Les déterminants du climat. Cours Pour l'école Bordeaux-Sciences Agro (2e année). 2022

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Climate « change » ?

What is climate ?

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INRAE
UMR ISPA

The climate - Section 1

1. Climate: definitions and determinants

2. Quantitative aspects

3. The vegetation- climate equilibrium: the global ecosystem

The climate disturbance. Section 2

- Past and recent changes
- The state of the Earth system in 2022
- Scenarios for 2022-2120

Part 1. Climate: usual definitions

- **Climate**
  - Climate is commonly defined as **the weather averaged over a "long" period.** The standard averaging period is **30 years** (WMO) that is allowing to define statistics: a **normal (mean value over 30 years)**, magnitudes of day-to-day or year-to-year variations, events frequency, min. max. etc .

- **Microclimate**
  - Climate corresponding to the boundary layer coating an homogeneous surface (corn field, lake, forest plot…)

- **Climatology**
  - Interdisciplinary scientific research discipline related to the climate and aiming at the characterisation of the climate, classification of climate types, their location on the earth ,their determinants and the analysis of their temporal variability .

- **Meteorology**
  - Interdisciplinary scientific research discipline related to the atmosphere chemistry and physics which explains and forecasts weather events. Meteorology has application in many diverse fields such as the military, energy production, transport, agriculture and construction, health, ...

Part 1. The determinants of the temperature

Climate being summarised by the air temperature, what ingredients do we need for making a climate ?

Answer: first, energy !

Planck, Stefan Boltzmann laws:

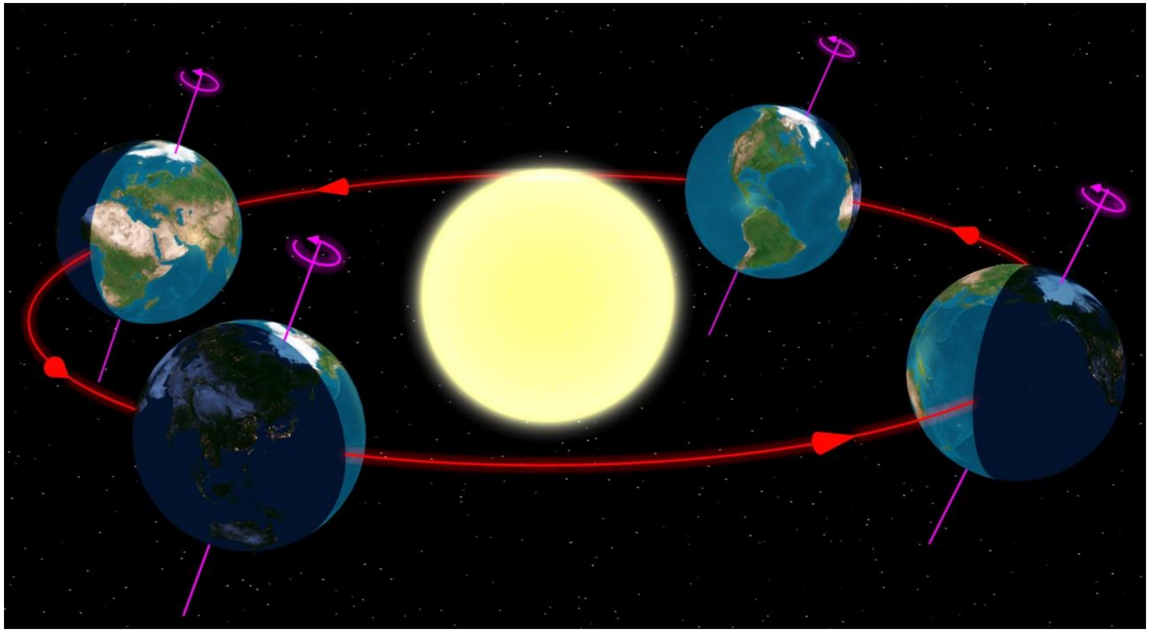
$$j = \varepsilon \sigma T^4$$

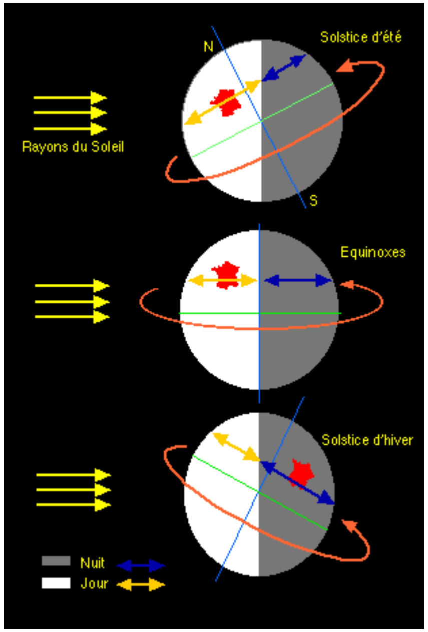
j	energy emitted or radiant emittance(J s^{-1} m^{-2} or W m^{-2}),
ε	emissivity
σ	S-B constant,
T	surface temperature (K)

Part 1. The determinants of the temperature: 1. **solar radiation**

The **sun and earth radiation emissions** are the almost unique, ultimate sources of energy
(Earth geothermic energy is~0.03% of earth surface energy balance)

1. Earth rotation and obliquity causes the short term variations of earth insolation (hour-year).

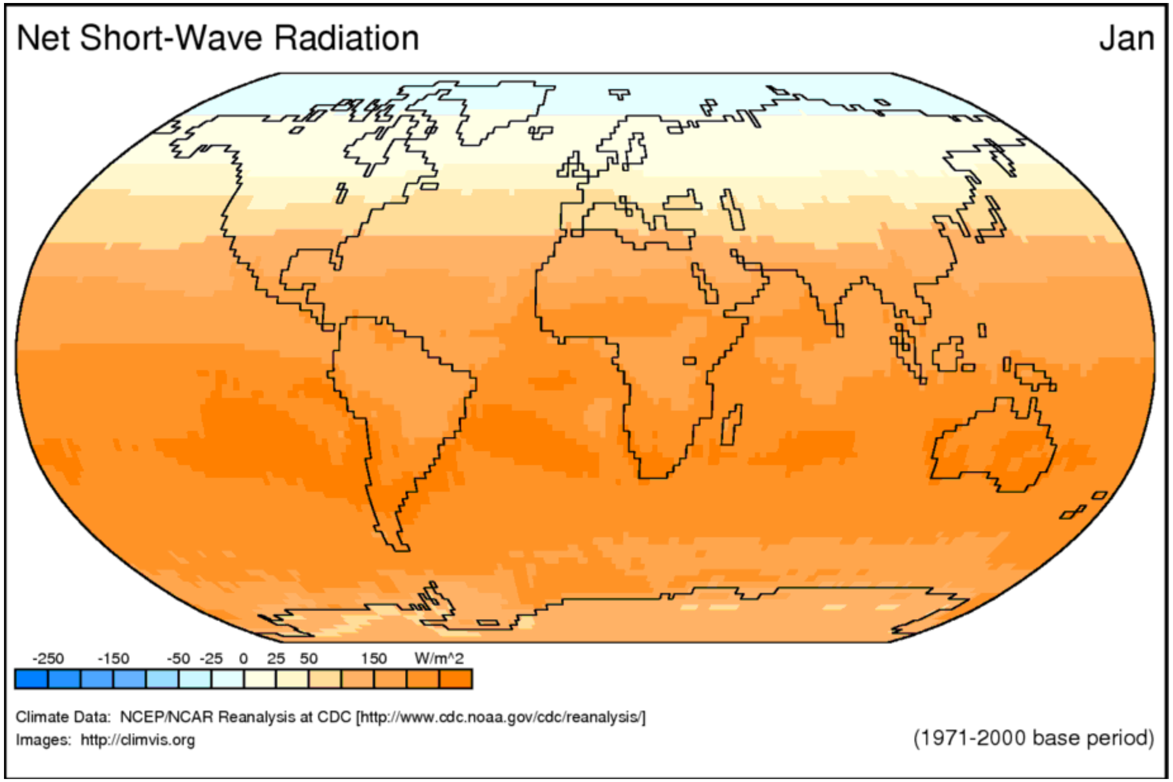




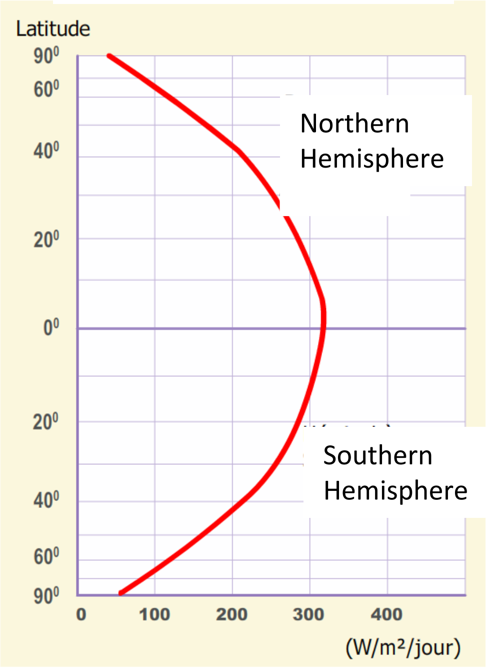
Part 1. The determinants of the temperature: 1. **solar radiation**

Global distribution of incident solar radiation (SW ↓)

http://climvis.org/anim/maps/global/nswrs.html



Mean SW Radiation absorbed

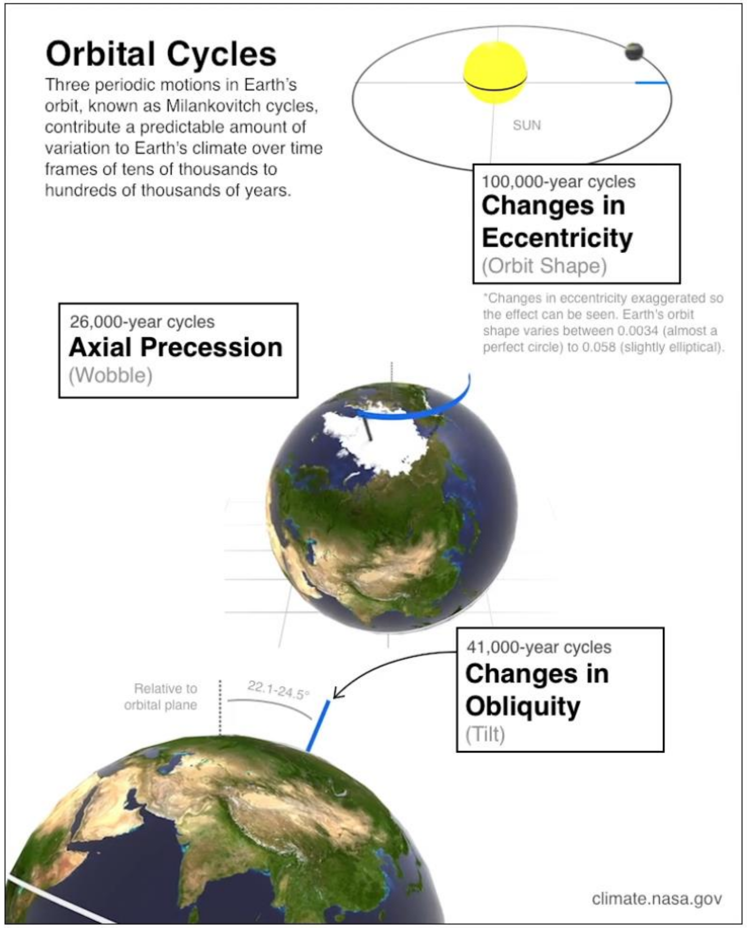


Part 1. The determinants of the temperature: 1. **solar radiation**

2. Long term variations of incoming solar radiation are caused by changes in:

- Eccentricity (10 000 yr ±1%)
- Obliquity (41 000 yr, 22.5 to 24°)
- Axial precession, for high latitudes irradiance (26 000yr)

