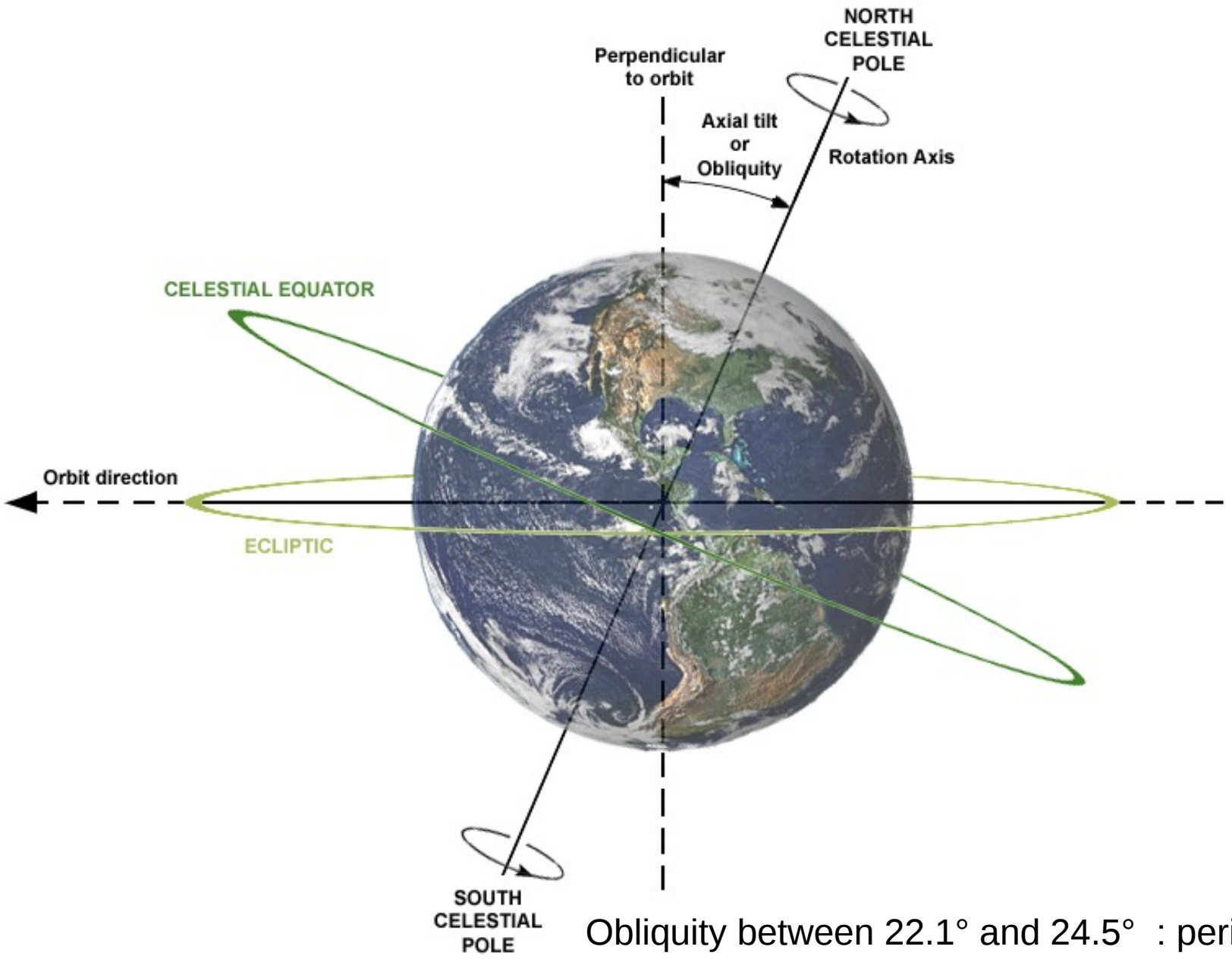
Liége Crue de la Meuse 1925-1926
Vue prise du Pont des Arches vers l'Université et la Passerelle

# Climate change

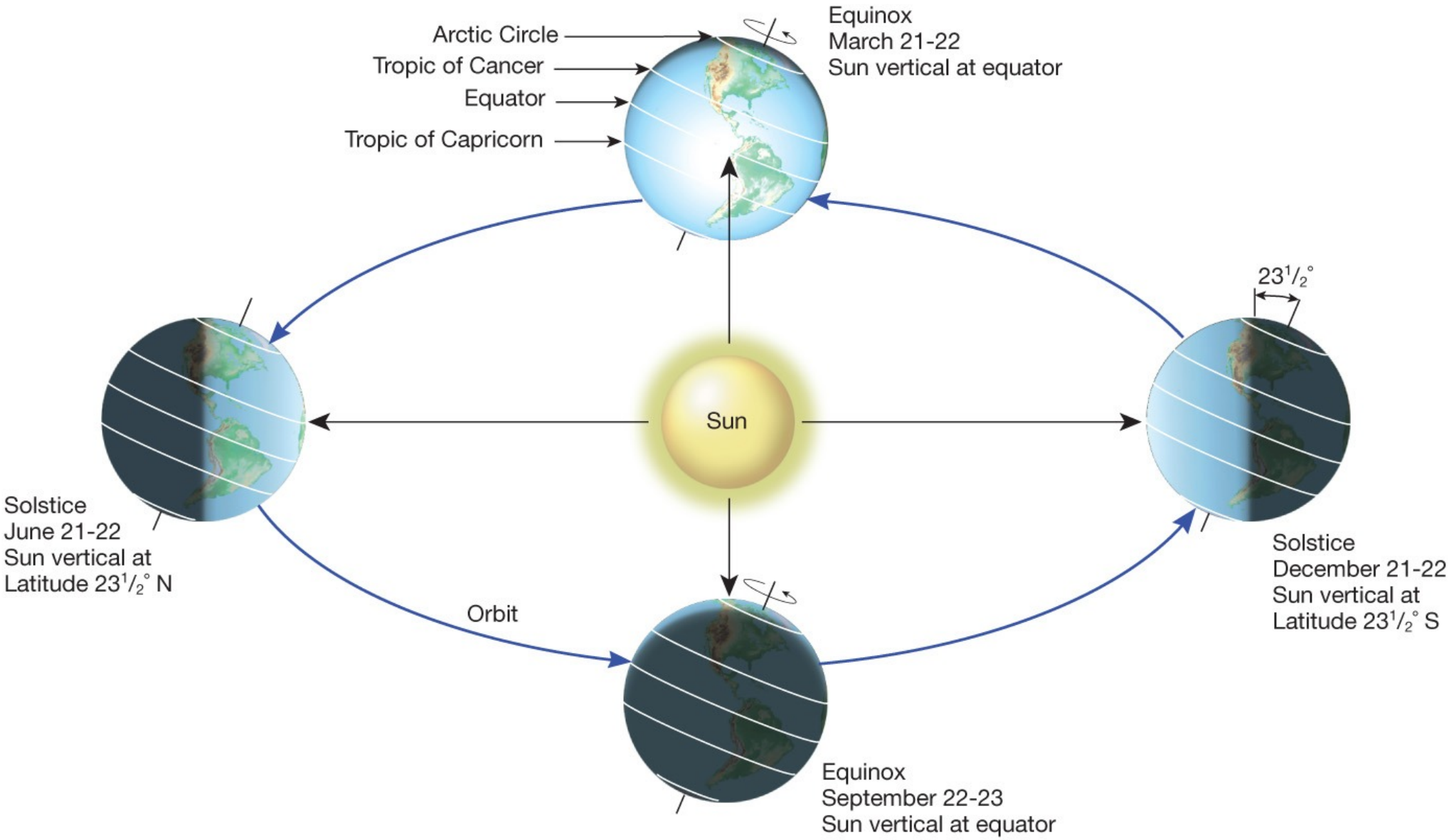
1. Why did the climate vary?
2. Energy balance and greenhouse gases
3. Climate models
4. CO2 increase vs global warming
5. Future scenarios
6. Future changes in Belgium
7. Renewable energy

# 1. Why did the climate vary?




Obliquity between 22.1° and 24.5° : period 41kyr

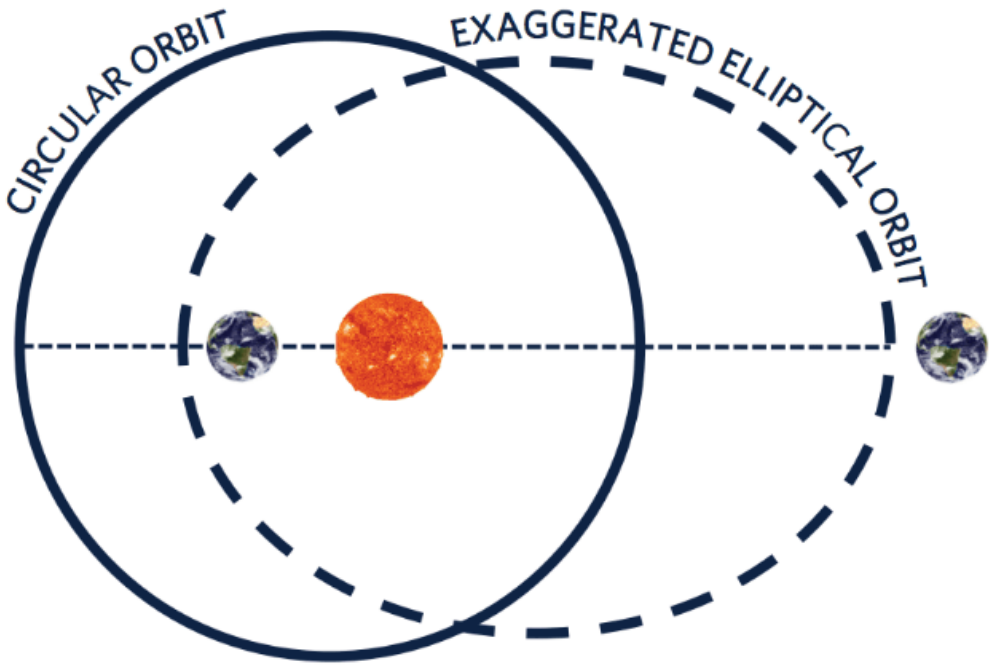
# 1. Why did the climate vary?






Precession: period 26kyr

# 1. Why did the climate vary?

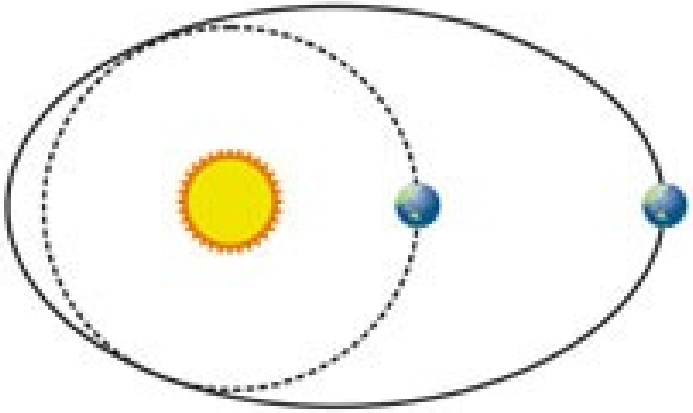



Eccentricity

Eccentricity: period 100kyr

# 1. Why did the climate vary?

## Milankovitch Cycles



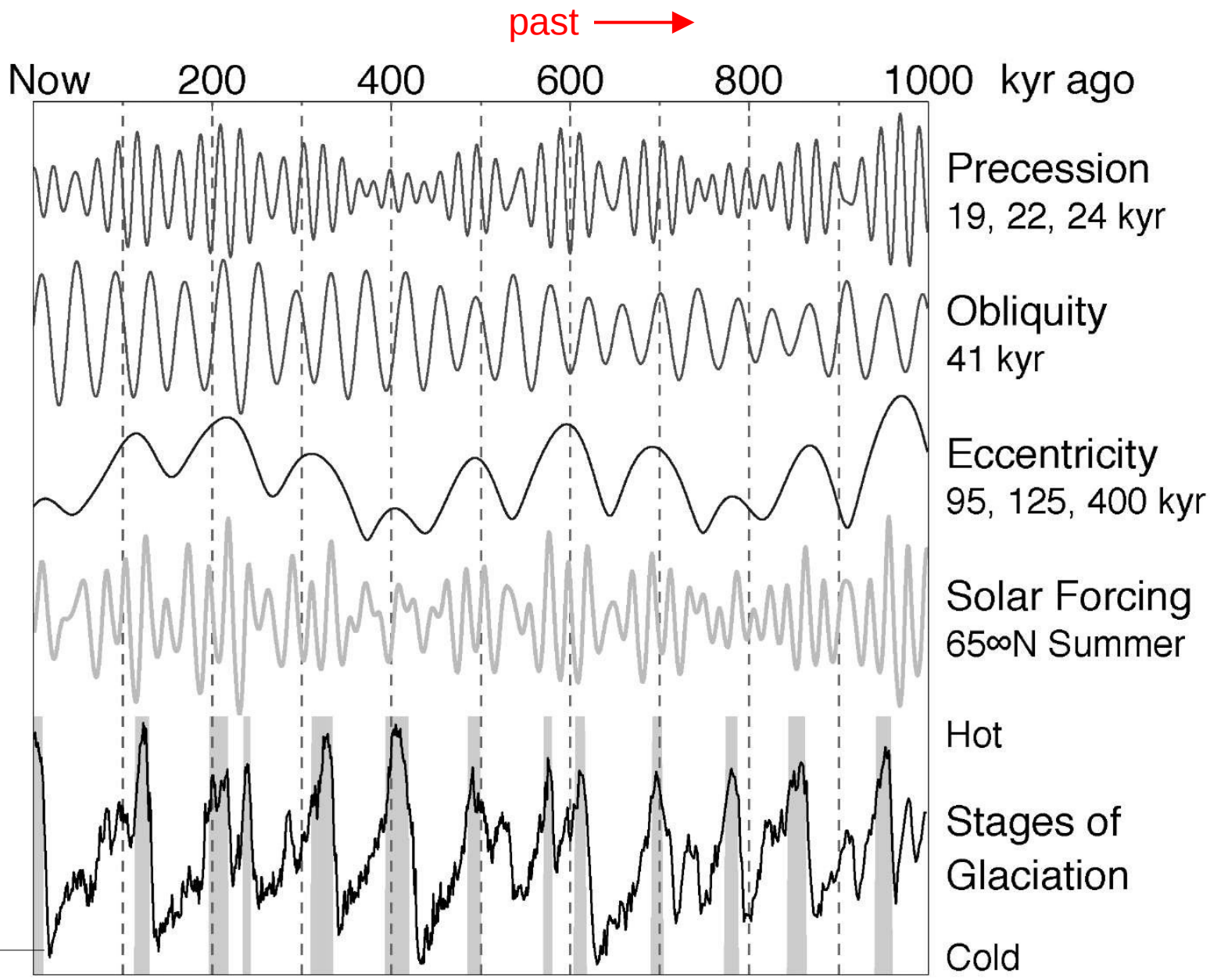
Eccentricity


Obliquity

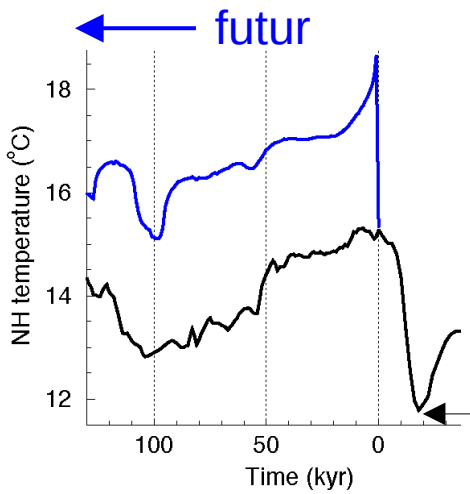

Precession

| Period: | 100ky | 41ky | 26ky |
|---|---|---|---|

# 1. Why did the climate vary?

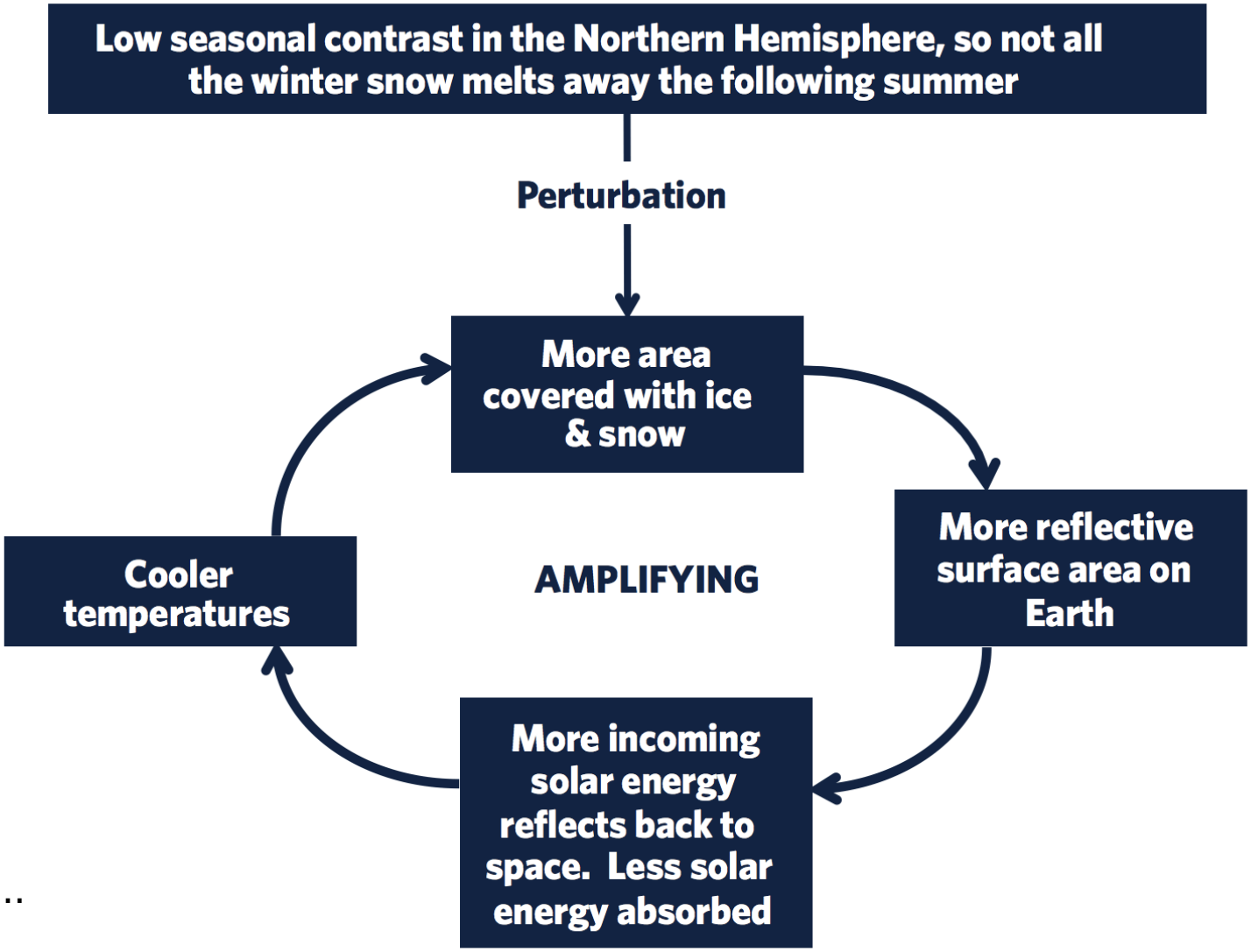



We are going towards a glaciation in 100kyr...



