Changement climatique : les messages clés du 6ème cycle d'évaluation du GIEC

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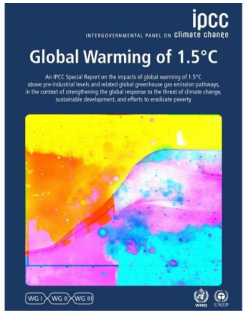
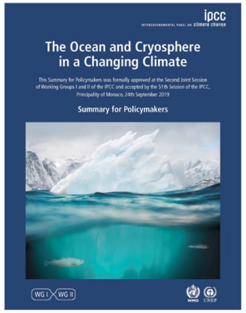
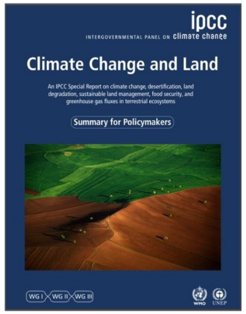
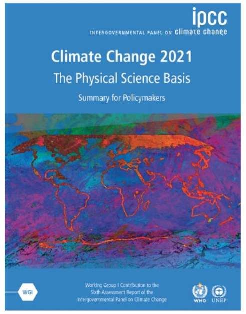
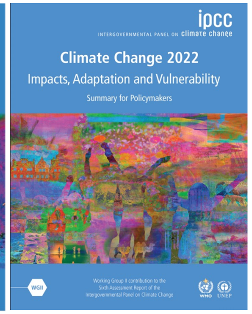
Auteure rapport de synthèse

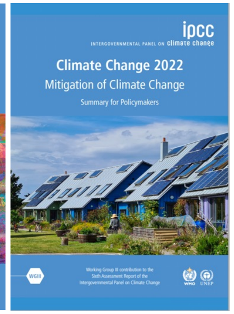












Gravité
Urgence
Action

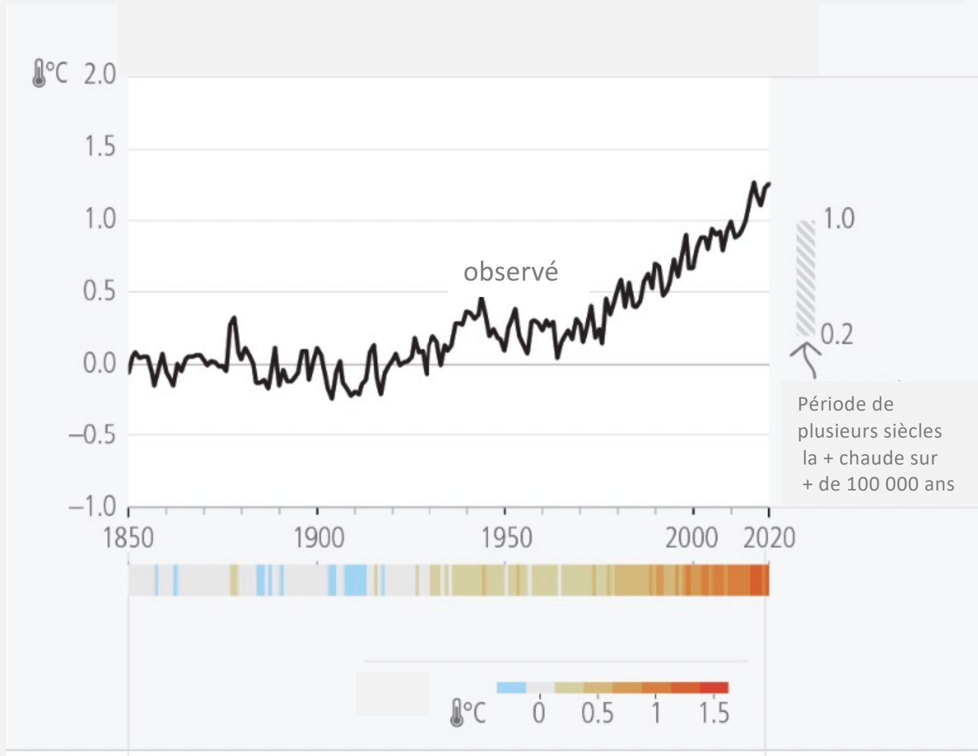
https://www.ipcc.ch/report/ar6/syr/


Où en sommes-nous
aujourd'hui?

Le changement climatique causé par l'homme a entraîné :

des changements physiques, étendus et rapides dans l'atmosphère, l'océan, la cryosphère et la biosphère

Le réchauffement planétaire atteint +1,1°C en 2011-2020 par rapport à 1850-1900



Le changement climatique causé par l'homme a entraîné :

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Le réchauffement planétaire :

+1,1°C

[2011-2020]

par rapport à [1850-1900]

des évènements extrêmes + fréquents et + intenses

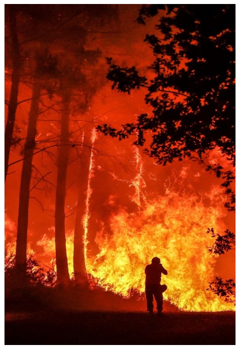
Canicules

Précipitations intenses

Sècheresses

Cyclones tropicaux intenses

des changements physiques qui se combinent



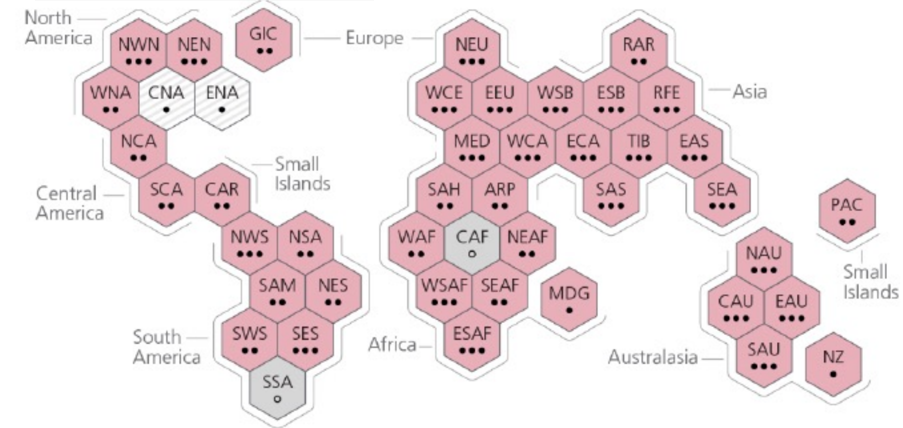
Sècheresse
+ Vagues de chaleur

Acidification
+ vagues de chaleur
+ déoxygénation

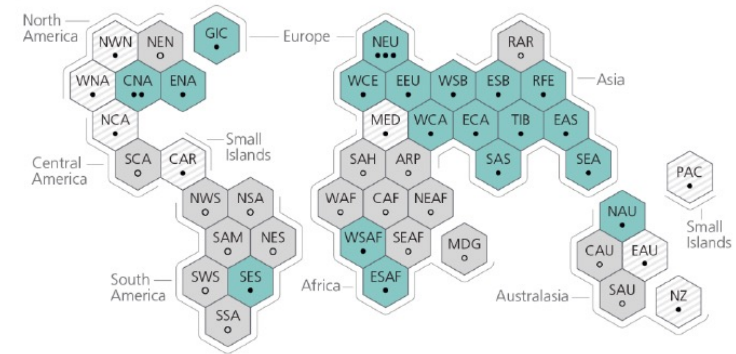
Montée des mers +
Fortes précipitations /
Cyclones de forte intensité

Le réchauffement planétaire dû aux activités humaines entraîne des évènements extrêmes + fréquents et + intenses

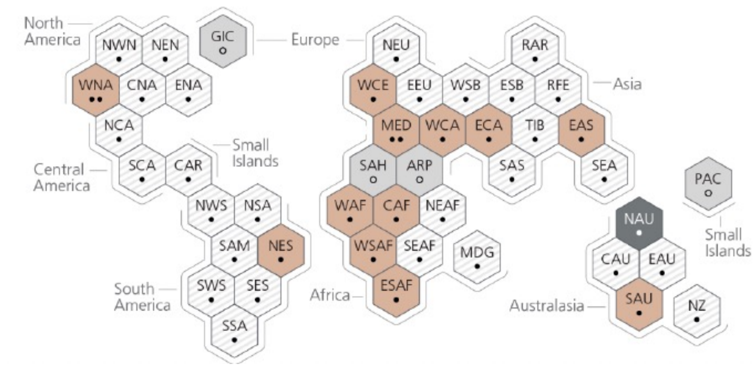
Extrêmes chauds



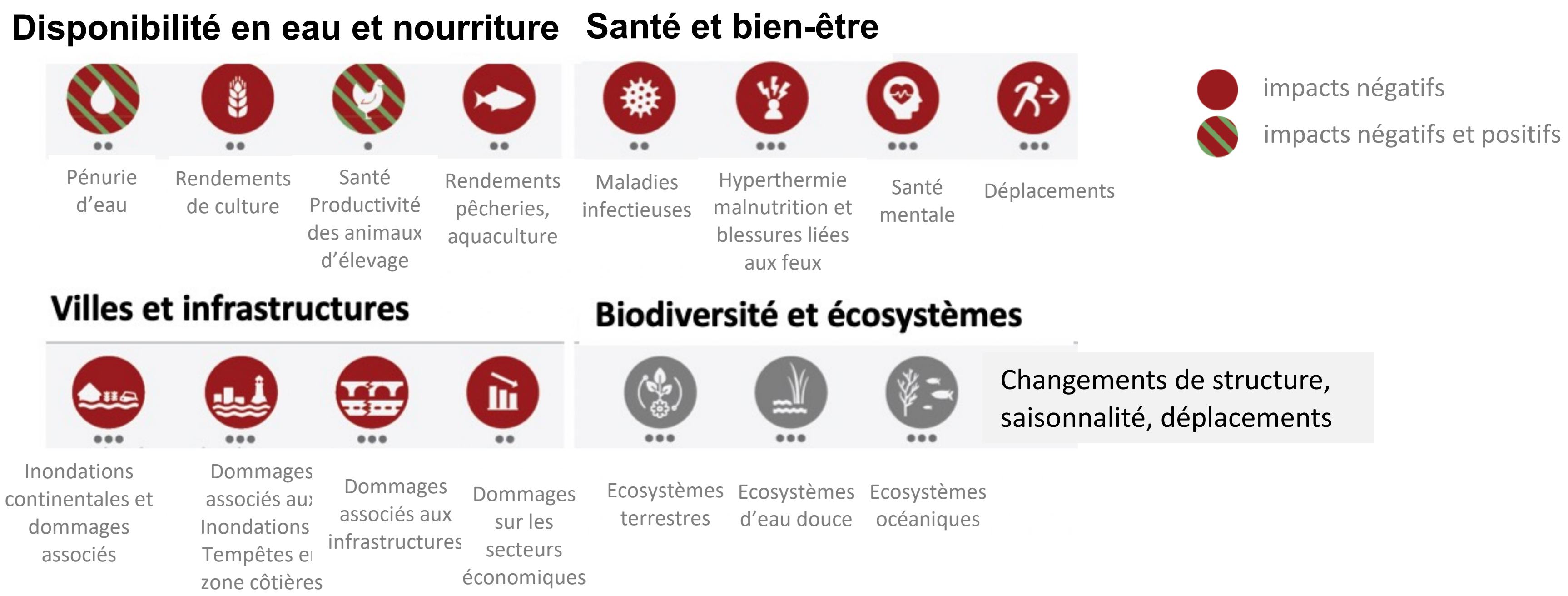
Pluies extrêmes



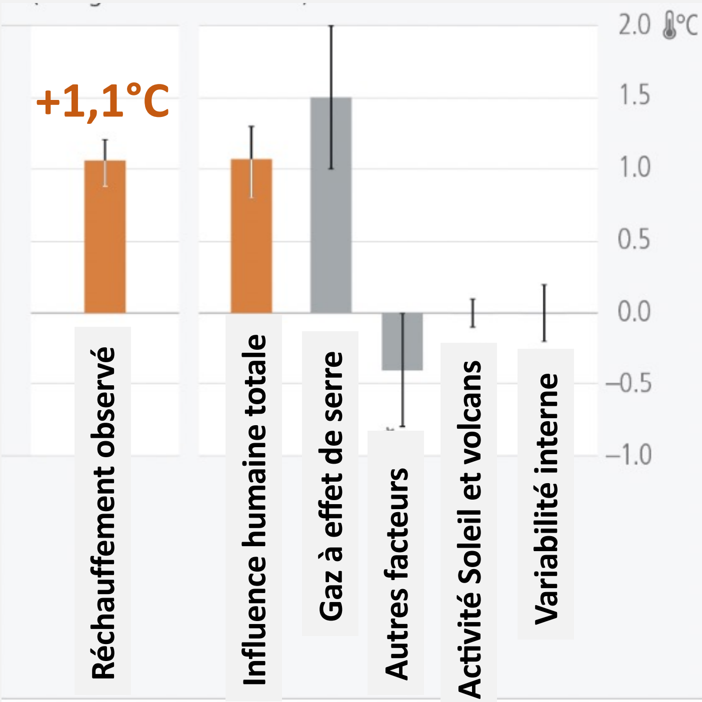
Sécheresses agricoles



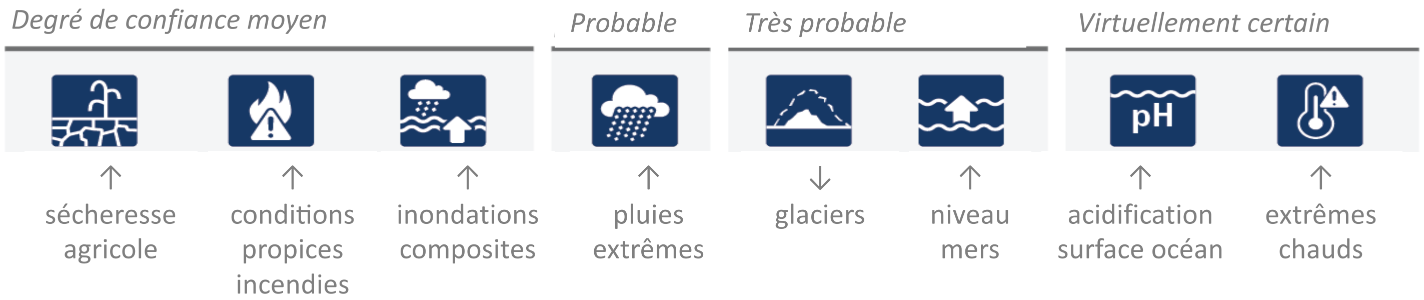
Une généralisation d'impacts graves, et de pertes et dommages attribués au changement climatique



Les activités humaines sont responsables du réchauffement planétaire



Le réchauffement dû aux émissions de gaz à effet de serre est partiellement masqué par l'effet refroidissant des particules de pollution



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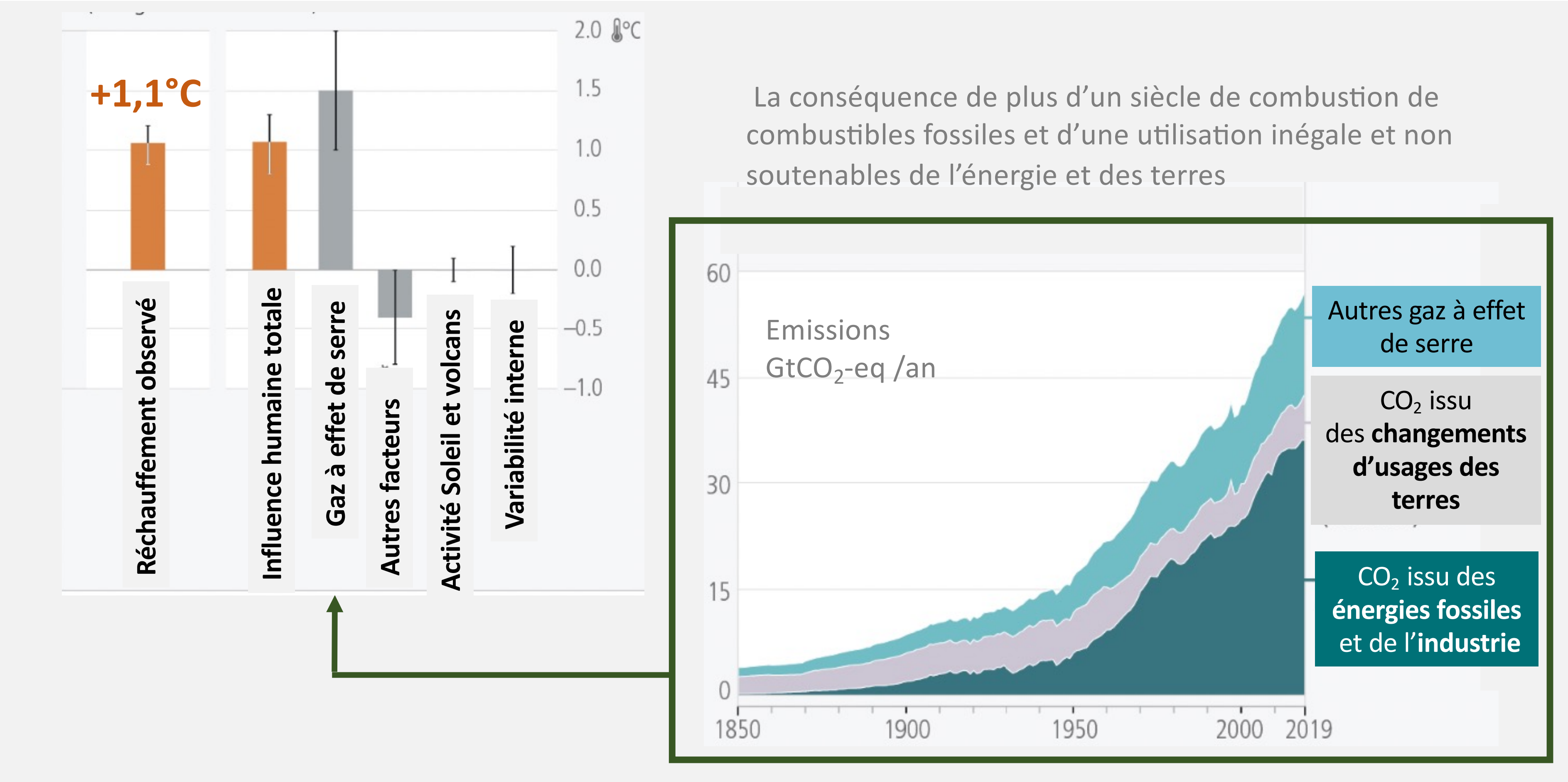
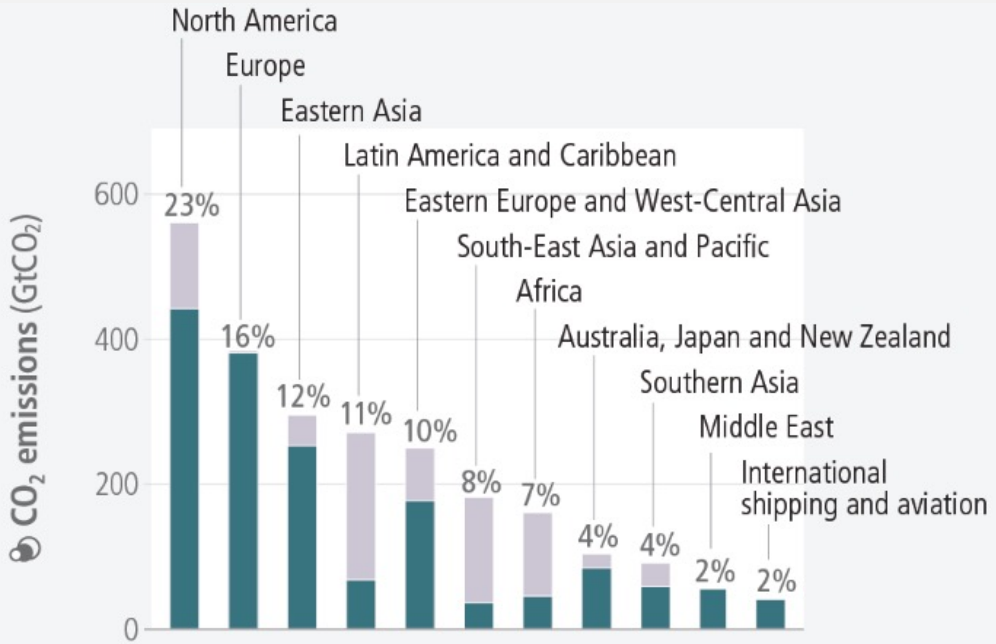


