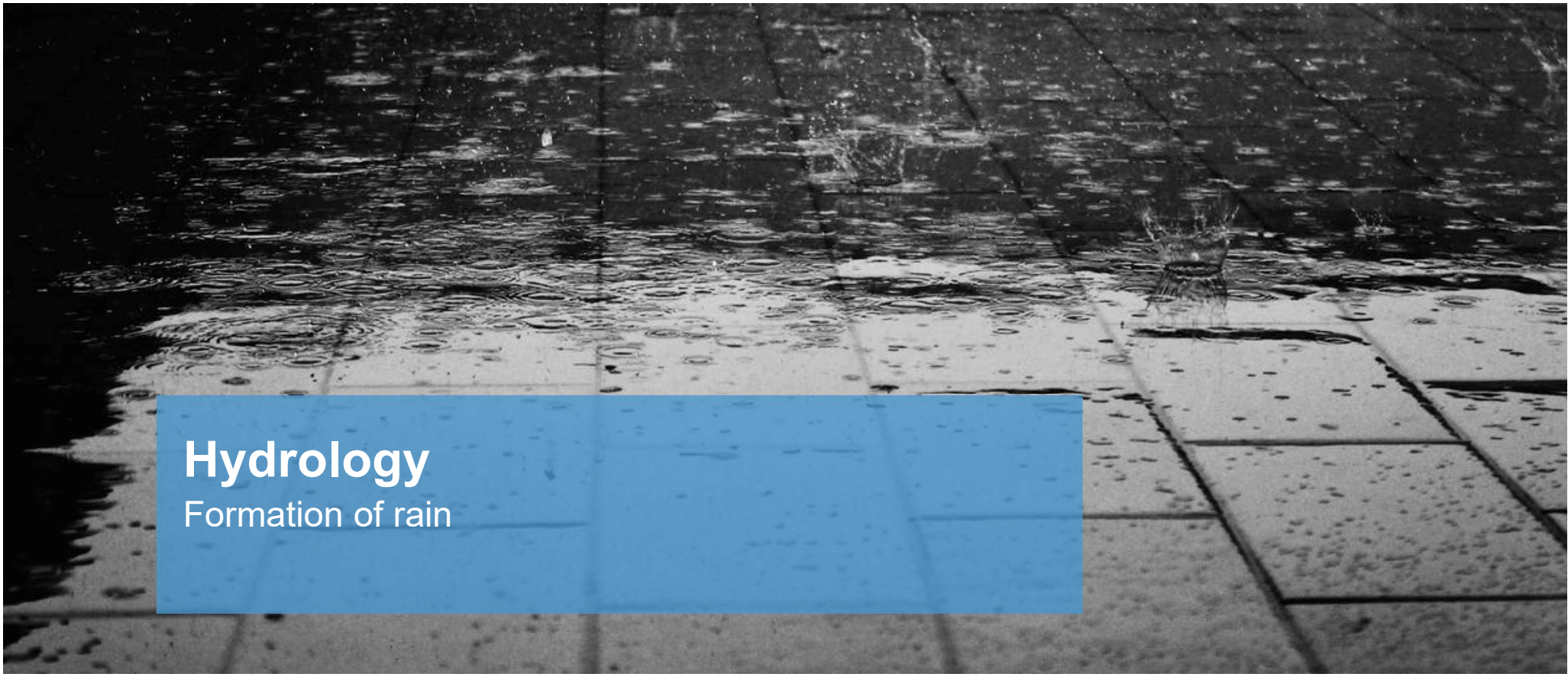
UCLouvain

École polytechnique de Louvain

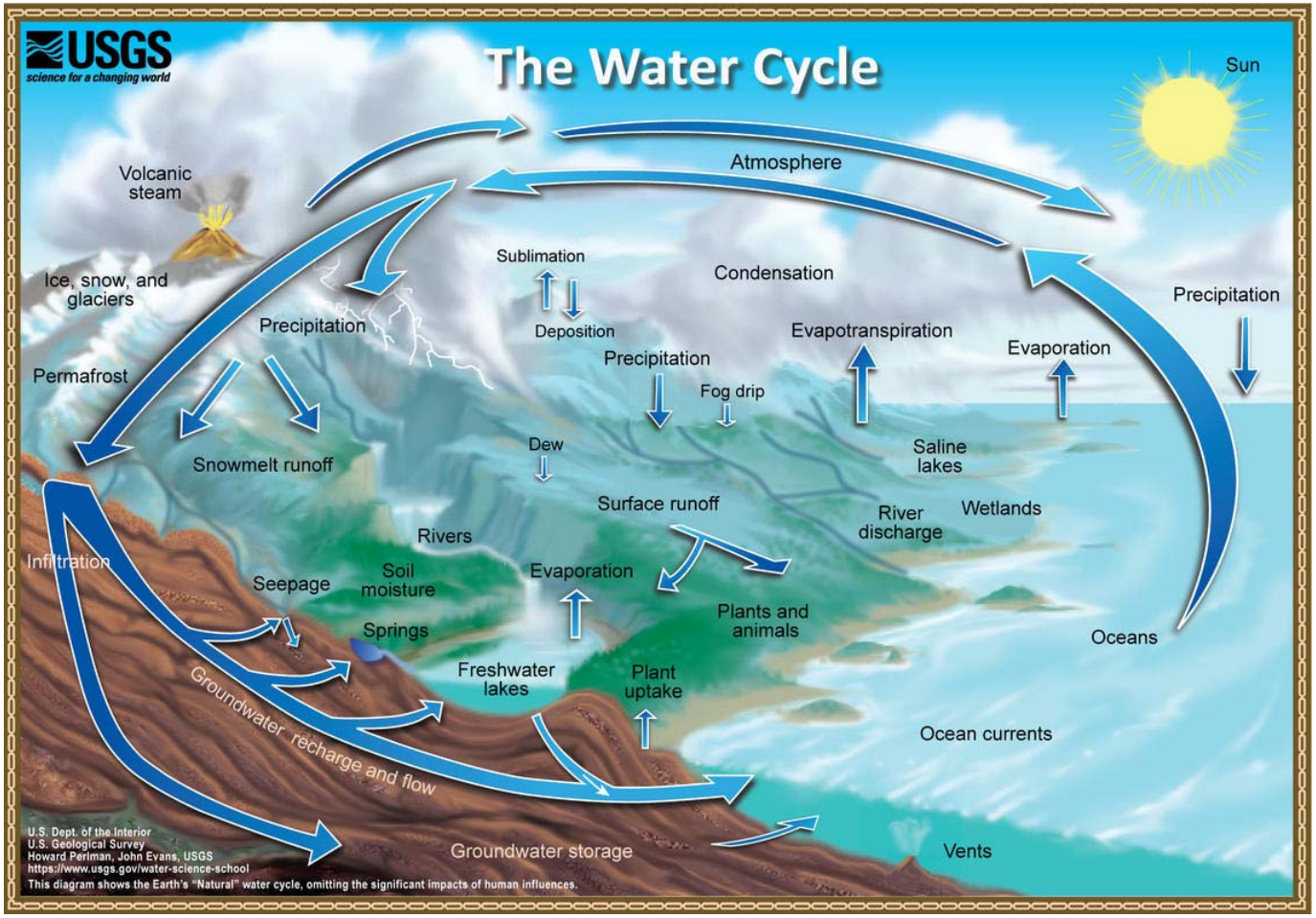
ÉCOLE POLYTECHNIQUE DE LOUVAIN



Hydrology

Formation of rain

Origin of precipitations

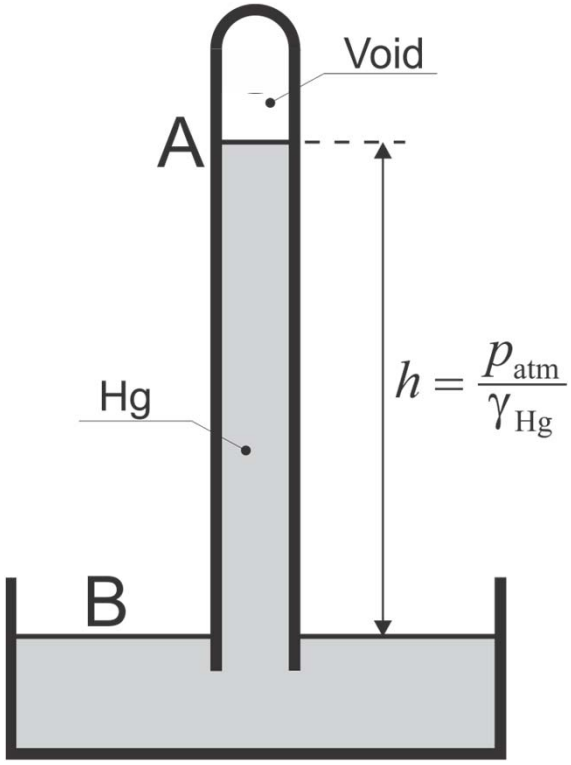


Thermodynamics

Units
Pressure p (Pa = N/m²)
Volume V (m³)
Temperature T (°K)
Temperaure t (°C)

- Ideal gases
  - Boyle-Mariotte : $pV = \text{const}$ if $T = \text{const}$
  - Gay-Lussac : $\frac{P}{T} = \text{const}$ if $V = \text{const}$ and $\frac{V}{T} = \text{const}$ if $P = \text{const}$
  - Ideal gas law : $pV = nRT$
    - For a constant mass of gas: $\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$
  - Mixing of gases (Dalton) : $p = \sum_i p_i$
  - Adiabatic compression / expansion : $p_1 v_1^{\gamma} = p_2 v_2^{\gamma}$ $\gamma_{air} = 1.4$

