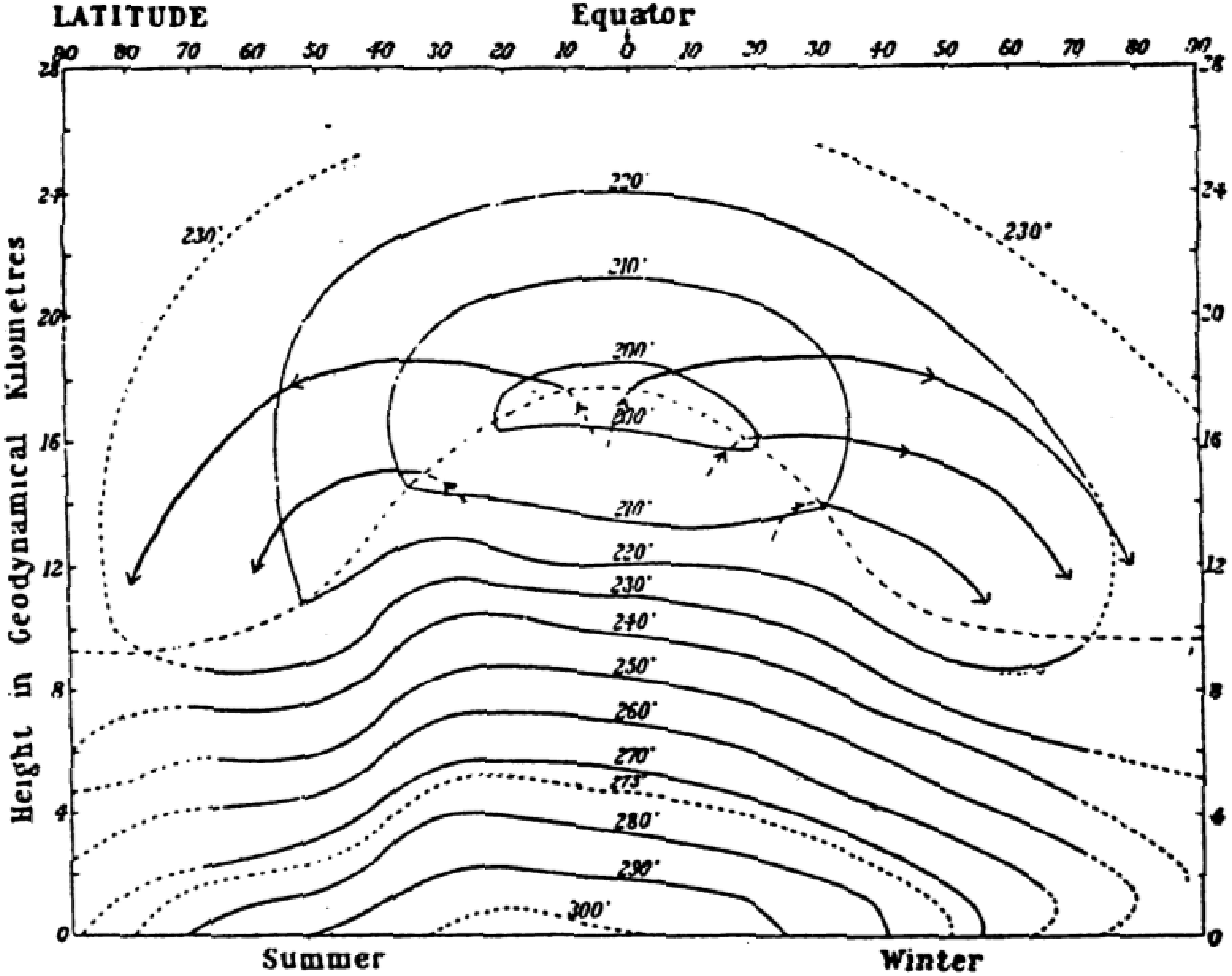
Coupling vertical and latitudinal coordinates

The Brewer-Dobson circulation or mean meridional circulation



Isotherms over the Globe

Fig. 5. A supply of dry air is maintained by a slow mean circulation from the equatorial tropopause.

