

Modernes Bild der
Brewer-Dobson-Zirkulation
↳ meridionale Winde
langsamer Transport

winterliche
Polarwirbel:
Abkühlung
Tiefdrucksystem

Welle hat Impuls:
Pole entgegen
gerichtet → Pole
Störung

extratropical
suction
pump

Kolton et al.
early 1990s

Polarwertsbergung

Fig. 3.15. Streamlines of the diabatic circulation obtained by Dunkerton (1978). (Copyright by the American Meteorological Society).

Meridional temperature and the Brewer-Dobson Circulation

- The zonal mean of temperature shows a minimum at the Tropics near the tropopause (also referred to as the „cold Tropical tropopause layer“). Water reaching this altitude is freezing and therefore, through sedimentation, hindered to mix into the stratosphere.
- The streamlines of circulation show in the Winter Hemisphere a slow meridional circulation from the Tropics towards the Winter Pole (Alan Brewer 1949)
- This circulation is driven by propagating waves in the mid-latitudes and referred to as the „extratropical pump“.
- The circulation has large implications for ozone transport: in the Winter Hemisphere ozone is shifted from its source region (Equator) towards the Pole

MEASURES OF ATMOSPHERIC COMPOSITION

Concentration of species "s"

Measures:	Symbols	Dimension, Einheiten
molecule number density	$n_s = [s]$, z.B. $n_{O_3} = [O_3]$	$\frac{\# \text{ molecules "s"}}{\text{Volumen}}$, z.B. cm^{-3}
mass density	m_s , z.B. m_{O_3}	$\frac{\text{mass of "s"}}{\text{Volumen}}$, z.B. $\frac{\text{g}}{\text{m}^3}$
volume mixing ratio	χ_s , z.B. χ_{O_3}	$\frac{\# \text{ molecule "s"}}{\# \text{ molecule air}}$, z.B. $10^{-6} = \text{ppmv}$ $10^{-9} = \text{ppbv}$ $10^{-12} = \text{pptv}$
mass mixing ratio	μ_s , z.B. μ_{O_3}	$\frac{\text{mass of "s"}}{\text{mass of air}}$, z.B. $\mu\text{g}/\text{kg}$
column density	$C_s = \int_0^{\infty} n_s dz$	Einheit z.B. cm^{-2}
speziell O_3	$C_{O_3} = \int n_{O_3} dz$	$\text{DU} \approx \text{Dobson units (STP)}$ $\approx 10^{-2} \text{ mm pure } O_3$

Number density n_X [molecules cm^{-3}]

$$n_X = \frac{\text{\# molecules of X}}{\text{unit volume of air}}$$

Proper measure for

- calculation of reaction rates
- optical properties of atmosphere

n_X and χ_X are related by the ideal gas law:

$$n_X = n_a \chi_X = \frac{N_A P}{RT} \chi_X$$

ideale Gasgleichung:
$$P = n_a kT = n_a \frac{R}{N_A} T$$

Also define the mass concentration (g cm^{-3}):

$$\rho_X = \frac{\text{mass of X}}{\text{unit volume of air}} = \frac{M_X n_X}{N_A}$$

Column concentration = $\int_0^{\infty} n(z) dz$

**Proper measure for absorption of radiation
by atmosphere**

Mixing ratio or mole fraction χ_s [mol mol⁻¹]

$\chi_s = \frac{\text{\# moles of } s}{\text{mole of air}}$
 remains constant when air density changes
 \Rightarrow robust measure of atmospheric composition

GAS	MIXING RATIO (dry air) [mol mol ⁻¹]
Nitrogen (N ₂)	0.78
Oxygen (O ₂)	0.21
Argon (Ar)	0.0093
Carbon dioxide (CO ₂)	365x10 ⁻⁶ <i>heute 390 ppm</i>
Neon (Ne)	18x10 ⁻⁶
Ozone (O ₃)	(0.01-10)x10 ⁻⁶
Helium (He)	5.2x10 ⁻⁶
Methane (CH ₄)	1.7x10 ⁻⁶
Krypton (Kr)	1.1x10 ⁻⁶