Vapour pressure and condensation

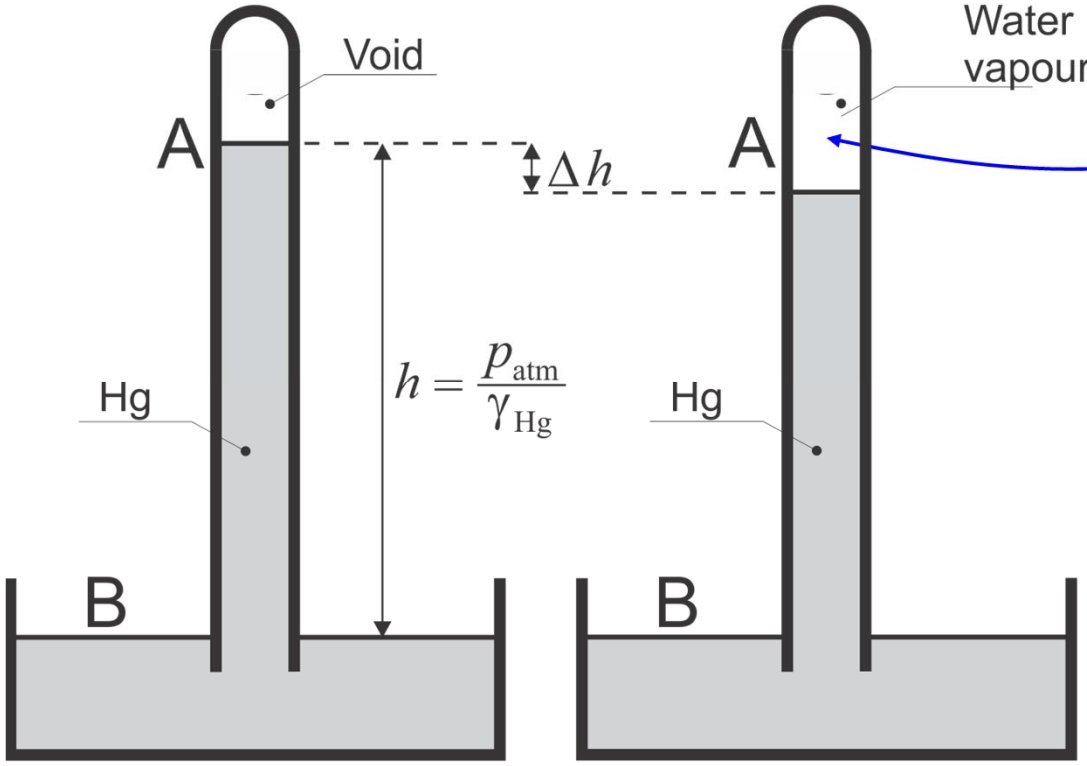


$$H_A = H_B$$

$$z_A + 0 = z_B + \frac{p_{atm}}{\gamma_{Hg}}$$

$$h = z_A - z_B = \frac{p_{atm}}{\gamma_{Hg}} = 760\,\text{mm}$$

Vapour pressure and condensation



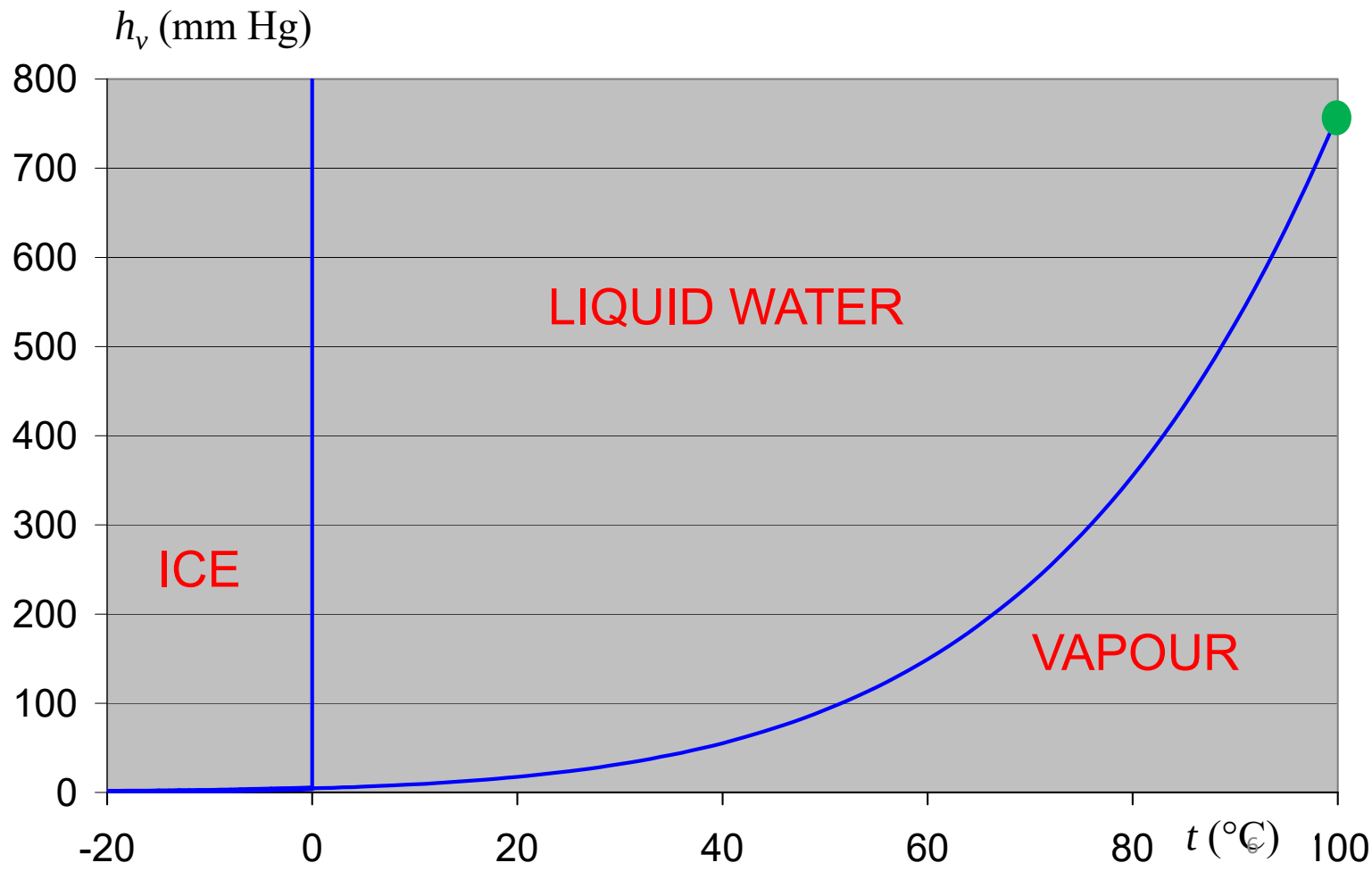
$$h_v = \frac{p_v}{\gamma_{Hg}} = \frac{\Delta h_{max}}{\gamma_{Hg}}$$

$$h - \Delta h + \frac{p_A}{\gamma_{Hg}} = \frac{p_{atm}}{\gamma_{Hg}}$$

$$\frac{p_A}{\gamma_{Hg}} = \Delta h$$

Saturated vapour pressure and condensation

t	h_v
°C	mm Hg
0	4.6
10	9.2
20	17.6
30	31.9
40	55.4
50	92.7



Saturated vapour pressure and condensation

t	h_v	h_v
°C	mm Hg	bar
0	4.6	0.00608
10	9.2	0.0123
20	17.6	0.0234
30	31.9	0.0424
40	55.4	0.0738
50	92.7	0.123

(1) $$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

(2) $$m = \rho_1 V_1 = \rho_2 V_2$$

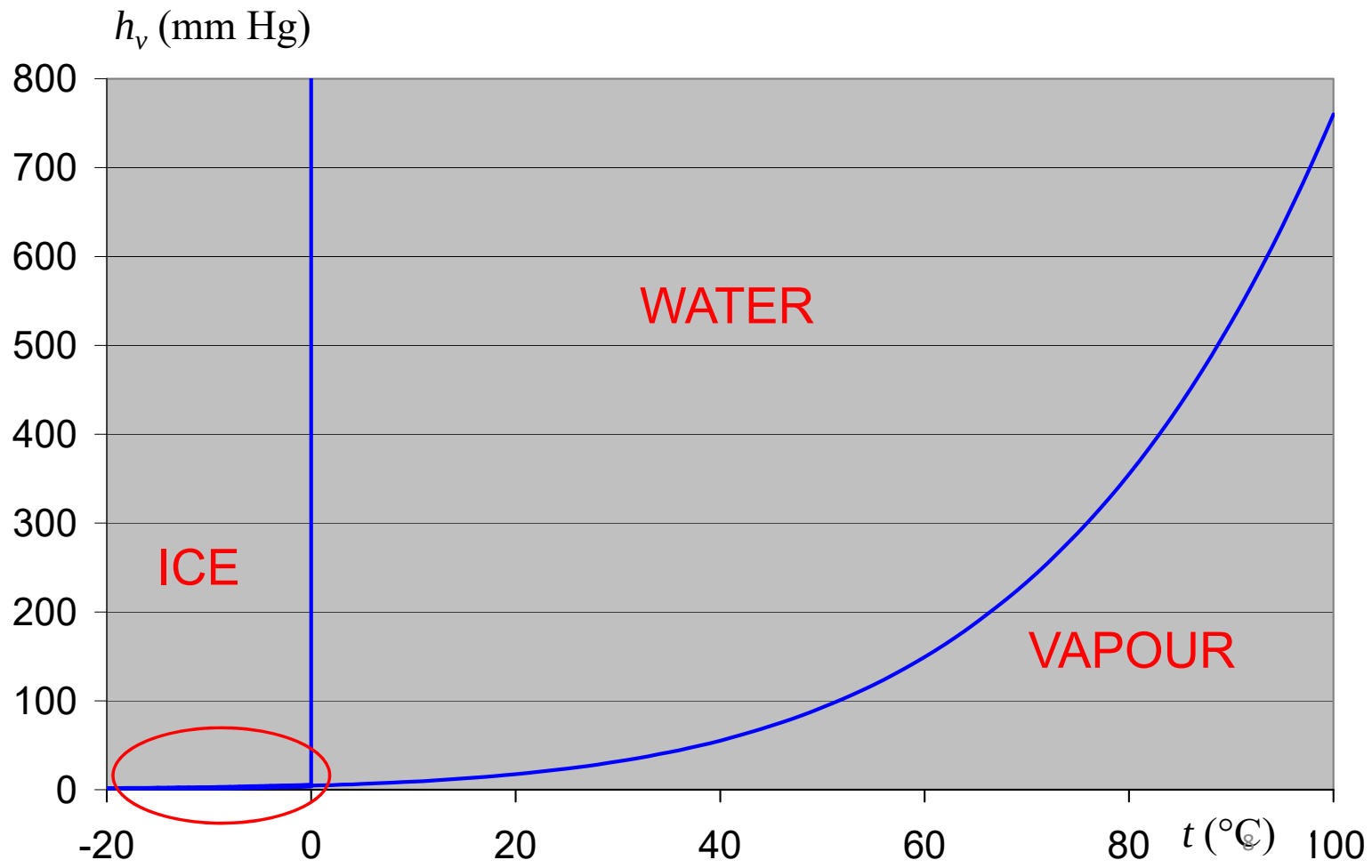
(3) $$\frac{V_1}{V_2} = \frac{p_2}{p_1}\frac{T_1}{T_2} = \frac{\rho_2}{\rho_1}$$

t_1 (°C)	T_1 (°K)	P_1 (bar)	ρ_1 (g/m³)
0	273,15	1,013	804

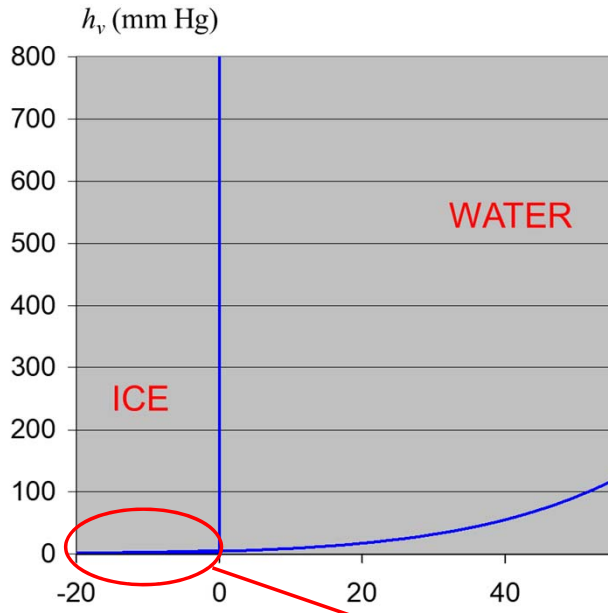
t_2 (°C)	T_2 (°K)	P_2 (bar)	ρ_2 (g/m³)
0	273.15	0.00608	4.826
10	283.15	0.0123	9.417
20	303.15	0.0234	17.304
30	313.15	0.0424	30.320

