

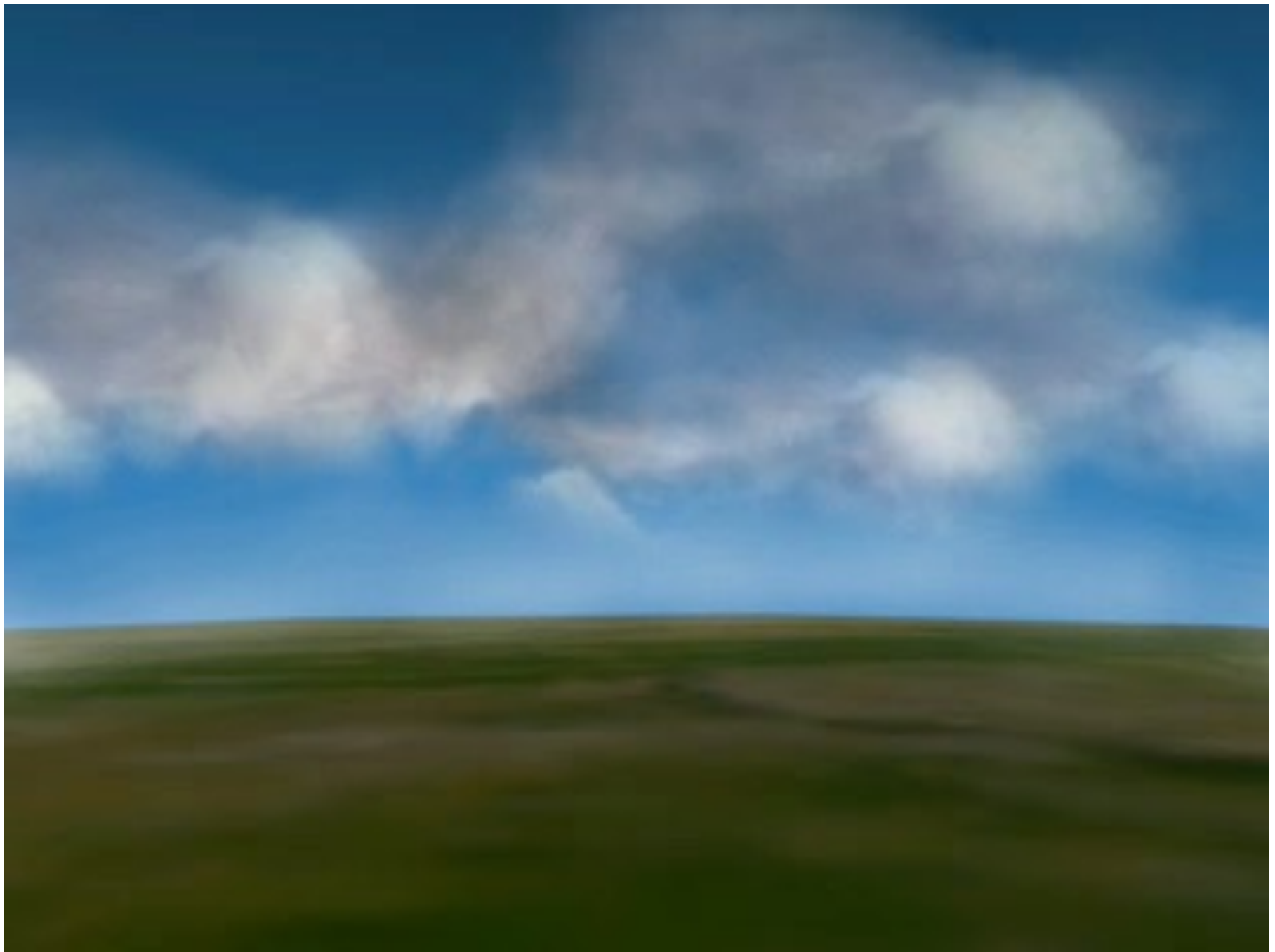
Atmosphere of the Earth and Space Environment SPAT0048 - SPAT0055

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Atmosphere of the Earth

- 5×10^{18} kg (Earth $\sim 6 \times 10^{24}$ kg)
- 75% spreading below 11 km
- N_2 , O_2 , Ar, H_2O , ...
- no clear boundary with space (100 km)
- protects life on Earth (abs. UV)
- heats surface (greenhouse effect)
- damps out day/night variations (Moon: -150 to 250°C)



Atmosphere of the Earth – D. Grodent

Composition of Earth's dry atmosphere (by volume)