Trace gases

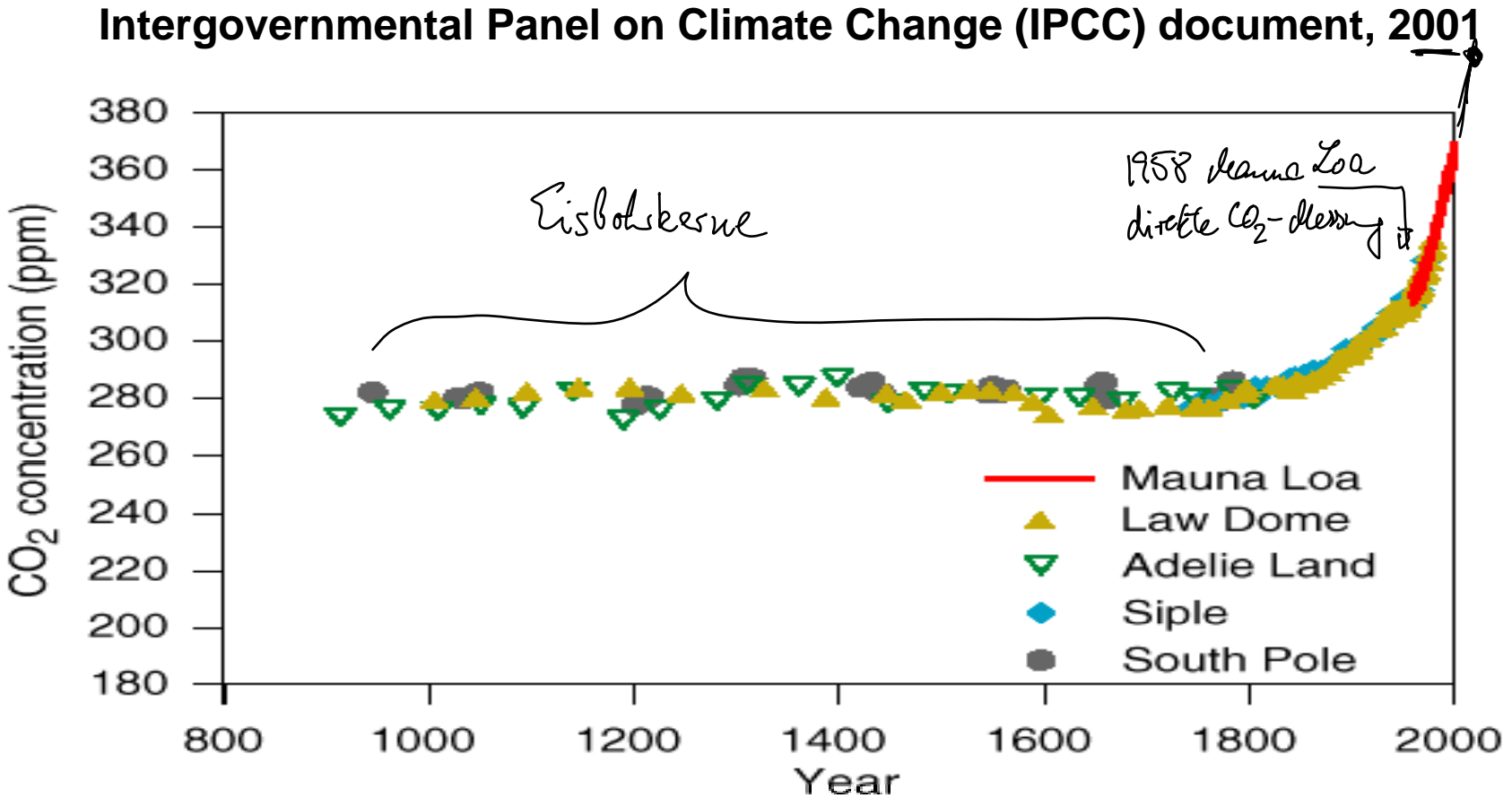
- Air also contains variable H₂O vapor (10⁻⁶-10⁻² mol mol⁻¹) and aerosol particles

- Trace gas concentration units:
 1 ppmv = 1x10⁻⁶ mol mol⁻¹
 1 ppbv = 1x10⁻⁹ mol mol⁻¹
 1 pptv = 1x10⁻¹² mol mol⁻¹

- Molecular weight of dry air:
 $M_a = (0.78 \times 28) + (0.21 \times 32) + (0.01 \times 40)$
 $= 29.0 \text{ g mol}^{-1}$

\rightarrow ~ 10 ppbv troposphärisch
 10 ppm stratosphärisch

ATMOSPHERIC CO₂ INCREASE OVER PAST 1000 YEARS



Concentration units: parts per million (ppm)
number of CO₂ molecules per 10⁶ molecules of air

