Changements climatiques : un problème très physique, ouvert à d'autres disciplines

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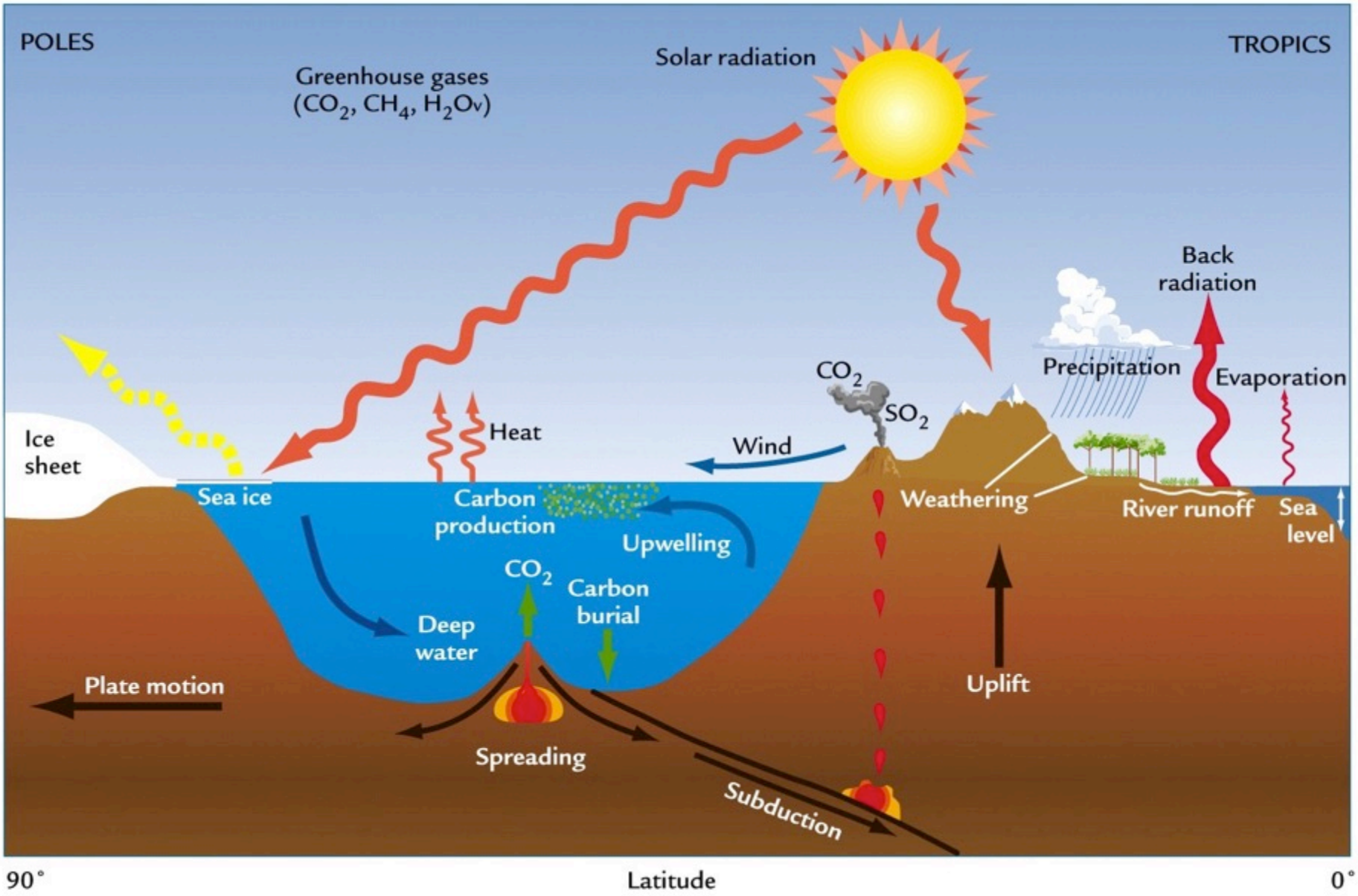
Définitions

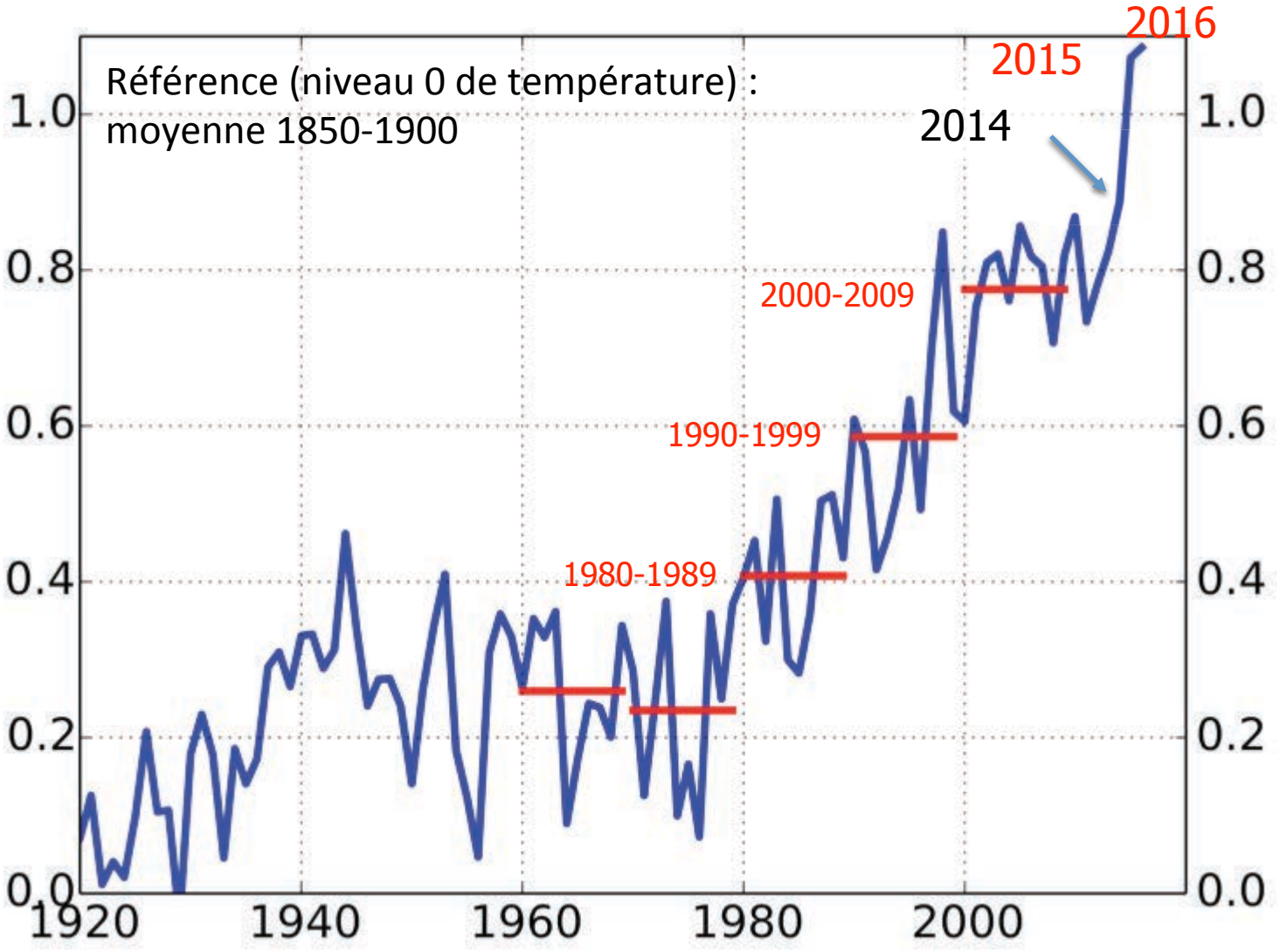
- **Système climatique**: constitué par l'atmosphère, les océans, la cryosphère (glace), la surface des continents, la biosphère…
- **Le climat** =moyenne de l'état de ce système, en particulier du temps sur 30 ans, + variabilité autour de cette moyenne


POLES
TROPICS
Solar radiation
Greenhouse gases
(CO_2, CH_4, H_2Ov)
Back radiation
Precipitation
Evaporation
CO_2
SO_2
Heat
Wind
Ice sheet
Sea ice
Carbon production
Upwelling
Weathering
River runoff
Sea level
CO_2
Carbon burial
Deep water
Plate motion
Uplift
Spreading
Subduction
90°
Latitude
0°

Le système climatique terrestre

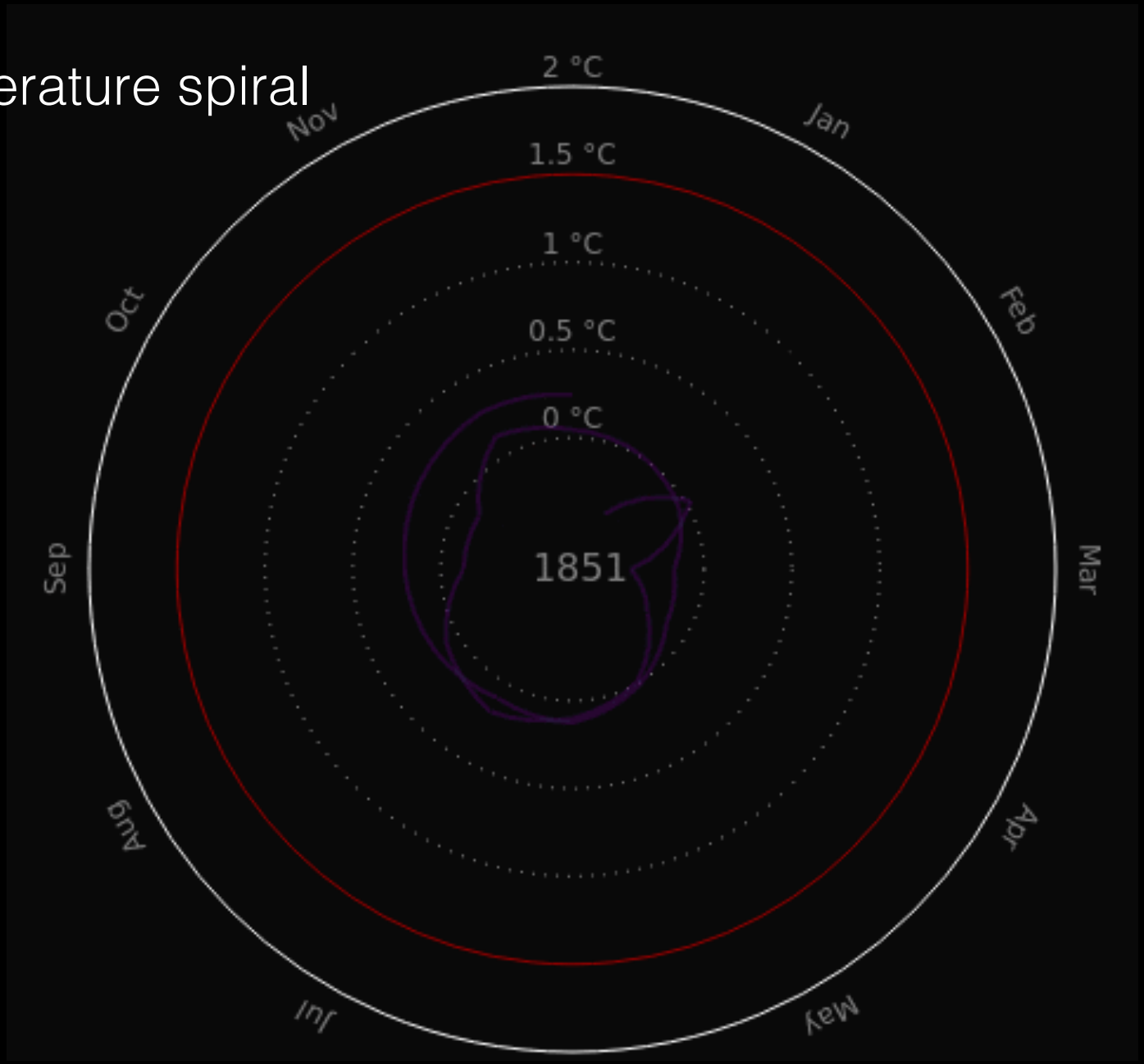
- Machine thermique alimentée en énergie par le Soleil (1400 Wm^{-2} au sommet de l'atmosphère)
- « Sphère » en rotation : dynamique des fluides complexe
- Océan= 70% de la surface,
- Très fine atmosphère (N_2, O_2, H_2O, CO_2,…)
- Effet de serre
- Cycles bio-géo-chimiques

Température moyenne planétaire observée en surface (continent + océan)



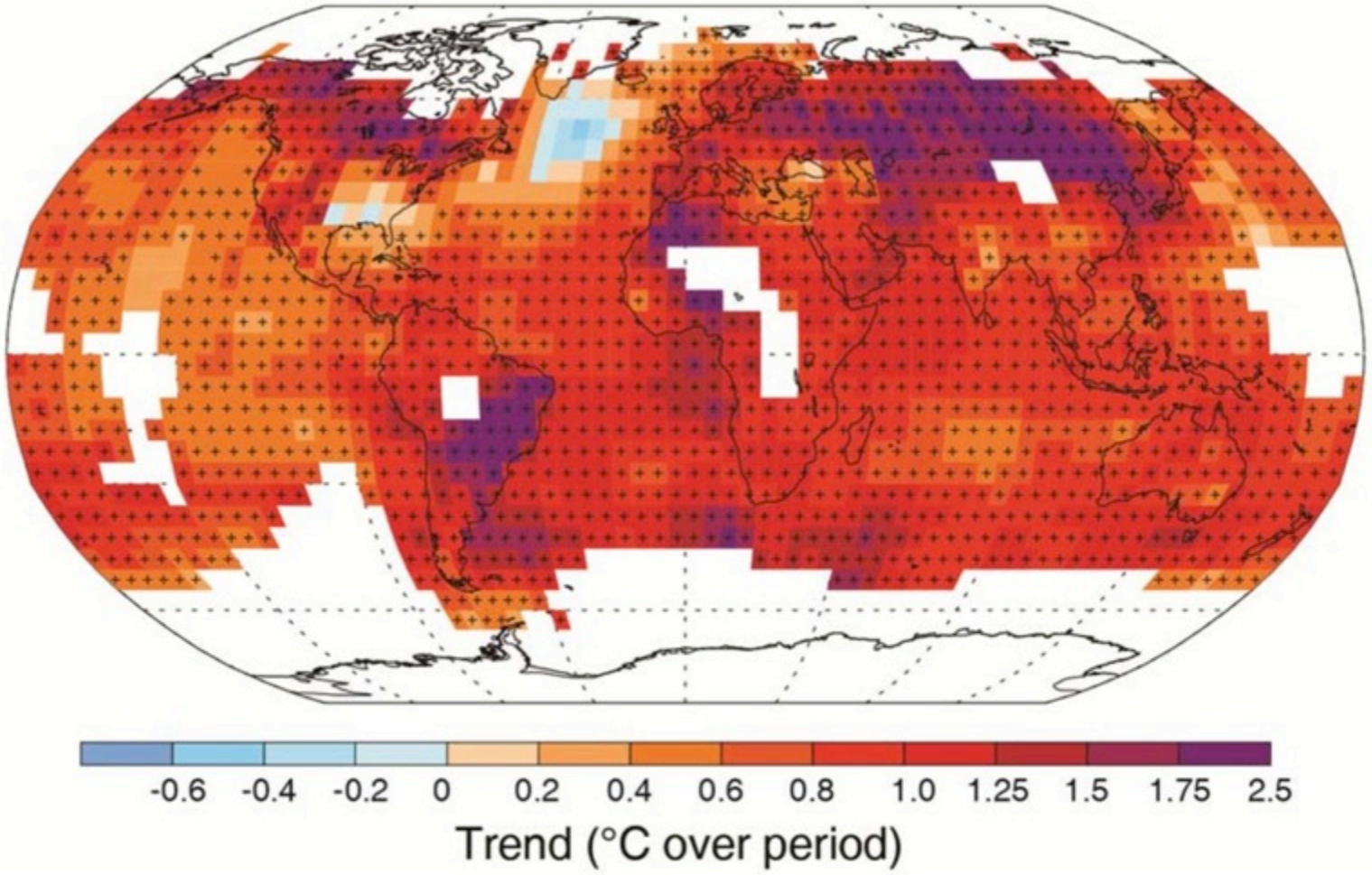
Source des données : Climate Research Unit, University of East Anglia, UK Graphique: P. Marbaix, TECLIM-UCL

Temperature spiral



Global Mean Temperature in °C relative to 1850 – 1900
Graph: Ed Hawkins (Climate Lab Book) – Data: HadCRUT4 global temperature dataset
Available on http://openclimatedata.net/climate-spirals/temperature

Evolution de la température moyenne en surface 1901-2012: +0.89°C



(IPCC 2013, Fig. SPM.1b)

Le réchauffement du système climatique est sans équivoque

Résumé (1)

