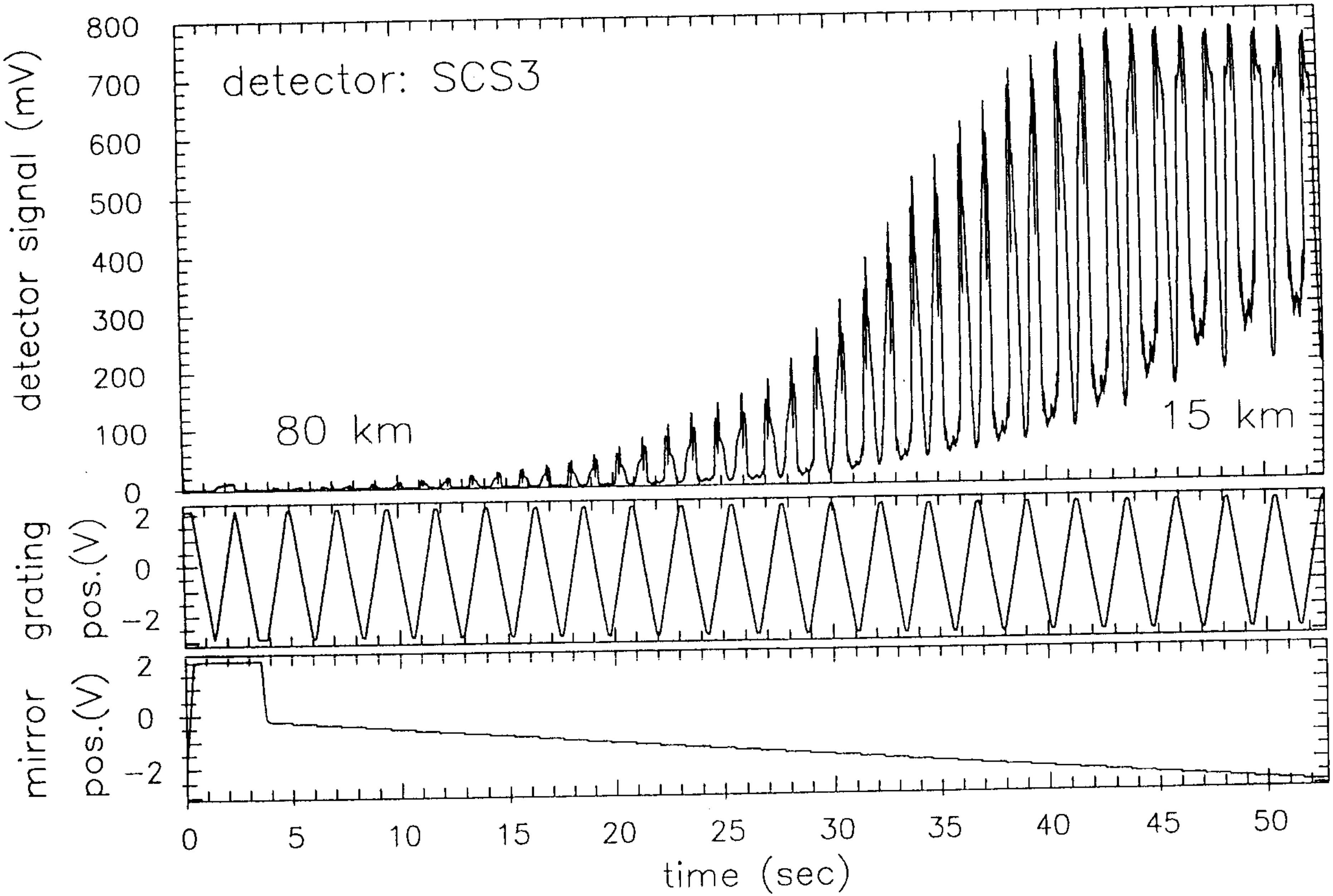


CLAES Temperature at 21 km: SH



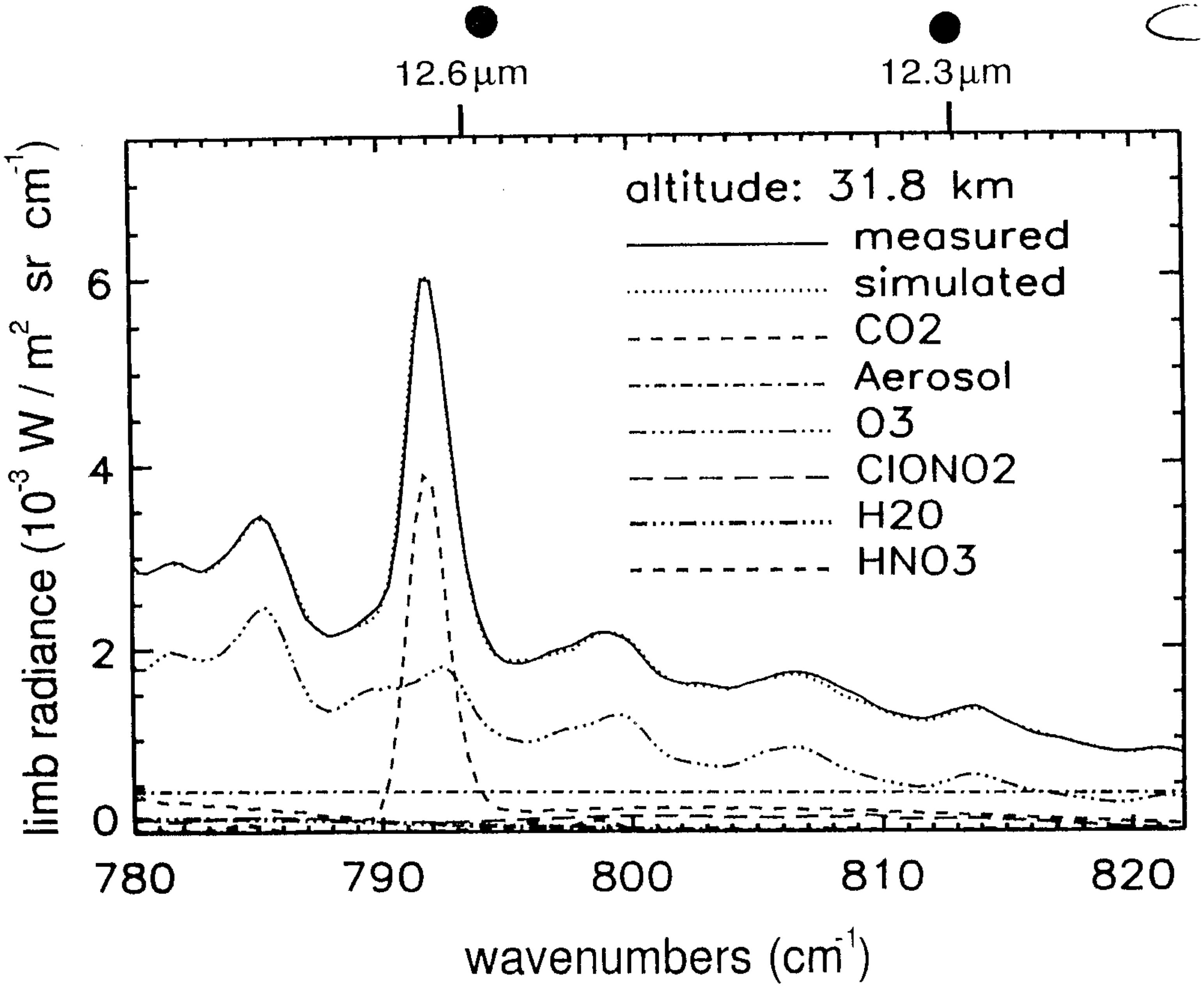

CLAES data: Feb 22, 1993: Northern Winter
Temperature
K
Aerosol
ClONO2
HNO3


ASTRO-SPAS carrier
CRISTA telescope
orbital flight direction
earth horizon
18°
18°
650 km
650 km

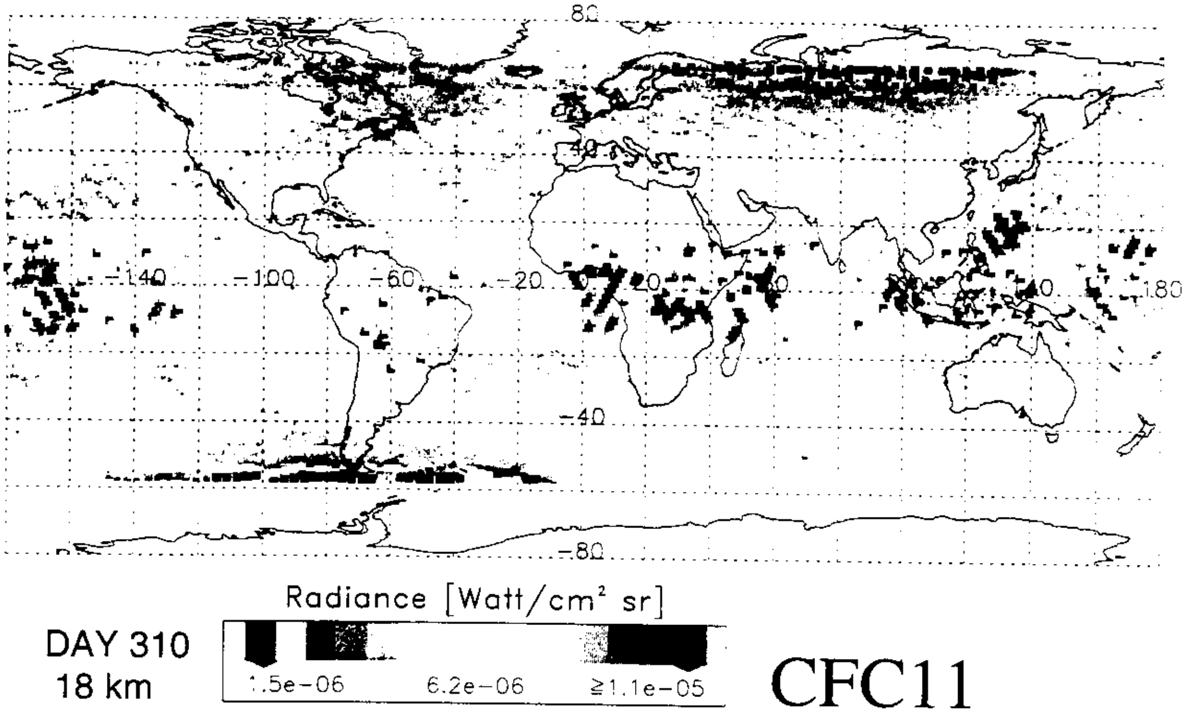


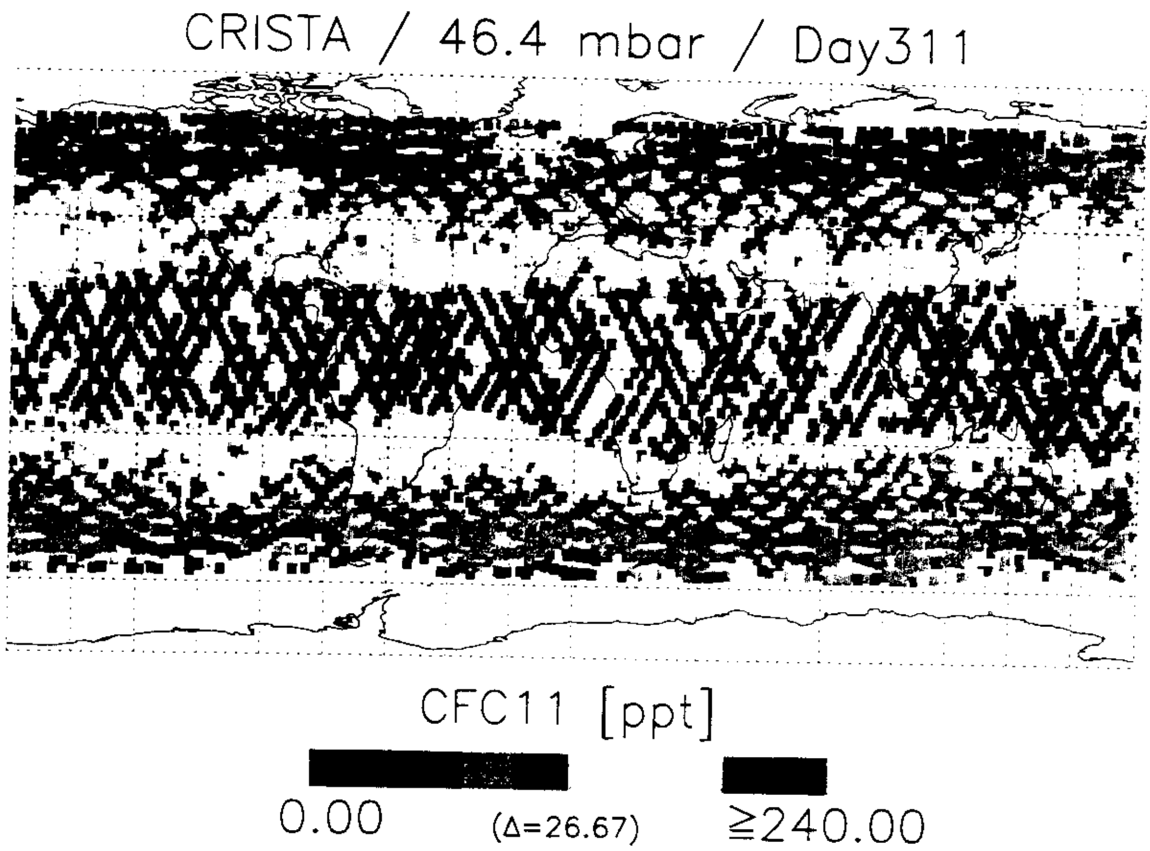
detector: SCS3
80 km
15 km
detector signal (mV)
800
700
600
500
400
300
200
100
0
grating pos.(V)
2
0
−2
mirror pos.(V)
2
0
−2
0
5
10
15
20
25
30
35
40
45
50
time (sec)

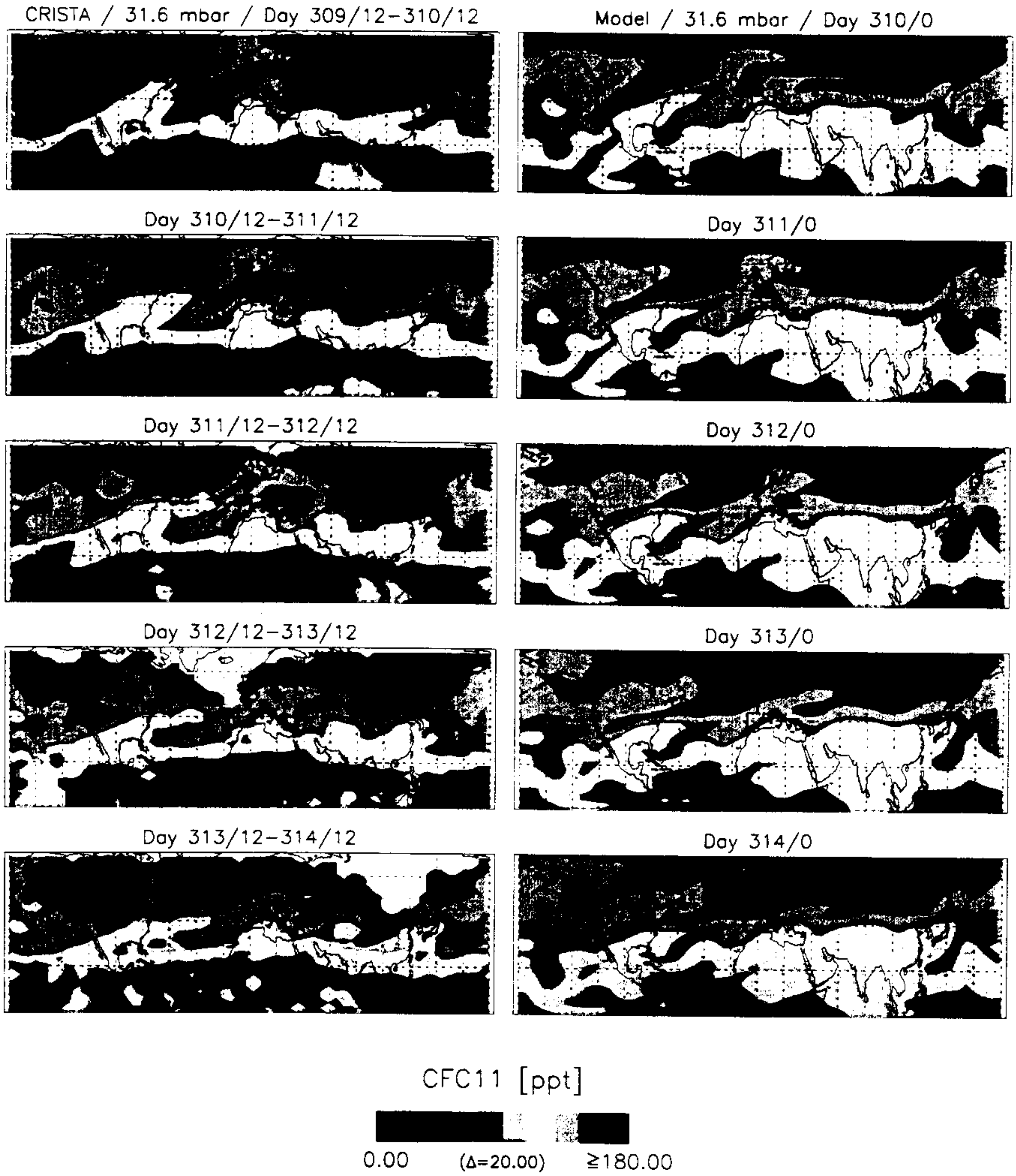
CHRISTA



spectral resolution: ~ 2cm⁻¹


80
40
-140
-100
-60
-20
180
-40
-80
Radiance [Watt/cm² sr]
DAY 310
18 km
1.5e-06
6.2e-06
≥1.1e-05
CFC11


CRISTA / 46.4 mbar / Day311
CFC11 [ppt]
0.00
(Δ=26.67)
≧240.00


CRISTA / 31.6 mbar / Day 309/12-310/12
Model / 31.6 mbar / Day 310/0
Day 310/12-311/12
Day 311/0
Day 311/12-312/12
Day 312/0
Day 312/12-313/12
Day 313/0
Day 313/12-314/12
Day 314/0
CFC11 [ppt]
0.00
(Δ=20.00)
≧180.00

LECTURE # 2

MIPAS

MEASUREMENT OBJECTIVES → REQUIREMENTS

Atmospheric trace constituents

MEASUREMENT OBJECTIVES	REQUIREMENTS
simultaneously	Fourier Transform Spectrometer (FTS)
many species	high spectral resolution, broadband coverage, mid IR
detecting the unexpected	FTS
day- and nighttime (diurnal cycles)	emission mode
high sensitivity	limb sounding (instrument cooling, detectors, pointing system)
high vertical resolution	limb sounding (telescope)

MIPAS PROJECT

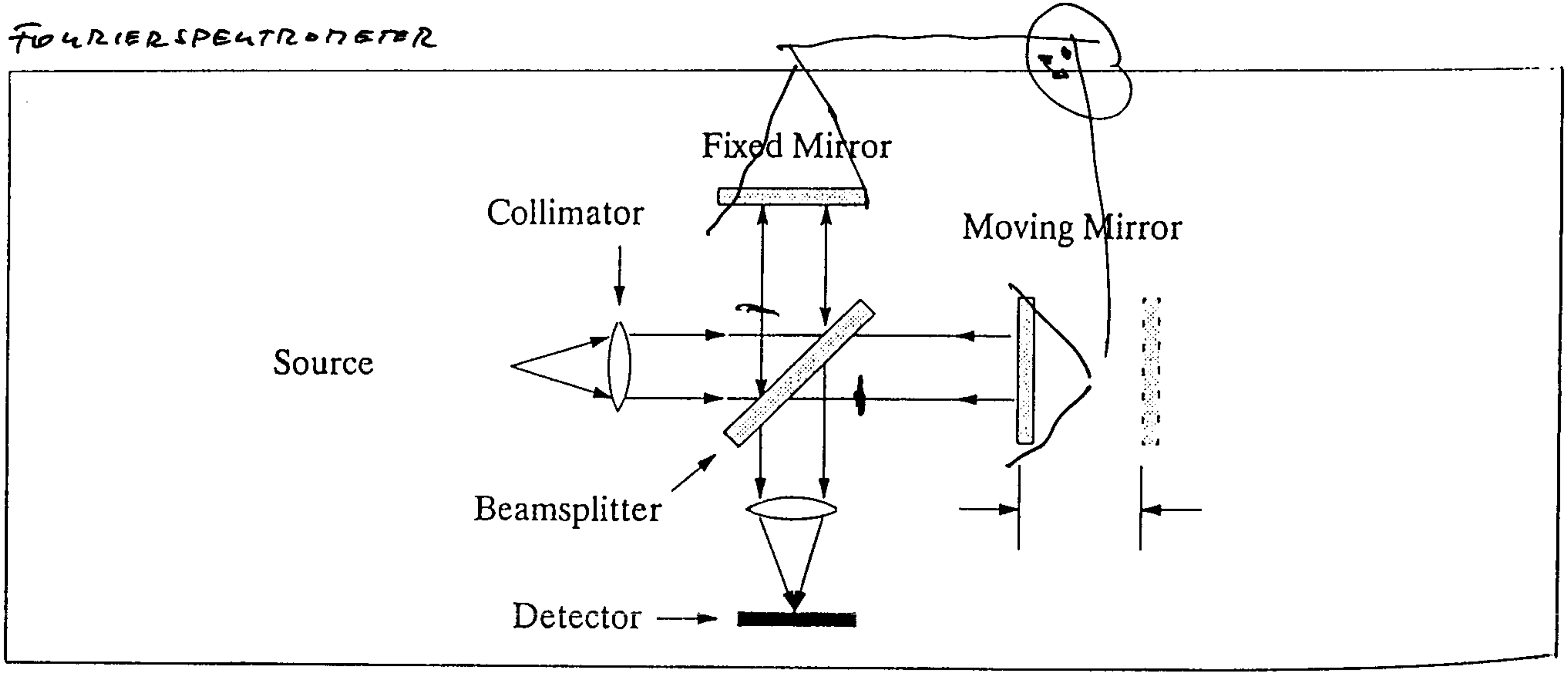
MIPAS Michelson Interferometer for Passive Atmospheric Sounding