From Brewer's original work 1949

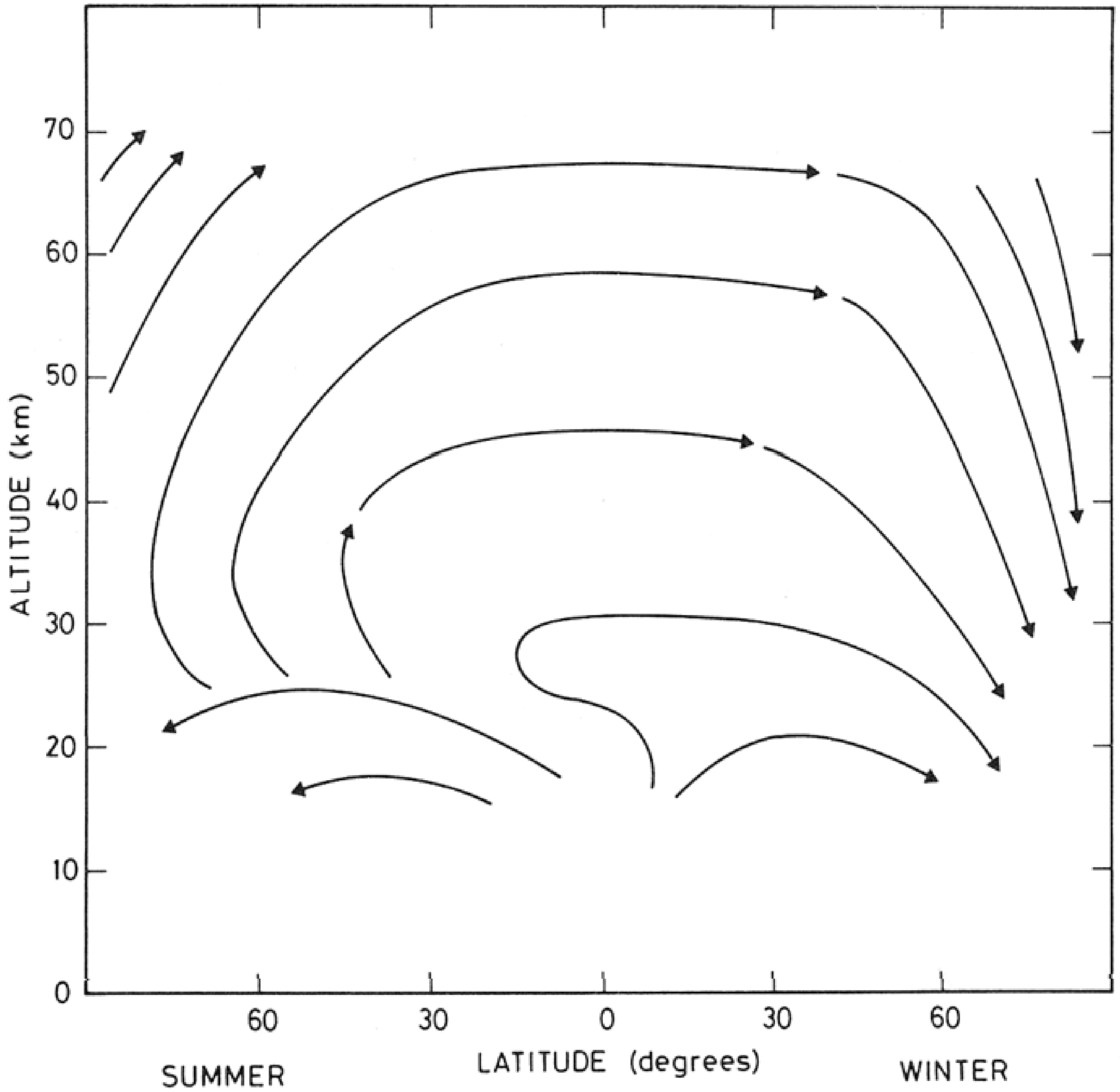


Fig. 3.15. Streamlines of the diabatic circulation obtained by Dunkerton (1978). (Copyright by the American Meteorological Society).