Les émissions de gaz à effet de serre issues des activités humaines continent d'augmenter

Une distribution inégale des émissions de gaz à effet de serre

Cumul historique des émissions nettes de CO_2 par région (1850-2019)

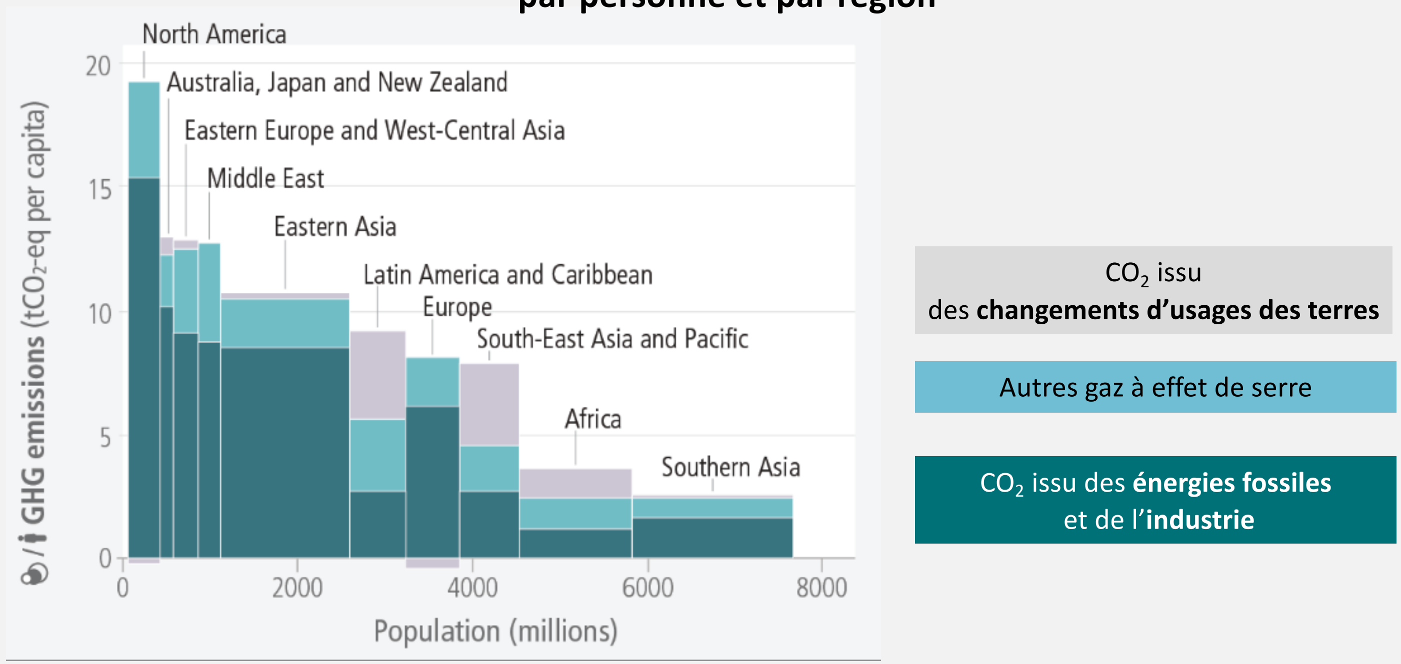


CO₂ issu des **changements d'usages des terres**

CO₂ issu des **énergies fossiles** et de l'**industrie**

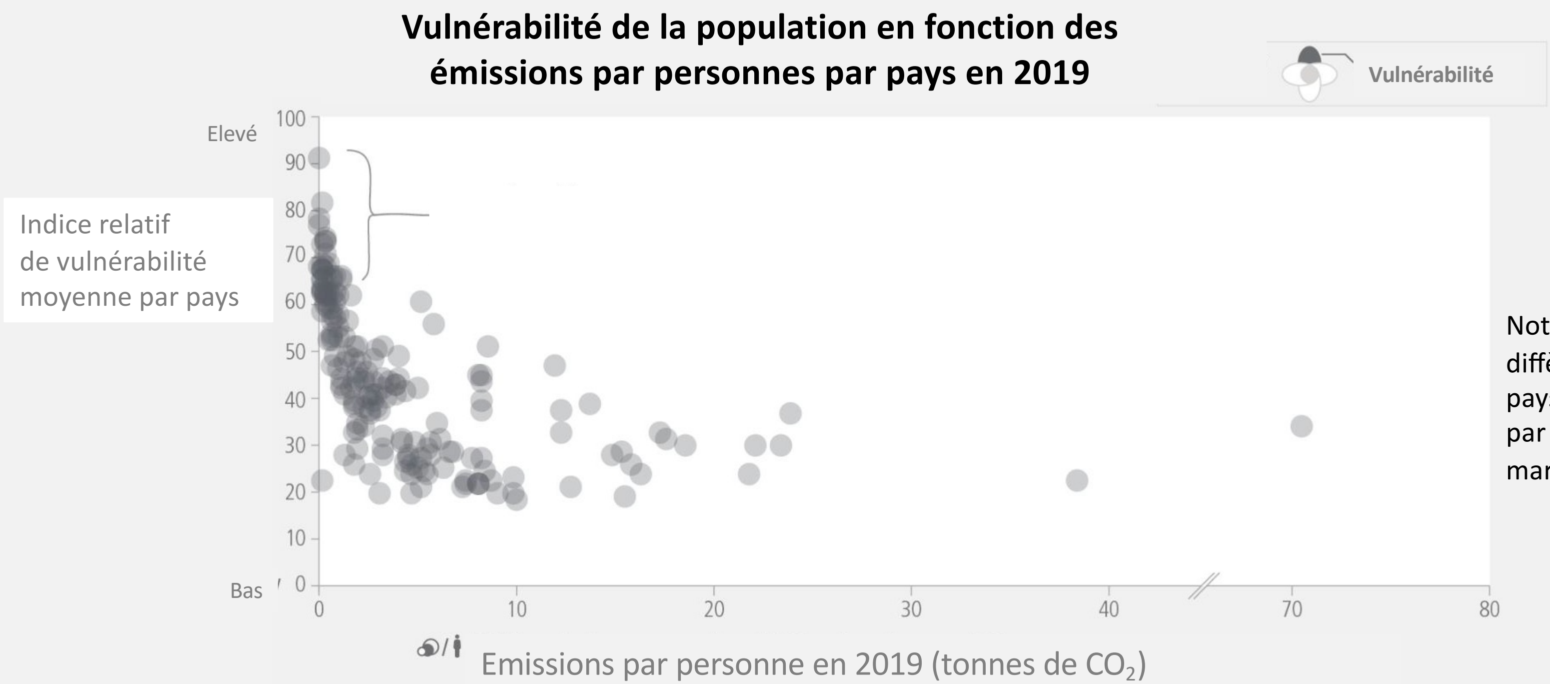
Une distribution inégale des émissions de gaz à effet de serre

Emissions nettes tous gaz à effet de serre en 2019
par personne et par région



10% des ménages à l'empreinte carbone la + élevée : ~40% des émissions mondiales
50% des ménages à l'empreinte carbone la + faible : ~14% des émissions mondiales

Les communautés vulnérables, qui ont le moins contribué au réchauffement actuel, sont affectées de manière disproportionnée



Note: La vulnérabilité diffère aussi au sein d'un pays et est exacerbée par les inégalités et la marginalisation

3,3-3,6 milliards de personnes vivent dans des contextes de vulnérabilité élevée au changement climatique
La moitié de la population mondiale fait face à de graves pénuries d'eau

Une action pour le climat qui monte en puissance

Baisse régulière des **émissions de gaz à effet de serre** dans plus de 18 pays

Plus de la moitié des émissions de gaz à effet de serre dans le monde sont dans le périmètre de politiques publiques

Les politiques publiques ont permis d'éviter plusieurs milliards de tonnes d'émissions de CO2-équivalent

Energies renouvelables, batteries :
baisse des coûts et augmentation des capacités installées

Efficacité énergétique, maîtrise de la demande, electrification, réduction du gaspillage alimentaire sont des techniques réalisables, **à bas coût et à forte acceptabilité**

Progrès de la **planification de l'adaptation** et de sa mise en oeuvre,

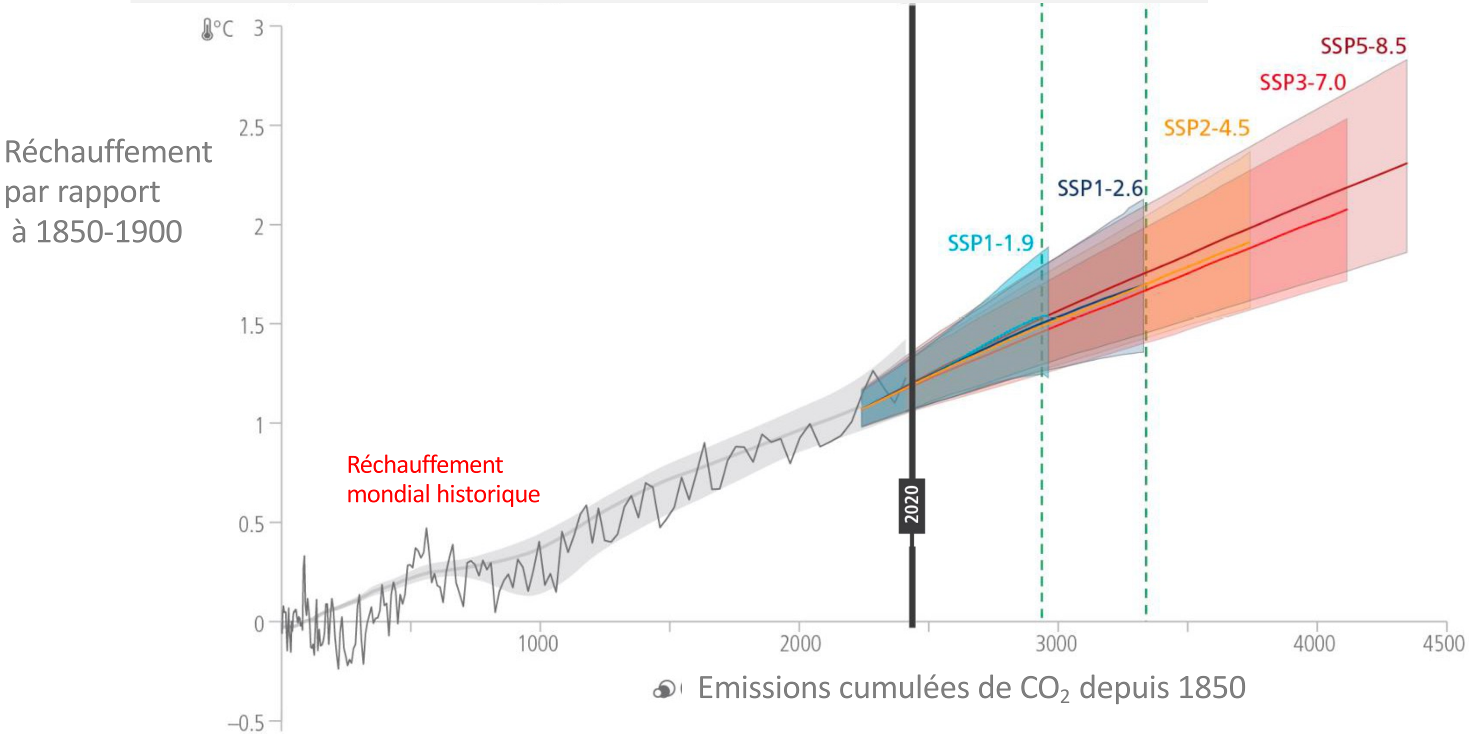
mais des réponses fragmentées, des limites atteintes dans certaines régions/écosystèmes, et un décalage croissant par rapport aux besoins, et des maladaptations

Des flux financiers insuffisants


Quels sont les
futurs possibles?

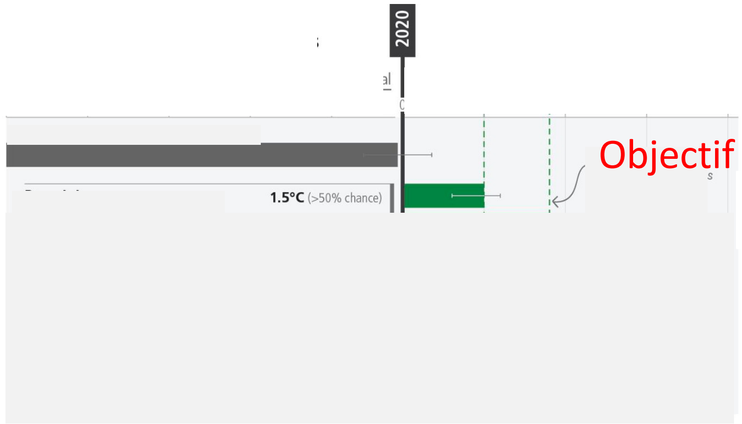
Chaque tonne de CO_2 émise contribue à un réchauffement supplémentaire

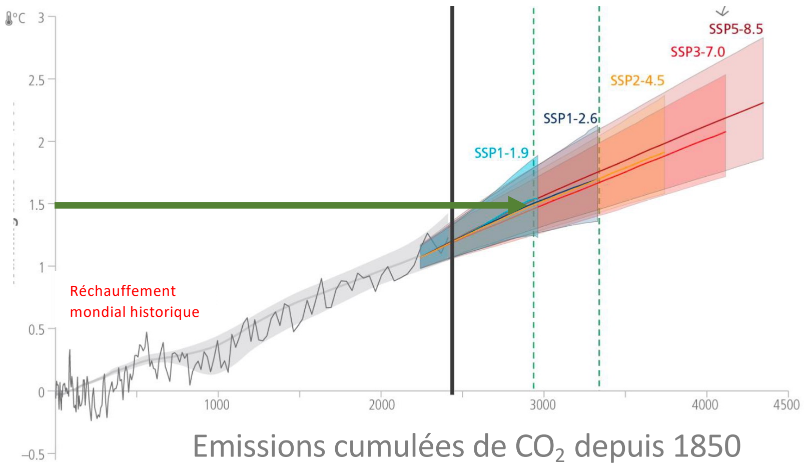
Emissions cumulées de CO_2 et réchauffement d'ici 2050



Le niveau de réchauffement futur dépend essentiellement des émissions futures de CO_2

Les budgets carbones restants permettant de limiter le réchauffement à 1,5°C seront bientôt épuisés, et ceux pour 2°C largement amoindris





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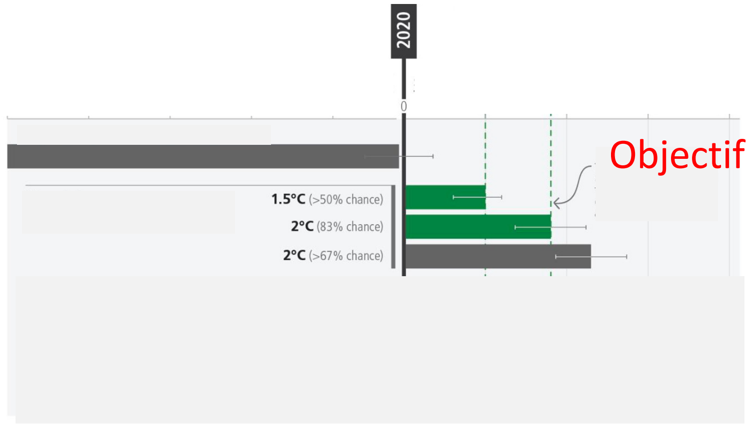