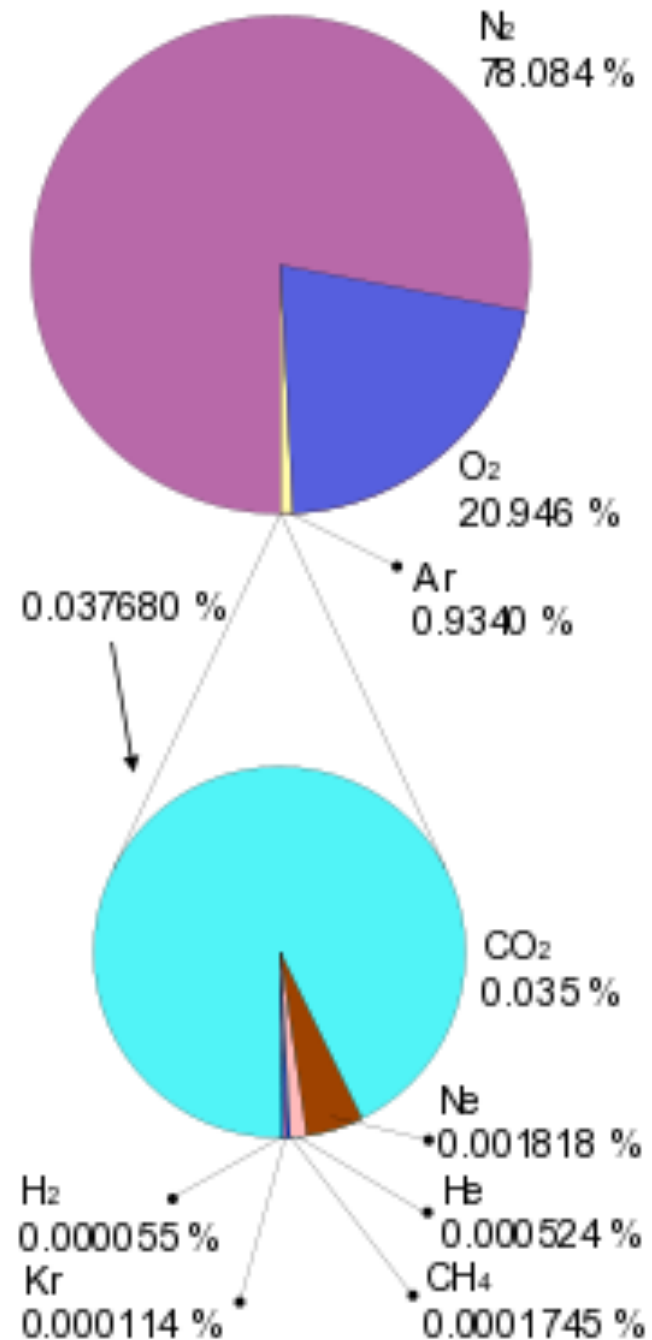
Dalton's Law of Partial Pressures states: (1) Each gas in a mixture of gases exerts a pressure, known as its partial pressure, that is equal to the pressure the gas would exert if it were the only gas present; (2) the total pressure of the mixture is the sum of the partial pressures of all the gases present.

$$P_{\text{total}} = \sum P_{\text{partial}} = 1.01325 \times 10^5 \text{ Pa} \quad \text{1 bar}$$

"standard atmosphere"

Corollary: apply the same volume ratios to obtain partial pressures:

$$P_{\text{O}_2} = 20.946/100 P_{\text{total}} = 21.2 \text{ kPa}$$



$$P_{O_2} = 21.2 \text{ kPa}$$

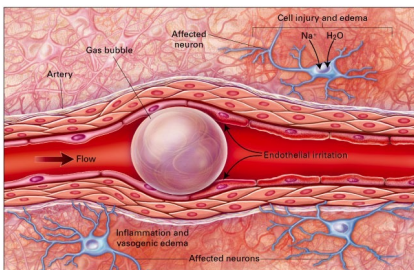
Modern space suits use pure oxygen.

To supply enough oxygen for respiration, a space suit using **pure oxygen** must have a pressure of about 32.9 kPa (*)

"Alveolar gas equation"

This is equal to the 21.2 kPa partial pressure of oxygen in the Earth's atmosphere at sea level, plus 5.3 kPa CO_2 and 6.4 kPa water vapor pressure present in the lungs (at the end of each exhalation the adult human lungs still contain 2,500–3,000 mL of air).

Low pressure $\Rightarrow$ problem with N_2 dissolved in blood forming bubbles.
 $\Rightarrow$ breath pure O_2 and empty N_2 from blood before decreasing pressure of suit.



(*) Gas embolism

Rigidity of suit is proportional to pressure



Alveolar gas equation

$$PAO_2 = FiO_2 \times (P_{atm} - P_{H_2O}) - \frac{PaCO_2}{R}$$

PAO₂ = Alveolar partial pressure of oxygen (13.4 kPa: normal air; **20.0 kPa: suit**)

FiO₂ = Fraction of inspired oxygen (0.21: normal air; **100%: suit**)

P_{atm} = Atmospheric pressure (≈ 101.3 kPa: sea level; **32.9 kPa: suit**)