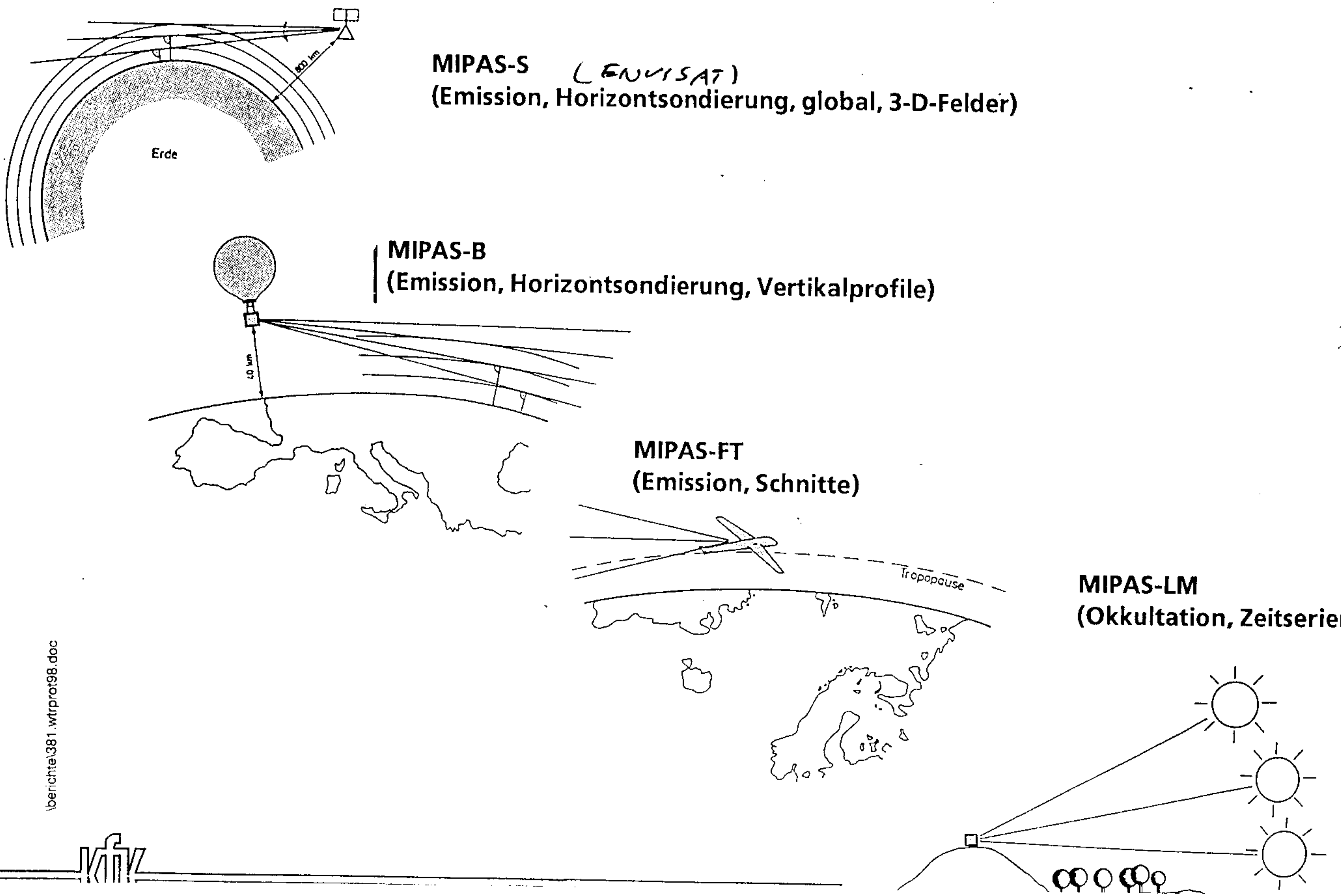
Simultaneous detection of more than 20 trace gases

Ground-based measurements:	Kiruna: 1990-1993	**MIPAS-LM**
Balloon-borne measurements:	4 flights 1989-1992 (MIPAS-B1) 2 flights 1995 (MIPAS-B2) 3 flights 1997 (MIPAS-B2) 1 flight 1998 (MIPAS-B2) 2 flights 1999 "	**MIPAS-B**
Airborne measurements:	Transall 1991-1995 Geophysica-instrument in ~~construction~~ successfully flown	**MIPAS-FT** **MIPAS-STR**
Satellite experiment:	European Space Agency ESA ENVISAT 2000, phase C/D	**MIPAS-S**

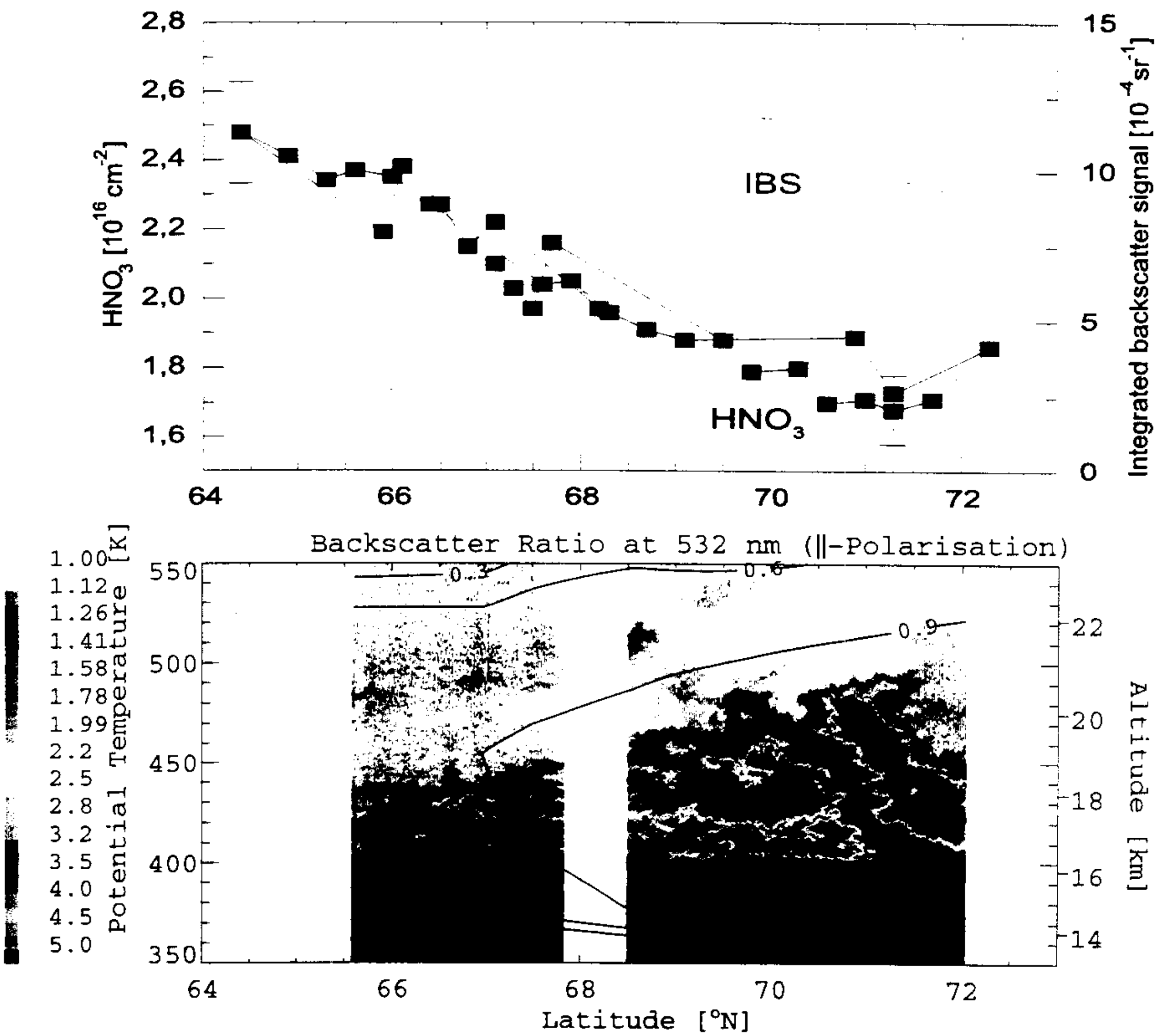
47

FOURIERSPEKTROMETER




MIPAS-S (ENVISAT)
(Emission, Horizontsondierung, global, 3-D-Felder)
800 km
Erde
MIPAS-B
(Emission, Horizontsondierung, Vertikalprofile)
40 km
MIPAS-FT
(Emission, Schnitte)
Tropopause
MIPAS-LM
(Okkultation, Zeitserien)

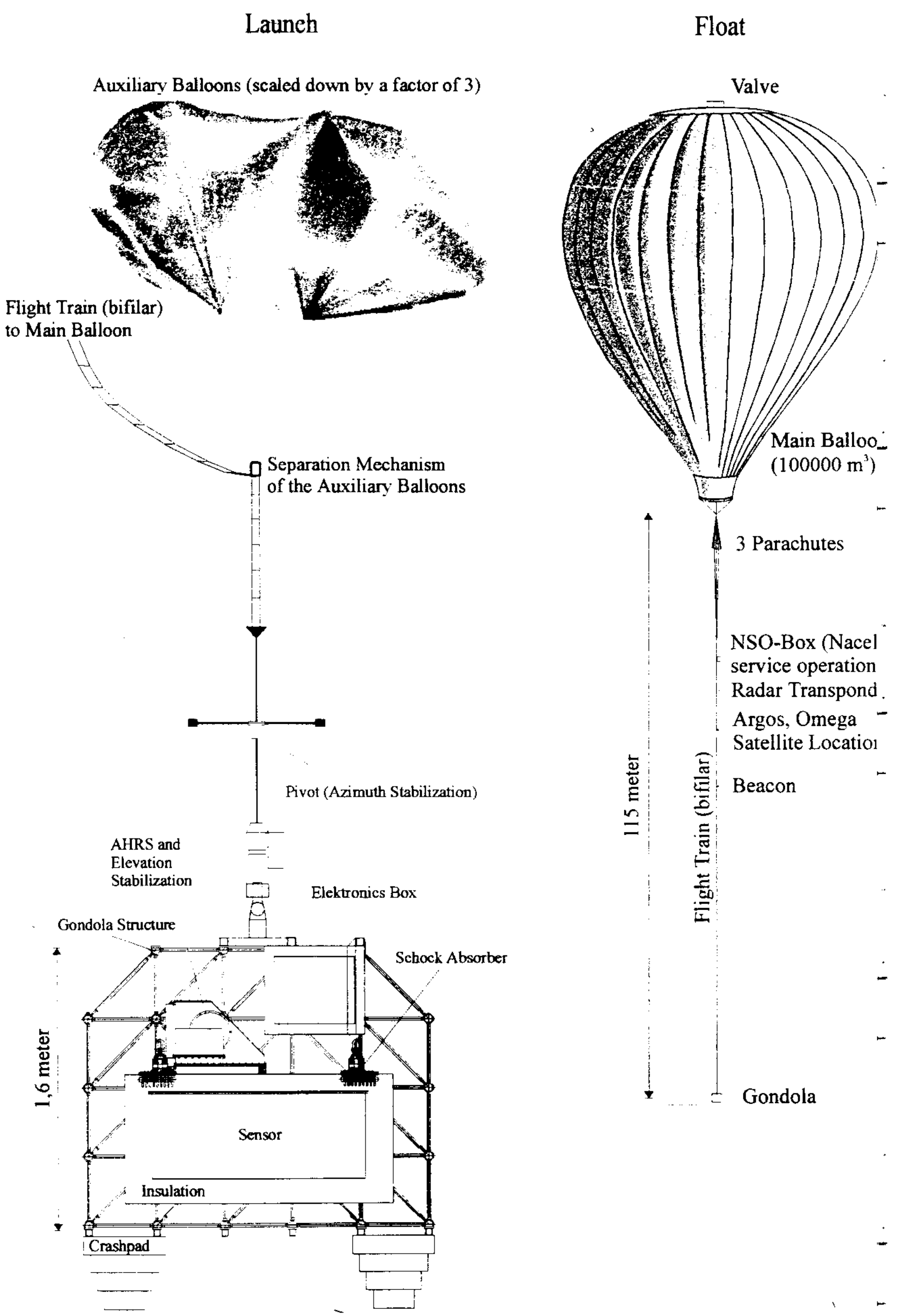
4 r



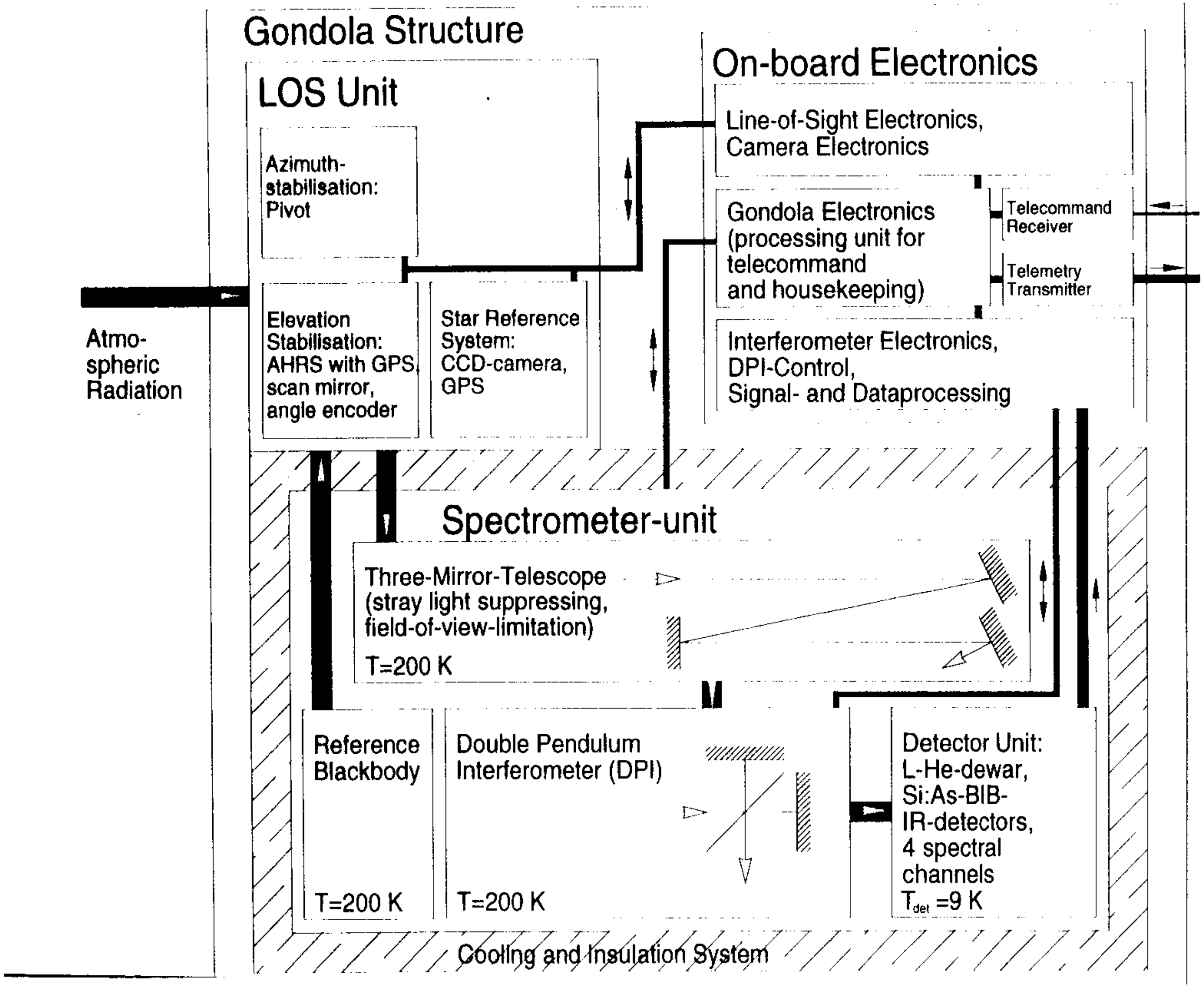
Höpfner et al., JGR, 1996

DESIGN DRIVERS & INSTRUMENT SPECIFICATIONS

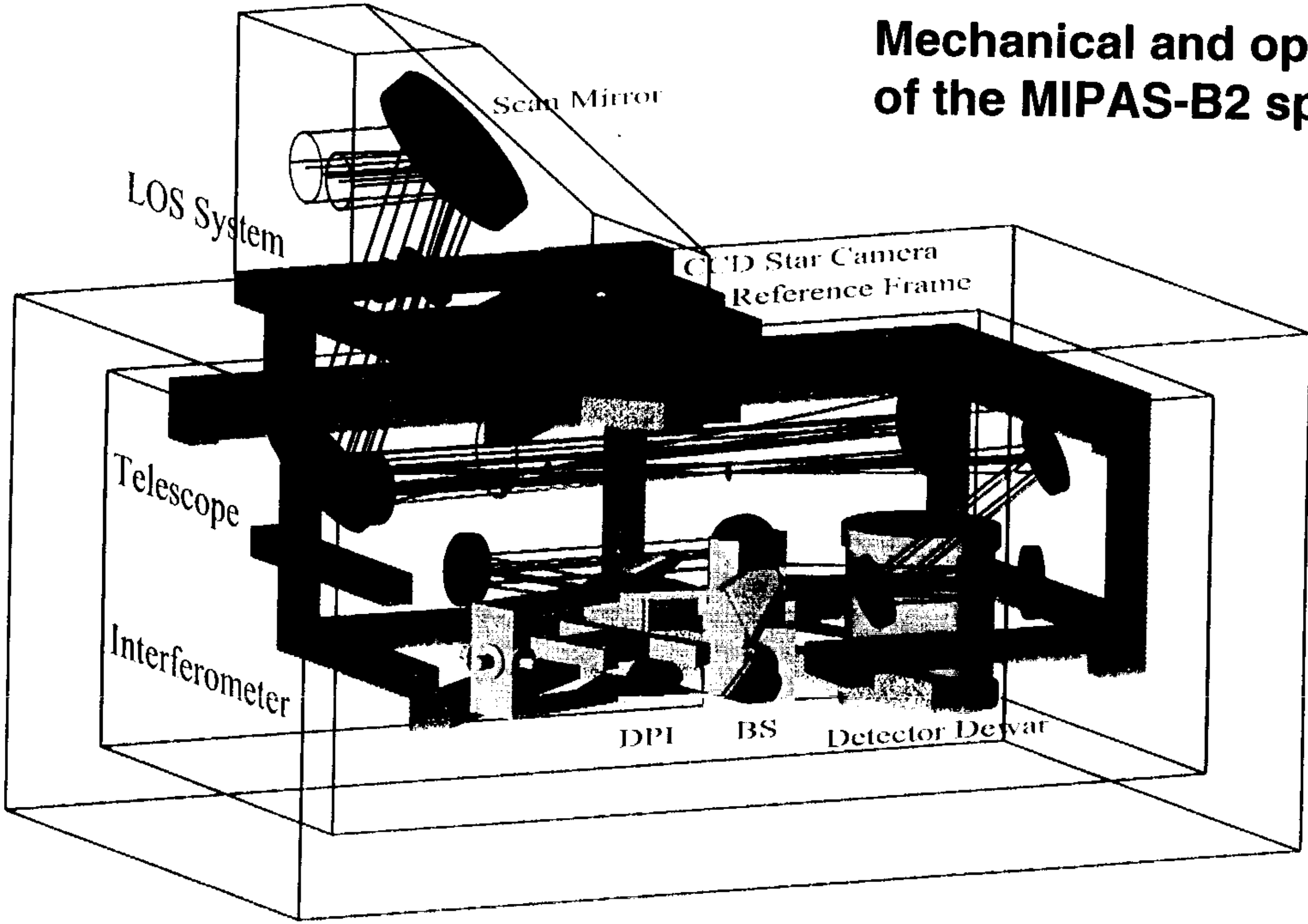
Primary scientific objective:	use in the arctic winter and in mid-latitudes $\Rightarrow$ limb emission sounding
Vertical geometrical resolution:	< 3 km at the horizon $\Rightarrow$ telescope
Stability and knowledge of tangent point:	< 300 m $\Rightarrow$ pointing system
Angle range of pointing system:	-6° to 20° in elev., 0 to 360° in azimuth
Simultaneous measurements $\Rightarrow$ Spectral range and resolution:	750 - 1950 cm^{-1} (5.1 - 13.3 μm) 0.033 cm^{-1} ($\lambda/\Delta\lambda$ = 23000 … 59000)
Sensitivity (NESR):	$3 \times 10^{-9} - 2 \times 10^{-8}$ W/(cm^2 sr cm^{-1}) $\Rightarrow$ high performance detectors (4K), cryogenic operation (200K), restriction of bandwidths


Launch
Float
Auxiliary Balloons (scaled down by a factor of 3)
Valve
Flight Train (bifilar)
to Main Balloon
Main Balloo
(100000 m³)
Separation Mechanism
of the Auxiliary Balloons
3 Parachutes
NSO-Box (Nacel
service operation
Radar Transpond
Argos, Omega
Satellite Locatio
Beacon
115 meter
Flight Train (bifilar)
Pivot (Azimuth Stabilization)
AHRS and
Elevation
Stabilization
Elektronics Box
Gondola Structure
Schock Absorber
1,6 meter
Sensor
Insulation
Crashpad
Gondola