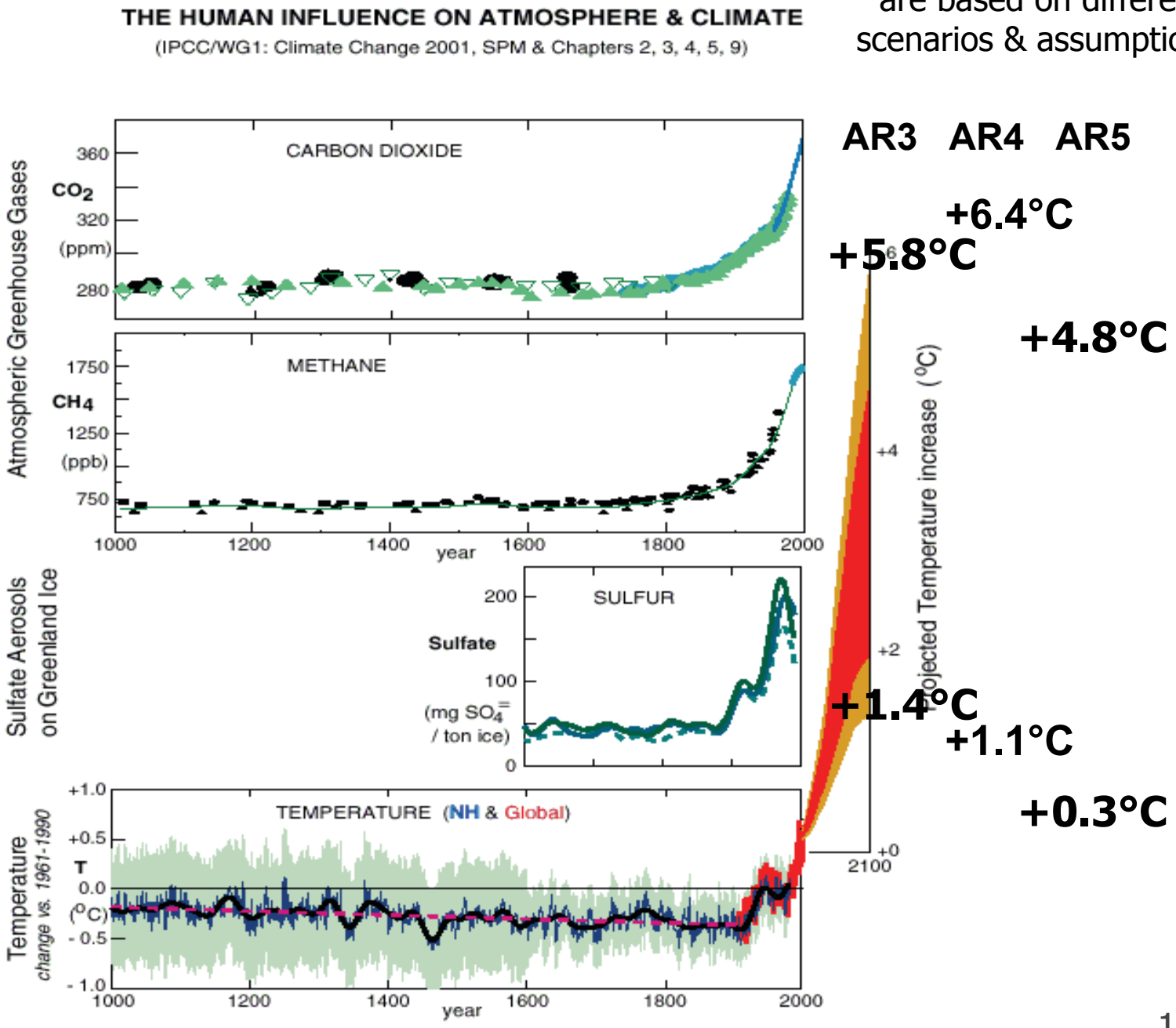
- $C + O_2$ = chaleur + CO_2 (inévitable)
- 80% de d'énergie mondiale viennent des combustibles fossiles, contenant du "C" (carbone); le déboisement contribue aussi à l'émission de CO_2
- Ce gaz "à effet de serre" piège la chaleur
- De façon simplifiée : actuellement la moitié du CO_2 émis reste environ 100 ans dans l'atmosphère;
  il s'y accumule: [CO_2] +40% depuis 1750

Résumé (2)

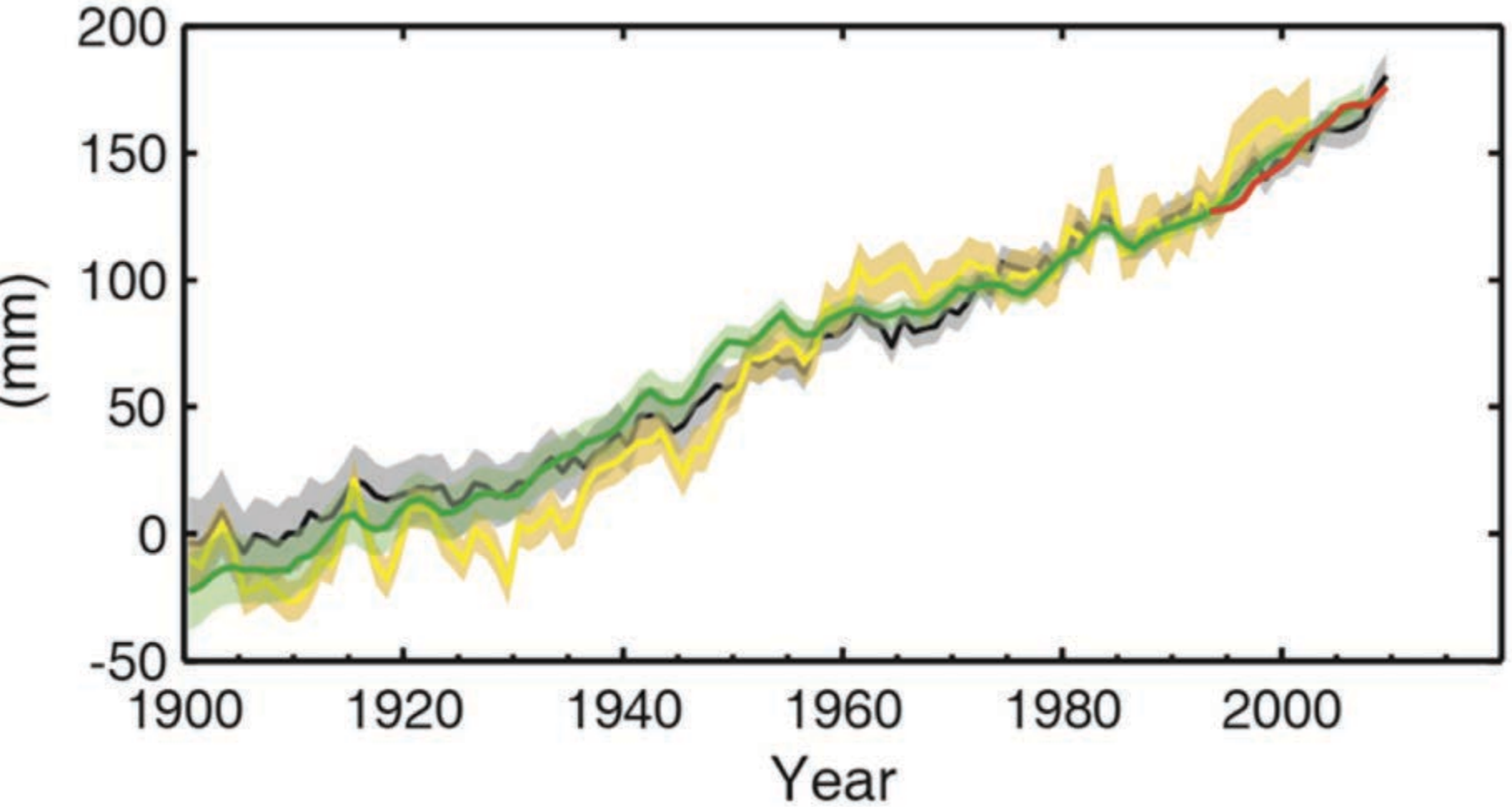
- La température globale augmente (déjà 0.85°C de 1880 à 2012) & augmentera (+0.3 à +4.8°C de ≈1995 à ≈2090; gamme « probable » de l'AR5)
- Des impacts importants sont attendus
- Limiter l'augmentation de température à +2°C (// pré-industriel)
  = réduire les émissions mondiales nettes à ≈0 < 2100!

IPCC AR3 (2001):

Caution: these numbers are based on different scenarios & assumptions



Change in average sea-level change

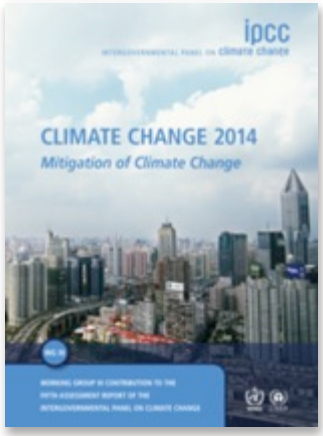


GIEC : Groupe d'experts Intergouvernemental sur l'Evolution du Climat (=IPCC en anglais)

- Créé par l'OMM et le PNUE en 1988 (rés. Nat. Unies 43/53)
- Mandat : évaluer les informations scientifiques, techniques et socio-économiques liées à la compréhension des risques associés aux changements climatiques et aux options de réponse (base scientifique, impacts potentiels, prévention et adaptation)
- Membres : pays membres des Nations Unies et de l'OMM
- Des milliers de scientifiques contribuent aux rapports
  - Principal produit : « rapports d'évaluation » (1990, 1996, 2001, 2007, 2013-14) (Cambridge University Press)
- Web: www.ipcc.ch voir notamment le document«Understanding climate change, 22 years of IPCC assessment », IPCC, Novembre 2010

WG I (Physical science basis): 209 lead authors, 2014 pages, 54.677 review comments

WG II (Impacts, Adaptation and Vulnerability): 243 lead authors, 2000 pages, 50.492 review comments



WG III (Mitigation of Climate Change): 235 coordinating and lead authors, 2000 pages, 38.315 review comments

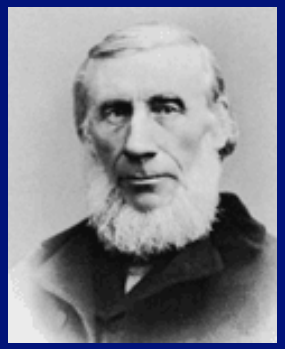
Some recent IPCC Special reports

- Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX, 2012)
- Renewable Energy Sources and Climate Change Mitigation (SRREN, 2011)
- Carbon Dioxide Capture and Storage (2005)
- Safeguarding the Ozone Layer and the Global Climate System (2005)
- Methodological and Technological Issues in Technology Transfer (2000)
- Emissions Scenarios (SRES, 2000)

Discovery of the Greenhouse Effect

Joseph Fourier (1827)

Recognized that gases in the atmosphere might trap the heat received from the Sun.

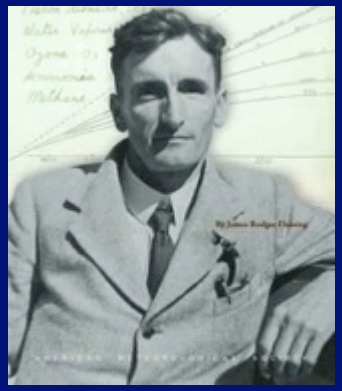


John Tyndall (1859)

Careful laboratory experiments demonstrated that several gases could trap infrared radiation. The most important was simple water vapor. Also effective was carbon dioxide, although in the atmosphere the gas is only a few parts in ten thousand.

Svante Arrhenius (1896)

Performed numerical calculations that suggested that doubling the amount of carbon dioxide in the atmosphere could raise global mean surface temperatures by 5-6°C. (not reliable yet : errors & lack of appropriate data)



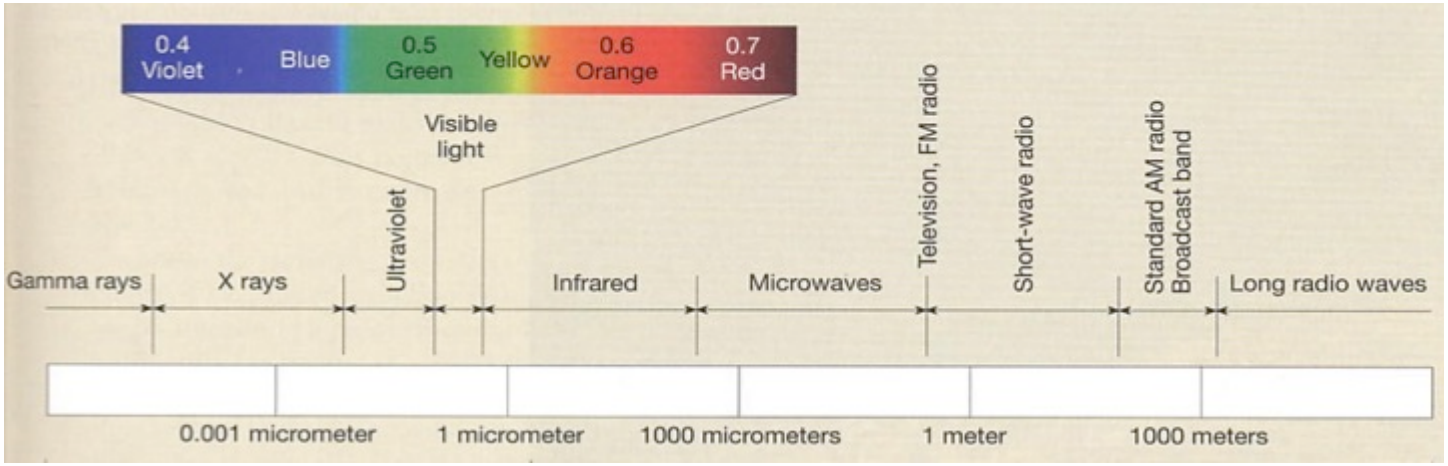
Guy Callendar (1939)

Argued that rising levels of carbon dioxide were responsible for measurable increases in Earth surface temperatures. Estimated that doubling the amount of CO2 in the atmosphere could raise global mean surface temperatures by 2°C.

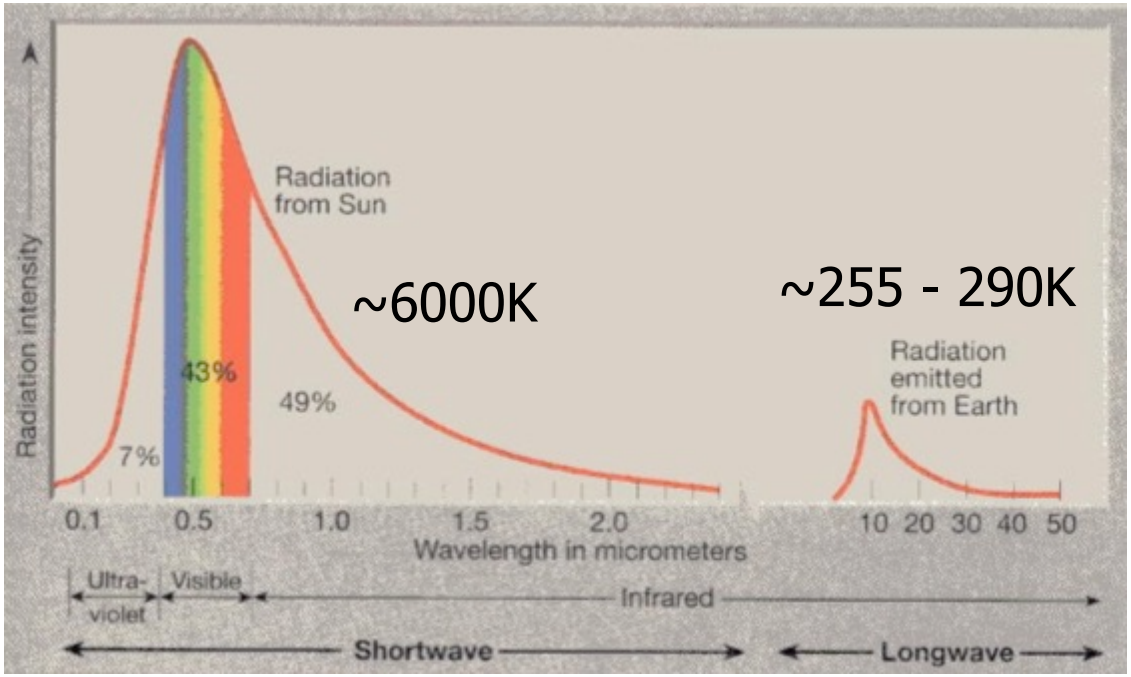
GREENHOUSE EFFECT?