That were described first by Milankovitch

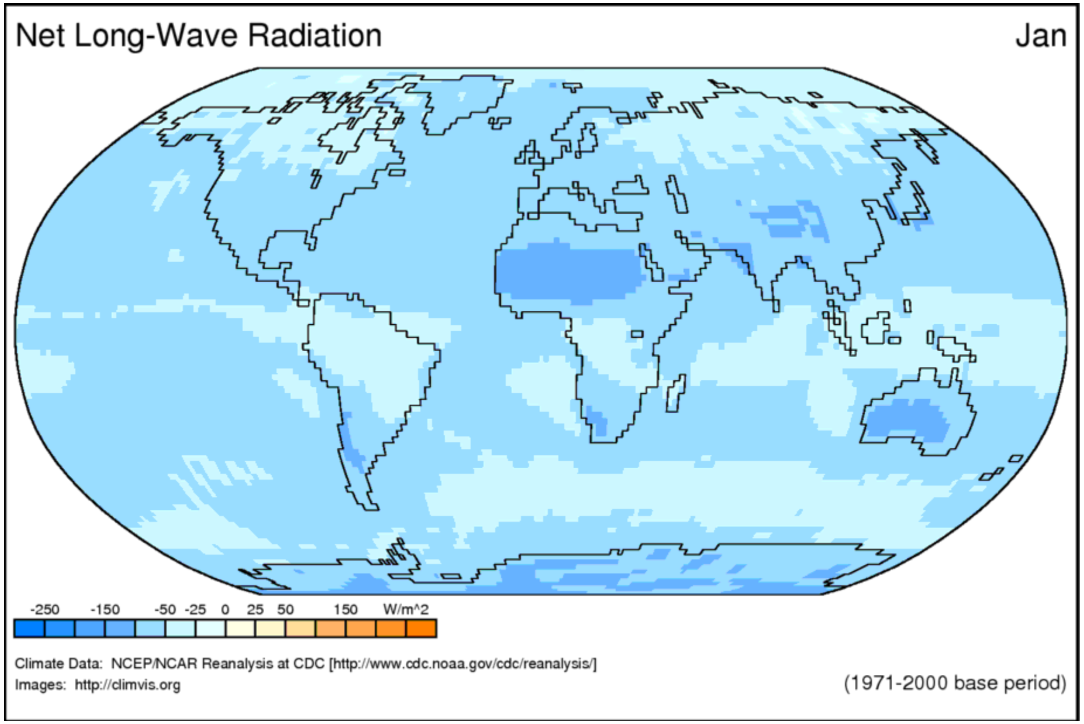


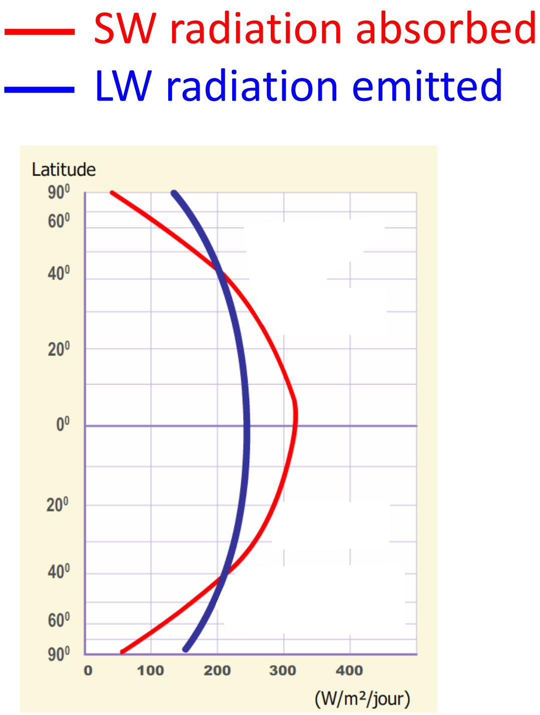
Credit: NASA/JPL-Caltech

https://climate.nasa.gov/blog/2949/why-milankovitch-orbital-cycles-cant-explain-earths-current-warming/

Global distribution of LW radiation balance

http://climvis.org/anim/maps/global/nswrs.html





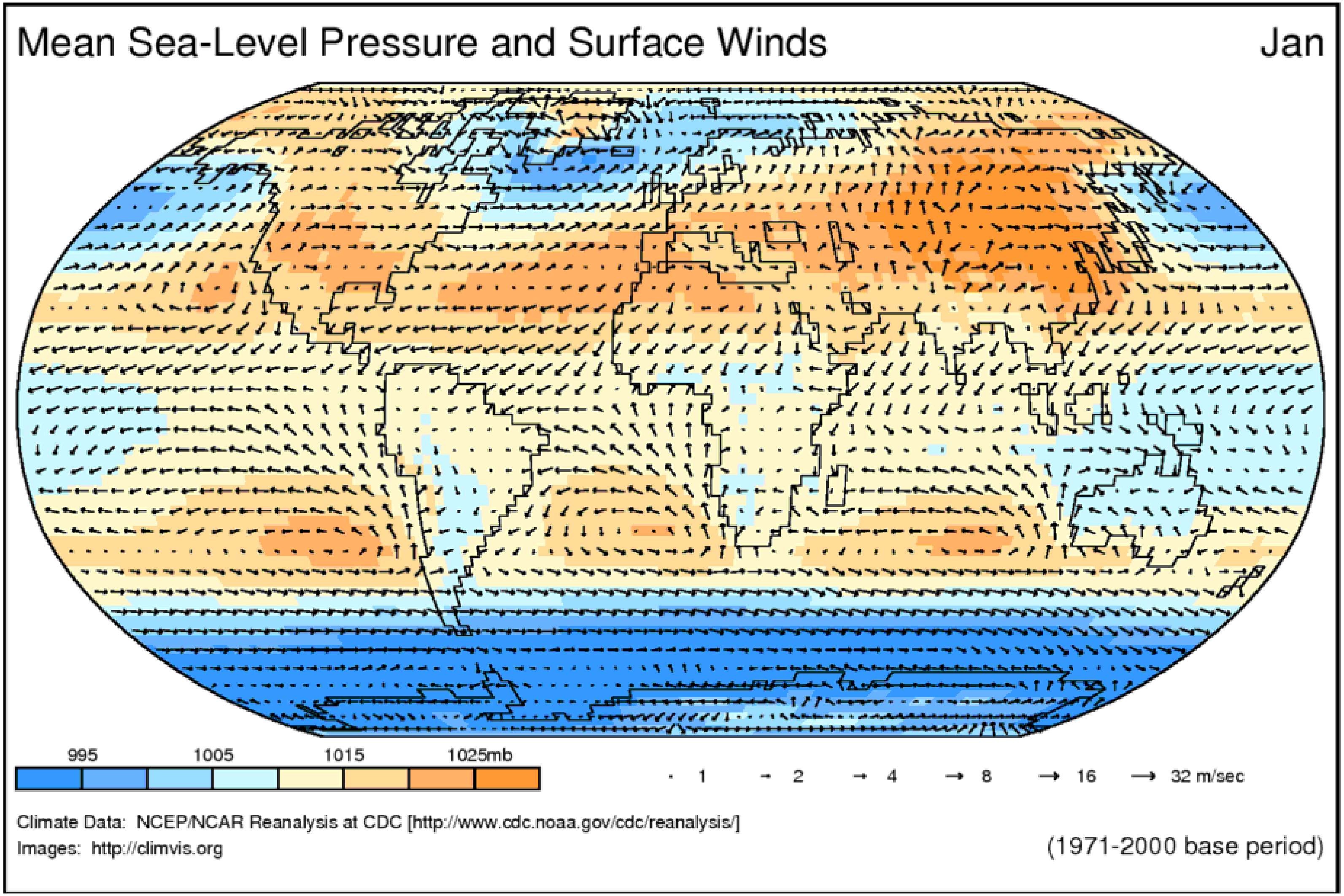
SW + LW earth radiative balance

- Imbalance between the poles (-) and equator(+)
- Creates the air convective mass transportation from Equator to the poles

Supports the <u>fast</u> transportation in fluid envelops of:

- Heat
- Water vapour ; liquid water
- Greenhouse gases: CO_2, CH_4, N_2O, O_3
- Pollutants: NO_x, NH_4, SO_3

ATMOSPHERE


Mean Sea-Level Pressure and Surface Winds
Jan
995
1005
1015
1025mb
1
2
4
8
16
32 m/sec
Climate Data: NCEP/NCAR Reanalysis at CDC [http://www.cdc.noaa.gov/cdc/reanalysis/]
Images: http://climvis.org
(1971-2000 base period)

Part 1. The climate determinants: 4. the « greenhouse » effect

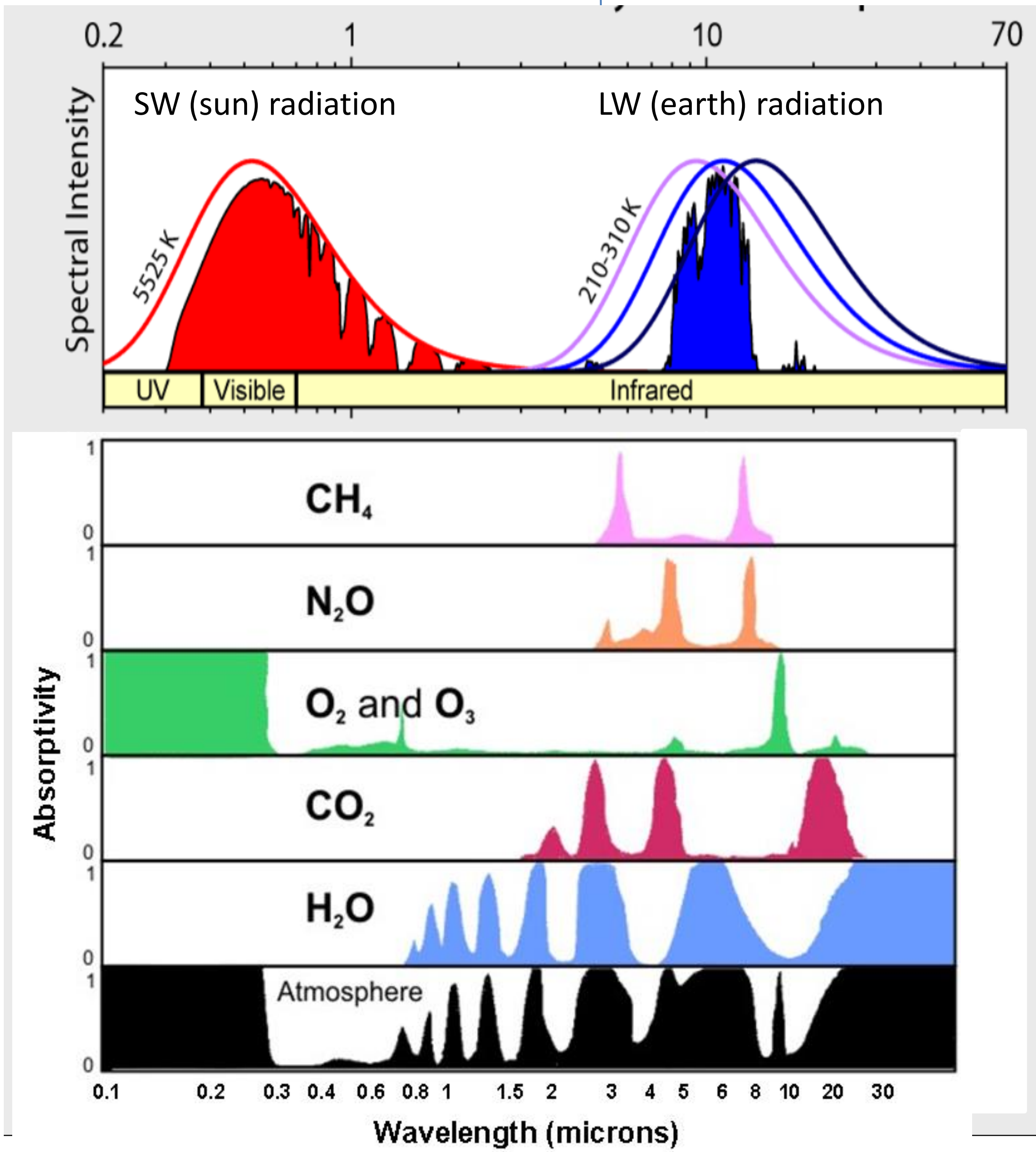
Radiative exchanges between the earth surface and the atmosphere

1. **Any body emits a radiation depending on its surface temperature that determines:**
   - its spectral composition (Wien's law)
   - Its energy (Stefan-Bolzmann's law).