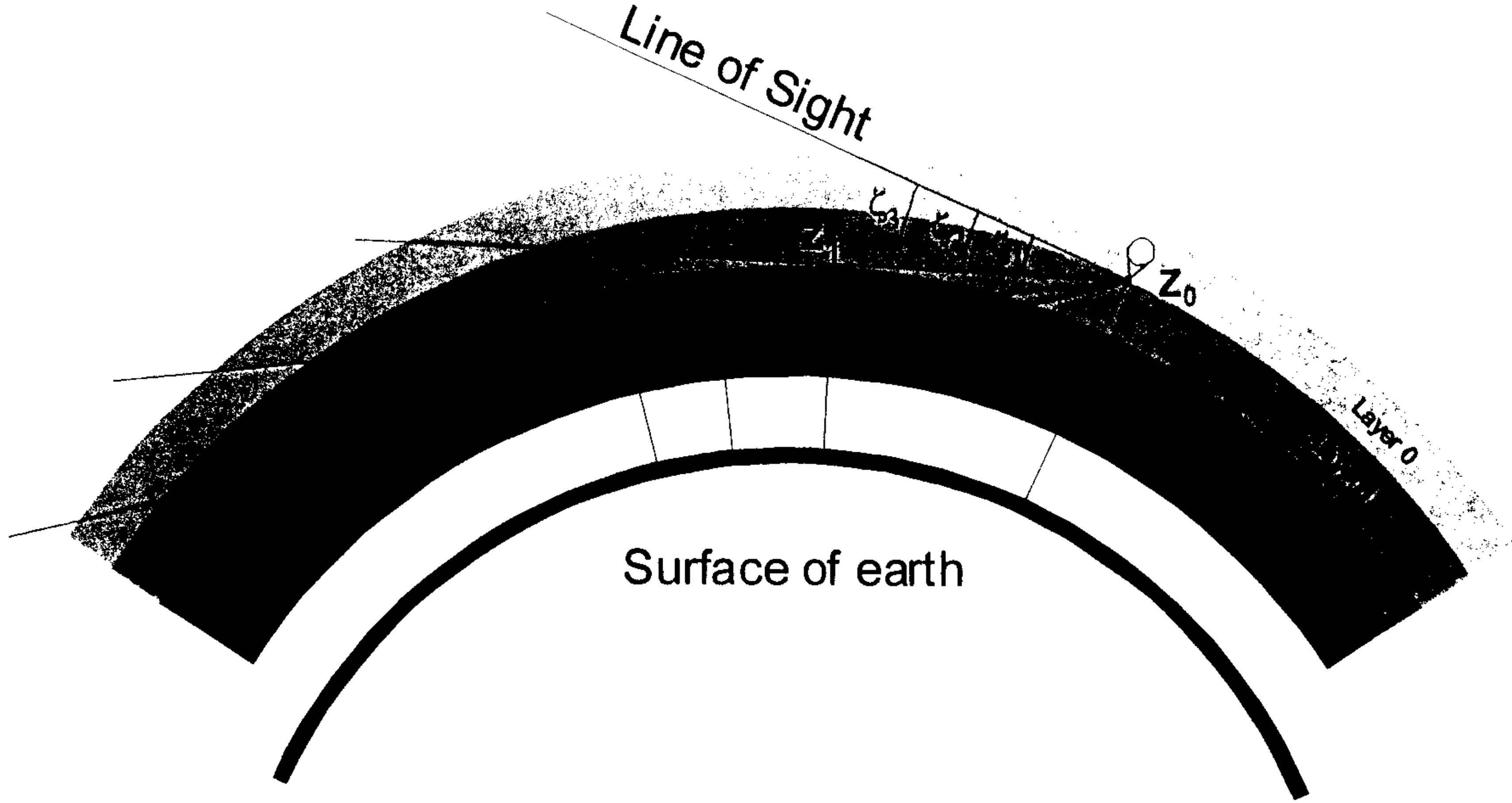
Functional Scheme MIPAS-B2



Mechanical and optical setup of the MIPAS-B2 spectrometer



Measurement geometry

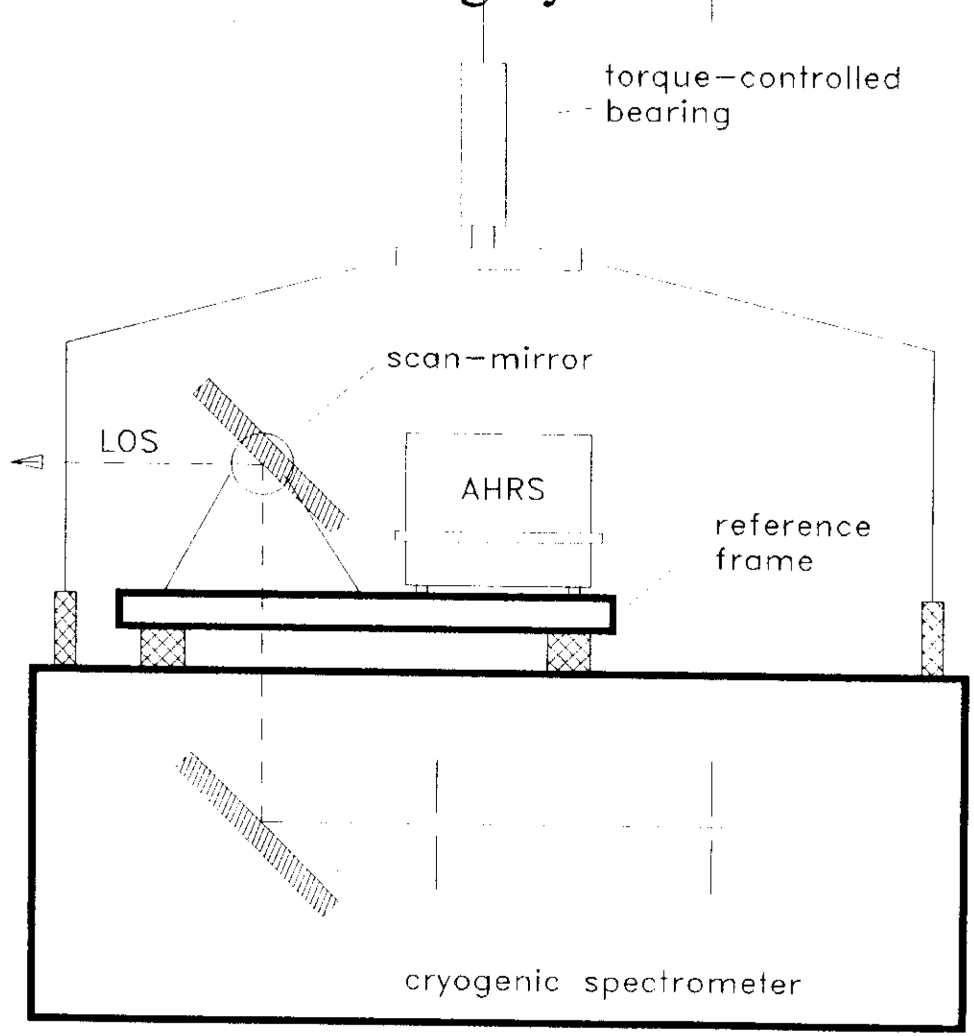


The Two Independent LOS Systems

- Pointing system - on line 'a priori' acquisition and stability that provides active pointing of the Line Of Sight in azimuth and elevation to perfom limb sequences

- Star reference system - off line 'a posteriori' knowledge by correlation of the LOS to the stars in the sky

Components of the Pointing System



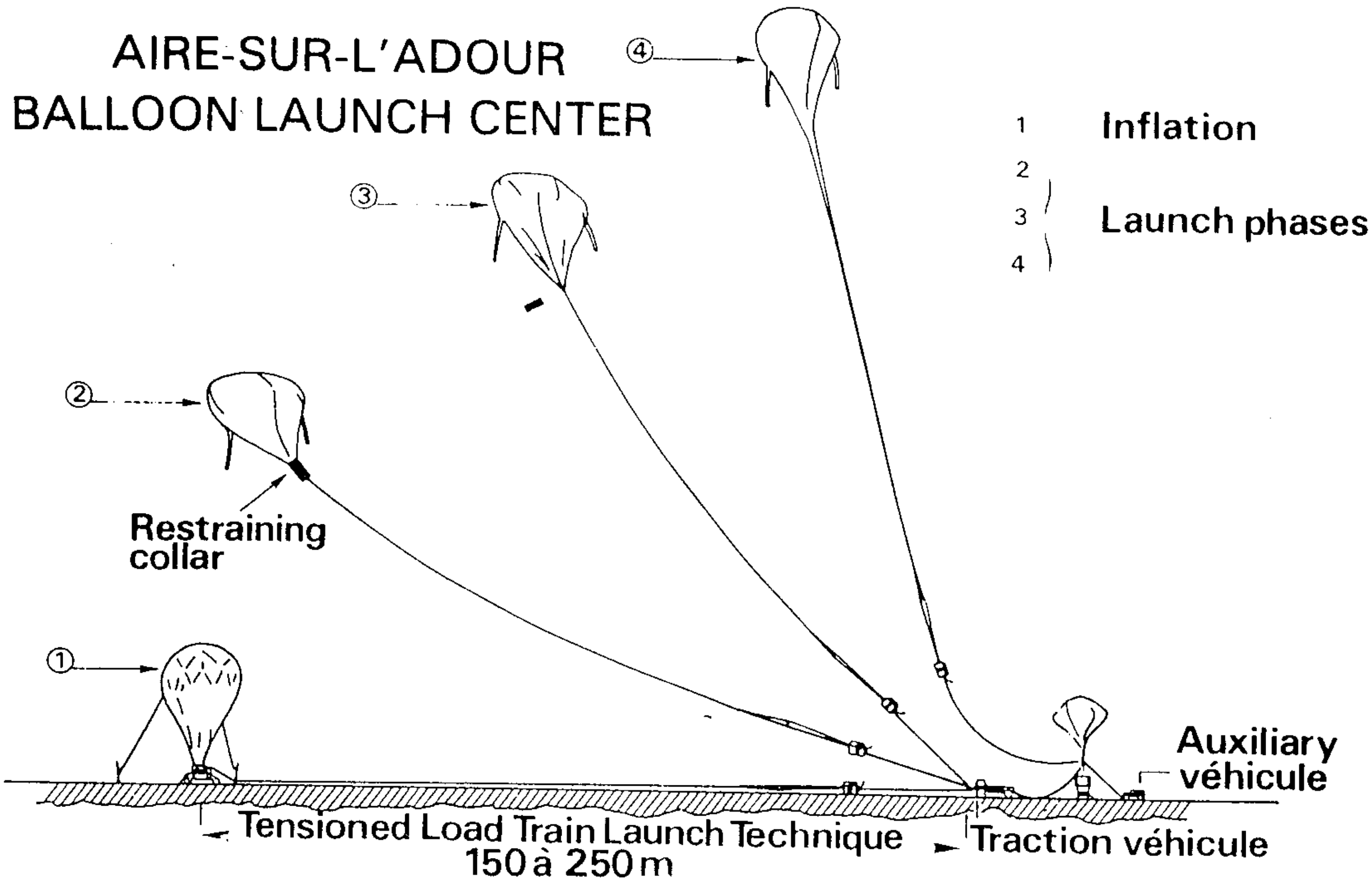
Forschungszentrum Karlsruhe
Technik und Umwelt

BALLOON EXPERIMENTS

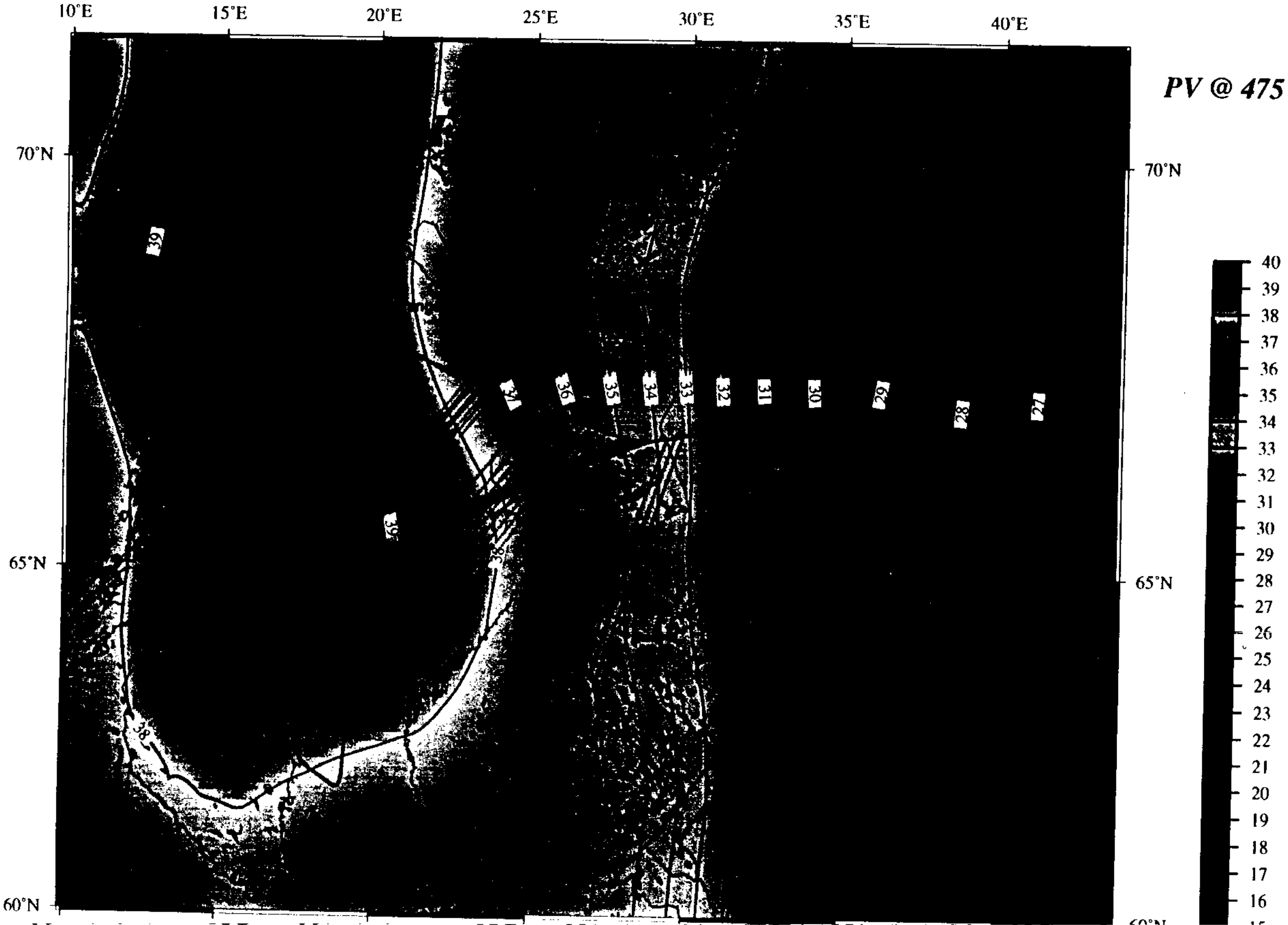
CONSTRAINTS, PRO'S & CONTRA'S

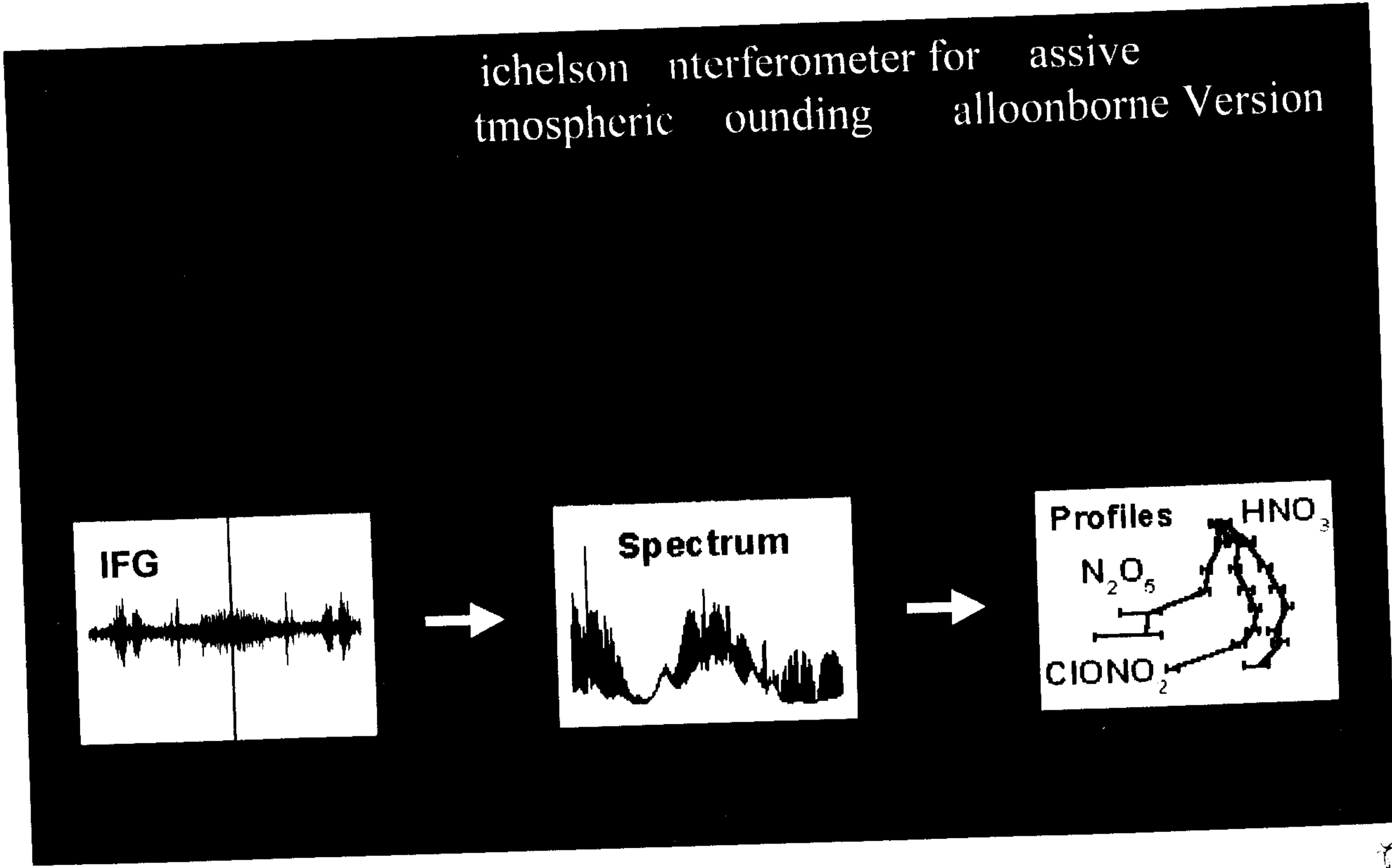
+ high 'observer' altitude	- small no. of launch bases
+ rel. good vertical resolution	- 'snap shots'
+ rel. high accuracy	- high cost and risk
+ many species simultaneously	
+ quasi-Lagrangian observations (-> diurnal variations)	- meteorol. constraints
+ suitable for validation of satellite measurements	- automatisation and remote control necessary

AIRE-SUR-L'ADOUR
BALLOON LAUNCH CENTER

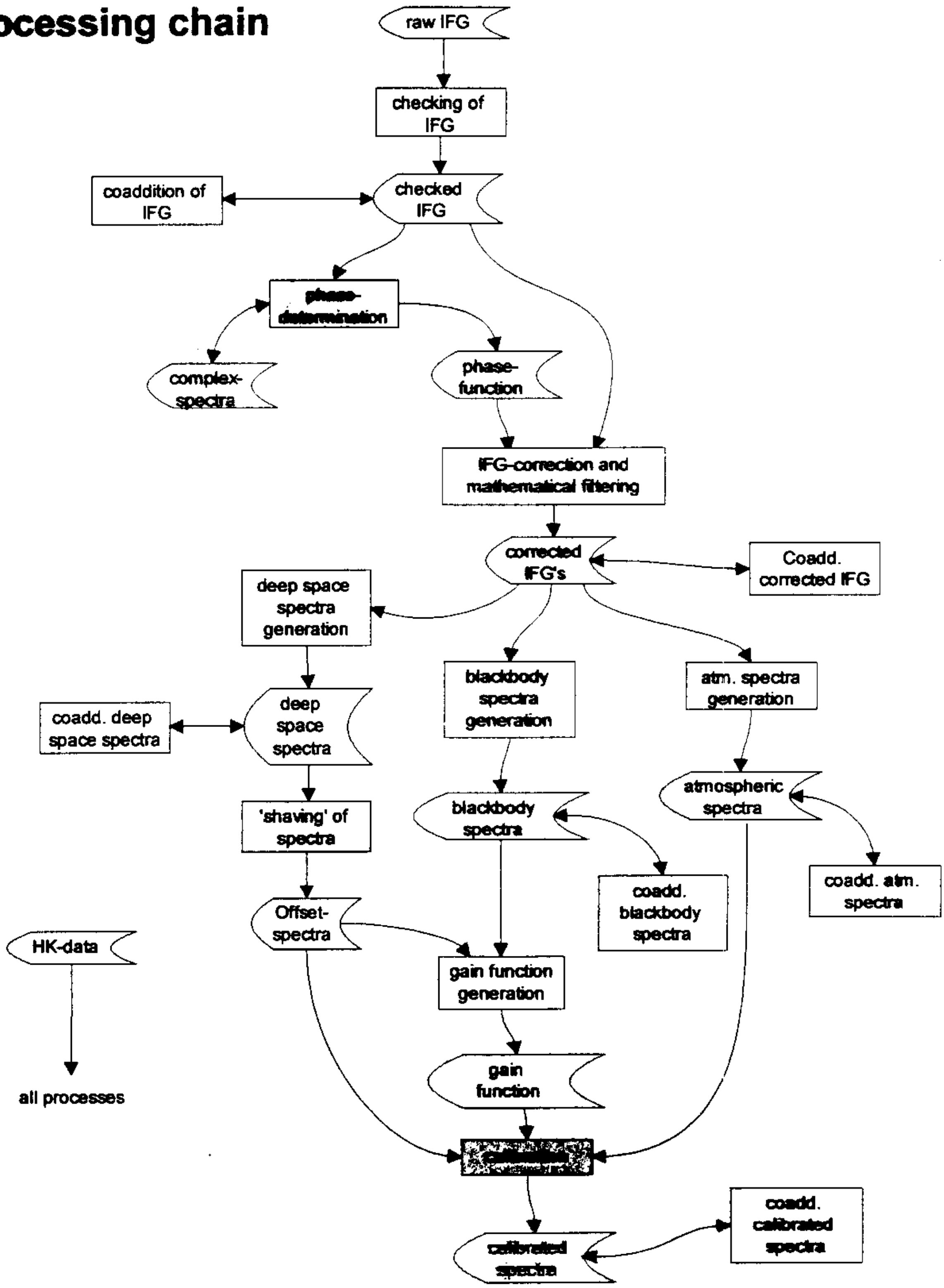


January 27, 1999, 06UT




ichelson nterferometer for assive
tmospheric ounding alloonborne Version
IFG
Spectrum
Profiles
HNO3
N2O5
ClONO2

processing chain



Data analysis

Ib → II

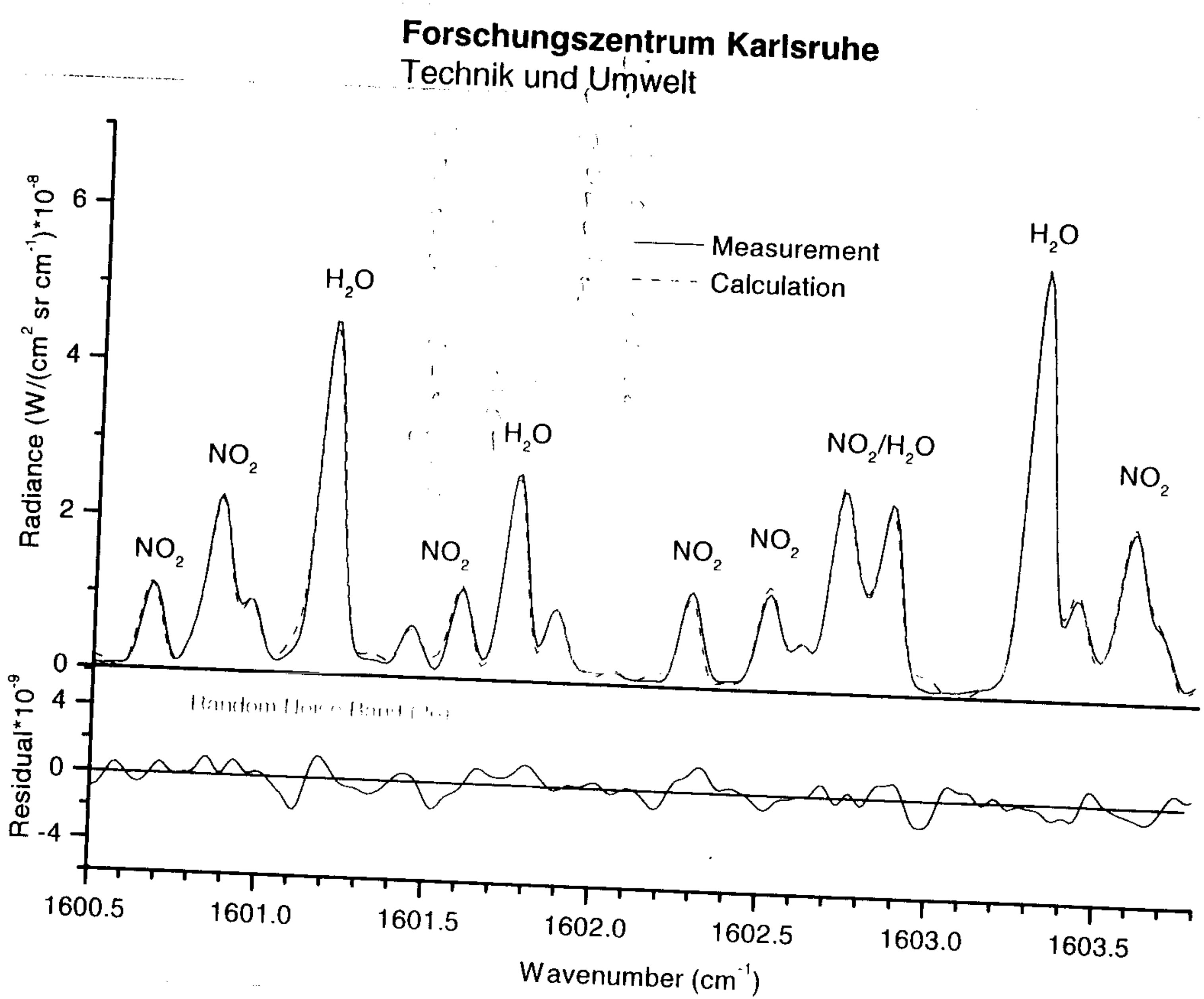
- **Onion-peeling retrieval** algorithm in combination with a non-linear multiparameter least squares fitting procedure
  - sequential processing of each tangent altitude starting with the highest one
- Fit of atmospheric parameters in several **microwindows** with relevant spectral contribution of target species