CO₂ CONCENTRATION IS MEASURED HERE AS MIXING RATIO

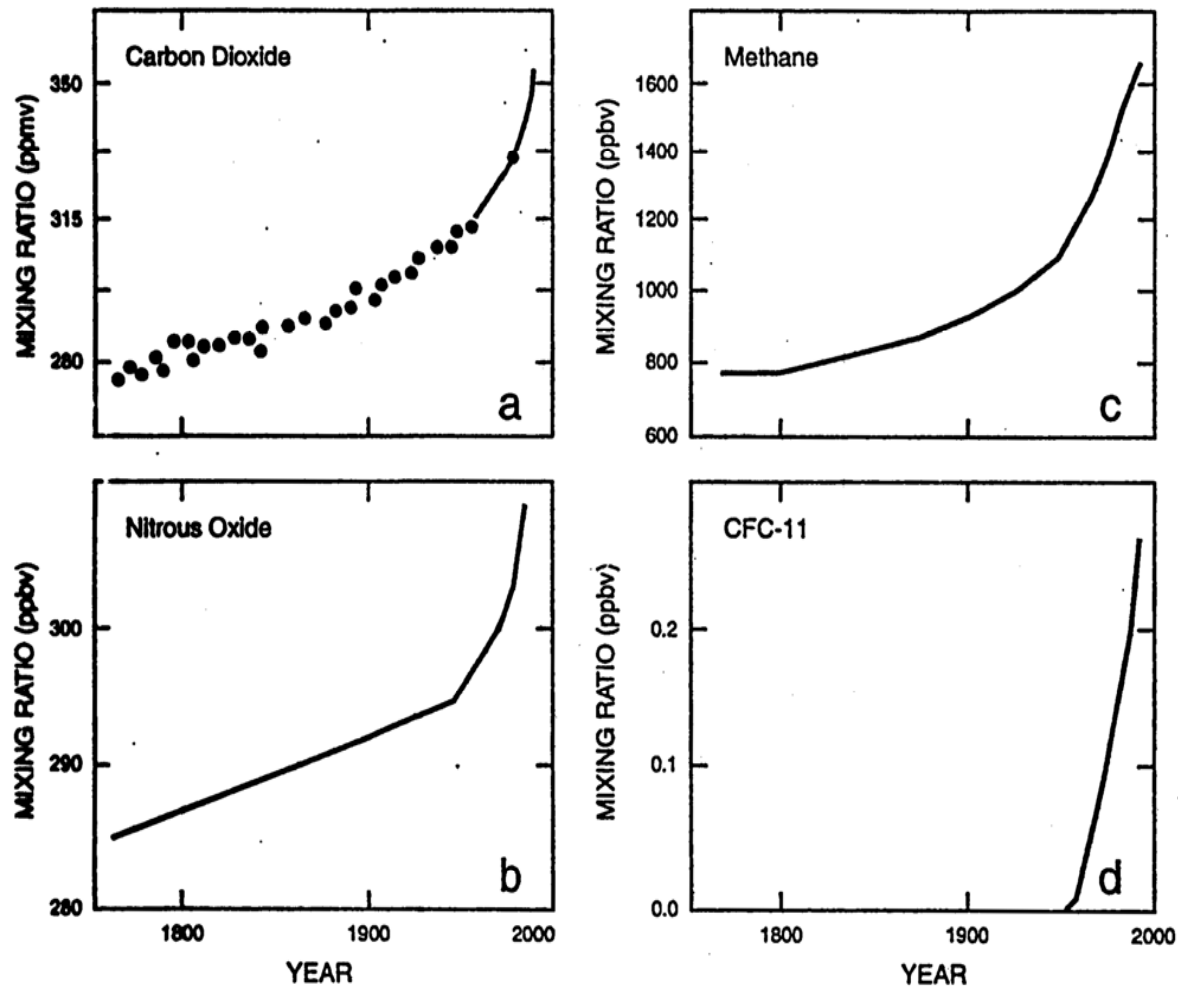
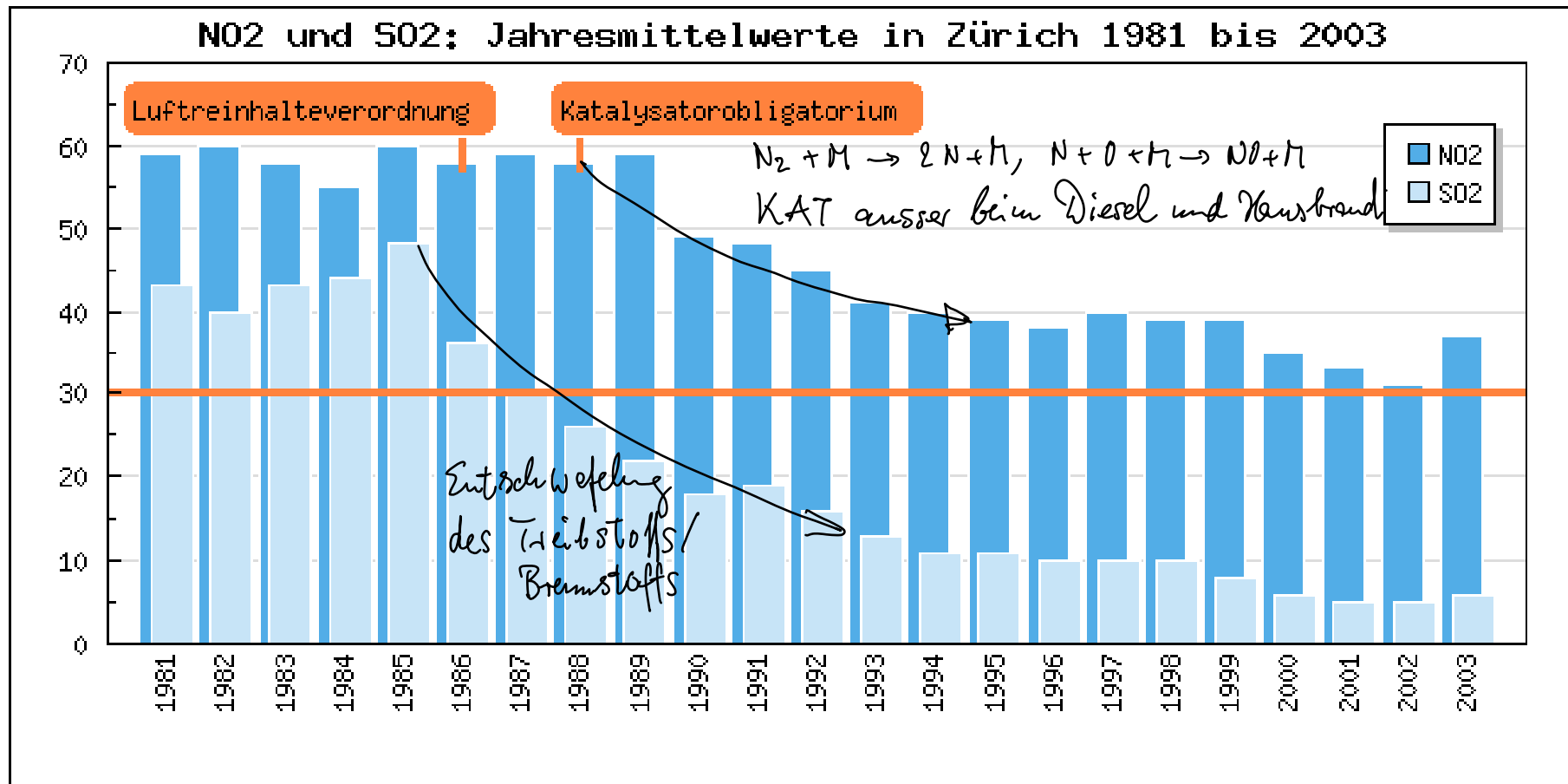