Source: Brasseur and Solomon, 1986

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:

molecule number density

mass density

volume mixing ratio

mass mixing ratio

column density

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:

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

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

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

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

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
⇨ **robust measure of atmospheric composition**

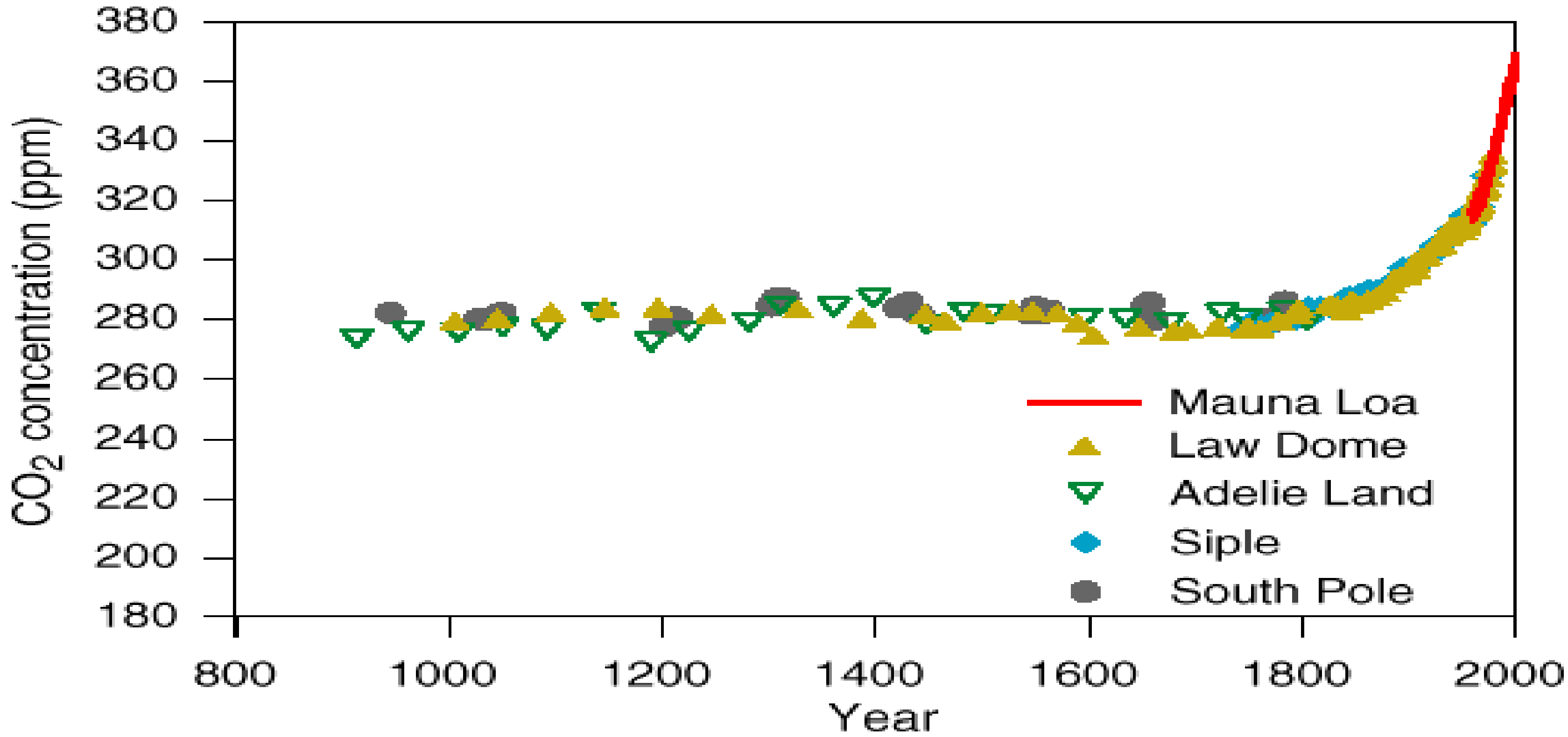
GAS	MIXING RATIO (dry air) [mol mol^{-1}]
Nitrogen (N_2)	0.78
Oxygen (O_2)	0.21
Argon (Ar)	0.0093
Carbon dioxide (CO_2)	365x10^{-6}
Neon (Ne)	18x10^{-6}
Ozone (O_3)	(0.01-10)x10^{-6}
Helium (He)	5.2x10^{-6}
Methane (CH_4)	1.7x10^{-6}
Krypton (Kr)	1.1x10^{-6}

Trace gases (Argon through Krypton)

- Air also contains variable H_2O 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:
  $M_a = (0.78 \times 28) + (0.21 \times 32) + (0.01 \times 40) = 29.0$ g mol^{-1}