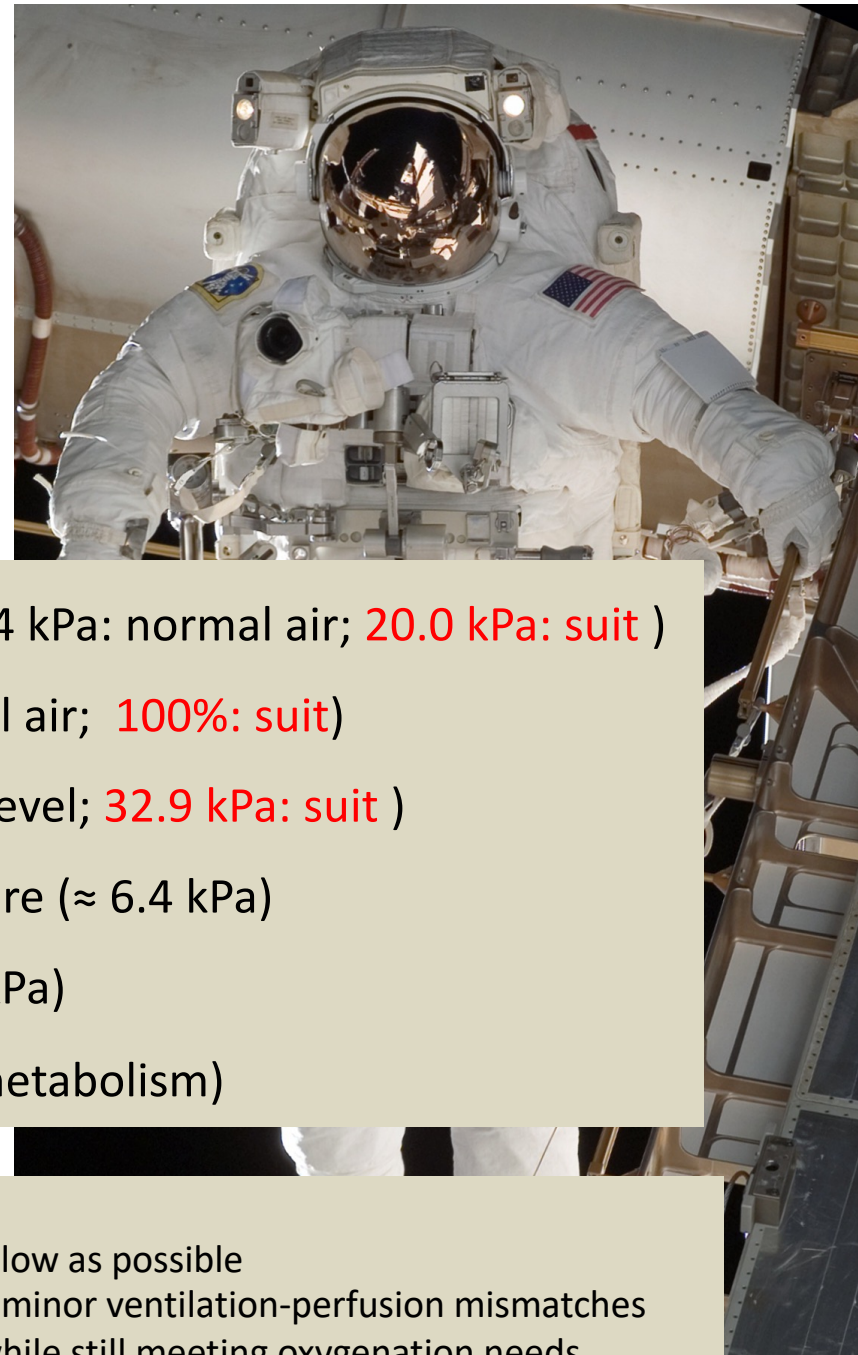
P_{h₂O} = Water vapor pressure at body temperature (≈ 6.4 kPa)

PaCO₂ = Arterial partial pressure of CO₂ (≈ 5.3 kPa)

R = Respiratory quotient (≈ 0.8 under normal metabolism)