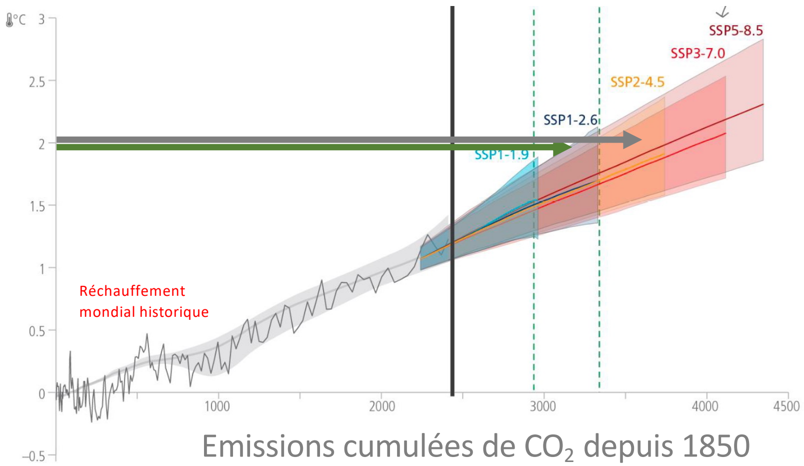

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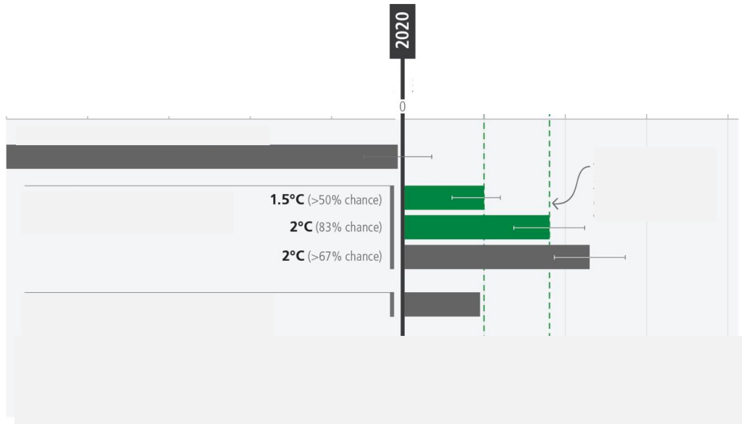
Emissions historiques 1850-1900

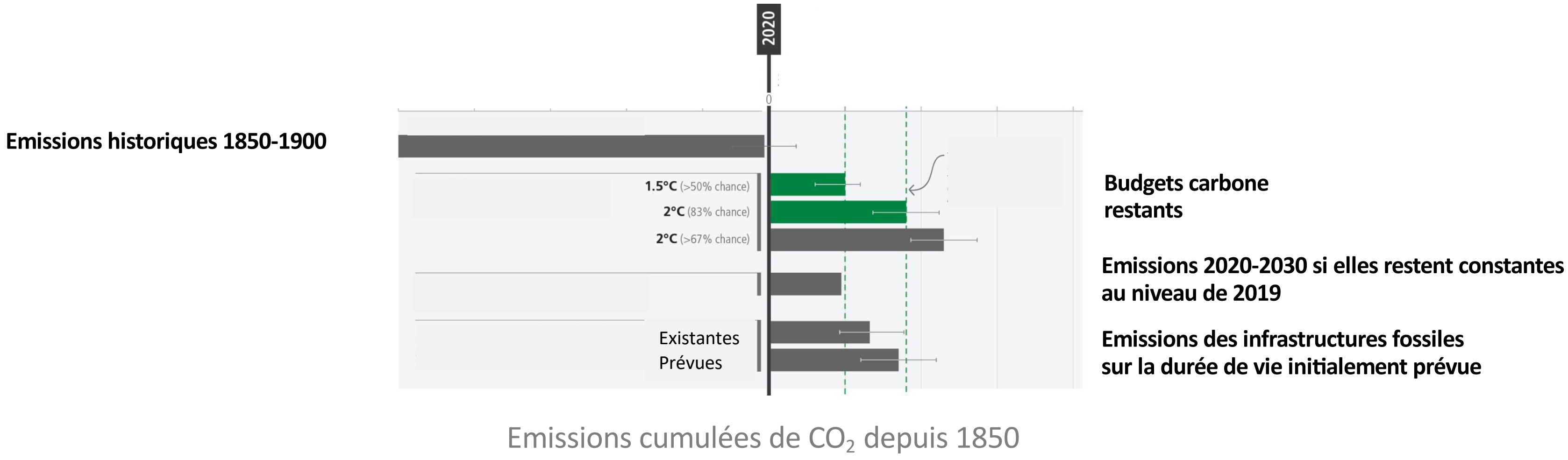


Budgets carbone restants

Emissions 2020-2030 si elles restent constantes au niveau de 2019

Emissions cumulées de CO_2 depuis 1850

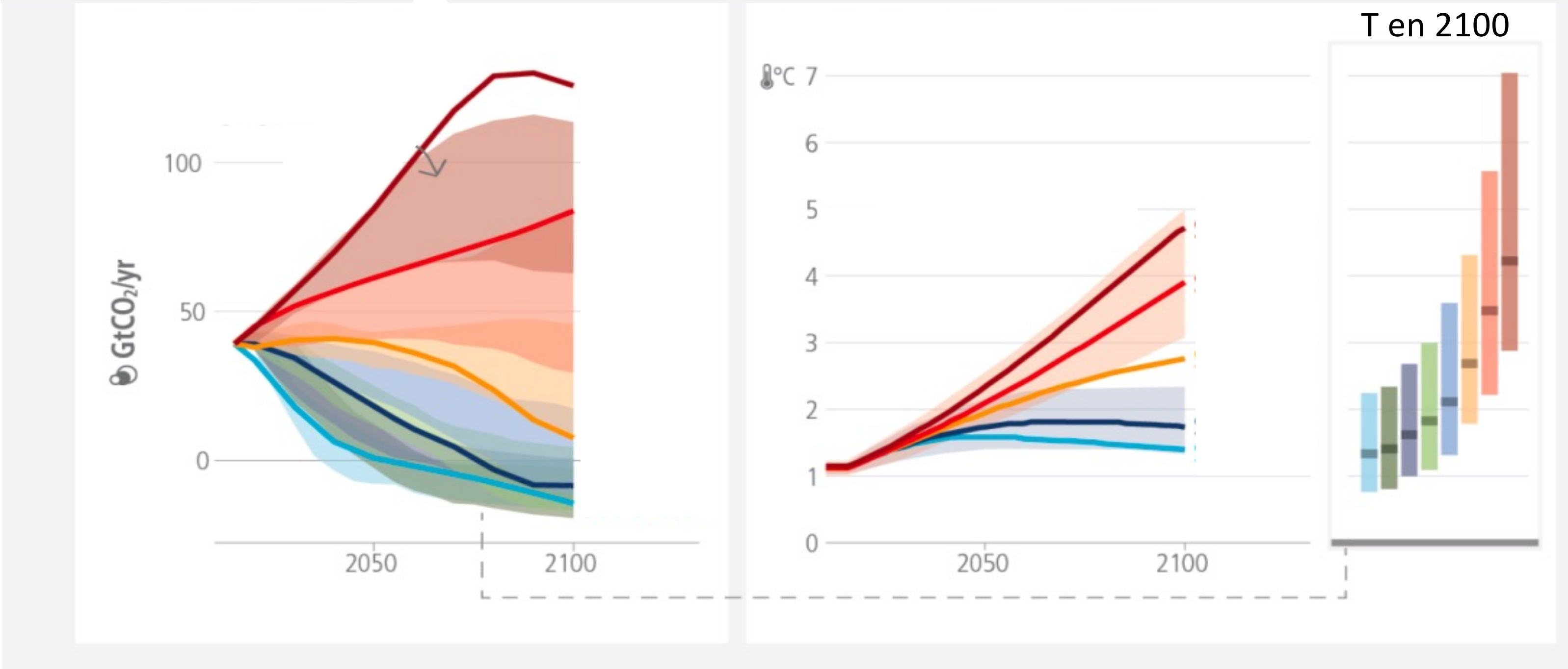
Les budgets carbones restants permettant de limiter le réchauffement à 1,5°C seront bientôt épuisés, et ceux pour 2°C largement amoindris



La poursuite des émissions de gaz à effet de serre va amplifier le réchauffement
Un niveau de 1,5°C de réchauffement sera atteint au début des années 2030

Emissions
scénarios et trajectoires

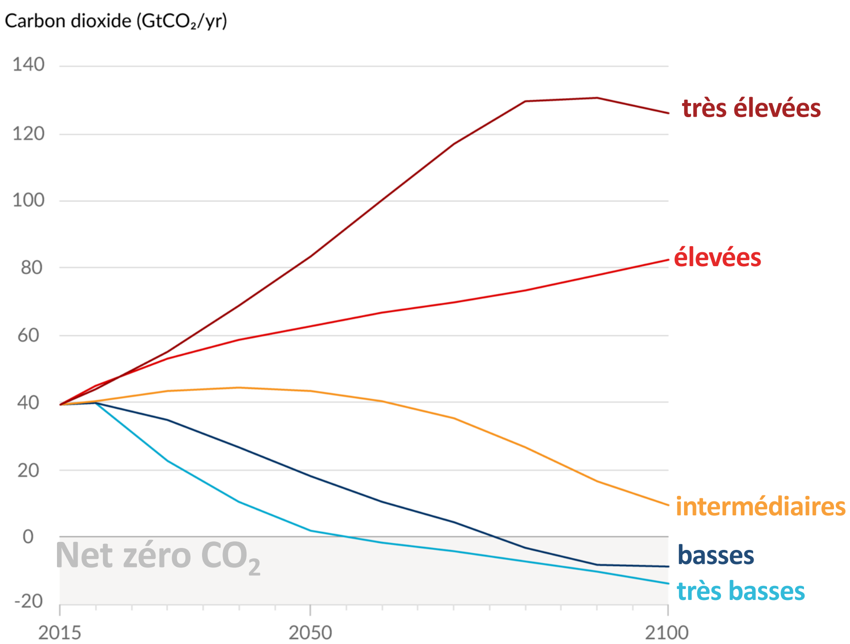
Changement de température
de surface planétaire

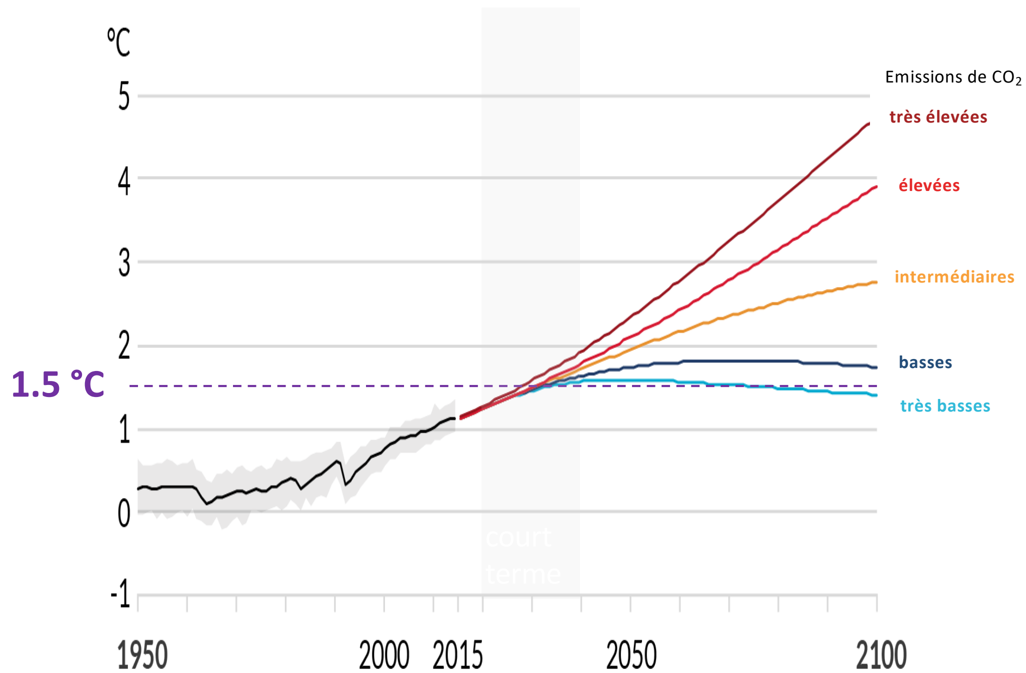


En cas de forte baisse des émissions,
des effets discernables d'ici environ 20 ans sur la T

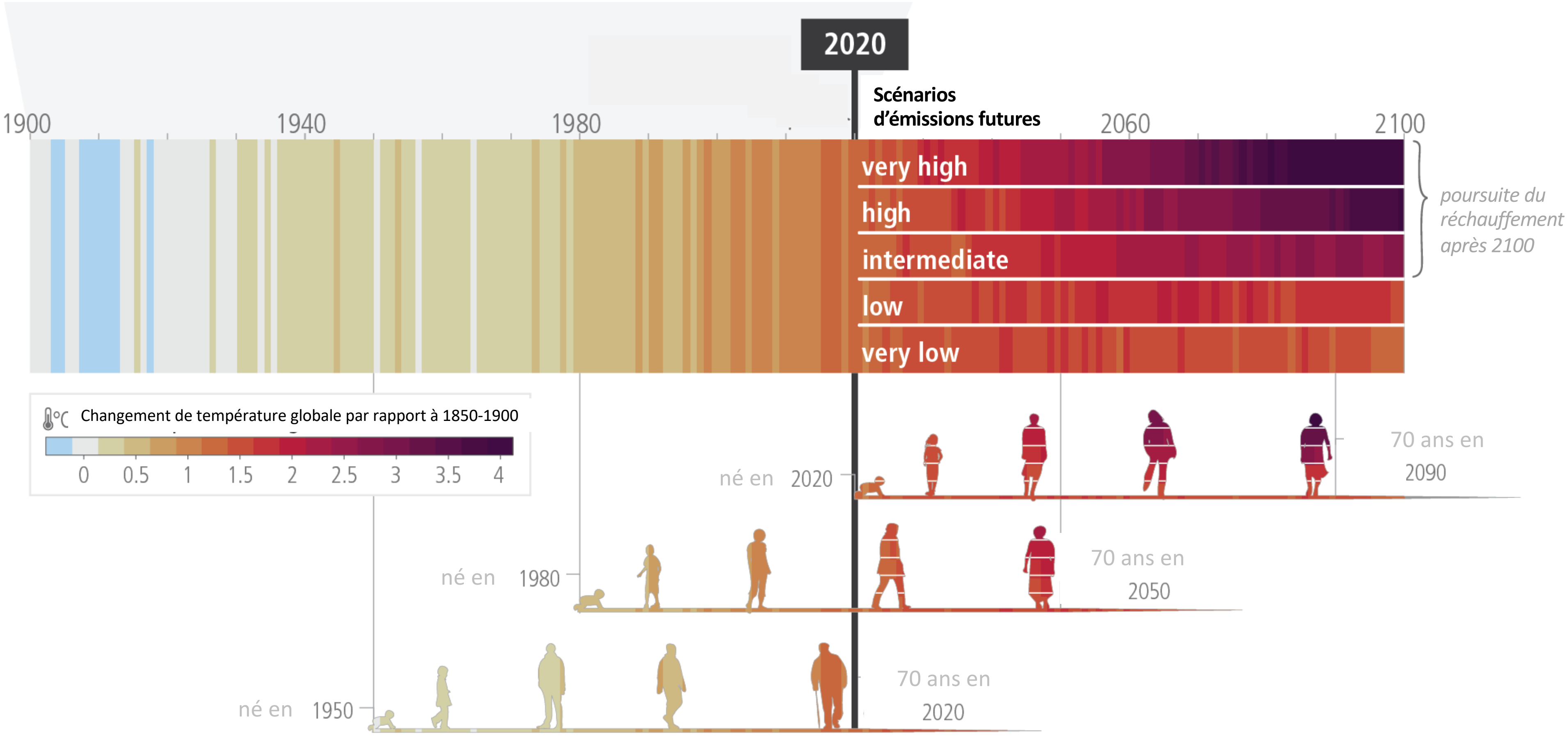
La poursuite des émissions de gaz à effet de serre va amplifier le réchauffement
Un niveau de 1,5°C de réchauffement sera atteint au début des années 2030

Emissions de CO_2 (Gt/an)

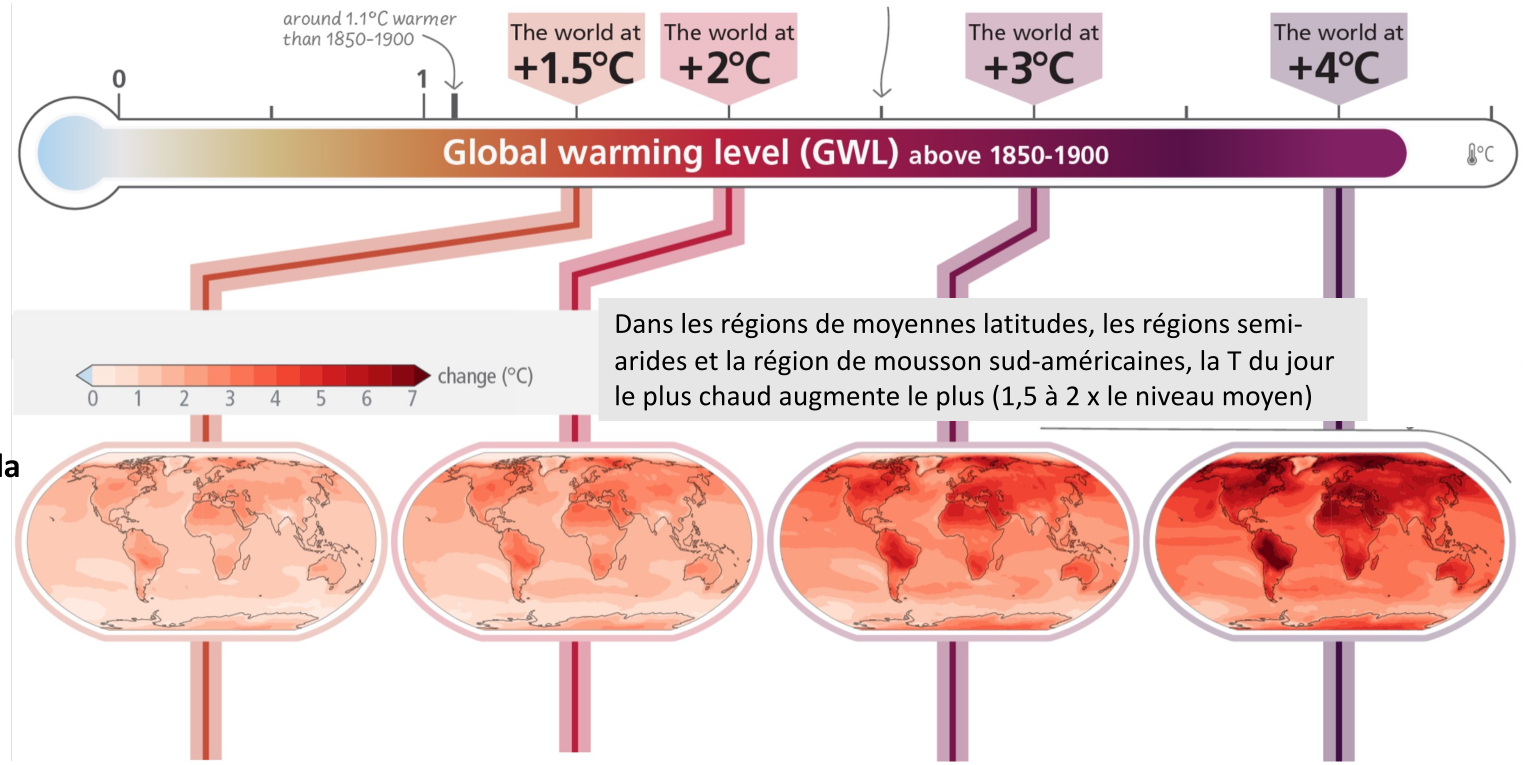




Le monde plus chaud, différent, que connaîtront les générations actuelles et futures dépend des choix effectués maintenant et à court terme