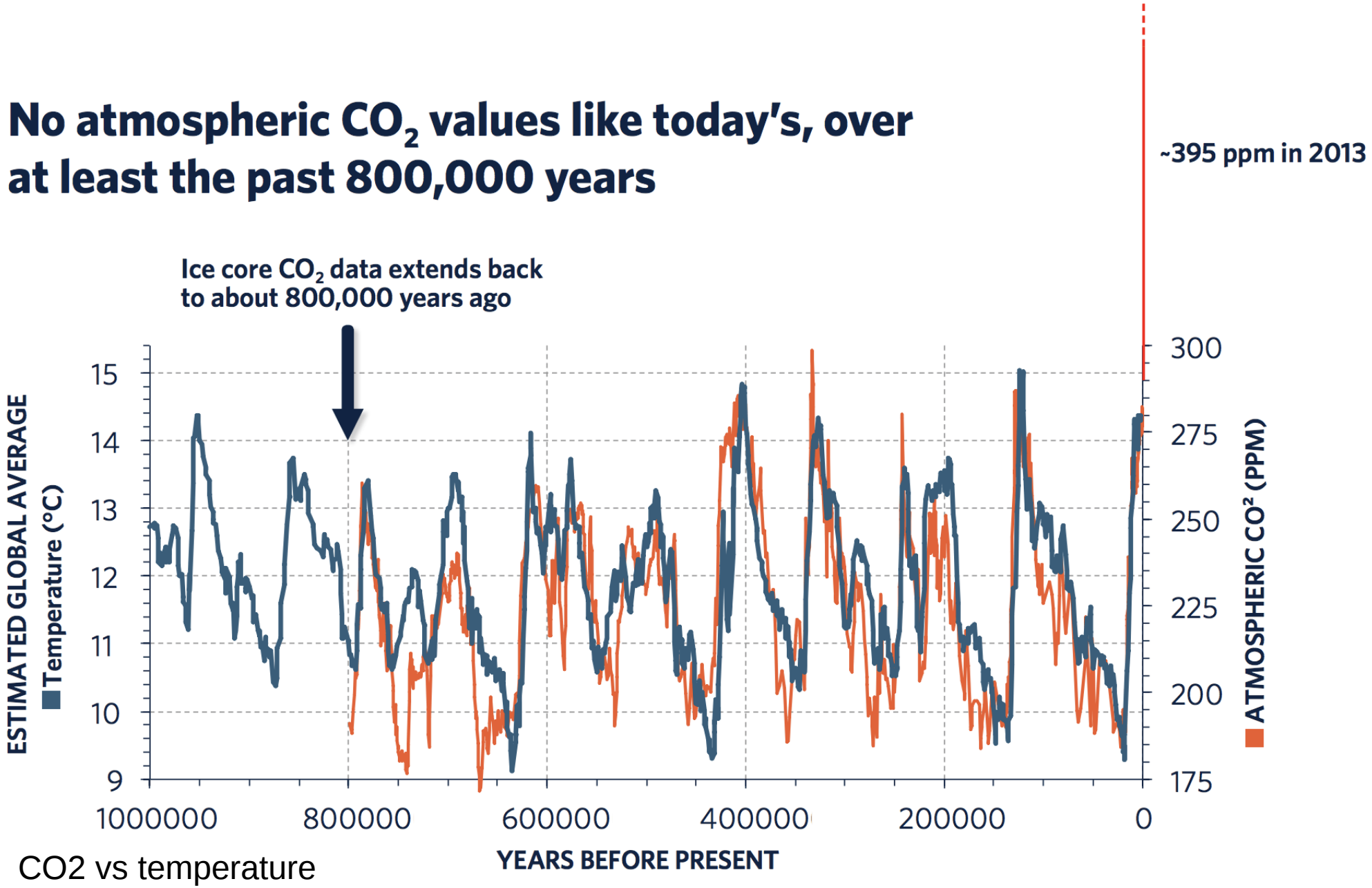
# 1. Why did the climate vary?

## Growing an ice sheet with the ice-albedo feedback




Towards a glaciation ...

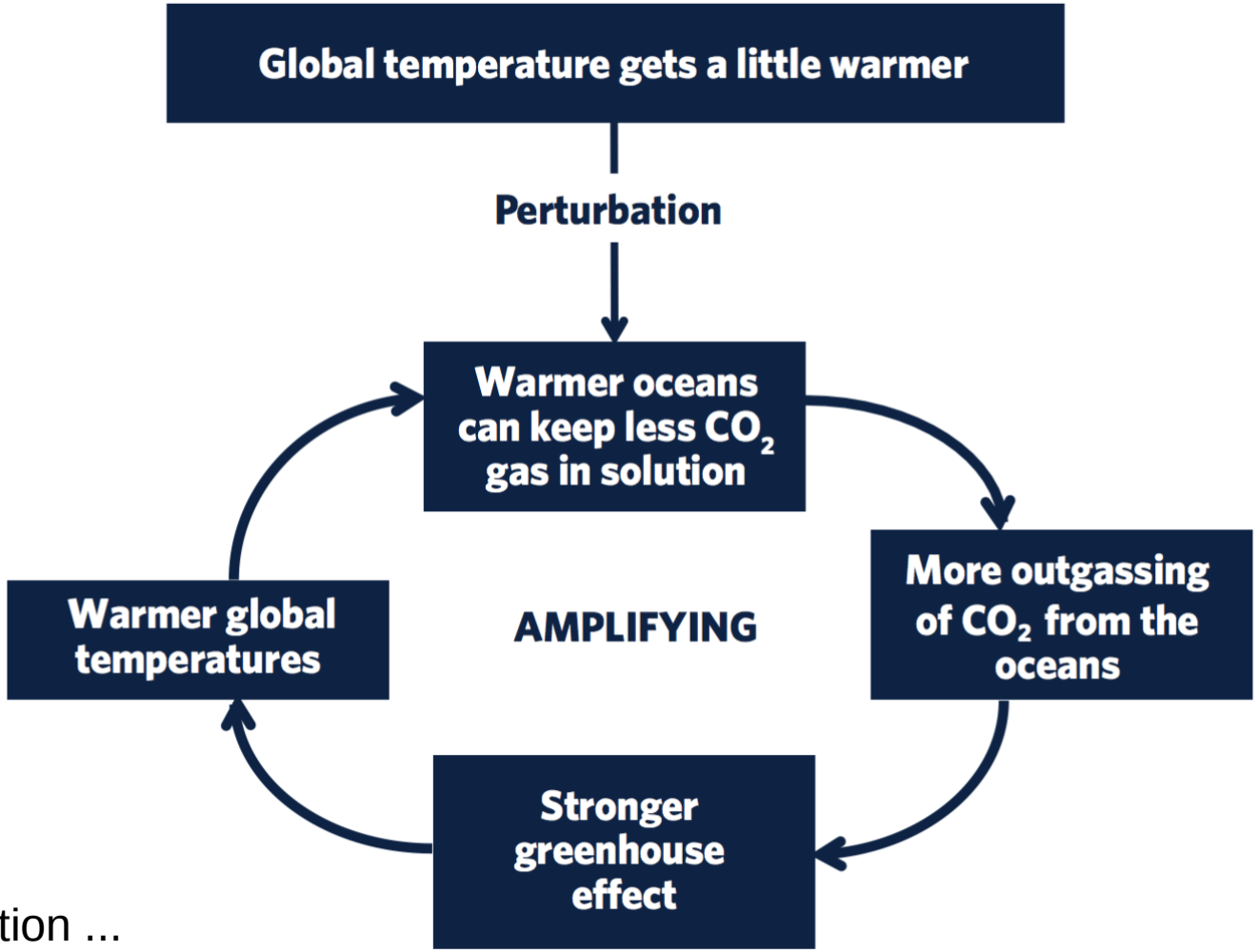
# 1. Why did the climate vary?




CO2 vs temperature

# 1. Why did the climate vary?

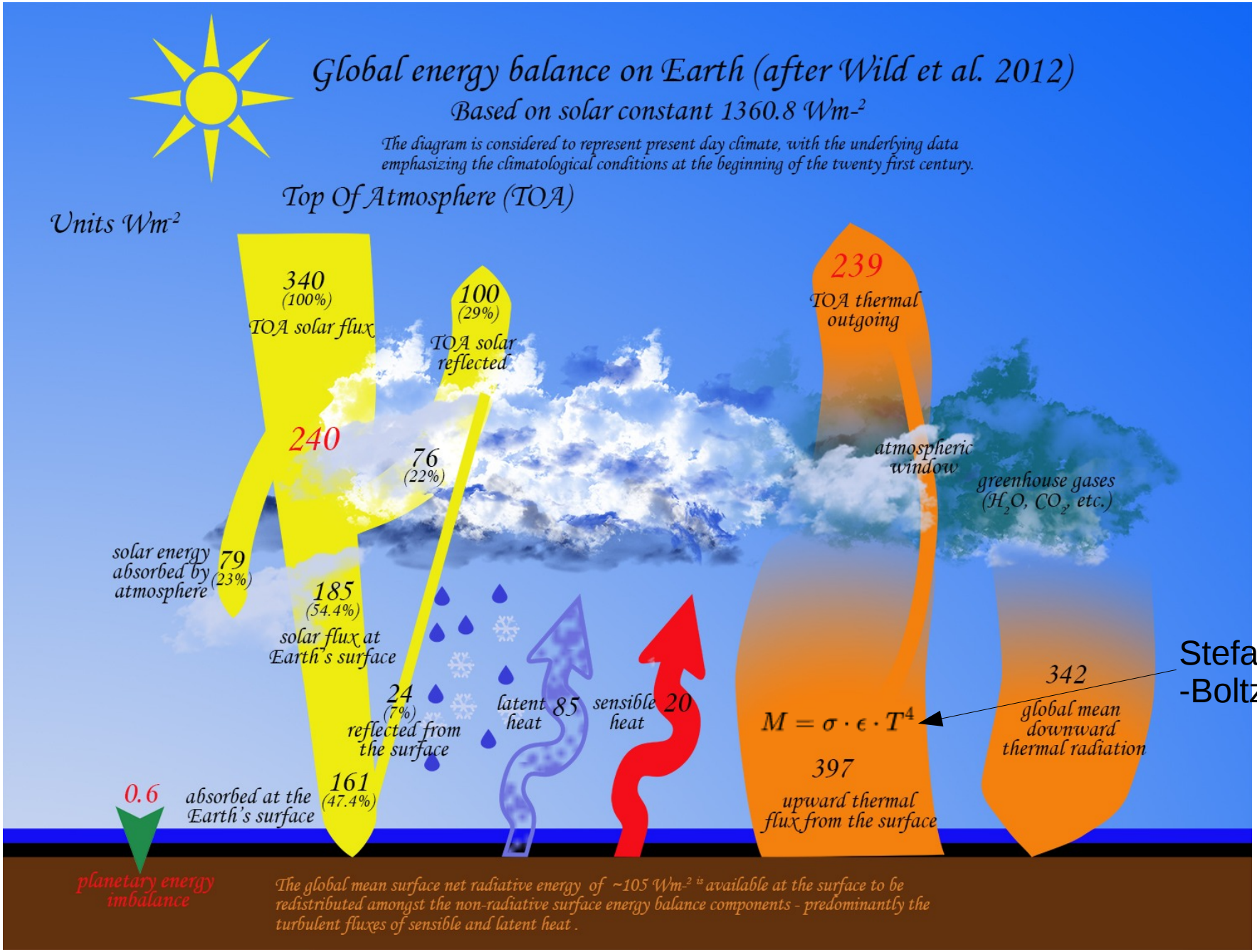
## Temperature and $CO_2$ — another amplifying feedback




Towards a deglaciation ...

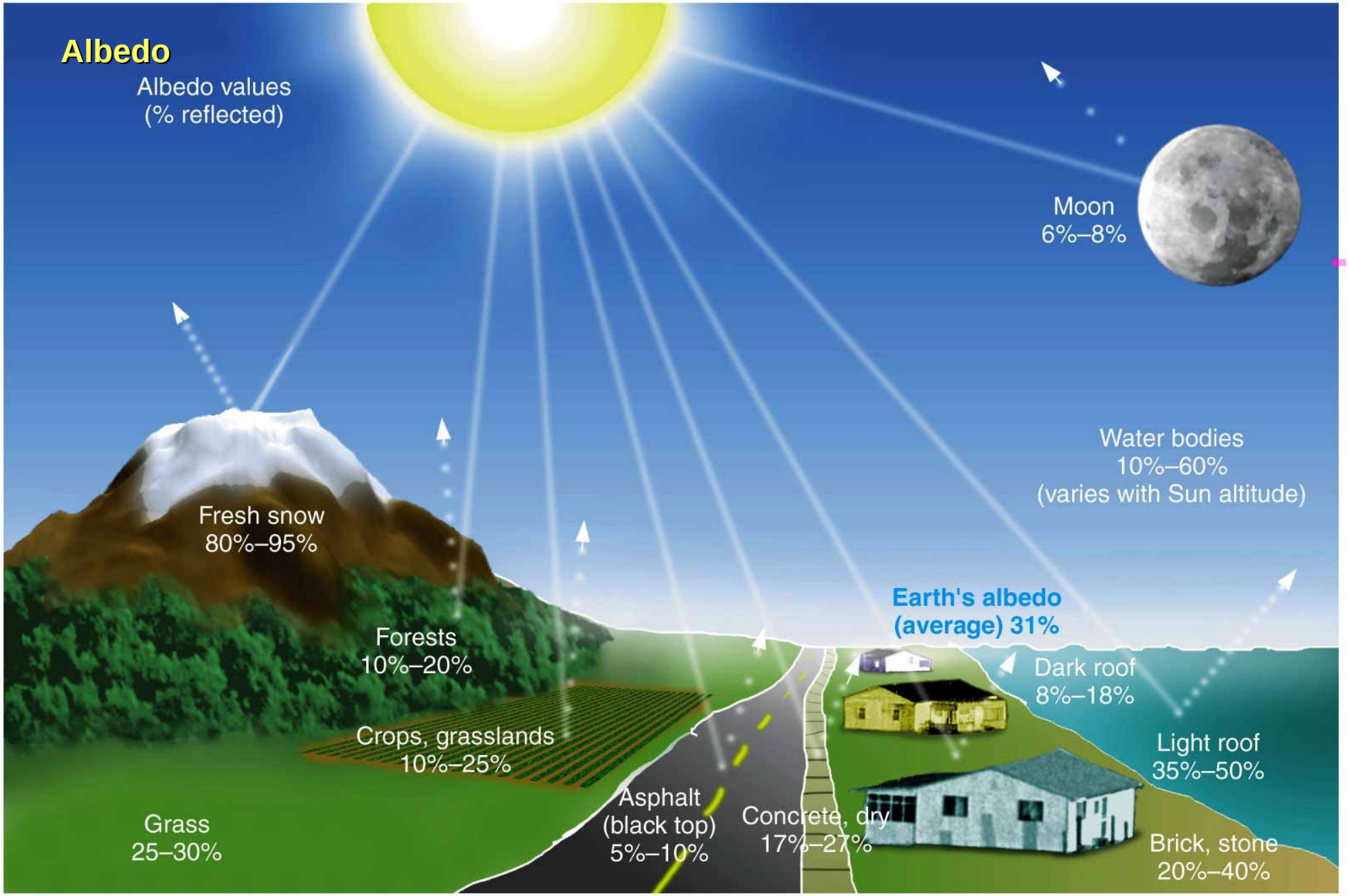
# 2. Energy Balance

Wien's law: $\lambda_{max} = \frac{2,898 \cdot 10^{-3}}{T}$




Stefan -Boltzmann

# 2. Energy Balance



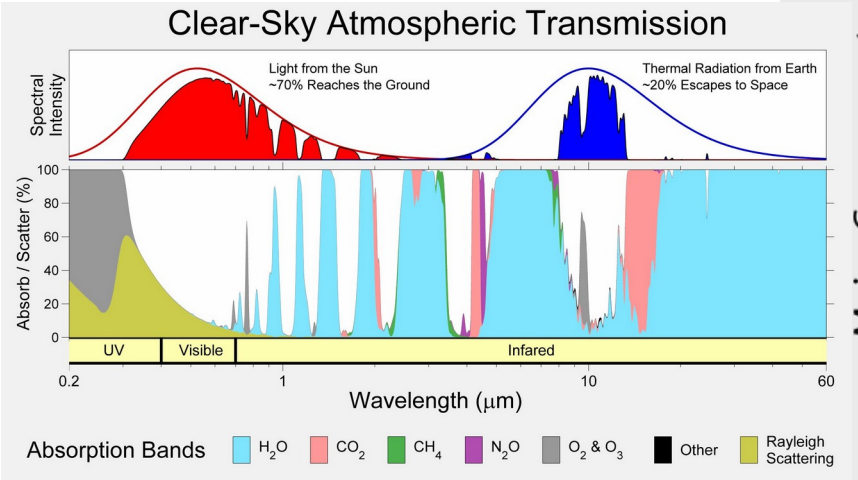
# 2. Energy Balance – Greenhouse gazes

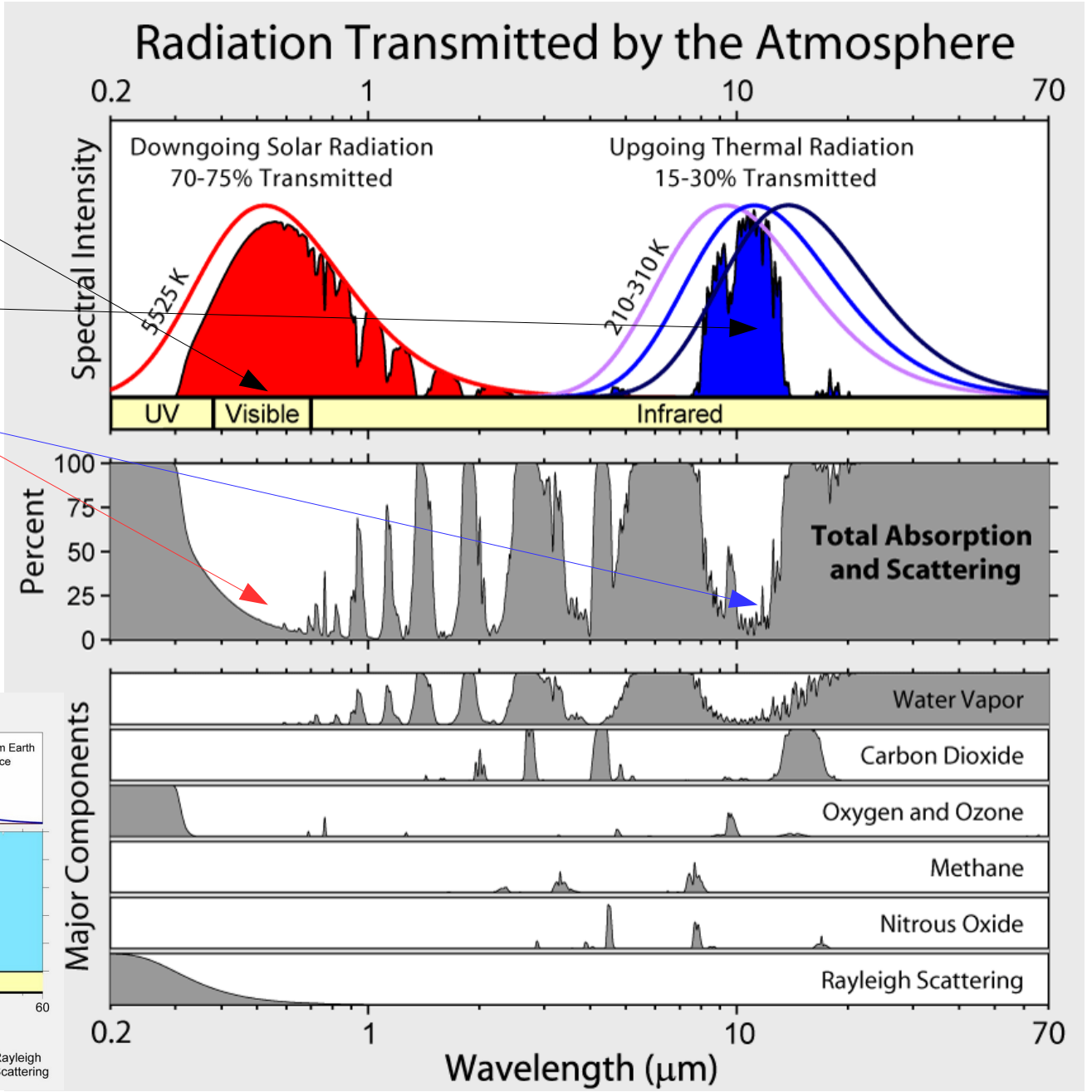
*Wien's law*

$$\lambda_{max} = \frac{2,898 \cdot 10^{-3}}{T}$$

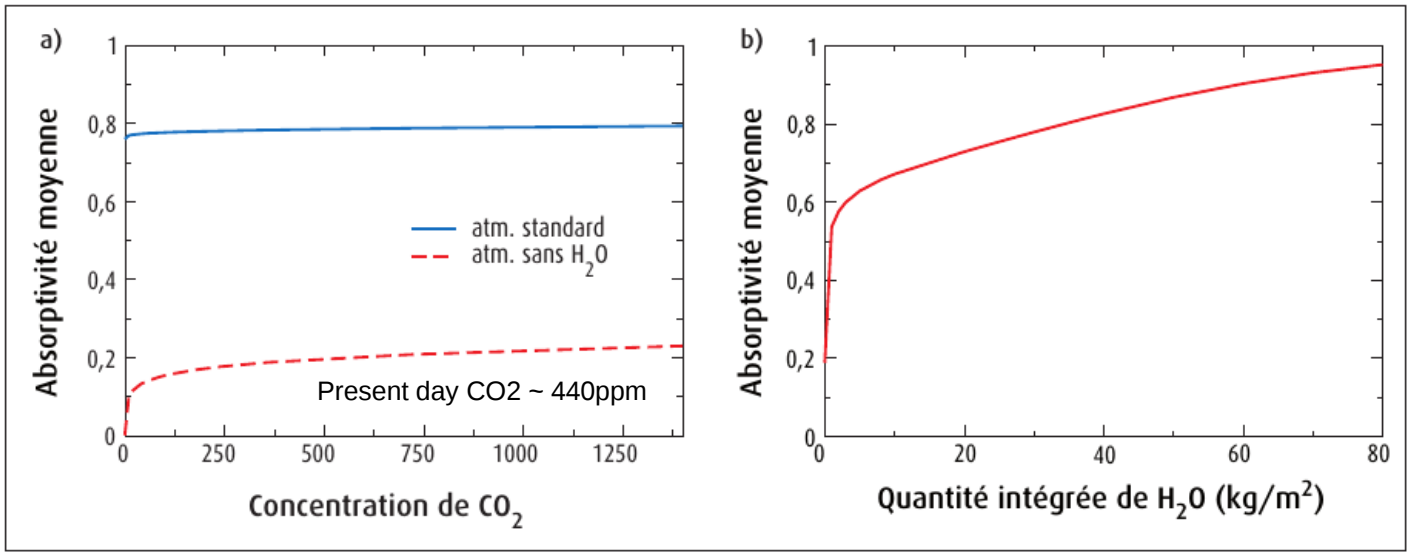
*Stefan-Boltzmann's law*
*LW up = σ $T^4$*