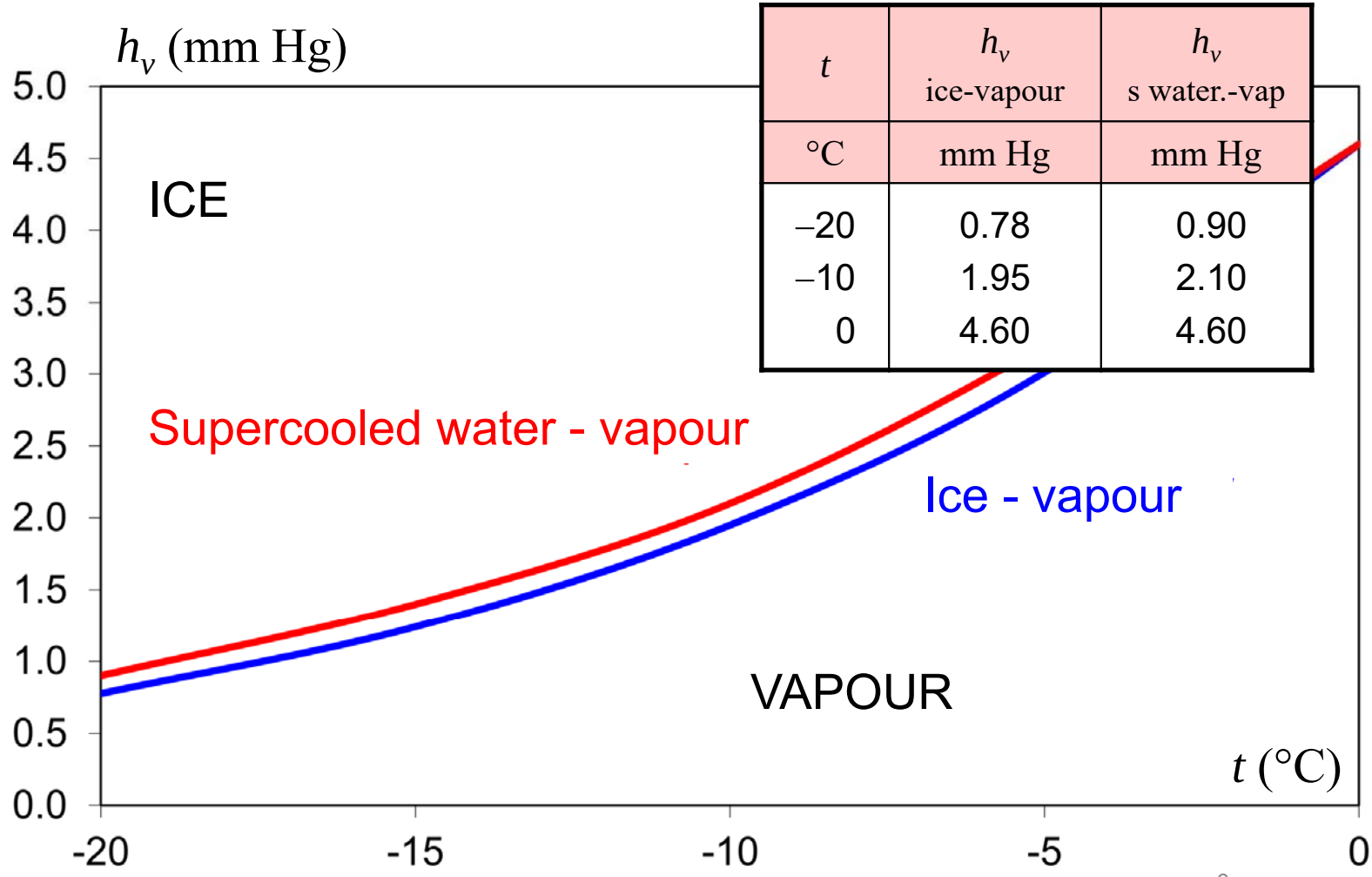
Saturated vapour pressure and condensation

t	h_v	ρ
°C	mm Hg	g/m³
0	4.6	4.83
10	9.2	9.42
20	17.6	17.30
30	31.9	30.32
40	55.4	51.09
50	92.7	82.51



Saturated vapour pressure and condensation

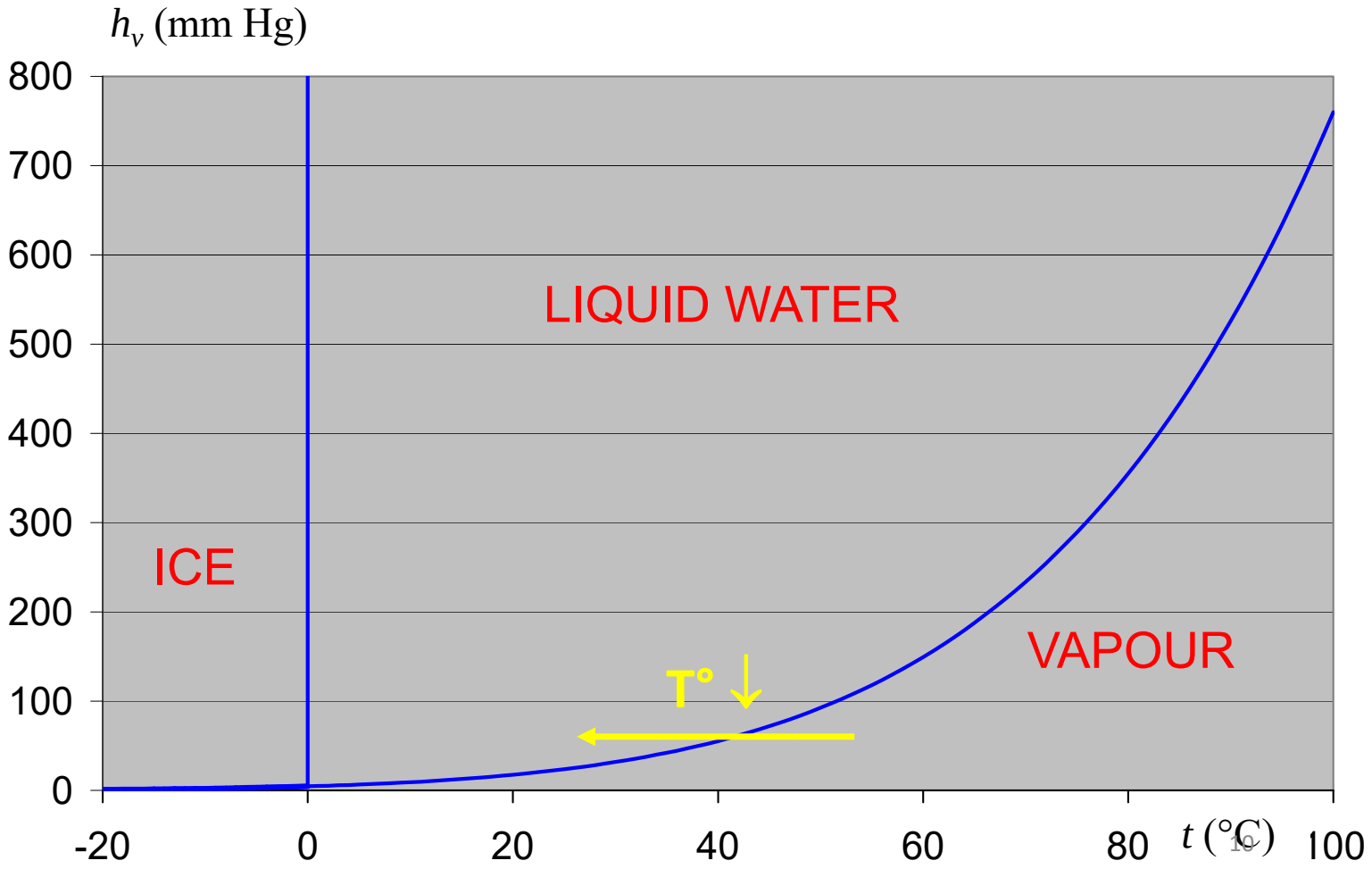




t	h_v ice-vapour	h_v s water.-vap
°C	mm Hg	mm Hg
–20	0.78	0.90
–10	1.95	2.10
0	4.60	4.60

Saturated vapour pressure and condensation

t	h_v	ρ
°C	mm Hg	g/m^3
–20	0.9	1.07
–10	2.1	2.28
0	4.6	4.84
10	9.2	9.33
20	17.6	17.13
30	31.9	30.03
40	55.4	50.88
50	92.7	82.47



Saturated vapour pressure and condensation

t	h_v	ρ
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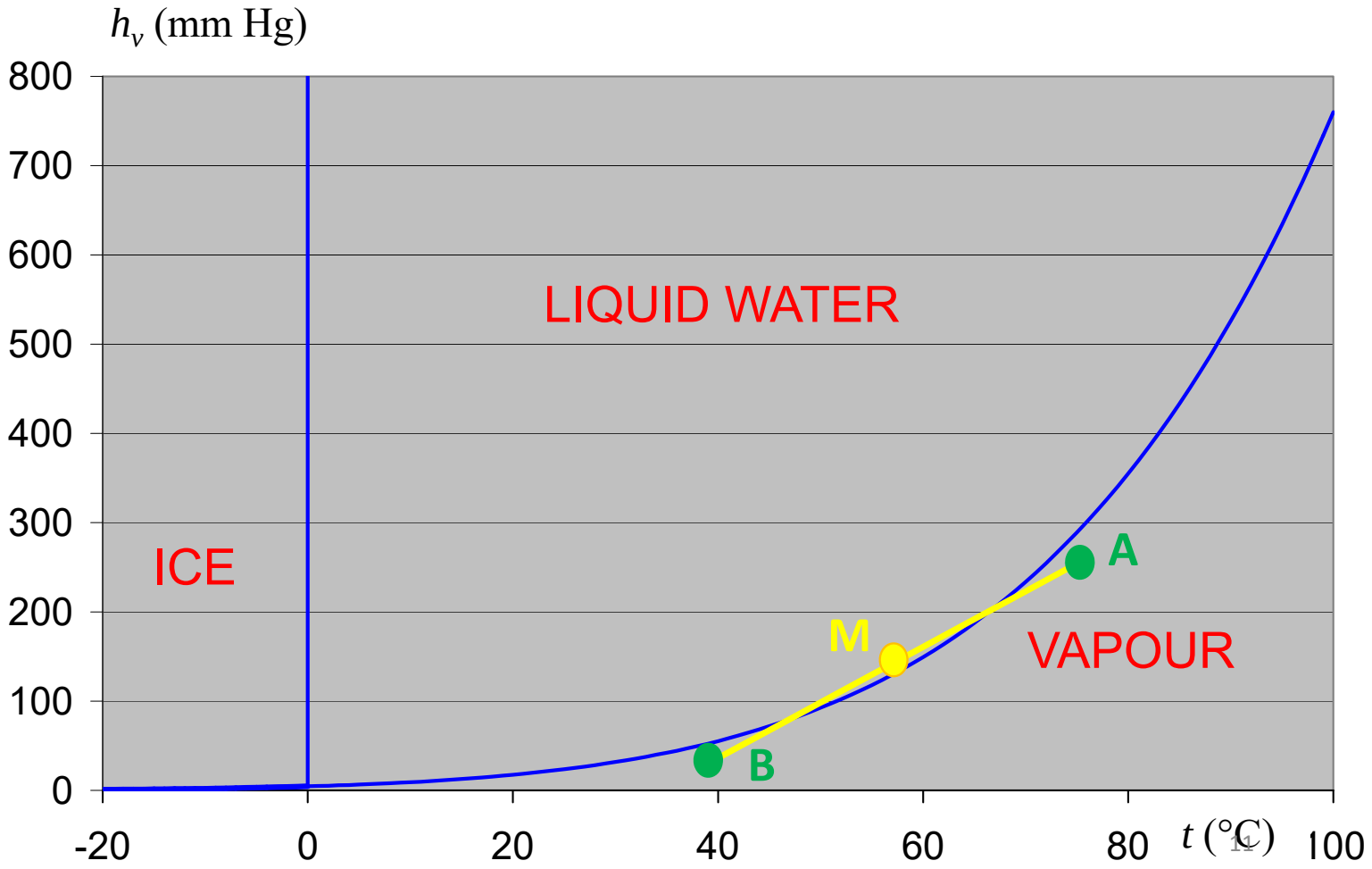