Pour chaque incrément de réchauffement supplémentaire, les changements régionaux de climat moyen et d'extrêmes deviennent plus généralisés et plus prononcés



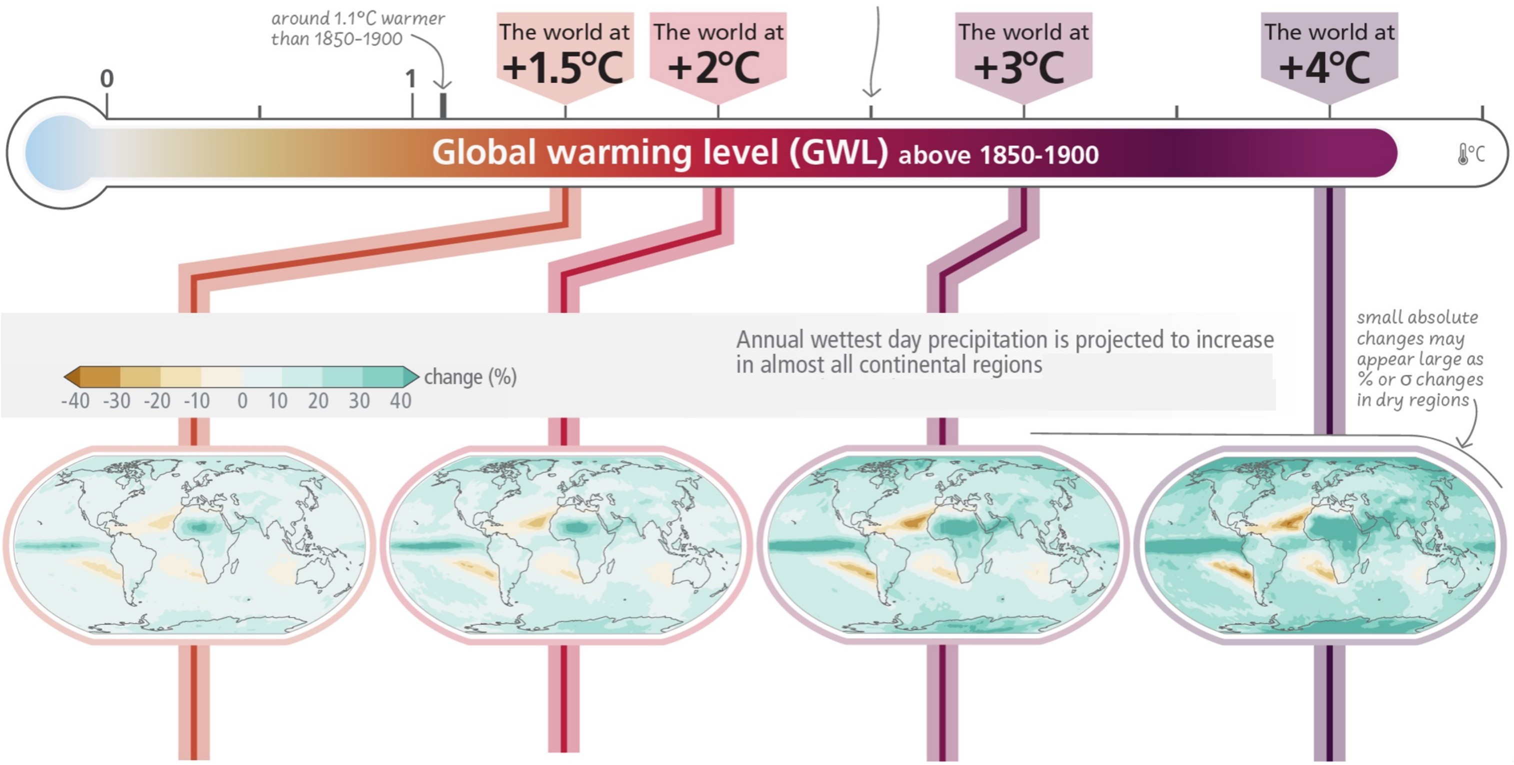
Dans les régions de moyennes latitudes, les régions semi-arides et la région de mousson sud-américaines, la T du jour le plus chaud augmente le plus (1,5 à 2 x le niveau moyen)

Changement de la température du jour le plus chaud

NB les extrêmes chauds sont amplifiés dans les zones urbanisées

Pour chaque incrément de réchauffement supplémentaire, les changements régionaux de climat moyen et d’extrêmes deviennent plus généralisés et plus prononcés

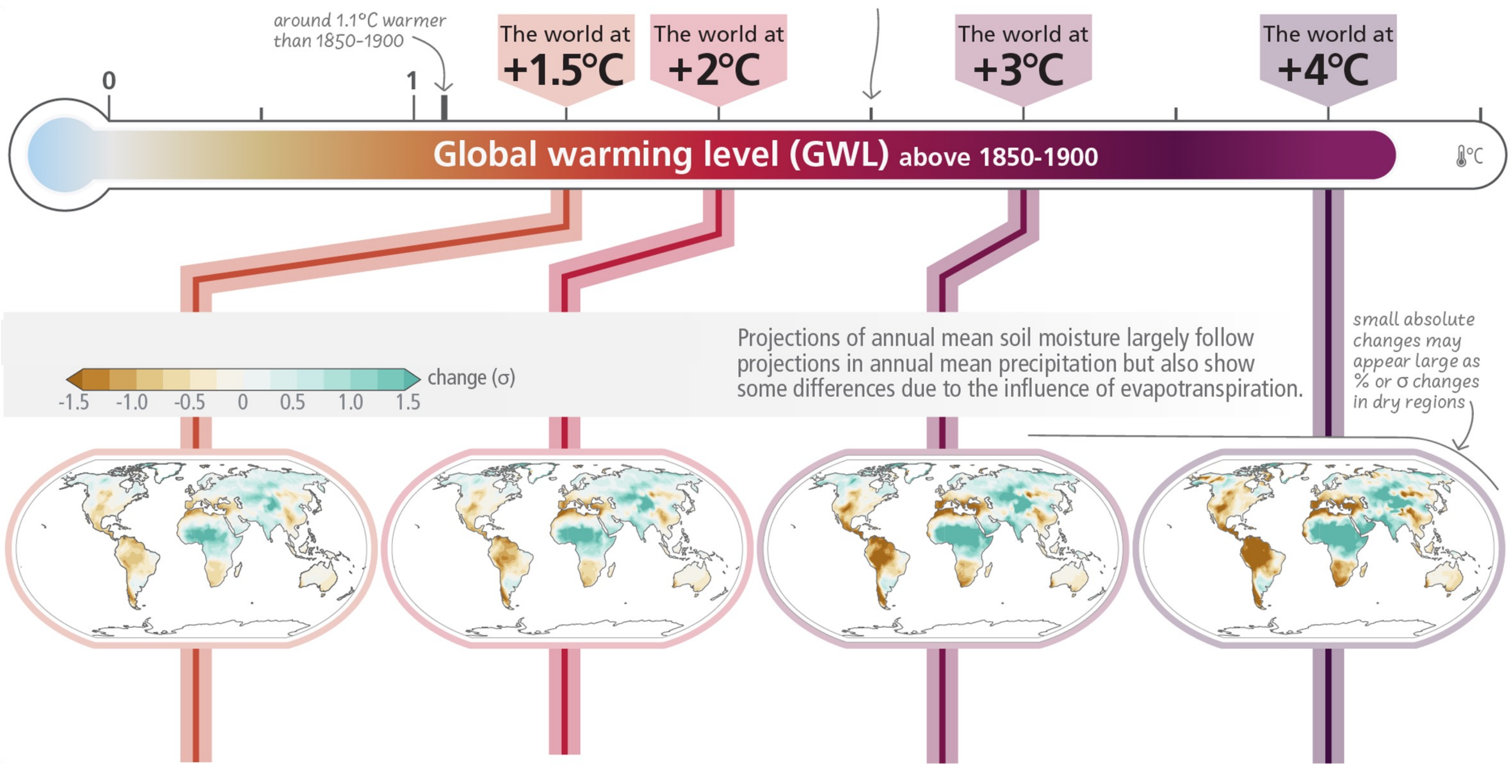
Changement de précipitations pour le jour le plus pluvieux



IPCC AR6 SYR Figure SPM.2c

Pour chaque incrément de réchauffement supplémentaire, les changements régionaux de climat moyen et d'extrêmes deviennent plus généralisés et plus prononcés

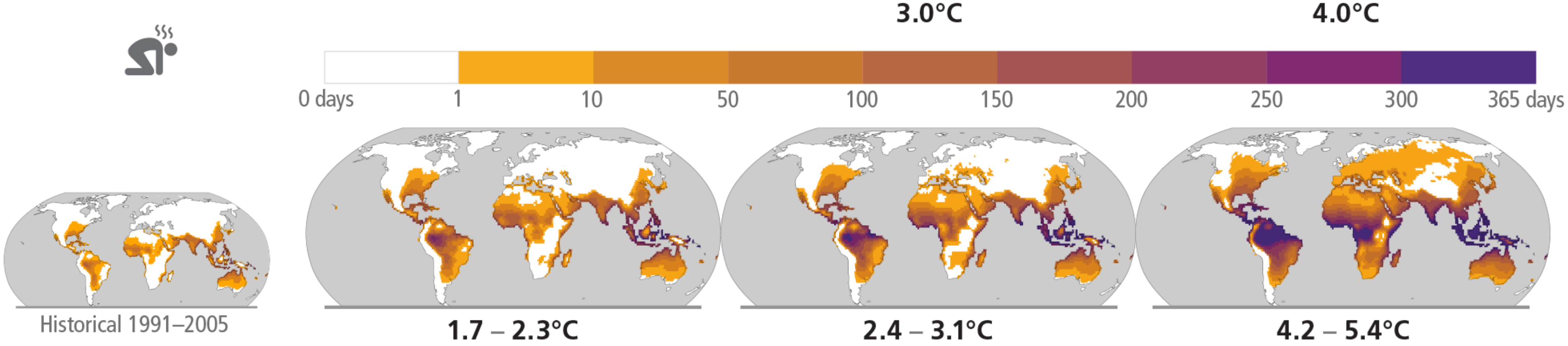
Changement de l'humidité des sols (moyenne annuelle)



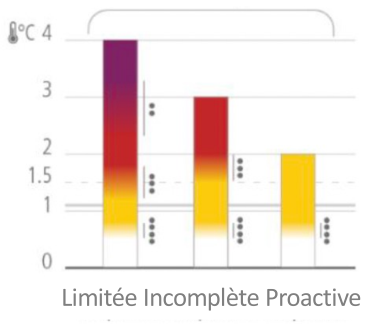
IPCC AR6 SYR Figure SPM.2a

Pour chaque incrément de réchauffement supplémentaire, les risques pour la santé augmentent, et dépendent des actions d'adaptation

Nombre de jours par an où les conditions de température et d'humidité exposent les individus à un risque mortel



Morbidité et mortalité liée à la chaleur

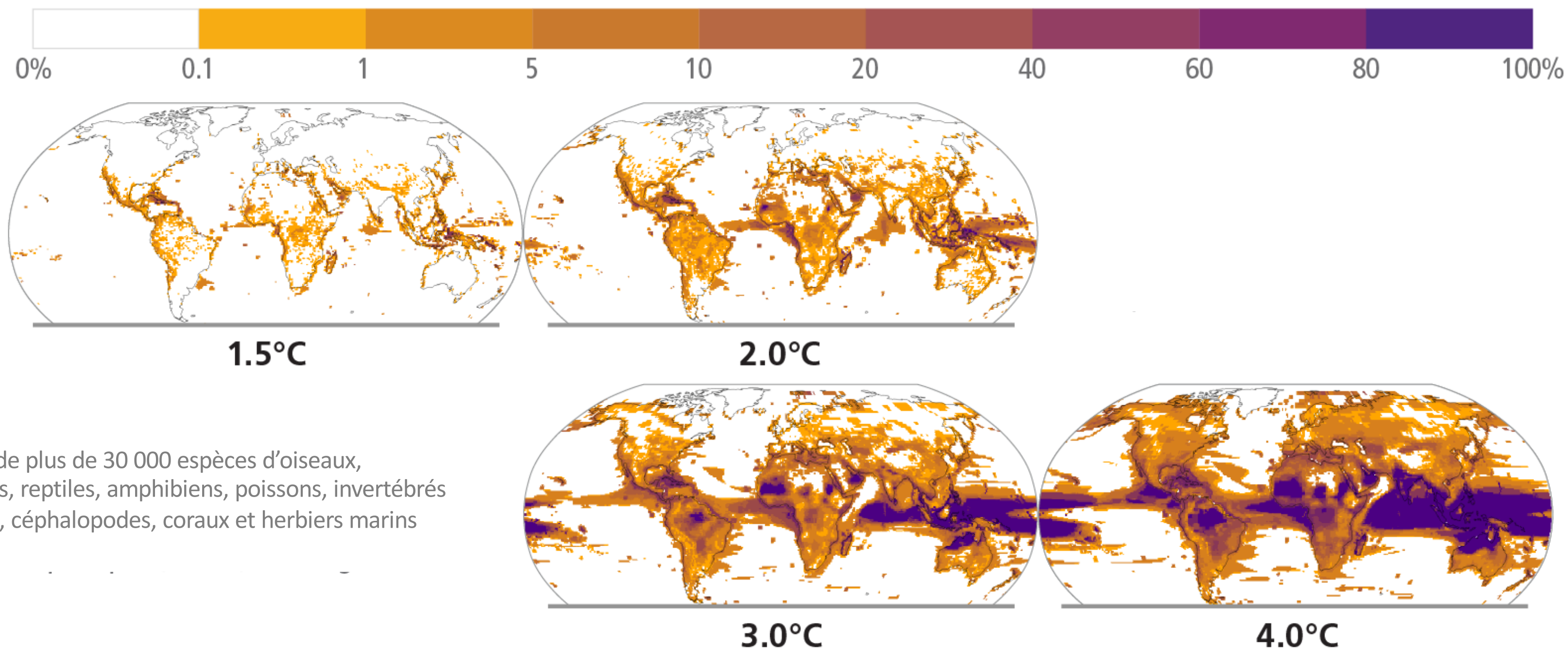


Adaptation

Investissements dans les systèmes de santé, planification de l'adaptation

Pour chaque incrément de réchauffement supplémentaire, les impacts sur les écosystèmes vont s'aggraver

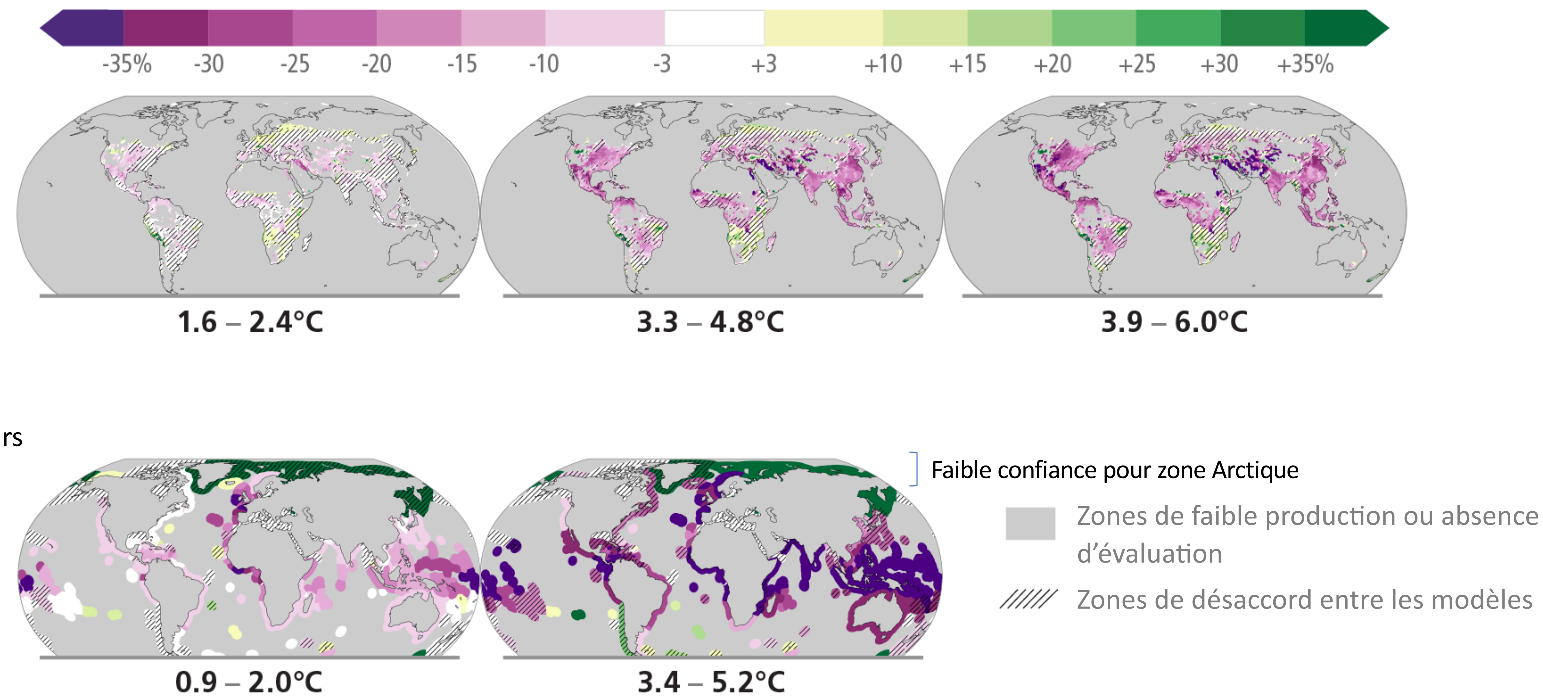
Pourcentage d'espèces animales exposées à des conditions de température potentiellement dangereuses (sans relocalisation)



sur la base de plus de 30 000 espèces d'oiseaux, mammifères, reptiles, amphibiens, poissons, invertébrés marins, krill, céphalopodes, coraux et herbiers marins