  ☺ reduces the unknown parameters

  ☺ no a-priori knowledge of the spectral distribution of aerosol is needed

  ☺ only transitions whose spectroscopic data are well known are used

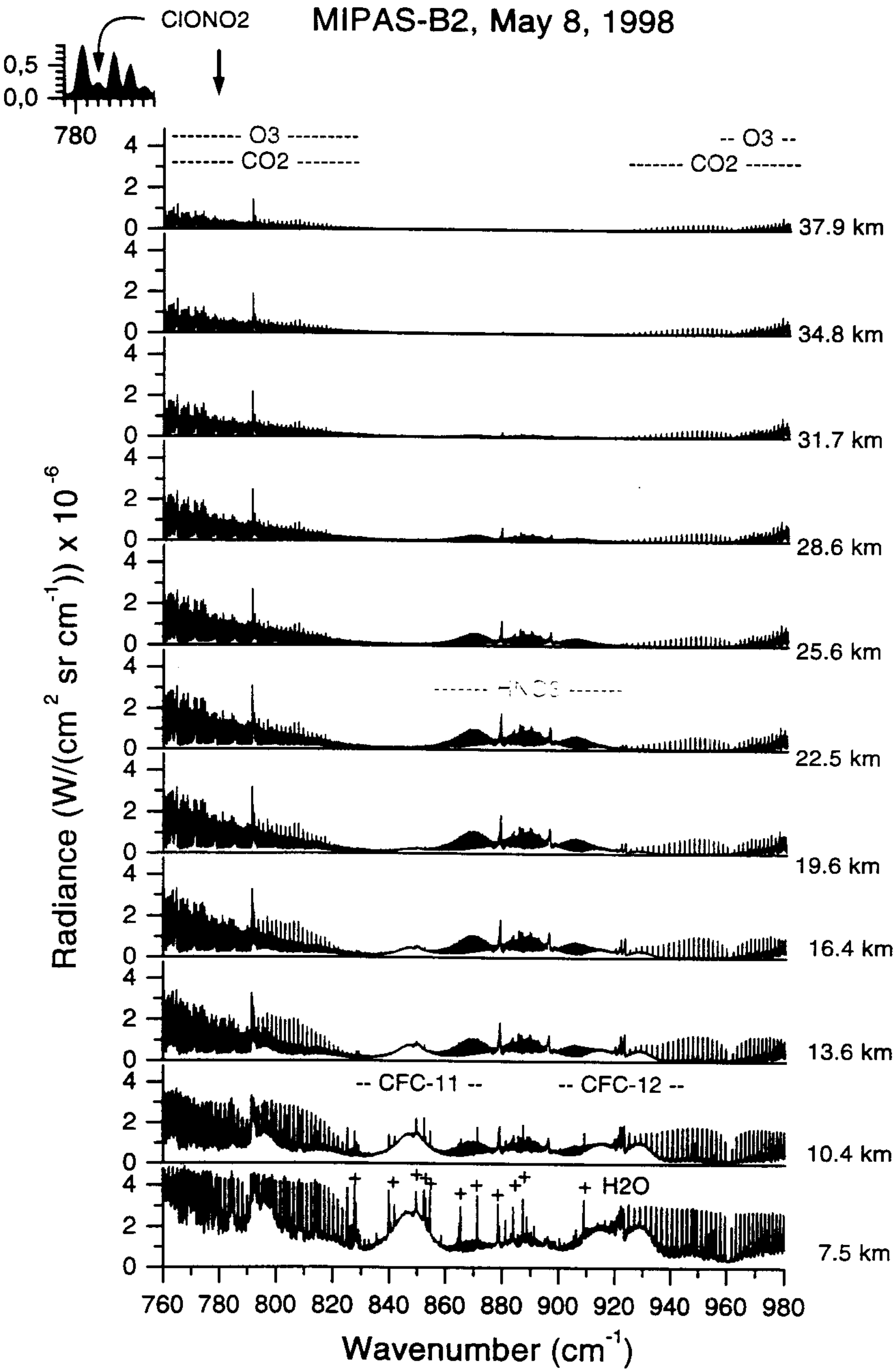
  ☹ a lot of redundant information is not utilized for the retrieval: a better SNR is needed


Forschungszentrum Karlsruhe
Technik und Umwelt
Measurement
Calculation
NO2
NO2
H2O
NO2
H2O
NO2
NO2
NO2/H2O
H2O
NO2
Radiance (W/(cm^2 sr cm^-1)*10^-8
6
4
2
0
Residual*10^-9
4
0
-4
1600.5
1601.0
1601.5
1602.0
1602.5
1603.0
1603.5
Wavenumber (cm^-1)

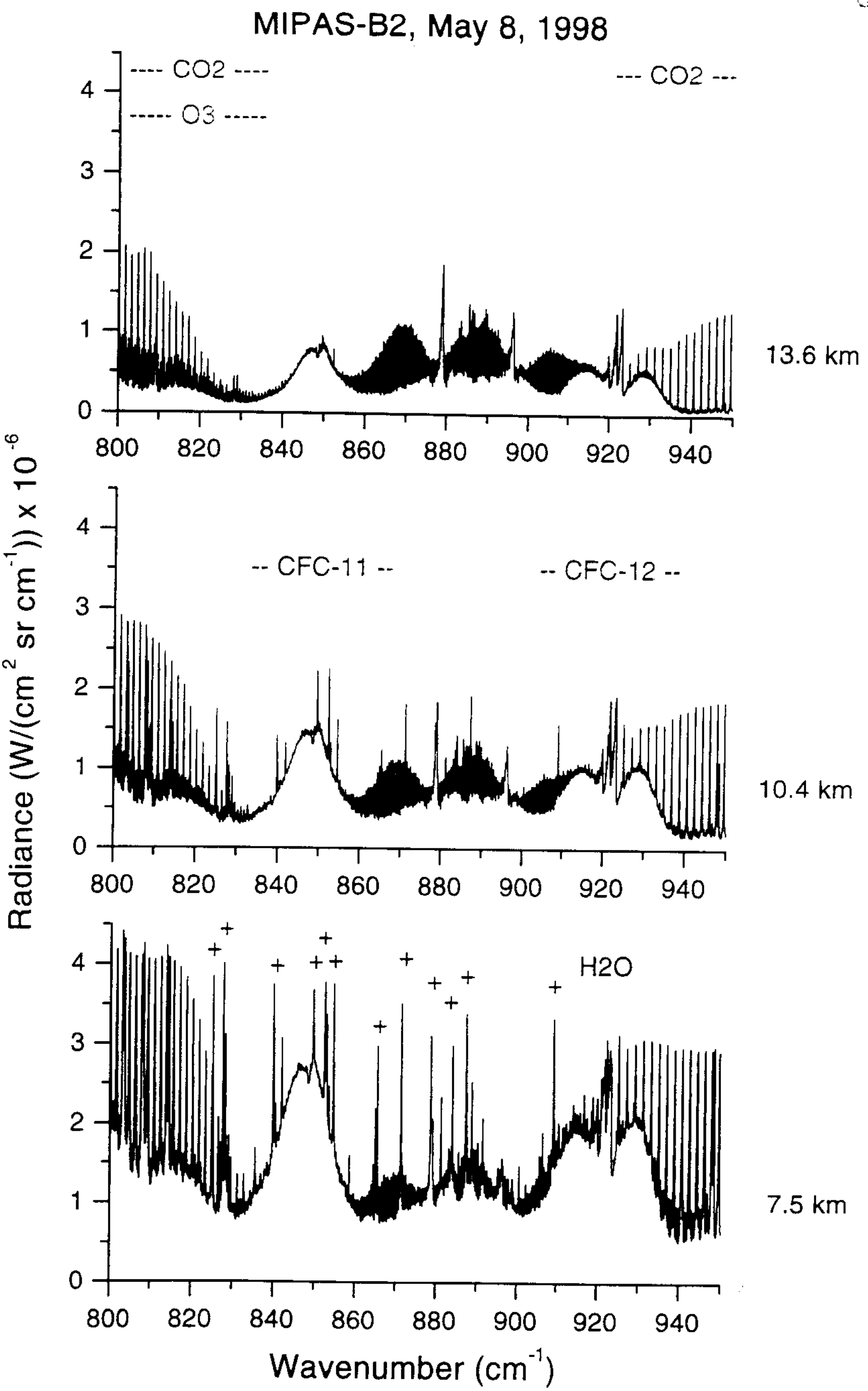
MIPAS-B2: MEASURABLE QUANTITIES

Parameter	Altitude Range	Quality
O_3	10 - ZB	+++
H_2O	7 - ZB	+++
HDO	15 - ZB	++
CH_4	7 - ZB	+++
N_2O	7 - ZB	+++
NO	18 - ZB	tbd
NO_2	18 - ZB	++
HNO_3	10 - ZB	+++
HO_2NO_2	18 - 30	+
N_2O_5	18 - ZB	++
$ClONO_2$	12 - ZB	++
HOCl	25 - ZB	upper limit
ClO	14 - 20	special event
$CFCl_3$	7 - 20	++
CF_2Cl_2	7 - 22	++
CHF_2Cl	7 - 22	++
CCl_4	7 - 16	+
CF_4	14 - ZB	++
COF_2	tbd	tbd
SF_6	tbd	tbd
OCS	tbd	tbd
C_2H_6	tbd	tbd
⋮	⋮	⋮
aerosol ext.	10 - 18	
vol. density	10 - 18	
composition	10 - 18	
Temperature	10 - ZB	< 1 K

ZB: Float Altitude
Overall Accuracy: +++ : <10%, ++ : < 20%, + : <30%



MIPAS-B2, May 8, 1998
ClONO2
0,5
0,0
780
O3
CO2
HNO3
CFC-11
CFC-12
+ H2O
37.9 km
34.8 km
31.7 km
28.6 km
25.6 km
22.5 km
19.6 km
16.4 km
13.6 km
10.4 km
7.5 km
Radiance (W/(cm² sr cm⁻¹)) x 10⁻⁶
Wavenumber (cm⁻¹)
760 780 800 820 840 860 880 900 920 940 960 980


MIPAS-B2, May 8, 1998
---- CO2 ----
---- O3 ----
--- CO2 ---
13.6 km
-- CFC-11 --
-- CFC-12 --
10.4 km
H2O
7.5 km
Radiance (W/(cm2 sr cm-1)) x 10-6
Wavenumber (cm-1)

MIPAS - B

[illegible]

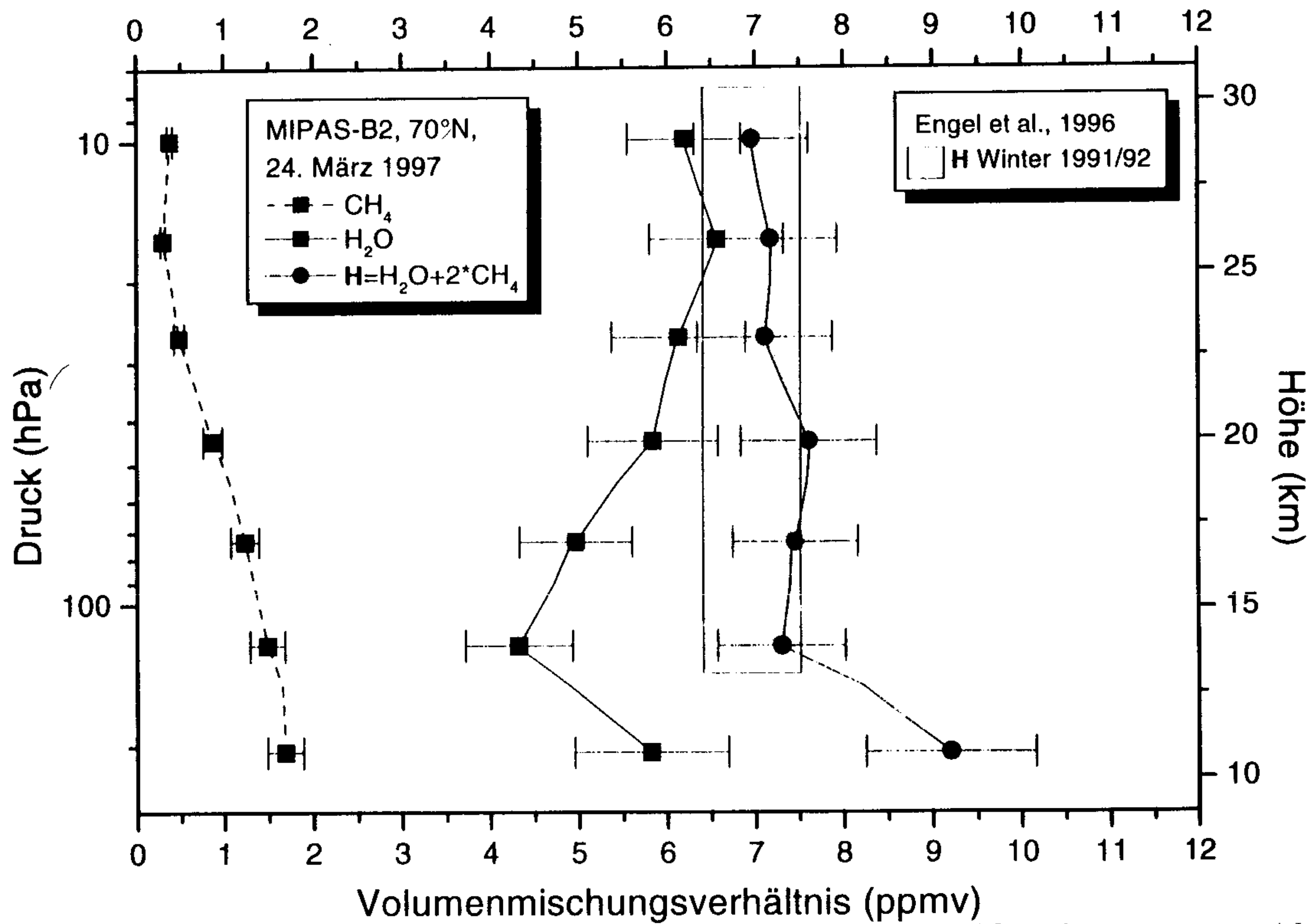
- [illegible]
- [illegible]
- [illegible]
- [illegible]
  - [illegible]
  - [illegible]
  - [illegible]
- [illegible]

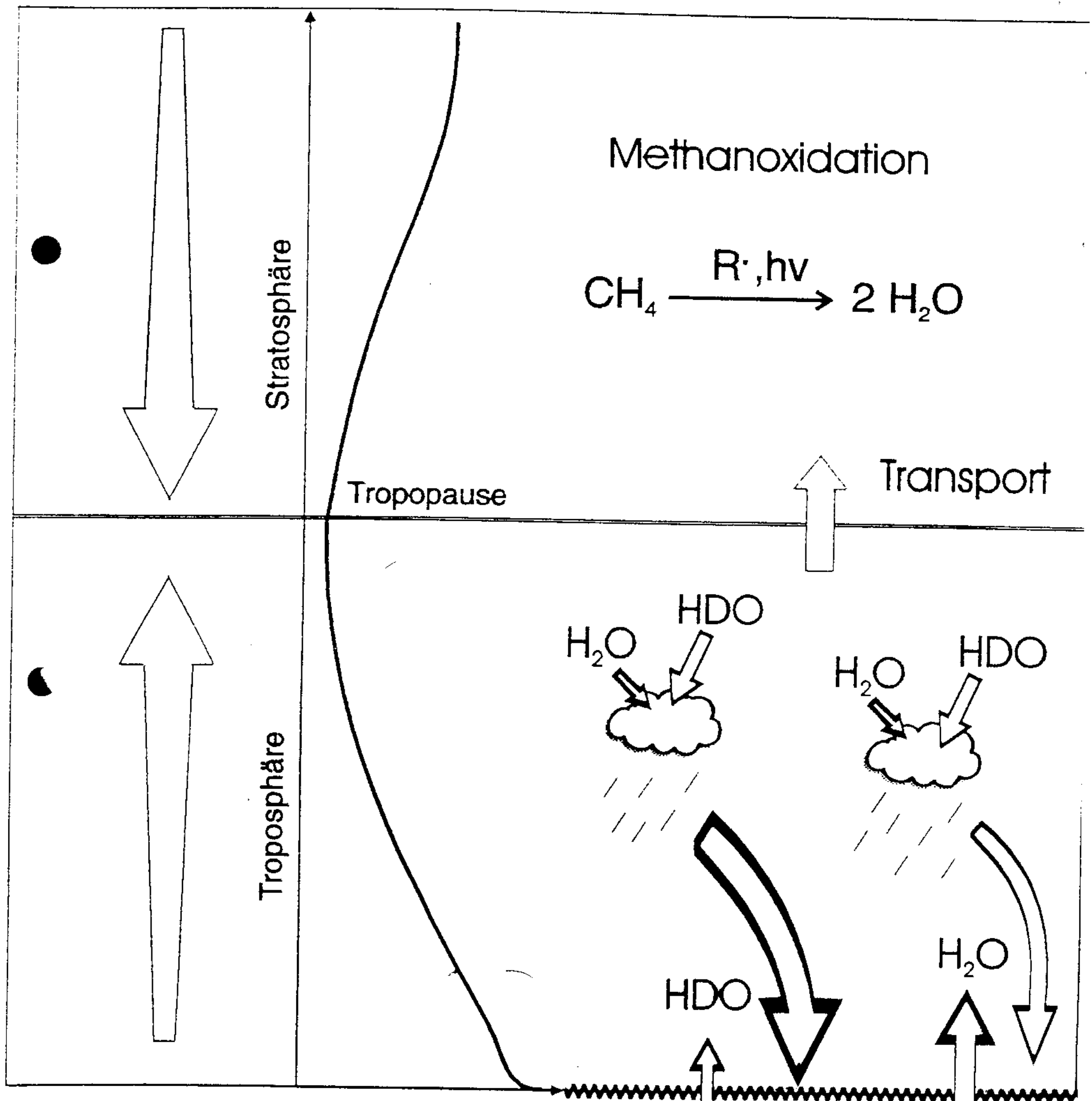
Chemistry of CH_4, H_2O and N_2O

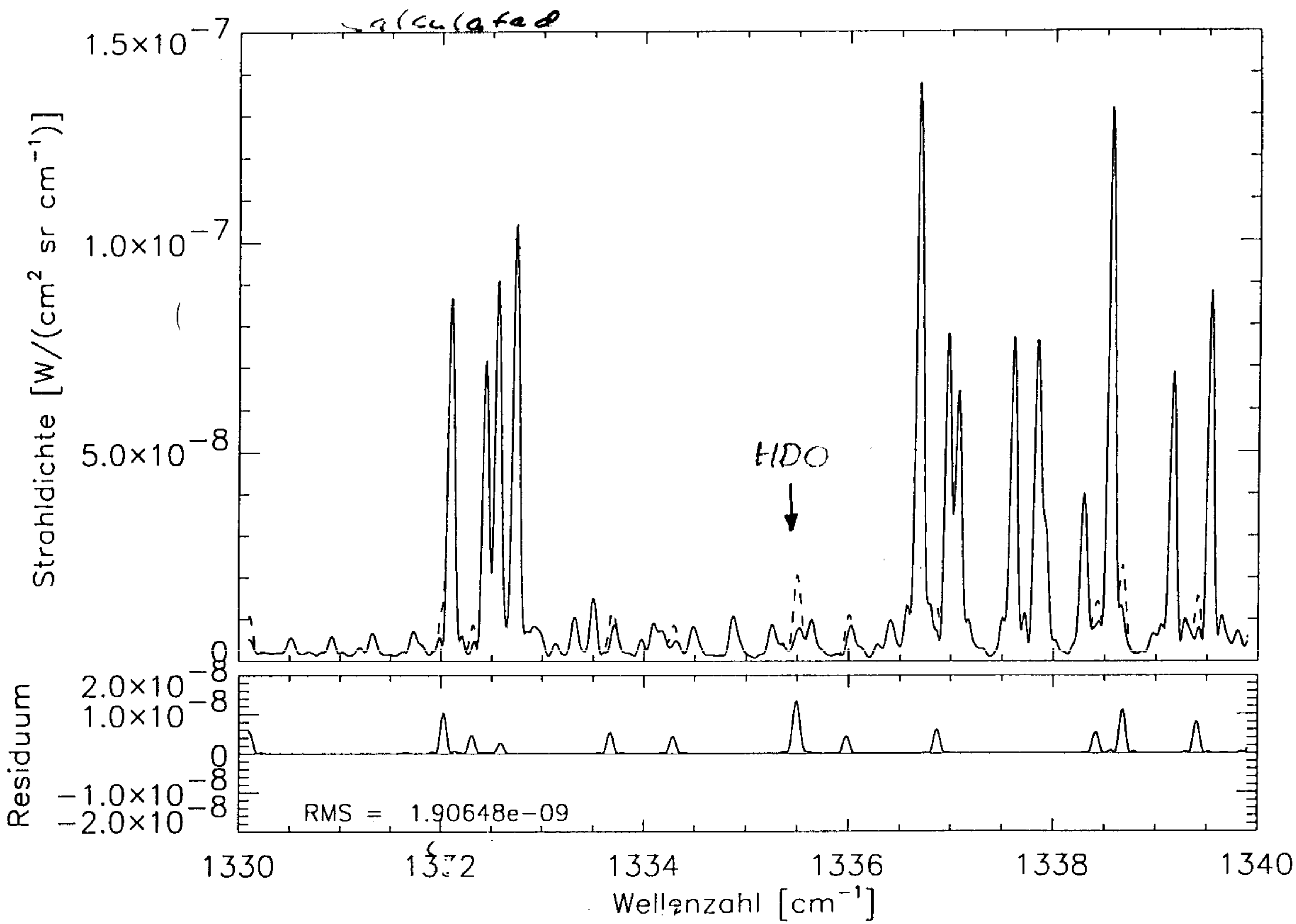
- Oxidation of one CH_4 molecule produces around two H_2O molecules in the stratosphere and is an important source of CO and CH_2O
- H_2O is involved in the sulfate and OH chemistry
- N_2O is the main source of NO_y