2. 70% of the solar radiation (T=5600 K) enters into the atmosphere, 30% is reflected.

3. The earth surface T~ 288 K.

4. 40% of earth radiation is absorbed by the atmosphere and transformed in heat : this is the **greenhouse effect. 30%**

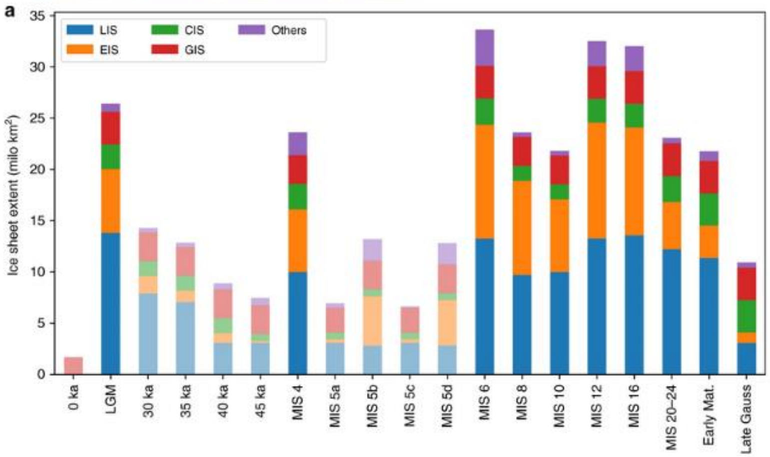


The climate determinants: 5. Surface feedbacks –radiative properties

Ice sheet extent variations affect surface albedo

Fig. 2

From: The configuration of Northern Hemisphere ice sheets through the Quaternary

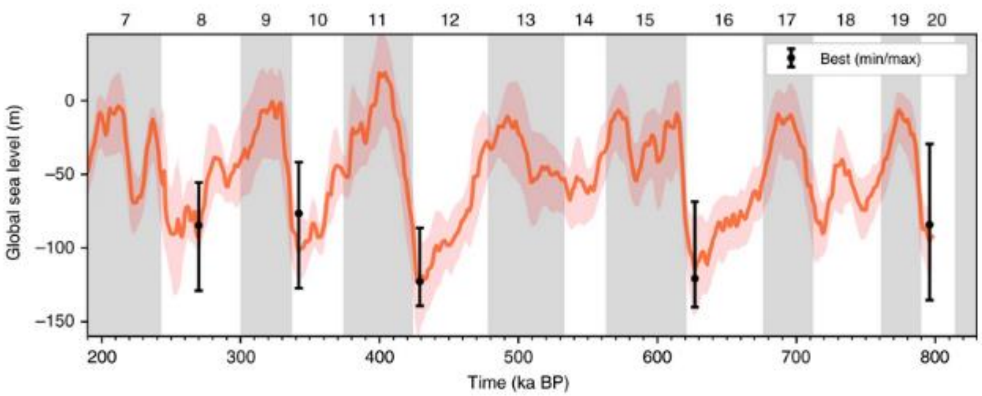


The configuration of Northern Hemisphere ice sheets through the Quaternary

Christine L. Batchelor, Martin Margold, Mario Krapp, Della K. Murton, April S. Dalton, Philip L. Gibbard, Chris R. Stokes, Julian B. Murton & Andrea Manica

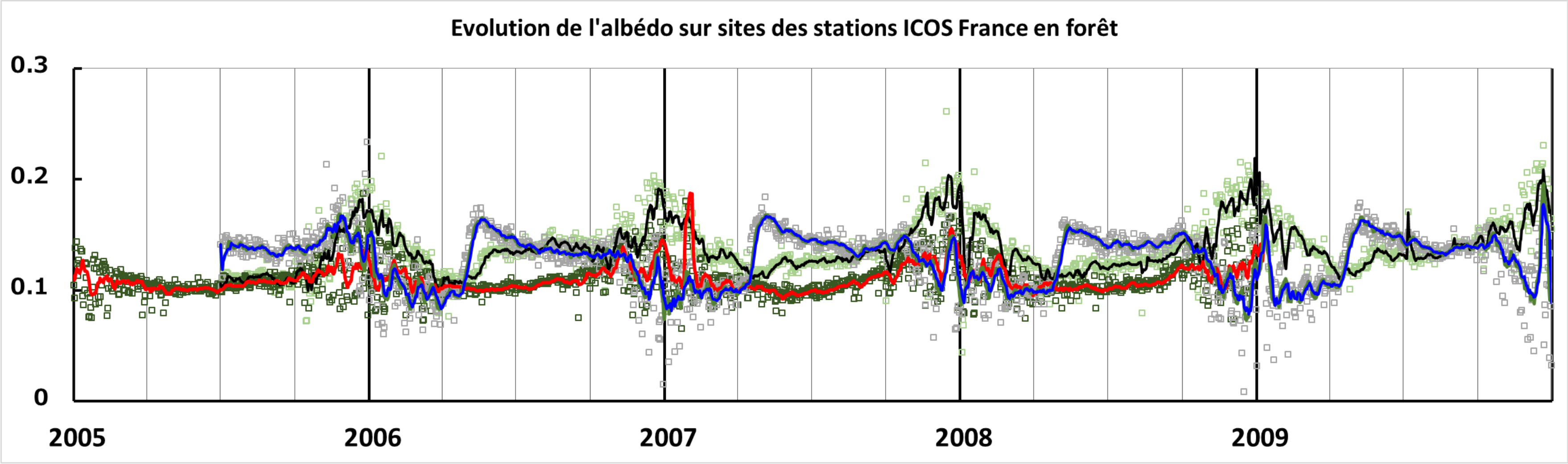
Nature Communications **10**, Article number: 3713 (2019) | Cite this article

and sea level, so continental surface area.



The climate determinants: 5. Surface feedbacks –radiative properties

— Ok, Hornbeam —Pines —Holm Oak + Pines



✓ The albédo varies from 0.06 to 2.25 according to species.

The climate determinants: 5. Surface feedbacks – air humidity effects

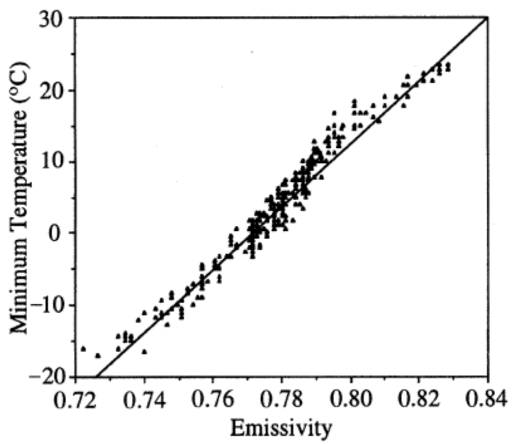
Heat exchanges between surface and atmosphere: the latent heat case.

1st Feed back +: the air humidity increases the emissivity

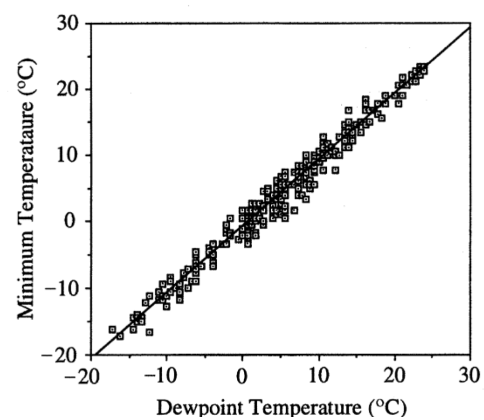
ETR → air humidity ↑ → LW radiation ↑ → T min ↑

2nd Feed back +: condensation is a net source of heat

ETR → air humidity ↑ → dew point T ↑ → Latent heat for condensation ↑ & Tmin ↑



Correlation between atmospheric emissivity and min. Temperature for 222 stations in N Americ.



Corrélation between dew point temperature and min Temperature for 222 met. stations .