… un peu d'analogie, mais grande différence de principe

Spectre du rayonnement électromagnétique

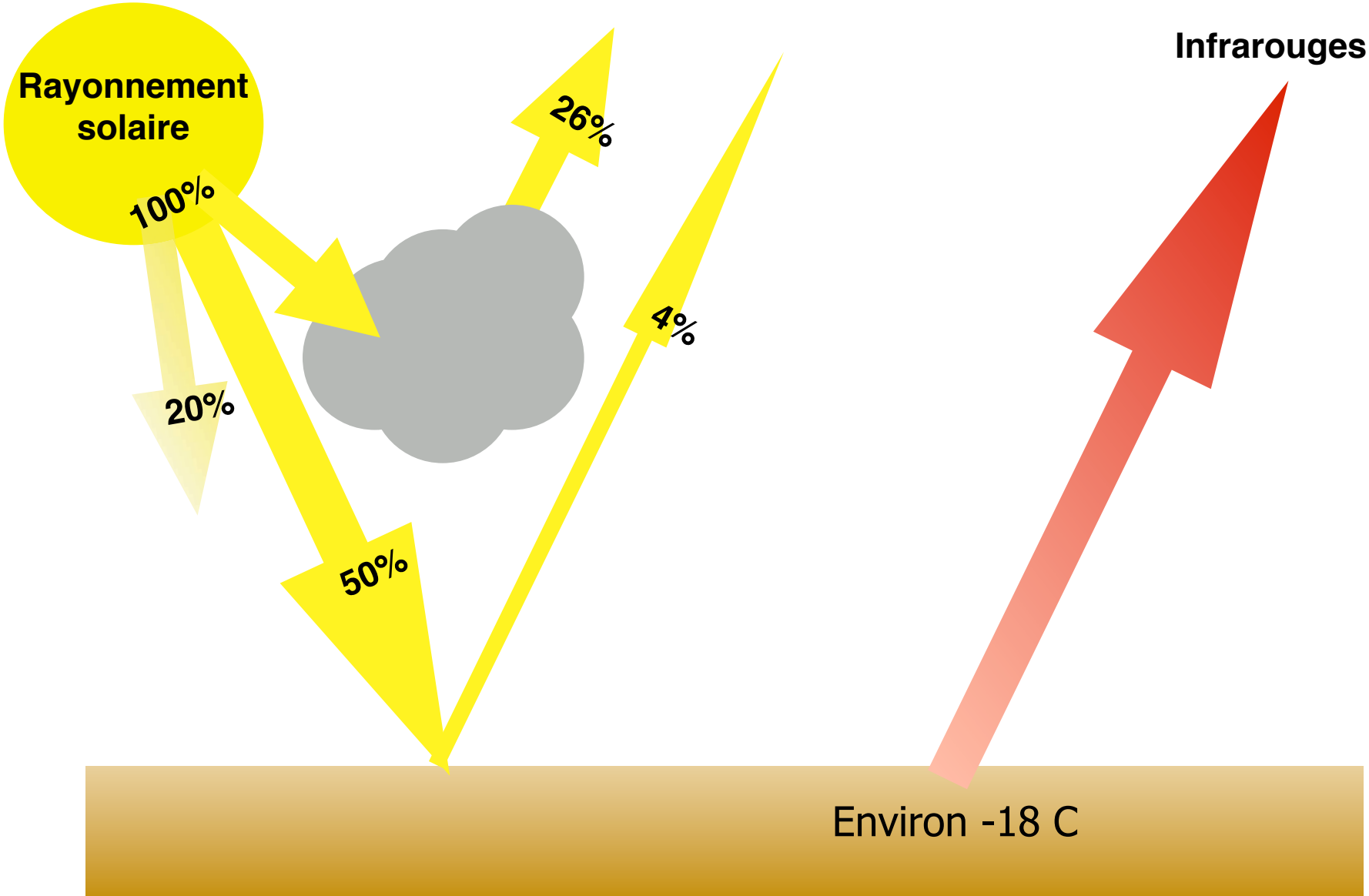


Spectres des rayonnements solaire et terrestre

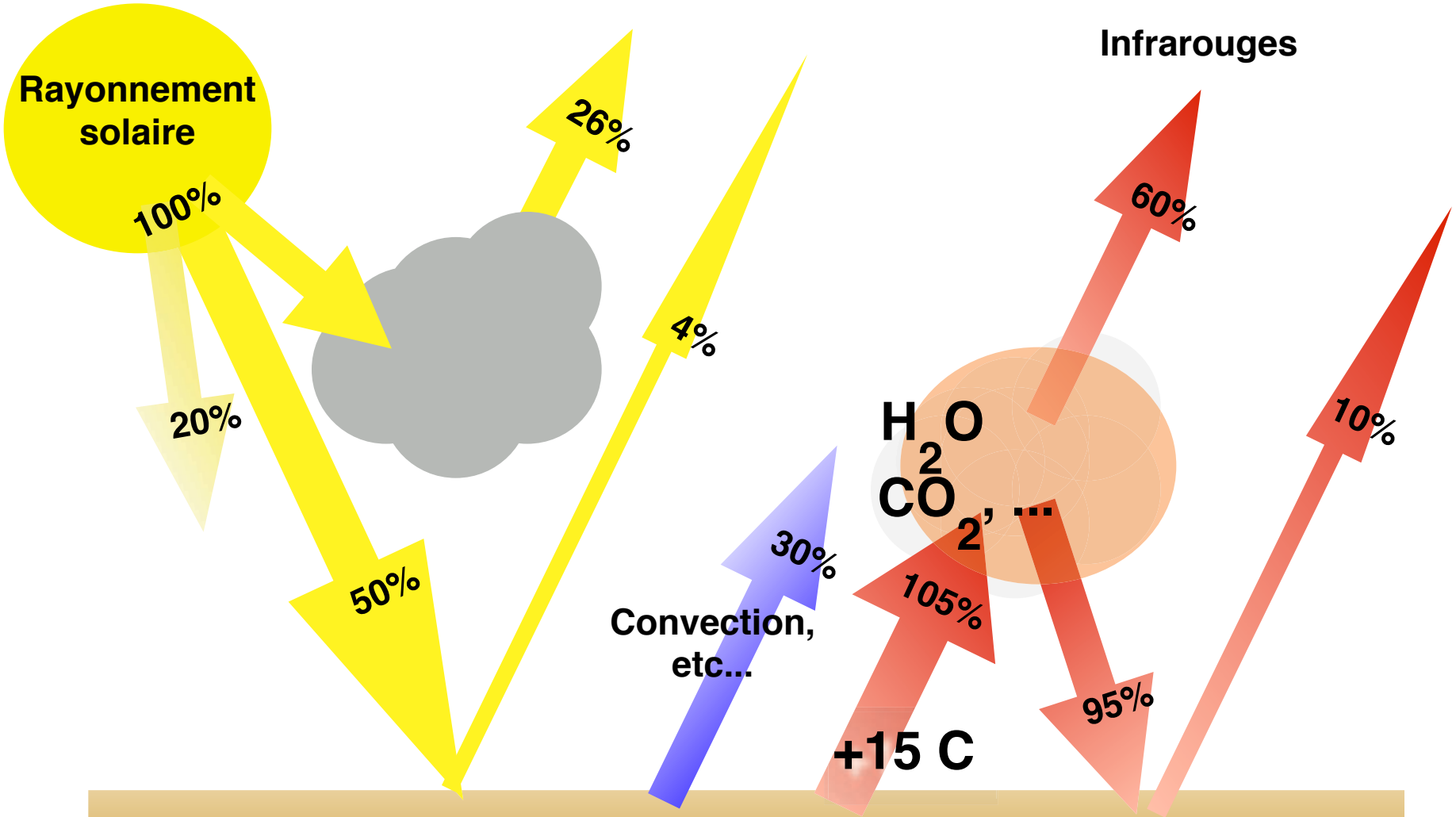


(0°C = +273K)

Energie et effet de serre

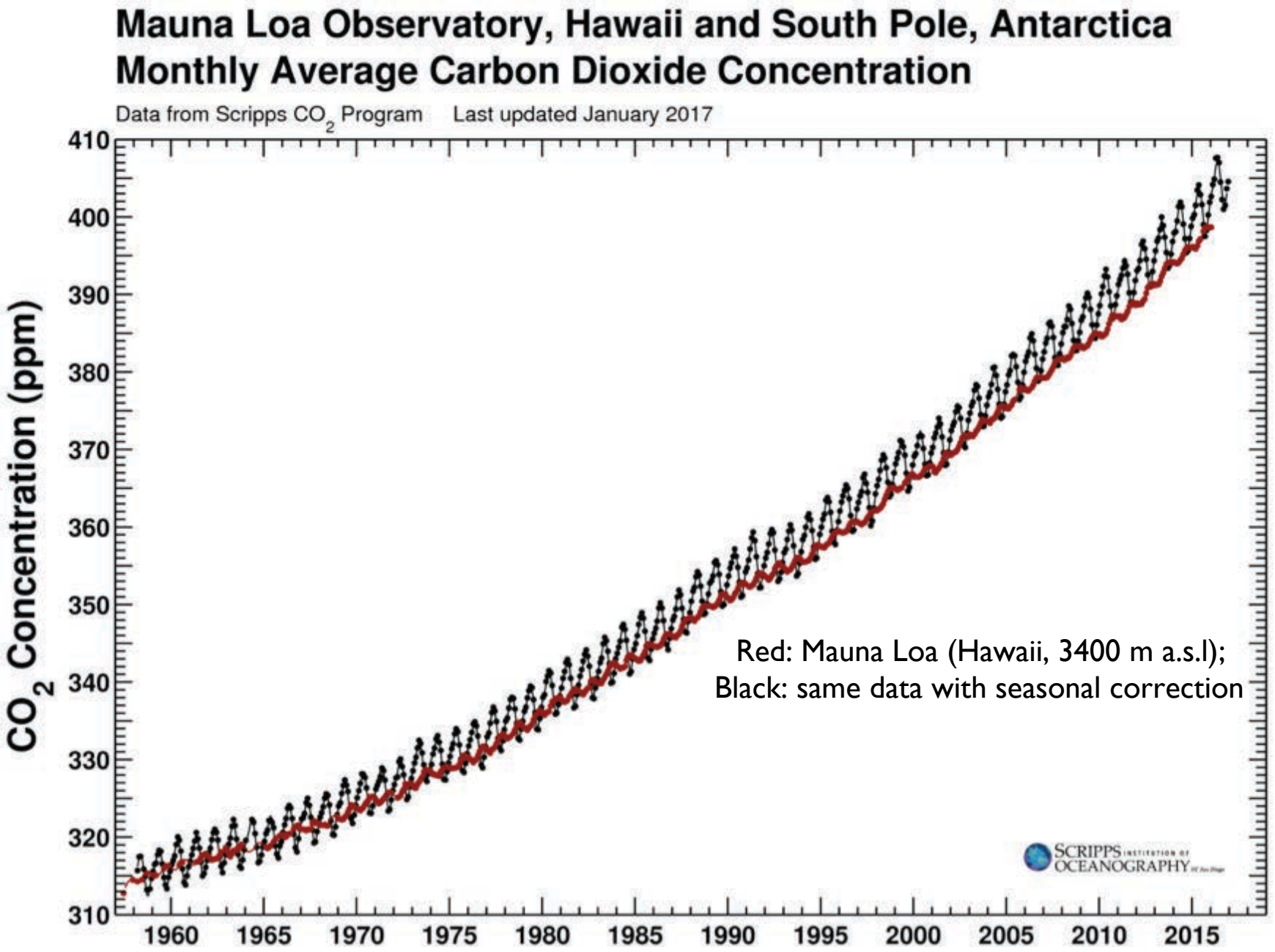


Energie et effet de serre

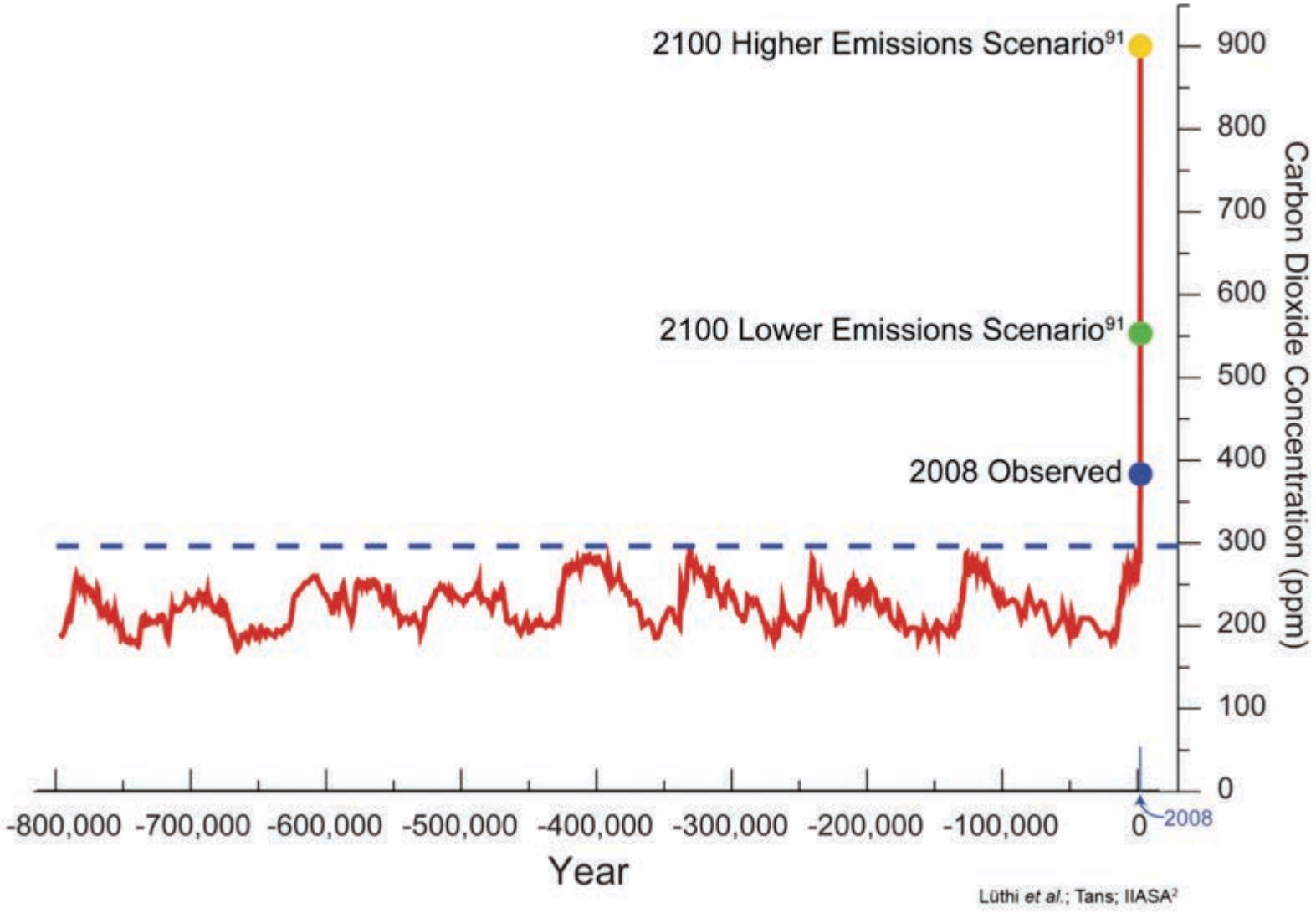


Source : **AR4**

Atmospheric CO_2 concentration

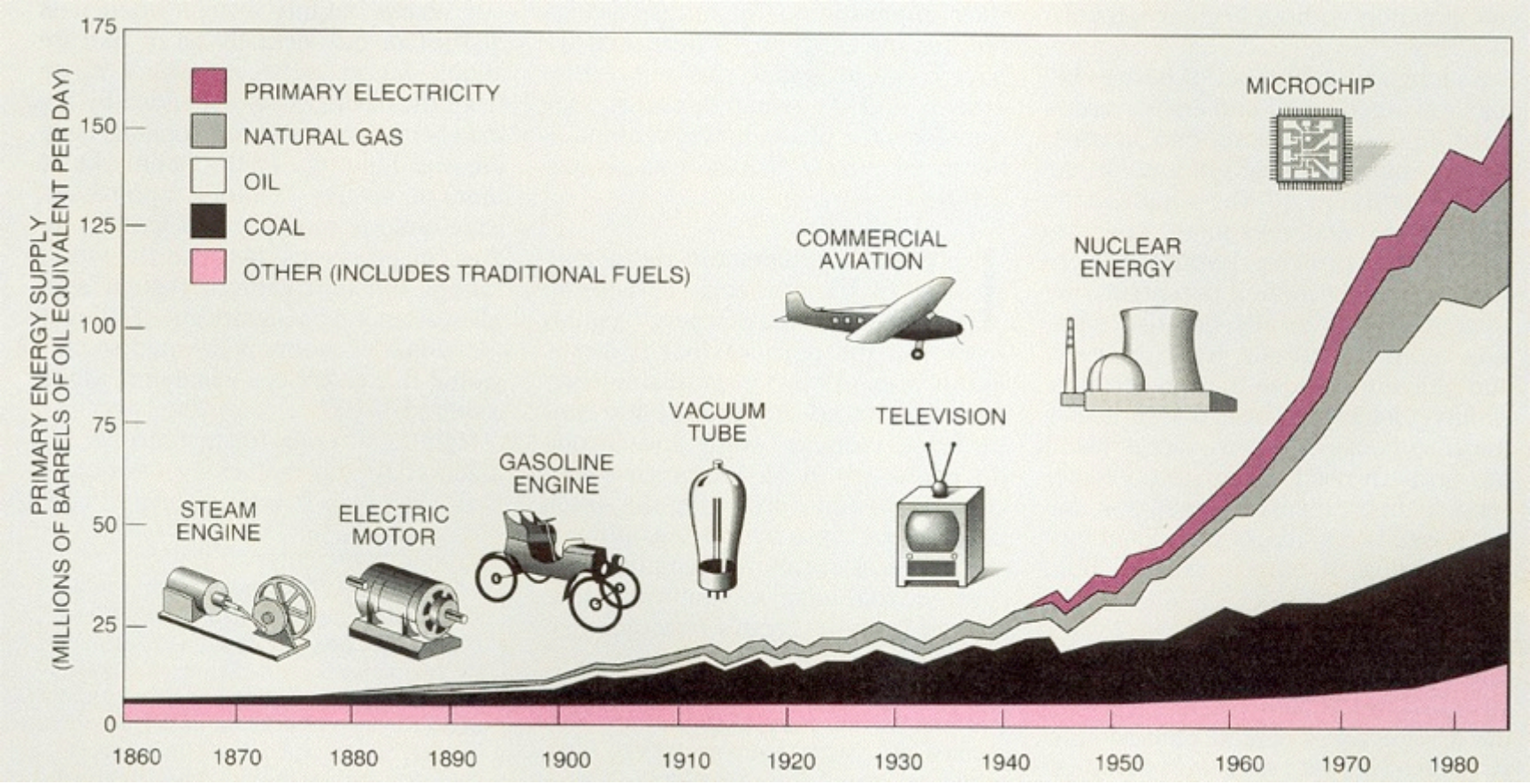


Atmospheric CO_2 over the last 800000 years



U.S. Global Change Research Program:Lüthi *et al.*; Tans; IIASA2

Consommation d'énergie primaire 1860-1990



(analyse + complète dans le cours WGIII)

REPARTITION DES SOURCES D'ENERGIE (E primaire, monde)

2005:

Biomasse : 9%
Hydroélec : 5%
Nucléaire : 5%

Charbon : 25%
Pétrole : 33%
Gaz naturel : 22%

Combustibles fossiles

80%

Autres : < 1%

$$C + O_2 \longrightarrow CO_2 + \text{Chaleur}$$

Source : GIEC 2007, AR4 WGIII table 4.2; valeurs arrondies (dia corrigée 2016)

Quantité de CO_2 émise par unité d'énergie consommée

Combustibles	kg CO_2 / Gigajoule
Charbon	95
Gasoil	74
Essence	69
LPG	63
Gaz naturel	56