*Atmospheric windows*



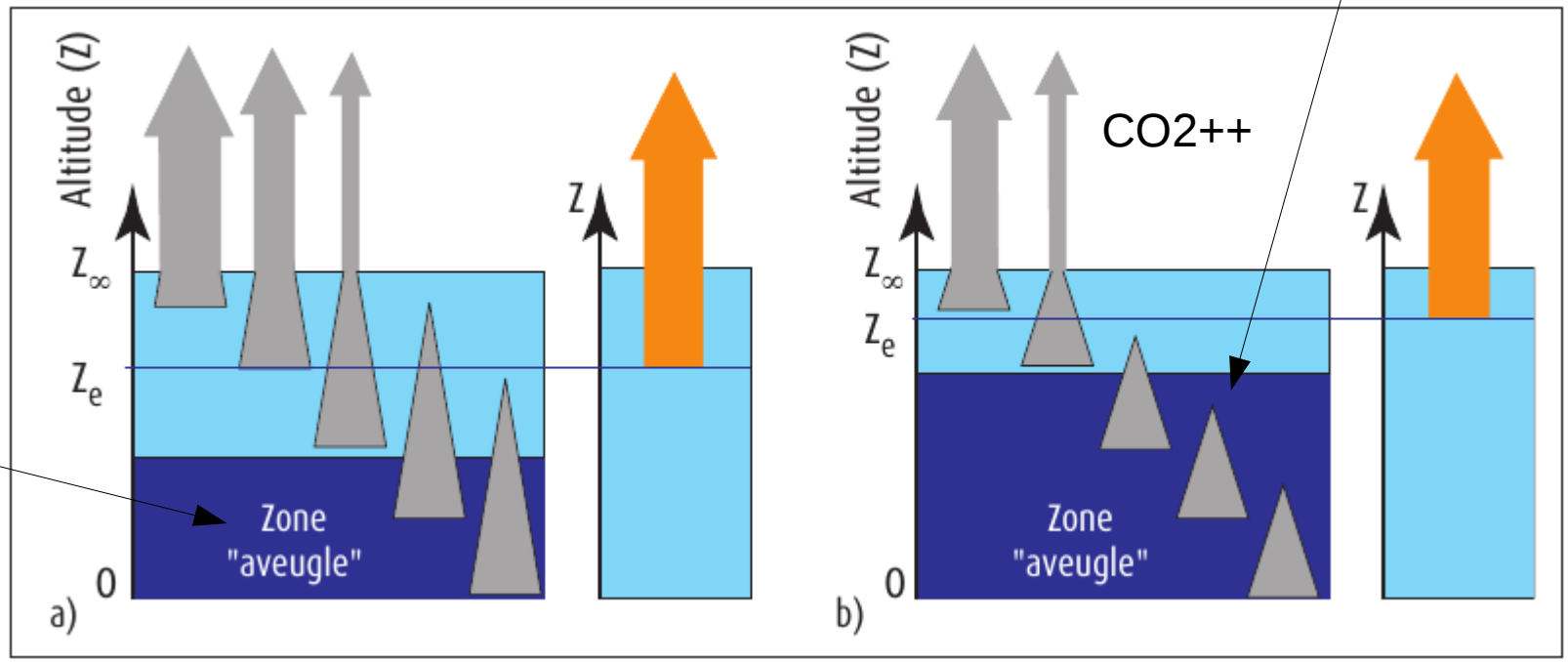



# 2. Energy Balance – Greenhouse gazes

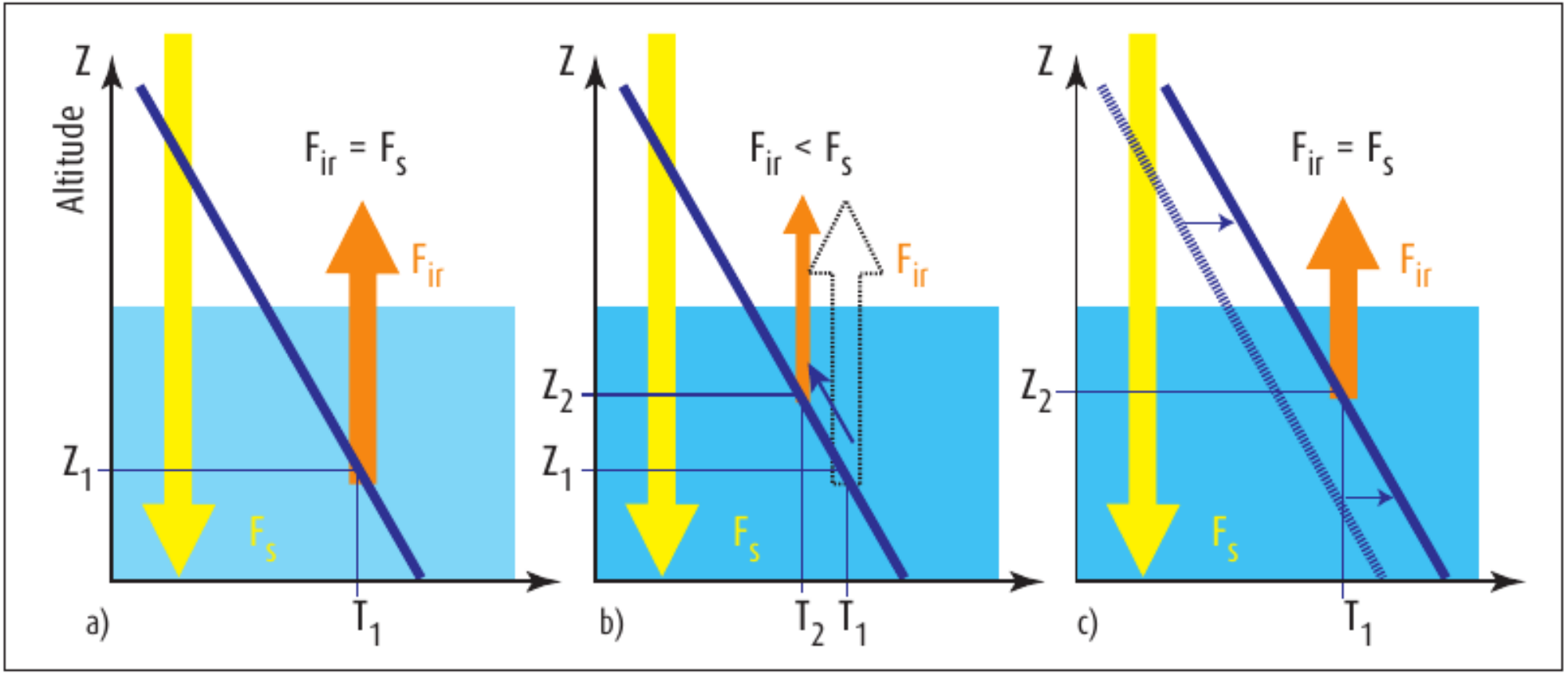



*this "blind" zone reached altitude with less $H_2O$*

*atmospheric zone where infrared absorption is saturated*

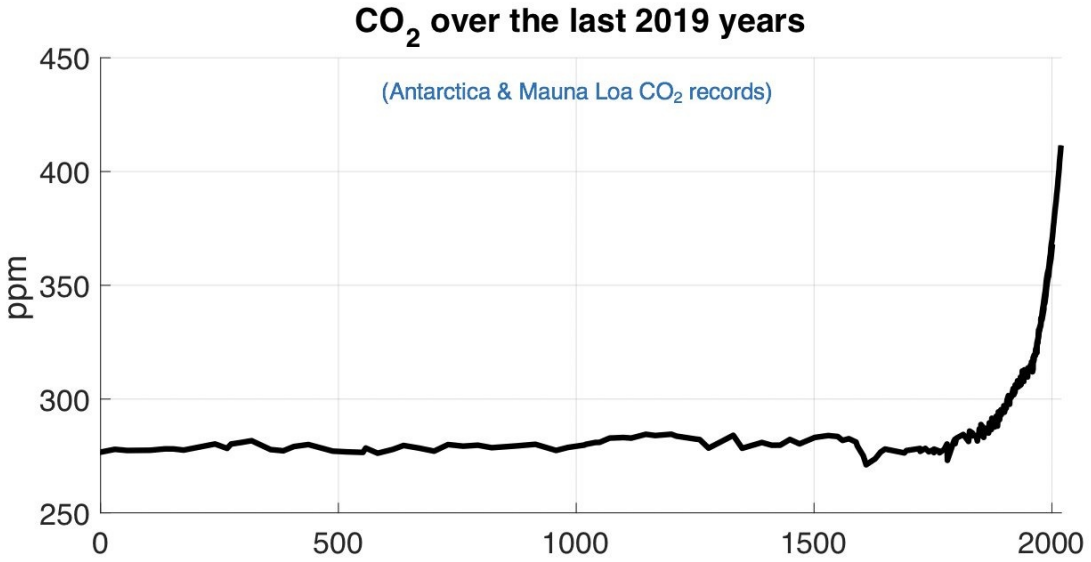


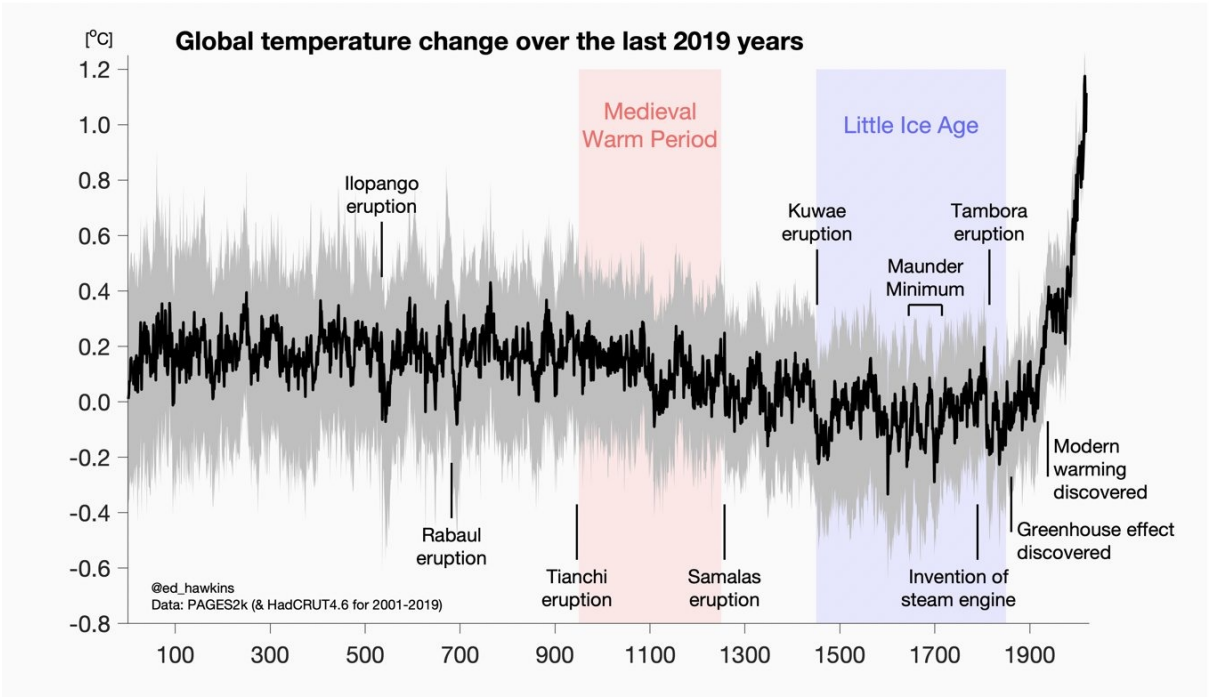
# 2. Energy Balance – Greenhouse gazes




*As the t ° gradient is fixed ~ 1 ° C / 100m if dry and 0.5 ° C / 100m if wet, the temperature rise in altitude is reflected towards the surface even if the layer is "blind".*

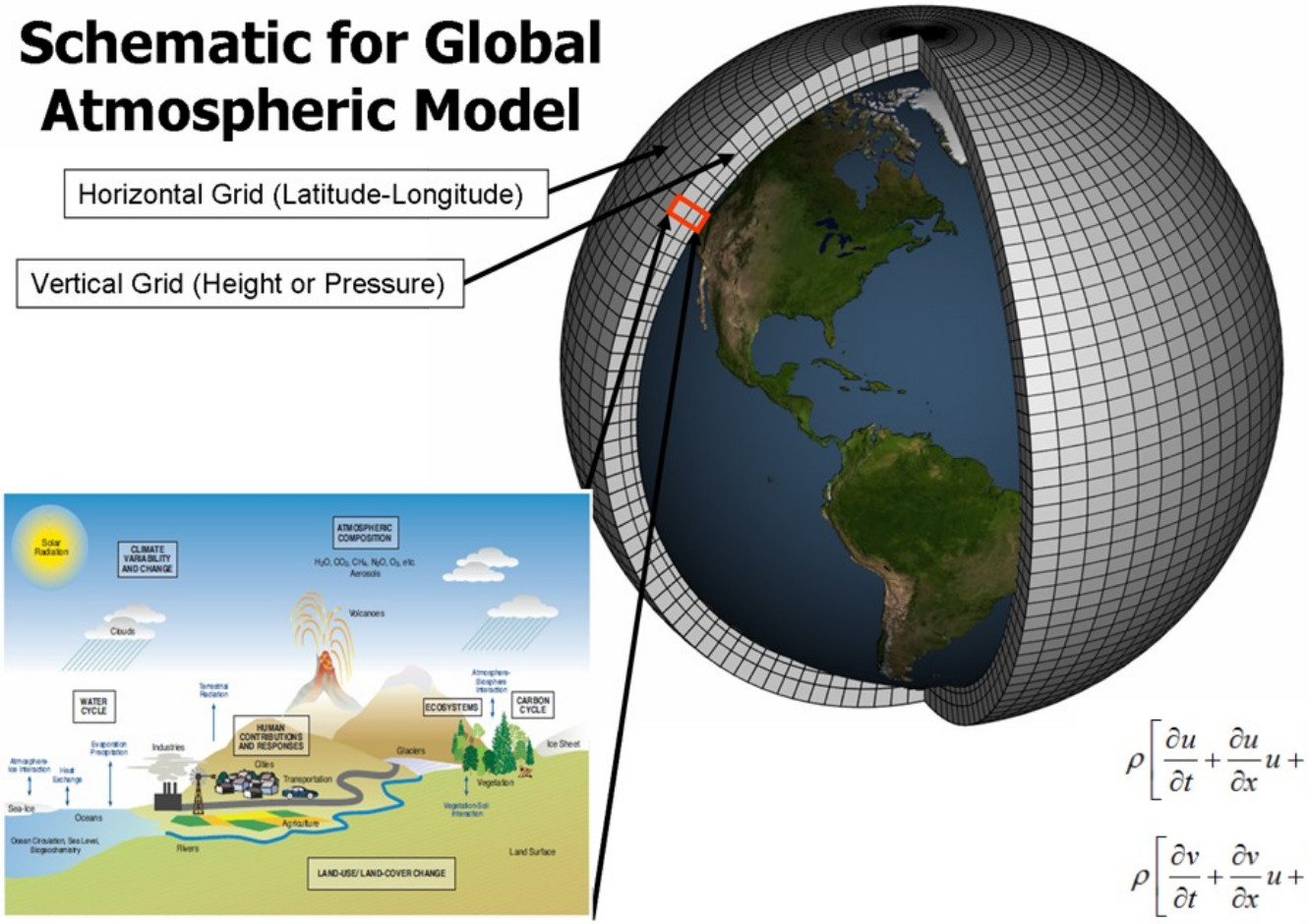
# 3. Climate models




Are the current observed global warming due to the $CO_2$ increase ?

# 3. Climate models




The impact of the sub-grid processes are parametrised but not resolved.

Eg: convection, turbulence, ...

$$\rho\left[\frac{\partial u}{\partial t}+\frac{\partial u}{\partial x}u+\frac{\partial u}{\partial y}v+\frac{\partial u}{\partial z}w\right]=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)+\rho g_x$$

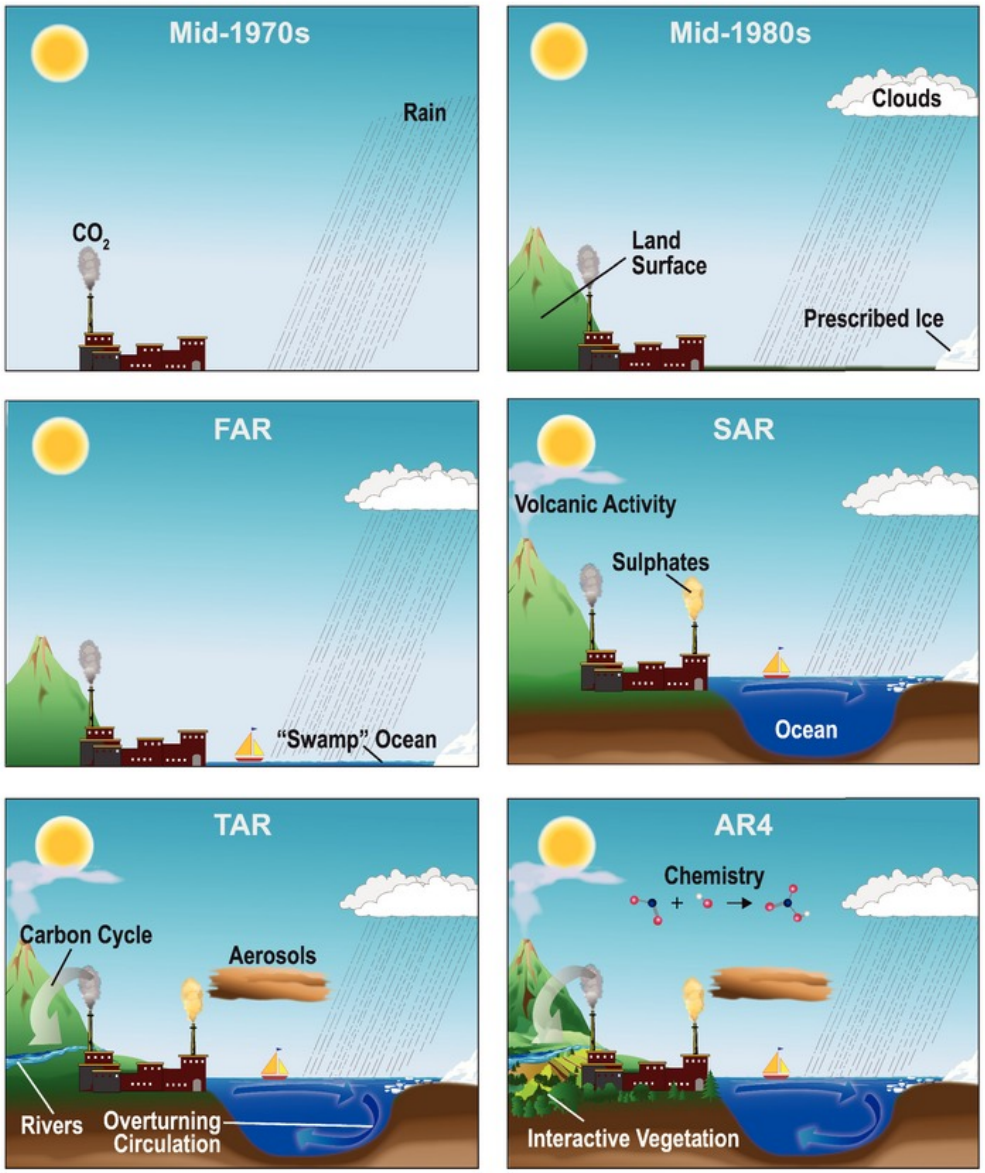
$$\rho\left[\frac{\partial v}{\partial t}+\frac{\partial v}{\partial x}u+\frac{\partial v}{\partial y}v+\frac{\partial v}{\partial z}w\right]=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)+\rho g_y$$

$$\rho\left[\frac{\partial w}{\partial t}+\frac{\partial w}{\partial x}u+\frac{\partial w}{\partial y}v+\frac{\partial w}{\partial z}w\right]=-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)+\rho g_z$$

fluid (atmosphere + ocean) motion are explicitly simulated by numerically resolving/approximating the Navier-Stokes equations in Fortran or C