The climate determinants: 5. Surface feedbacks – air humidity effects

Tmin = 27 °C

Tmin = 12 °C

Observations

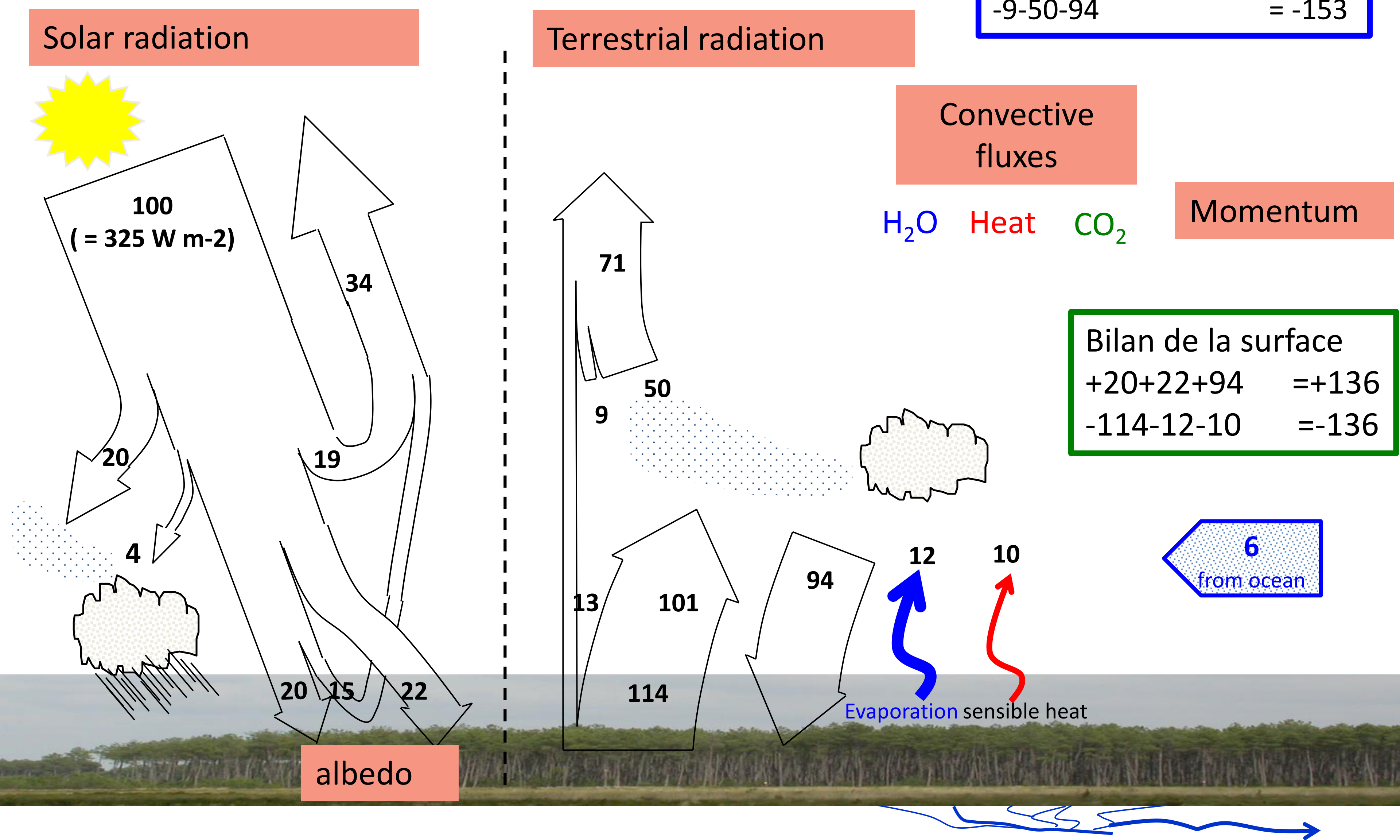
Simulation with no evapotranspiration

Part 1. Synthesis: the earth surface energy balance

Annual mean energy balance components over land

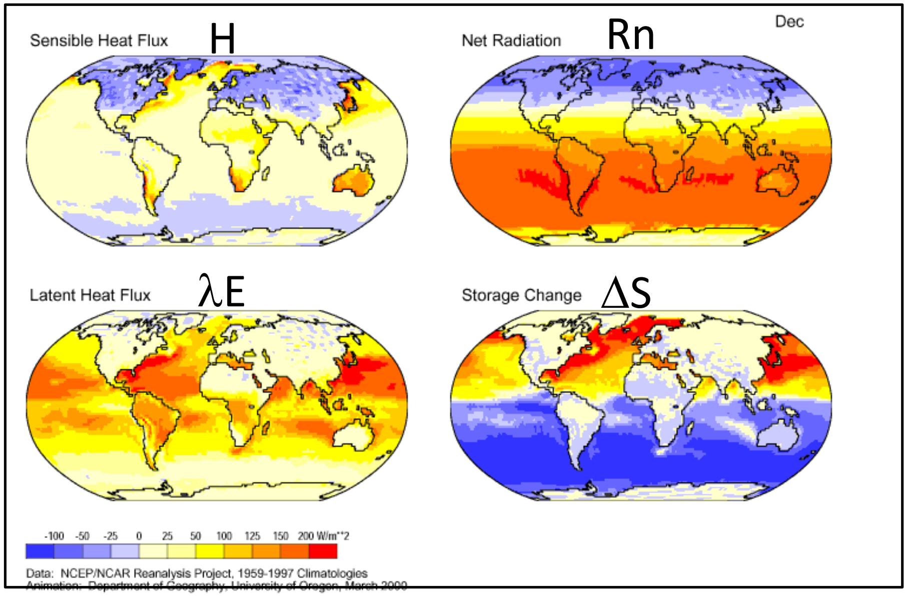
(Wild et al. 2015. Clim. Dynamics, DOI 10.1007/s00382-014-2430-z)

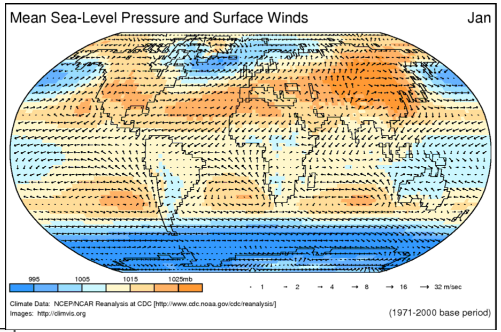
Bilan de l'atmosphère
+20+4+101+12+10+6 = +153
-9-50-94 = -153

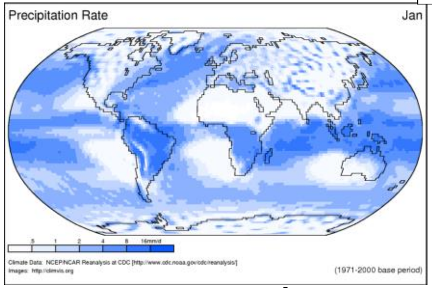


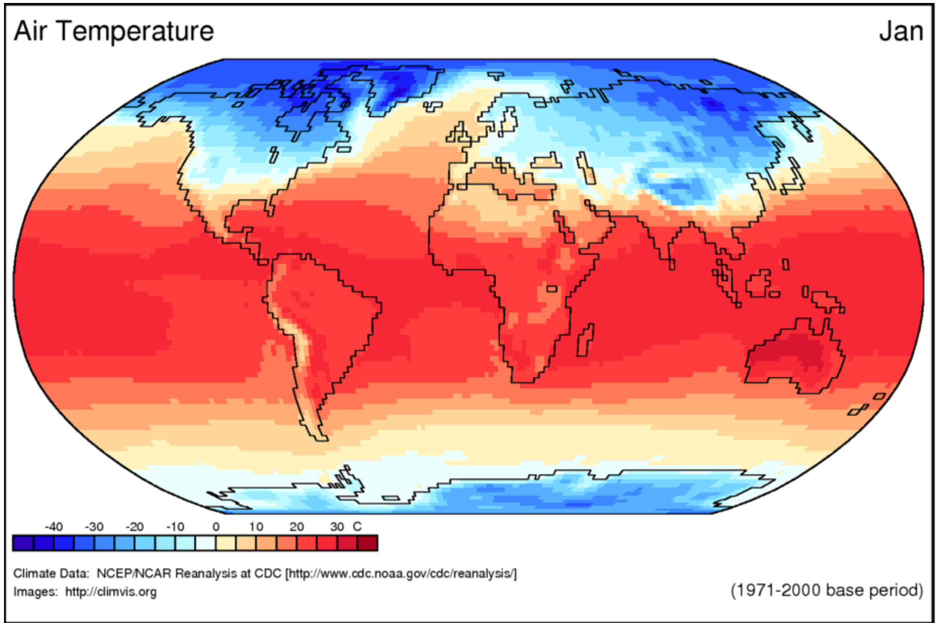
Bilan de la surface
+20+22+94 =+136
-114-12-10 =-136

Part 1. The earth energy balance









http://climvis.org/content/global.htm

The determinants of the climate: questions

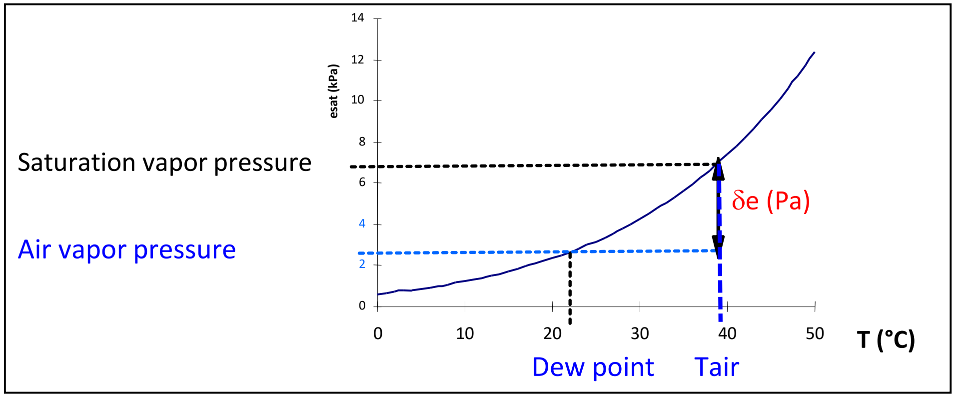
Bilan de l'atmosphère
+20+4+101+12+10+6 = +153
-9-50-94 = -153

Bilan de la surface
+20+22+94 =+136
-114-12-10 =-136

What would happen in case the energy budget is not balanced ?

Temperature: degree Celsius, Kelvin.

Air water content : water vapor pressure (e in Pa), saturation pressure , saturation deficit of water vapor (δe).



→The water vapor saturation deficit increases with the air temperature

→ δe is the driver of plant and animal transpiration :

→ when $e_{(surface)} - e_{(air)} = 0$, transpiration = 0

→ List the situation allowing transpiration to be >0 . Same for transpiration <0

NB. The air relative humidity (HR = Pair / Psat) has no physical meaning. Should be avoided.

Part 2. The climate , quantitative aspects : meteorological variables and their measurement

Radiation ($J.T^{-1}.L^{-2}$):

quantum(Photons.m^{-2})

energy (Joule . s^{-1} . m^{-2} = W . m^{-2}).

Pressure

Pressure is force applied on a surface. Unit force per unit area, with SI unit = pascal

(Pa = $N.m^{-2}$ = $J.m^{-3}$ = $Kg.m^{-1}.s^{-2}$):

NB 1mBar = 1hPa =100 Pa.

Wind: a displacement of air caused by pressure differences. Wind flow can be zero, laminar (rare) of turbulent. Most often, only the horizontal component is given.

Unit ($L^3.L^{-2}.T^{-1}$) = $L.T^{-1}$ = $m.s^{-1}$

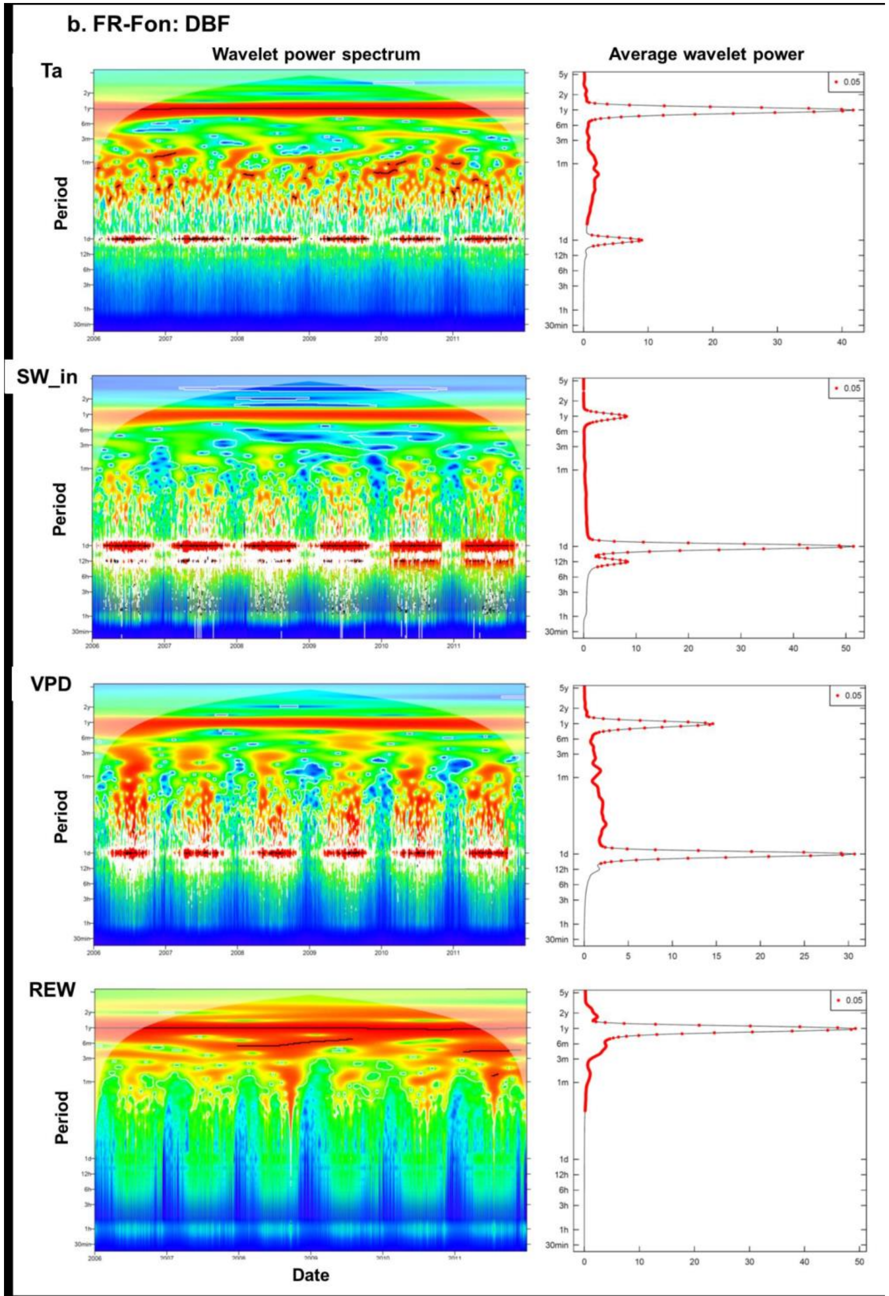
Precipitations: downward flow of solid or liquid water on to the surface. Type (snow, ice, rain, fog) intensity, interception, (mass.$T^{-1}.L^{-2}$)

Part 2. How often do climate variables change?