Conservation, protection et restauration des écosystèmes

Pour chaque incrément de réchauffement supplémentaire, les risques pour la production alimentaire vont s'aggraver



Rendement maïs (%)
ne tient pas compte de la limitation en eau, maladie, changements techniques futurs

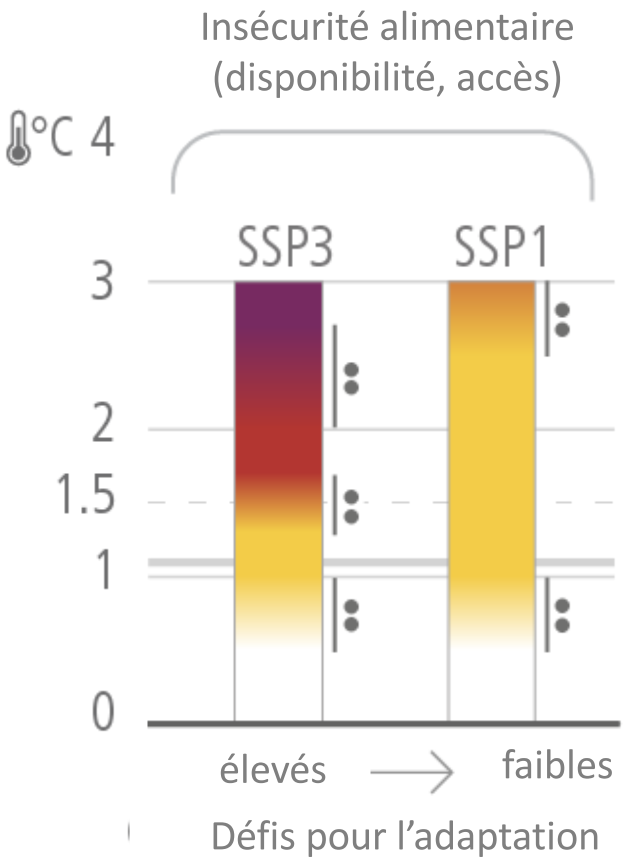
Potentiel de prises de pêches(%)
considère changements de T, oxygène, production nette primaire mais pas pêche et extrêmes climatiques

Pour chaque incrément de réchauffement supplémentaire, les risques pour la sécurité alimentaire vont s'aggraver, et dépendent des choix socio-économiques

Trajectoire SSP3 :

Rivalité régionale - nationalisme renaissant, préoccupations concernant la compétitivité et la sécurité, et conflits régionaux. Les pays se concentrent sur des questions nationales. ↘ Investissements éducation et développement technologique. Développement économique est lent, Consommation intensive en matériaux. Inégalités persistent ou s'aggravent avec le temps. Démographie mondiale ↗. Faible priorité internationale pour répondre aux enjeux environnementaux => forte dégradation de l'environnement dans certaines régions.

Forte demande en nourriture, peu d'amélioration des technologies => prix de l'alimentation plus élevée et plus de population soumises à un risque de pénurie alimentaire

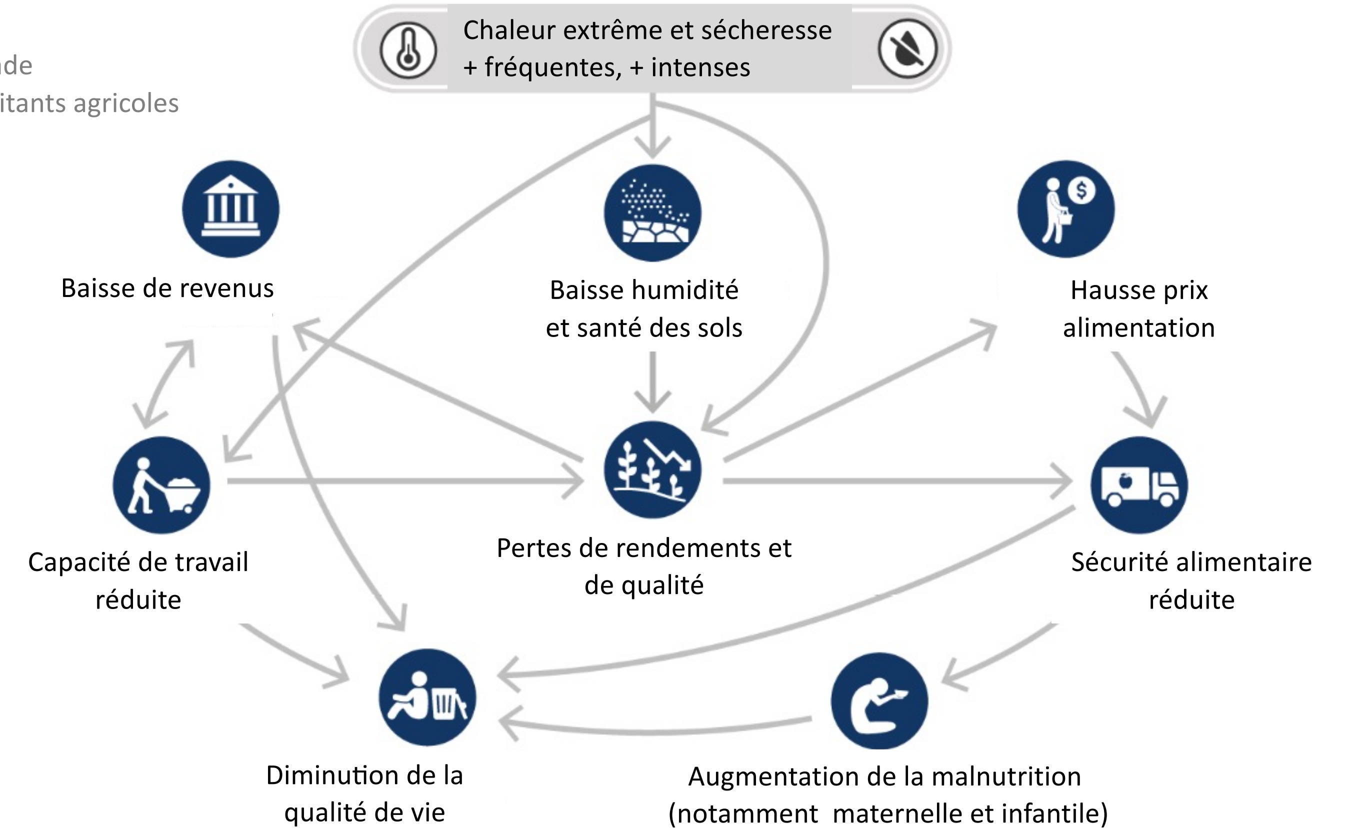


Trajectoire SSP1 :

faible croissance démographique, revenus élevés, inégalités réduites, systèmes de production alimentaire à faibles émissions, réglementation efficace de l'utilisation des terres, forte capacité d'adaptation

Des risques de plus en plus complexes et difficiles à gérer

Risques composites ou en cascade
illustrés ici pour les petits exploitants agricoles

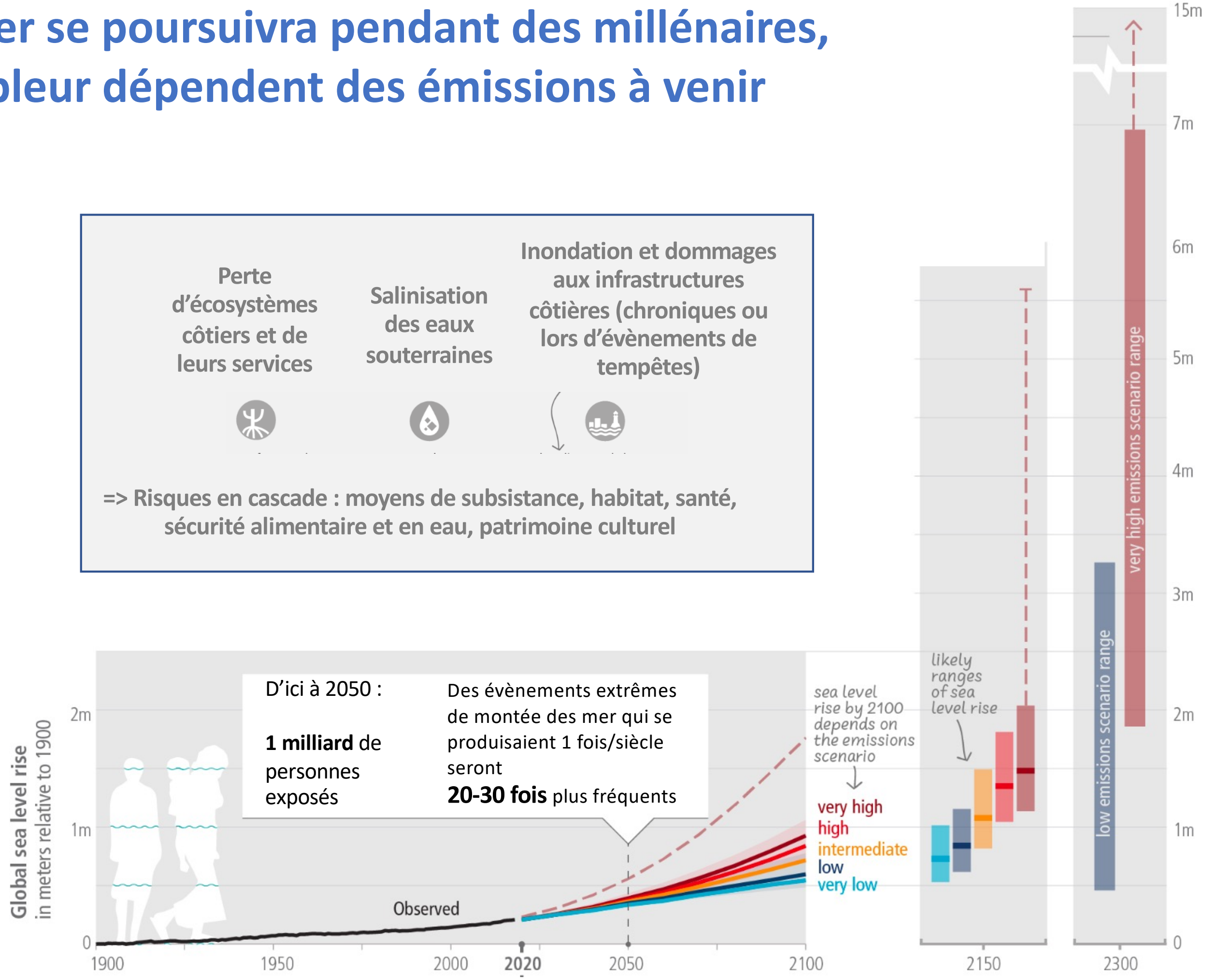


La montée du niveau de la mer se poursuivra pendant des millénaires, mais sa vitesse et son ampleur dépendent des émissions à venir

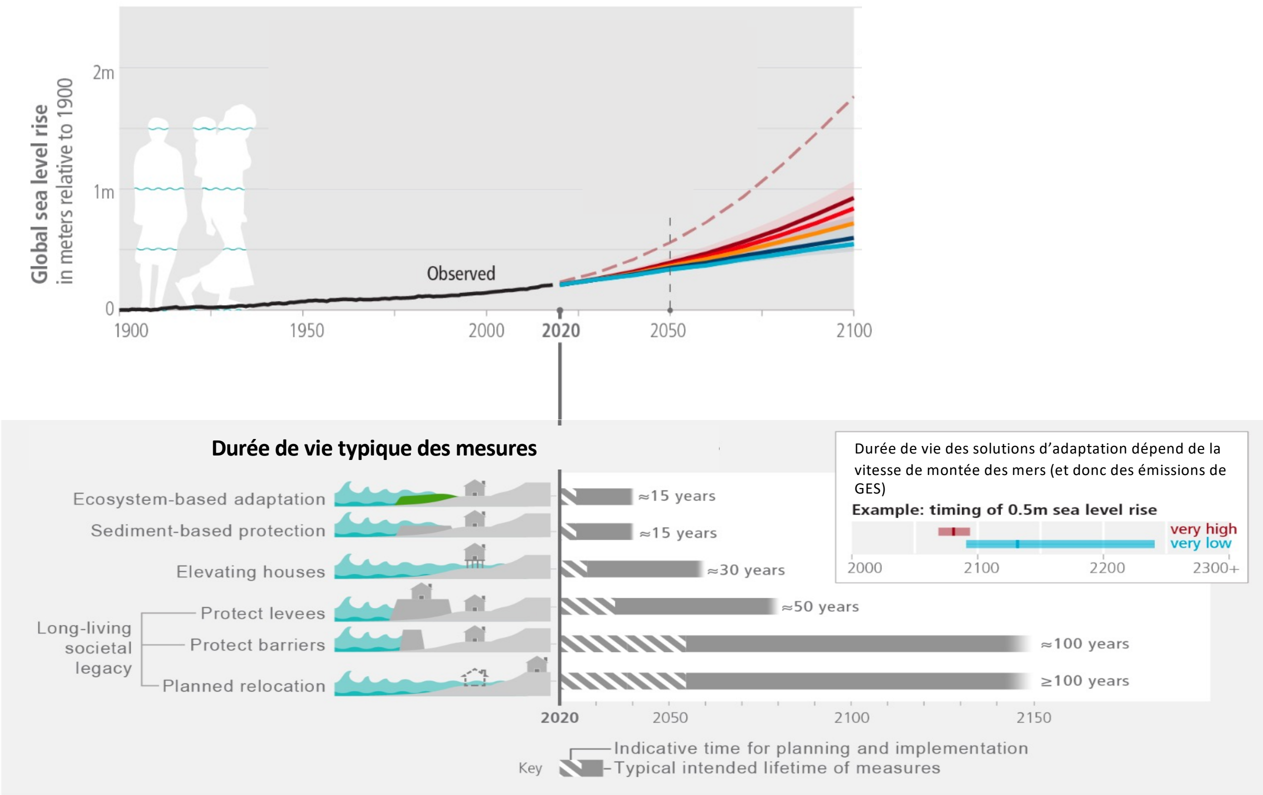
La probabilité de changements abrupts et/ou irréversibles augmente avec le niveau de réchauffement planétaire

Perte d'écosystèmes côtiers et de leurs services	Salinisation des eaux souterraines	Inondation et dommages aux infrastructures côtières (chroniques ou lors d'évènements de tempêtes)

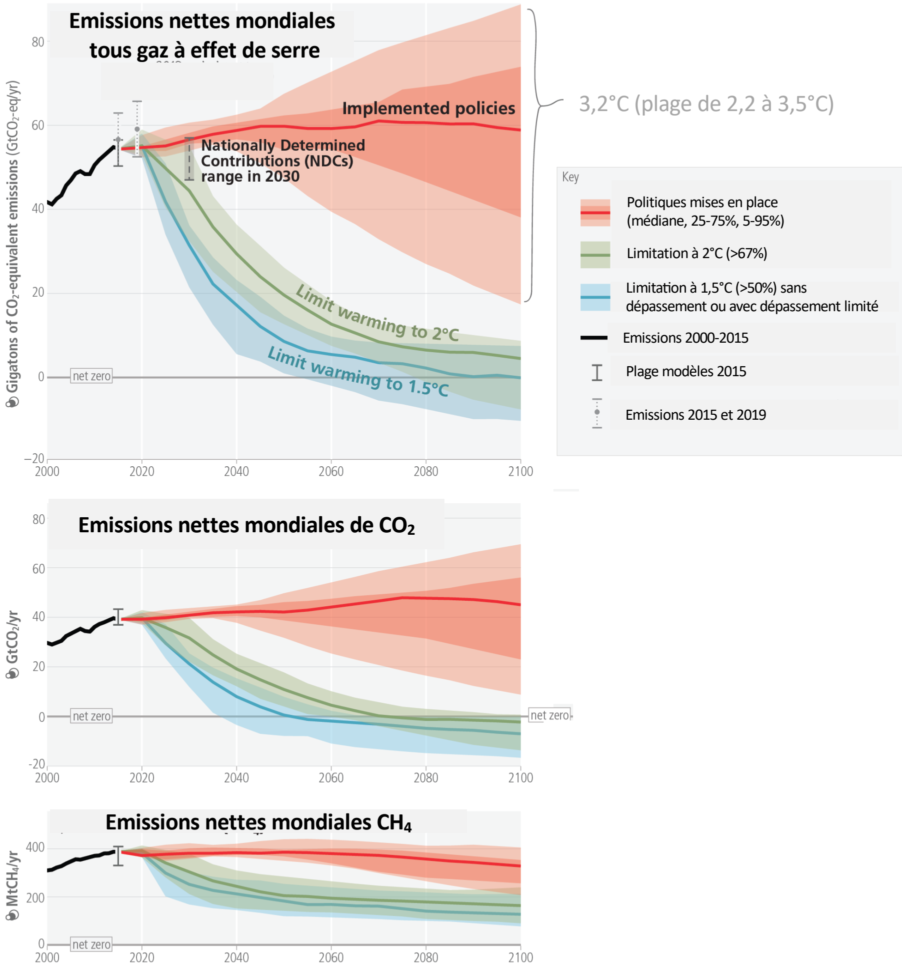
=> Risques en cascade : moyens de subsistance, habitat, santé, sécurité alimentaire et en eau, patrimoine culturel



Les mesures pour y faire face demandent une planification à long terme



Limiter le réchauffement à 2°C ou proche de 1,5°C demande des réductions immédiates, rapides et profondes des émissions de gaz à effet de serre



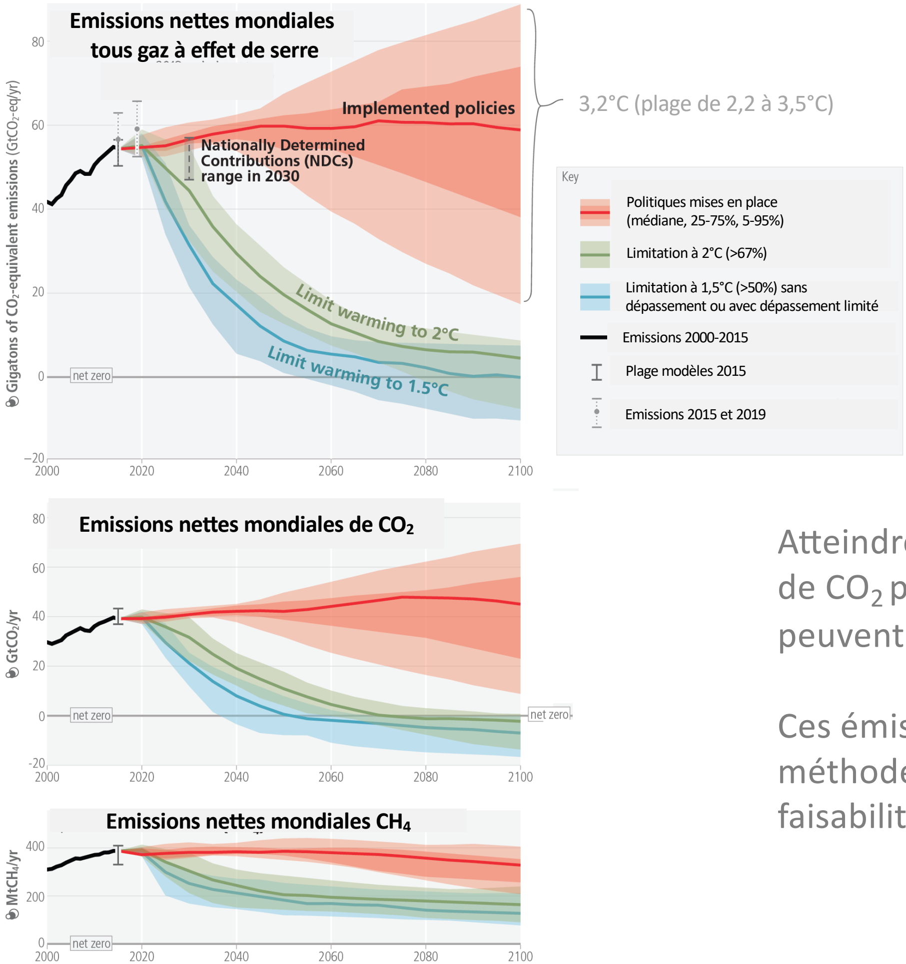
Emissions GES en 2030 (par rapport à 2010)

+5%

-26%

-43%

Limiter le réchauffement à 2°C ou proche de 1,5°C demande des réductions immédiates, rapides et profondes des émissions de gaz à effet de serre



Atteindre **net zéro CO2** nécessite des émissions négatives de CO_2 pour compenser les regions/secteurs qui ne peuvent atteindre zéro.