Isotope effects in the atmosphere

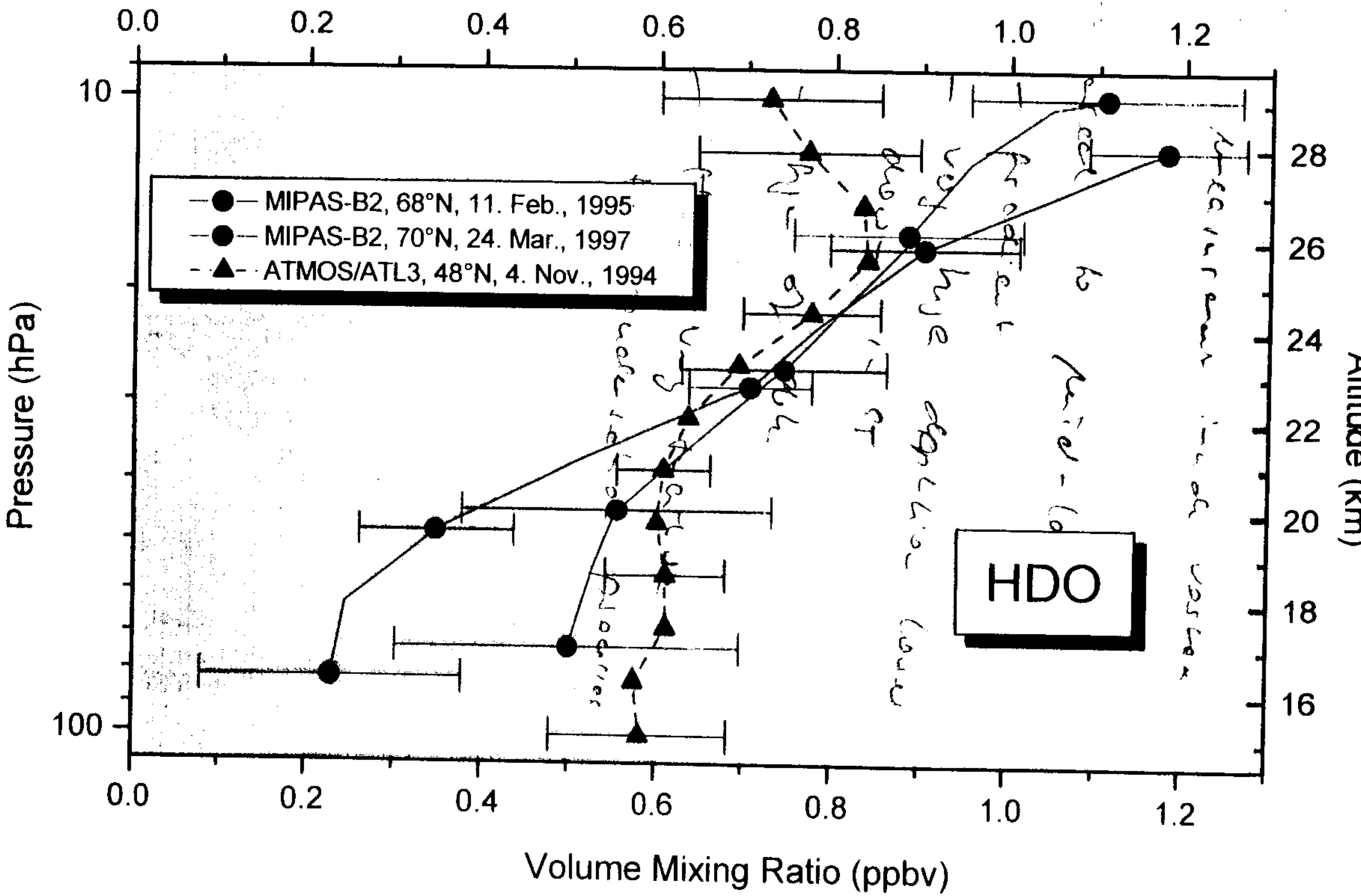
- Observed HDO abundances are reported in a δ-notation in permil enrichment relative to standard mean ocean water (SMOW)
- Tropospheric air entering the stratosphere is deuterium depleted due to the vapor pressure isotope effect
- D content of H_2O in the stratosphere should increase with altitude owing to a smaller D depletion of CH_4


MIPAS-B2, 70°N,
24. März 1997
CH4
H2O
H=H2O+2*CH4
Engel et al., 1996
H Winter 1991/92
Druck (hPa)
10
100
Höhe (km)
30
25
20
15
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Volumenmischungsverhältnis (ppmv)


Methanoxidation
$CH_4 \xrightarrow{R^{\cdot},h\nu} 2\ H_2O$
Stratosphäre
Tropopause
Transport
Troposphäre
HDO
H_2O
HDO
H_2O
HDO
H_2O
-600
0
Fraktionierungsfaktor
δD-Profil in ‰
SMOW

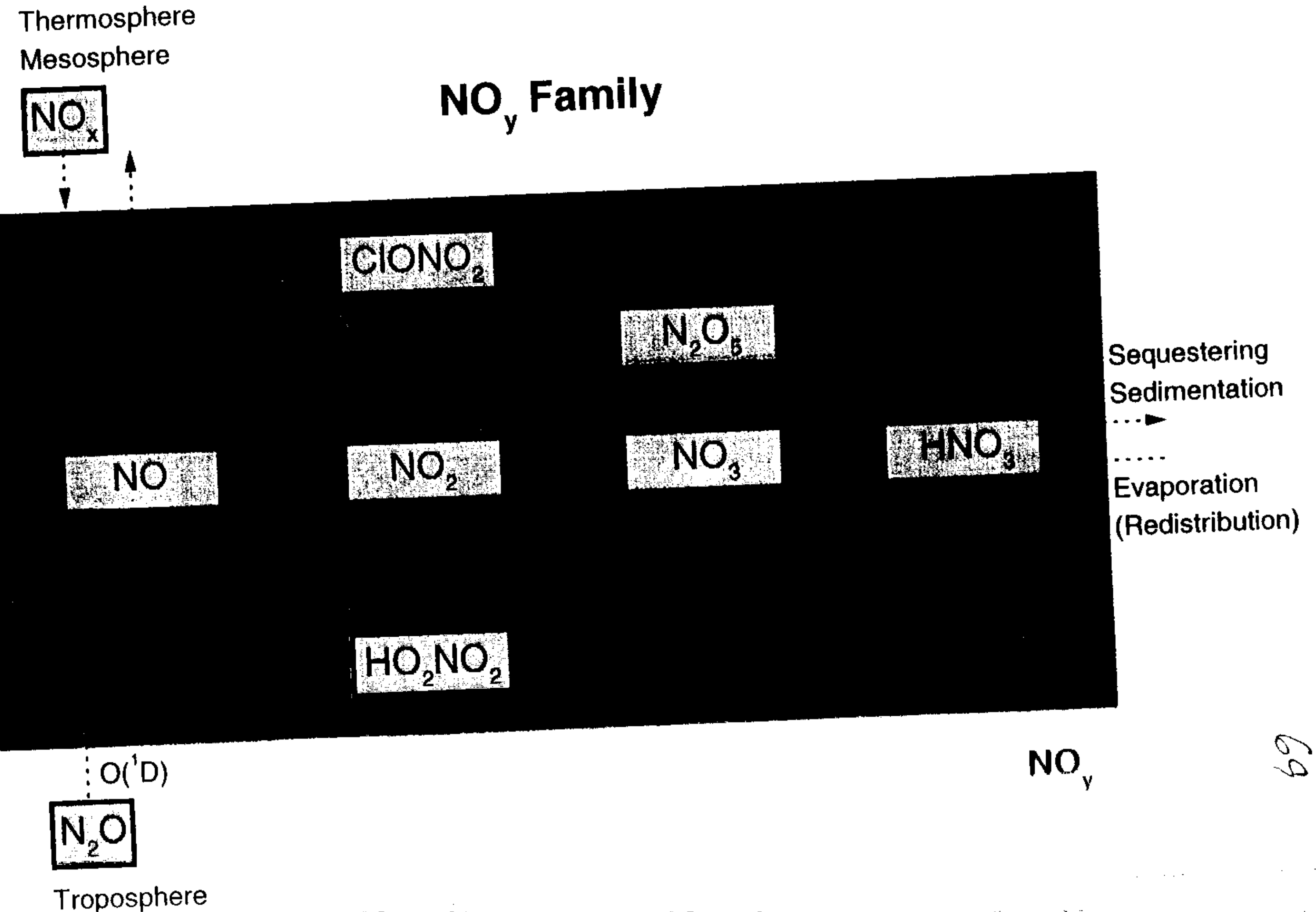


calculated
1.5×10⁻⁷
1.0×10⁻⁷
5.0×10⁻⁸
0
Strahldichte [W/(cm² sr cm⁻¹)]
HDO
2.0×10⁻⁸
1.0×10⁻⁸
0
−1.0×10⁻⁸
−2.0×10⁻⁸
Residuum
RMS = 1.90648e-09
1330
1332
1334
1336
1338
1340
Wellenzahl [cm⁻¹]

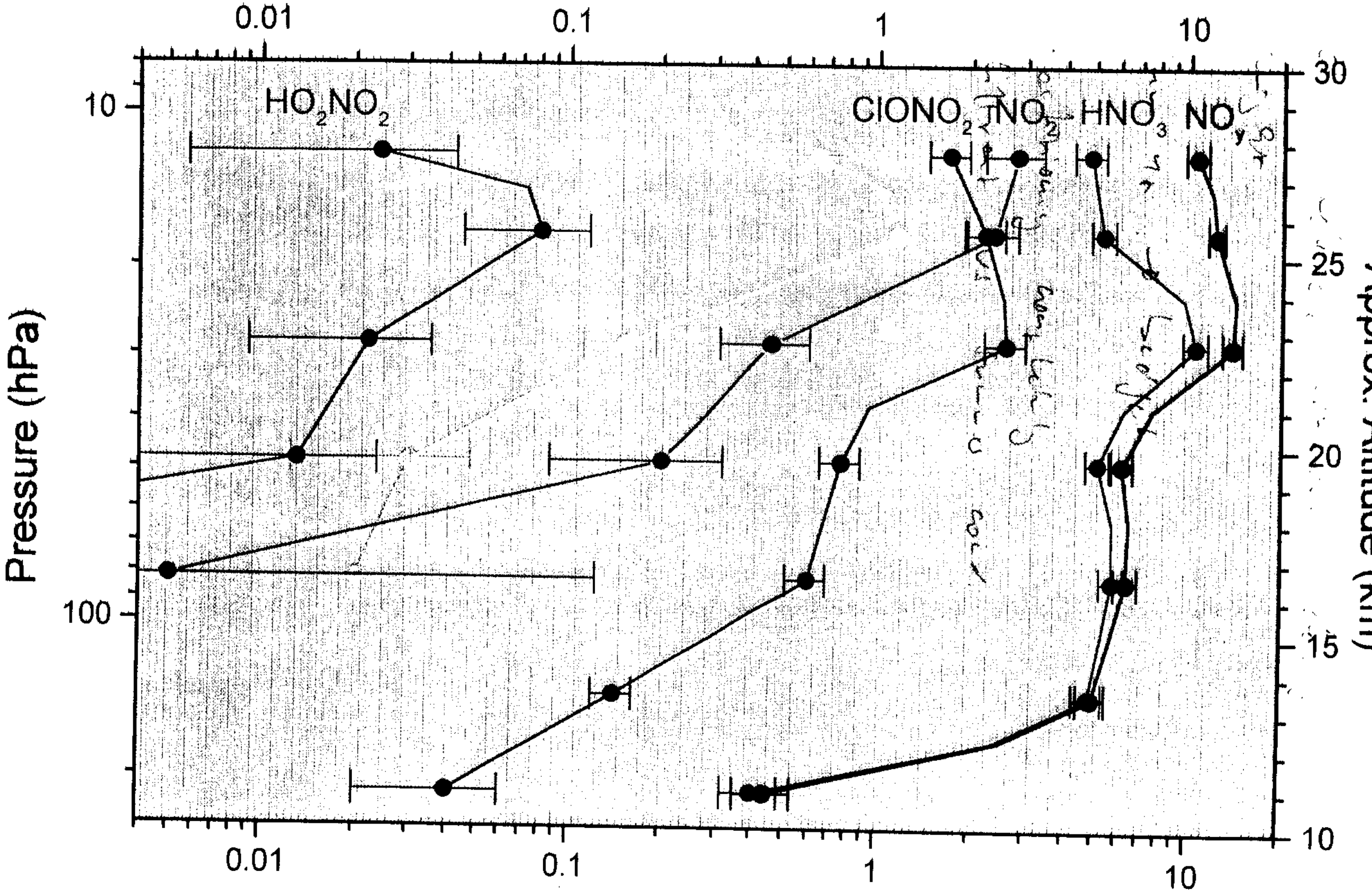


MIPAS-B2, 68°N, 11. Feb., 1995
MIPAS-B2, 70°N, 24. Mar., 1997
ATMOS/ATL3, 48°N, 4. Nov., 1994
HDO
Pressure (hPa)
Altitude (km)
Volume Mixing Ratio (ppbv)

NO_y Family


Thermosphere
Mesosphere
NOx
ClONO2
N2O5
NO
NO2
NO3
HNO3
HO2NO2
Sequestering
Sedimentation
Evaporation
(Redistribution)
O(1D)
N2O
Troposphere
NOy

MIPAS-B2, 68°N, Feb. 11, 1995, Night



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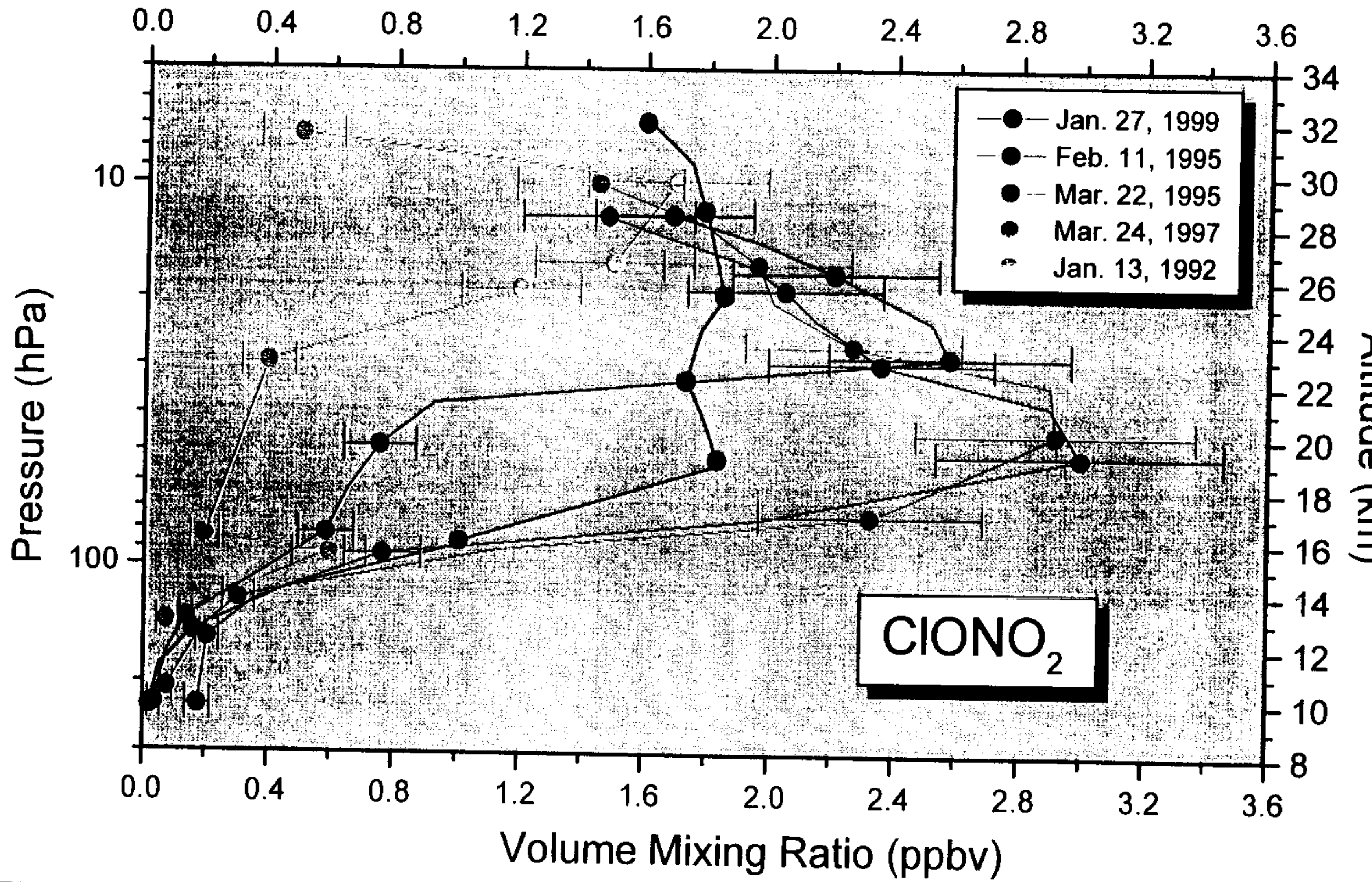
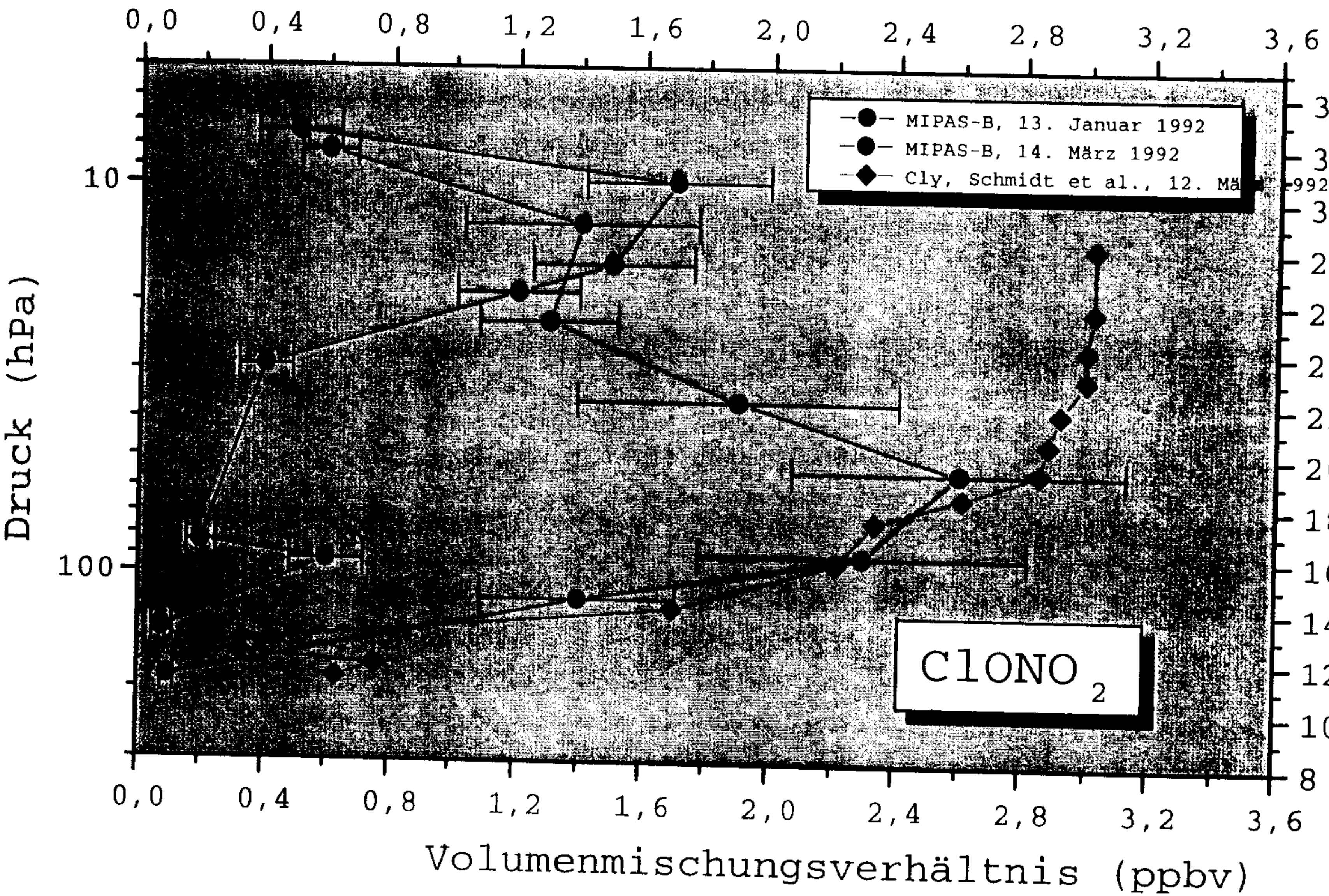
Technik und Umwelt