Saturated vapour pressure and condensation

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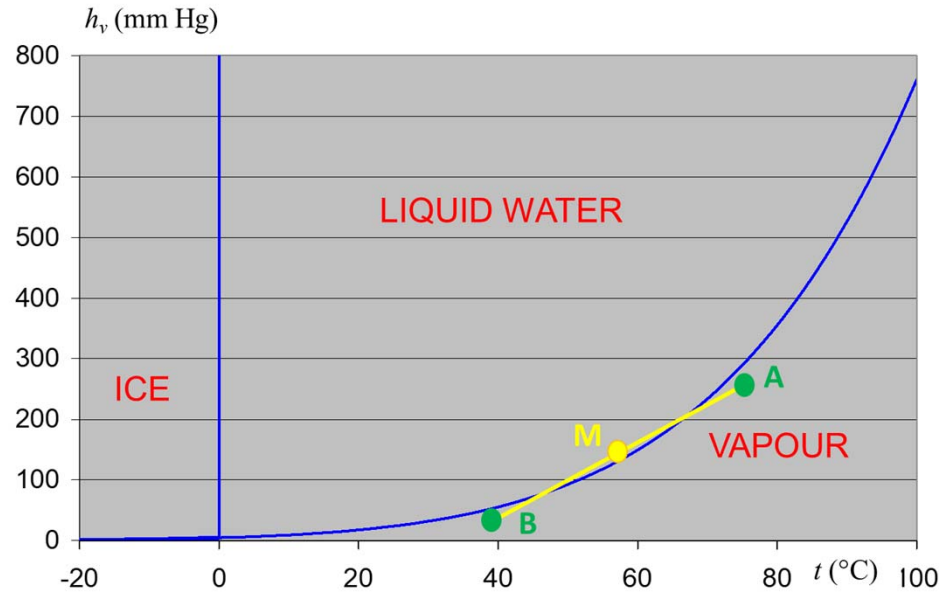
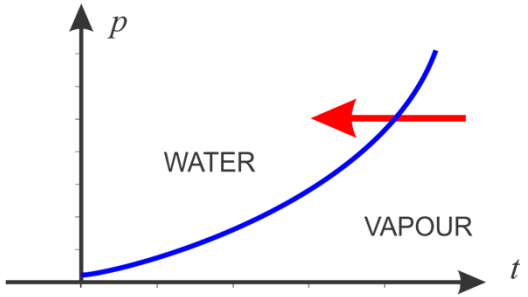


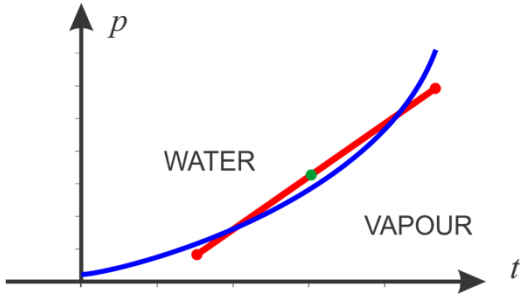
	1 m³	10°C	9 g
+	1 m³	30°C	29 g
=	2 m³	20°C	38 g
=	1 m³	20°C	19 g

Condensation

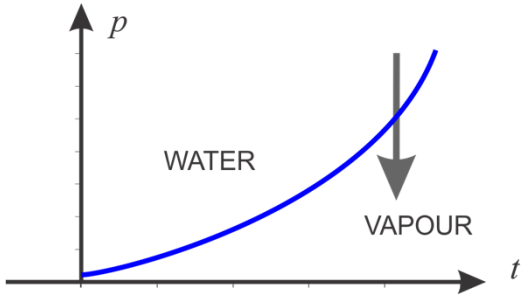
- Temperature decrease

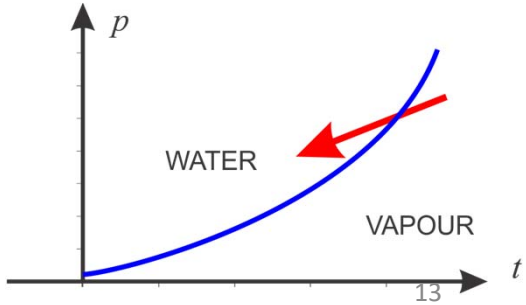


- Mixing



- Expansion





Evolution of temperature with rising altitude

(1) $$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

(2) $$p_1 V_1^{\gamma} = p_2 V_2^{\gamma} \qquad \gamma_{air} = 1{,}4$$

(3) $$\frac{T_2}{T_1} = \frac{p_2 V_2}{p_1 V_1} = \frac{p_2}{p_1}\left(\frac{p_1}{p_2}\right)^{\frac{1}{\gamma}} = \left(\frac{p_2}{p_1}\right)^{1-\frac{1}{\gamma}}$$

(4) $$273.15 + t_2 = (273.15 + t_1)\left(\frac{p_2}{p_1}\right)^{1-\frac{1}{\gamma}}$$

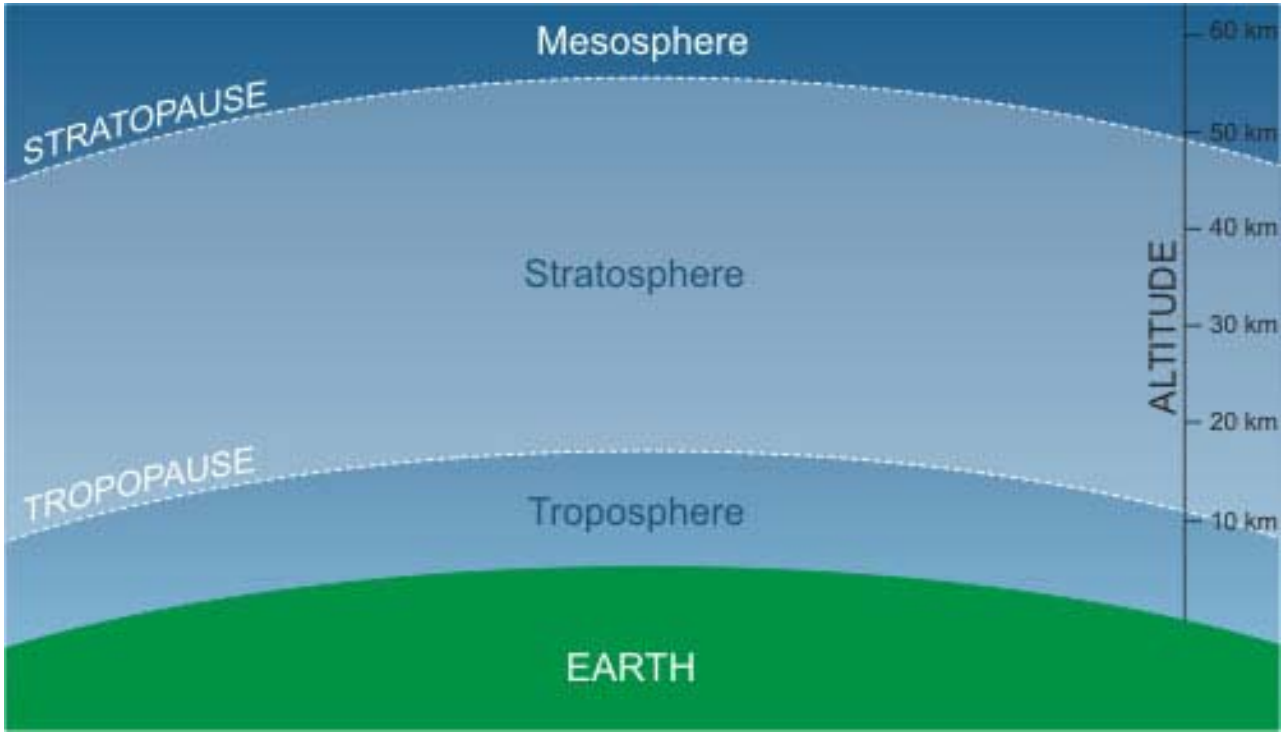
Assumption
dry air

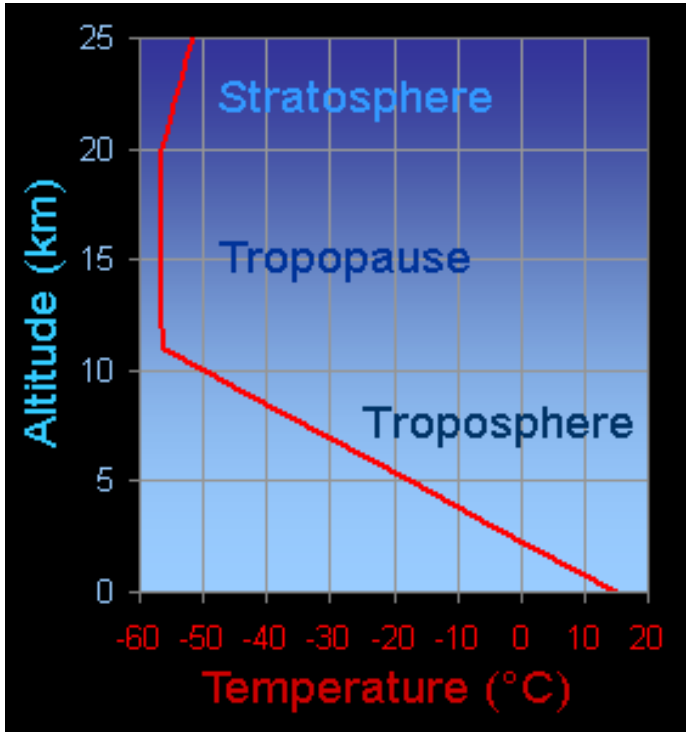
Altitude (m)	*p* (bar)	*t* (°C)
0	1.013	20
4000	0.613	-19