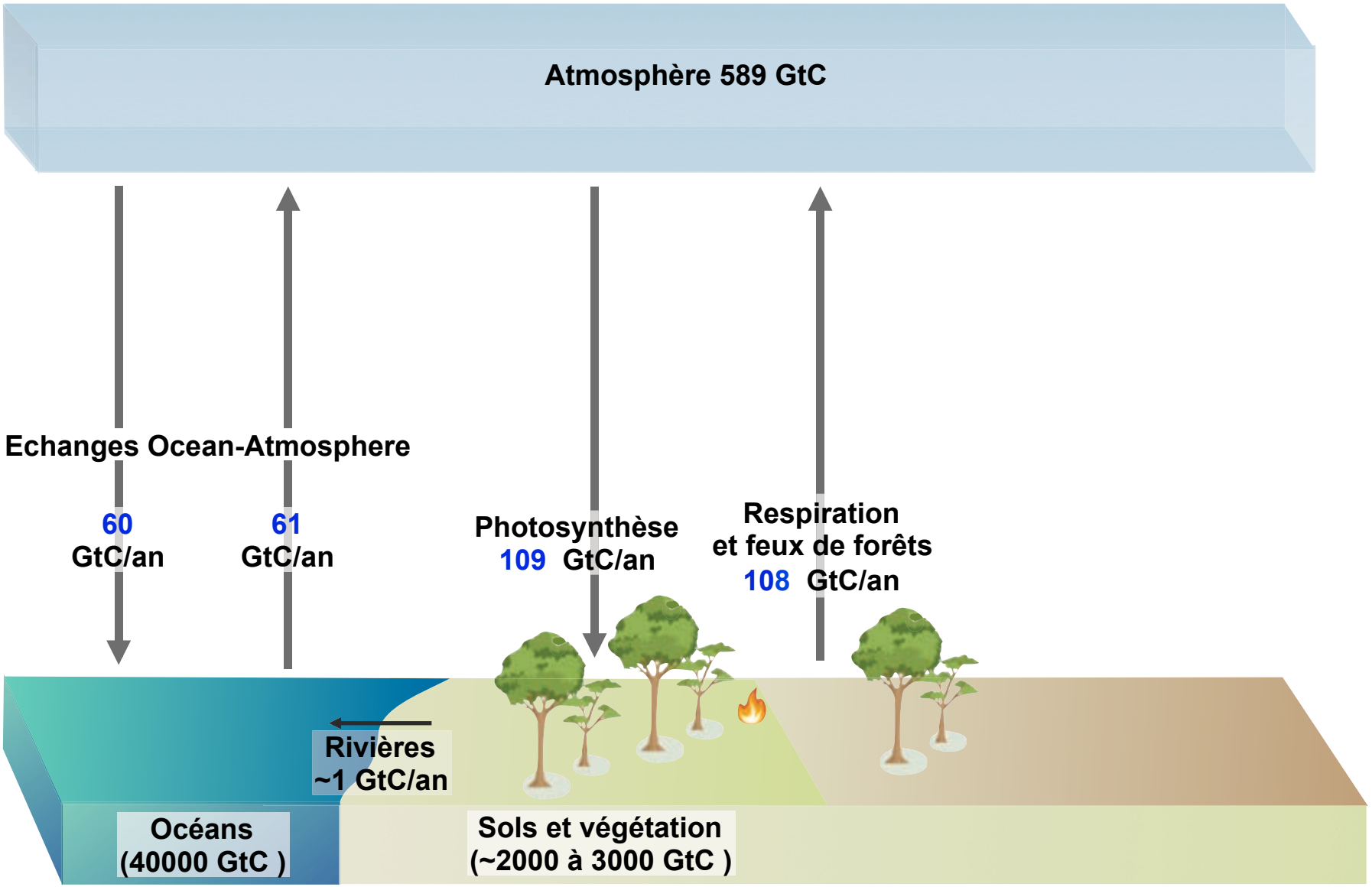
Source : VITO (1991)

Cycle du carbone

Données mises à jour AR5 (2013)

Etat pré-industriel

GtC = milliards de tonnes de carbone
1 GtC = 3,7 milliards de tonnes de CO_2
l'AR5 utilise parfois 1 PgC = 1 GtC

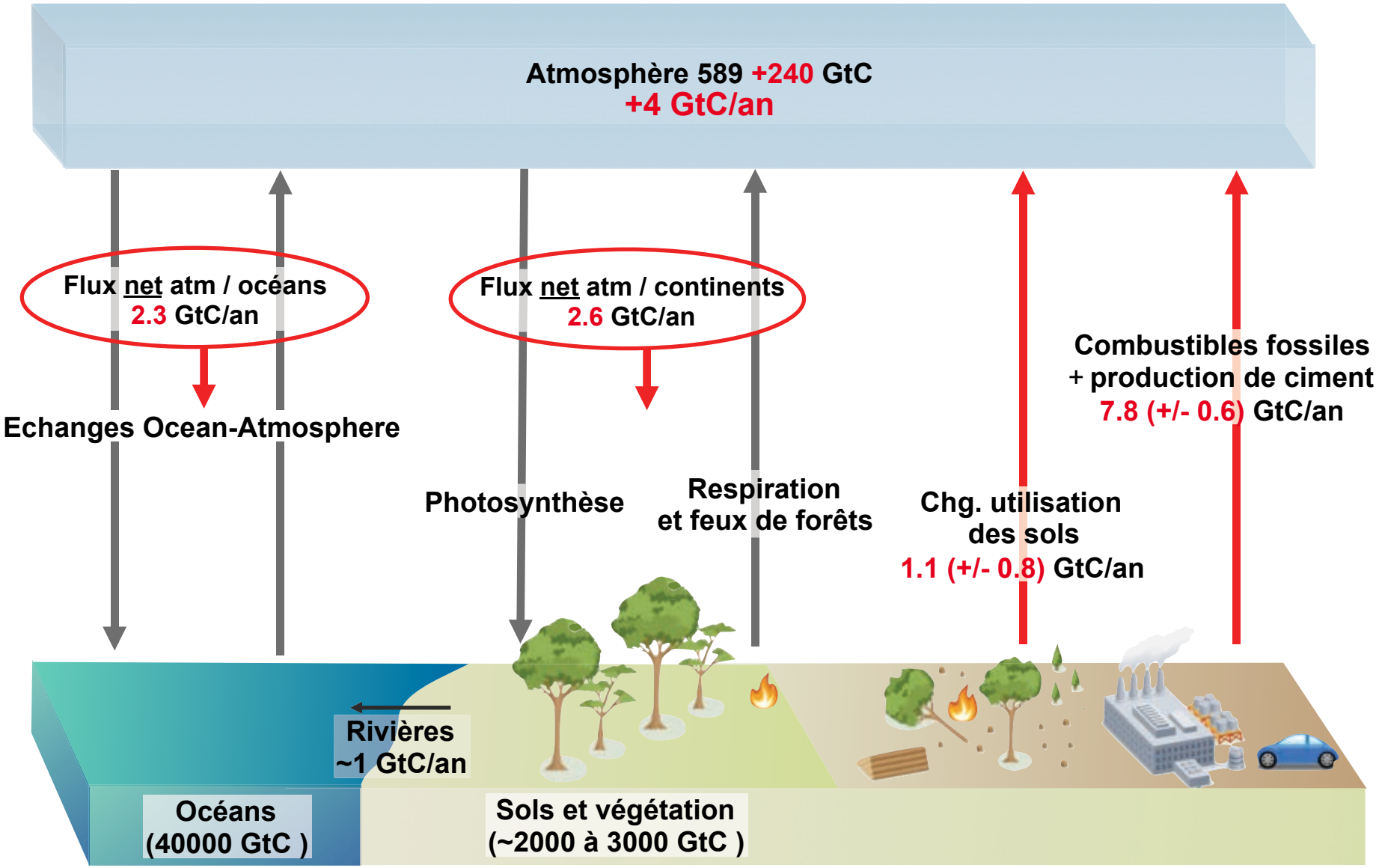


Source : AR5 chapitre 6 (figure 6.2) - adapté / simplifié

Cycle du carbone

Données mises à jour AR5 (2013)

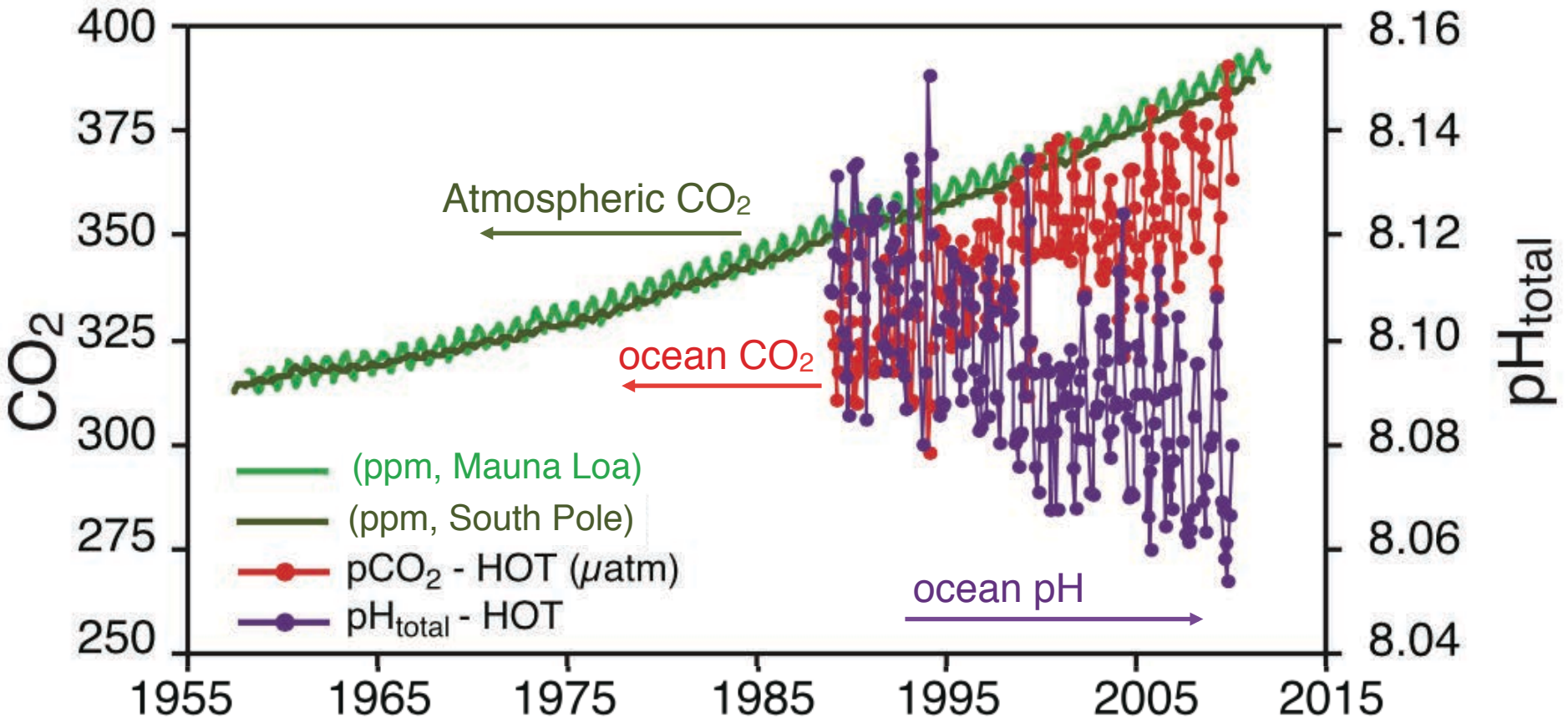
Bleu : pré-industriel
Rouge : influence humaine (années 2000)
GtC = milliards de tonnes de carbone
1 GtC = 3,7 milliards de tonnes de CO_2



Source : AR5 chapitre 6 (figure 6.2) - adapté / simplifié

Atmospheric CO_2 and ocean pH

- Les océans ont absorbé ~40% du CO_2 émis par les activités humaines

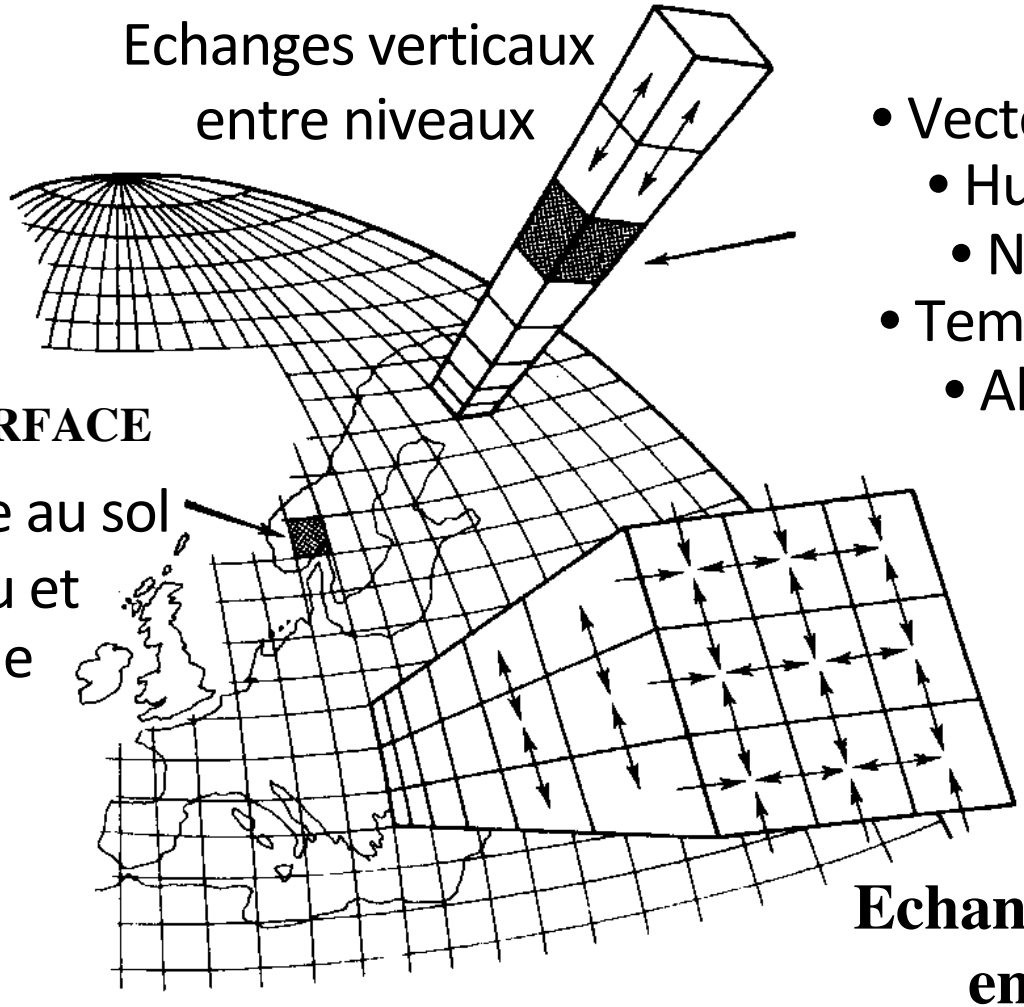


Formation d'acide carbonique $CO_{2(aq)} + H_2O \rightleftarrows H_2CO_3$

Source : IPCC AR5 WGI figure TS.5

Modèles climatiques

DANS LA COLONNE ATMOSPHERIQUE



Echanges verticaux entre niveaux

- Vecteurs vent
- Humidité
- Nuages
- Température
- Altitude

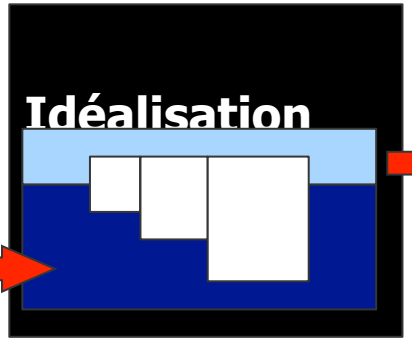
A LA SURFACE

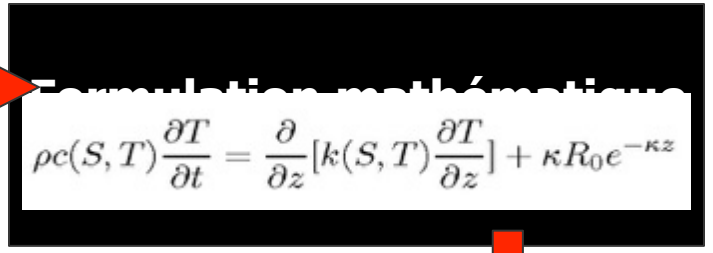
- Température au sol
- Flux d'eau et d'énergie

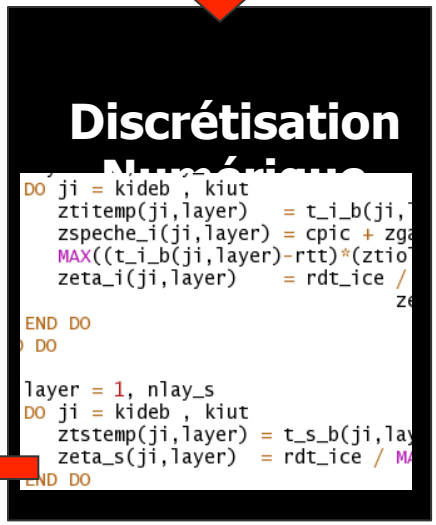
Echanges horizontaux entre colonnes

Résolution typique ~ 2°x 2°(modèle global, atmosphère)
Intervalle de temps typique : ≤ 30 minutes