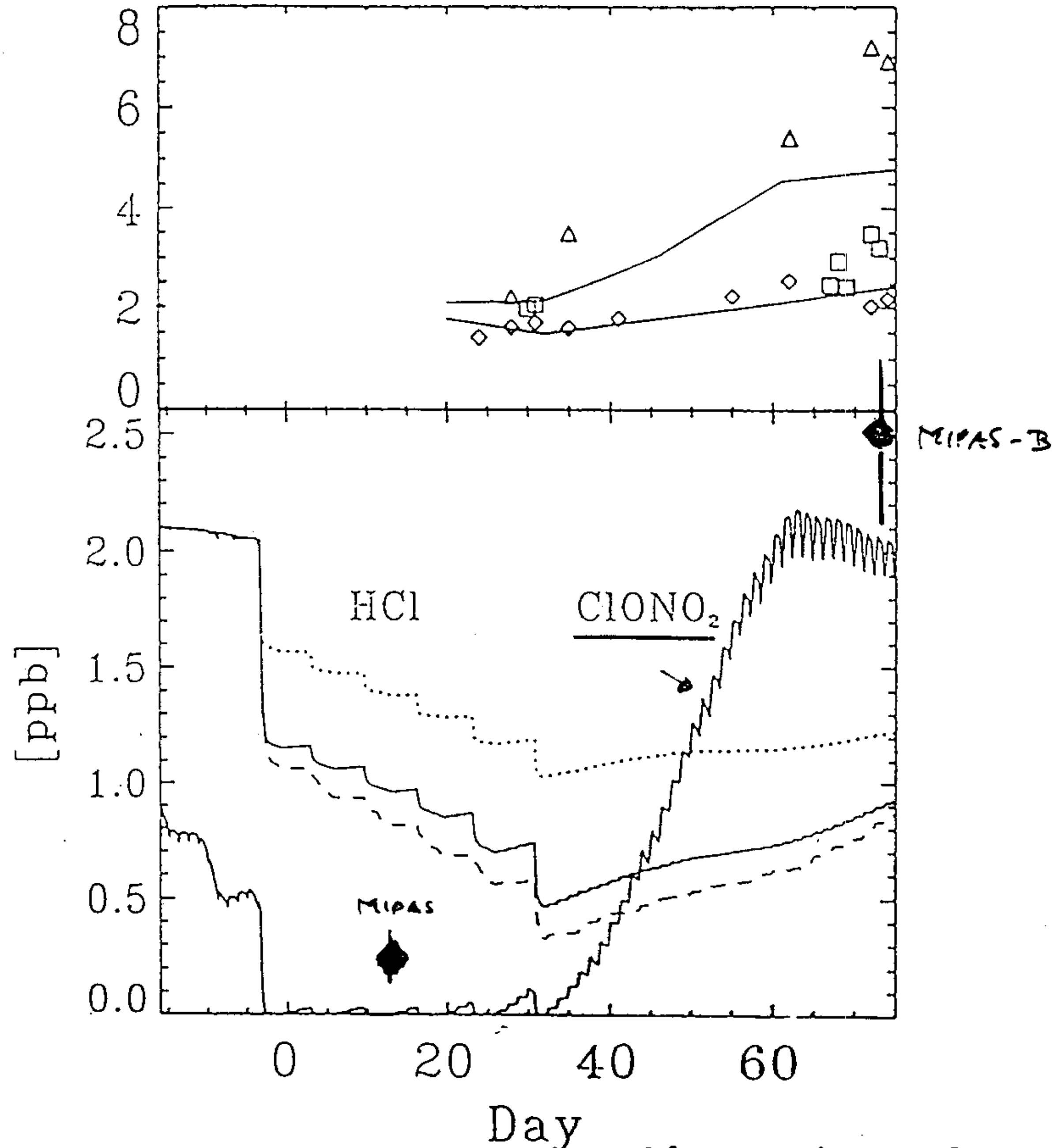


MIPAS-B, 13. Januar 1992
MIPAS-B, 14. März 1992
Cly, Schmidt et al., 12. Mä
ClONO 2
Druck (hPa)
Höhe (km)
Volumenmischungsverhältnis (ppbv)
0,0
0,4
0,8
1,2
1,6
2,0
2,4
2,8
3,2
3,6
10
100
34
32
30
28
26
24
22
20
18
16
14
12
10
8

GEOPHYSICAL RESEARCH LETTERS, VOL. 21, NO. 13, PAGES 1427-1430, JUNE 22, 1994

Chlorine chemistry and the potential for ozone depletion in the arctic stratosphere in the winter of 1991/92

R. Müller,[1] Th. Peter,[1] P. J. Crutzen,[1] H. Oelhaf,[2] G. P. Adrian,[2] Th. v. Clarmann,[2] A. Wegner,[2] U. Schmidt,[3] and D. Lary[4]

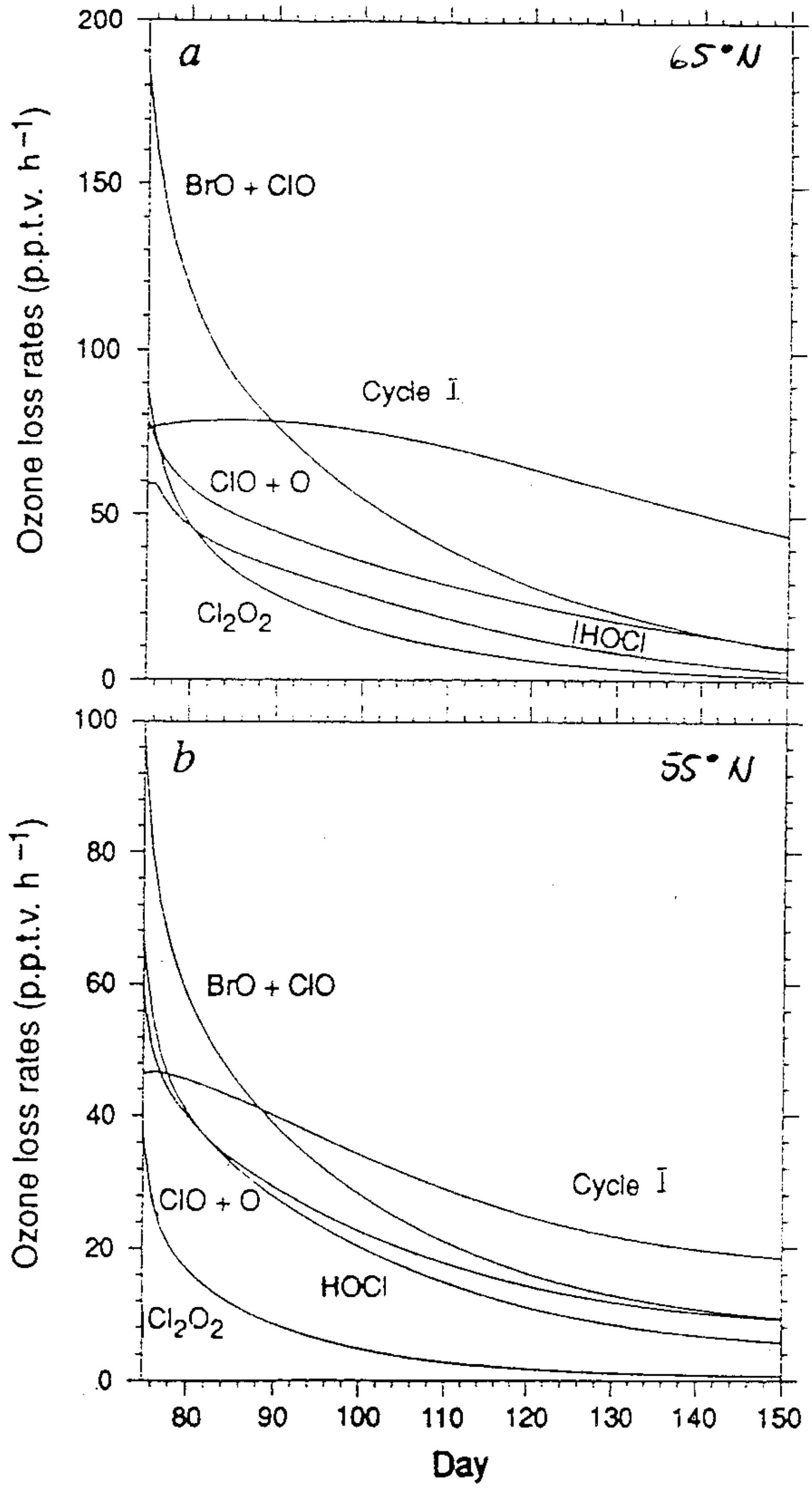


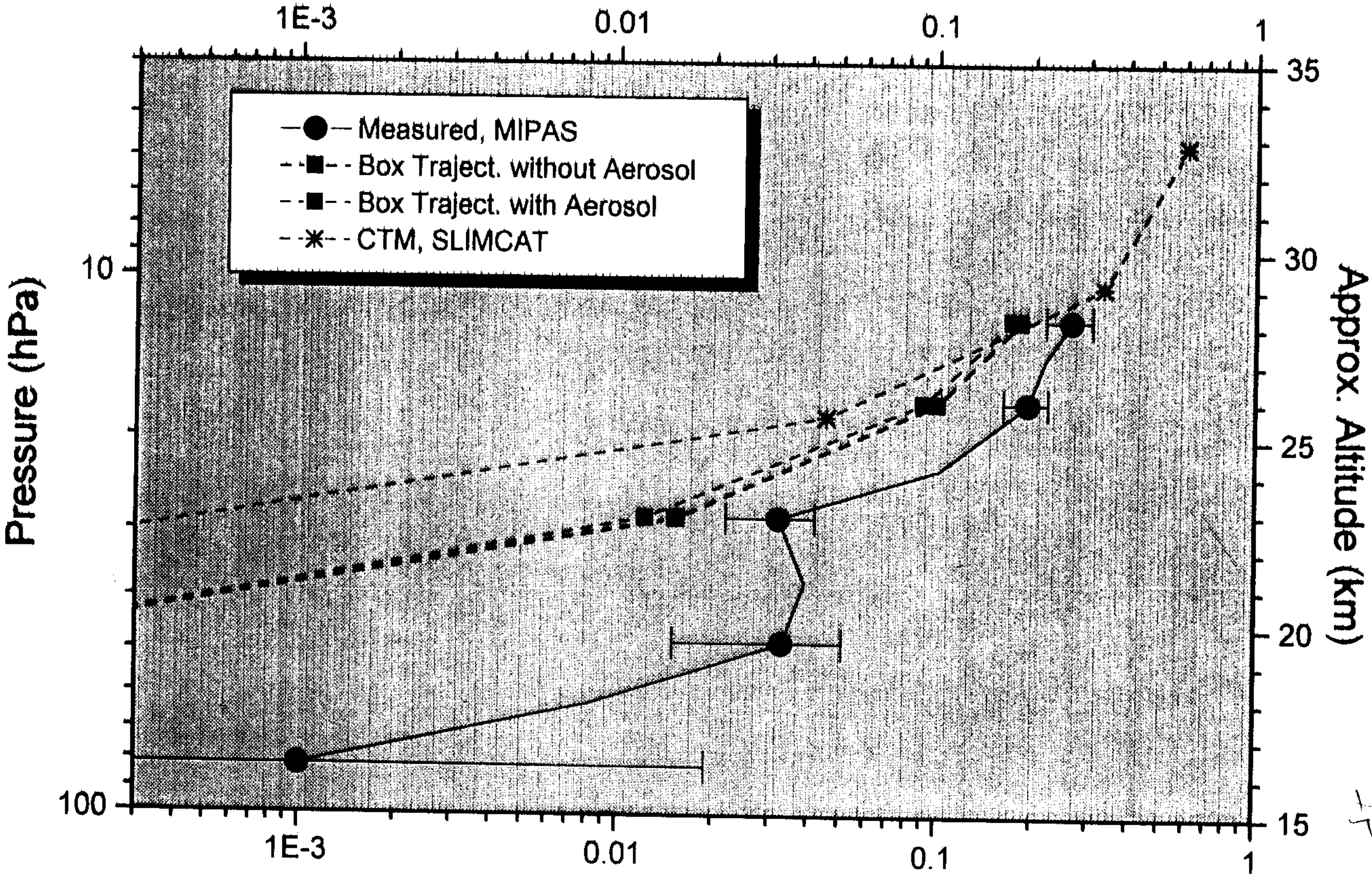
← – PSCs – – → : $ClONO_2 + HCl \rightarrow Cl_2 + HNO_3$

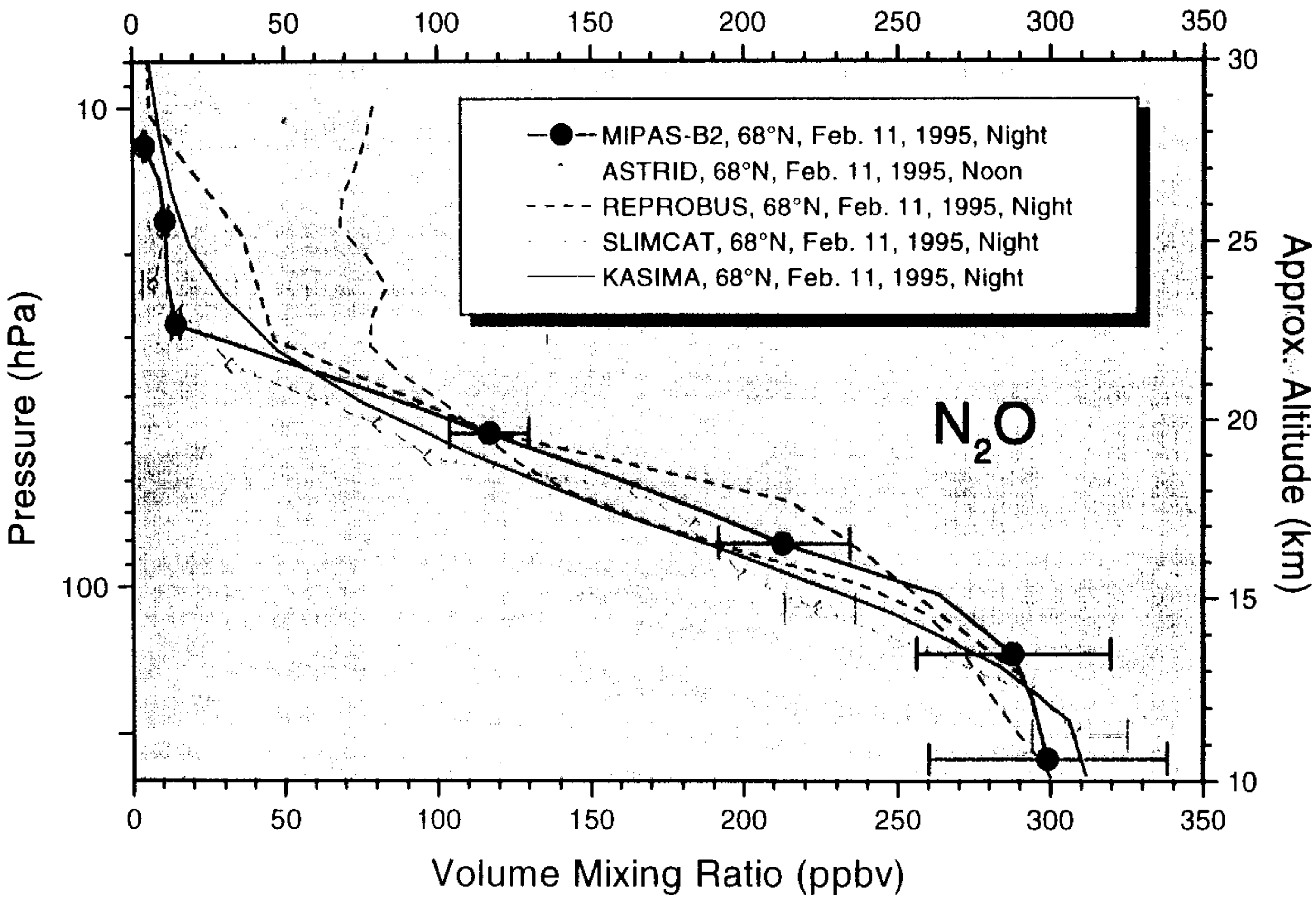
$HOCl + HCl \rightarrow Cl_2 + H_2O$

$\frac{[HCl]}{[ClONO_2]} \approx 3$ $\frac{[HCl]}{[ClONO_2]} \approx 0.3$

Toumi et al., Nature, 365, 1993




Pressure (hPa)
Approx. Altitude (km)
1E-3
0.01
0.1
1
10
100
35
30
25
20
15
Measured, MIPAS
Box Traject. without Aerosol
Box Traject. with Aerosol
CTM, SLIMCAT


MIPAS-B2, 68°N, Feb. 11, 1995, Night
ASTRID, 68°N, Feb. 11, 1995, Noon
REPROBUS, 68°N, Feb. 11, 1995, Night
SLIMCAT, 68°N, Feb. 11, 1995, Night
KASIMA, 68°N, Feb. 11, 1995, Night
N2O
Pressure (hPa)
10
100
Approx. Altitude (km)
30
25
20
15
10
0
50
100
150
200
250
300
350
Volume Mixing Ratio (ppbv)

Wetzel et al.