ATMOSPHERIC CO_2 INCREASE OVER PAST 1000 YEARS

Intergovernmental Panel on Climate Change (IPCC) document, 2001



Concentration units: parts per million (ppm)
number of CO_2 molecules per 10^6 molecules of air

CO_2 CONCENTRATION IS MEASURED HERE AS MIXING RATIO

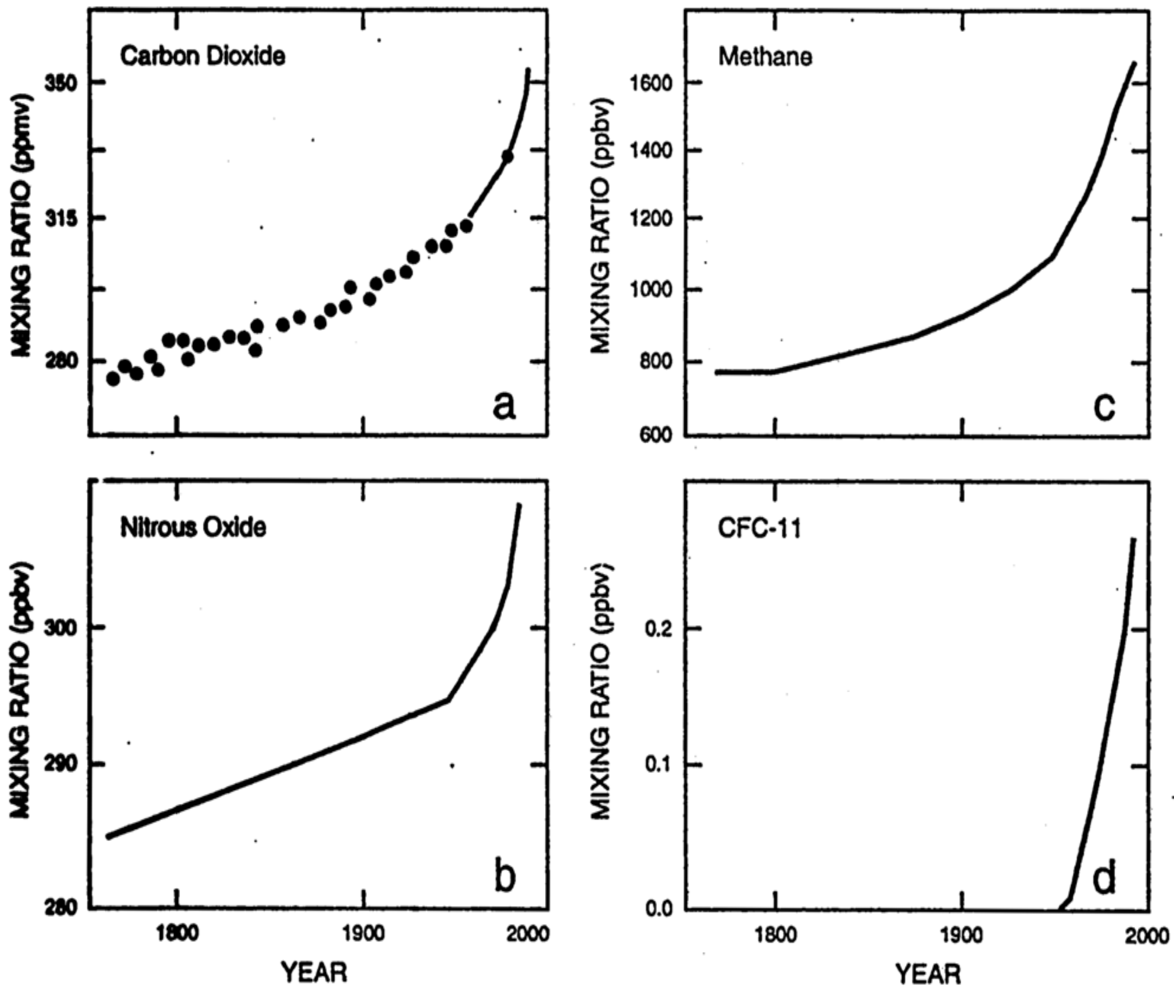


Figure 1.2. Observed increase in the atmospheric abundance of carbon dioxide, nitrous oxide, methane, and chlorofluorocarbon-11 in the surface level atmosphere (Houghton *et al.*, 1990). See Box 1.4 for the definition and units of mixing ratio.