Thermal gradient ~ -10°C / km

Vertical distribution of temperature

- Temperature profile in the troposphere

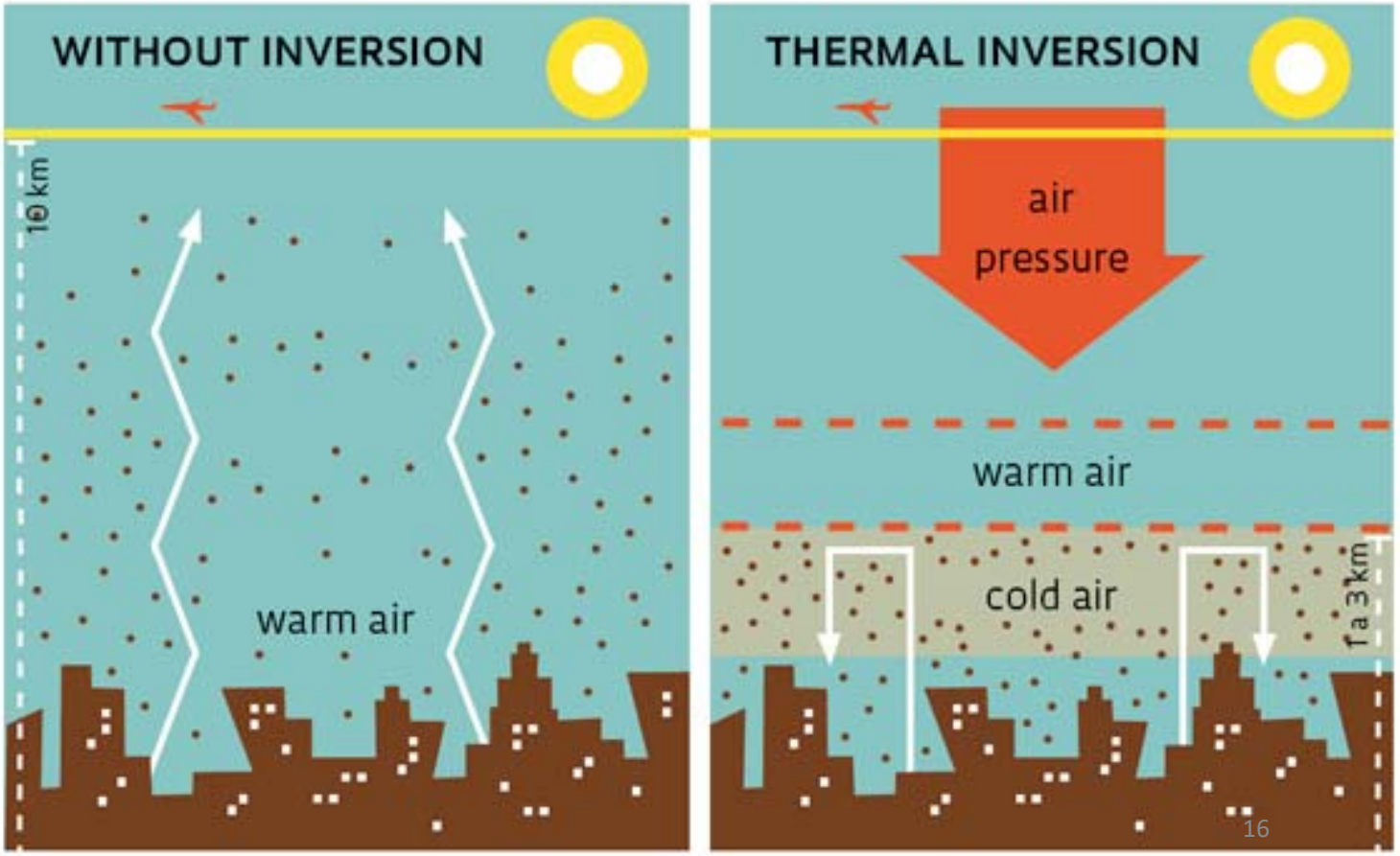




https://www.skepticalscience.com/print.php?r=136

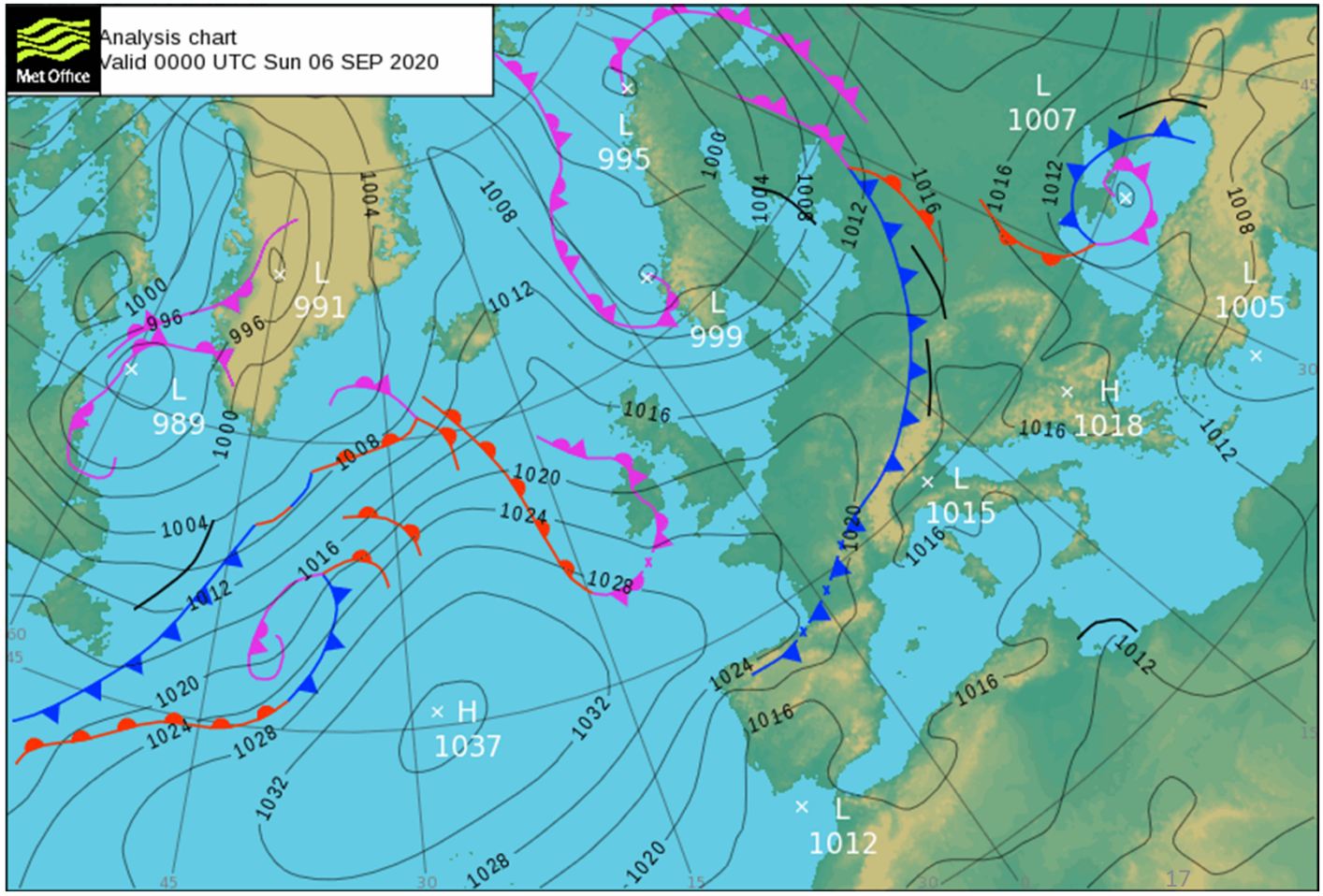
Vertical distribution of temperature

- Thermal inversion



Weather, pressures and winds

- Geostrophic model

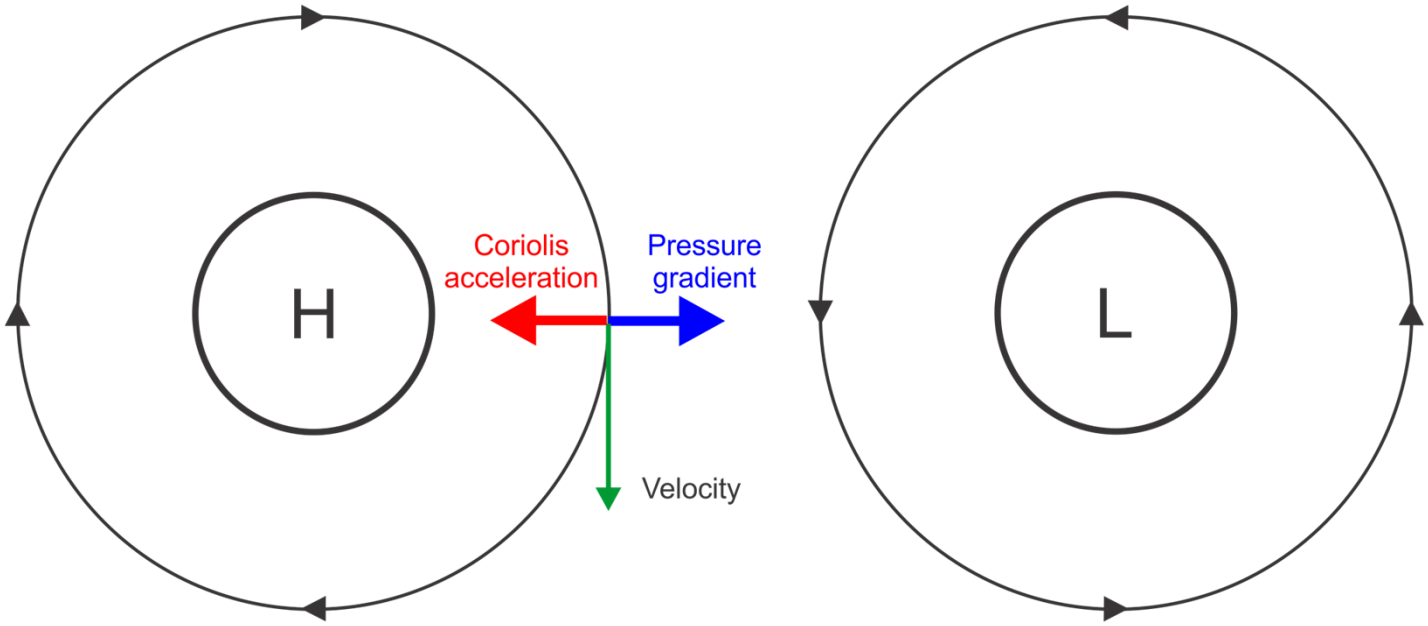


Weather, pressures and winds

- Geostrophic model

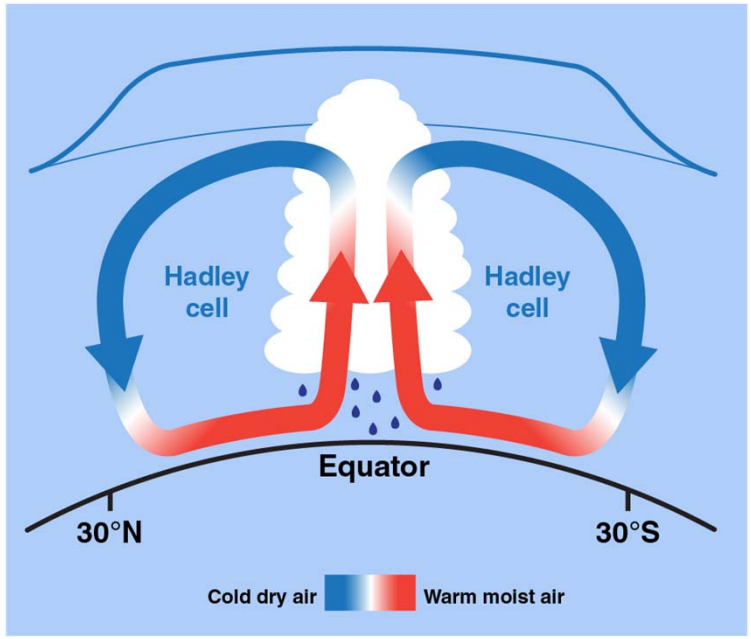
$$\frac{1}{\rho}\vec{\nabla}p = \mathbf{F} - \frac{d\,\mathbf{V}}{d\,t}$$