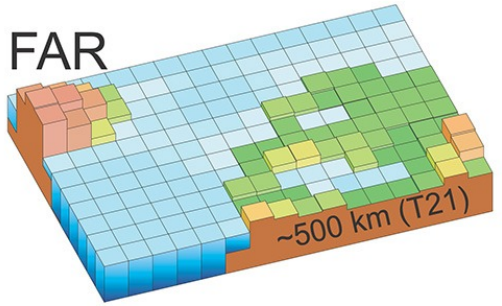
# 3. Climate models

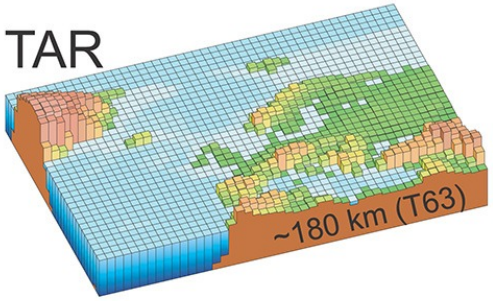
Improvements of the climate models …

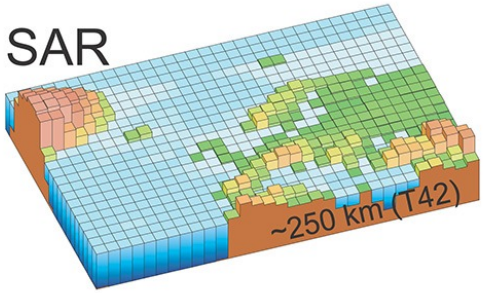


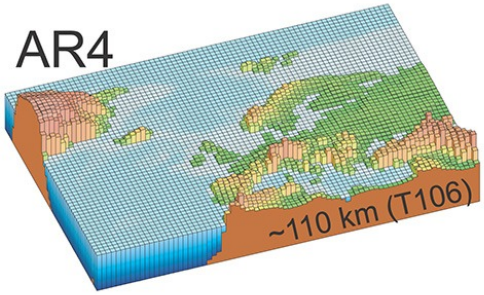

FAR = AR1 (1990)
SAR = AR2 (1995)
TAR = AR3 (2001)
AR4 (2007)

AR = assessment report from IPCC



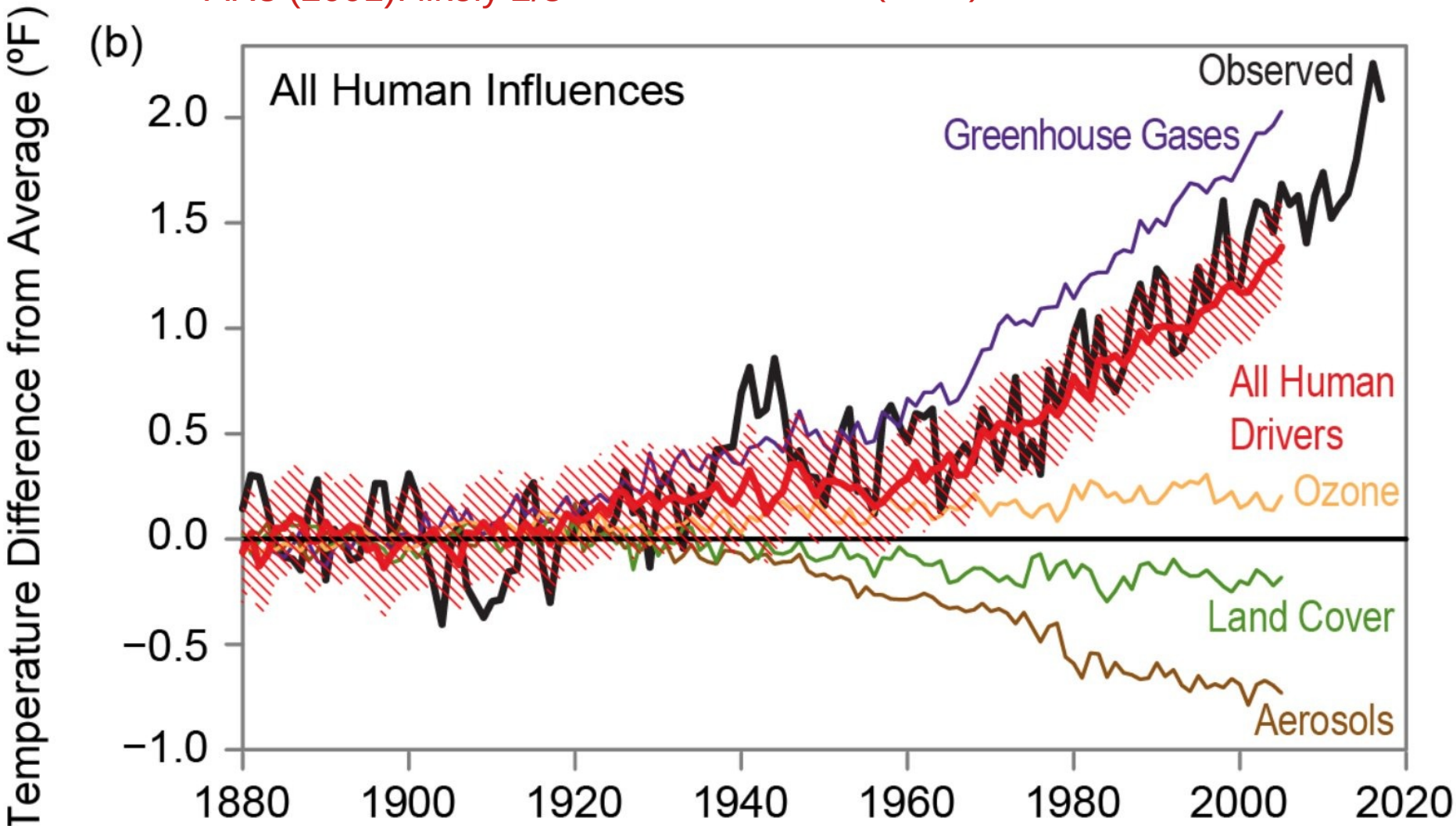



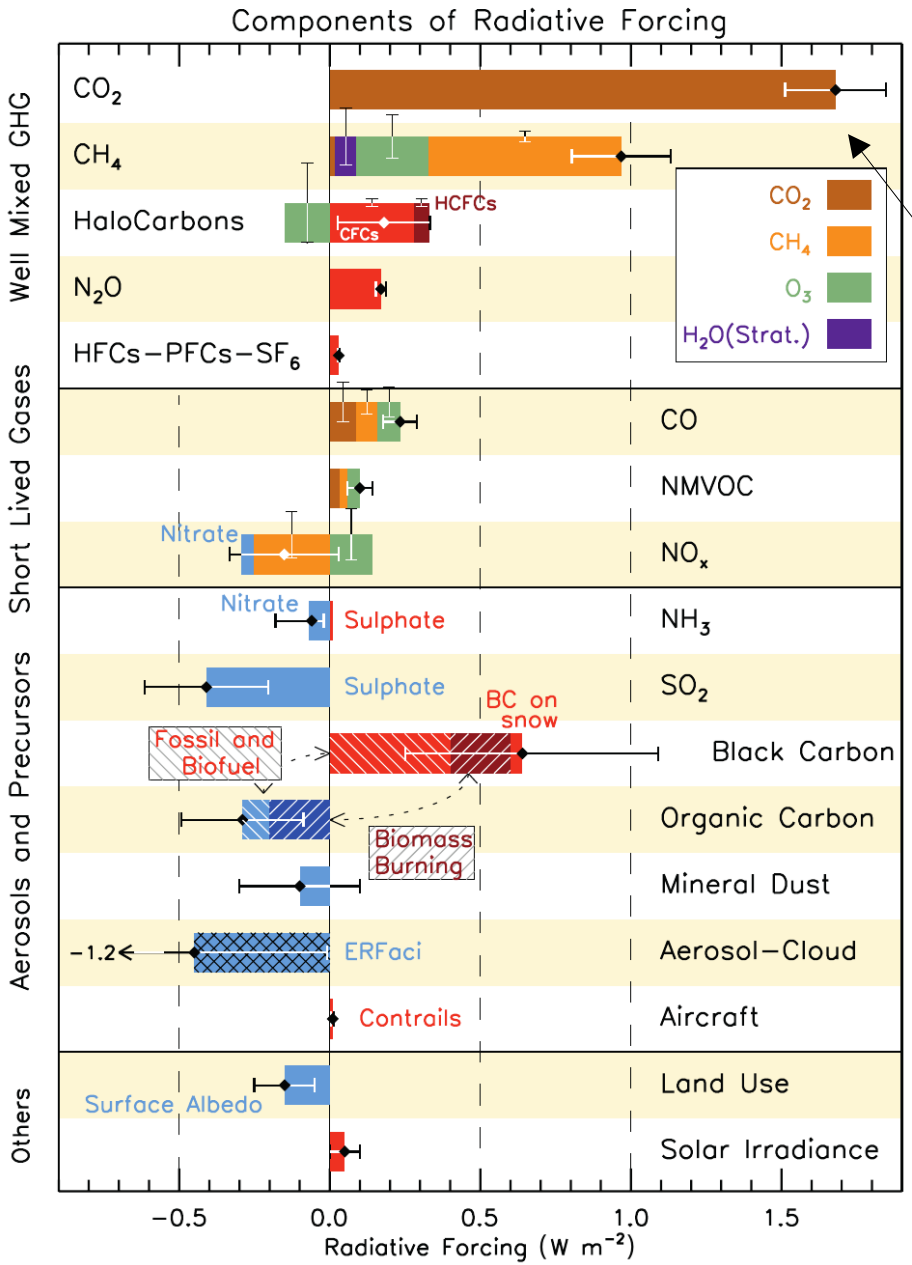
# 4. CO2 increase vs global warming

**IPCC : Global warming is due to human activities ?**

- AR1 (1990): nothing confirms it
- AR2 (1995): discernible
- AR3 (2001): likely 2/3
- AR4 (2007): very likely 9/10
- AR5 (2013): extremely likely 9.5 / 10
- AR6 (2022): close to certain ~ 10/10



# 4. CO2 increase vs global warming

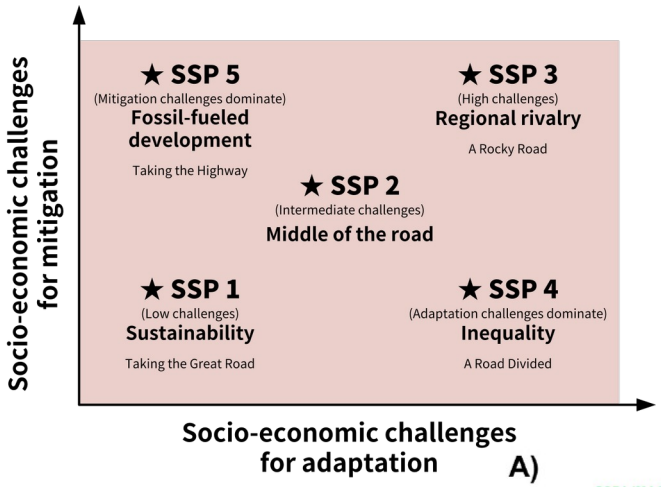



Radiative forcing in 2010 vs 1750

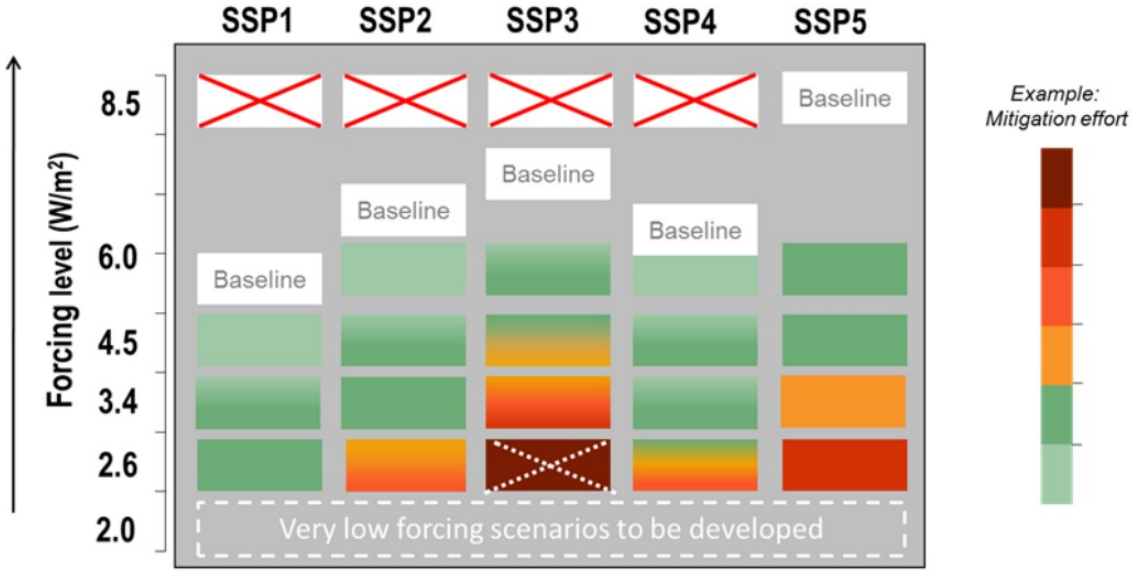
Future scenarios are also defined in radiative forcing in 2100.

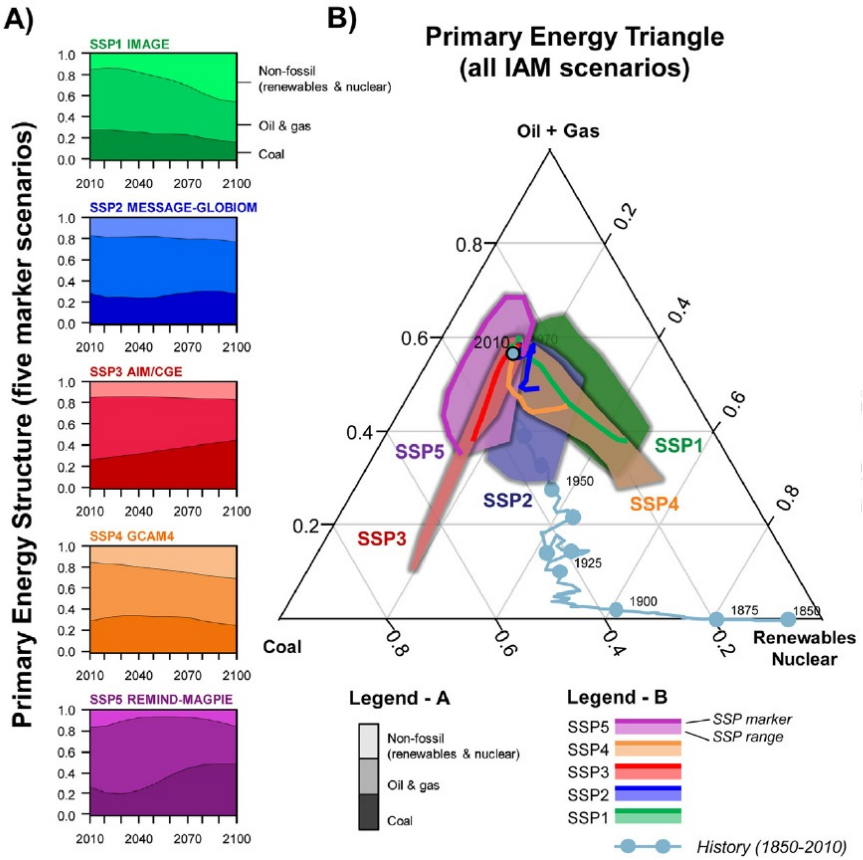
SSPx1.6 => +1.6W/m2
SSPx8.5 => +8.5W/m2
en 2100

# 5. Futures scenarios and projections



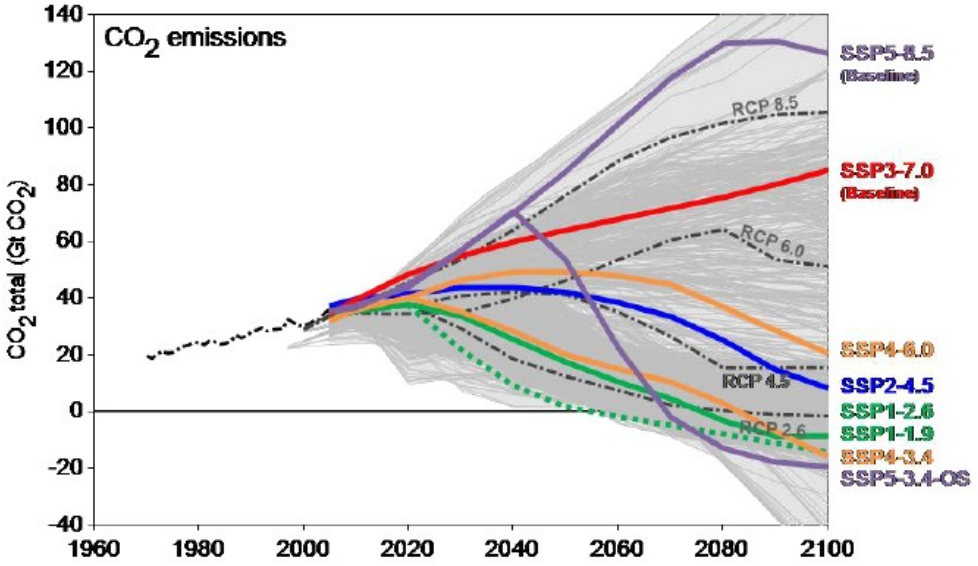

Target (radiative forcing in 2100)