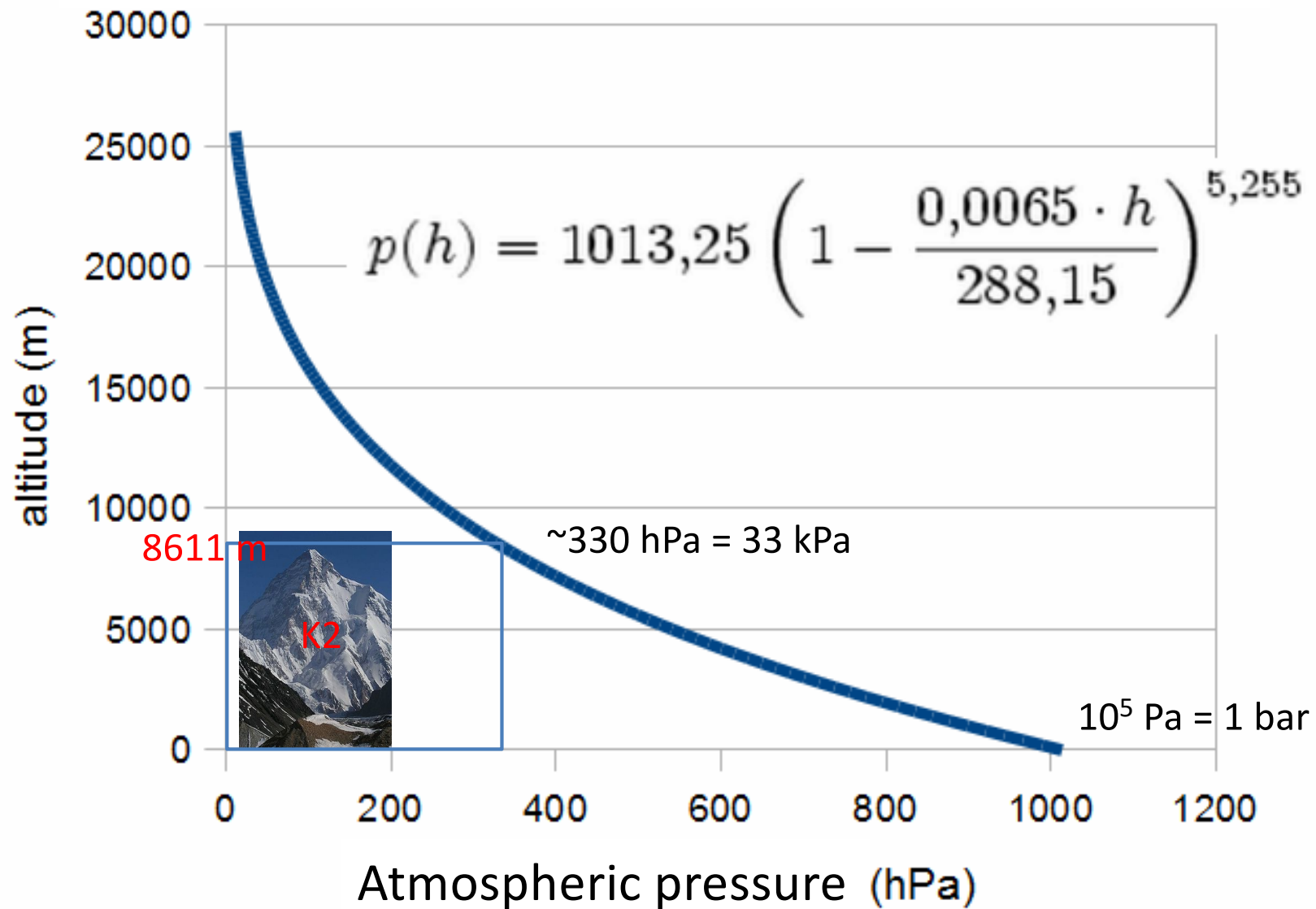
Why 32.9 kPa O₂?

- comfortable PAO₂ with total suit pressure as low as possible
- enough of O₂ even during heavy exertion or minor ventilation-perfusion mismatches
- simpler suit design by minimizing pressure while still meeting oxygenation needs.