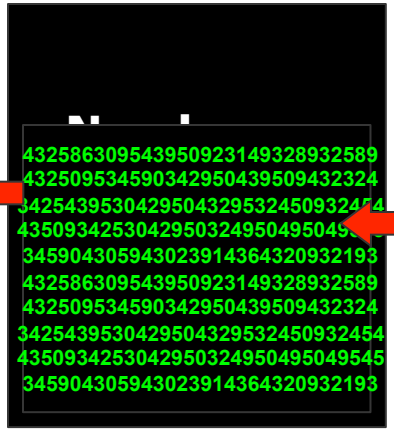
Aperçu de principe de la modélisation

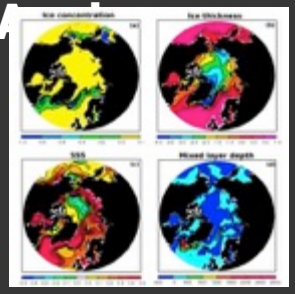






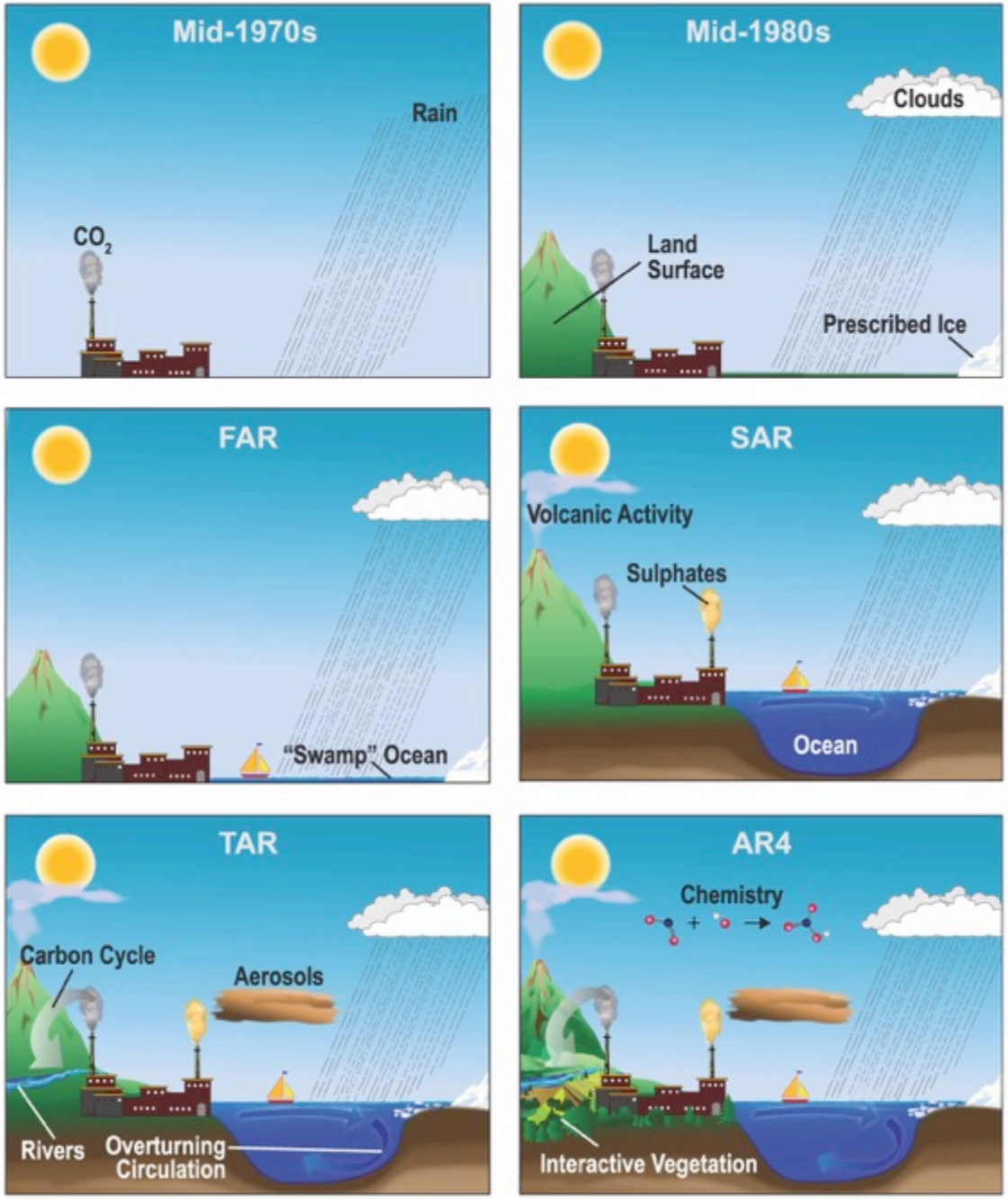
1) Validation
2) Sensibilité





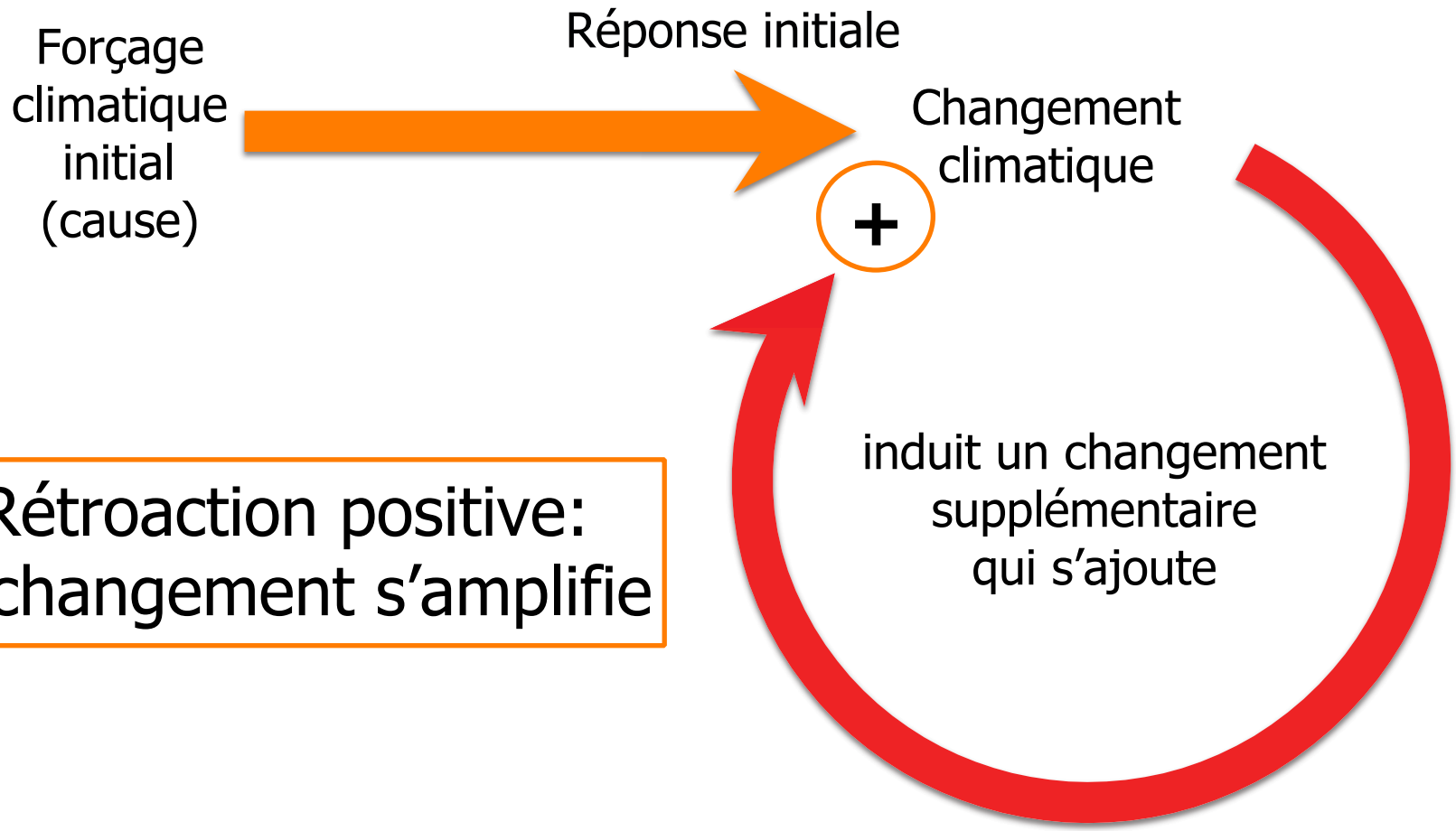
Martin Van Coppenolle (UCL)

The World in Global Climate Models



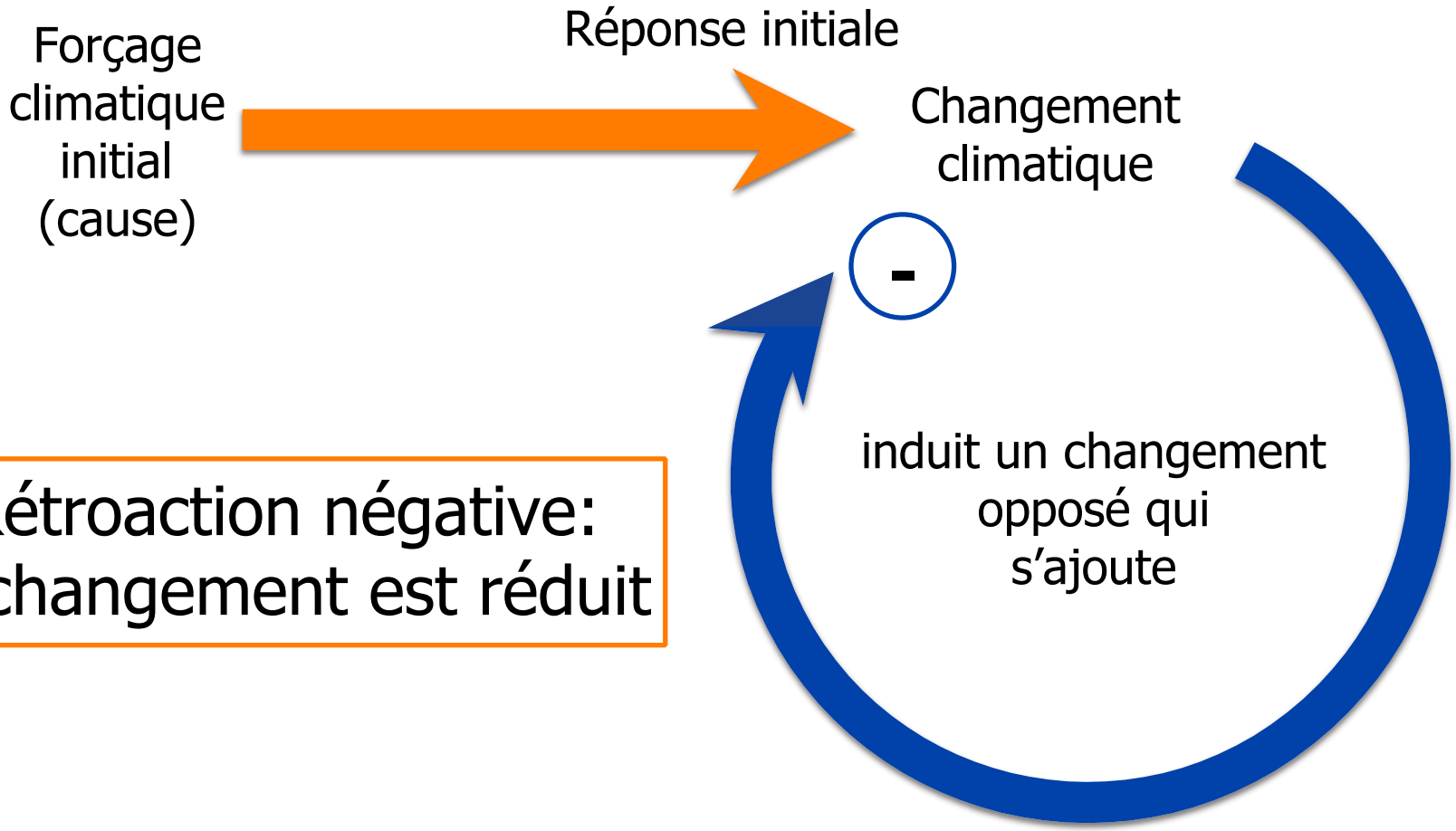
IPCC, AR4, WGI, Fig. 1.2

Rétroactions (Feedbacks) : principe



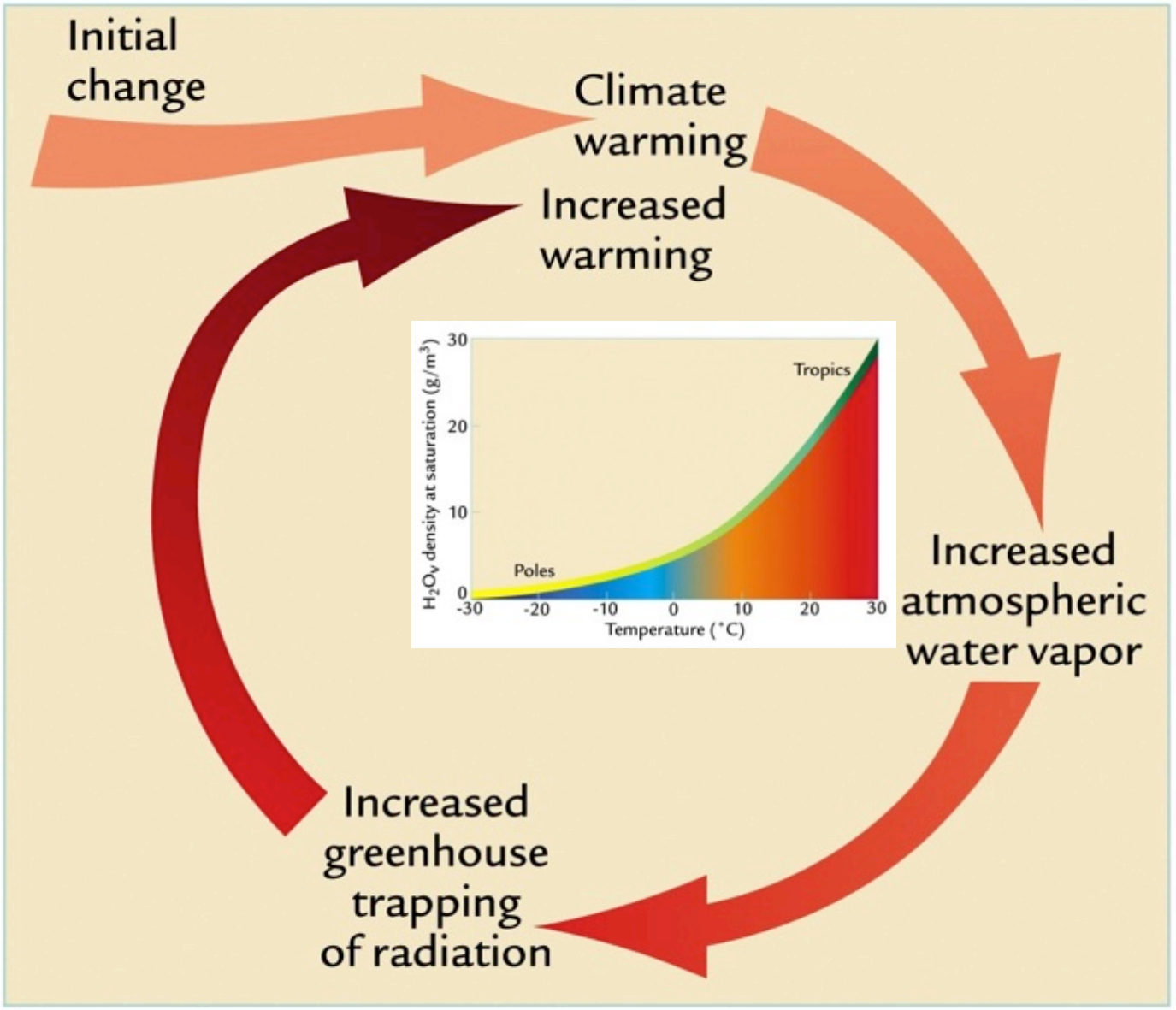
Rétroaction positive:
le changement s'amplifie