$$\left(\frac{d\,\mathbf{V}}{dt}\right)_{gr} = -\frac{1}{\rho}\vec{\nabla}p$$

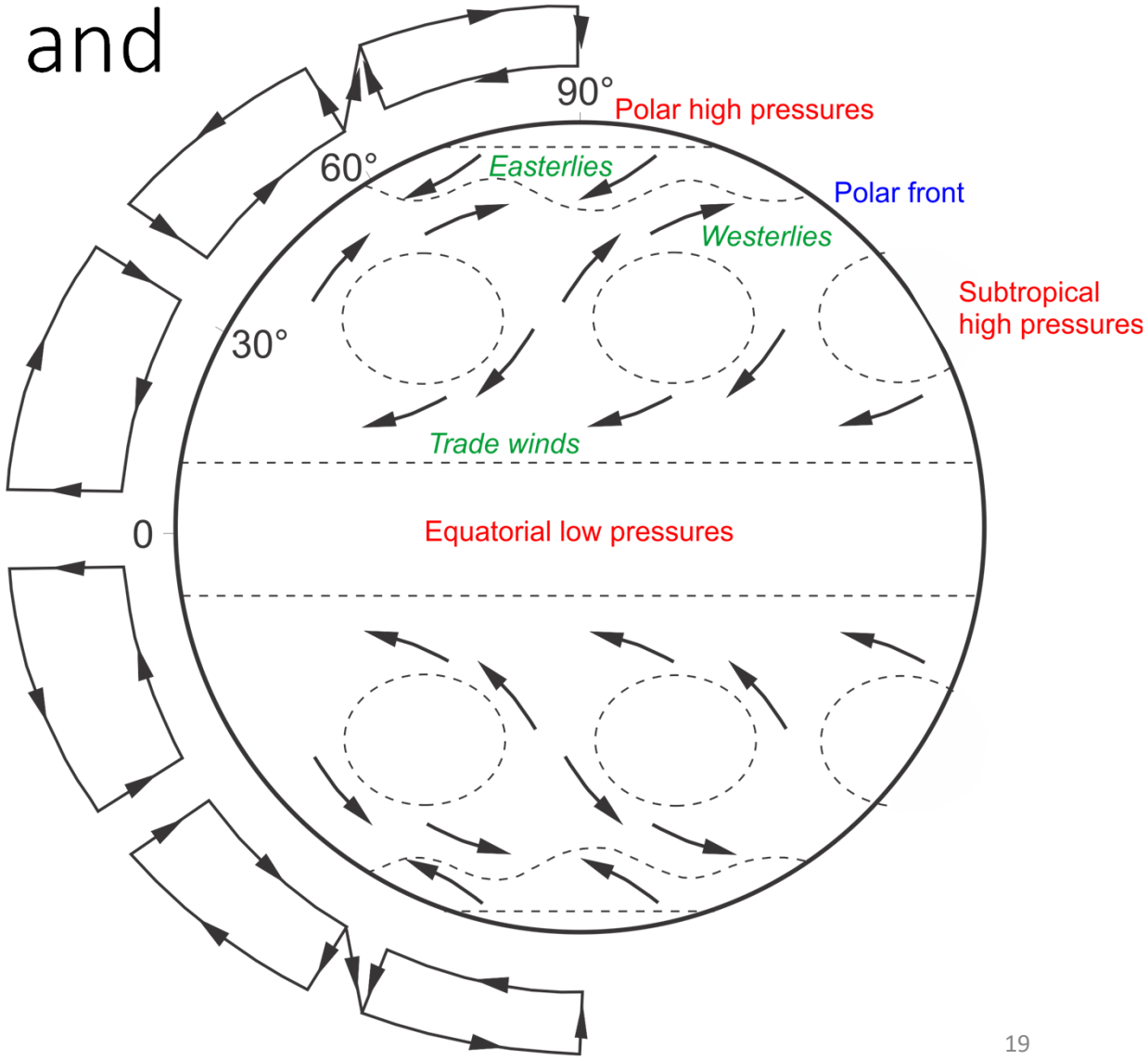


Weather, pressures and winds

- Pressure and wind fields

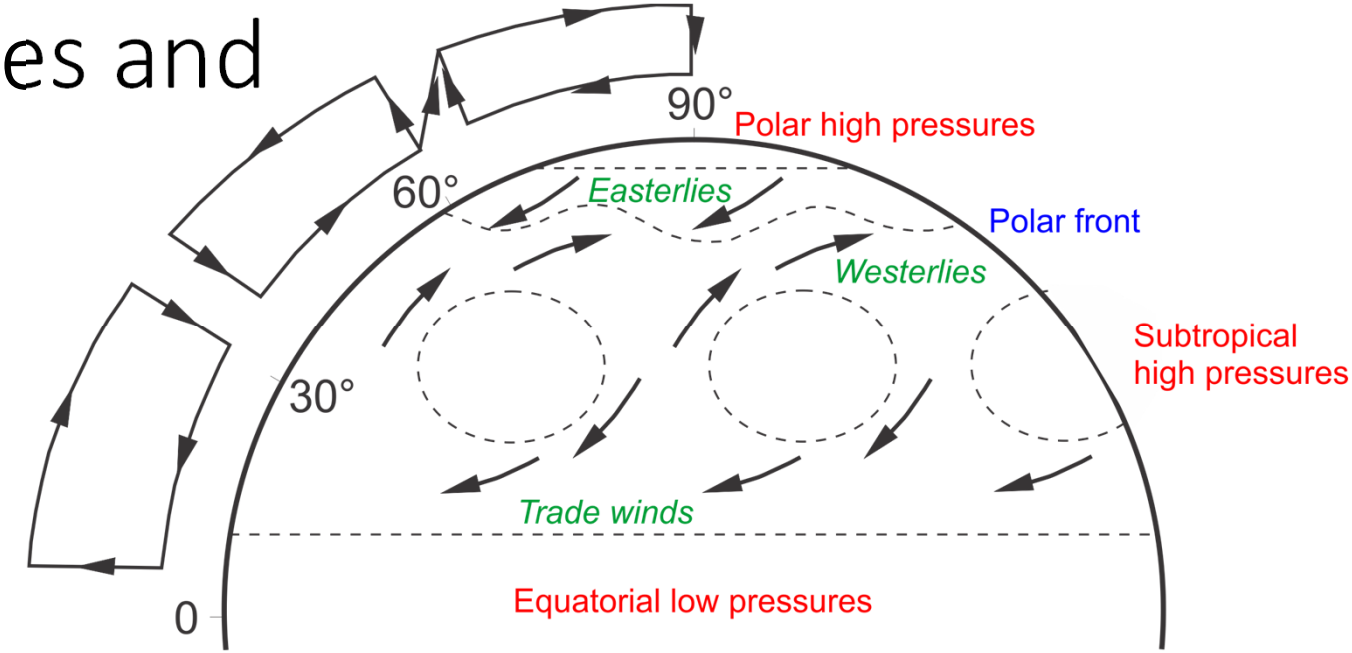


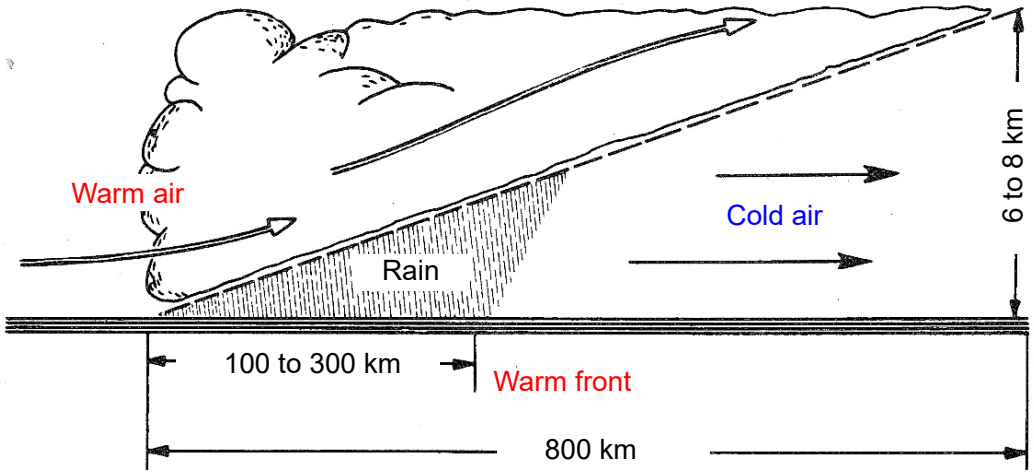
NASA/JPL-Caltech



Weather, pressures and winds

- Pressure and wind fields

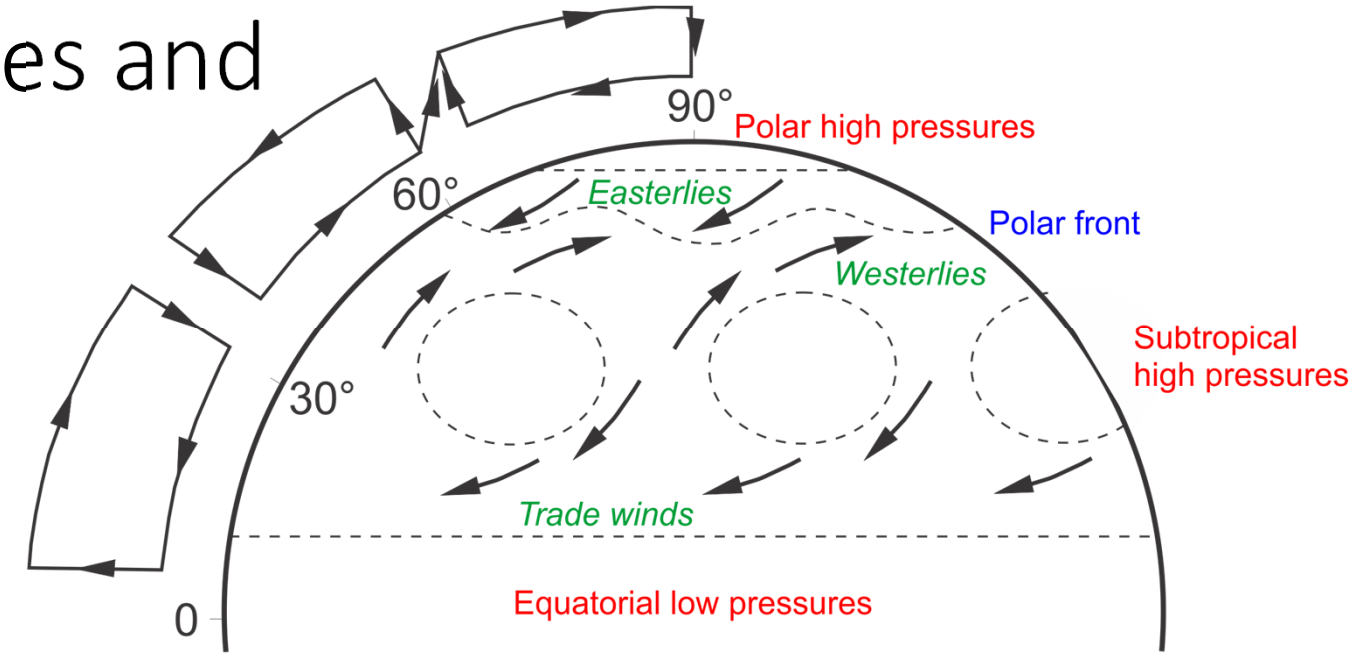


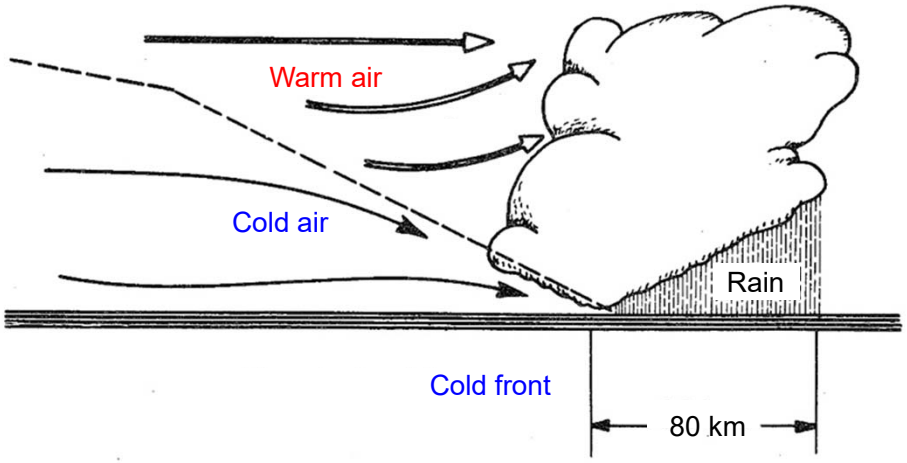


Warm front

Weather, pressures and winds