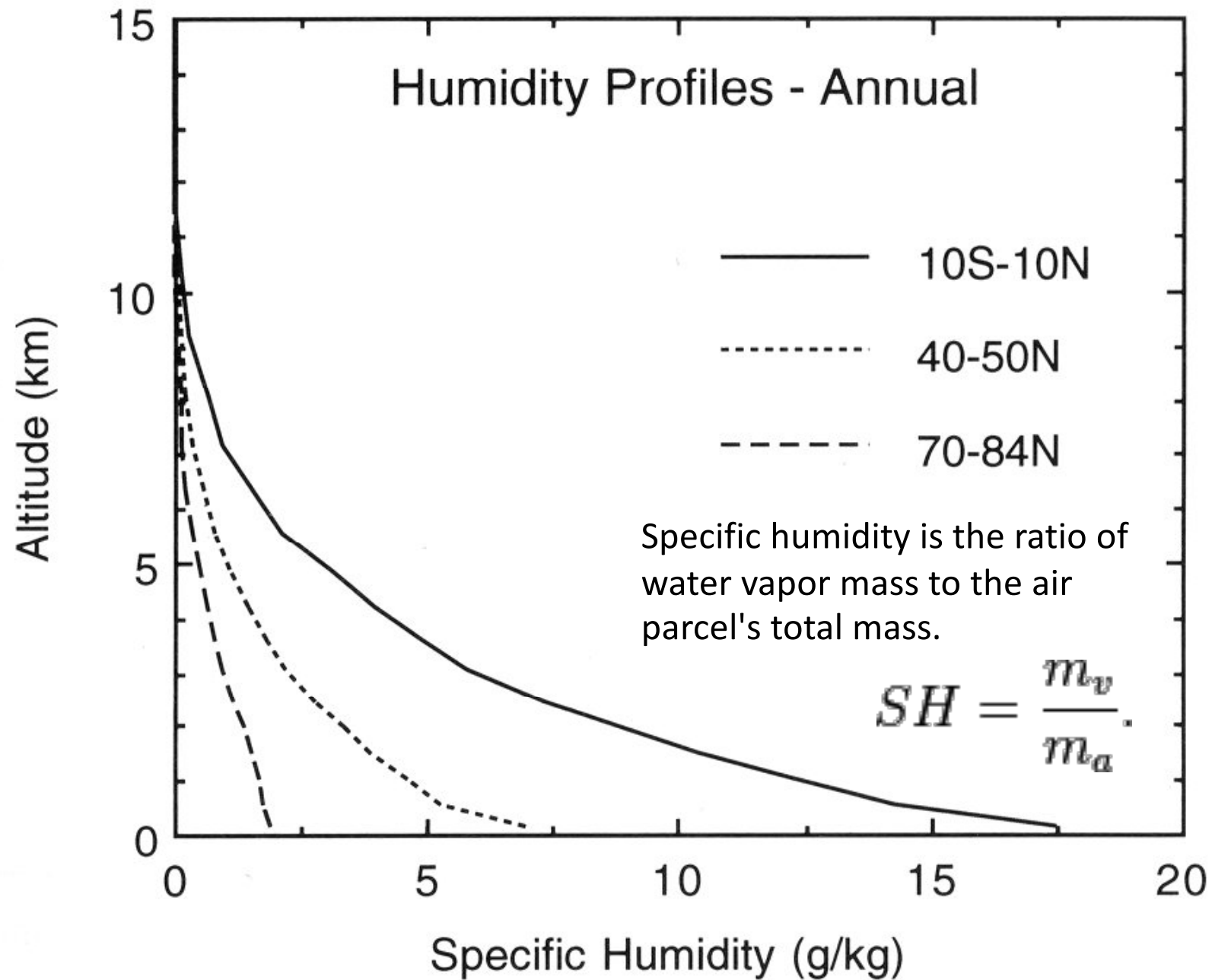
$P_{\text{suit}} = 32.9 \text{ kPa}$

Atmospheric Pressure in normalized atmosphere (ISA)



Composition of dry atmosphere, by volume^[▽note 1]