Figure 1.2. Observed increase in the atmospheric abundance of carbon dioxide, nitrous oxide, methane, and chlorofluorocarbon-11 in the surface level atmosphere (Houghton *et al.*, 1990). See Box 1.4 for the definition and units of mixing ratio.

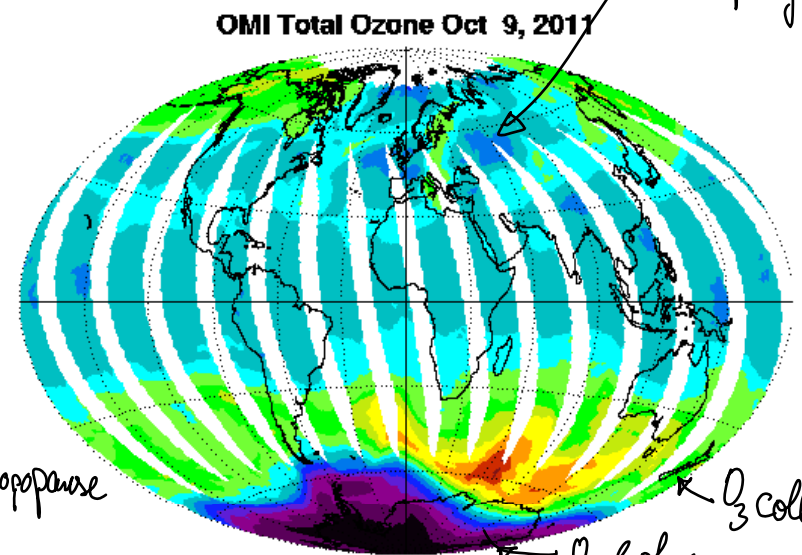
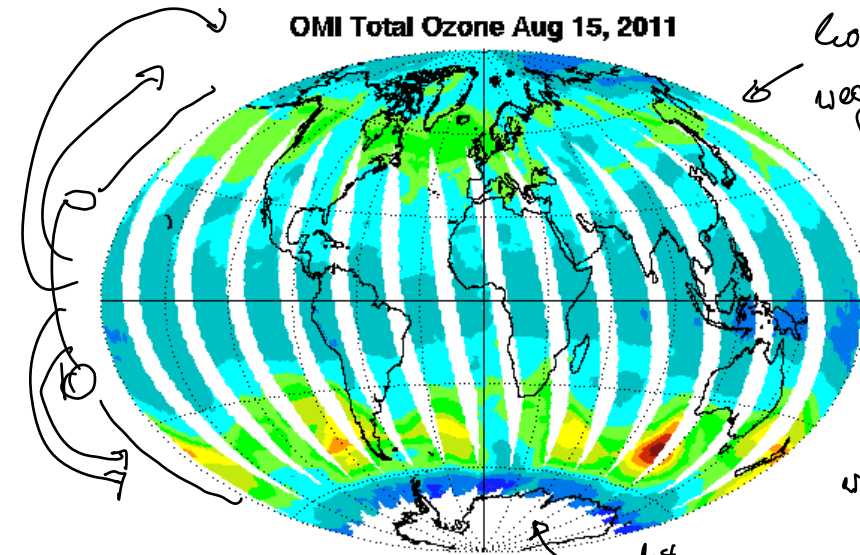


NO₂ and SO₂ during past 2 decades in Zurich. NABEL measurement station at Kasernenhof. Annual mean of NO₂ and SO₂ in µg/kg (= ppb) from 1981 to 2003. Note the decline of NO₂ from 1989 onward and the decline of SO₂ from 1985 onward in response to political and technological measures. The red line marks the legal annual mean concentration limit (30 µg/kg (LRV)) for both NO₂ and SO₂.

(Source: «NABEL Luftbelastung», Schriftenreihe Umwelt Nr. 307, BUWAL, Bern, 2004).