Poster #60

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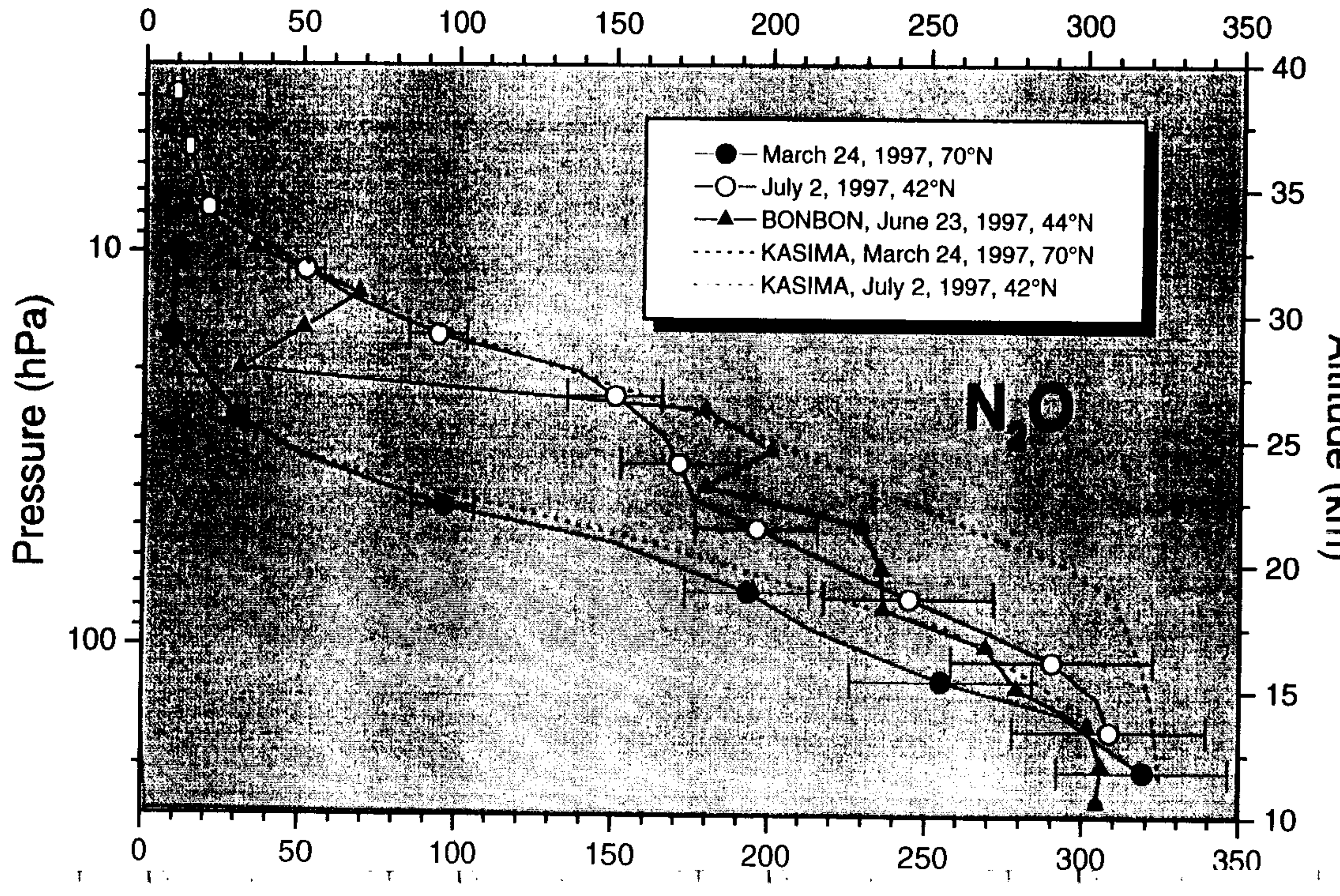
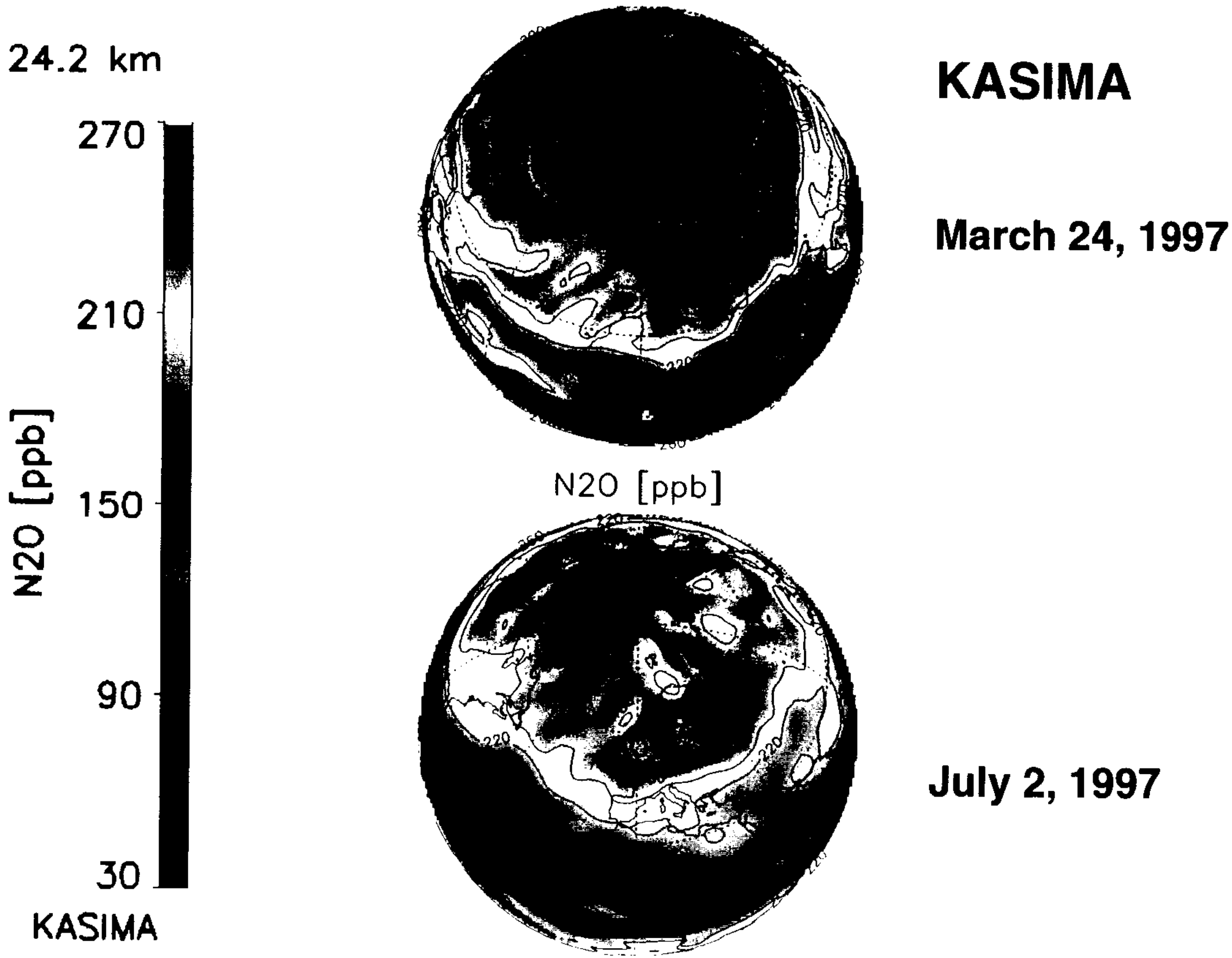
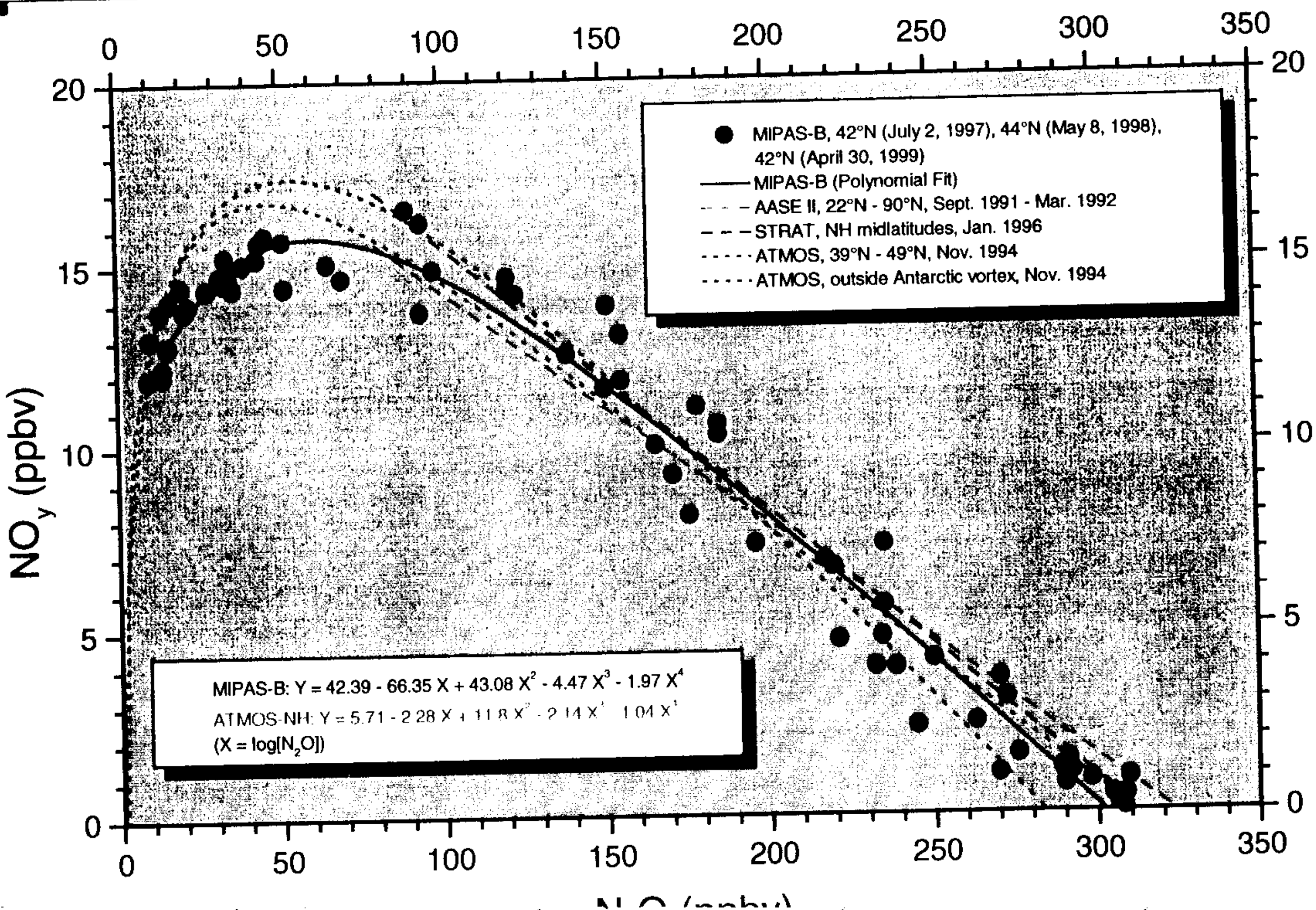
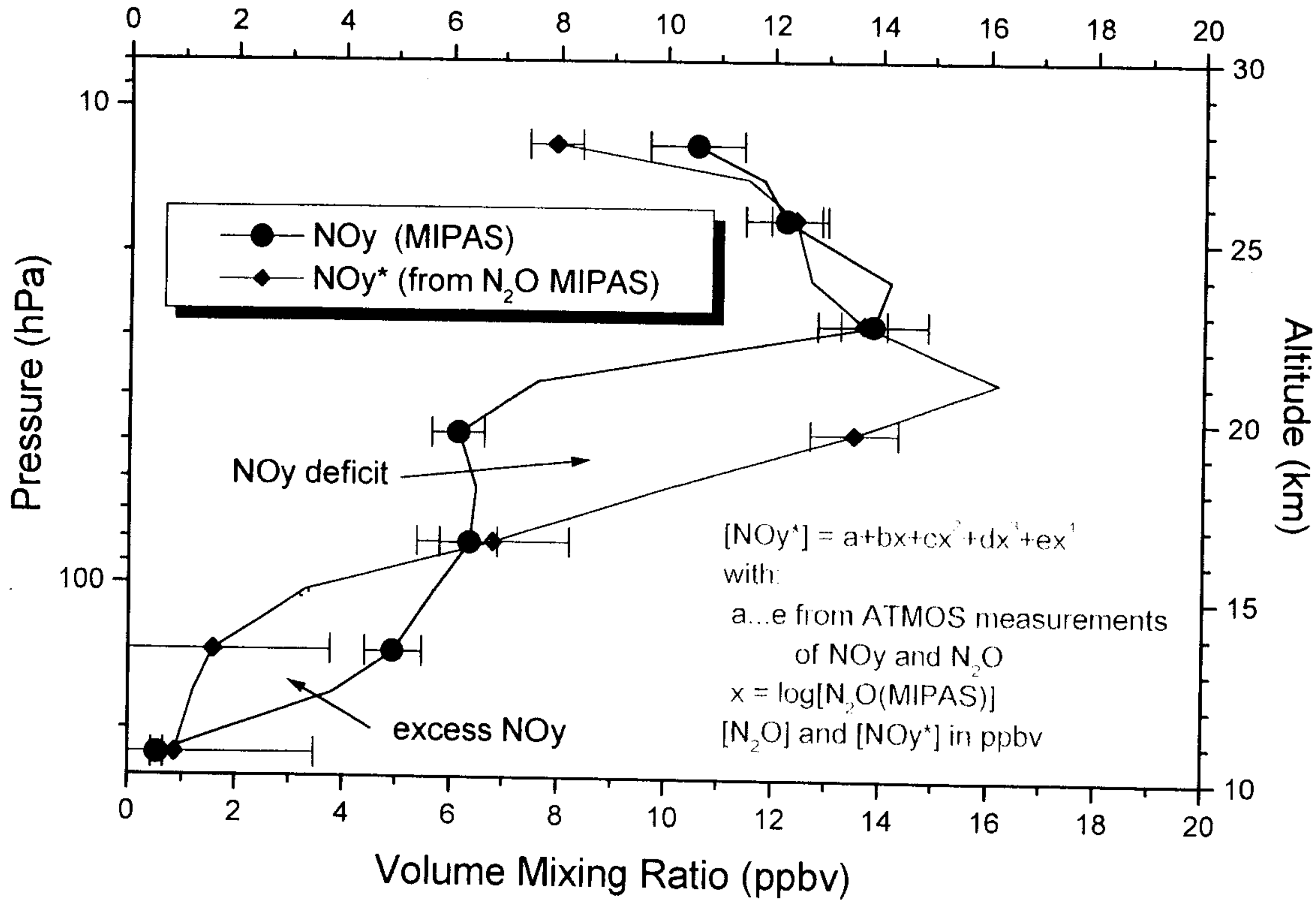
Technik und Umwelt



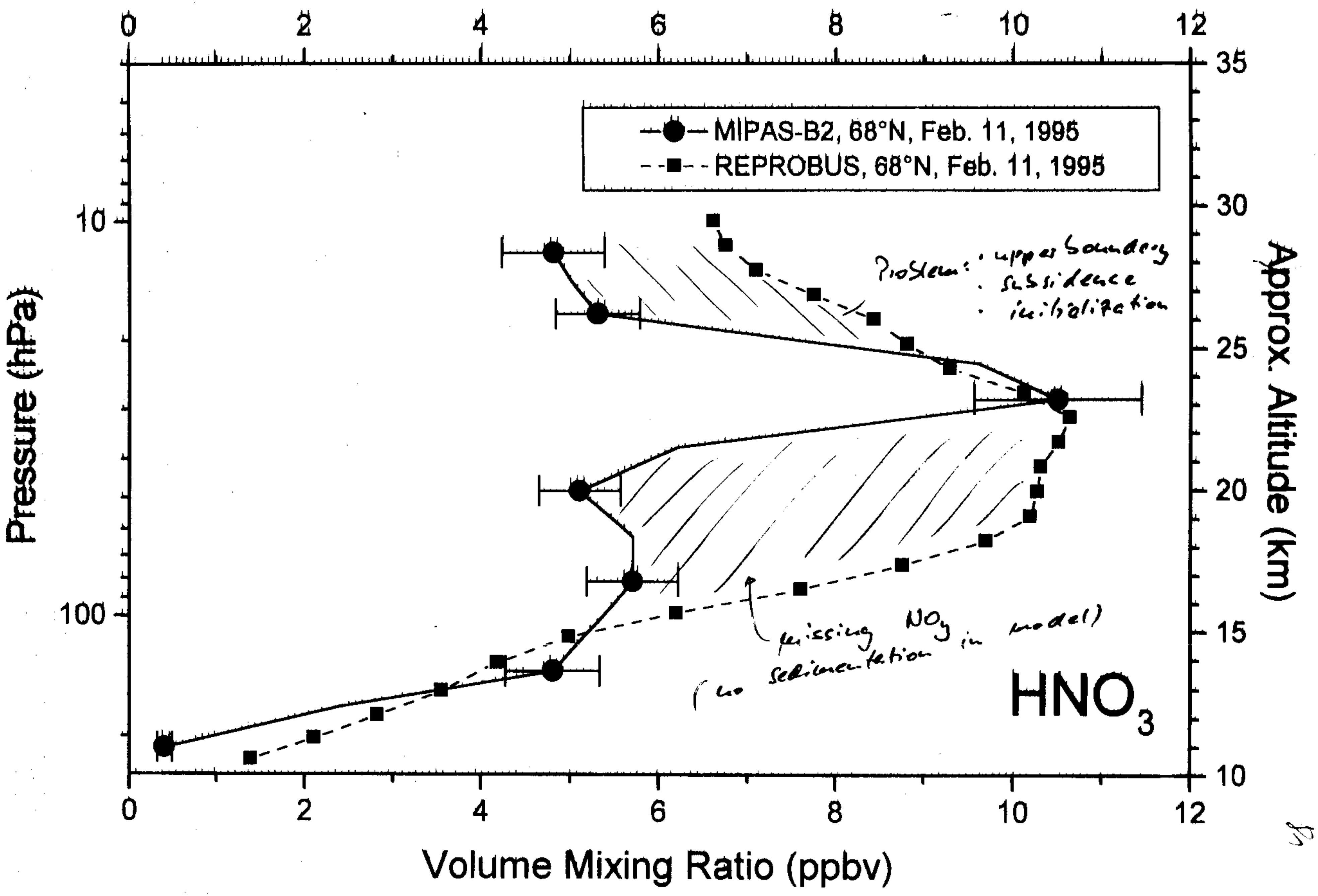

24.2 km
270
210
150
90
30
N2O [ppb]
KASIMA
N2O [ppb]
KASIMA
March 24, 1997
July 2, 1997


MIPAS-B, 42°N (July 2, 1997), 44°N (May 8, 1998), 42°N (April 30, 1999)
MIPAS-B (Polynomial Fit)
AASE II, 22°N - 90°N, Sept. 1991 - Mar. 1992
STRAT, NH midlatitudes, Jan. 1996
ATMOS, 39°N - 49°N, Nov. 1994
ATMOS, outside Antarctic vortex, Nov. 1994
MIPAS-B: Y = 42.39 - 66.35 X + 43.08 X2 - 4.47 X3 - 1.97 X4
(X = log[N2O])
NOy (ppbv)
0
50
100
150
200
250
300
350
0
5
10
15
20



Pressure (hPa)
Altitude (km)
Volume Mixing Ratio (ppbv)
NOy (MIPAS)
NOy* (from N_2O MIPAS)
NOy deficit
excess NOy
$[NOy^*] = a+bx+cx^2+dx^3+ex^4$
with:
a...e from ATMOS measurements
of NOy and N_2O
$x = \log[N_2O(MIPAS)]$
$[N_2O]$ and $[NOy^*]$ in ppbv

REPROBUS : CTM   courtesy : F. Lefèvre, Meteo France

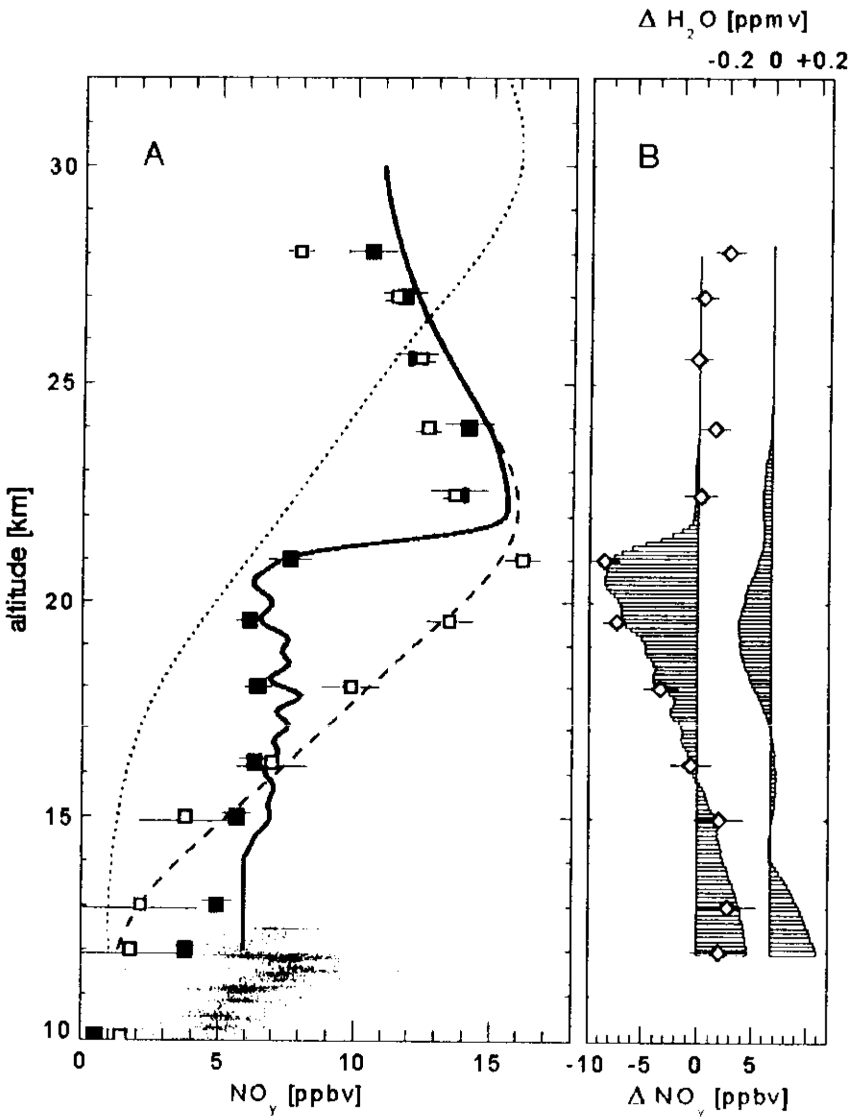


Reprint Series
26 March 1999, Volume 283, pp. 2064–2069

SCIENCE

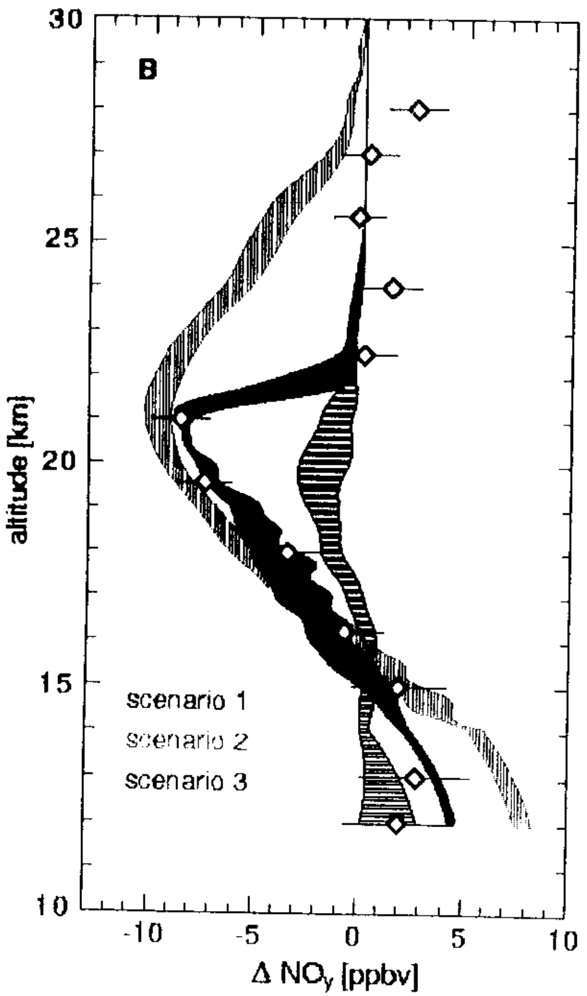
Arctic Ozone Loss Due to Denitrification

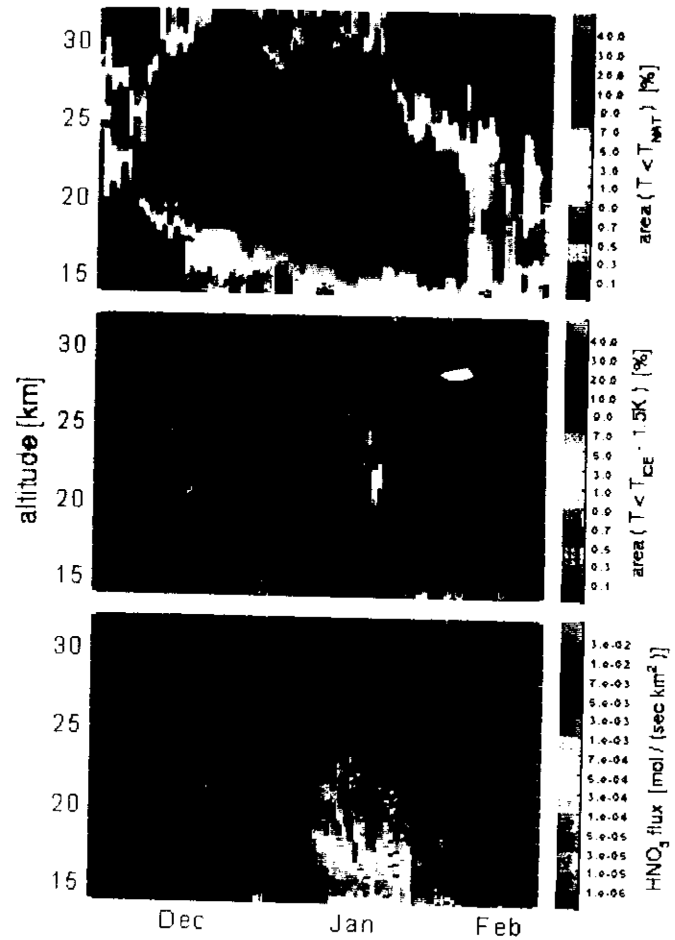
A. E. Waibel,[1*] Th. Peter,[1†] K. S. Carslaw,[1‡] H. Oelhaf,[2]
G. Wetzel,[2] P. J. Crutzen,[1] U. Pöschl,[1§] A. Tsias,[1] E. Reimer,[3]
and H. Fischer[1]