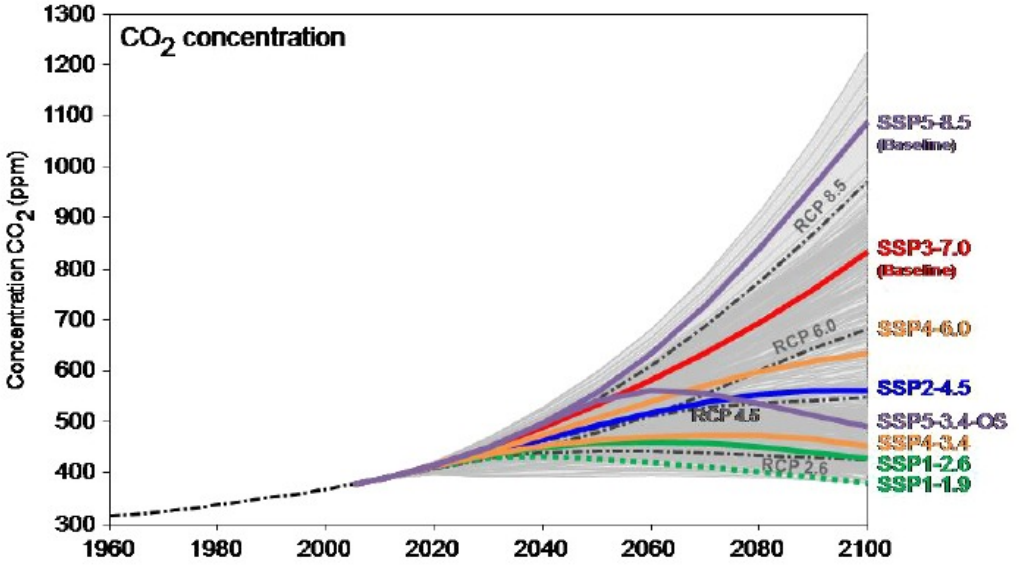


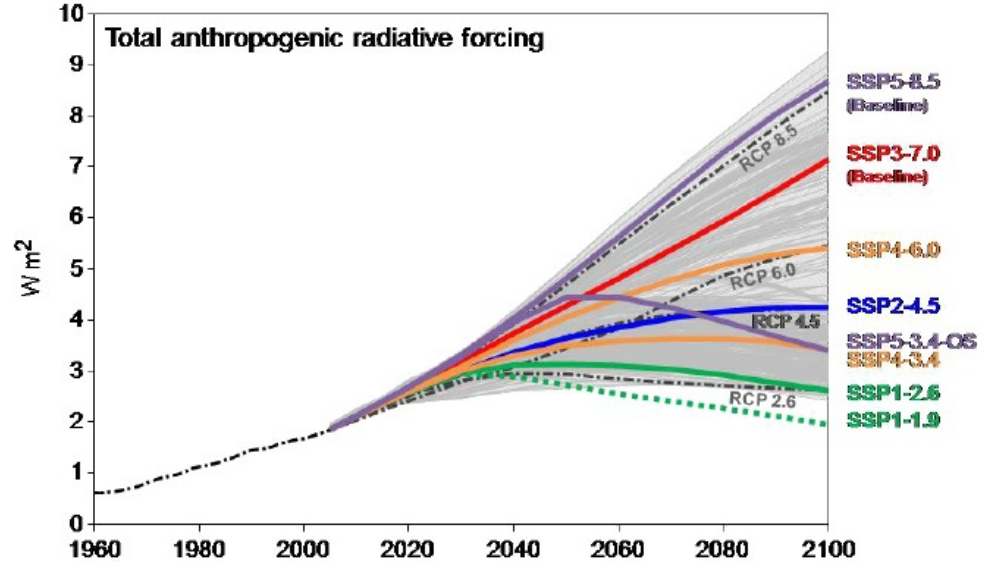



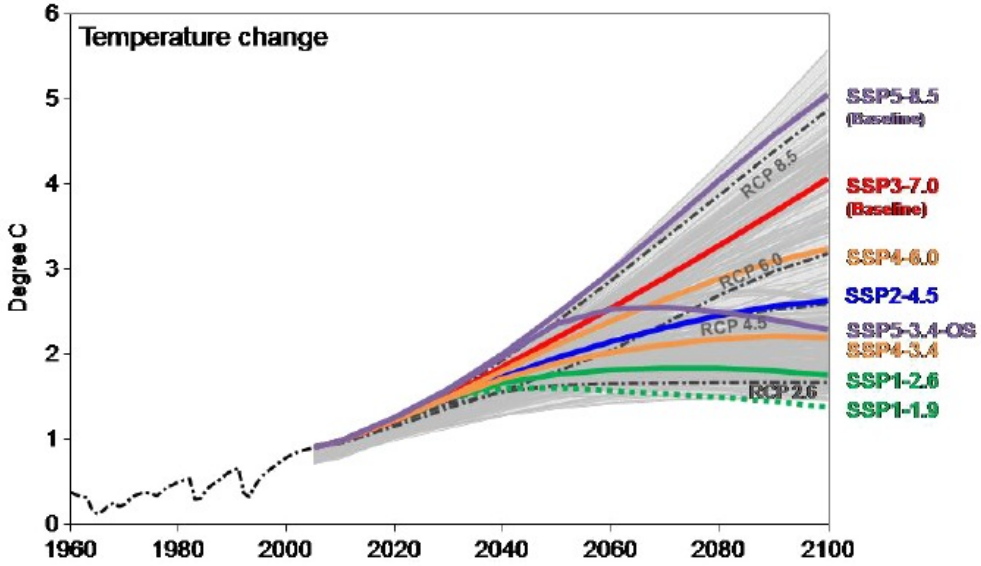

Baseline = no mitigation

# 5. Futures scenarios and projections

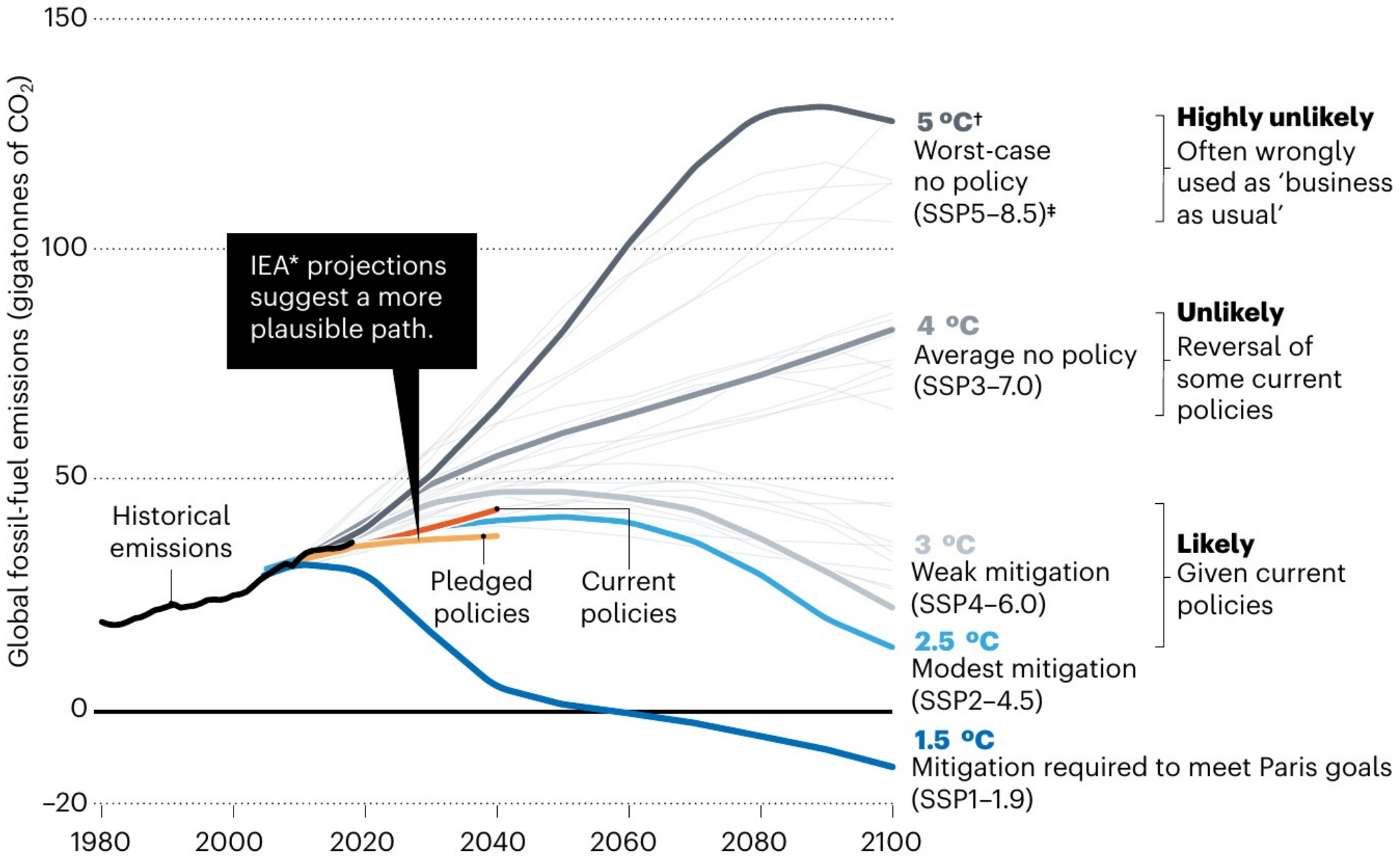


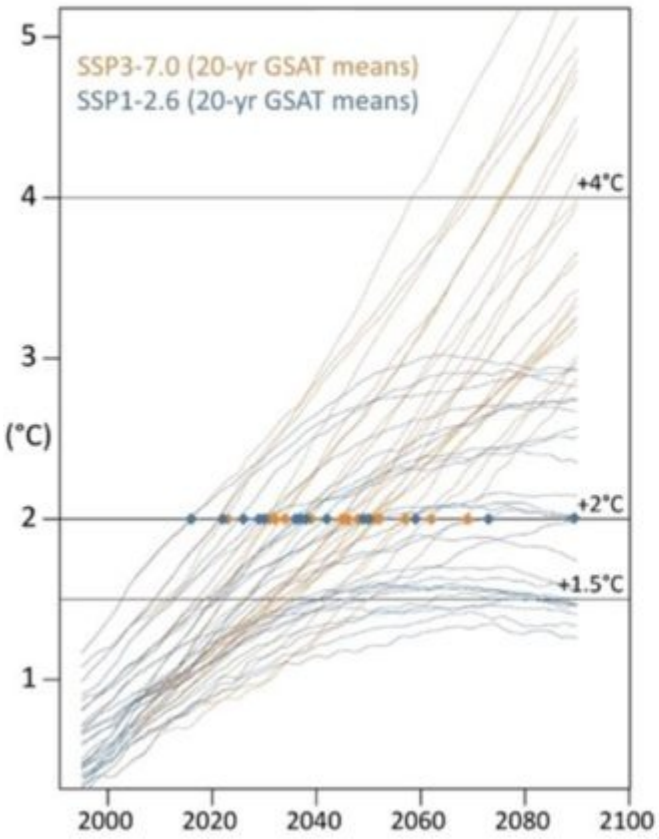



# 5. Futures scenarios and projections



# 5. Futures scenarios and projections

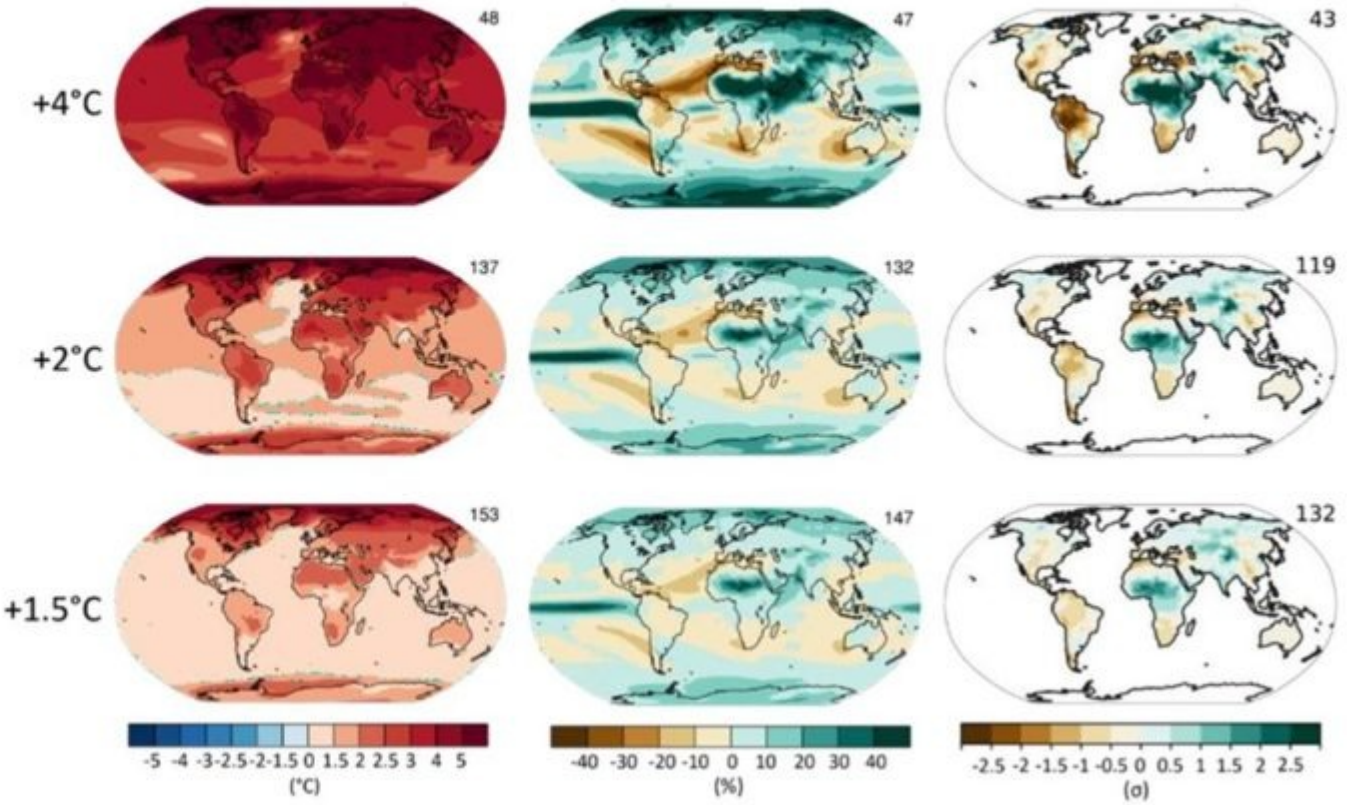
temperature
change from CMIP6 (°C)




temperature
change (°C)

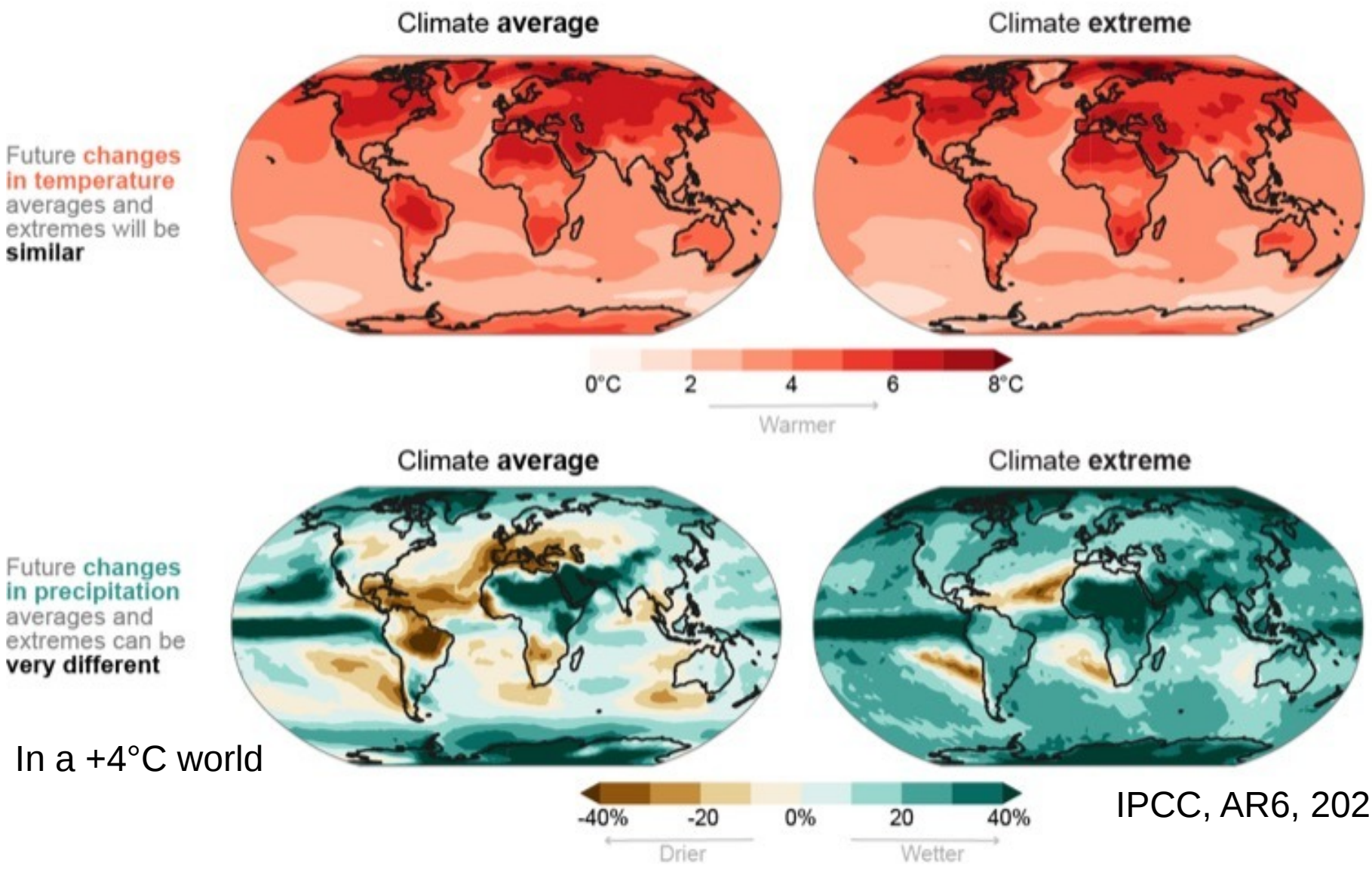
precipitation
change (%)

soil moisture
content




IPCC, AR6, 2021

# 5. Futures scenarios and projections




In a +4°C world

IPCC, AR6, 2021

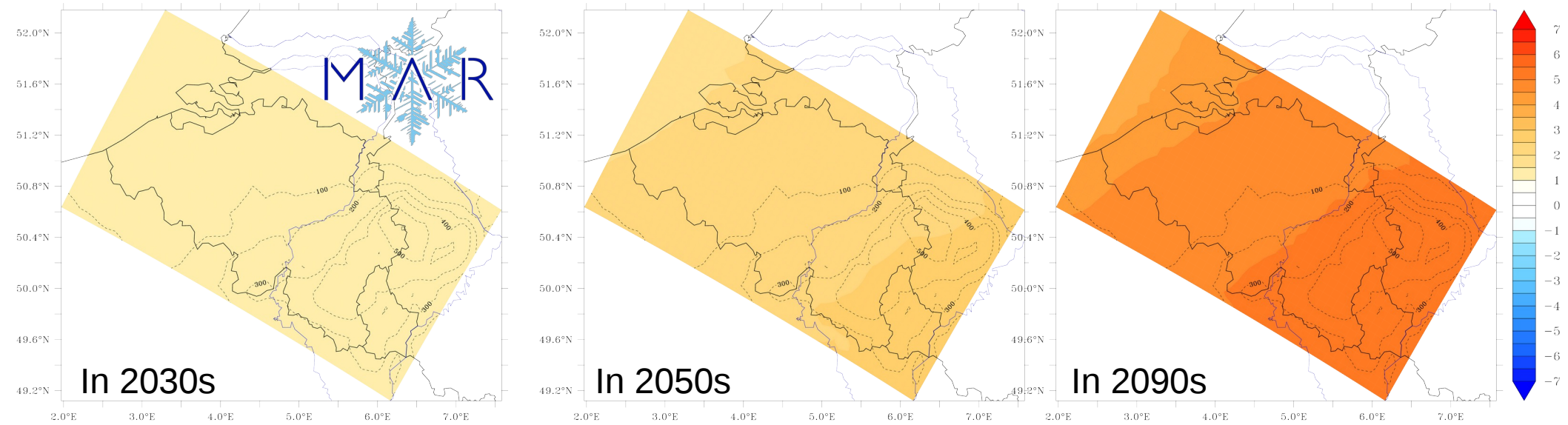
- +7% humidity in atmosphere/degree
- slow-down of atmospheric dynamics as Poles should warm faster than Equator

# 5. Futures scenarios and projections

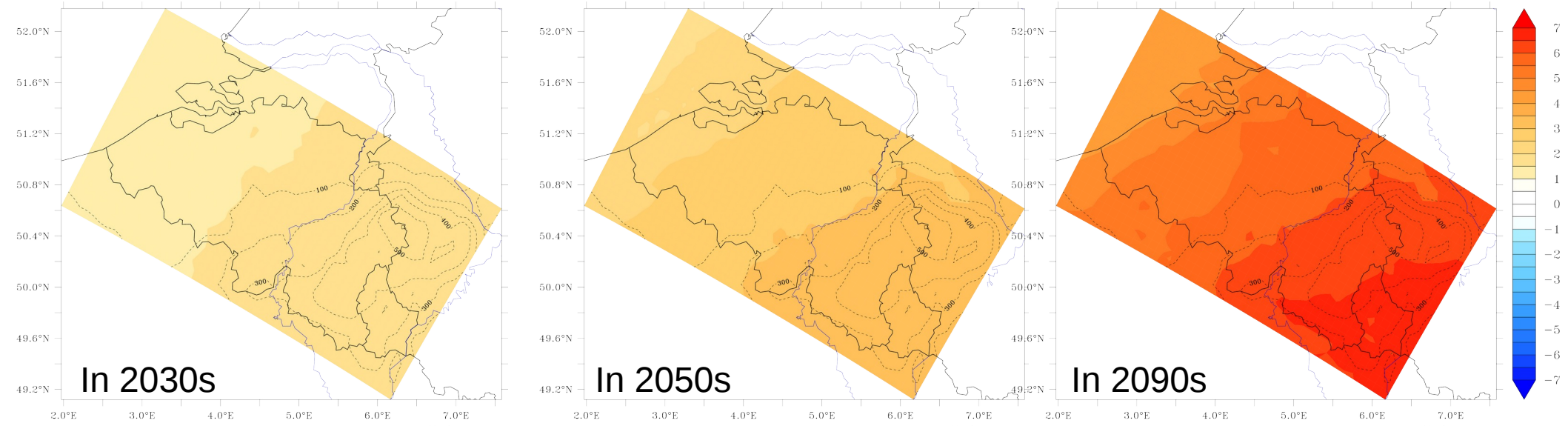
## Risk = Hazard x Vulnerability x Exposure


# 6. In Belgium

*Based on 4 SSP585 forced MAR simulations*



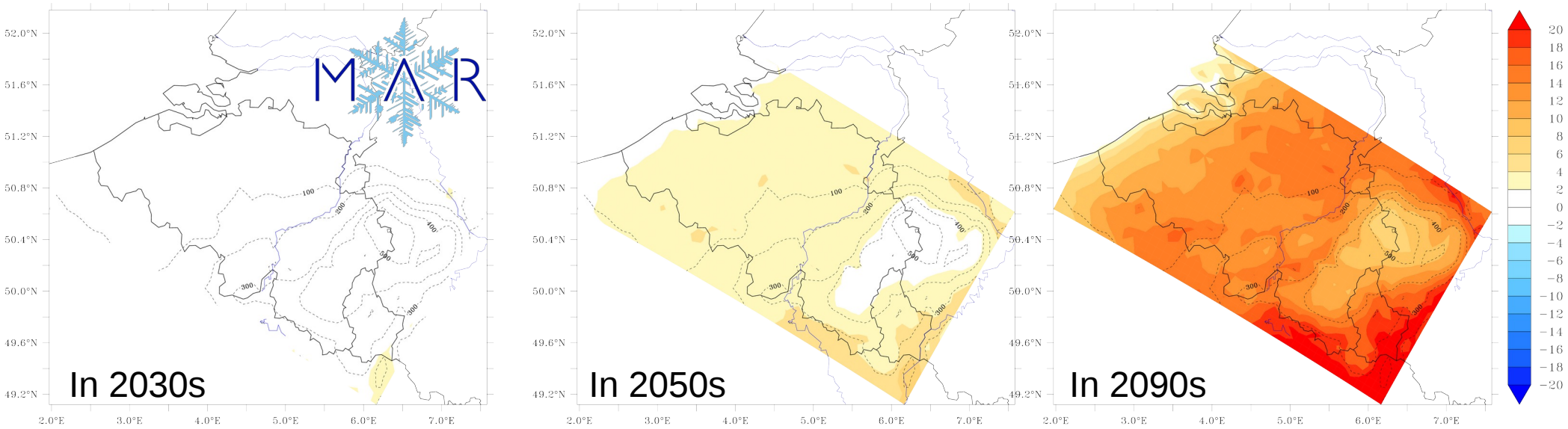

Annual temperature anomaly with respect to 1981-2010 (°C)