Power spectra of climate variables over the Fontainebleau forest, France, 2007-2012. (Moreaux et al. Tellus b, 2020).

- Radiation (SW) and temperature (Ta) variation patterns are forwarded to the air water vapour saturation deficit (VPD)

- Precipitation and soil water (REW), influenced by surface and local conditions shows distinctive patterns(weak high-frequency variations).



Which variables are relevant for describing the atmosphere ?

Physician answer : all of them !

Practical answer : the ones we can measure ! (Temperature, Precipitations,....)

Which statistics ?

Average values ? Min Max ? n^{th} order moments ?

The time characteristics of meteorological variables:

Temporal spectrum of meteorological variables matches the time characteristics of drivers:

PERIOD	DRIVER	EFFECT
10^4 yr	Milankovich cycles	glaciation cycles
10^{2-3} yr	Fossil GHG emissions	« climate change »
1 yr	Earth ellipsoïd around Sun	Annual period
0.25 yr	Surface inclination angle	Season (mid latitude)
Week-day	Frontal wind regime	Anticyclone, depression
12 hours	Earth rotation	Night – Day sea / earth breeze
6 hours (tide)	Sun – Moon – Earth alignment	Tides
hour	Cloud passage duration	Sky fraction, direct/diffuse light
mn-sec-0.1 sec	Surface roughness length	Turbulence

Which is the relevant temporal scale for defining a climate?

→ pragmatic answer: 30 yrs (man's memory ?)

→ Mathematical answer : the shortest duration at which statistics (n^{th} order moments) are steady.

Part 3. The connection between vegetation and climate types:

1) phytogeography

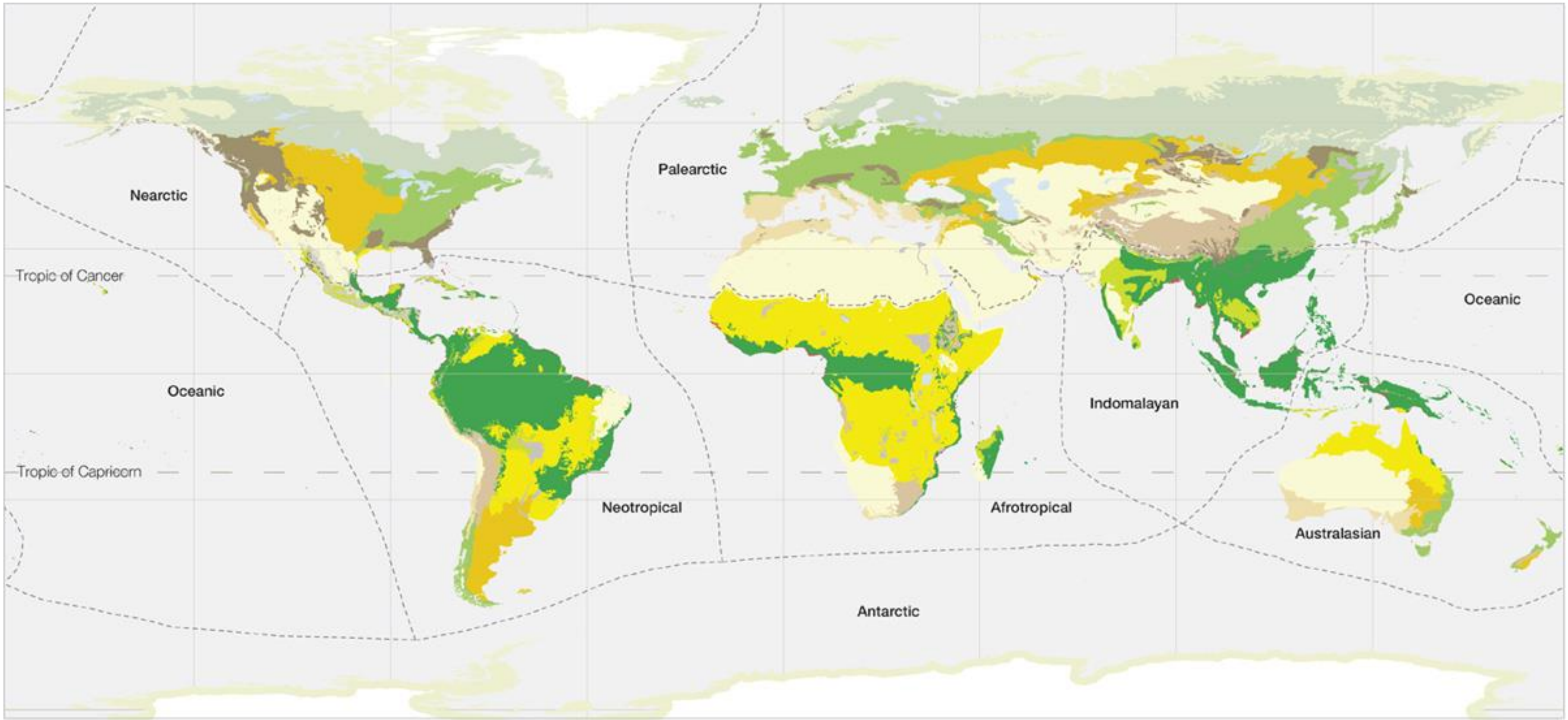
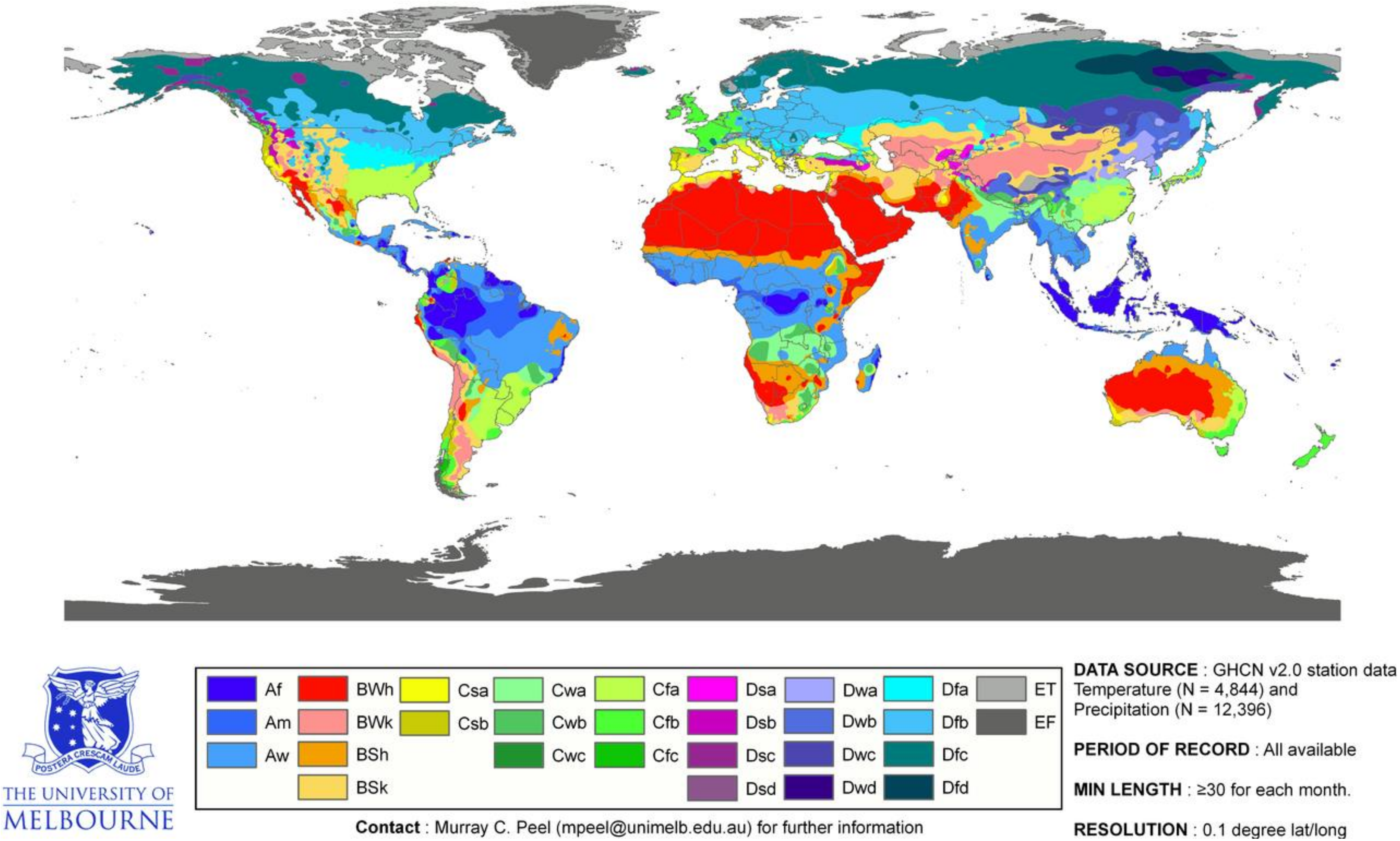


Fig. 8: **TERRESTRIAL BIOGEOGRAPHIC REALMS AND BIOMES**

- Tropical and subtropical moist broadleaf forests
- Tropical and subtropical dry broadleaf forests
- Tropical and subtropical coniferous forests
- Temperate broadleaf and mixed forests
- Temperate coniferous forests
- Boreal forests/taiga
- Tropical and subtropical grasslands, savannahs and shrublands
- Temperate grasslands, savannahs and shrublands
- Flooded grasslands and savannahs
- Montane grasslands and shrublands
- Tundra
- Mediterranean forests, woodlands and scrub
- Deserts and xeric shrublands
- Mangroves
- Water bodies
- Rock and ice

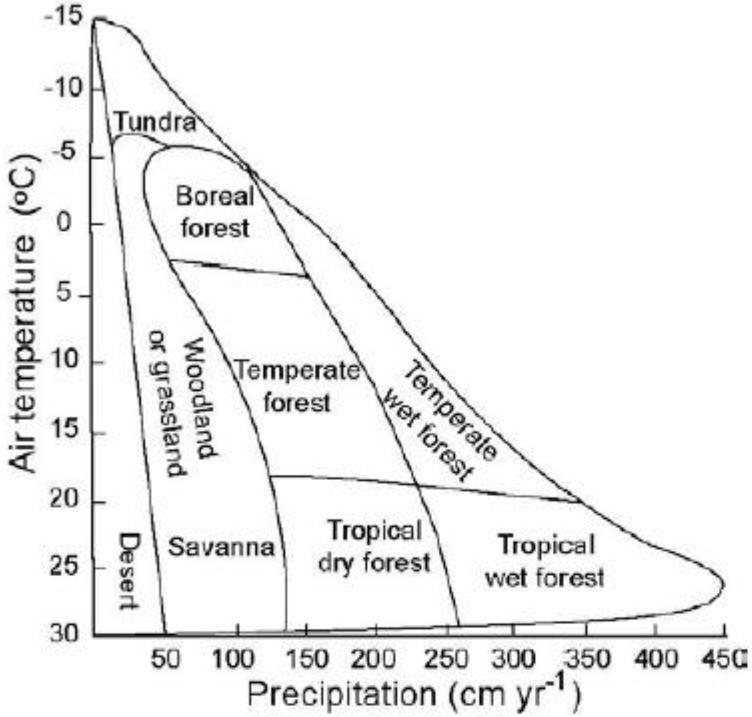
LIVING PLANET REPORT 2008

Part 3. Climate classification / types



Par Peel, M. C., Finlayson, B. L., and McMahon, 2007 T. A.(University of Melbourne) — Hydrology and Earth System Sciences: "Updated world map of the Köppen-Geiger climate classification" (Supplement) - https://commons.wikimedia.org/w/index.php?curid=2906492