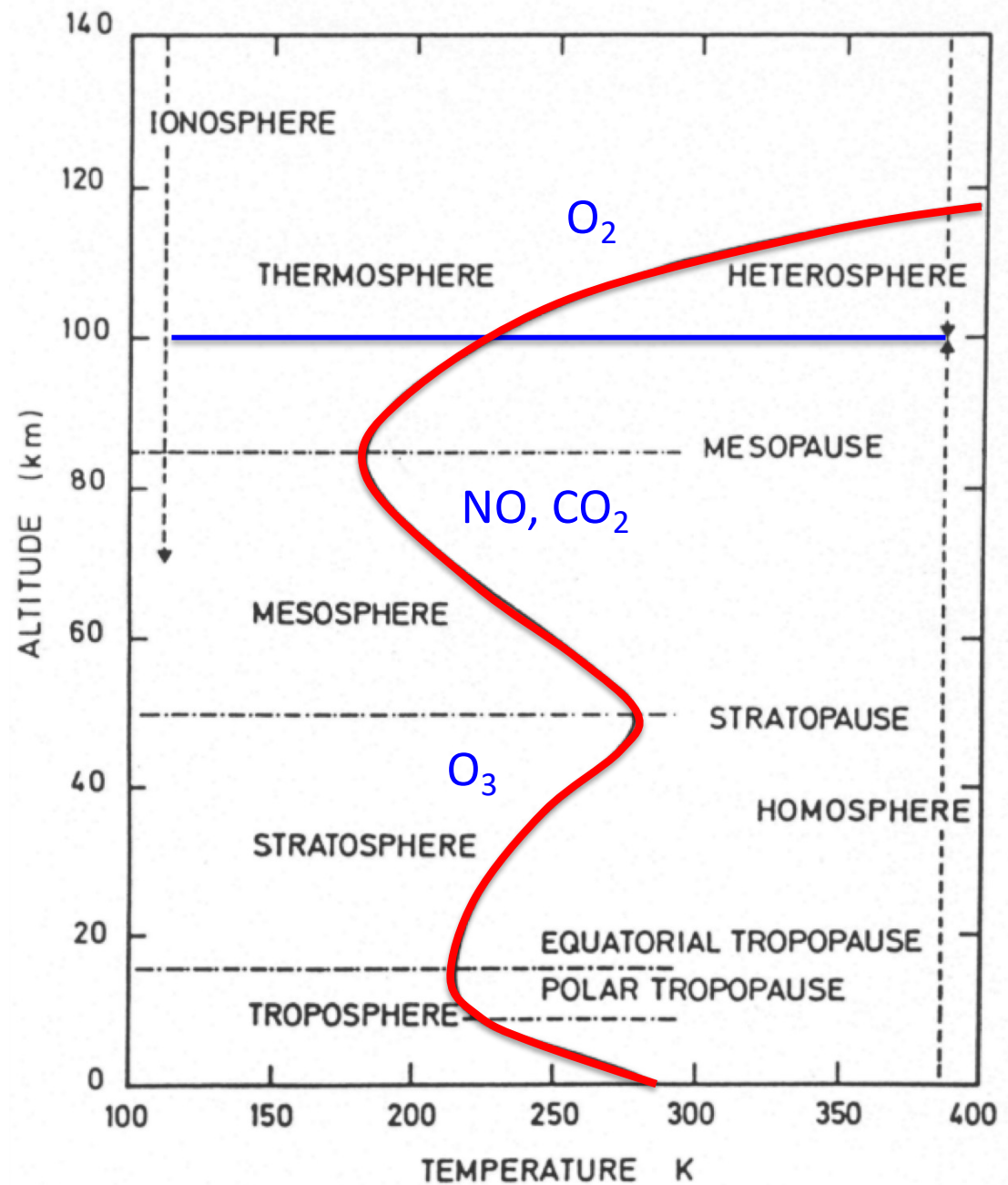
Gas (and others)		Volume by various ^{[15][▽note 2]}		Volume by CIPM-2007 ^[16]		Volume by ASHRAE ^[17]	
		ppmv ^[▽note 3]	percentile	ppmv	percentile	ppmv	percentile
Nitrogen	(N ₂)	780,800	(78.080%)	780,848	(78.0848%)	780,818	(78.0818%)
Oxygen	(O ₂)	209,500	(20.950%)	209,390	(20.9390%)	209,435	(20.9435%)
Argon	(Ar)	9,340	(0.9340%)	9,332	(0.9332%)	9,332	(0.9332%)
Carbon dioxide	(CO ₂)	397.8	(0.03978%)	400	(0.0400%)	385	(0.0385%)
Neon	(Ne)	18.18	(0.001818%)	18.2	(0.00182%)	18.2	(0.00182%)
Helium	(He)	5.24	(0.000524%)	5.2	(0.00052%)	5.2	(0.00052%)
Methane	(CH ₄)	1.81	(0.000181%)	1.5	(0.00015%)	1.5	(0.00015%)
Krypton	(Kr)	1.14	(0.000114%)	1.1	(0.00011%)	1.1	(0.00011%)
Hydrogen	(H ₂)	0.55	(0.000055%)	0.5	(0.00005%)	0.5	(0.00005%)
Nitrous oxide	(N ₂ O)	0.325	(0.0000325%)	0.3	(0.00003%)	0.3	(0.00003%)
Carbon monoxide	(CO)	0.1	(0.00001%)	0.2	(0.00002%)	0.2	(0.00002%)
Xenon	(Xe)	0.09	(0.000009%)	0.1	(0.00001%)	0.1	(0.00001%)
Nitrogen dioxide	(NO ₂)	0.02	(0.000002%)	-	-	-	-
Iodine	(I ₂)	0.01	(0.000001%)	-	-	-	-
Ammonia	(NH ₃)	trace	trace	-	-	-	-
Sulphur dioxide	(SO ₂)	trace	trace	-	-	-	-
Ozone	(O ₃)	0.02 to 0.07 [▽note 4]	(2 to 7 × 10 ⁻⁶ %) [▽note 4]	-	-	-	-
Trace to 30 ppm ^[▽note 6]	(----)	-	-	-	-	2.9	(0.00029%)
Dry air total	(air)	1,000,065.265	(100.0065265%)	999,997.100	(99.9997100%)	1,000,000.000	(100.0000000%)
Not included in above dry atmosphere:							
Water vapor	(H ₂ O)	~0.25% by mass over full atmosphere, locally 0.001%–5% by volume. ^[21]					



Guiding thread

Thermal
structure of
Earth's
atmosphere

$T(z)$



Learning outcomes

This course is meant to provide students with basic concepts of atmospheric physics and space environment.

The common thread of the course is the vertical thermal profile of Earth's atmosphere.

At the end of the course, students should be able to explain the overall shape of this thermal profile and to link it with the chemical composition and the energy balance of the atmosphere.