THE STRATOSPHERIC OZONE LAYER NOW:

TOMS : Total O₃ Mapping Spectrometers : $C_{O_3} = \int_0^{\infty} n_{O_3} dz$



1 "Dobson Unit (DU)" = 0.01 mm ozone at STP = 2.69×10^{16} molecules cm^{-2}

THICKNESS OF OZONE LAYER IS MEASURED AS A COLUMN CONCENTRATION

Lifetimes and budgets

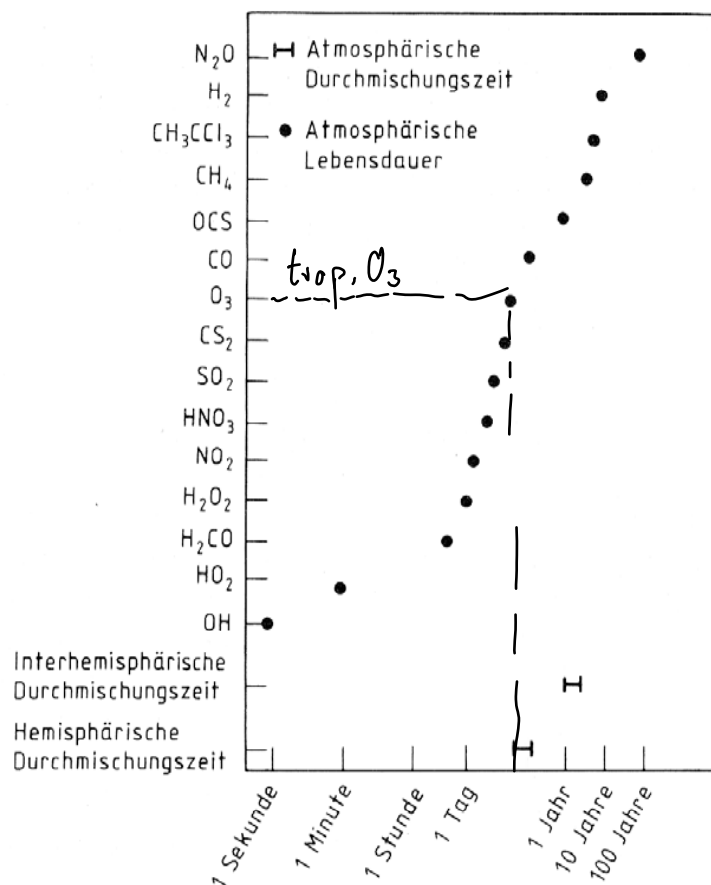


Abb. 20. Atmosphärische Lebensdauern von Spurengasen variieren von einer Sekunde bis zu einem Jahrhundert. (Nach [60])

Table 1. Carbon pools in the major reservoirs on Earth.

Pools	Quantity (Gt)
Atmosphere	720
Oceans	38,400
Total inorganic	37,400
Surface layer	670
Deep layer	36,730
Total organic	1,000
Lithosphere	
Sedimentary carbonates	>60,000,000
Kerogens	15,000,000
Terrestrial biosphere (total)	2,000
Living biomass	600–1,000
Dead biomass	1,200
Aquatic biosphere	1–2
Fossil fuels	4,130
Coal	3,510
Oil	230
Gas	140
Other (peat)	250

Lifetime and Budgets

- Lifetime of important atmospheric compounds (dots) compared to duration of atmospheric air mixing (bars)
- Lifetime of trace gases range from seconds to centuries. This is an important factor for the distribution of species in the atmosphere:
Intra-hemispheric mixing of air lasts several months whereas inter-hemispheric mixing is in the range of 1 to 5 years.
- Compared to the estimation of carbon storage in other compartments (especially the oceans and the lithosphere) the amount in the atmosphere is relatively small, yet very important. Potentially available fossil fuels are about six times larger than today's atmospheric carbon content.

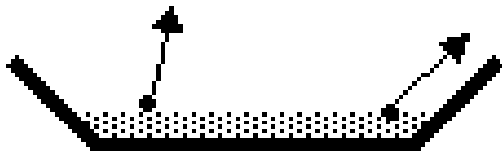
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Partial pressure P_s [Pa]

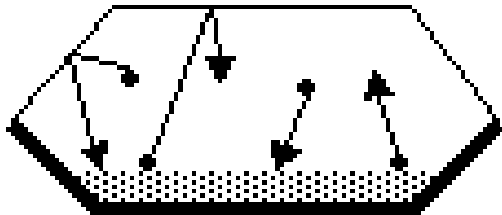
Dalton's law: $P_s = \chi_s P$

Partial pressure is the proper measure for phase change (such as condensation of H_2O)

Evaporation of liquid water from a pan:



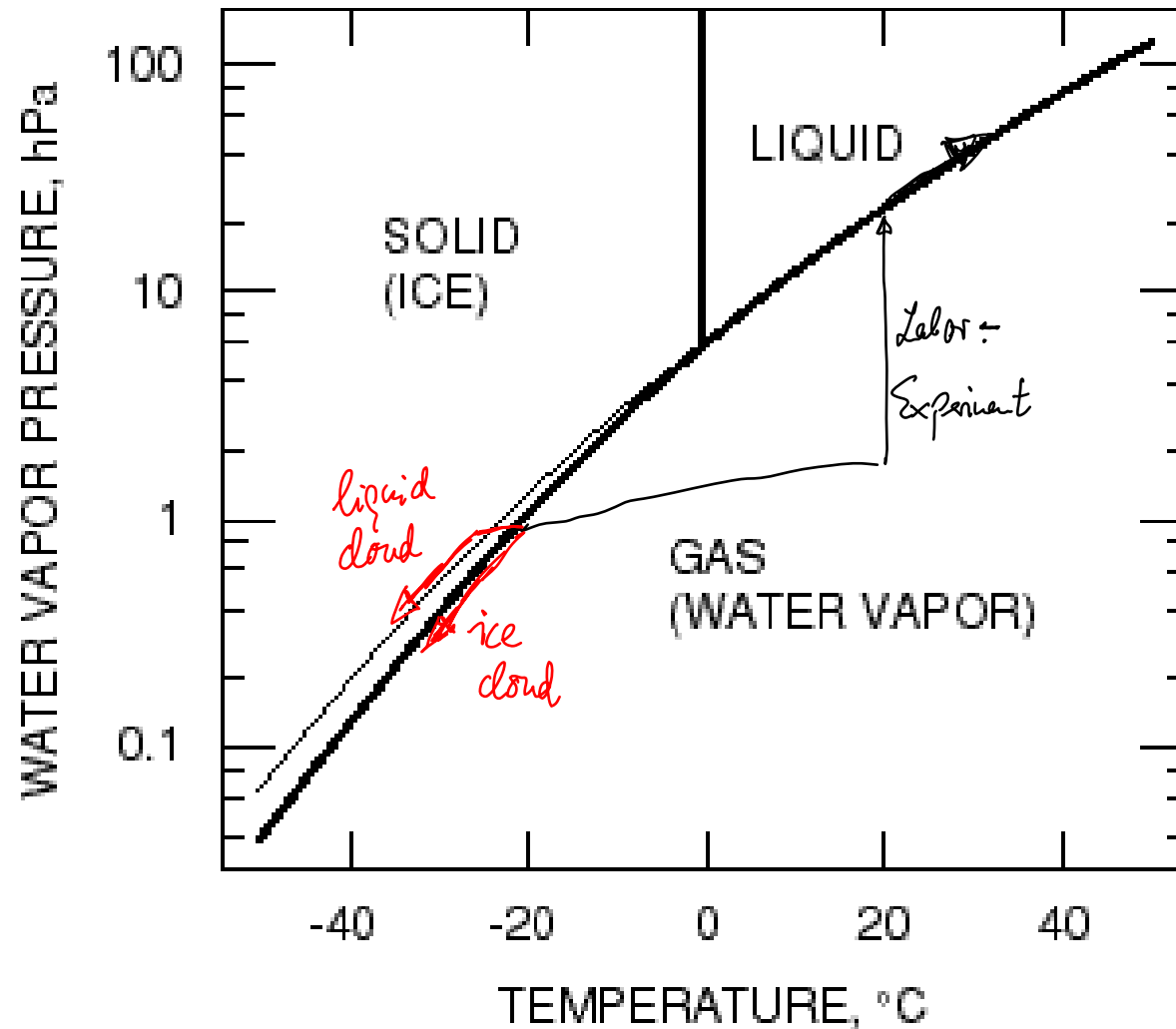
No lid: water molecules escape from pan to atmosphere (evaporation)



Add a lid:

- escaping water molecules collide on lid and return to surface; collision rate measures P_{H_2O}
- eventually, flux escaping = flux returning : saturation ($P_{H_2O,SAT}$)
- growth of cloud formation in atmosphere requires $P_{H_2O} > P_{H_2O,SAT}$
- $T \nearrow \Rightarrow P_{H_2O,SAT} \nearrow$

PHASE DIAGRAM FOR WATER



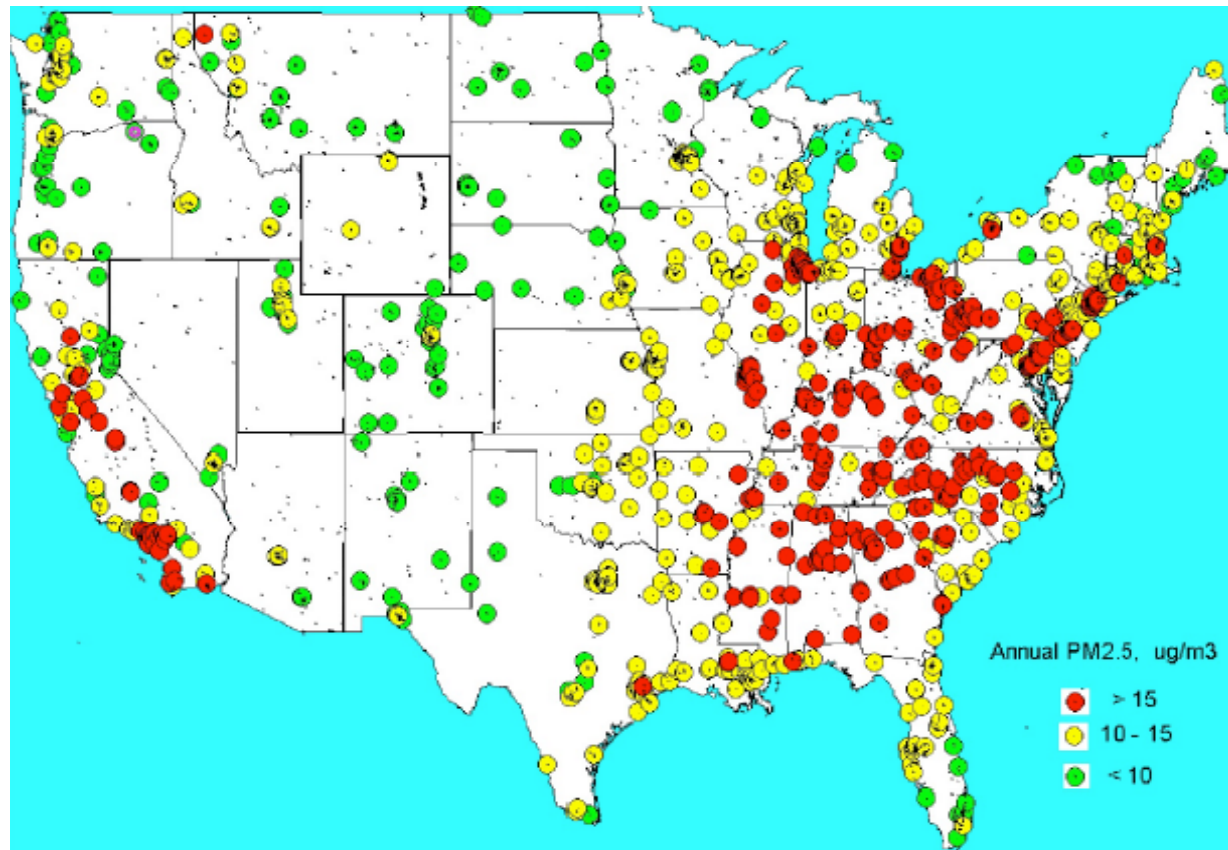
Relative humidity = saturation ratio = $P_{H_2O}/P_{H_2O,SAT}$