Part 3. Climates: linking biomes to climate types

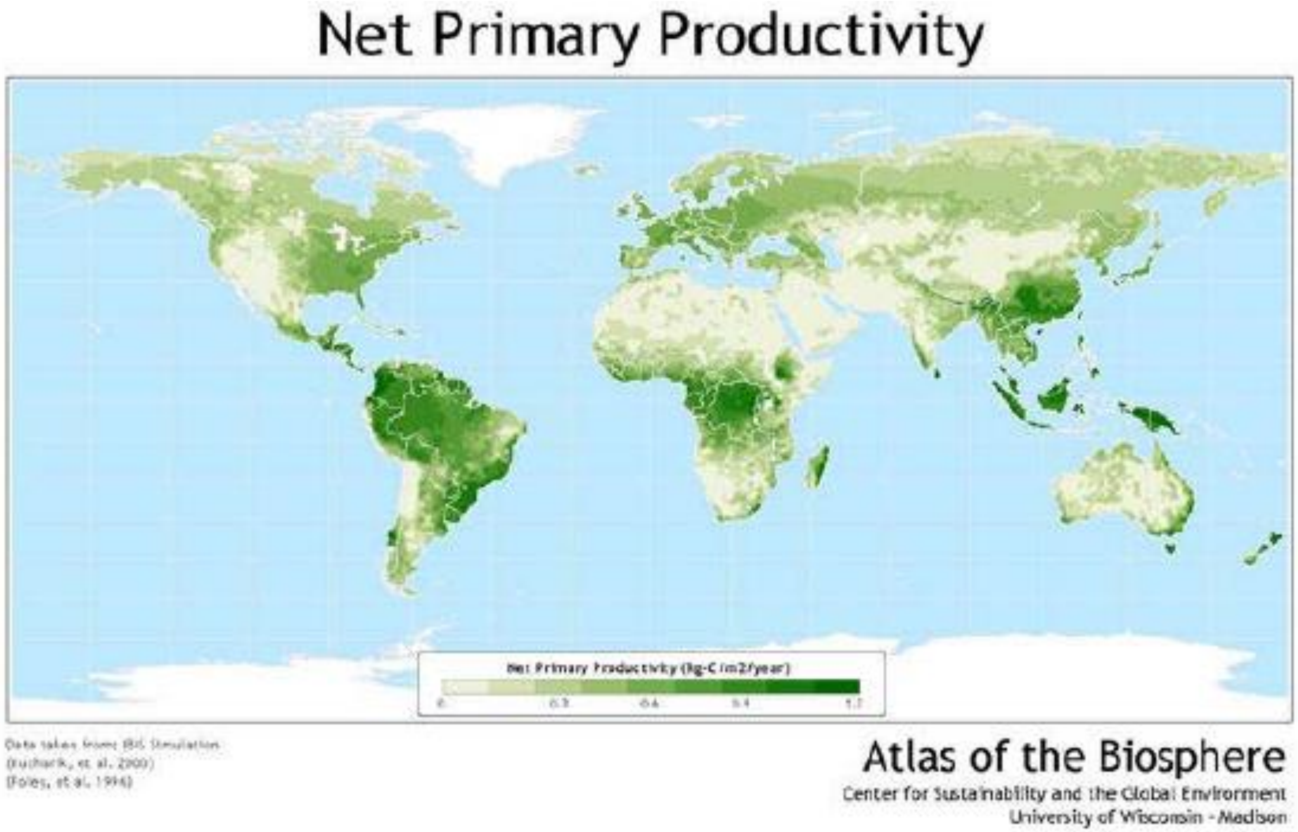


A biome is a biotic community defined by its dominant vegetation (« vegetation belts »).

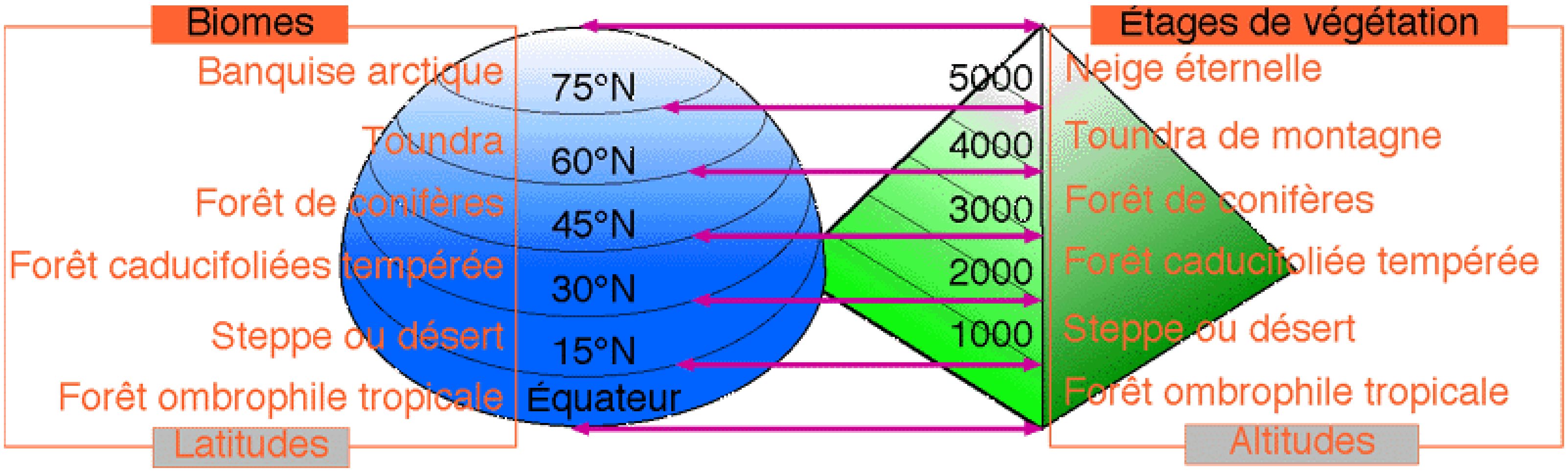
The distribution of the vegetation in biomes can be deduced from the climate types.
(NB *y* axis reversed).

Part 3. The connection between vegetation and climate :

2) biogeochemistry



Part 3. The connection between vegetation and climate



La pression de sélection climatique donne lieu au phénomène de **convergence fonctionnelle ou convergence adaptative** qui est l'apparition des mêmes caractéristiques adaptatives chez les espèces non apparentées soumises à une pression identique.

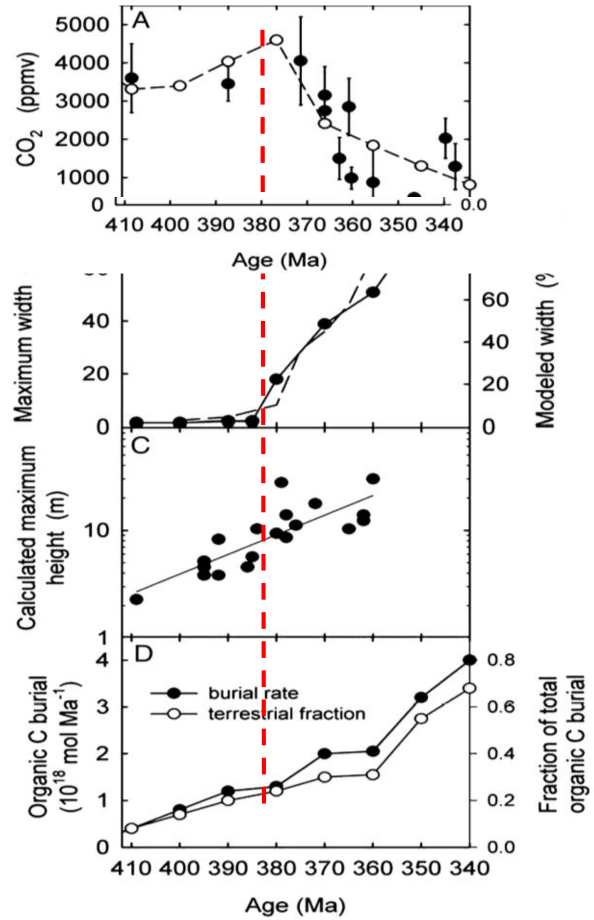
Ex. : métabolisme CAM, Succulence, sclérophyllie, métabolisme C3 / C4, phénotypes de Raunkier etc…

Part 3. Vegetation and climate : a story of reciprocal interactions

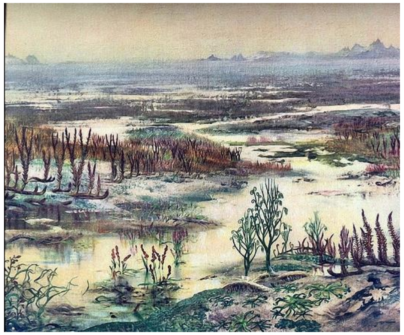
Concise history of the GHG atmospheric concentration:

Link with land colonisation

- CO_2 atmospheric concentration →
- Conductive plant tissues (tracheids) →
- Wood (lignin), leaves
- Trees (coniferous) →
- Soil →



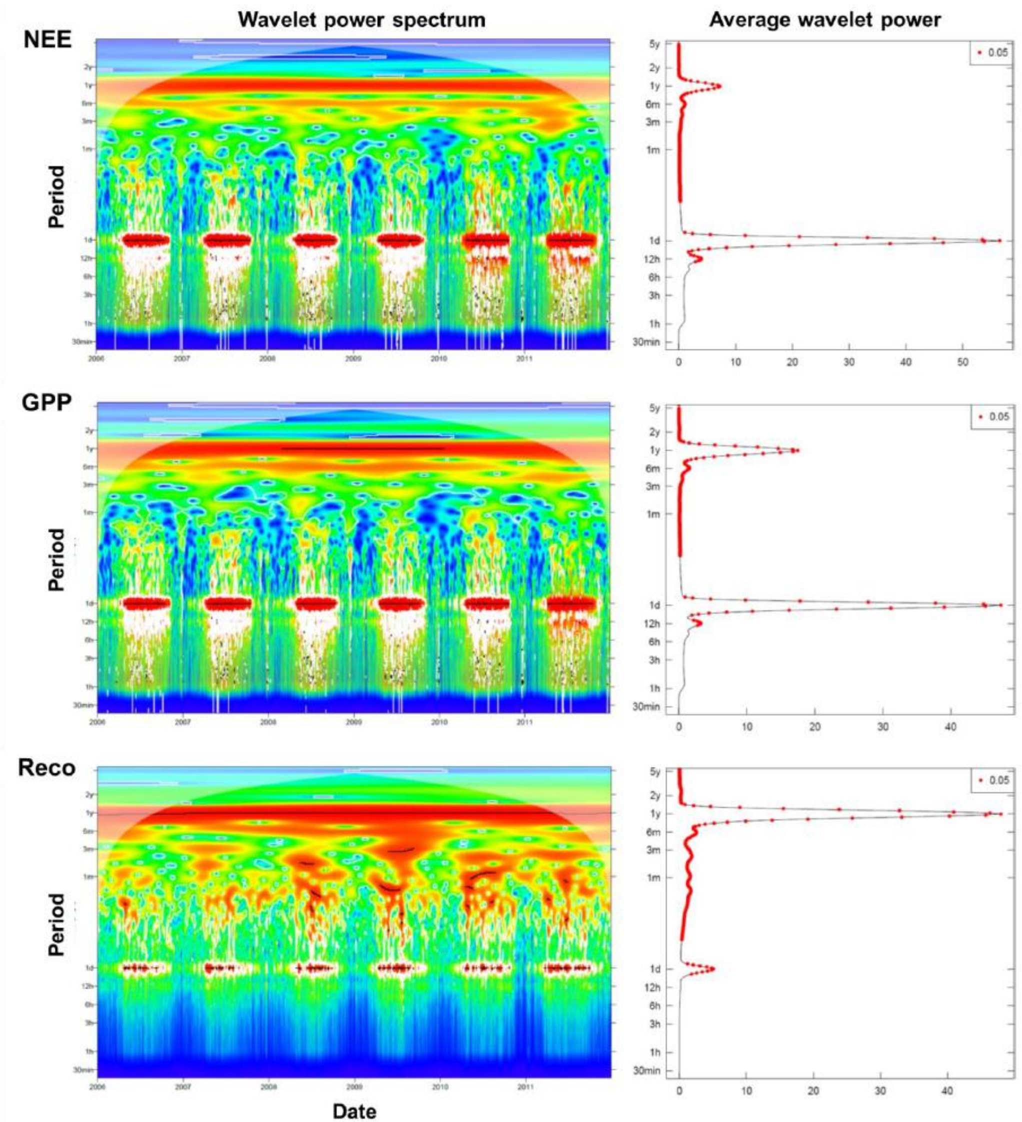
Beerling D J , Berner R A
PNAS 2005;102:1302-1305