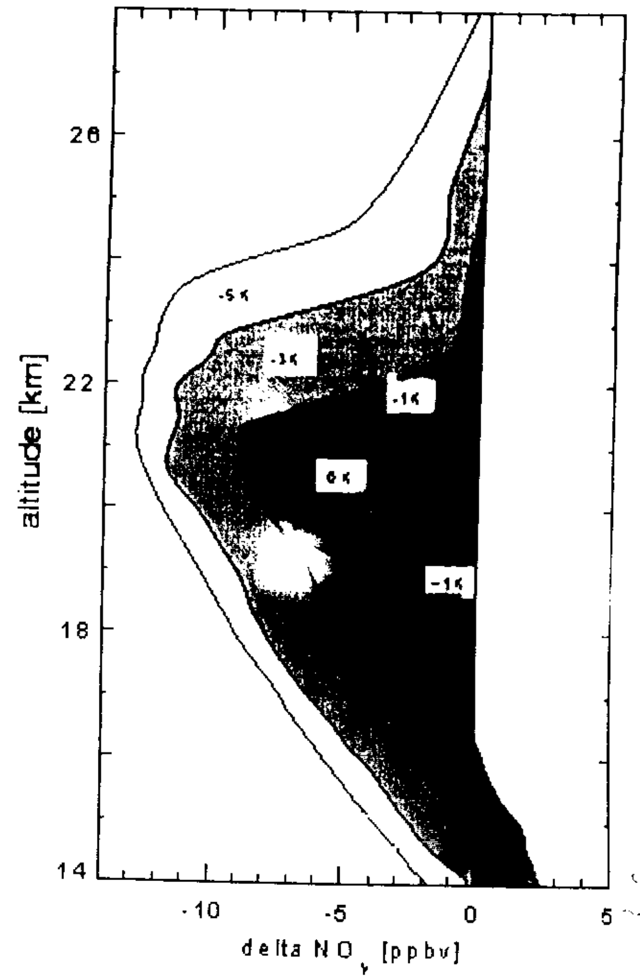

A
B
altitude [km]
NO_y [ppbv]
ΔNO_y [ppbv]
ΔH_2O [ppmv]
-0.2 0 +0.2
30
25
20
15
10
0
5
10
15
-10
-5
0
5

Forschungszentrum Karlsruhe
Technik und Umwelt

Waibel et al.
Science, 238, 1999







Waibel et al., Science 238, 1999

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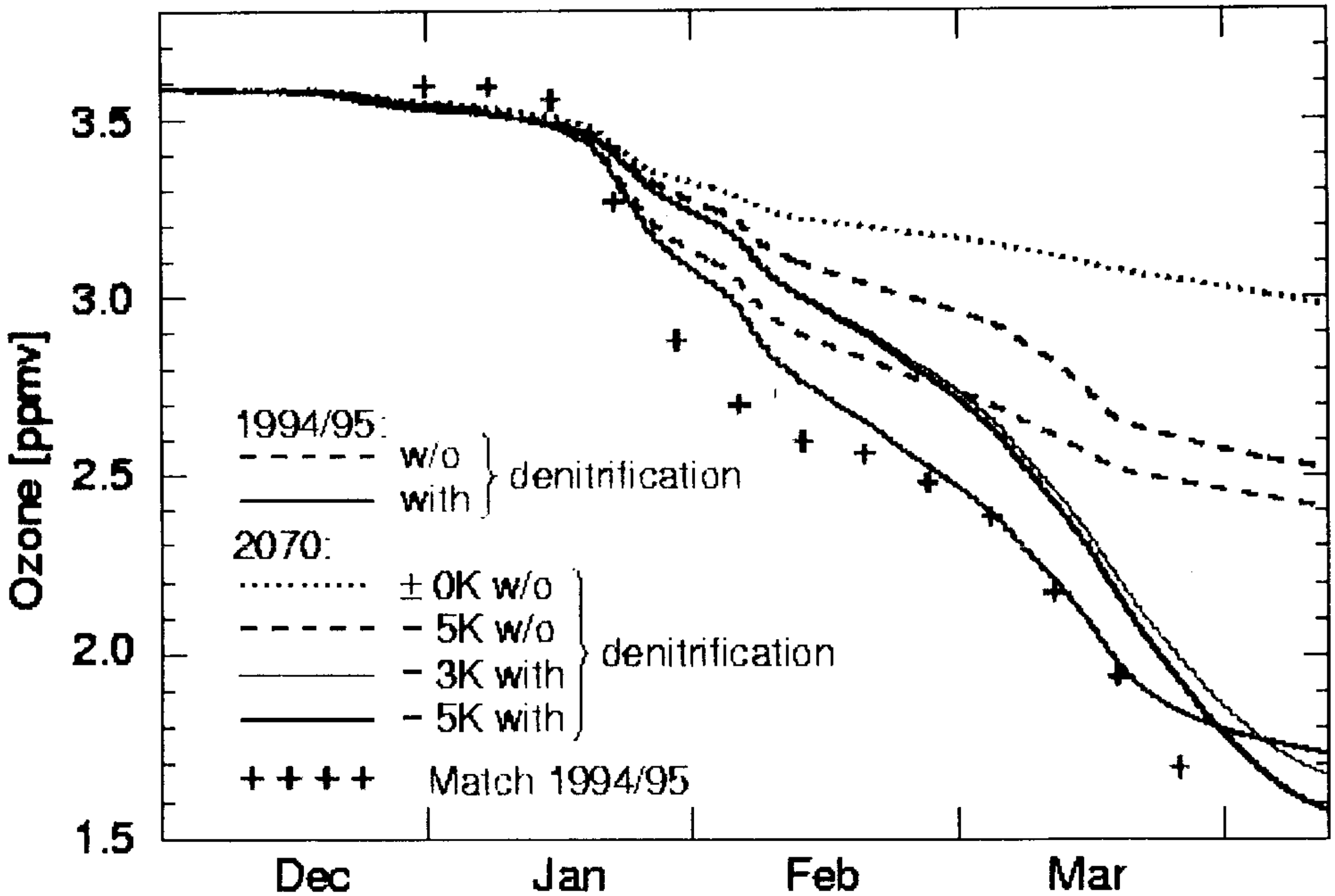
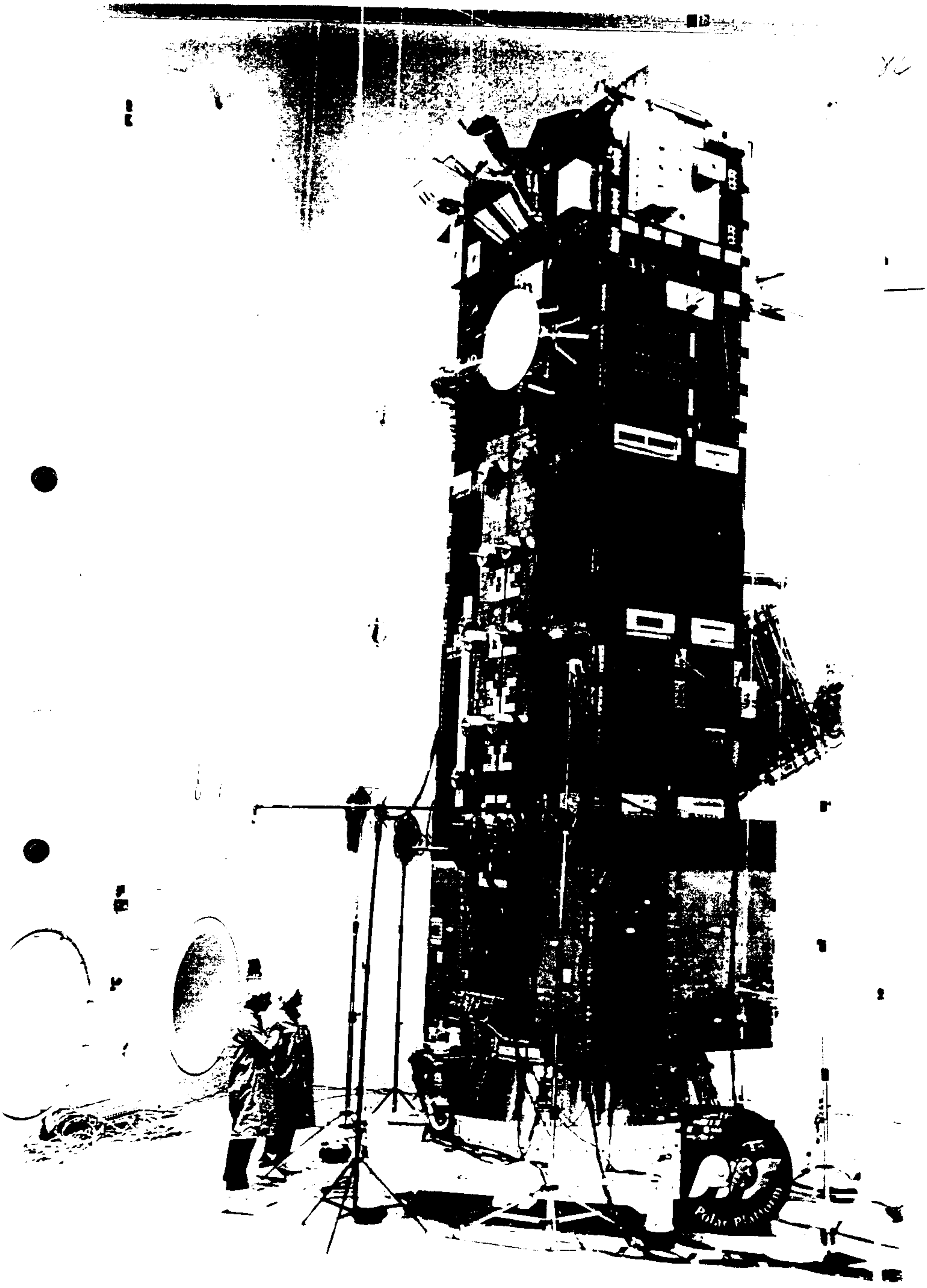
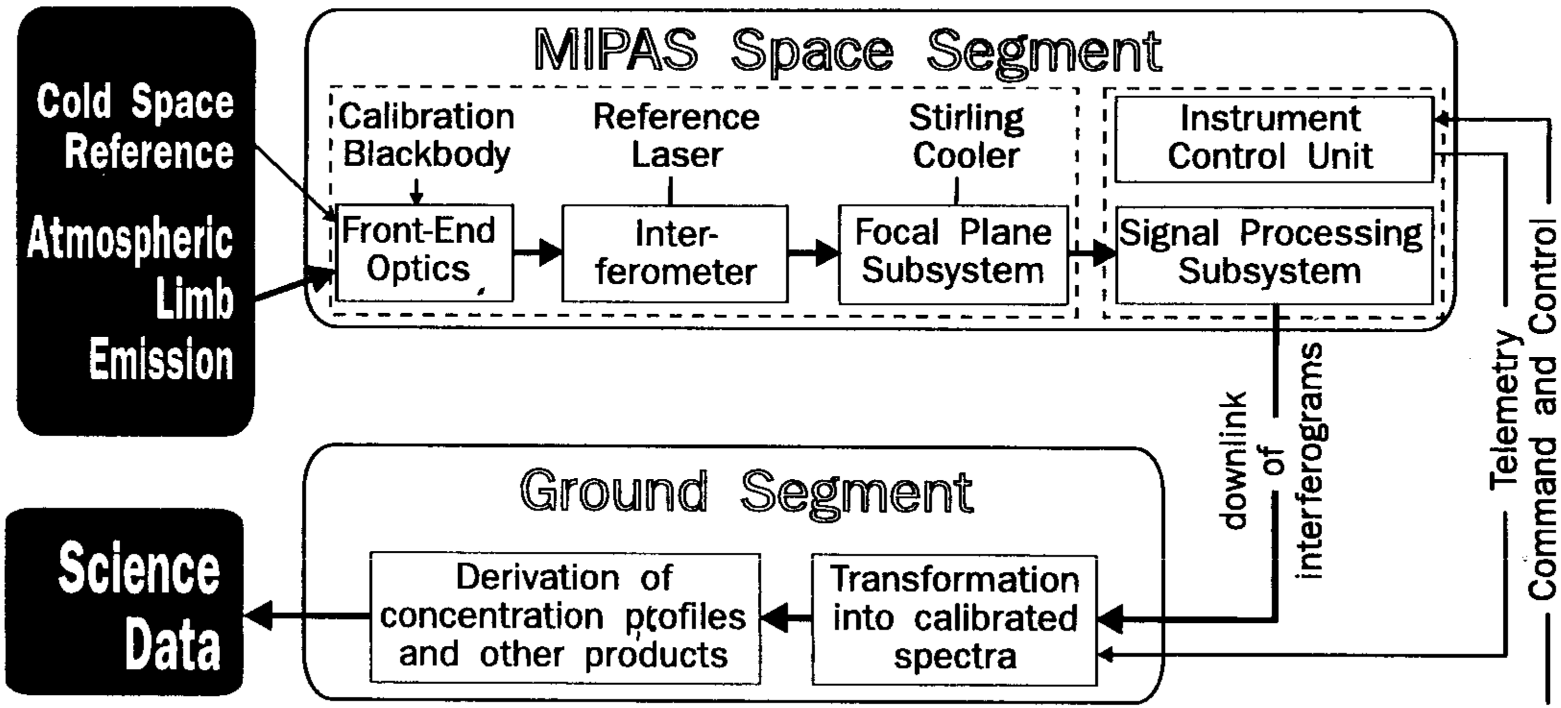



Polar Platform

Subsystem Breakdown



II. Science

Science Objectives

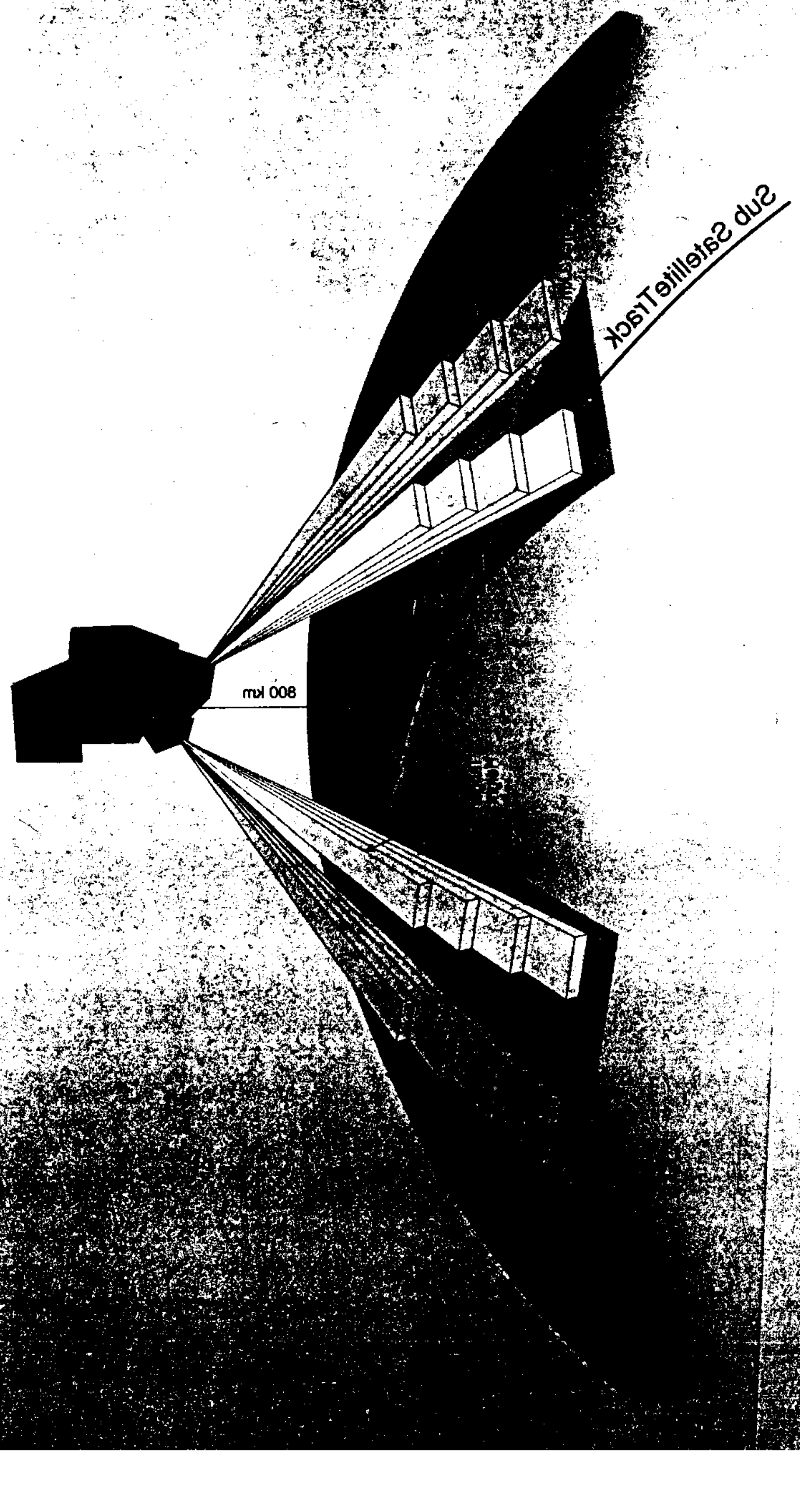
MIPAS has been conceived to derive data for

Stratospheric Chemistry:
- global Ozone problem, polar stratospheric clouds..

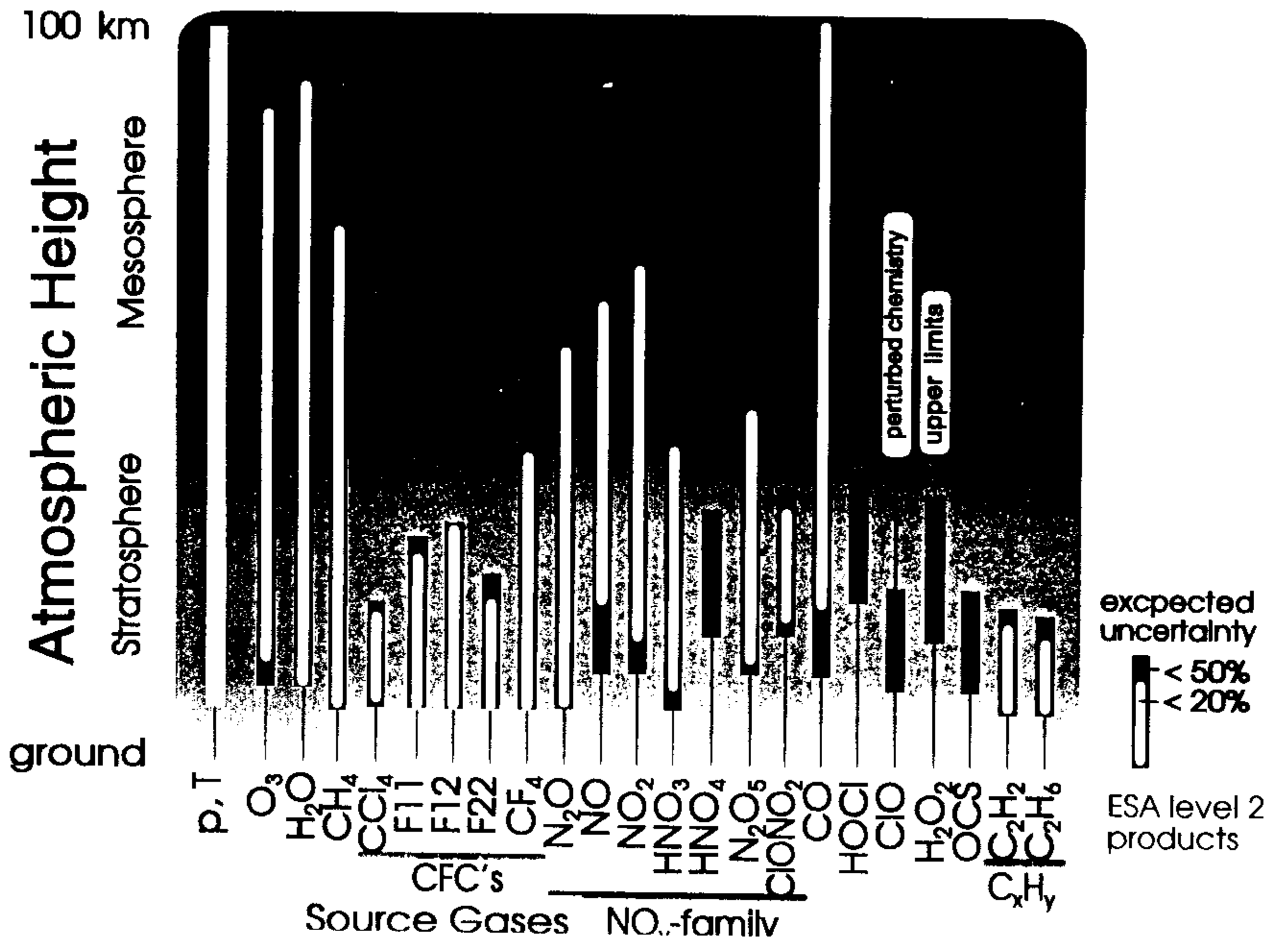
Global Climatology:
- global distribution of climate relevant constituents..

Atmospheric Dynamics:
- stratospheric transport, tropospheric/stratospheric exchange..

Upper Tropospheric Chemistry:
- correlation of gas distribution with human activities..


Sub SatelliteTrack
800 km

Detectable Atmospheric Species



Special Observation Modes

(V3.1, February 99)

No.	Scientific Objectives	Primary Target Parameters/Gases	Altitude Range	Vertical Spacing	Horizontal Spacing	Azimuth Mode	Coverage	Frequency of Observations (prelim.)/ Remarks
S1	Polar Chemistry and Dynamics (perturbed chemistry at increased spatial resolution, denitrification, vortex erosion, transport of vortex air)	p,T, O3, N2O, CH4, H2O, HNO3, NO, NO2, N2O5, ClO, HOCl, ClONO2, aerosol, PSCs	55 – 8 km	55, 45, 37, 30, then 26 to 8 km in 2km steps	~440 km (14 angles per limb sequence)	RW[1]	40 to 90 ° winter hemisphere	regularly from 2[nd] year on switch between NH and SH on June 1[st] and Dec 1; to be combined with mode N in (sub)tropics and summer hemisphere
S2	• Troposph./Stratosph. Exchange Processes (upward/downward transport, altitude of hygropause/tropop.) • Tropospheric Chemistry;	p,T, O3, N2O, CH4, H2O, CO, CFCs, SF6, C2H2, C2H6, HNO3, (NO2), (NO), others (tbd), cirrus clouds	40 – 5 km	40, 30, 25 km, then 20 to 5 km in 1.5 km steps	~440 km (14 angles per limb sequence)	RW[1]	global	each one week per month over one year
S3	Impact of Aircraft Emissions	p,T, O3, H2O, HNO3, NO, NO2, ClONO2, N2O, CH4, aerosol, PSCs	40 -6 km	40, 30, 23, 18 km, then 15 to 6 km in 1.5 km steps	~340 km (RW option) (11 angles per limb sequence)	RW[1] or CT[2] (tbd)	primarily north of 25° N latitude	a few days in summer and winter sideways option preferred

Data Processing