Rétroactions (Feedbacks) : principe

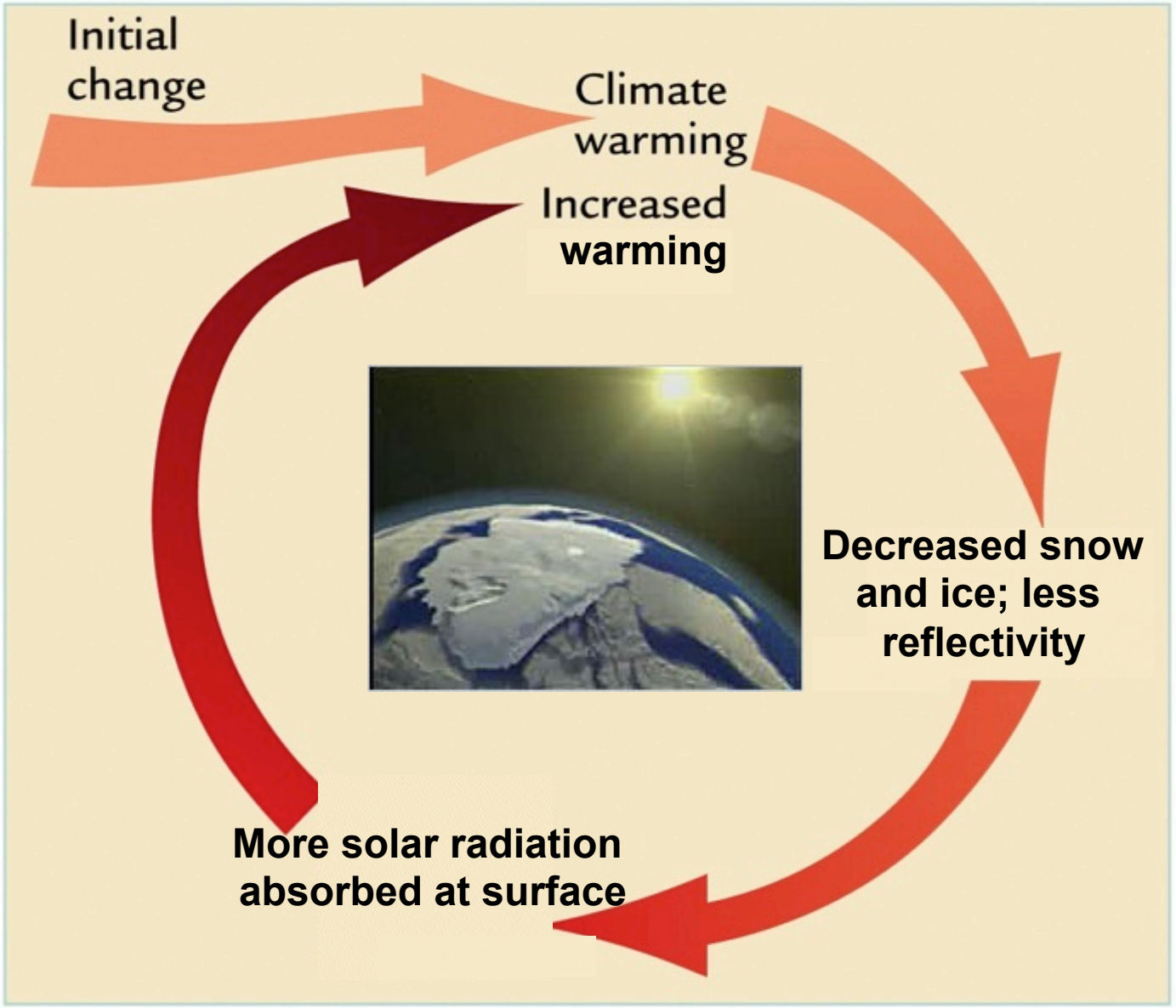


Rétroaction négative:
le changement est réduit

Water Vapor Feedback

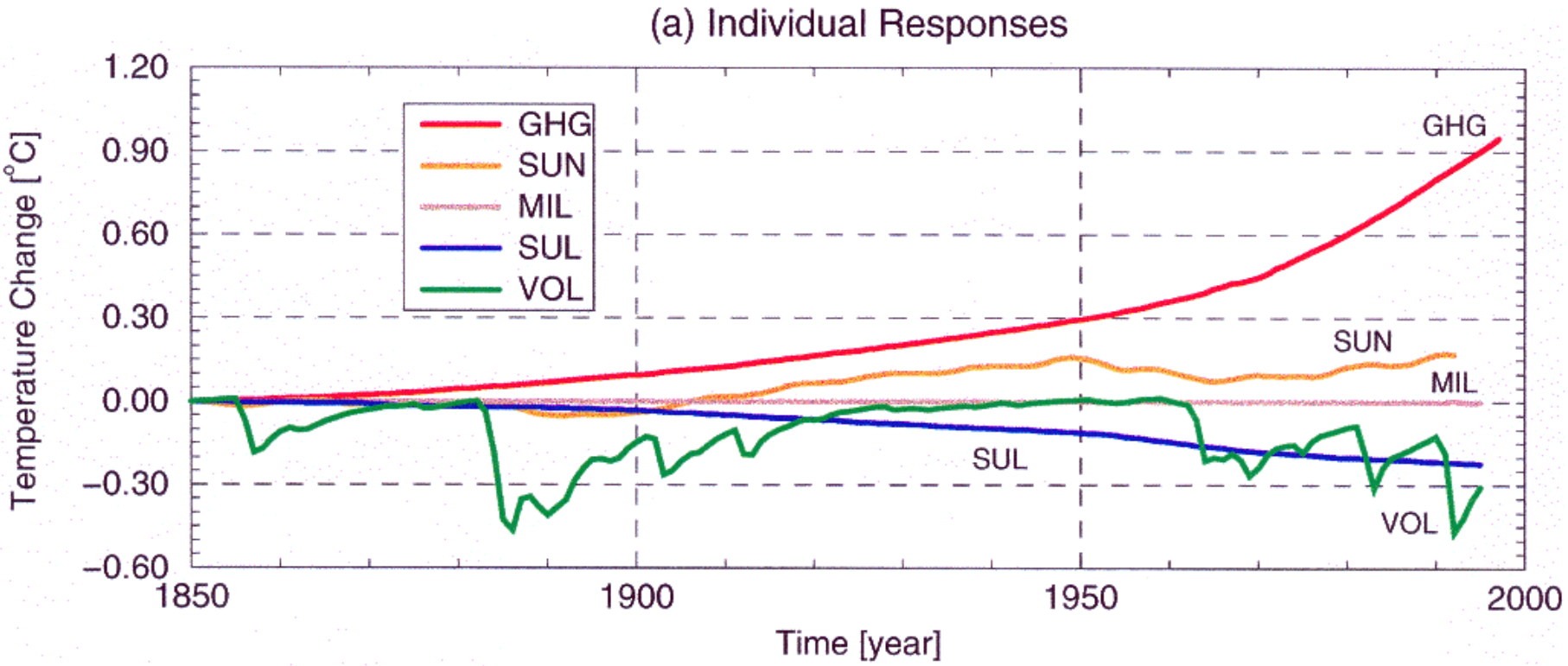


Ice-Albedo Feedback



Note : il y a d'autres rétroactions, dont l'échange d'énergie air/océan facilité si pas de glace

Effet des différents facteurs sur le modèle 2D de LLN



Bertrand et al. 2001

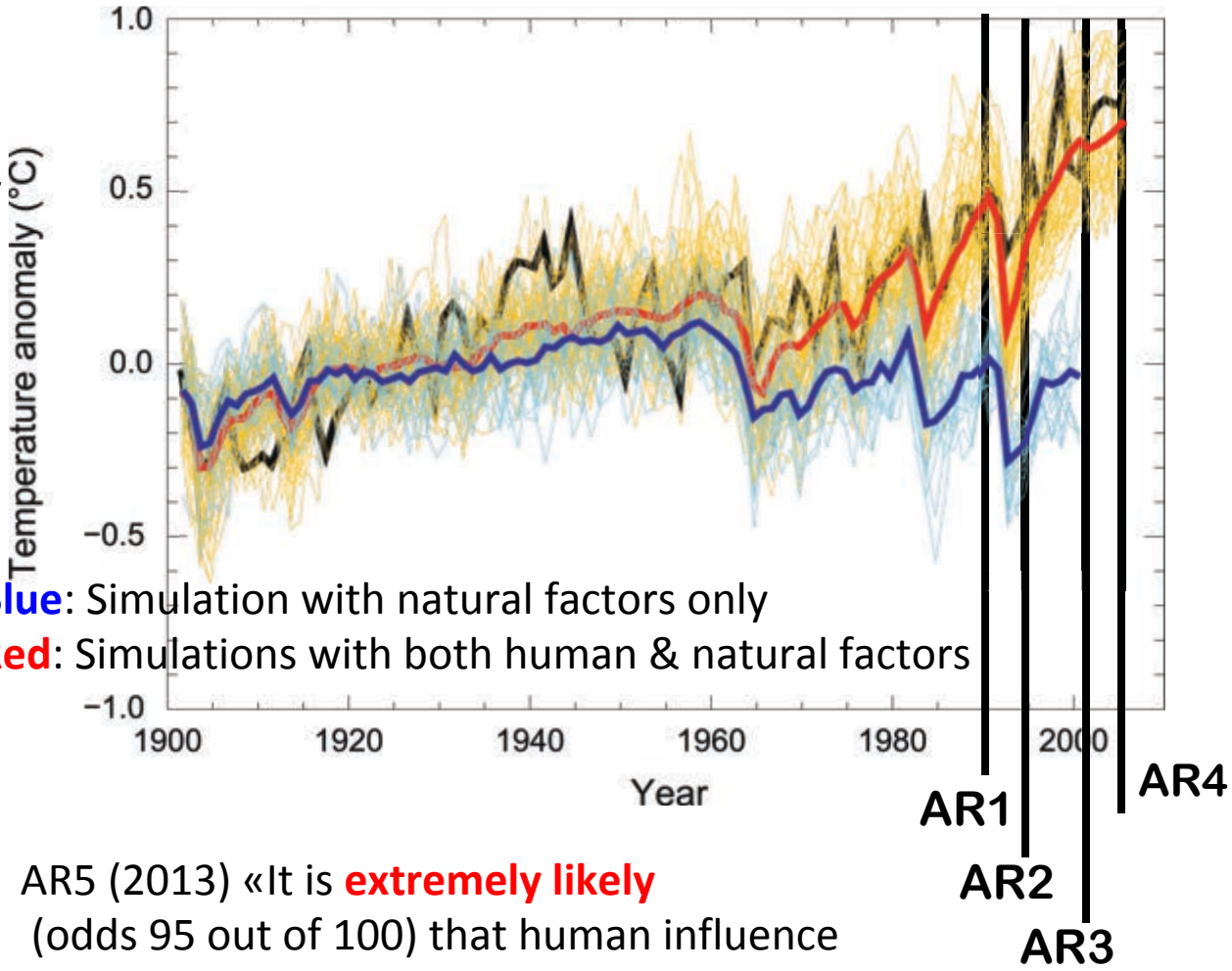
A Progression of Understanding: Greater and Greater Certainty in Attribution

AR1 (1990): "unequivocal detection not likely for a decade"

AR2 (1995): "balance of evidence suggests **discernible** human influence"

AR3 (2001): "most of the warming of the past 50 years is **likely** (odds 2 out of 3) due to human activities"

AR4 (2007): "most of the warming is **very likely** (odds 9 out of 10) due to greenhouse gases"



AR5 (2013) «It is **extremely likely** (odds 95 out of 100) that human influence has been the dominant cause… »

Que disaient les modèles climatiques, il y a presque 40 ans ?

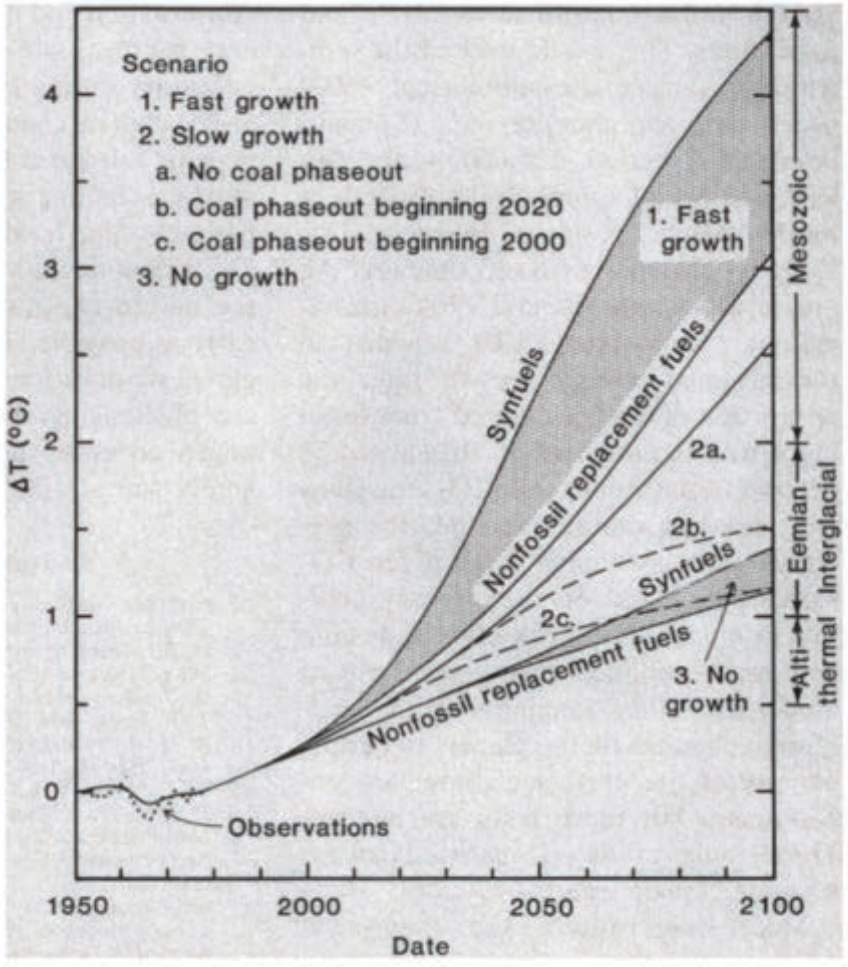
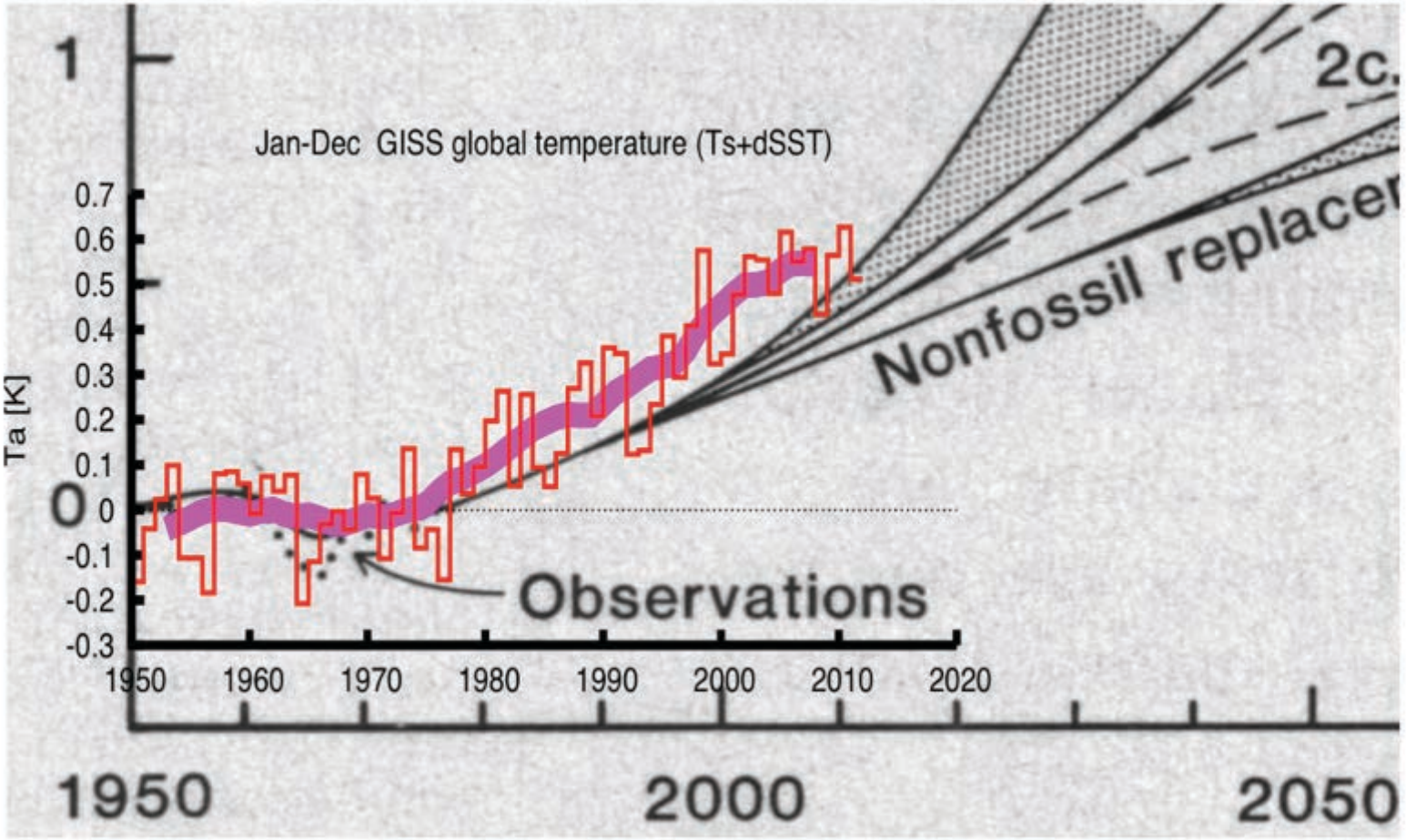


Fig. 6. Projections of global temperature. The diffusion coefficient beneath the ocean mixed layer is 1.2 cm^2 sec^{-1}, as required for best fit of the model and observations for the period 1880 to 1978. Estimated global mean warming in earlier warm periods is indicated on the right.

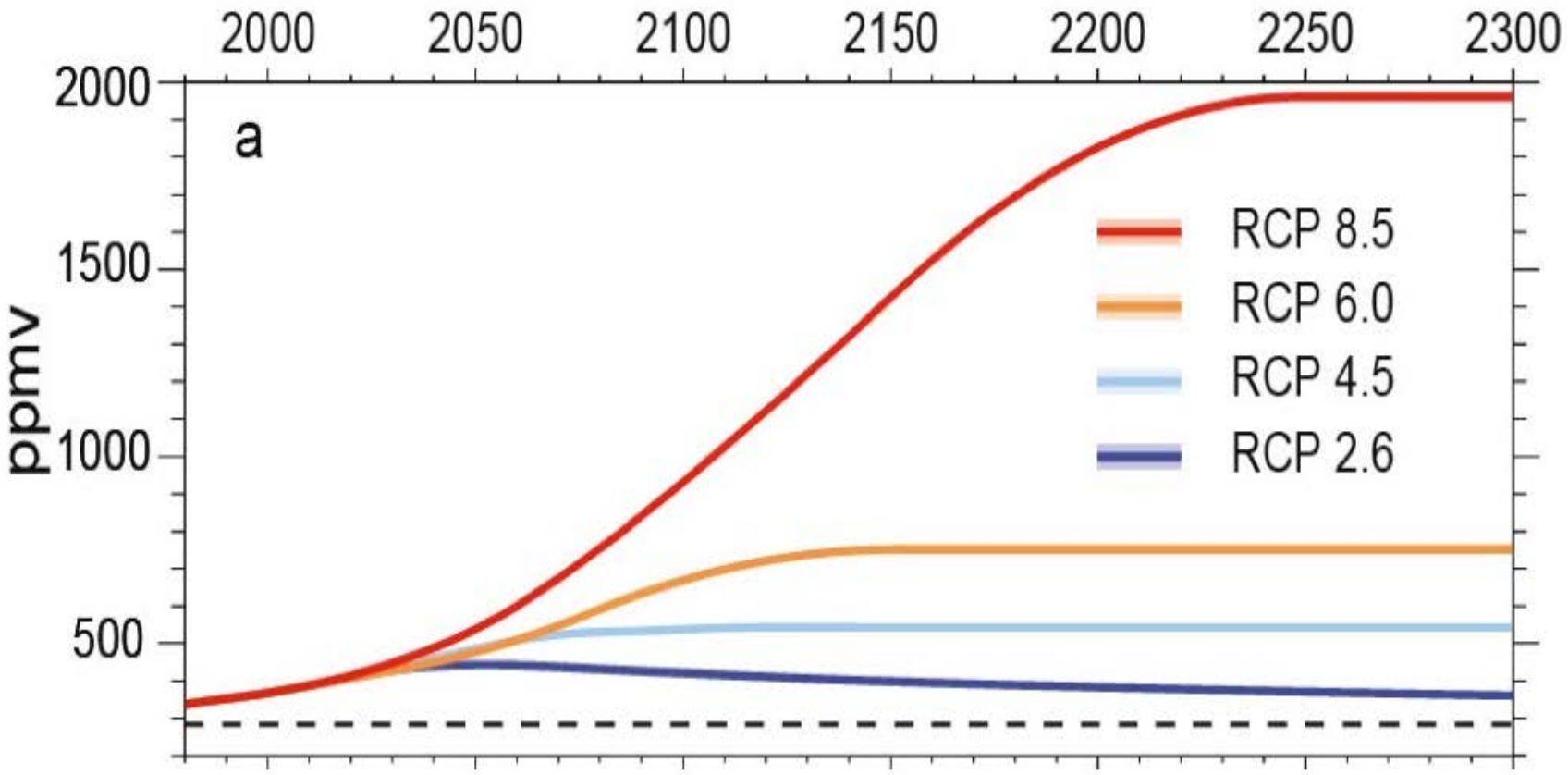
Hansen et al. (1981, Science)