Ces émissions négatives reposent sur le déploiement de méthodes d'éliminations qui pose des questions de faisabilité, de soutenabilité et de risques

Des limites…

- des **limites géophysiques**

les budgets carbone restants

des puits naturels de carbone qui absorbent une fraction plus faible des émissions dans des scénarios de réchauffements élevés

des changements irréversibles enclenchés (réchauffement océanique, montée du niveau des mers, fonte de calottes de glace)

- des **limites physiologiques** face au changement climatique

pour les écosystèmes (fontes sols gelés, mortalité des arbres, feux, assèchement des tourbières) et la santé humaine (e.g. impossibilité à mener un travail à l'extérieur)

- des **limites dures à l'adaptation**, l'adaptation ne peut prévenir toutes les pertes et dommages

atteintes pour certains écosystèmes (certain(e)s coraux d'eaux chaudes, zones humides côtières, forets humides, écosystèmes côtiers ou de montagnes)

Pour des niveaux de réchauffement qui pourront être atteints dans les prochaines décennies, d'autres limites dures seront atteintes :

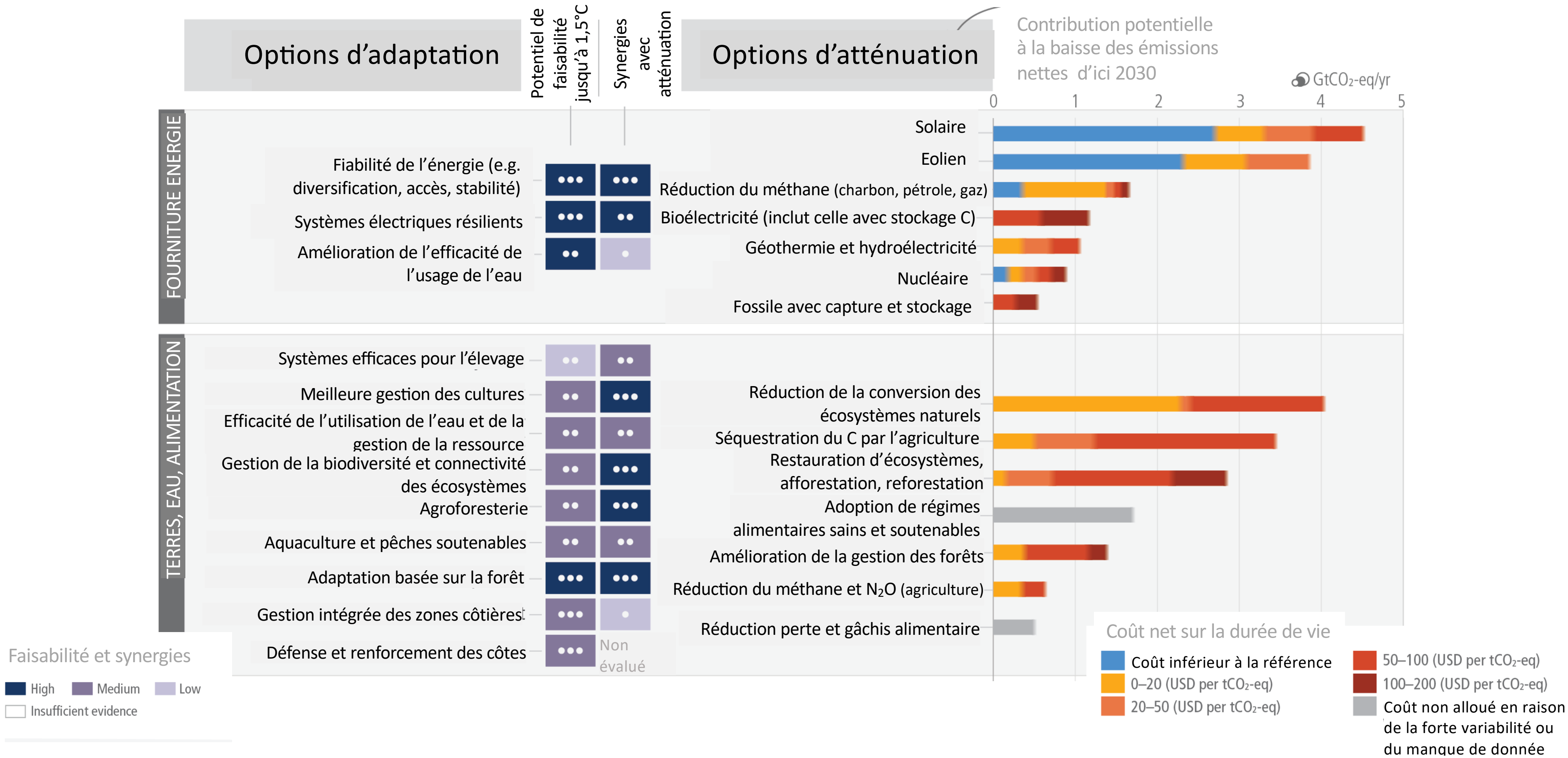
disponibilité des ressources en eau restreinte par le recul de l'enneigement et la perte de glaciers,

solutions fondées sur la nature peuvent devenir inopérantes

Des capacités de réponses limitées par temps de retour plus brefs d'évènements plus graves / composites / en cascade


Comment accélérer
l’action?

De nombreuses options d'actions faisables, efficaces et abordables sont disponibles maintenant pour réduire les émissions et s'adapter à un climat qui change



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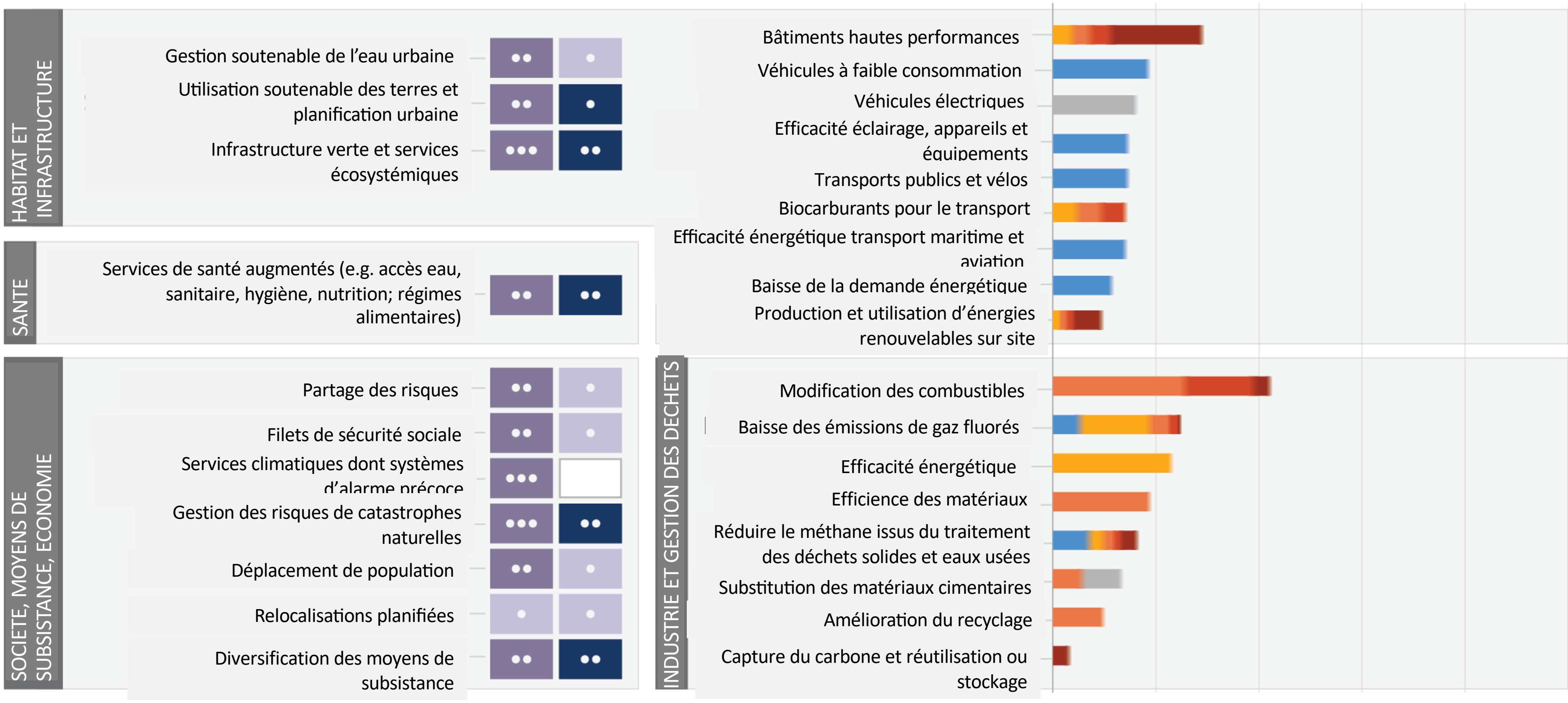
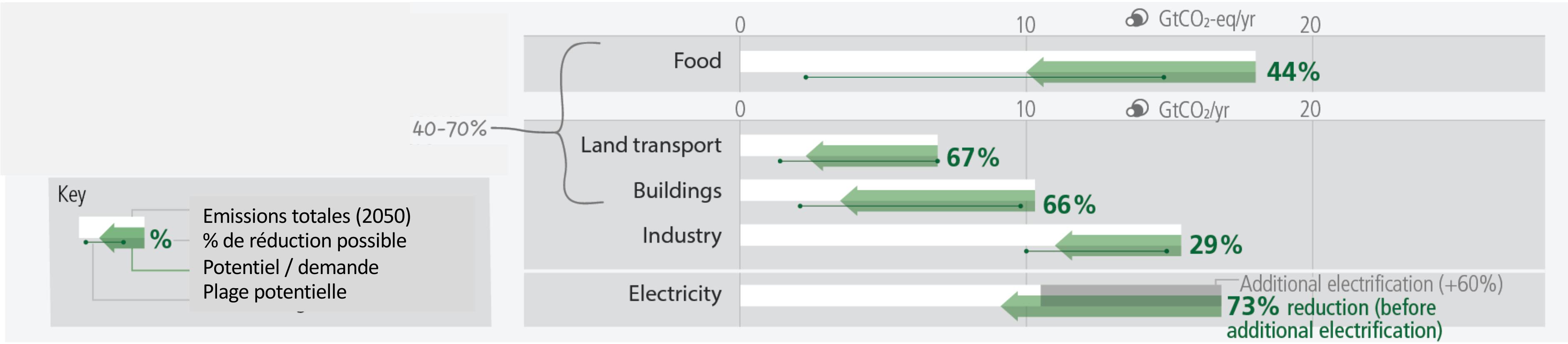


Les actions mises en place maintenant peuvent faire toute la différence

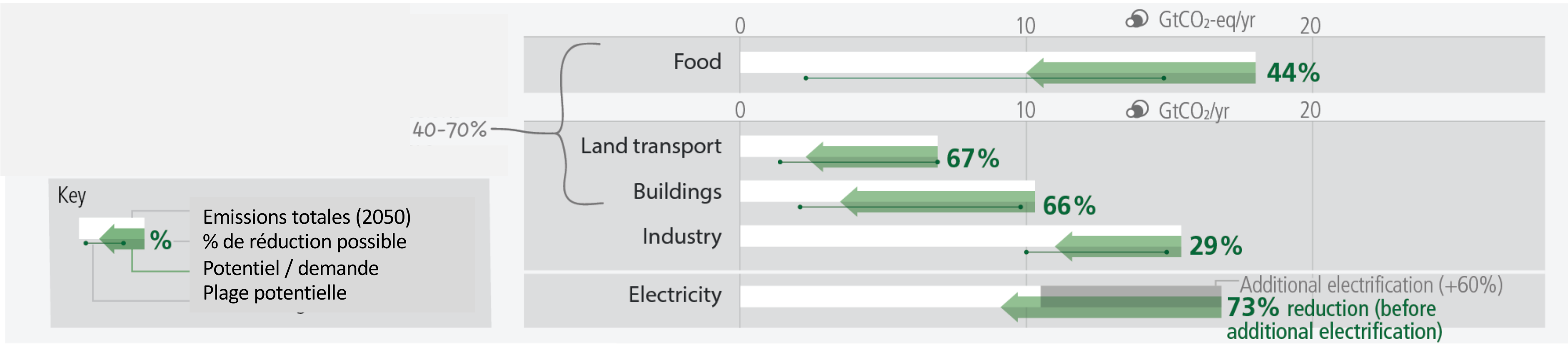
Potentiel à horizon 2050 des options d'atténuation basées sur la demande



Les politiques publiques et infrastructures jouent un rôle clé pour rendre accessible des styles de vie sobres en carbone

Les actions mises en place maintenant peuvent faire toute la différence

Potentiel à horizon 2050 des options d'atténuation basées sur la demande

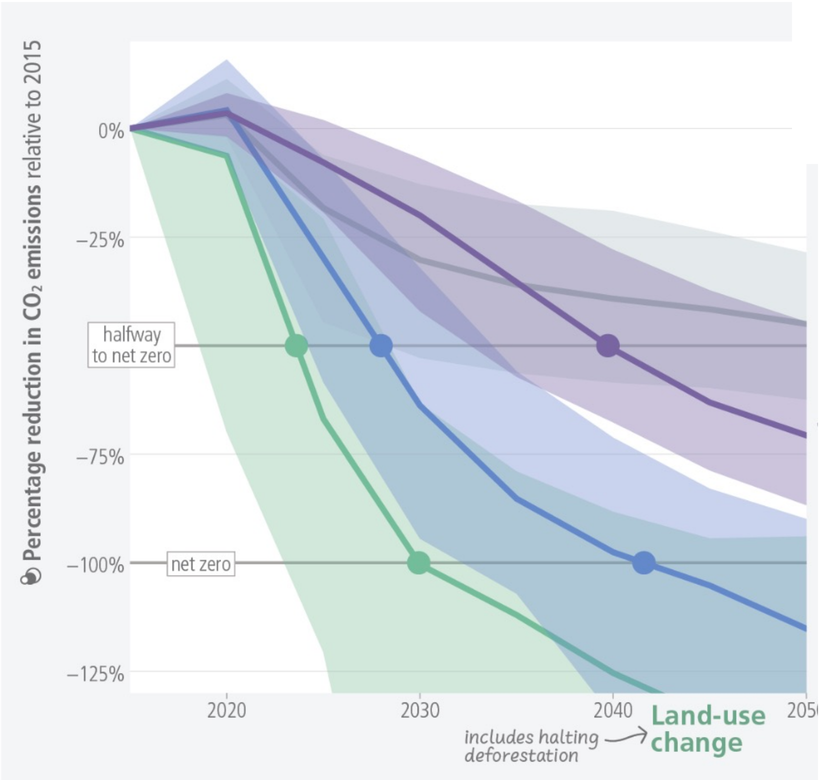


Les politiques publiques et infrastructures jouent un rôle clé pour rendre accessible des styles de vie sobres en carbone

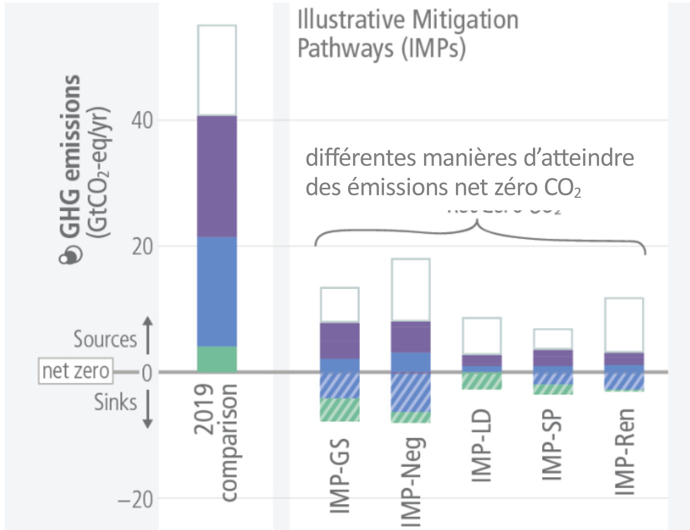
De nombreuses actions d'atténuation ont des bénéfices pour la santé : *qualité de l'air, mobilités actives, alimentation saine*