They will learn how atmosphere evolves in time and space

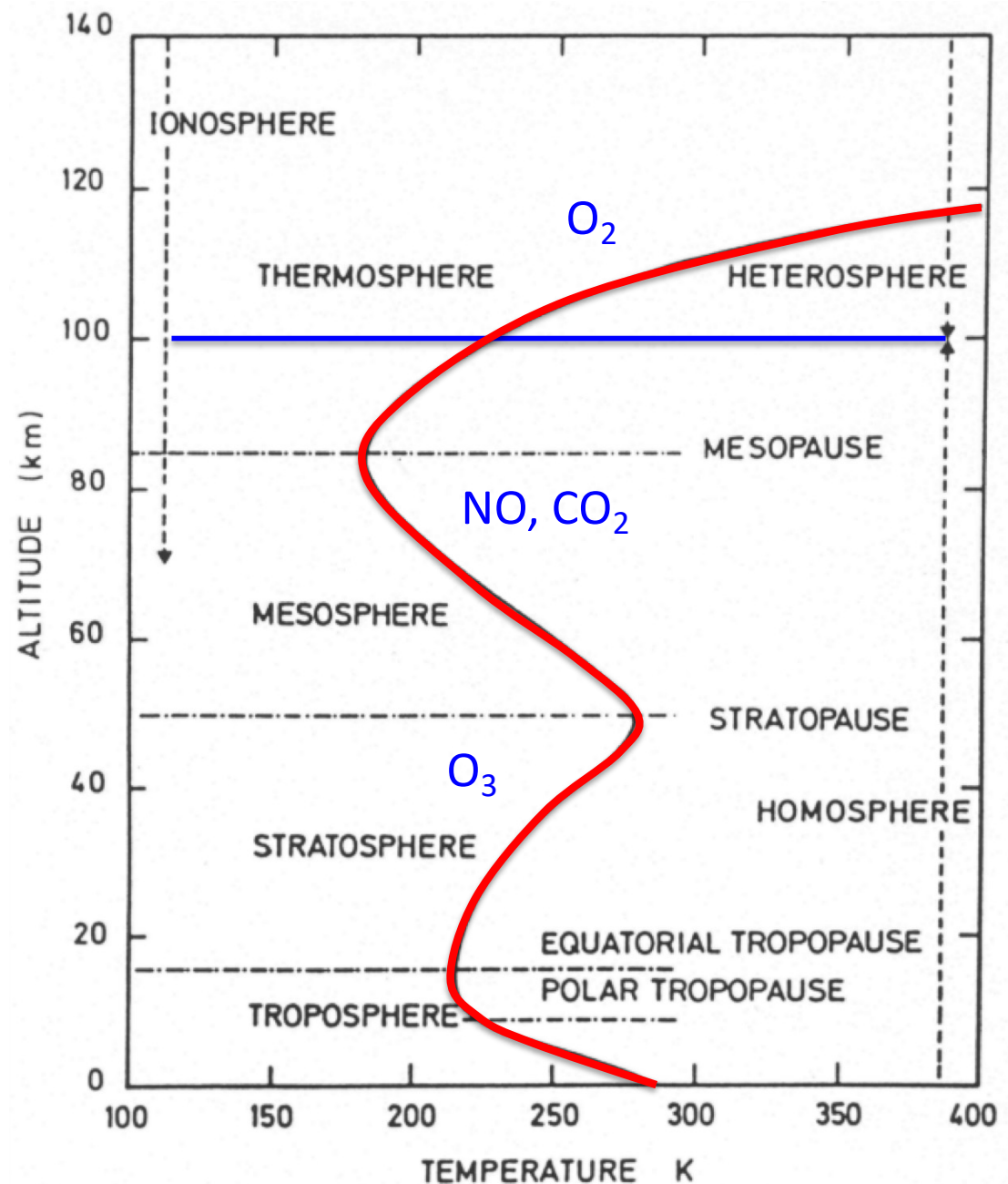


Table of Contents

Part 1 (Atmosphere of the Earth) SPAT0048C-a & SPAT0055

Part 2 (Space Environment) SPAT0048B-a

(optional in M. Sp. Sc. + SPAT0048A-d)

AERO0037, AERO0025 (space weather)

Table of Contents **Part 1 (Atmosphere of the Earth)**

SPAT0048C-a & SPAT0055

Chapter I : Atmospheric Structure

- Hydrostatic Equilibrium
- Thermal Structure
- Convection, radiation, conduction

Chapter II : Solar radiation – atmosphere Interactions

- Solar radiation spectrum
- Variability of the Sun's emissions
- Radiative transfer equation and applications
- Energy balance and climate
- Greenhouse effect

Table of Contents Part 1

Chapter III : Photochemical processes and composition

- Photochemical action of radiation
- Photochemistry of the atmosphere
- Ozone: production and destruction

Chapter IV : Atmospheric transport

- General equations of the atmospheric structure
- Molecular and turbulent vertical diffusion

Chapter V : The Ionosphere

- Formation and structure
- Chemical composition
- Neutrality and electric field

Table of Contents Part 2 (Space Environment)