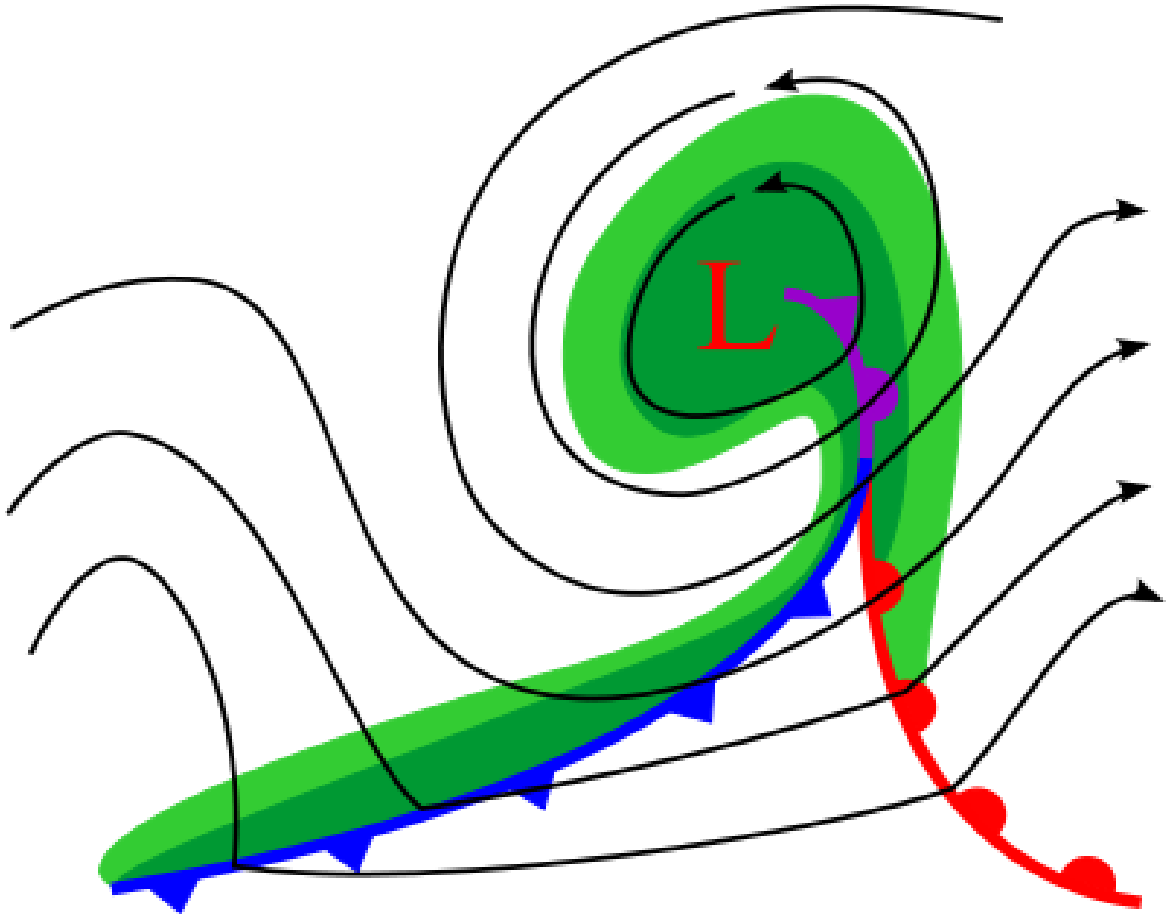
- Pressure and wind fields





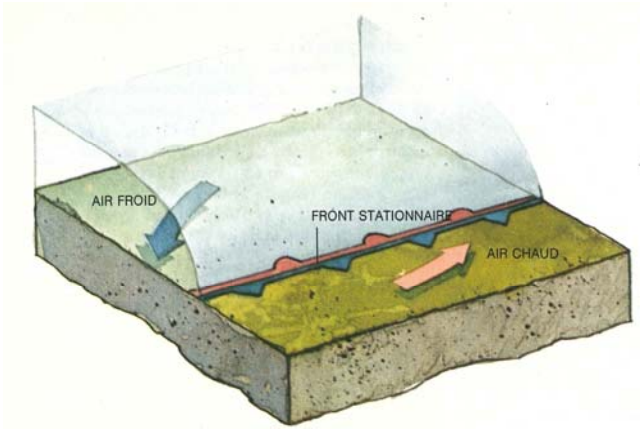
Cold front

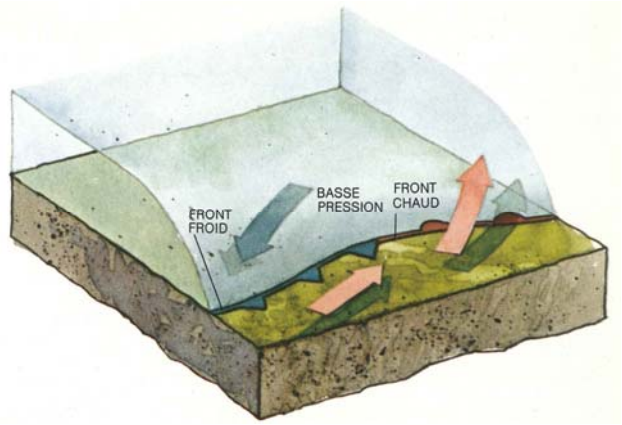
Occluded front

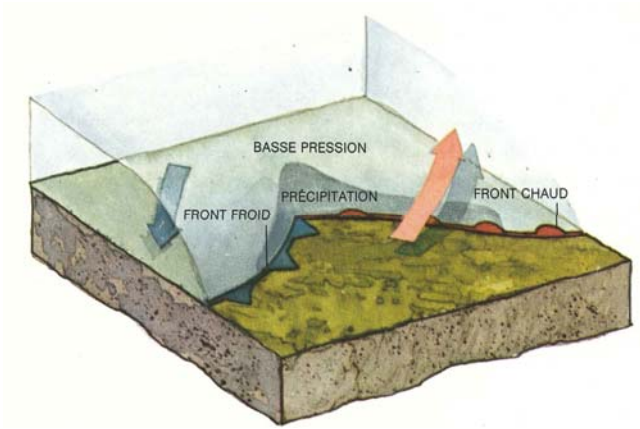


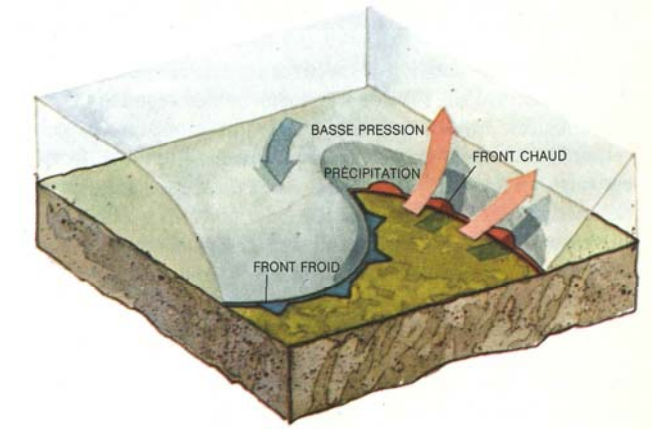
Occluded front

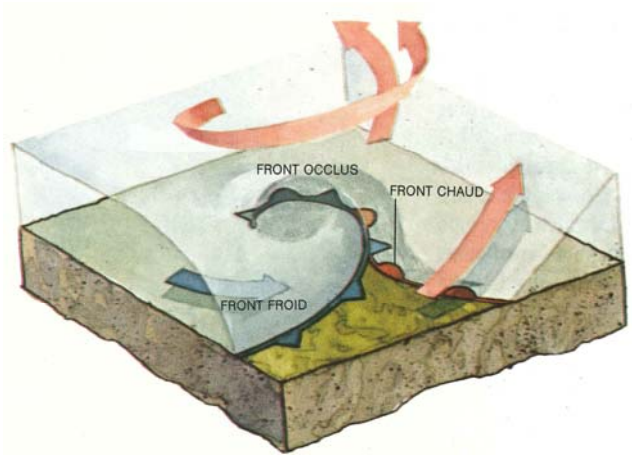
A.B.C. Whipple (1983)
Storms, Time-Life

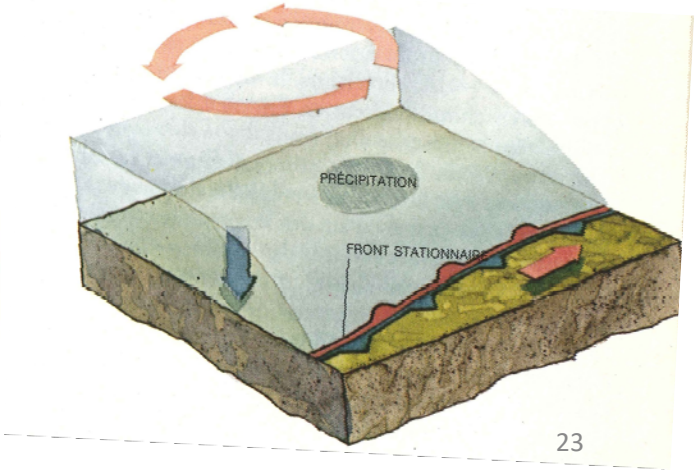




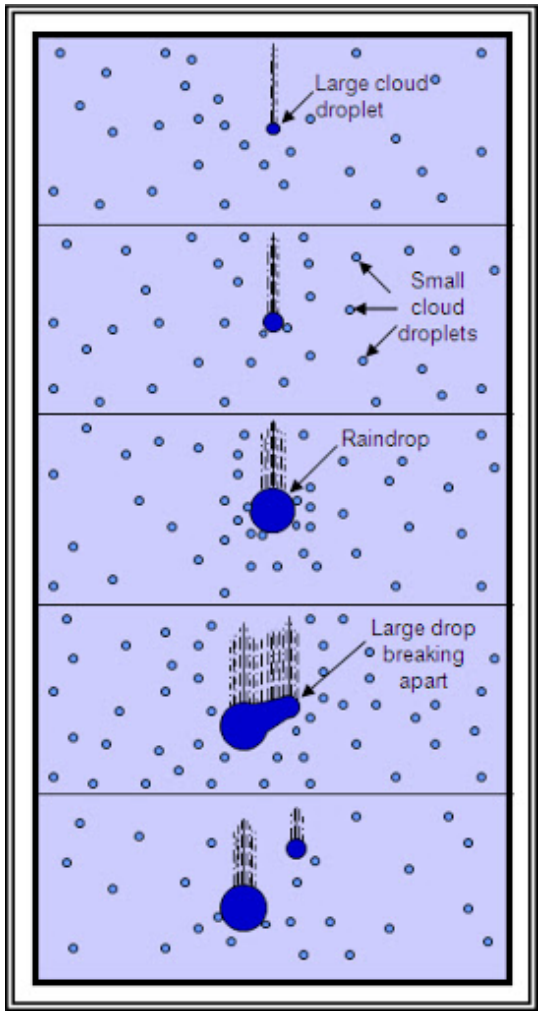