La transition vers des émissions net zéro de CO_2 aura des rythmes différents selon les secteurs

Emissions non CO_2
Transport, industrie, bâtiments
Production d'énergie (dont électricité)
Changements d'affectation des terres, foresterie

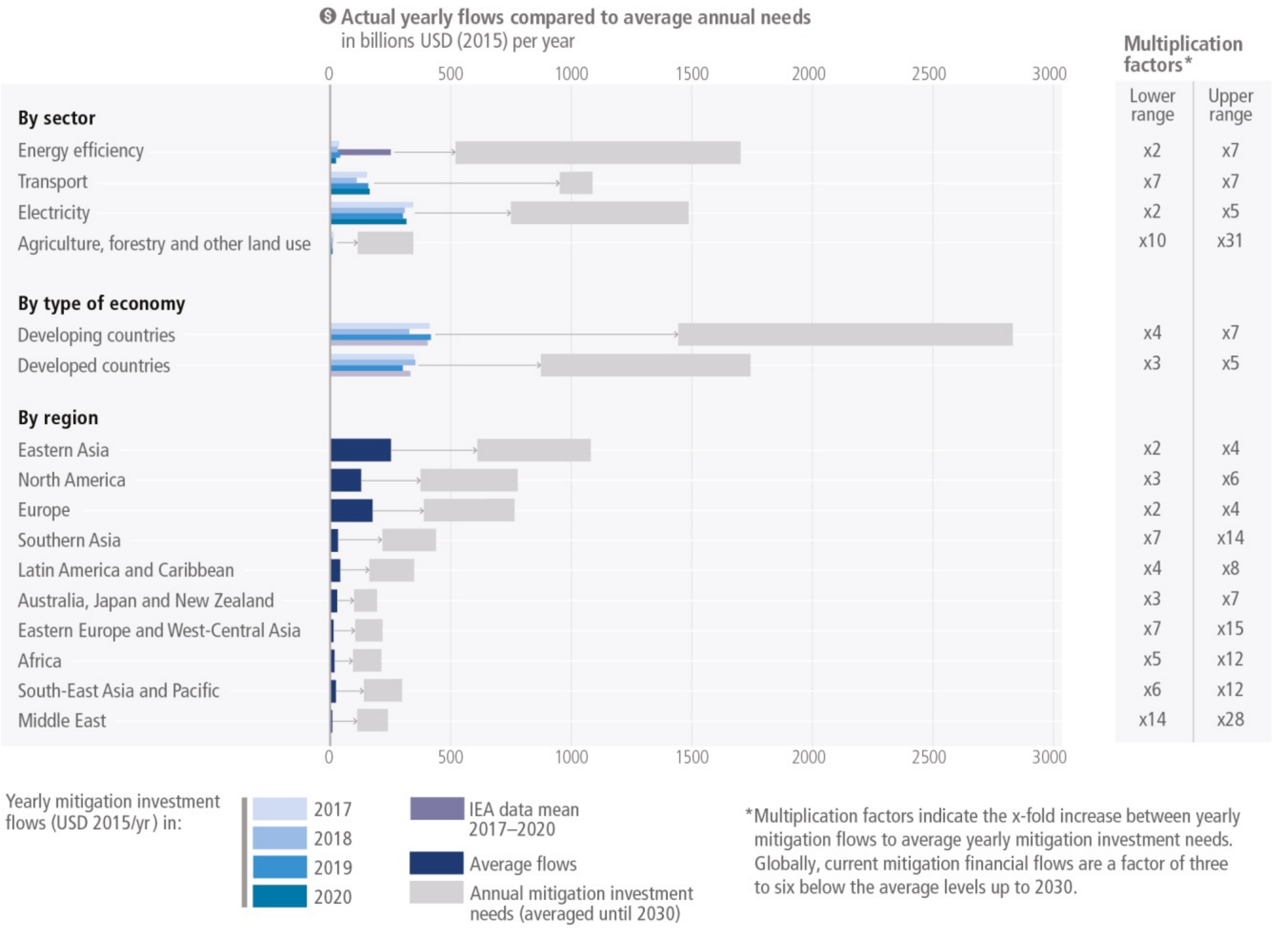


Les transferts de technologies permettent d'accélérer les transitions (leapfrogging)

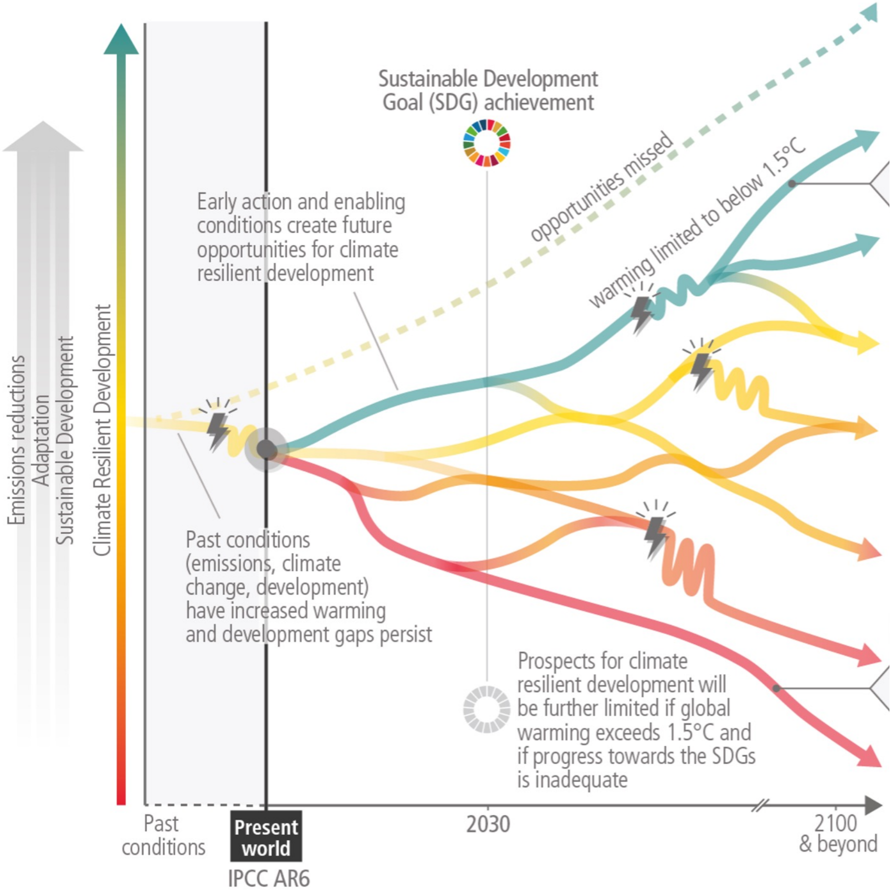


Conditions clés : finance, technologie, coopération internationale

Flux financiers annuels pour l’atténuation par rapport aux besoins à horizon 2030



Il est possible de construire un avenir viable et soutenable pour toutes et tous en agissant rapidement pour construire un développement résilient face au climat



nécessite :

Des **transitions profondes** dans tous les domaines (production d'énergie, infrastructures et aménagements du territoire, production d'alimentation, procédés industriels)

des **leviers d'action** :

- technologiques :
- maîtrise de la demande
- solutions fondées sur la nature

Des enjeux de transitions **éthiques, équitables et justes** (développement résilient, soutenable)

Conditions qui le permettent :

Gouvernance inclusive
Prise en compte des connaissances et valeurs variées
Finance
Innovation et Transfert technologique
Intégration entre les secteurs et échelles de temps
Gestion responsable des écosystèmes
Synergies entre actions de développement et actions climatiques
Changement comportementaux portées par des politiques publiques, des infrastructures et des facteurs socioculturels

IPCC AR6 SYR Figure SPM.2c

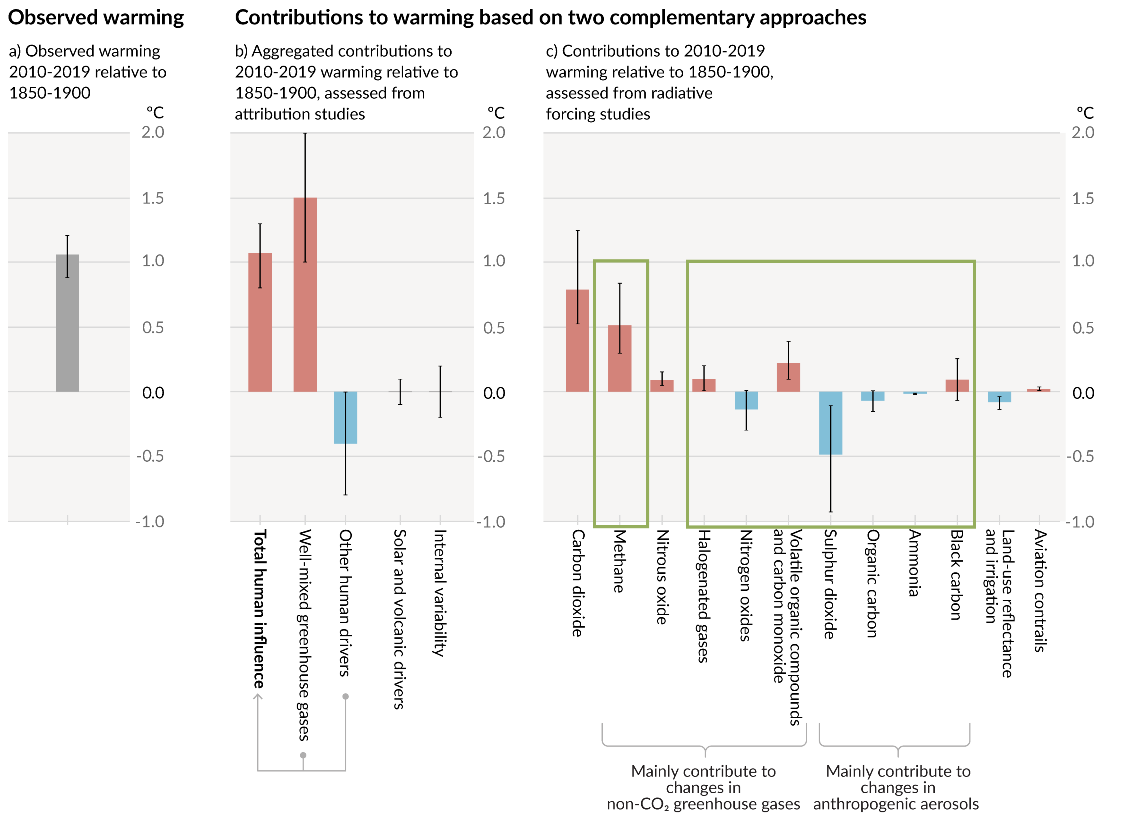

Nos choix
auront des répercussions
pendant des centaines
et des milliers d’années

Données et code des figures en accès libre

Site de **l'IPCC (GIEC),** une partie des documents en français
Atlas
FAQs /Box
Factsheets (e.g. Regional Factsheet « Europe », Sectoral Fact Sheet)

Résumé pour décideurs et résumés techniques (notamment figures et Box)

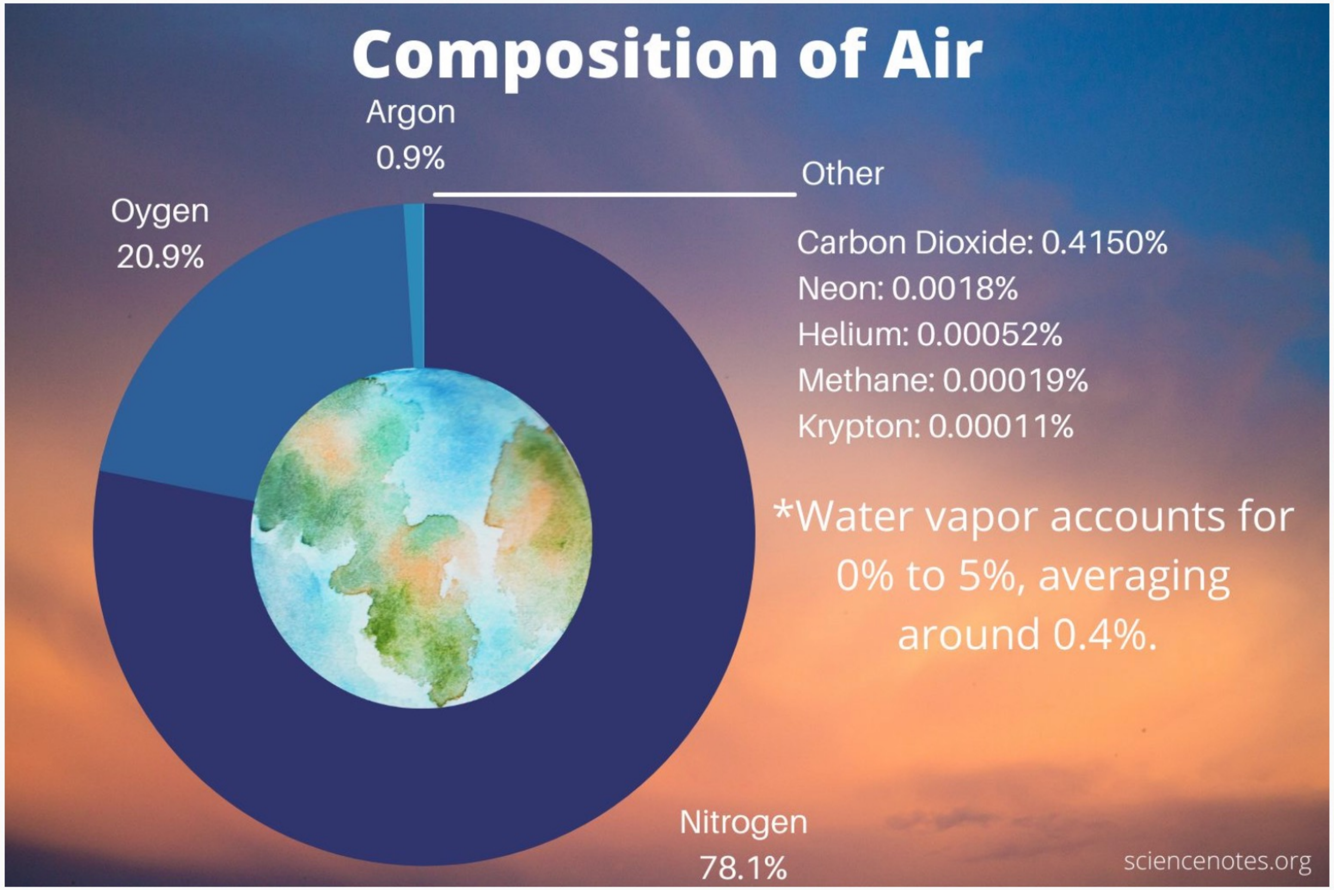
Influence de la chimie sur le climat



SLCF contributions

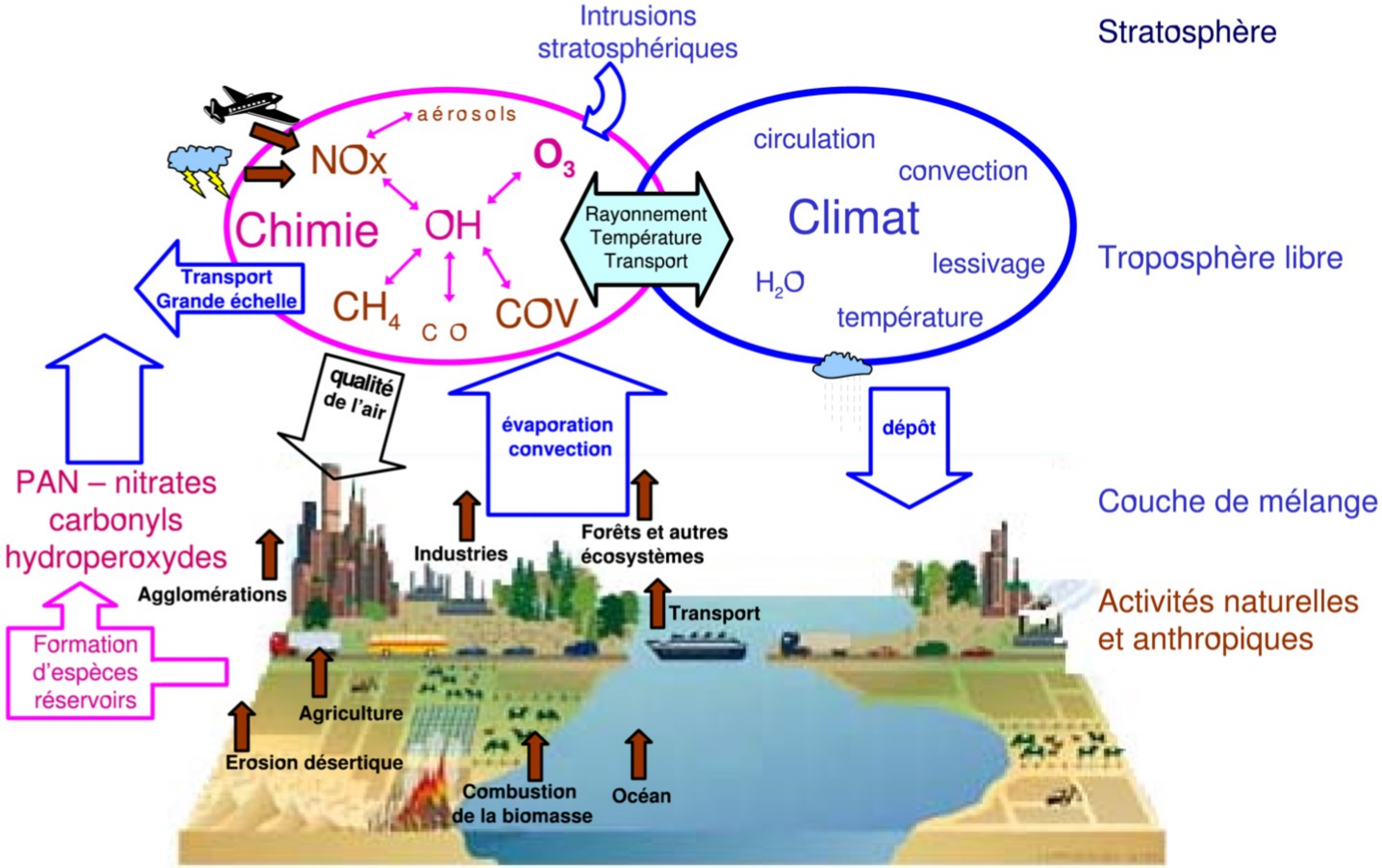
Figure SPM2 | Assessed contributions to observed warming in 2010-2019 relative to 1850-1900

La chimie atmosphérique



About 99% of the composition of air consists of nitrogen, oxygen, and argon. Water vapor (variable) and carbon dioxide are the main trace gases.