Dew point: Temperature T_d such that $P_{H_2O} = P_{H_2O,SAT}(T_d)$

ANNUAL MEAN PARTICULATE MATTER (PM) CONCENTRATIONS AT U.S. SITES, 1995-2000

EPA particulate matter assessment document (NARSTO), 2003

PM2.5 (aerosol particles < 2.5 μm diameter)



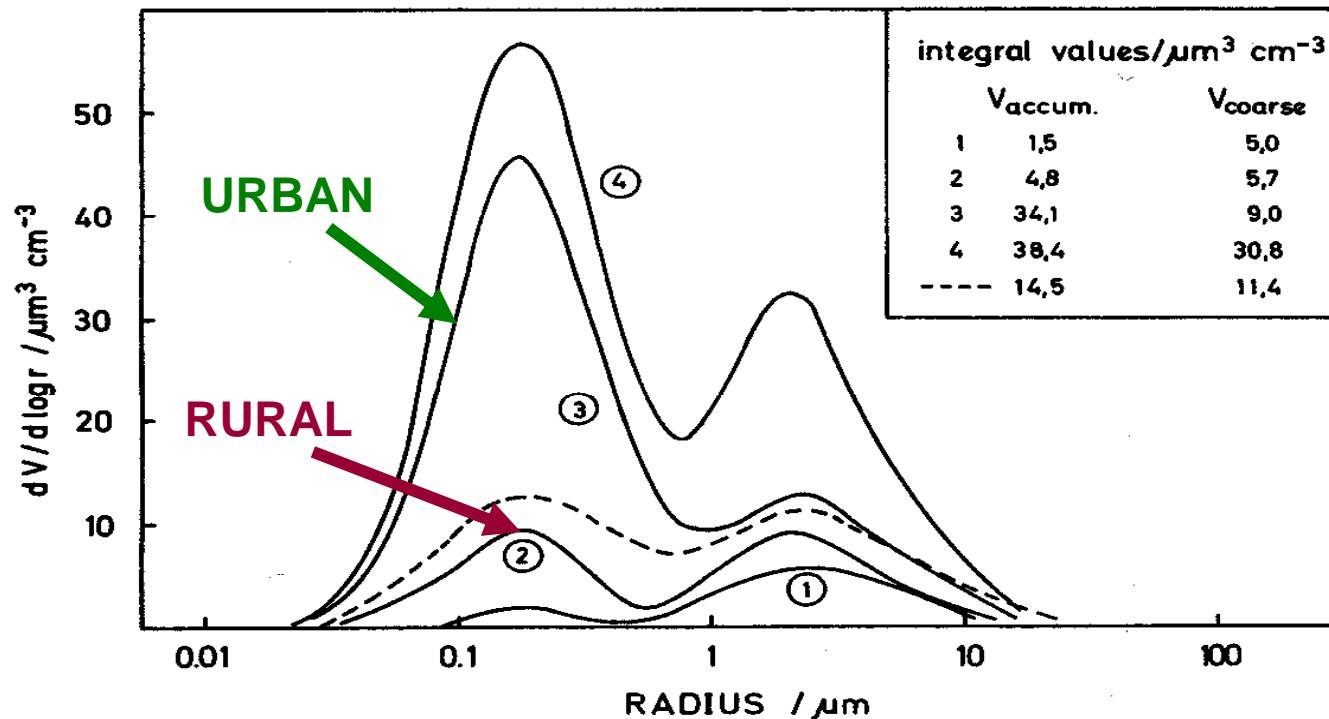
U.S. air quality standard:
PM2.5 = $15 \mu\text{g m}^{-3}$
(annual mean)