Les résultats des modèles sont proches de la réalité



Hansen et al. (1981, Science), observations ajoutées par www.realclimate.org

AR5 RCP: Atmospheric CO_2 concentration

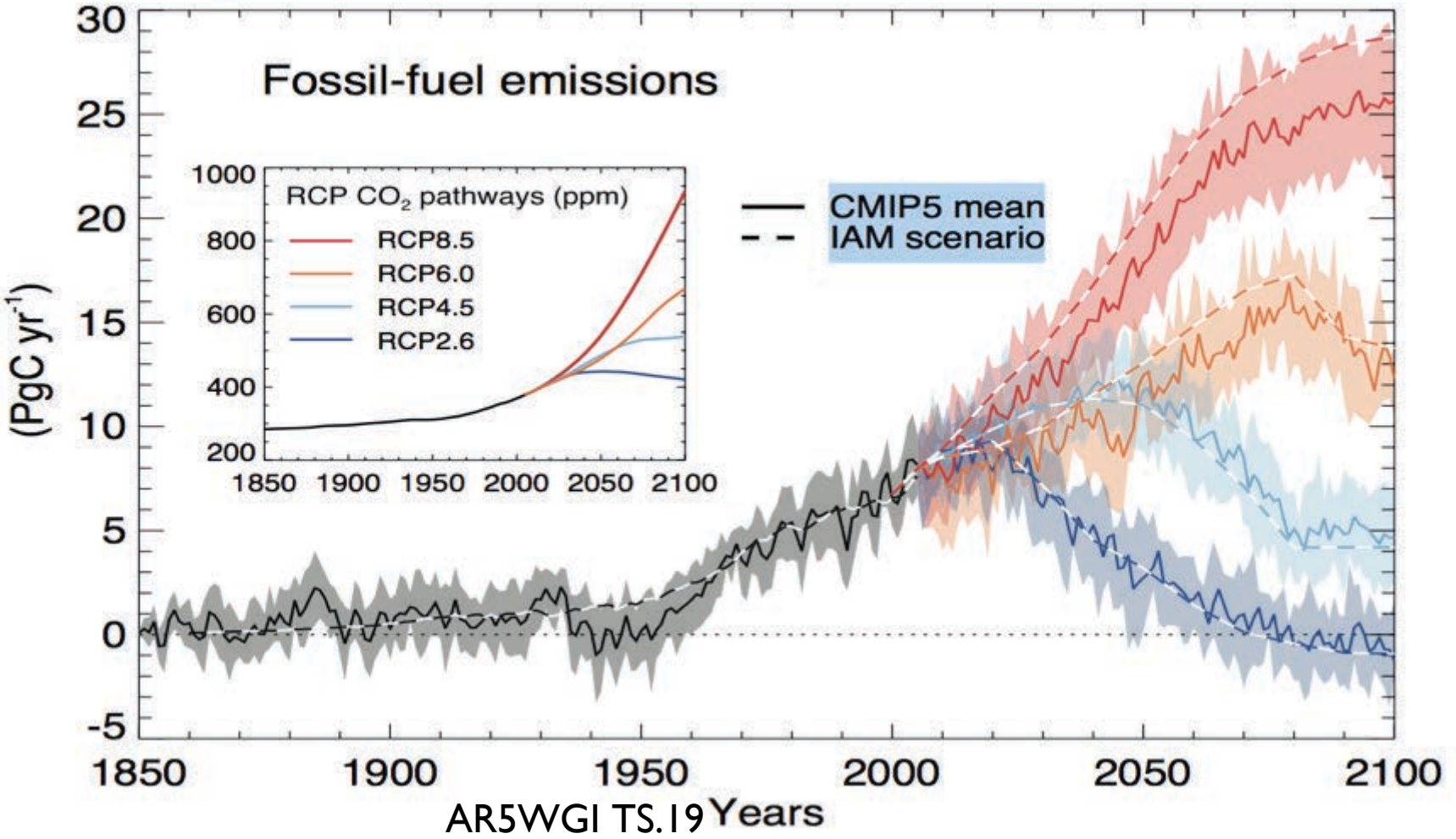


Most CMIP5 runs are based on the concentrations, but emissions-driven runs are available for RCP 8.5

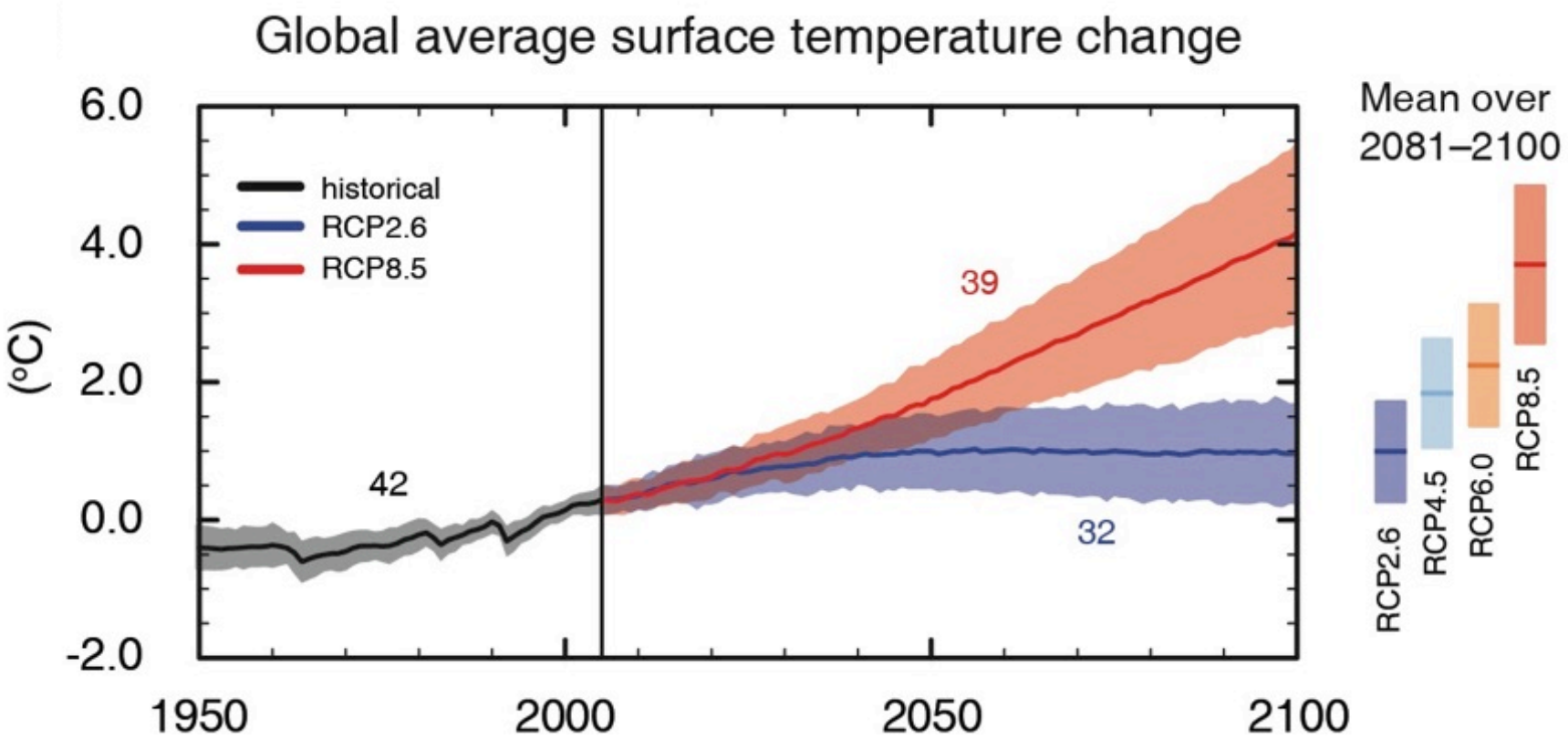
Note : « emission-driven » -> knowledge of C-cycle uncertainty

Compatible fossil fuel emissions simulated by the CMIP5 models for the four RCP scenarios (détail)

Les traits pleins donnent les émissions qu'il faudrait mettre dans les modèles climatiques complexes pour obtenir la concentration de chaque RCP,
en comparaison des émissions associées à chaque RCP par les modèles simples



Réchauffement moyen – scén. RCP, 21s



(IPCC 2013, Fig. SPM.7a)

Global mean surface temperature change projections

Increase over 21st century, from 1986-2005 to 2081-2100

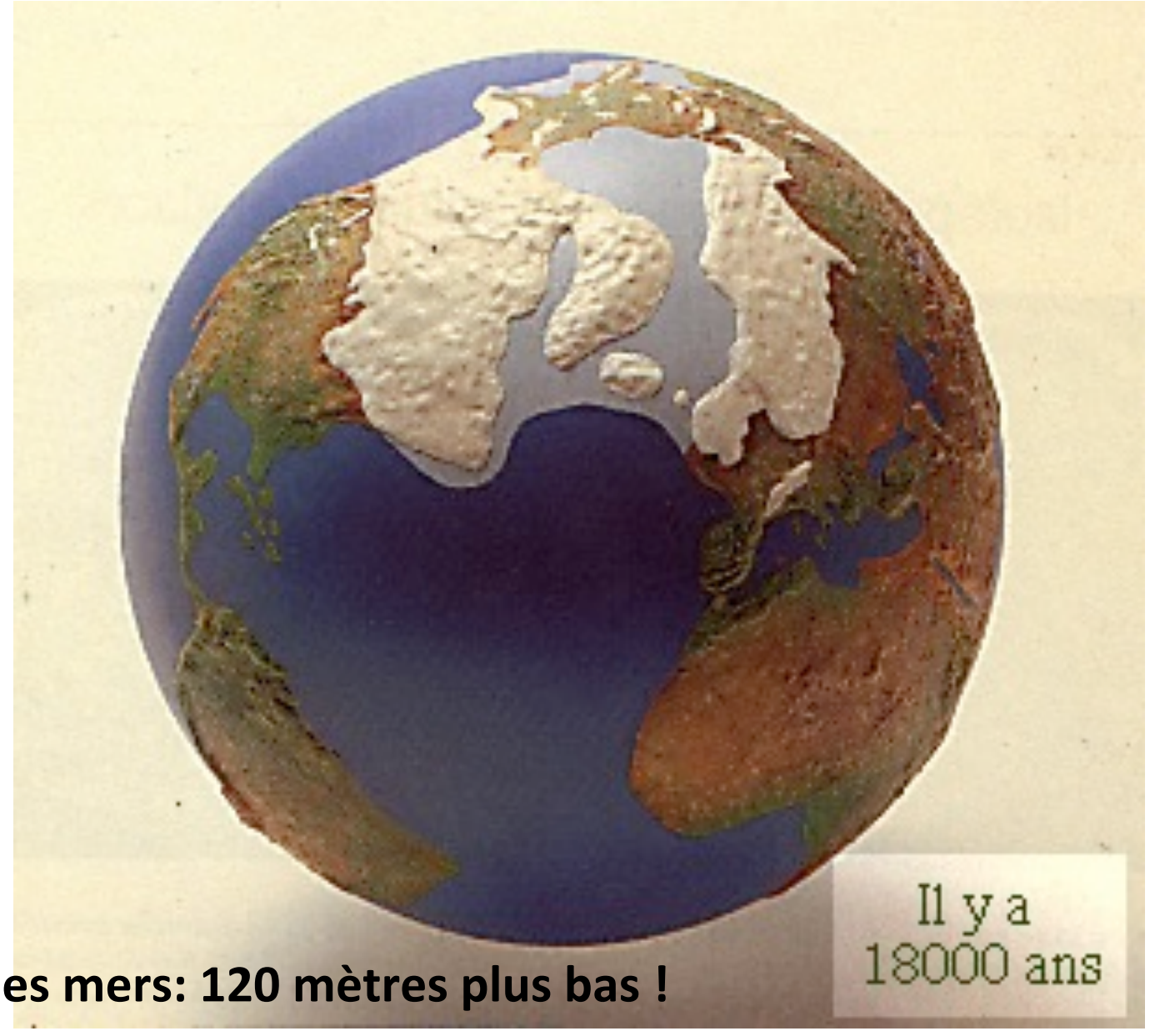
	mean	likely range
RCP2.6	1.0 (°C)	0.3 to 1.7 (°C)
RCP4.5	1.8	1.1 to 2.6
RCP6	2.2	1.4 to 3.1
RCP8.5	3.7	2.6 to 4.8

For 1850-1900 reference : add +0.61 [0.55 to 0.67] °C

Source : AR5 WGI SPM. Note : résultats de modèles très proches AR4

Il y a 18-20000 ans (Dernier Maximum Glaciaire)

With permission from Dr. S. Joussaume, in « Climat d'hier à demain », CNRS éditions.

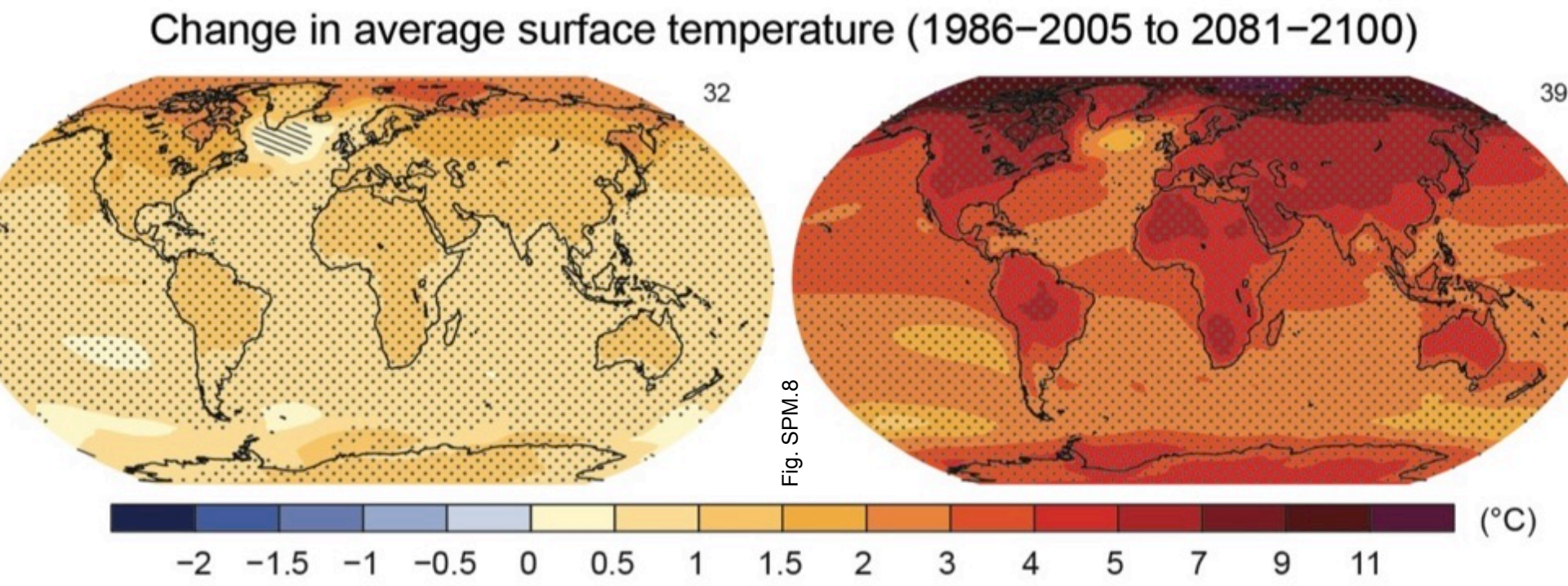


Niveau des mers: 120 mètres plus bas !

Aujourd’hui, avec +4 à 5°C en moyenne globale

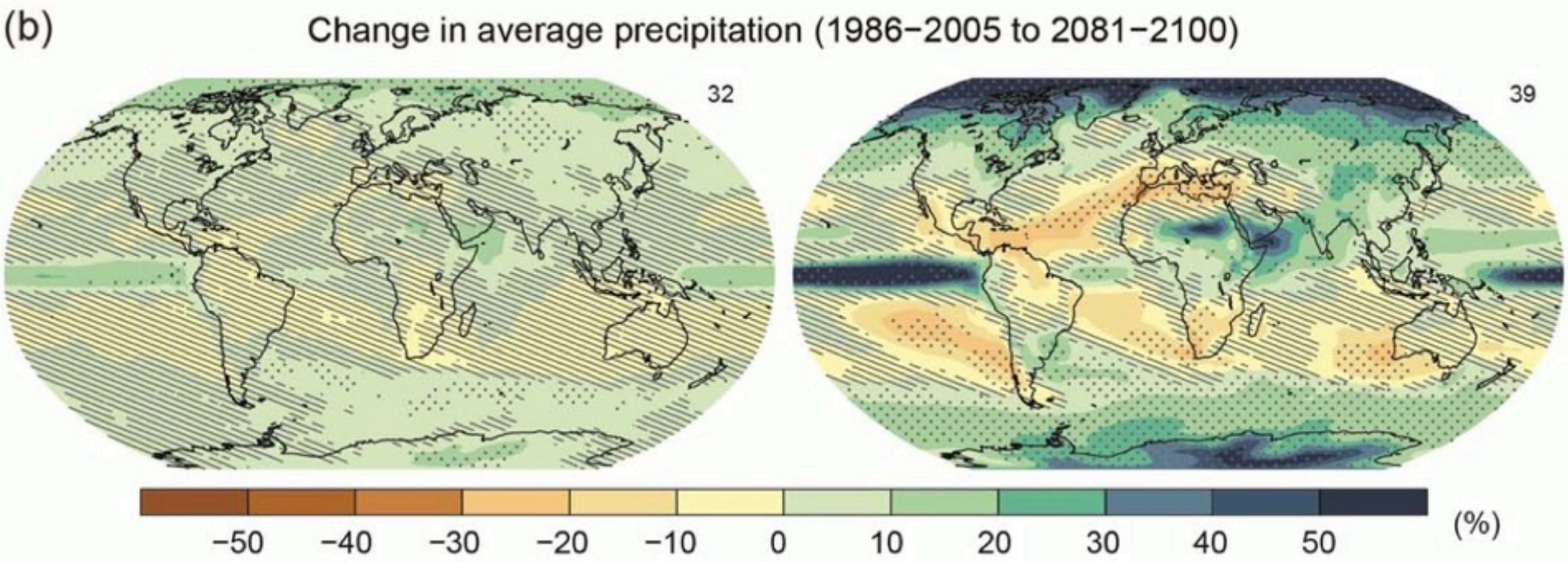
With permission from Dr. S. Joussaume, in « Climat d’hier à demain », CNRS éditions.