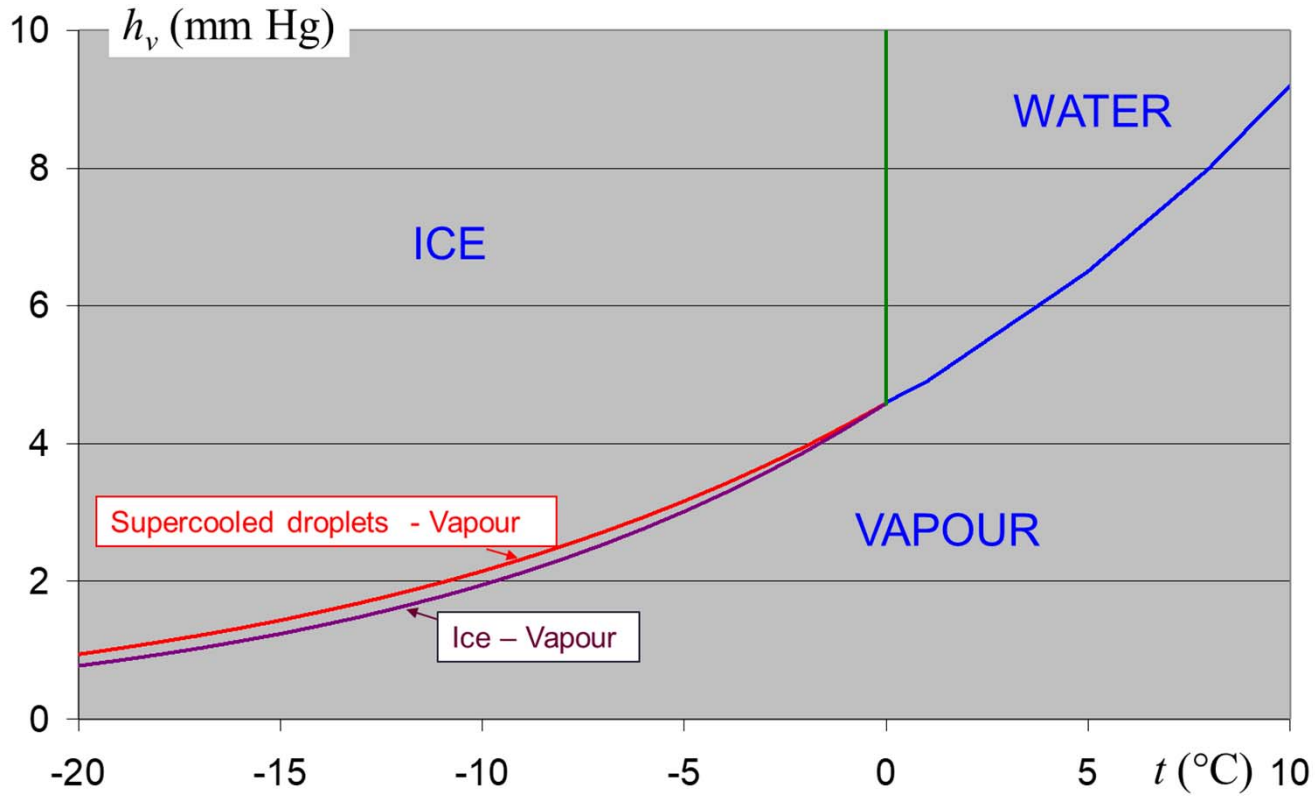




Formation of precipitation

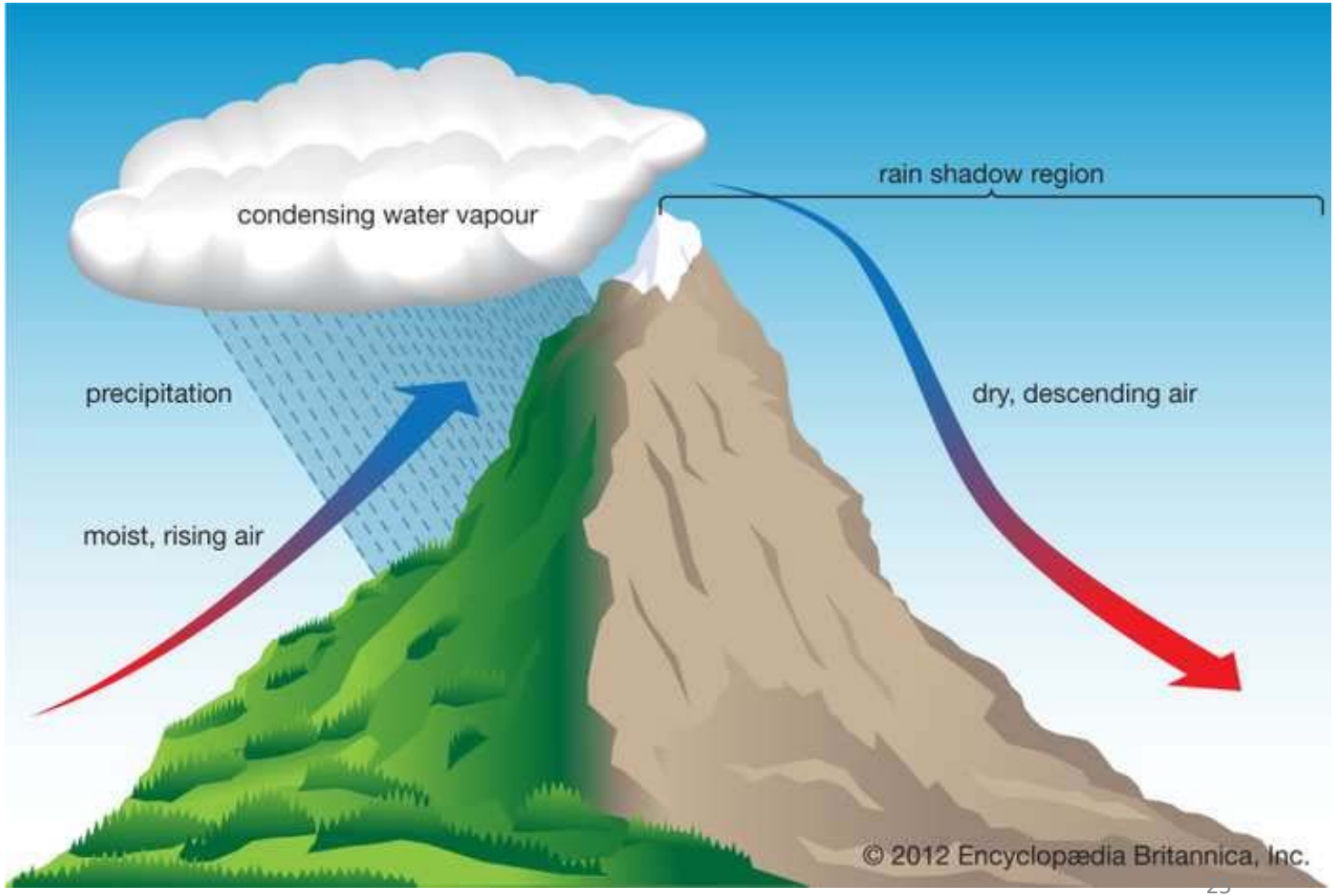


http://learntoflyblog.com/2016/10/03/weather-precipitation/



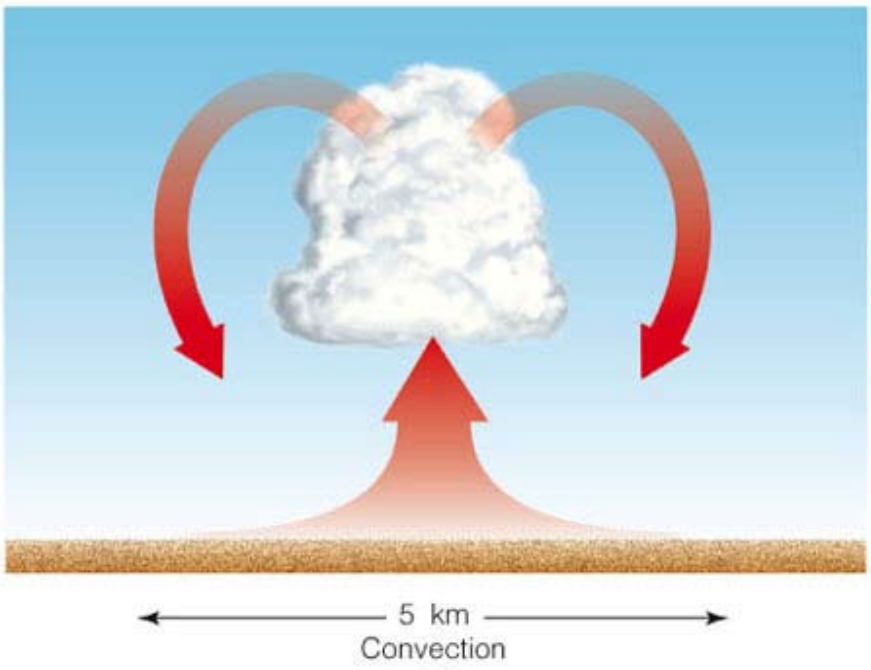
Types of precipitation

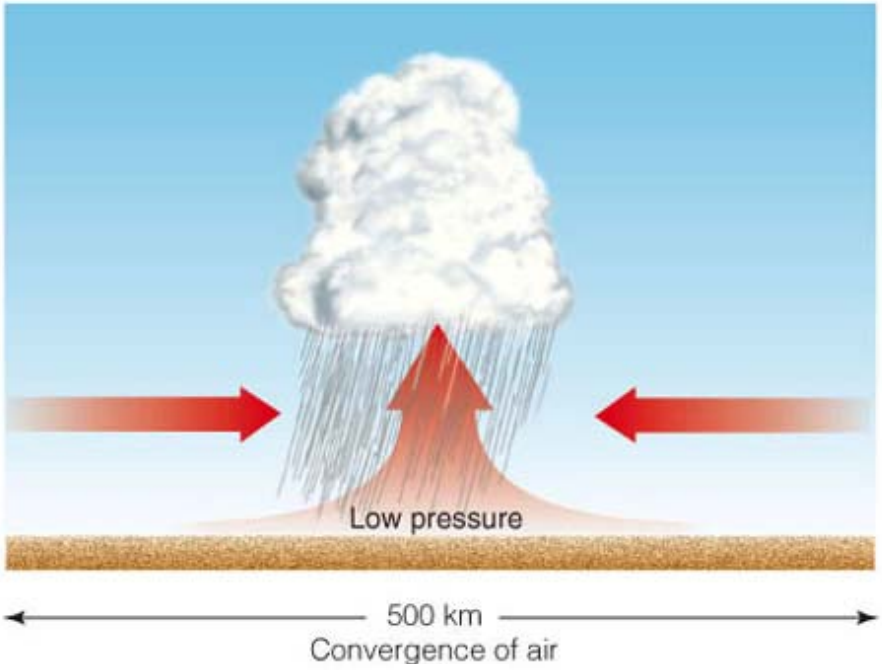
- Orographic



Types of precipitation

- Convectional

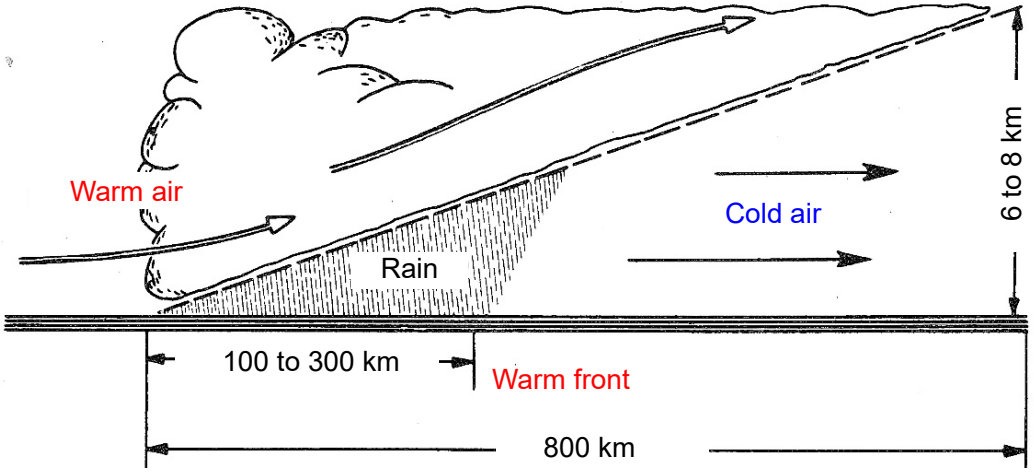




Types of precipitation

- Frontal

Warm front



Cold front