Part 3. Vegetation and climate : reciprocal interactions

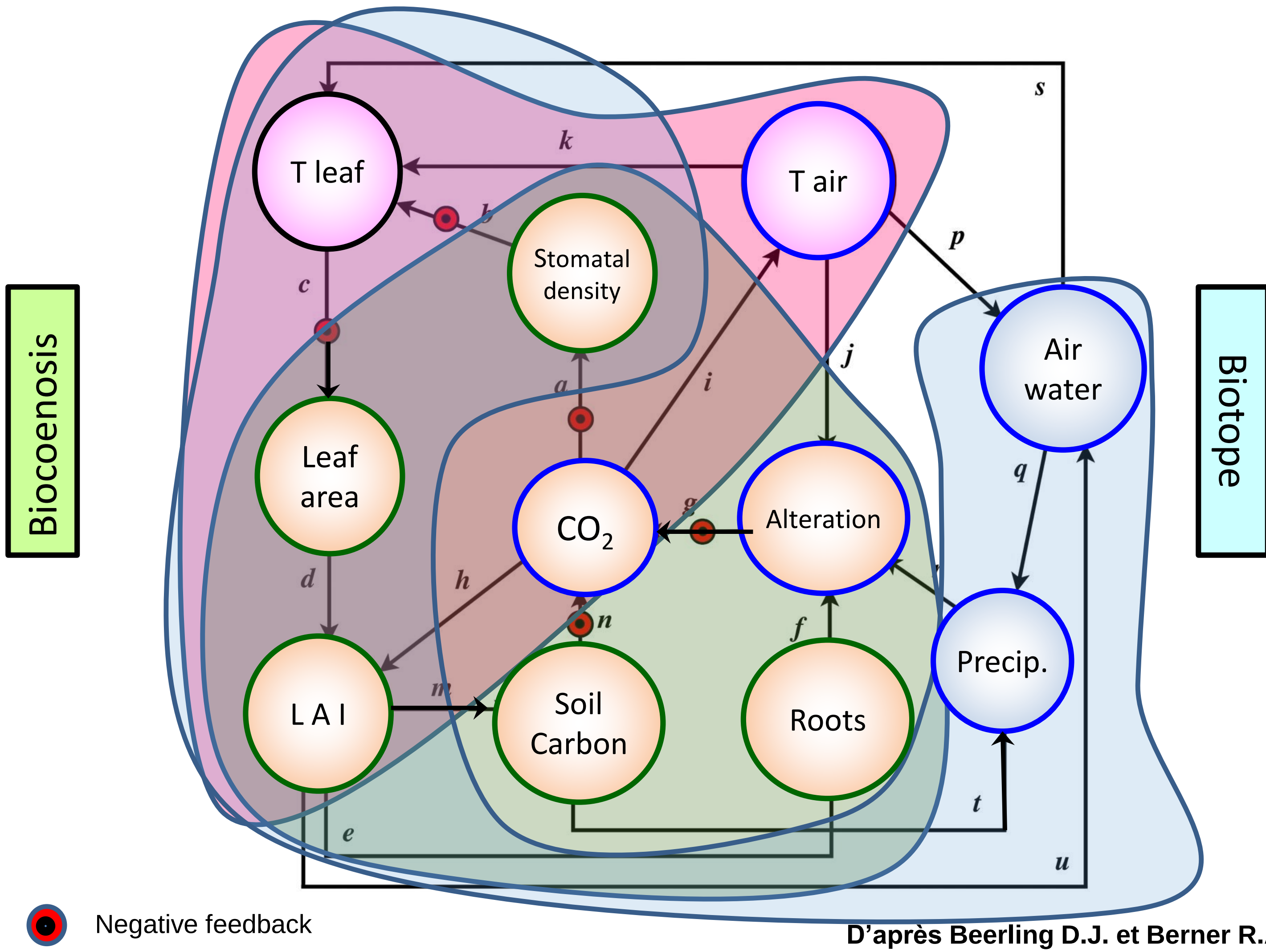
High frequency variations of Ecosystem physiology are controlled by meteo variables.

- The climate control (radiation) is tighter at high frequency
- Biological adjustements dampen the low frequency variability of ecosystem activity
- Respiration if more closely linked to temperature



Part 3. The global ecosystem concept

- Time constants = 1 to >10^6 yrs (from superfast to ultra slow)
- The connection between vegetation and atmosphere : a model of ecosystem



Interactions :
Biophysical

Biogeochemical

Hydrological

D'après Beerling D.J. et Berner R.A., PNAS 2005;102:1302-1305

Climate: few thoughts

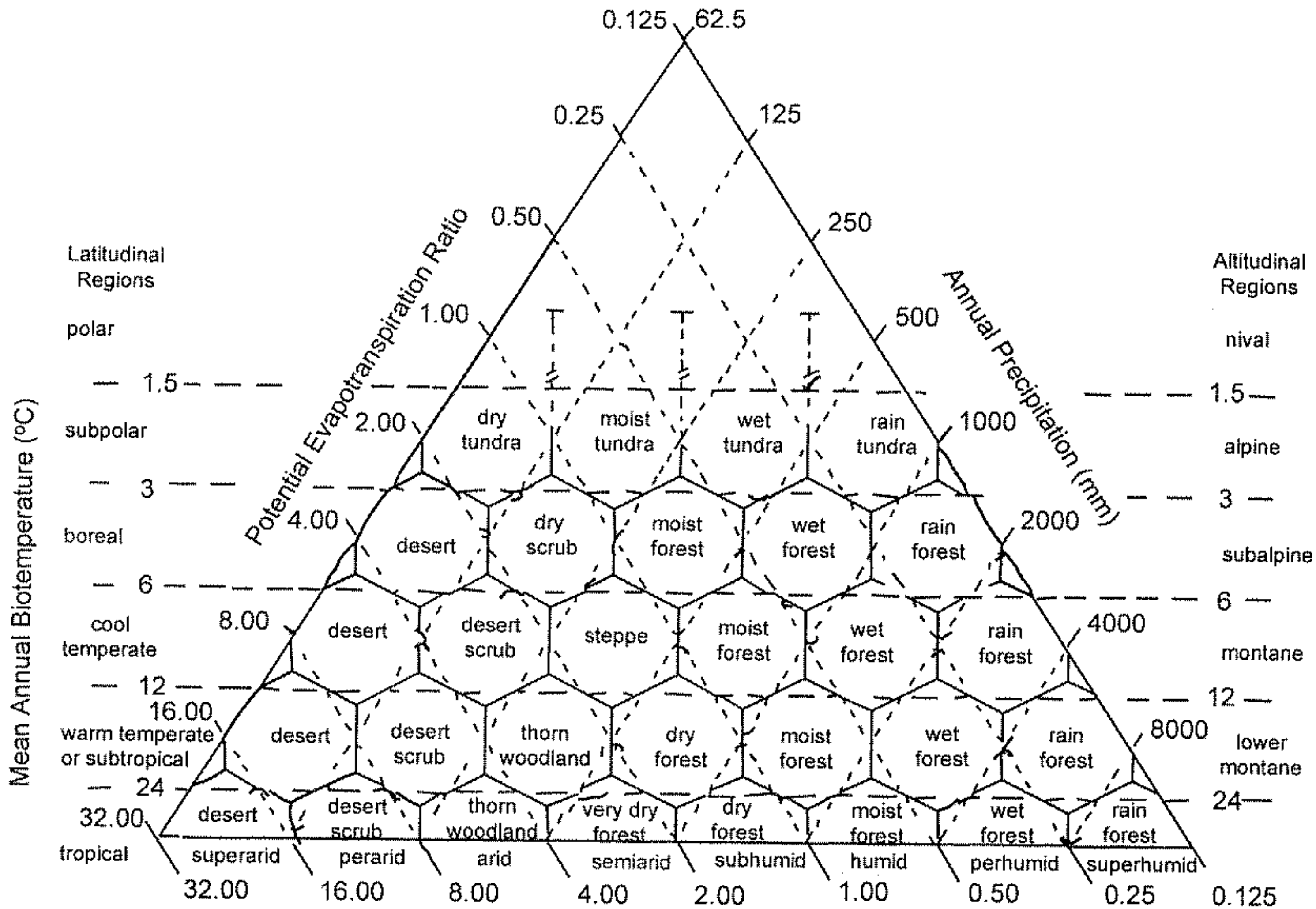
The concept of climate is based upon the **sensual perception by Man** of the weather.
The climate classification is based on statistics calculated over a typical 30yr time series (the memory of a human being).

Values of all climate variables are varying actually at different temporal resolutions along a variance spectrum from 10^5 to 10^{-12} Hz

This variability is well understood. It was shaped for the last 800 000 years by the fluctuations of mostly cosmic and secondarily atmospheric drivers.

Supplementary slides.

The climate – vegetation correspondence: the Holridge triangle.