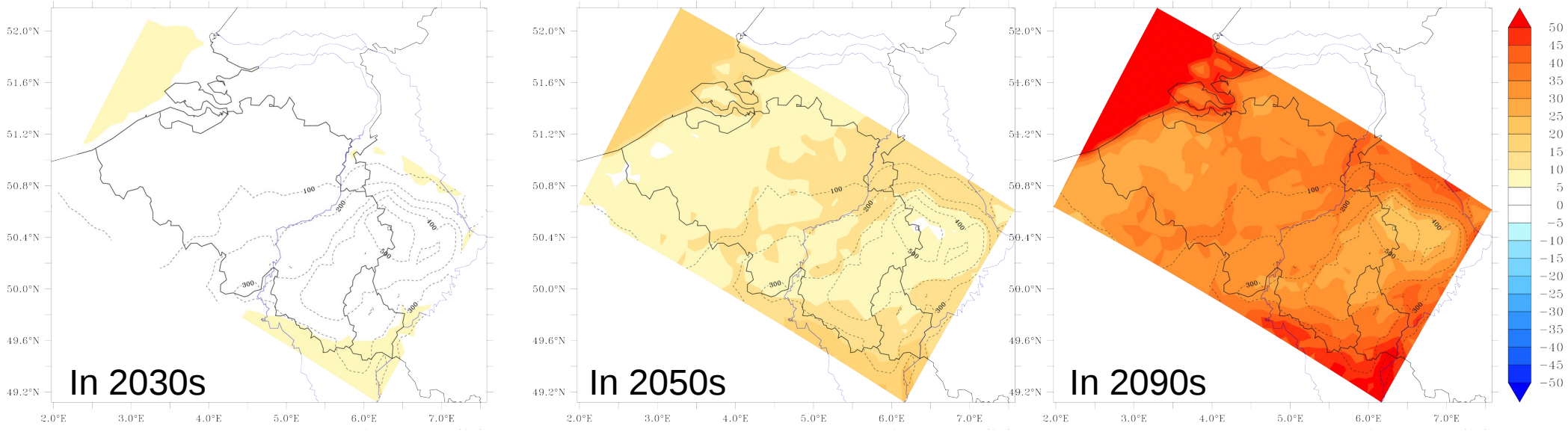

Summer temperature anomaly with respect to 1981-2010 (°C)

# 6. In Belgium

*Based on 4 SSP585 forced MAR simulations*



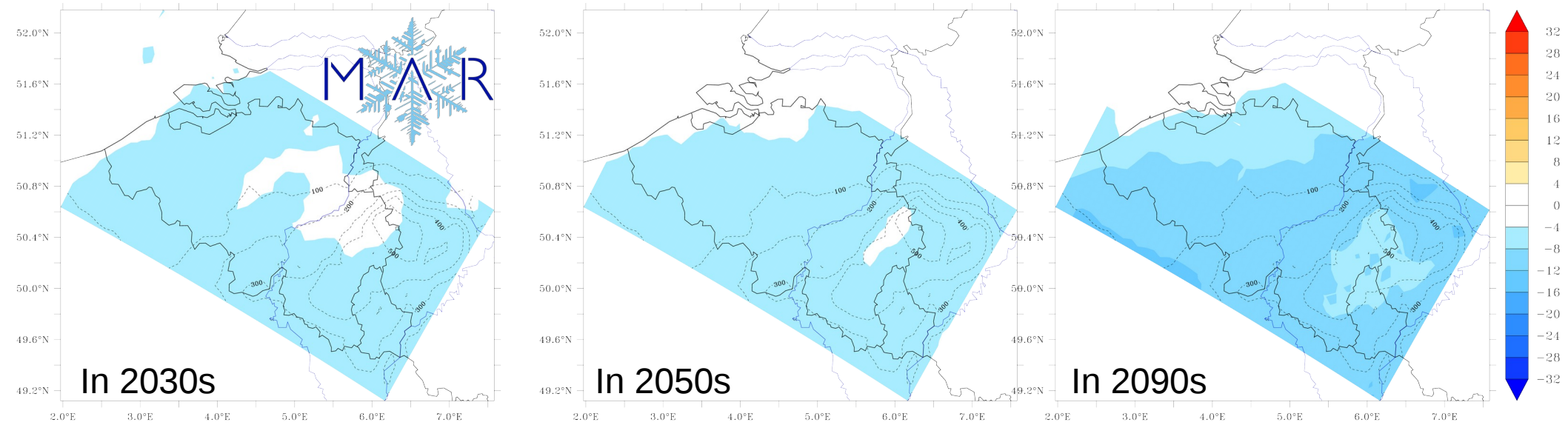

Anomaly of nbr of days with extreme temperature (Tmax > 35°C)



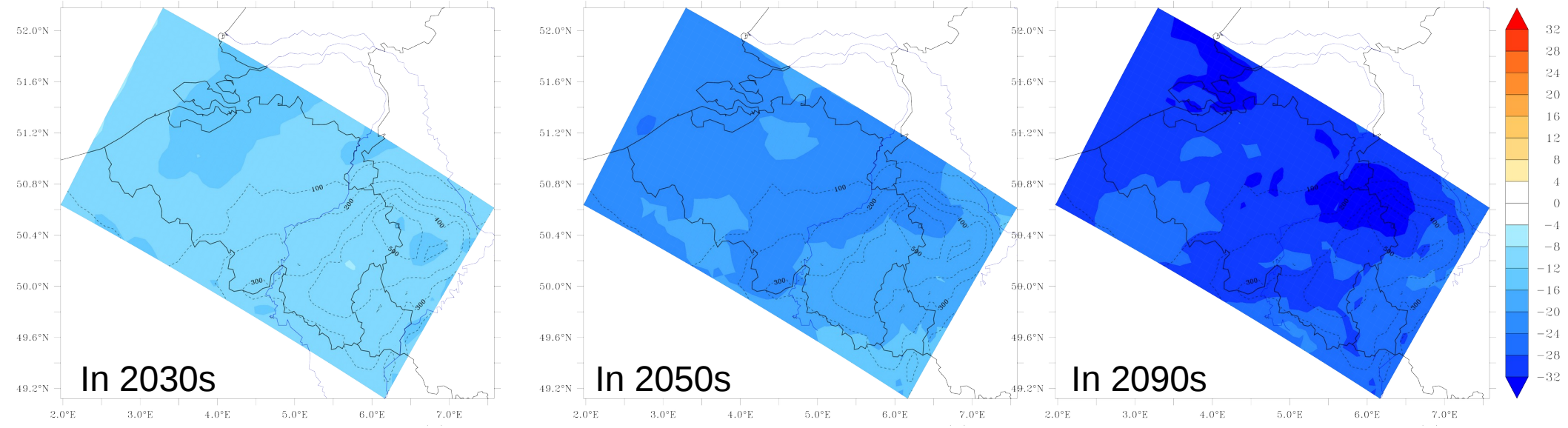

Anomaly of nbr of days with tropical night (Tmin > 20°C)

# 6. In Belgium

*Based on 4 SSP585 forced MAR simulations*



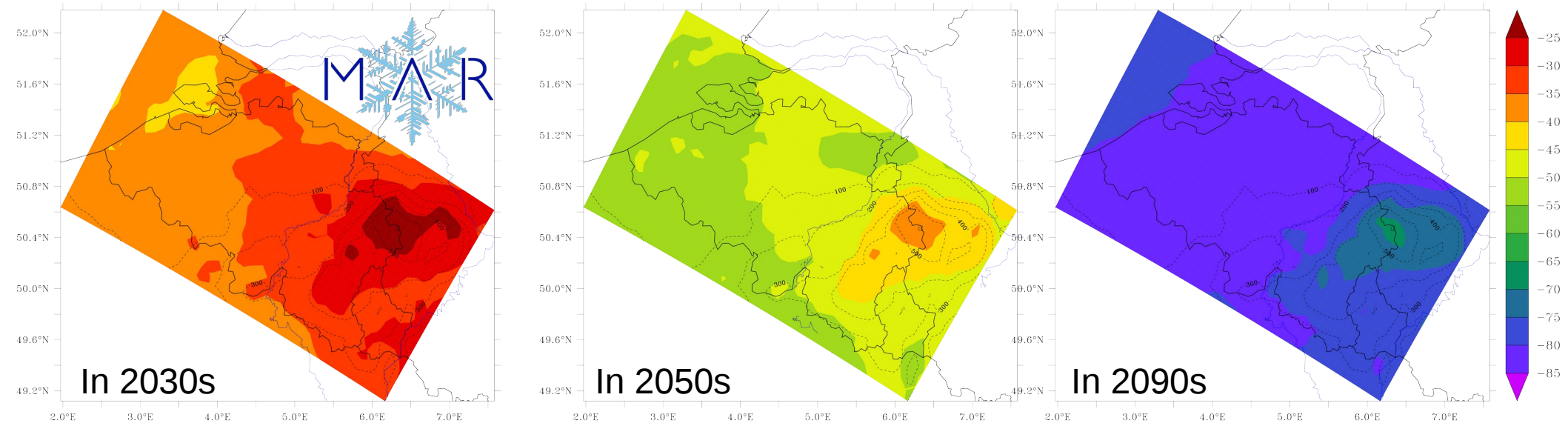

Anomaly of annual Precipitation (in %)



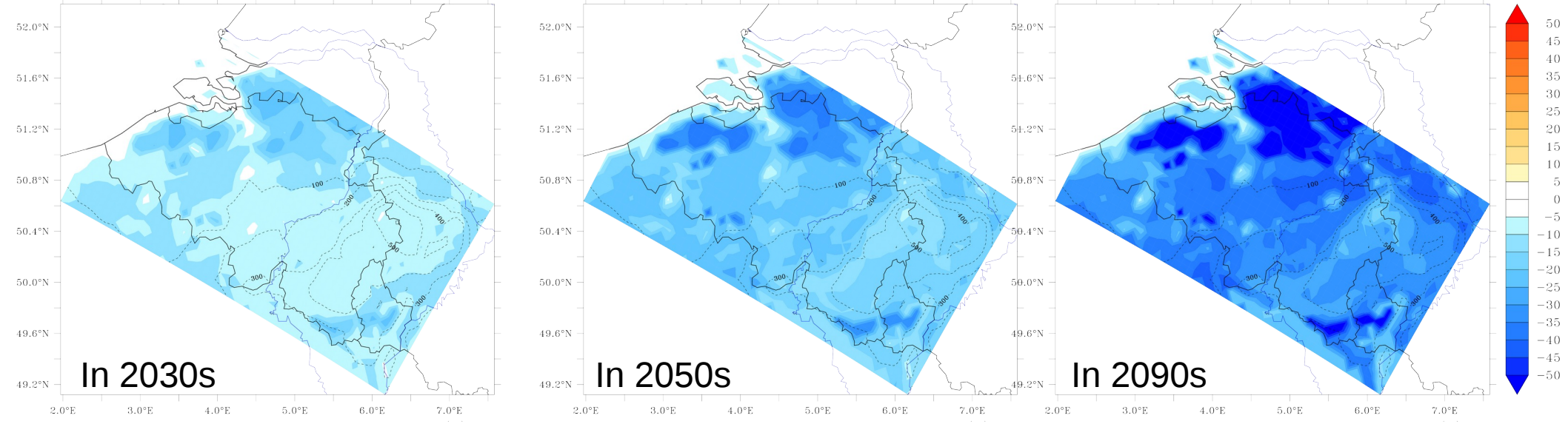

Anomaly of summer precipitation (in %)

# 6. In Belgium

*Based on 4 SSP585 forced MAR simulations*



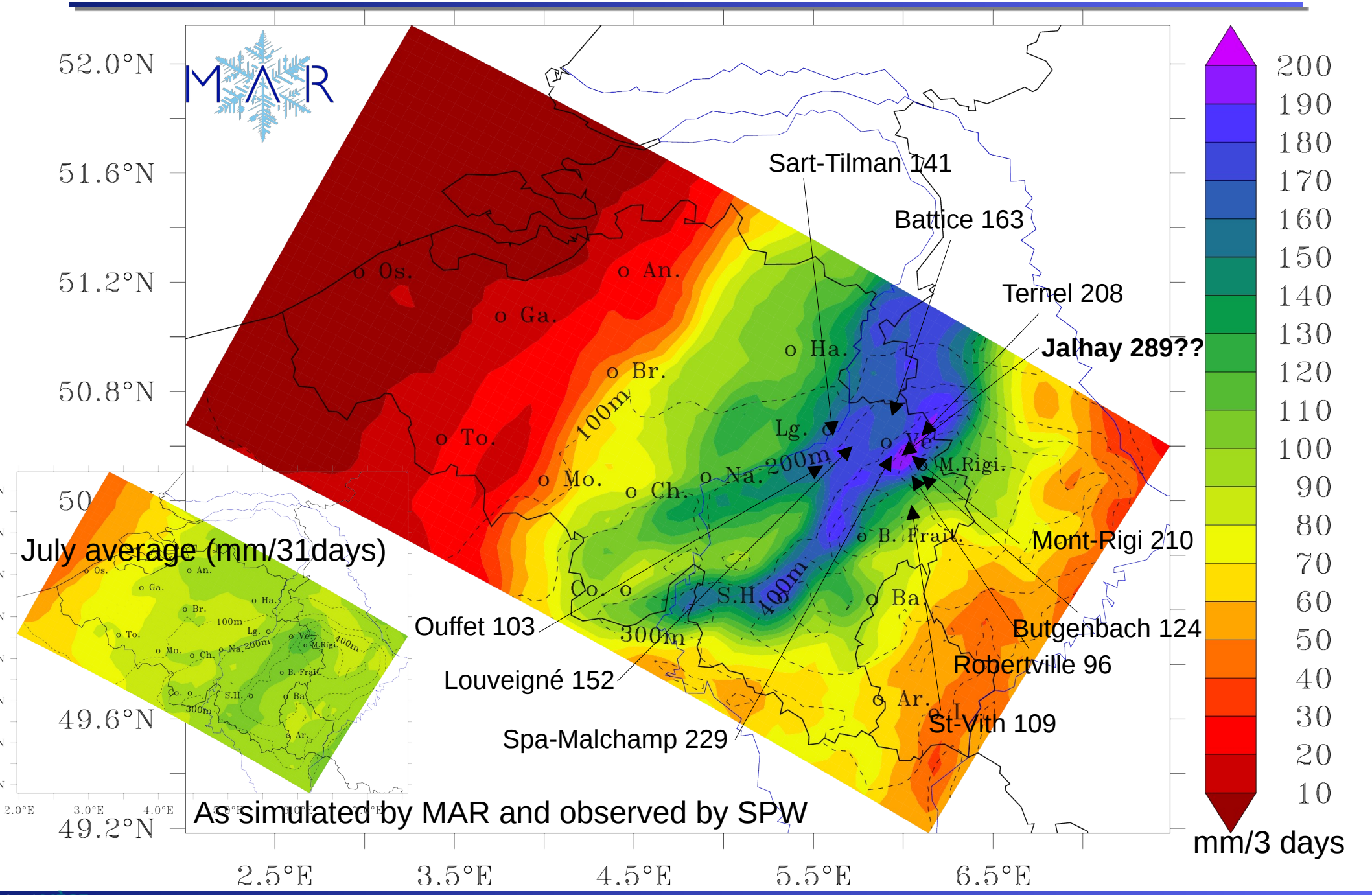

Anomaly of annual snowfall (in %)



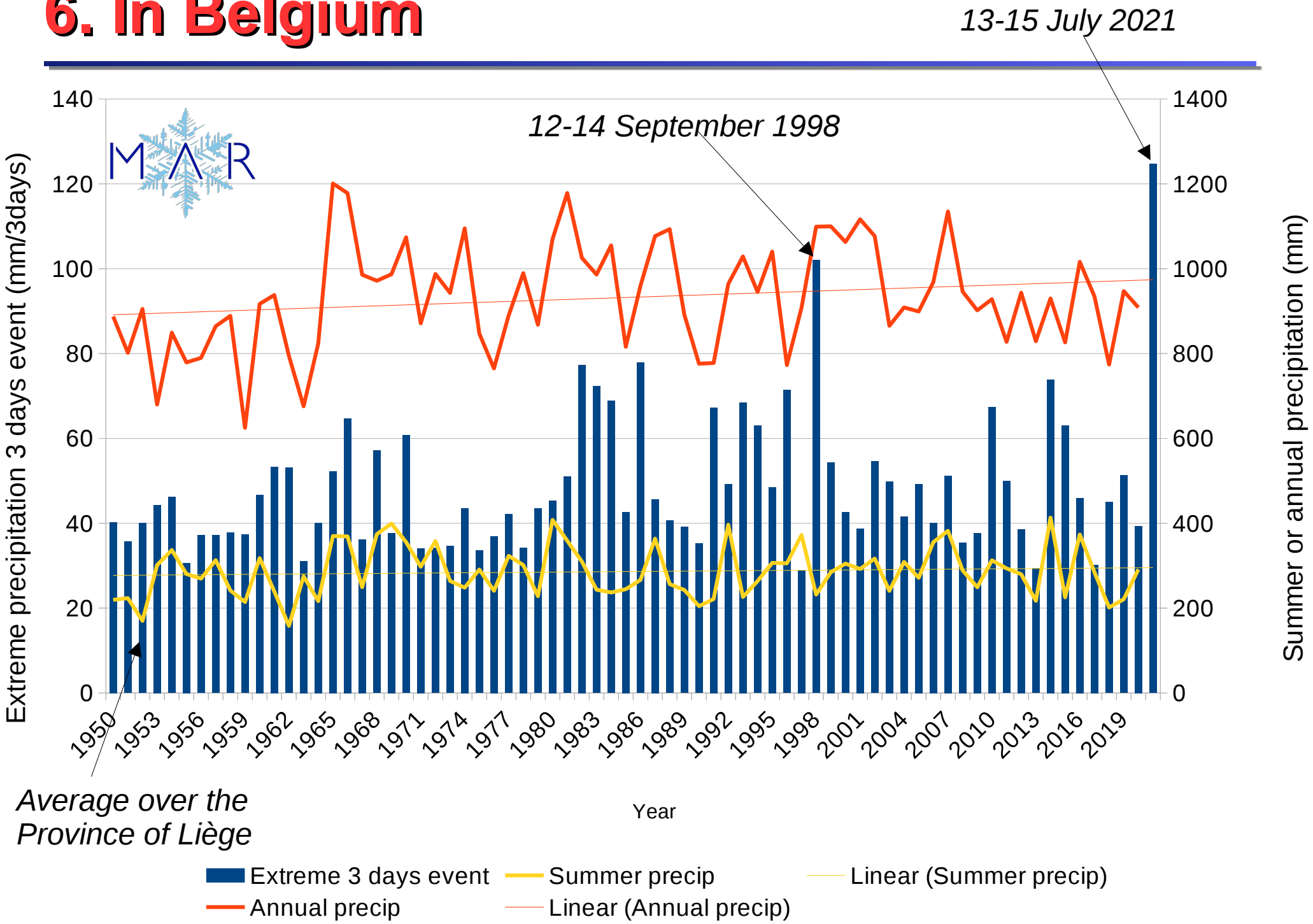

Anomaly of summer 1m soil water content (in %)

# 6. In Belgium

## Precipitation: 13-15 July 2021

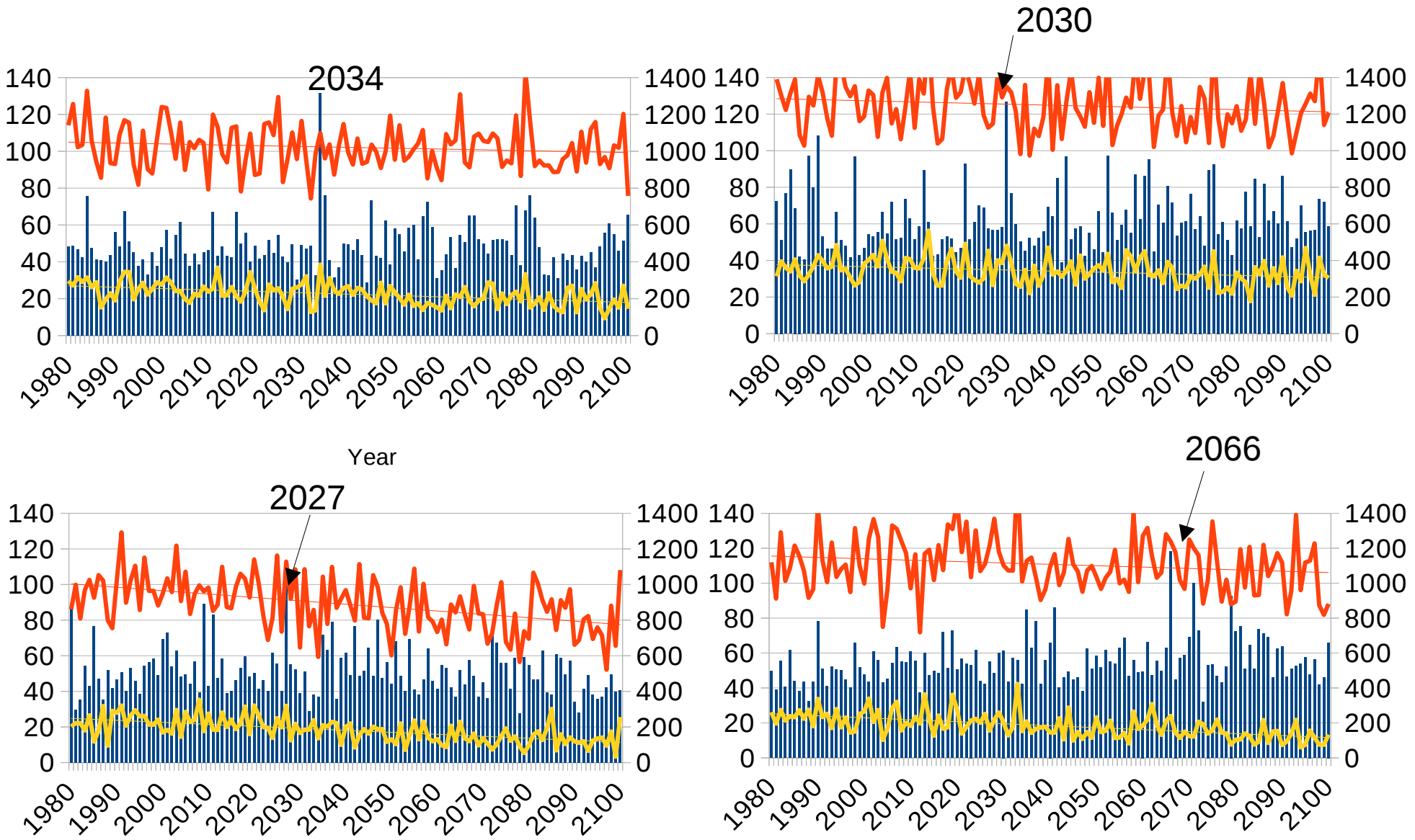


# 6. In Belgium


13-15 July 2021
12-14 September 1998
MAR
Extreme precipitation 3 days event (mm/3days)
Summer or annual precipitation (mm)
140
120
100
80
60
40
20
0
1400
1200
1000
800
600
400
200
0
1950
1953
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016
2019
Year
Average over the Province of Liège
Extreme 3 days event
Summer precip
Linear (Summer precip)
Annual precip
Linear (Annual precip)