RCP2.6 RCP8.5



Hatching [hachures] indicates regions where the multi-model mean is small compared to natural internal variability (i.e., less than one standard deviation of natural internal variability in 20-year means).
Stippling [pointillés] indicates regions where the multi-model mean is large compared to natural internal variability (i.e., greater than two standard deviations of natural internal variability in 20-year means) and where at least 90% of models agree on the sign of change

Projected Change in Precipitation



Hatching indicates regions where *the multi-model mean is small compared to natural internal variability* (i.e., less than one standard deviation of natural internal variability in 20-year means). **Stippling** indicates regions where the multi-model mean is large compared to natural internal variability (i.e., greater than two standard deviations of natural internal variability in 20-year means) and where at least 90% of models agree on the sign of change

Extreme weather and climate events

Phenomenon and direction of trend	Assessment that changes occurred (typically since 1950 unless otherwise indicated)	Assessment of a human contribution to observed changes	Likelihood of further changes	
			Early 21st century	Late 21st century
Warmer and/or fewer cold days and nights over most land areas	*Very likely*	***Very likely***	*Likely*	***Virtually certain***
Warmer and/or more frequent hot days and nights over most land areas	*Very likely*	***Very likely***	*Likely*	***Virtually certain***
Warm spells/heat waves. Frequency and/or duration increases over most land areas	***Medium confidence*** on a global scale Likely in large parts of Europe, Asia and Australia	***Likely***	Not formally assessed	***Very likely***
Heavy precipitation events. Increase in the frequency, intensity, and/or amount of heavy precipitation	*Likely more land areas with increases than decreases*	***Medium confidence***	*Likely* over many land areas	***Very likely*** over most of the mid-latitude land masses and over wet tropical regions
Increases in intensity and/or duration of drought	***Low confidence*** on a global scale Likely changes in some regions	***Low confidence***	*Low confidence*	***Likely*** *(medium confidence)* on a regional to global scale
Increases in intense tropical cyclone activity	***Low confidence*** in long term (centennial) changes Virtually certain in North Atlantic since 1970	***Low confidence***	*Low confidence*	***More likely than not*** in the Western North Pacific and North Atlantic
Increased incidence and/or magnitude of extreme high sea level	*Likely* (since 1970)	***Likely***	*Likely*	***Very likely***

IPCC, AR5, Table SPM.1

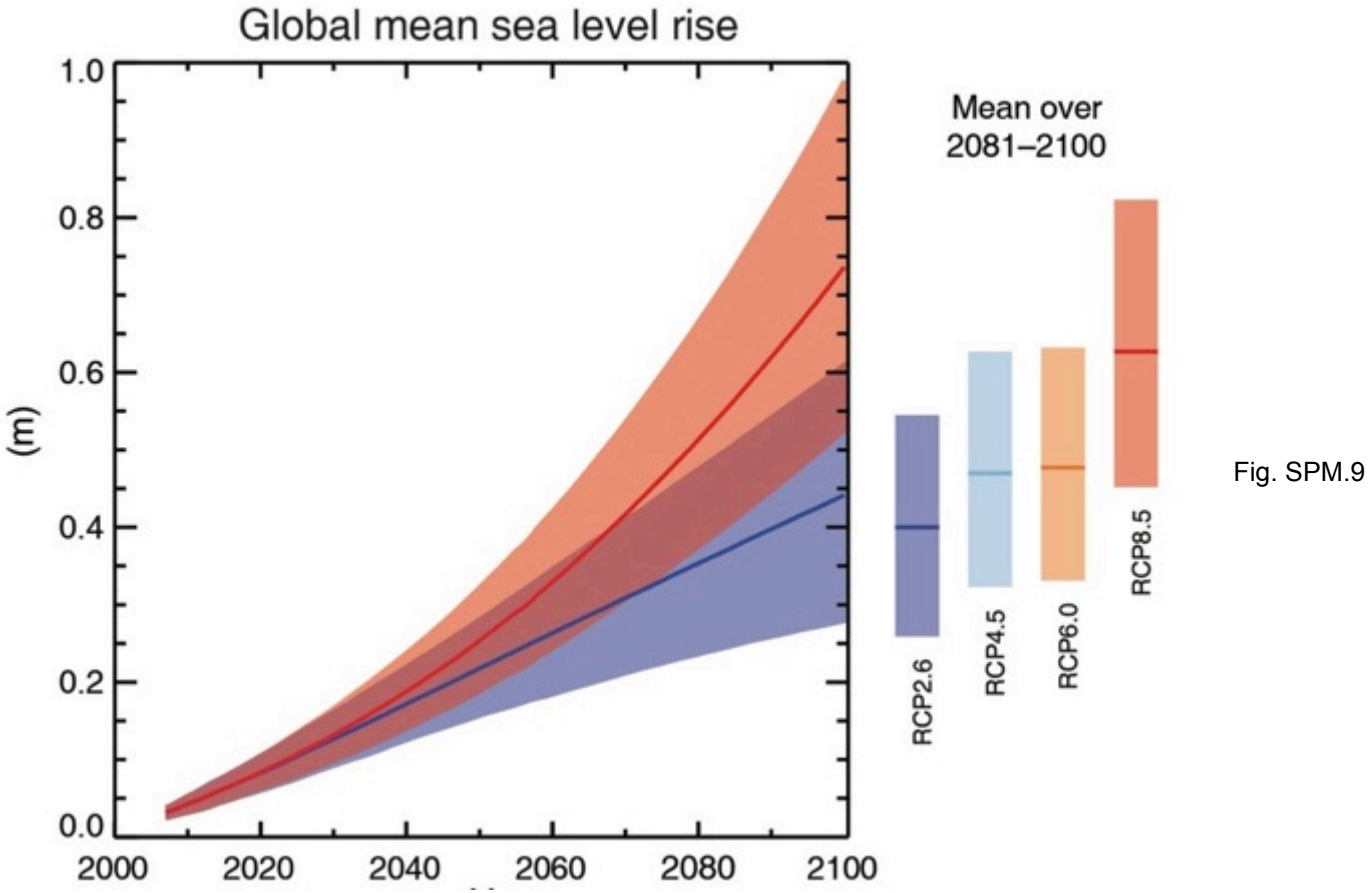
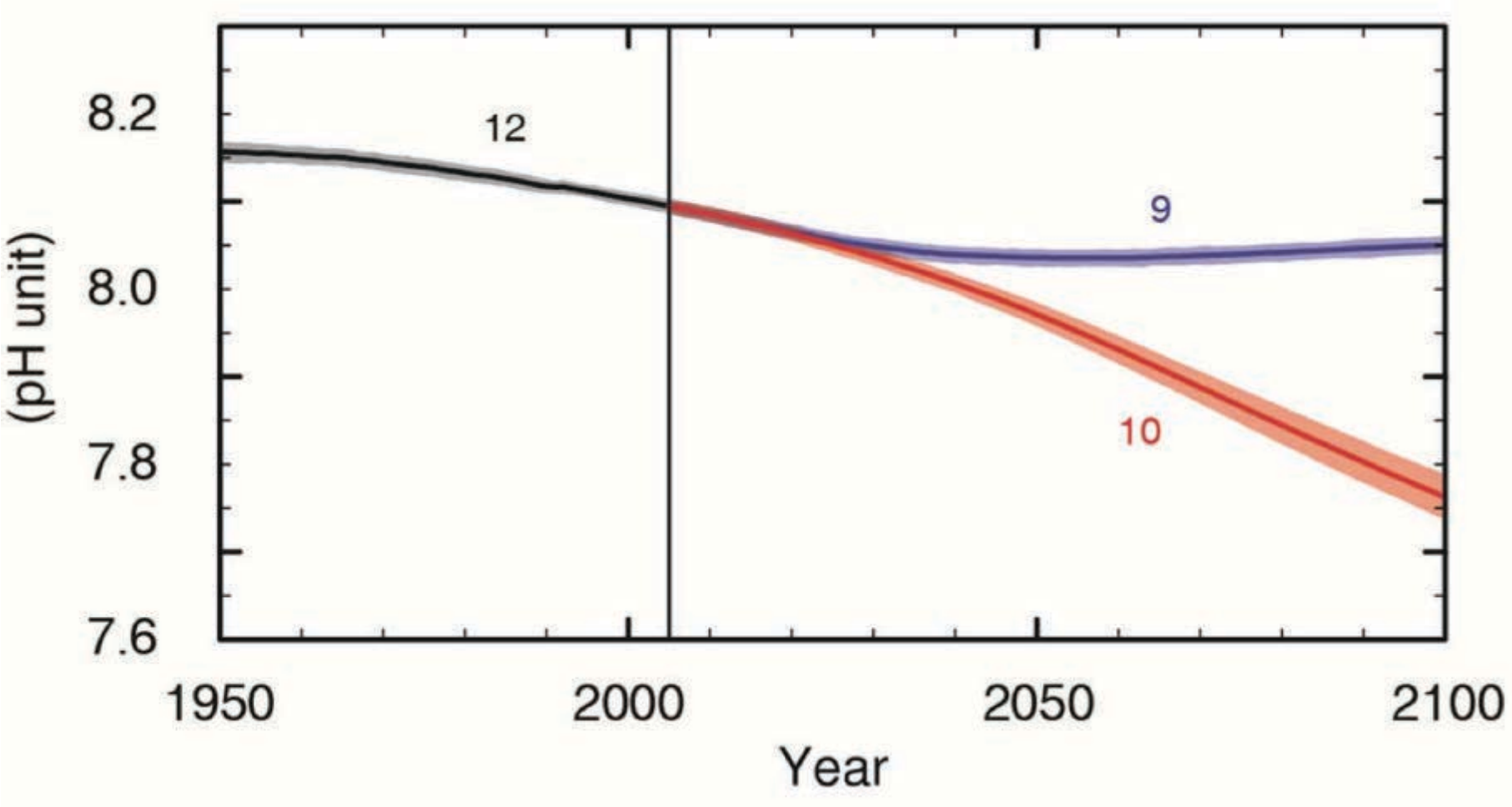


Fig. SPM.9

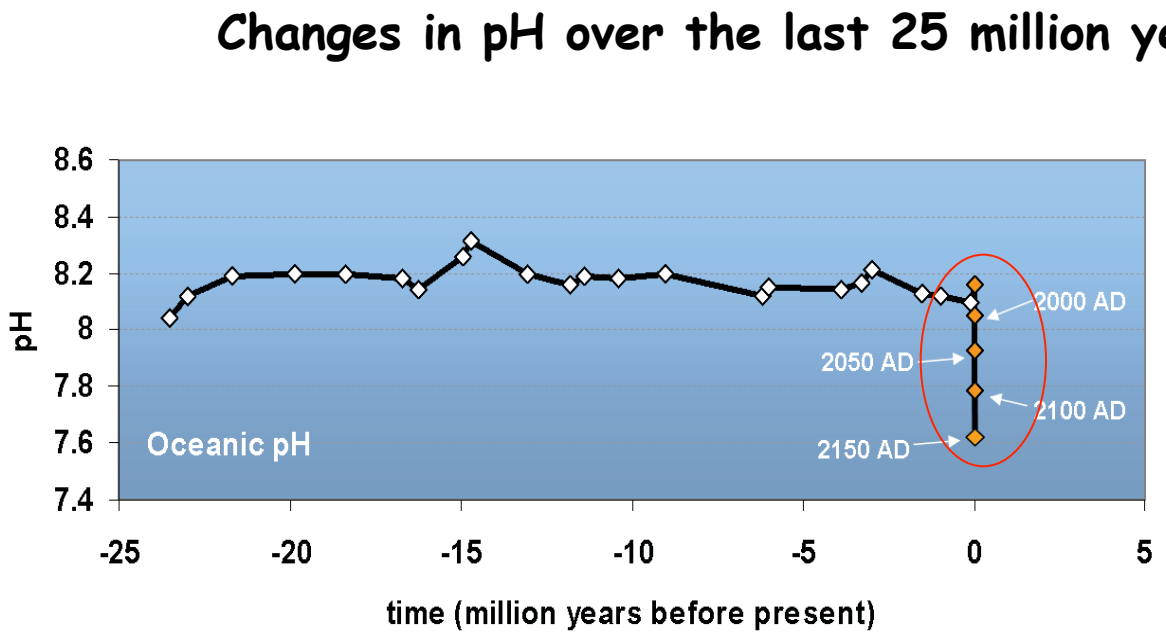
RCP2.6 (2081-2100), *likely* range: **26 to 55 cm**

RCP8.5 (in 2100), *likely* range: **52 to 98 cm**

Ocean Acidification, for RCP 8.5 (orange) & RCP2.6 (blue)



Oceans are Acidifying Fast …….



"Today is a rare event in the history of the World"

- **It is happening now, at a speed and to a level not experienced by marine organisms for about 60 million years**
- **Mass extinctions linked to previous ocean acidification events**
- **Takes 10,000's of years to recover**

Turley et al. 2006

Slide courtesy of Carol Turley, PML

Principales sources d'incertitudes

- **Microphysique des nuages**
- **Effets radiatifs des aérosols**
- **Interactions biosphère-atmosphère**
- **Stabilité de la circulation océanique**
- **Stabilité des calottes glaciaires**
- **Distribution des effets sur les pluies**
- **Fréquence & intensité des événements extrêmes (en partie)**

Principales « certitudes »

- **Les gaz à effet de serre d'origine humaine vont continuer à réchauffer le climat global**
- **Même les modèles « optimistes » montrent un réchauffement sans précédent au cours des 10.000 dernières années**
- **L'inertie du système est grande, en particulier pour le niveau des mers**
- **La stabilisation du climat requiert d'importantes réductions des émissions.**

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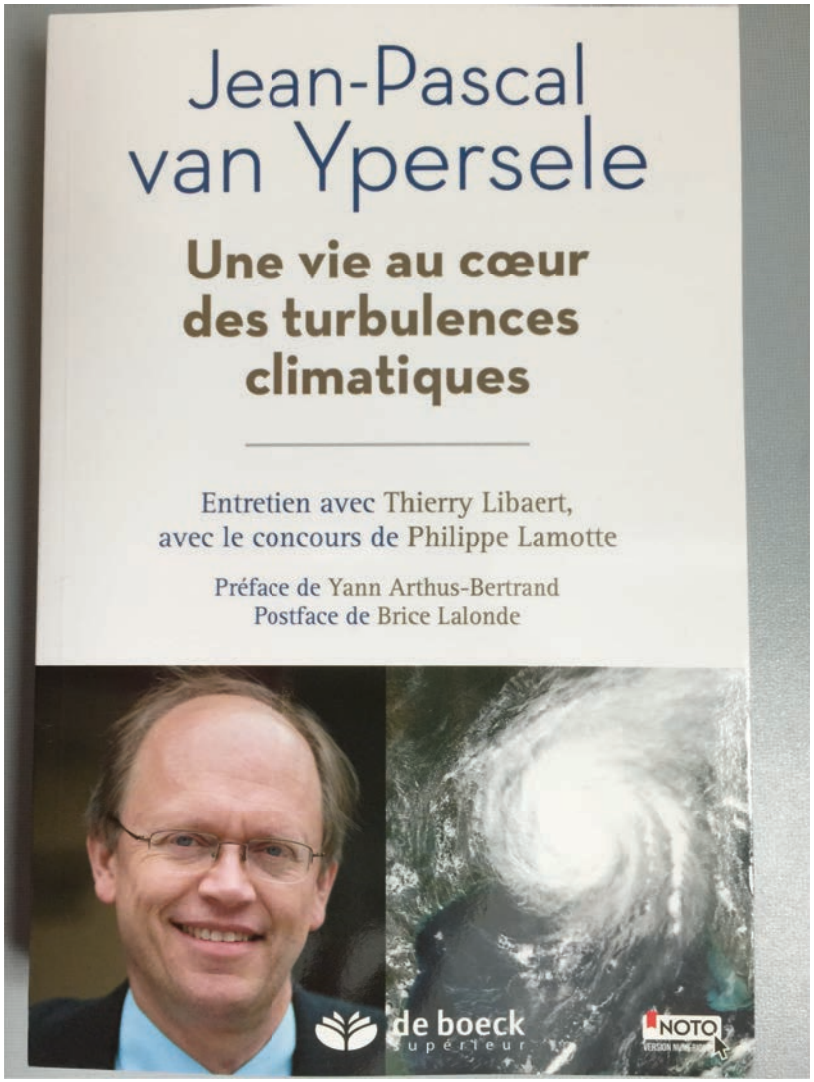

Pour en savoir plus…

- www.ipcc.ch : IPCC
- www.climatechange2013.org : IPCC WGI AR5
- www.climate.be/vanyp : slides and other documents
- www.skepticalscience.com: excellent responses to contrarians arguments
- On Twitter: @JPvanYpersele & @IPCC_CH

Useful links:

www.climate.be/desintox,

/demontage,

/pendules: rebuttal of some climate disinformation

IPCC WGI in video:

Can be found with the following Google keywords:
Working group I IPCC (9 minutes): youtube climate change 2013 IPCC

Direct link: http://www.youtube.com/watch?v=6yiTZm0y1YA&feature=youtu.be

IGBP (4 minutes): youtube climate change 2013 IGBP

Direct link: http://www.youtube.com/watch?v=_EWOrZQ3L-c