Red circles indicate
sites in violation of the
standard

STANDARD IS EXPRESSED AS A MASS CONCENTRATION PER UNIT VOLUME

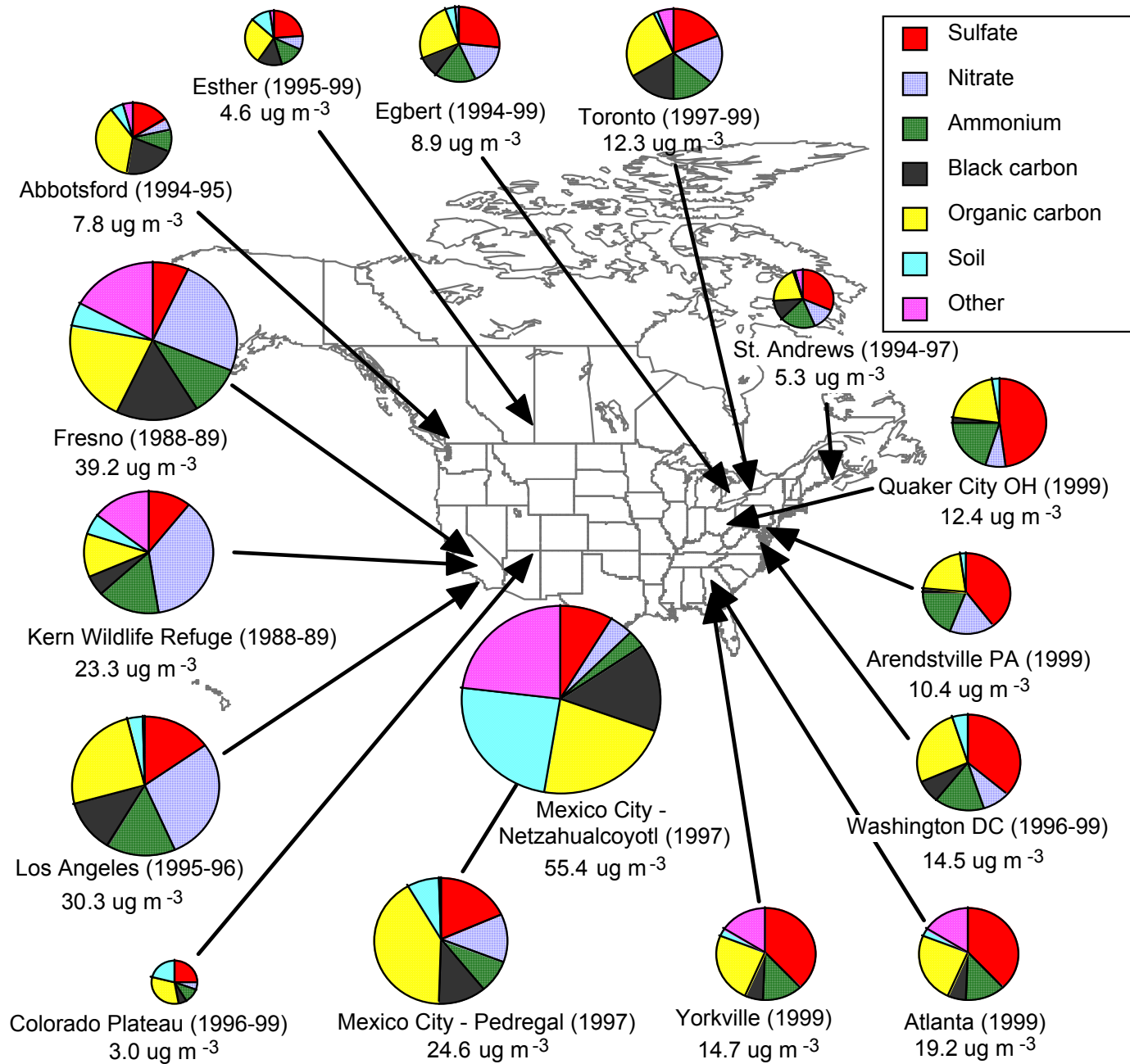
SPECIFIC ISSUES FOR AEROSOL CONCENTRATIONS

- A given aerosol particle is characterized by its **size, shape, phase, and chemical composition** – large number of variables!
- Measures of aerosol concentrations must be given in some **integral** form, by summing over all particles present in a given air volume
- The **aerosol size distribution** must be treated as a continuous function



Typical aerosol size distributions by volume

COMPOSITION OF PM_{2.5} (EPA/NARSTO PM ASSESSMENT, 2003)



Today's problems of atmospheric chemistry, aerosols and clouds

Problems	Compounds	Effects	Scale (temp./geogr.)
winter smog <i>"London Smog, ~1952"</i>	benzene (carcinogenic), SO ₂ , aerosol formation	toxic for humans	days / local (<u>inversions</u>)
summer smog <i>Los Angeles, 1990s</i>	formation of photo-oxidants from VOCs, CO and NO _x , and of aerosol particles <i>→ Volatile Org. Compounds</i> <i>→ photo-chemistry → in situ O₃ production</i>	harvest reductions human health	several days / regional (continental) <i>no winds!</i>
polluted precipi- tation, acid rain	H ₂ SO ₄ and HNO ₃ (from SO ₂ and NO _x)	acidification of soils, N-fertilization	days to weeks / continental
stratospheric ozone destruction	CFCs, halons, H-CFCs (in interaction with CH ₄ , N ₂ O, cloud particles)	UV-B increase at ground level	decades / global
greenhouse effect I	well-mixed GHGs: CO ₂ , CH ₄ , N ₂ O, CFCs; also H ₂ O, O ₃ etc	climate change: warming	decades to centuries / global
greenhouse effect II	aerosols and clouds, direct and indirect effects	partly compensa- ting climate effect: cooling	days to weeks