# 6. In Belgium

**13-15 July 2021: 120mm/3days**




3 on 4 future projections suggests event like July 2021 in the 2030's

# 6. In Belgium (extreme events)

**Less** temperature contrasts with the poles
for triggering extreme events
BUT
**More** energy to amplify these events.

| | |
|---|---|
| heat wave | ++ |
| cold wave + snow | -- |
| drought | + |
| heavy rainfall | + |
| wind | ?/- |
| tornadoes / hurricanes | ?/+ |
| winter flood | - |
| summer flash floods | + |

20 September 1982 at Léglise
(in the Ardennes)

# 6. In Belgium (extreme events)

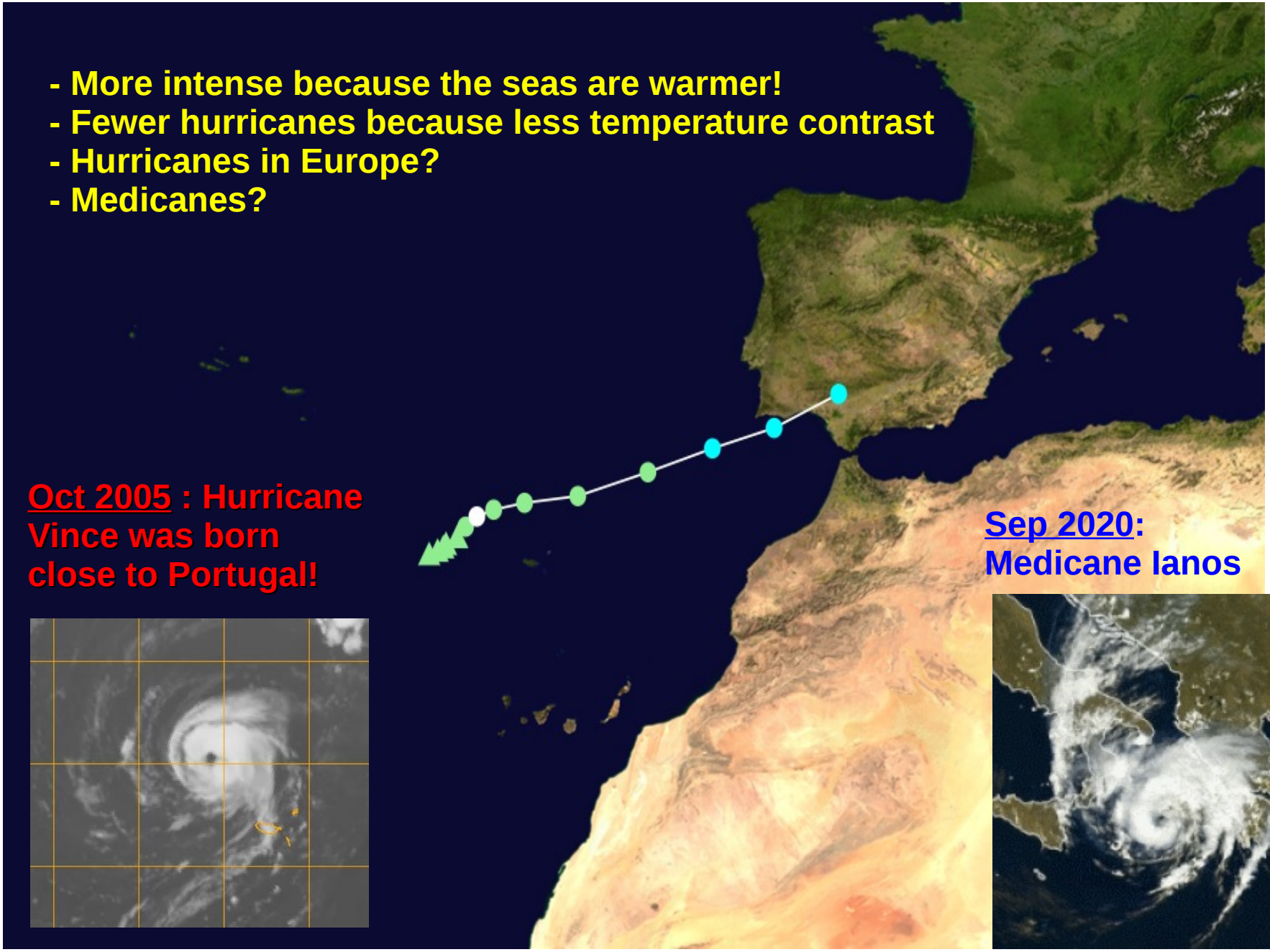

lots of uncertainties
about extreme events

**but**

with the increase
in population and buildings,
the same event will do more
damage than before !!

# 6. In Belgium (hurricane?)

- More intense because the seas are warmer!
- Fewer hurricanes because less temperature contrast
- Hurricanes in Europe?
- Medicanes?

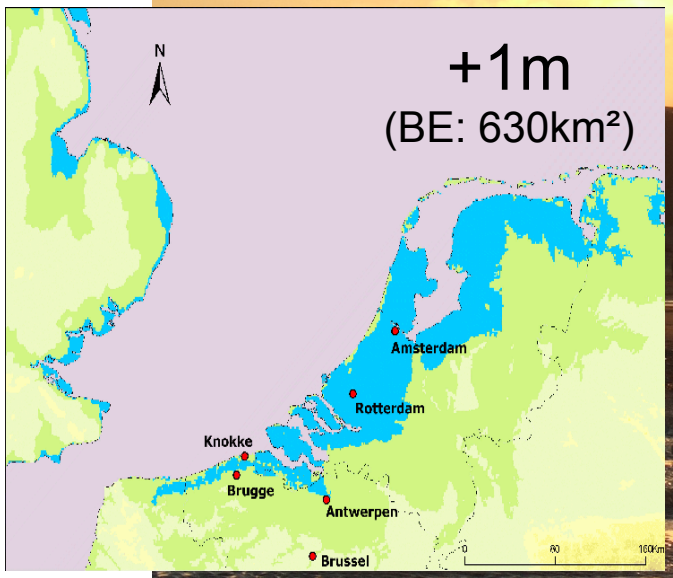


Oct 2005 : Hurricane Vince was born close to Portugal!



Sep 2020: Medicane Ianos

# 6. In Belgium (sea level rise)



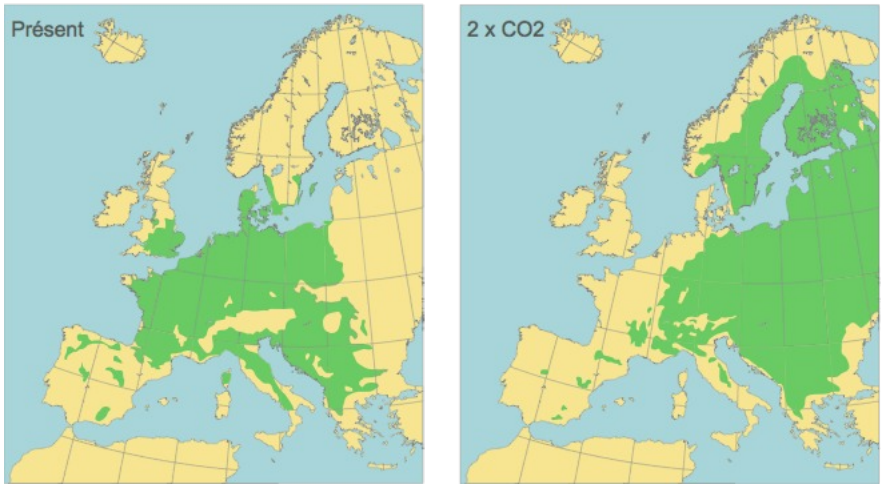
# 6. In Belgium (gulfstream)

## Gulfstream shutdown:

## => Glaciation in Europe?

# 6. In Belgium (vegetation)

**Warmer climate means:**
**1. Species from hot regions to cold regions**
**2. Species from cold regions: reduction ↓**




Area suitable for the Beech (Hêtre) tree

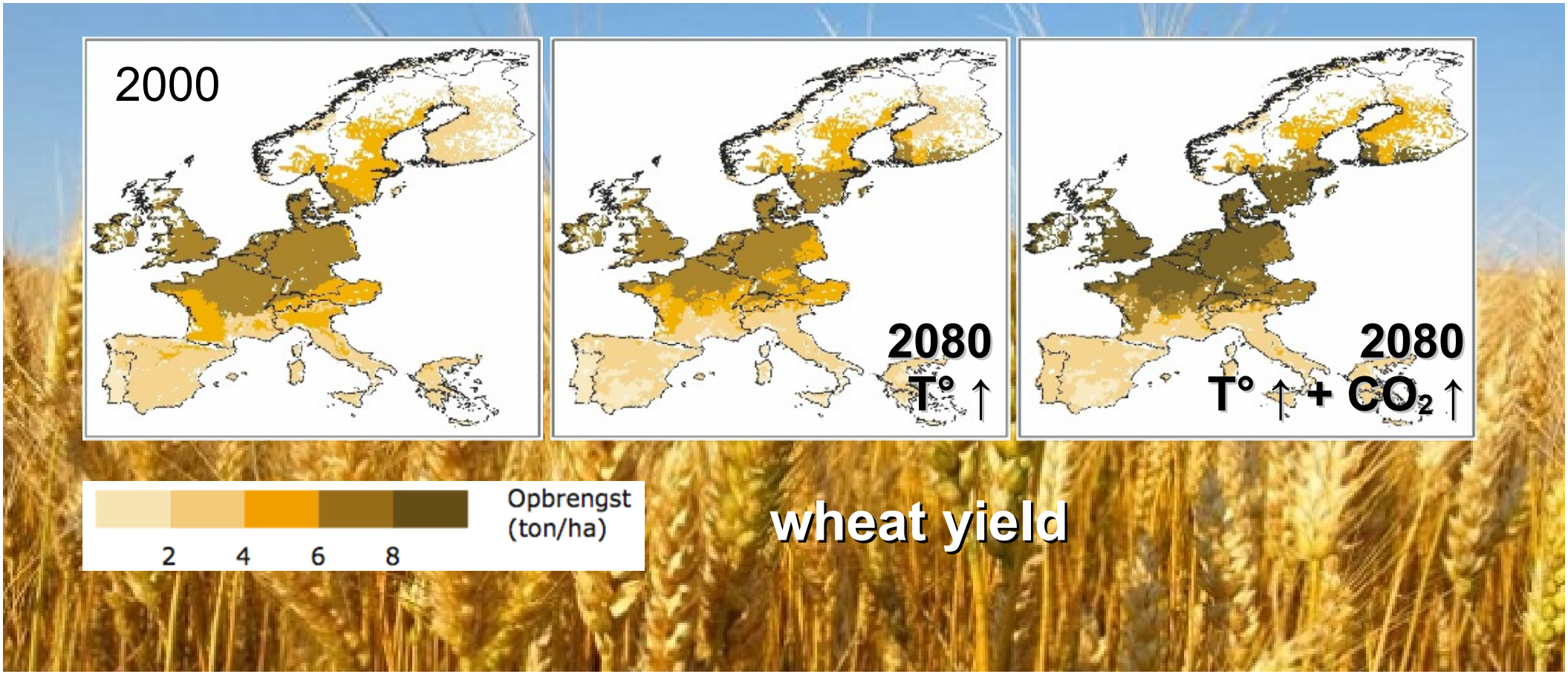

# 6. In Belgium (agriculture)

**Below + 3 ° C, limited impact.**

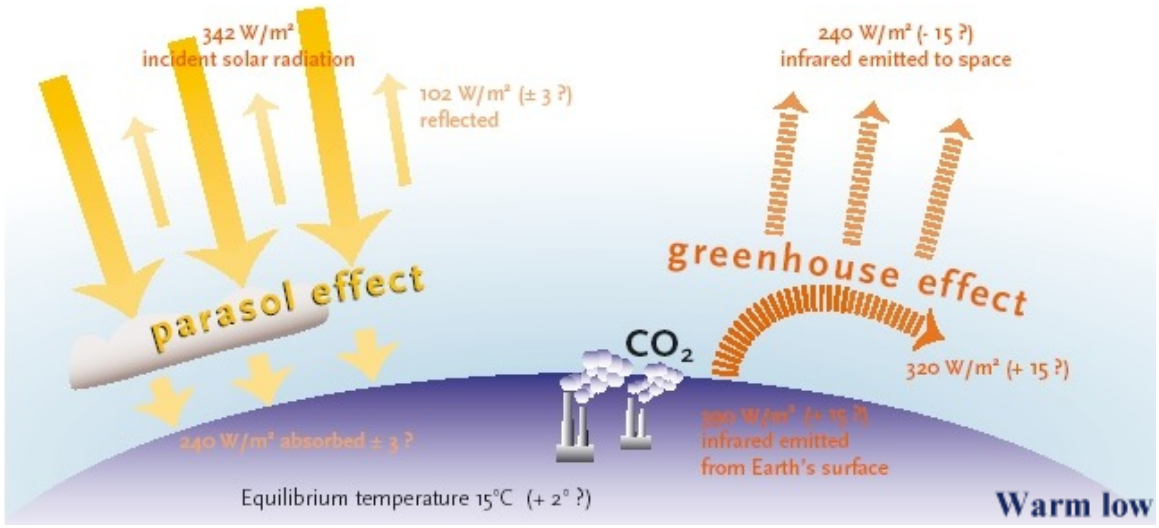
**Temprature ↑ yield decrease**

**$CO_2$ ↑ yield increase**

**but extreme events (drought, heatwave, ...)**

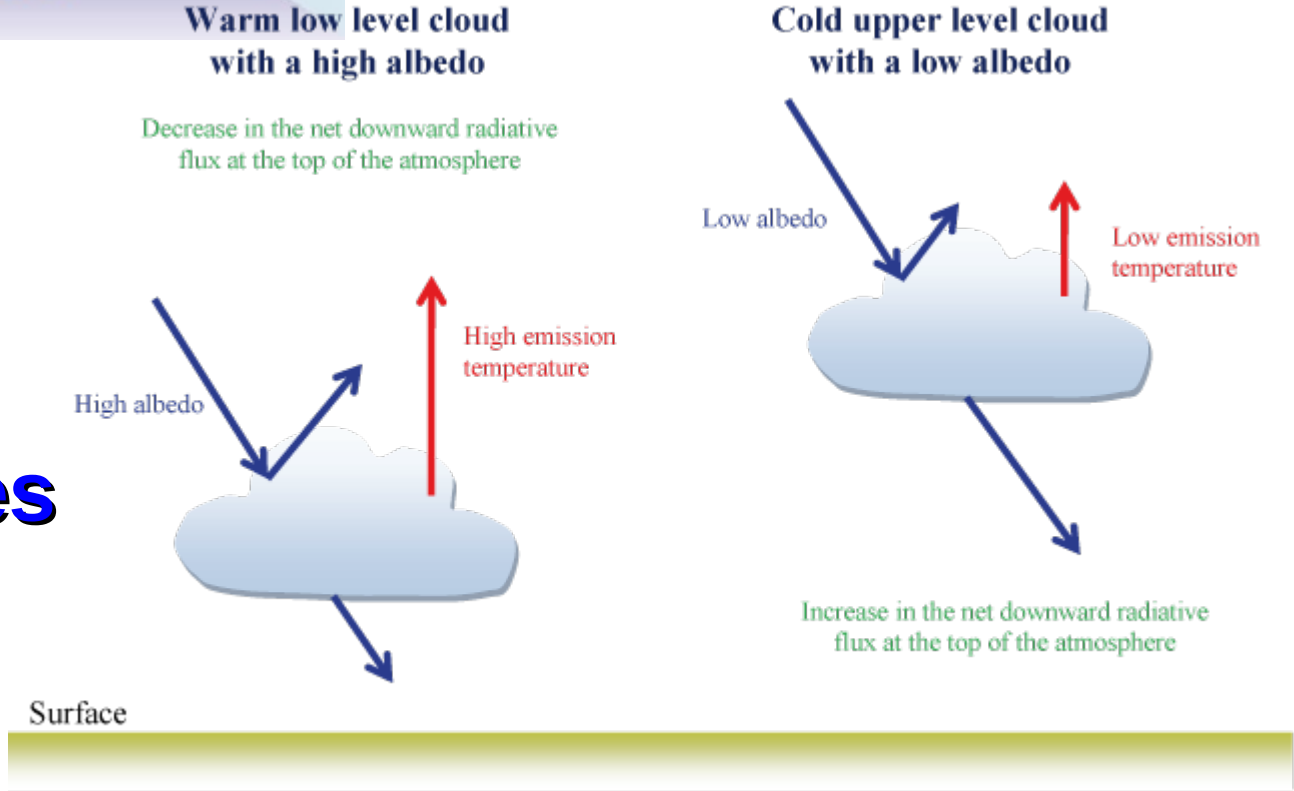


# 7. Renewable energy (solar)



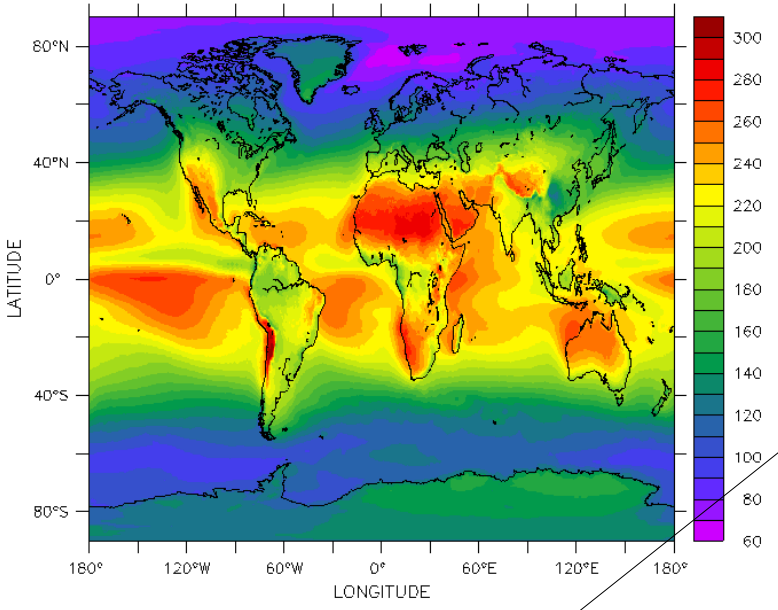

**Parasol vs greenhouse effect??**

**What about changes in clouds ???**

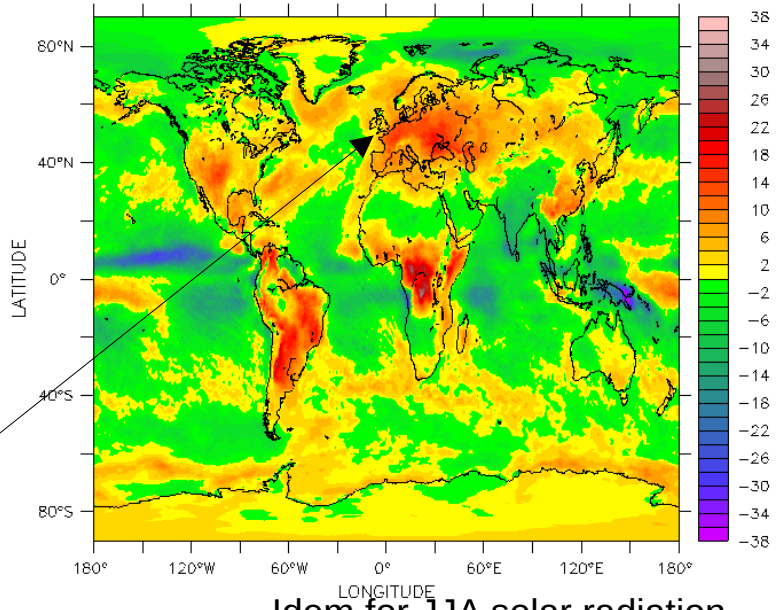


# 7. Renewable energy (solar)

Mean solar radiation over 1979-2020 (w/m2)