Climatology: The Koeppen classification

- 3 letters code based upon the temperature and precipitations
- Statistics calculated over 30-yr temporal series

1re lettre : type de climat [modifier | modifier le code]

Code	Type	Description
A	Climat tropical	• Température moyenne de chaque mois de l'année > 18 °C • Pas de saison hivernale • Fortes précipitations annuelles (supérieure à l'évaporation annuelle)

B	Climat sec	• Évaporation annuelle supérieure aux précipitations annuelles. Ce seuil est calculé de la manière suivante :
		  ◦ Si moins de 30 % des précipitations tombent en été (avril à septembre dans l'hémisphère nord) : Précipitations annuelles moyennes (mm) < 20 × température annuelle moyenne (°C)
		  ◦ Si plus de 70 % des précipitations tombent en été : Précipitations annuelles moyennes (mm) < 20 × température annuelle moyenne + 280
		  ◦ Autrement : Précipitations annuelles moyennes (mm) < 20 × température annuelle moyenne + 140

C	Climat tempéré	• Température moyenne du mois le plus froid comprise entre 0 °C et 18 °C • Température moyenne du mois le plus chaud > 10 °C • Les saisons été et hiver sont bien définies
D	Climat continental	• Température moyenne du mois le plus froid < 0 °C • Température moyenne du mois le plus chaud > 10 °C • Les saisons été et hiver sont bien définies
E	Climat polaire	• Température moyenne du mois le plus chaud < 10 °C • La saison d'été est très peu marquée

Climatology: The Koeppen classification

- 3 letters code based upon the temperature and precipitations
- Statistics calculated over 30-yr temporal series

2e lettre : régime pluviométrique [modifier | modifier le code]

Code	Description	S'applique à
S	• Climat de steppe • Précipitations annuelles comprises entre 50 et 100 % du seuil calculé	B
W	• Climat désertique • Précipitations annuelles < 50 % du seuil	B

w	• Saison sèche en hiver
	  • Pour A : climat de la savane, P du mois le hivernal le plus sec < 60 mm et < [100 – (précipitations annuelles moyennes)/25]
	  • pour C et D : P du mois hivernal le plus sec < 1/10 du mois le plus humide
		A-C-D

s	• Saison sèche en été
	  • Pour A : climat de la savane, P du mois le estival le plus sec < 60 mm et < [100 – (précipitations annuelles moyennes)/25][3]
	  • Pour C et D : P du mois estival le plus sec < 40 mm et < 1/3 du mois hivernal le plus humide)
		A-C-D

f	• Climat humide, précipitations tous les mois de l'année
	  • Pour A : climat de la forêt tropicale, P du mois le plus sec > 60 mm
	  • Pour C et D : pas de saison sèche, ni « w » ni « s »
		A-C-D

m	• Climat de mousson : • P du mois le plus sec < 60 mm et > [100 – (précipitations annuelles moyennes)/25]	A
T	• Température moyenne du mois le plus chaud comprise entre 0 °C et 10 °C	E
F	• Température moyenne du mois le plus chaud < 0 °C	E
M	• Précipitations abondantes • Hiver doux (Température moyenne du mois le plus froid > −10 °C)	E

Climatology: The Koeppen classification

- 3 letters code based upon the temperature and precipitations
- Statistics calculated over 30-yr temporal series

3e lettre : variations de température

Pour affiner les types B, C et D, une troisième lettre précise l'amplitude du cycle annuel des températures :

Code	Description	S'applique à
a : été chaud	• Température moyenne du mois le plus chaud > 22 °C	C-D
b : été tempéré	• Température moyenne du mois le plus chaud < 22 °C • Températures moyennes des 4 mois les plus chauds > 10 °C	C-D
c : été court et frais	• Température moyenne du mois le plus chaud < 22 °C • Températures moyennes mensuelles > 10 °C pour moins de 4 mois • Température moyenne du mois le plus froid > −38 °C	C-D
d : hiver très froid	• Température moyenne du mois le plus froid < −38 °C	D
h : sec et chaud	• Température moyenne annuelle > 18 °C	B
k : sec et froid	• Température moyenne annuelle < 18 °C	B

Climatology: The Koeppen classification

Köppen climate classification scheme symbols description table[1]

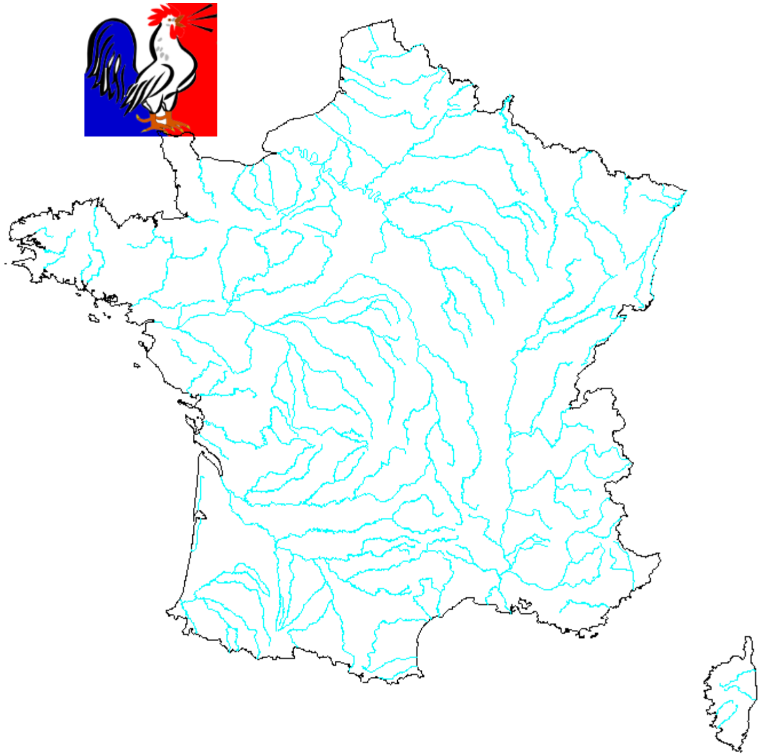
1st	2nd	3rd
A (Tropical)	f (Rainforest)	
	m (Monsoon)	
	w (Savanna, Wet)	
	s (Savanna, Dry)	
B (Arid)	W (Desert)	
	S (Steppe)	
		h (Hot)
		k (Cold)
		n (With frequent fog)[10]
C (Temperate)	s (Dry summer)	
	w (Dry winter)	
	f (Without dry season)	
		a (Hot summer)
		b (Warm summer)
		c (Cold summer)
D (Cold (continental))	s (Dry summer)	
	w (Dry winter)	
	f (Without dry season)	
		a (Hot summer)
		b (Warm summer)
		c (Cold summer)
		d (Very cold winter)
E (Polar)	T (Tundra)	
	F (Eternal winter (ice cap))	

Climatology: The Koeppen classification

Table 1: Key to calculate the climate formula of Köppen and Geiger for the main climates and subsequent precipitation conditions, the first two letters of the classification. Note that for the polar climates (E) no precipitation differentiations are given, only temperature conditions are defined. This key implies that the polar climates (E) have to be determined first, followed by the arid climates (B) and subsequent differentiations into the equatorial climates (A) and the warm temperate and snow climates (C) and (D), respectively. The criteria are explained in the text.

Type	Description	Criterion
A	**Equatorial climates**	$T_{min} \geq +18$ °C
Af	Equatorial rainforest, fully humid	$P_{min} \geq 60$ mm
Am	Equatorial monsoon	$P_{ann} \geq 25\,(100 - P_{min})$
As	Equatorial savannah with dry summer	$P_{min} < 60$ mm in summer
Aw	Equatorial savannah with dry winter	$P_{min} < 60$ mm in winter
B	**Arid climates**	$P_{ann} < 10\,P_{th}$
BS	Steppe climate	$P_{ann} > 5\,P_{th}$
BW	Desert climate	$P_{ann} \leq 5\,P_{th}$
C	**Warm temperate climates**	-3 °C $< T_{min} < +18$ °C
Cs	Warm temperate climate with dry summer	$P_{smin} < P_{wmin}$, $P_{wmax} > 3\,P_{smin}$ and $P_{smin} < 40$ mm
Cw	Warm temperate climate with dry winter	$P_{wmin} < P_{smin}$ and $P_{smax} > 10\,P_{wmin}$
Cf	Warm temperate climate, fully humid	neither Cs nor Cw
D	**Snow climates**	$T_{min} \leq -3$ °C
Ds	Snow climate with dry summer	$P_{smin} < P_{wmin}$, $P_{wmax} > 3\,P_{smin}$ and $P_{smin} < 40$ mm
Dw	Snow climate with dry winter	$P_{wmin} < P_{smin}$ and $P_{smax} > 10\,P_{wmin}$
Df	Snow climate, fully humid	neither Ds nor Dw
E	**Polar climates**	$T_{max} < +10$ °C
ET	Tundra climate	0 °C $\leq T_{max} < +10$ °C
EF	Frost climate	$T_{max} < 0$ °C

Climatology: the French case



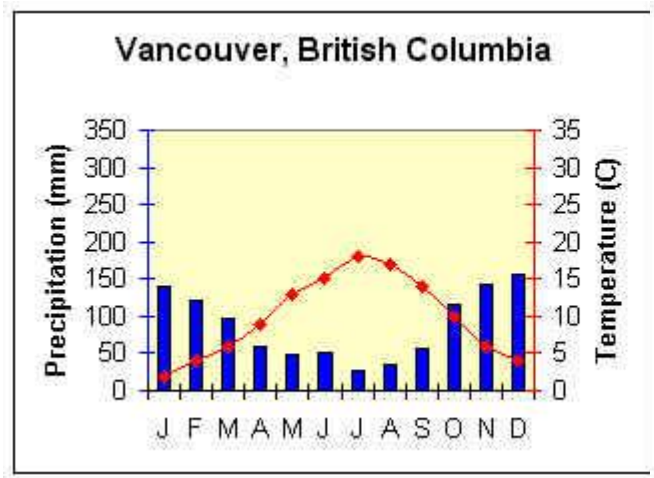
K-G climate in metropolitan France

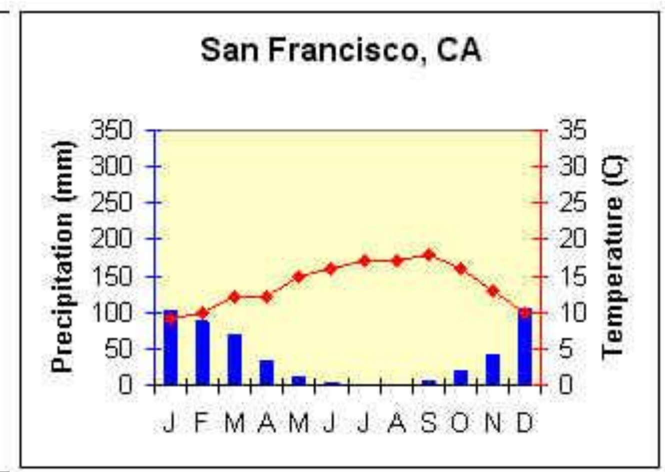
Cf:	Temperate
Cs:	Mediterranean
Dw :	Subarctic
ET:	Toundra

Climatology: examples

Maritime (Cf)

Mediterranean (Cs)





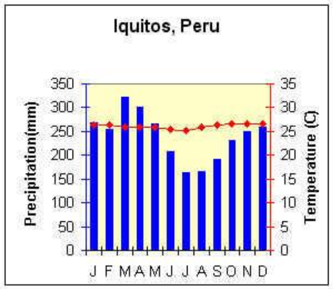
Wet temperate forests

clerophyllous forests

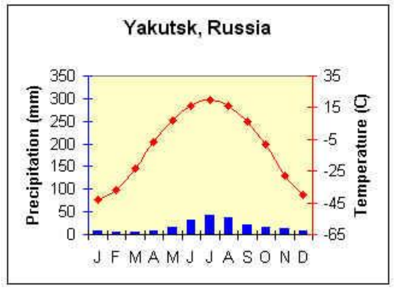
	Maritime (Cf)	Mediterranean (Cs)
Average Annual Temperature (oC) =	9.8	13.75
Annual Temperature Range (oC) =	16	9
Total Annual Precipitation (mm) =	1048	475
Summer Precipitation (mm) =	277	54
Winter Precipitation (mm) =	771	421

Climatology: examples

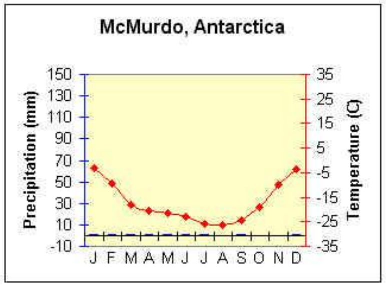
Tropical (Af)



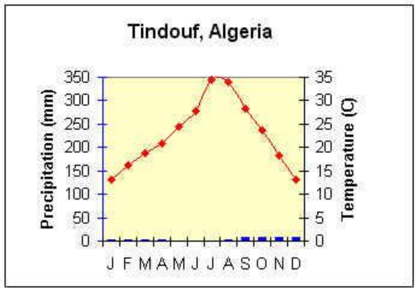
Subarctic



Polar



Desert (Bw)



	Tropical (Af)	Subarctic	Polar	Desert (Bw)
Annual T (°C)	26.1	-10	-17	22.8
Range (°C)	1.4	63	23	21.2
Annual Prec. ($mm.yr^{-1}$)	2879	213	7.8	44
Summer Prec. (mm)	1583	157	3.7	12
Winter Prec. (mm)	1294	56	4.1	32
Vegetation type	Tropical Rainforest	Coniferous	none	none