SPAT0048B-a

Chapter I : The solar wind

Chapter II : The geomagnetic field

Chapter III : The magnetosphere

Chapter IV : Charged particles motions

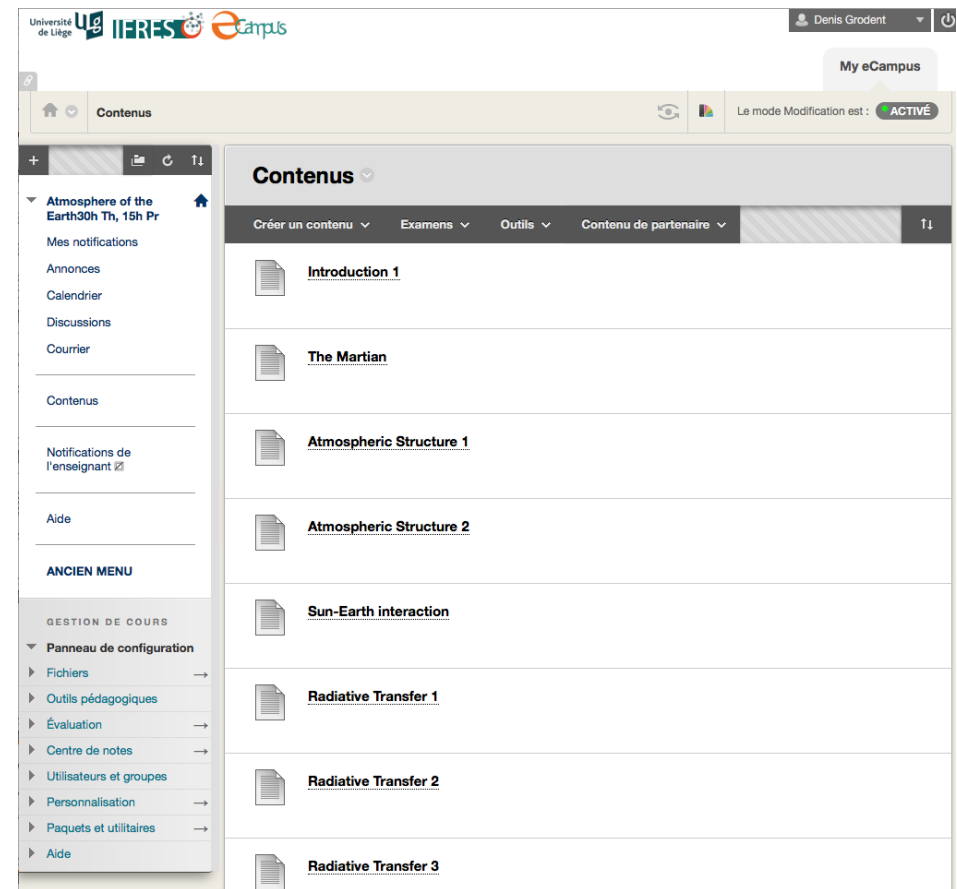
Chapter V : Storms and aurorae

Lecture notes

- Syllabus (~170 pages)
French printed version (10€)
- All lectures may be downloaded from **eCampus** as PDF files

ORBI to be updated

<http://hdl.handle.net/2268/239458>



Reference books

- "Atmospheric Science" Wallace & Hobbs
- "Introduction to atmospheric chemistry" Jacob
- "An introduction to dynamic meteorology" Holton

All books "available" in PDF format

SPAT0055 (M. Sp. Sc.) $\sim 45\text{h} \Rightarrow \sim 10\text{-}15$ lectures

SPAT0048CB (M. Aero. En.) $\sim 52\text{h} \Rightarrow \sim 12\text{-}17$ lectures

no problem-solving lessons, examples are included in course

Exams

SPAT0048: Oral

- 2 principal questions on Part 1 (1st question randomly chosen in a given list)
- 1 question on Part 2.

SPAT0055: Oral

- 2 principal questions on Part 1 (1st question randomly chosen in a given list)

How much does human breathing process contribute to Green House Effect and Climate Change?

Inhaled air (volume):

~ 78% N₂, 21% O₂, 0.03% CO₂

Exhaled air:

~ 78% N₂, 16% O₂, 1.4% CO₂

How much does human breathing process contribute to Green House Effect and Climate Change?

Currently (as of year 2020), human population on earth is 7.8 billions and counting.
(United Nations) (2025: 8.2 billions: +5%)

claim#1: an average person's respiration generates approximately 450 liters (roughly 900 grams) of carbon dioxide per day
Thus, the amount of CO₂ released by human per day is **0.9 kg/day**

claim#2: In an average resting adult, the lungs take up about 250ml of oxygen every minute while excreting about 200ml of carbon dioxide.
So, 200 ml per minute and thus $200 \text{ ml} \times 60 \times 24 = 288 \text{ liters/day}$
Or equivalent to $565.36\text{g/per day} = \mathbf{0.565 \text{ kg/day}}$ (after divide with standard molar volume constant and times with CO₂ molar weight).

How much does human breathing process contribute to Green House Effect and Climate Change?

Apparently claim#2 has lower CO₂ emission compared to claim#1, but we will use both anyway to show the comparison.

So, if there is 7.8 billions people out there and excreting CO₂ at the rate of 0.9 or 0.565 kg/day, the total CO₂ emission by human alone annually is:

claim#1: CO₂ emission = $0.90 \times 365 \times 7\,800\,000\,000$

= 2.6×10^9 tons/year

claim#2: CO₂ emission = $0.565 \times 365 \times 7\,800\,000\,000$

= 1.6×10^9 tons/year

These numbers alone
are not really
meaningfull

Human activities, through the fossil fuel burning activities, releases **24×10^9 tons per year** (wikipedia).

**So, human breathing process contributes to about
10.6 % (claim#1) or
6.7 % (claim#2) compared to the fuel burning related CO₂.**