Solar radiation change from 1979 to 2020 (w/m$^2$/42yrs)

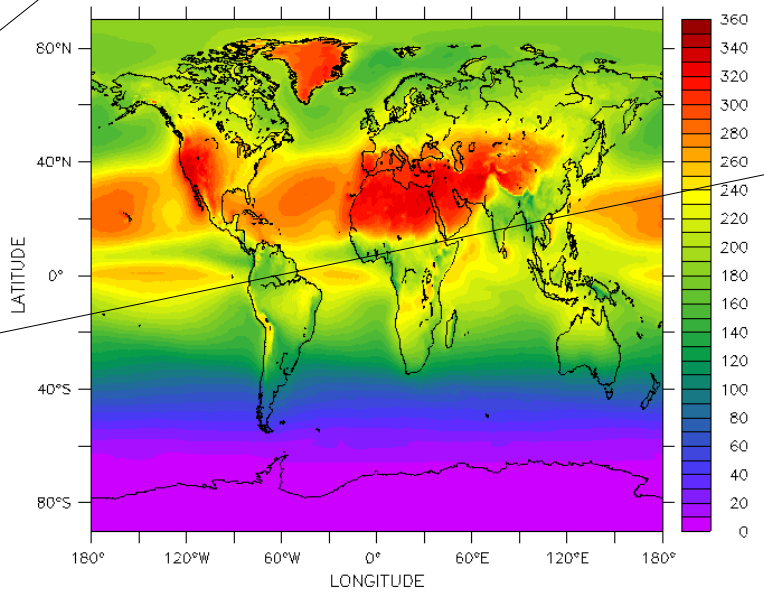


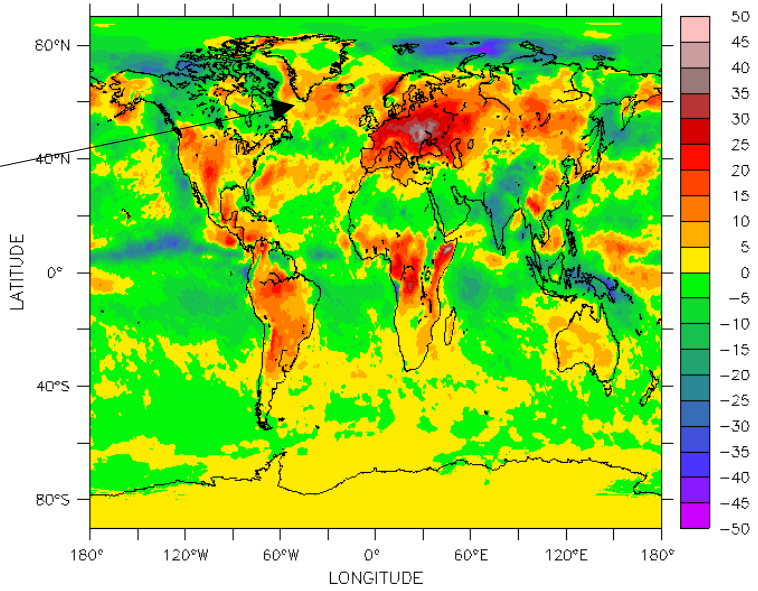

Due to reduction of pollution

**but also**

to circulation changes

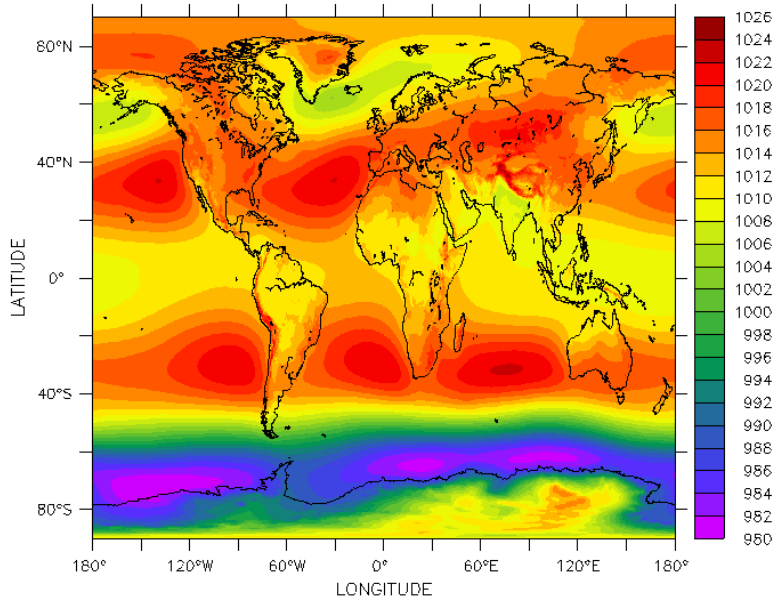
Idem for JJA solar radiation



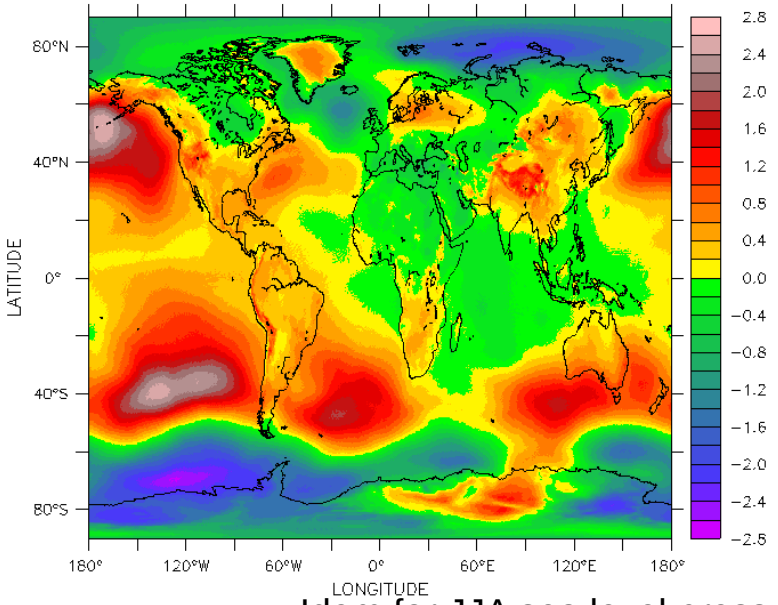



# 7. Renewable energy (circulation)

Mean sea level pressure over 1979-2020 (hPa)

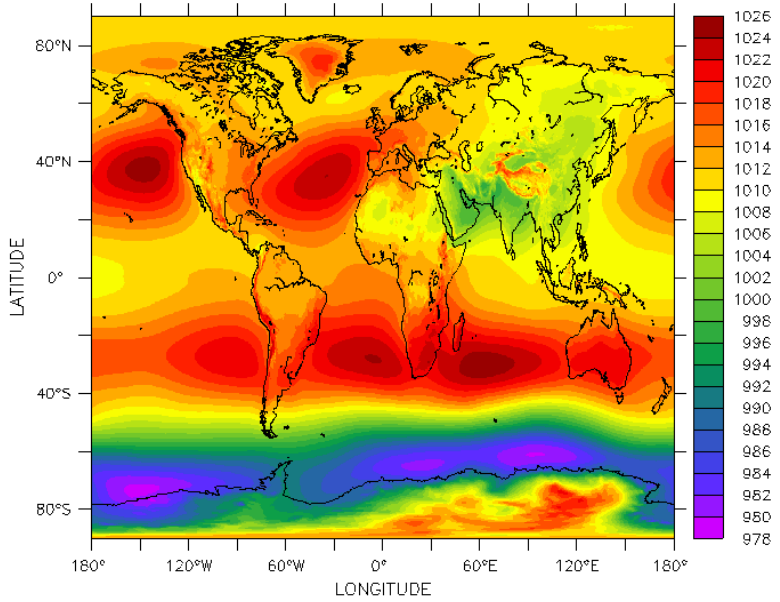


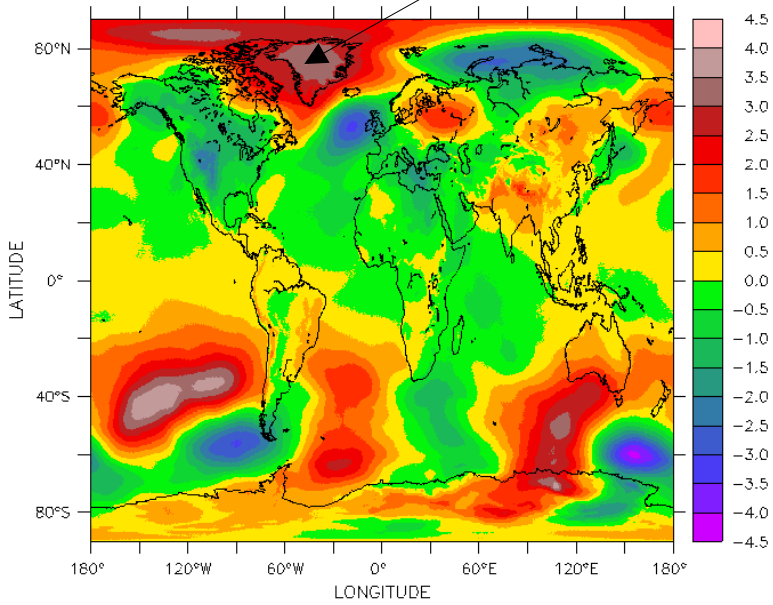

Sea level pressure change from 1979 to 2020 (hPa/42yrs)




Higher anticyclonic conditions (NAO<0)

Idem for JJA sea level pressure

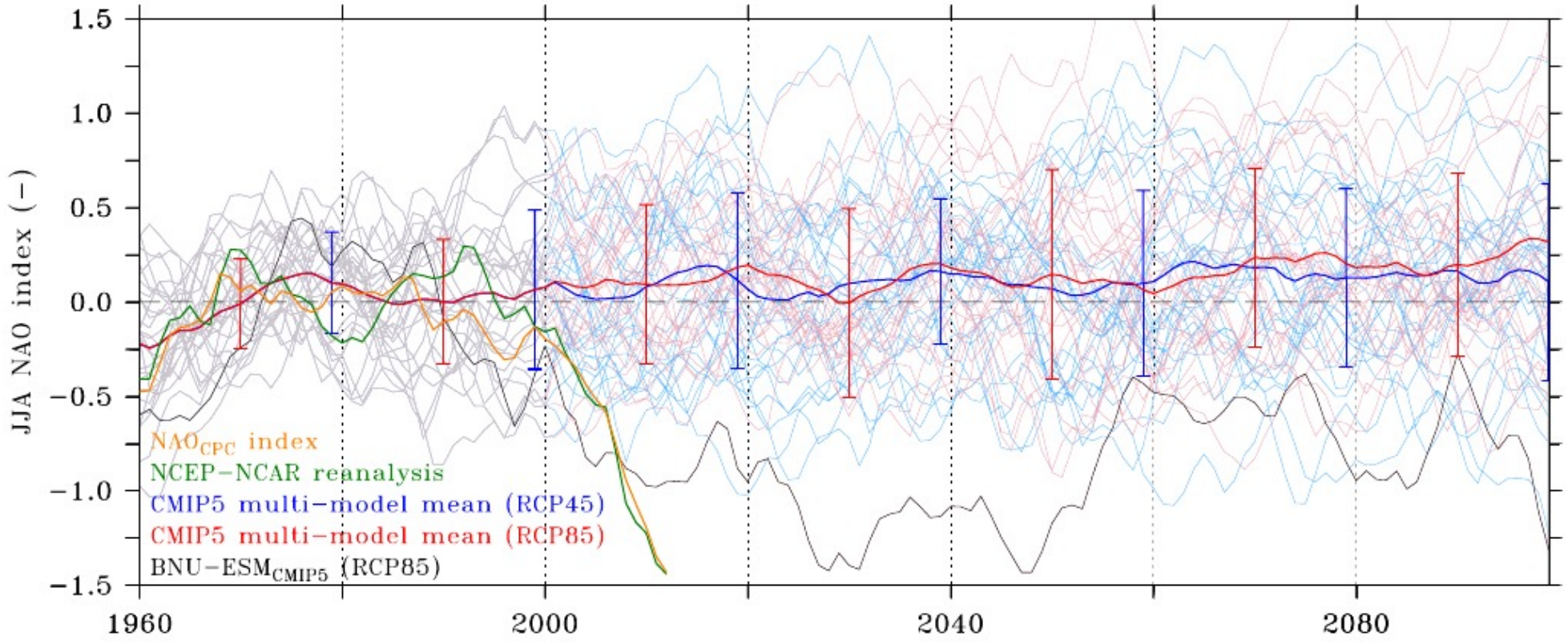


# 7. Renewable energy (circulation)

*NAO = normalised difference between the Azores High and the Islandic Low.*

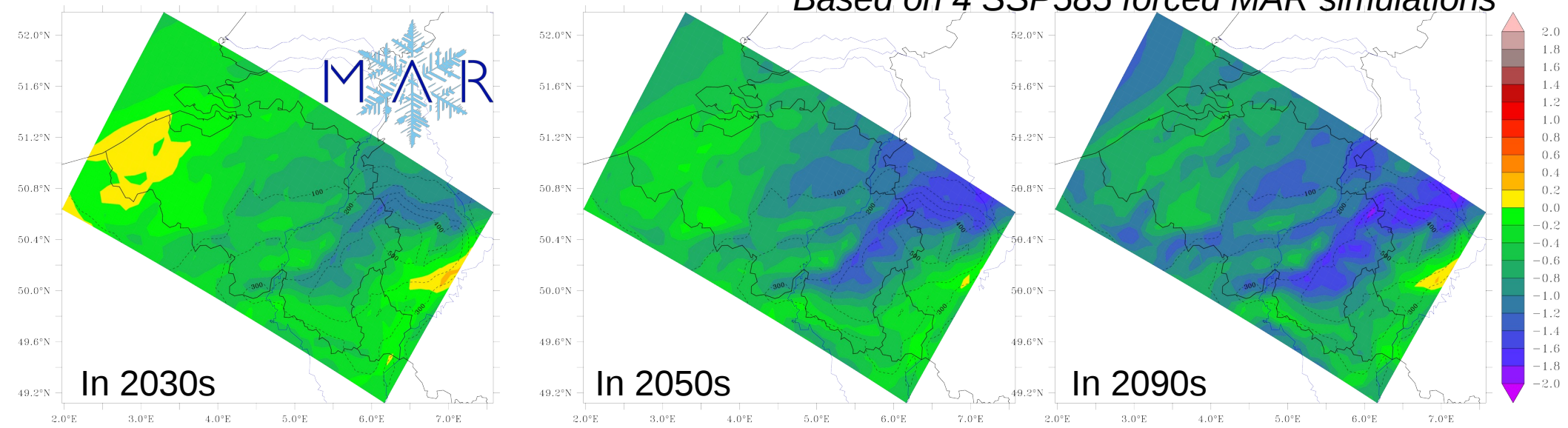
Current and future evolution of JJA NAO index...



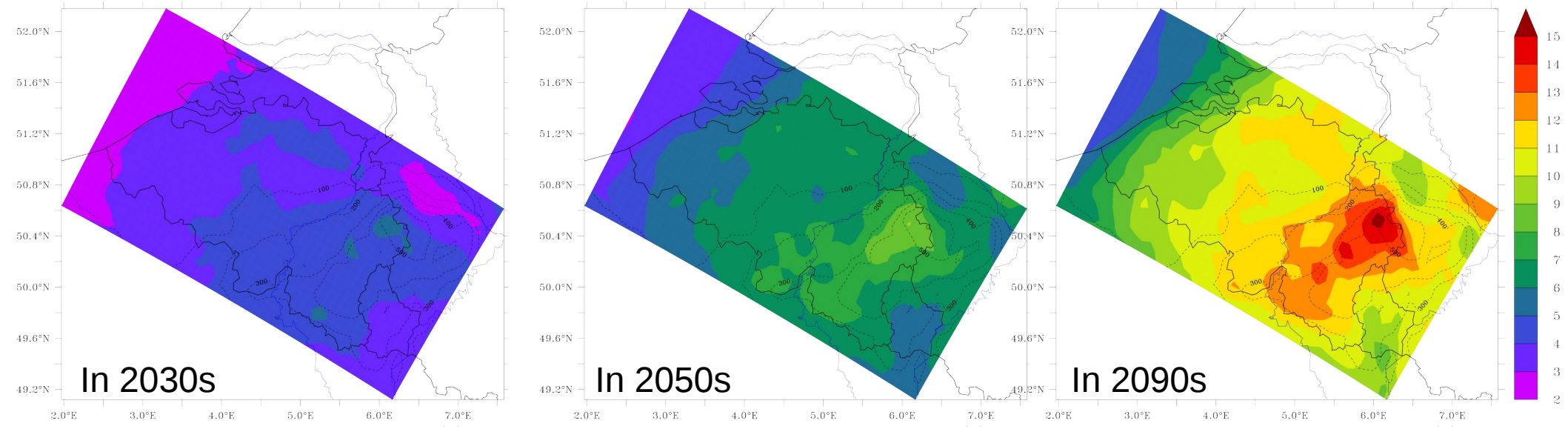

**Are the global models able to project changes in general circulation ?**

# 7. Renewable energy (Belgium)

*Based on 4 SSP585 forced MAR simulations*




Anomaly of annual 100m wind speed (in %)

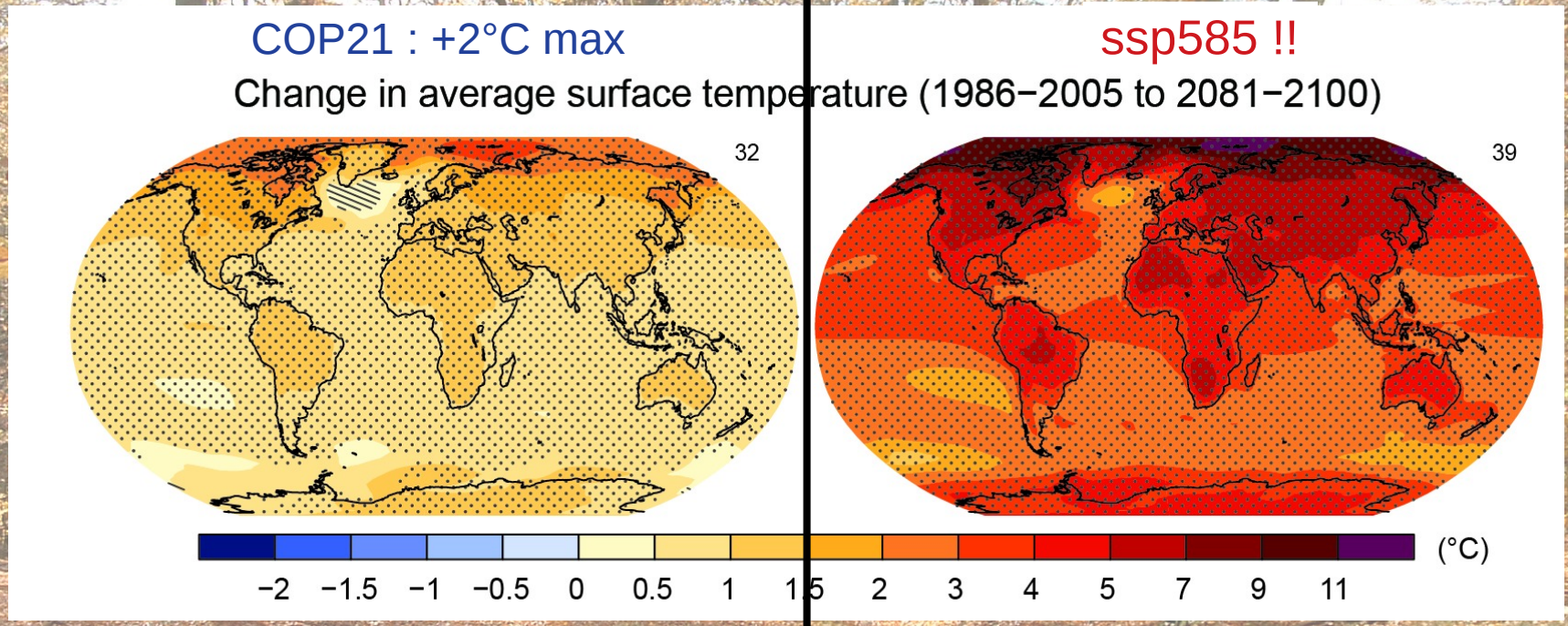



Anomaly of summer solar radiation (in %)

# Conclusion

COP21 : +2°C max

ssp585 !!




**+ irreversible tipping points for ice sheets and ecosystem**

**It is up to us to choose where we are going !!**