- Concerne des composés en quantité trace
- Consiste en une oxydation lente de ce qui est oxydable (donc pas le CO_2)
- L'énergie de cette chimie provient du rayonnement solaire



Interactions entre chimie troposphérique et climat

Composés ayant un impact climatique

Lifetime

LLCF Long lived climate forcers

CO_2
N_2O
CFC

WMGHG
well-mixed GHG

SLCF Short lived climate forcers

Composés chimiquement réactifs

CH_4
O_3
aérosols
others

What are SLCFs?

A set of chemically and physically reactive compounds with atmospheric **lifetimes typically shorter than two decades**

Compounds	Lifetime
CH_4	~9 years ~12 years (perturbation time)
O_3	Hours to weeks
NO_x (= NO + NO_2)	Hours to days
CO	1 to 4 months
NMVOCs**	Hours to months
SO_2	Days (trop.) to weeks (strat.)
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Very Short-lived Halogenated Species (VSLSs)	Less than 6 months
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Mineral dust	Minutes to Weeks

Overview of SLCFs of interest for Chapter 6 from **Table 6.1**

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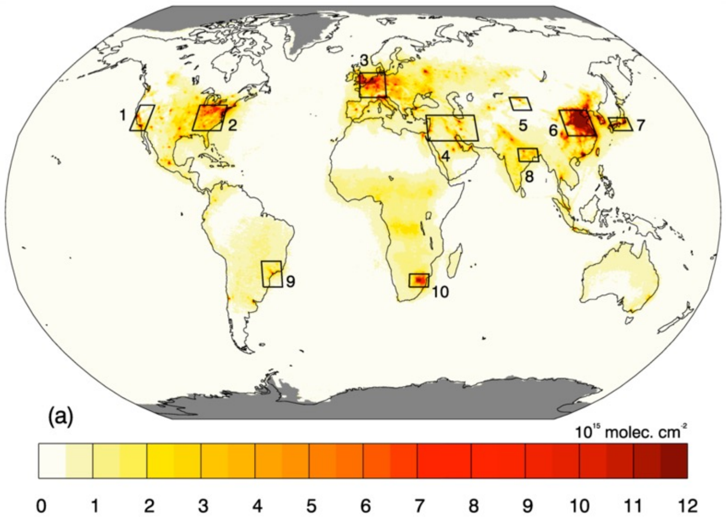

Long term climatological mean of tropospheric nitrogen dioxide (NO_2) vertical column density | From Figure 6.6

Overview of SLCFs of interest for Chapter 6 from Table 6.1

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Many SLCFs are also **air pollutants** with detrimental effects on human health and ecosystems

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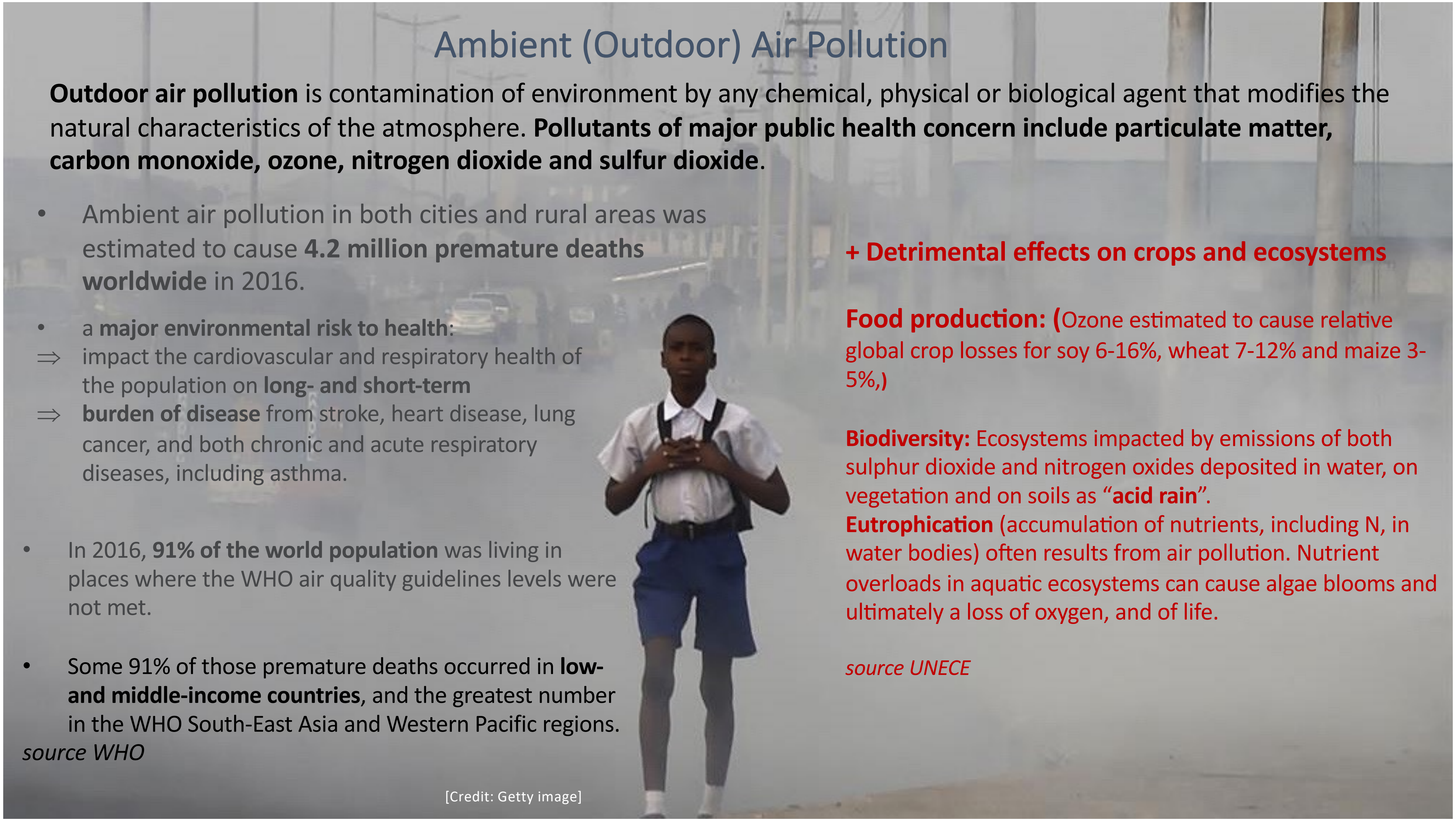

Ambient (Outdoor) Air Pollution

Outdoor air pollution is contamination of environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere. **Pollutants of major public health concern include particulate matter, carbon monoxide, ozone, nitrogen dioxide and sulfur dioxide**.

- Ambient air pollution in both cities and rural areas was estimated to cause **4.2 million premature deaths worldwide** in 2016.
- a **major environmental risk to health**:

⇒ impact the cardiovascular and respiratory health of the population on **long- and short-term**

⇒ **burden of disease** from stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases, including asthma.

- In 2016, **91% of the world population** was living in places where the WHO air quality guidelines levels were not met.
- Some 91% of those premature deaths occurred in **low- and middle-income countries**, and the greatest number in the WHO South-East Asia and Western Pacific regions.

source WHO

+ Detrimental effects on crops and ecosystems

Food production: (Ozone estimated to cause relative global crop losses for soy 6-16%, wheat 7-12% and maize 3-5%,)

Biodiversity: Ecosystems impacted by emissions of both sulphur dioxide and nitrogen oxides deposited in water, on vegetation and on soils as "**acid rain**".

Eutrophication (accumulation of nutrients, including N, in water bodies) often results from air pollution. Nutrient overloads in aquatic ecosystems can cause algae blooms and ultimately a loss of oxygen, and of life.

source UNECE

[Credit: Getty image]

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Replacements compounds of ozone depleting substances (Montreal protocol)

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NO_x (= NO + NO_2)	Hours to days
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Rapid response of abundances to change in emissions and consequently on climate effects

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Can influence the Earth's radiation budget **directly and/or indirectly**

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Rapid response of abundances to change in emissions and consequently on climate effects

+ intermediary compounds e.g. OH

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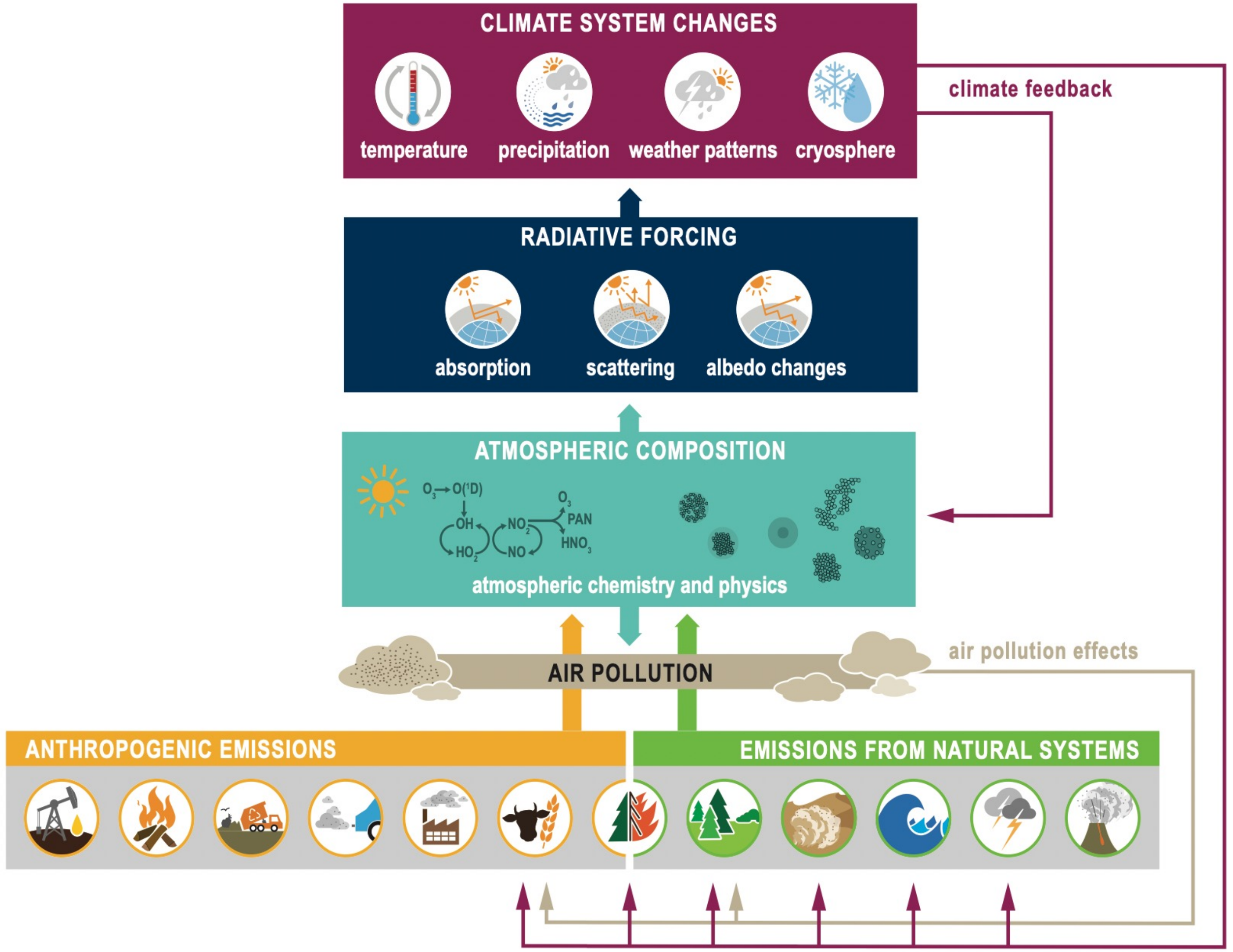
Sources and processes contributing to SLCFs and their effects on the climate system



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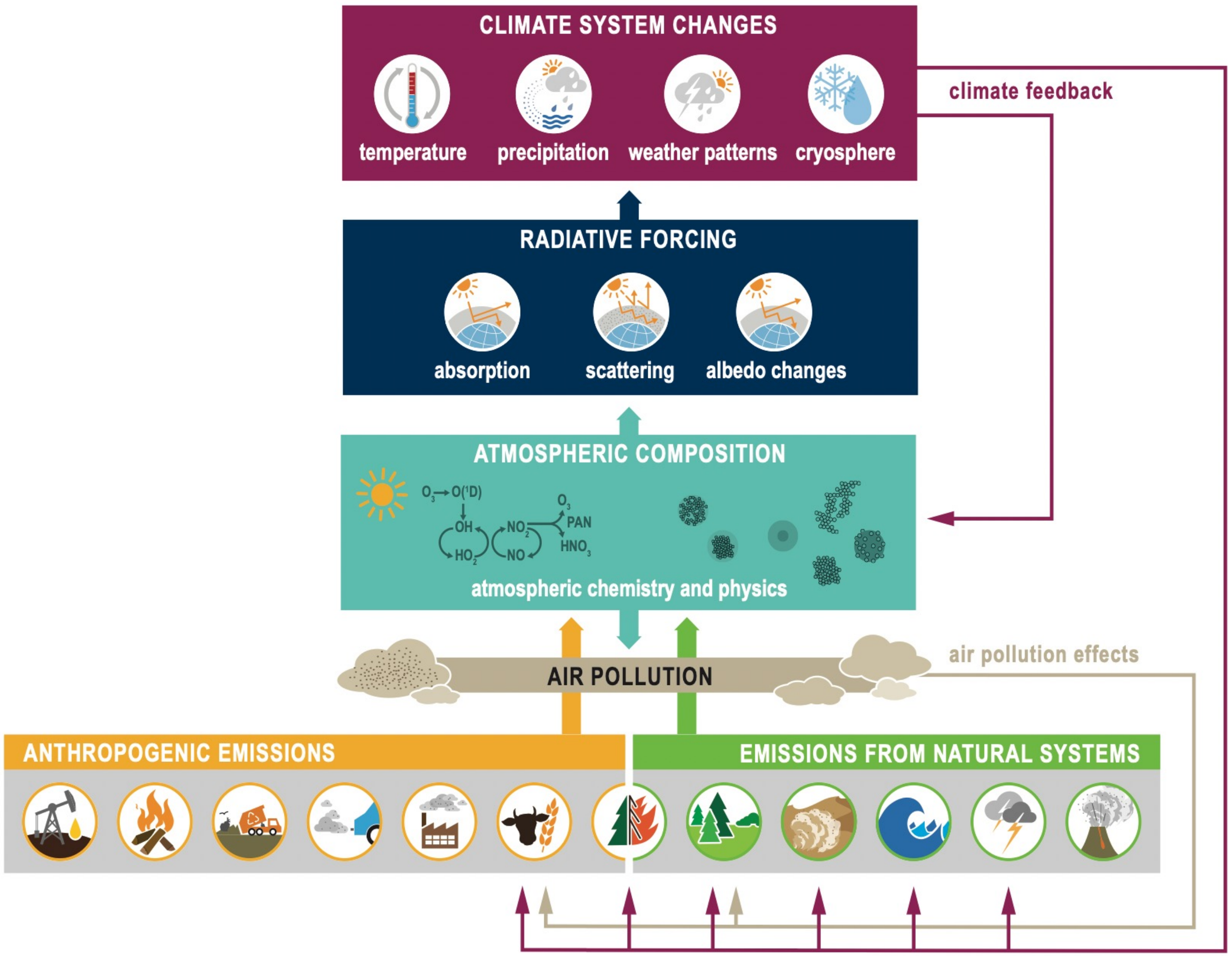
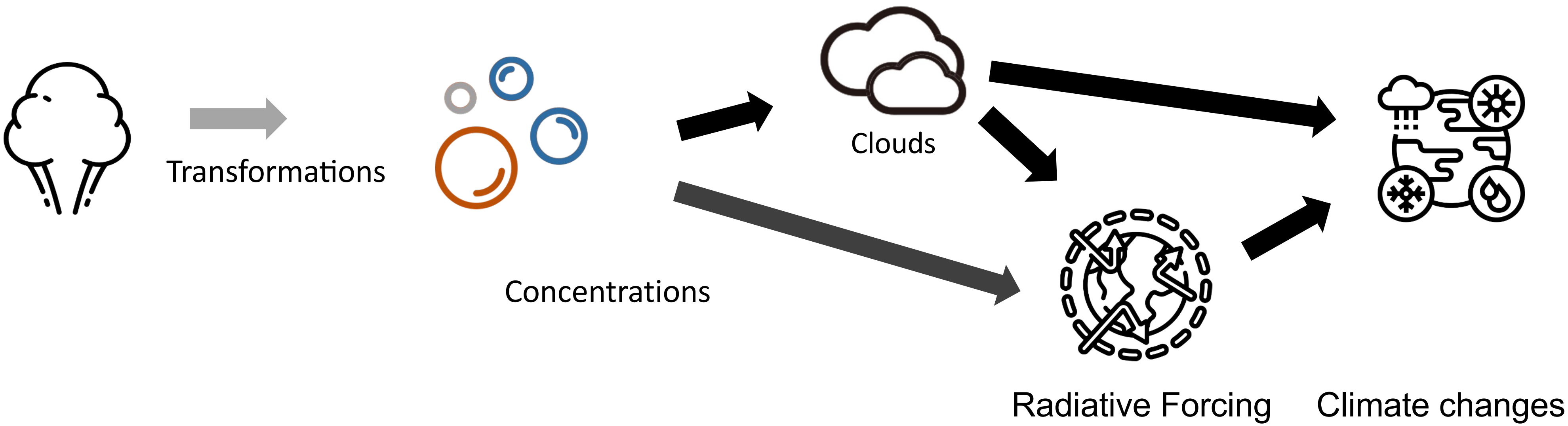


Connections with climate change:

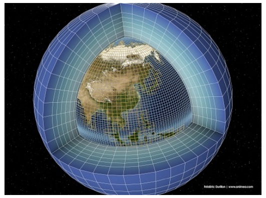
- Air pollutants act on climate directly or indirectly (action on climate forcers or on cloud properties)
- Climate Change impacts air pollution formation, removal and dispersion (and feedbacks on CC)
- Air pollution affects terrestrial biota and C and N cycles
- Air pollutants are co-emitted with GHGs by human activities (combustion of fossil fuel, agriculture..)

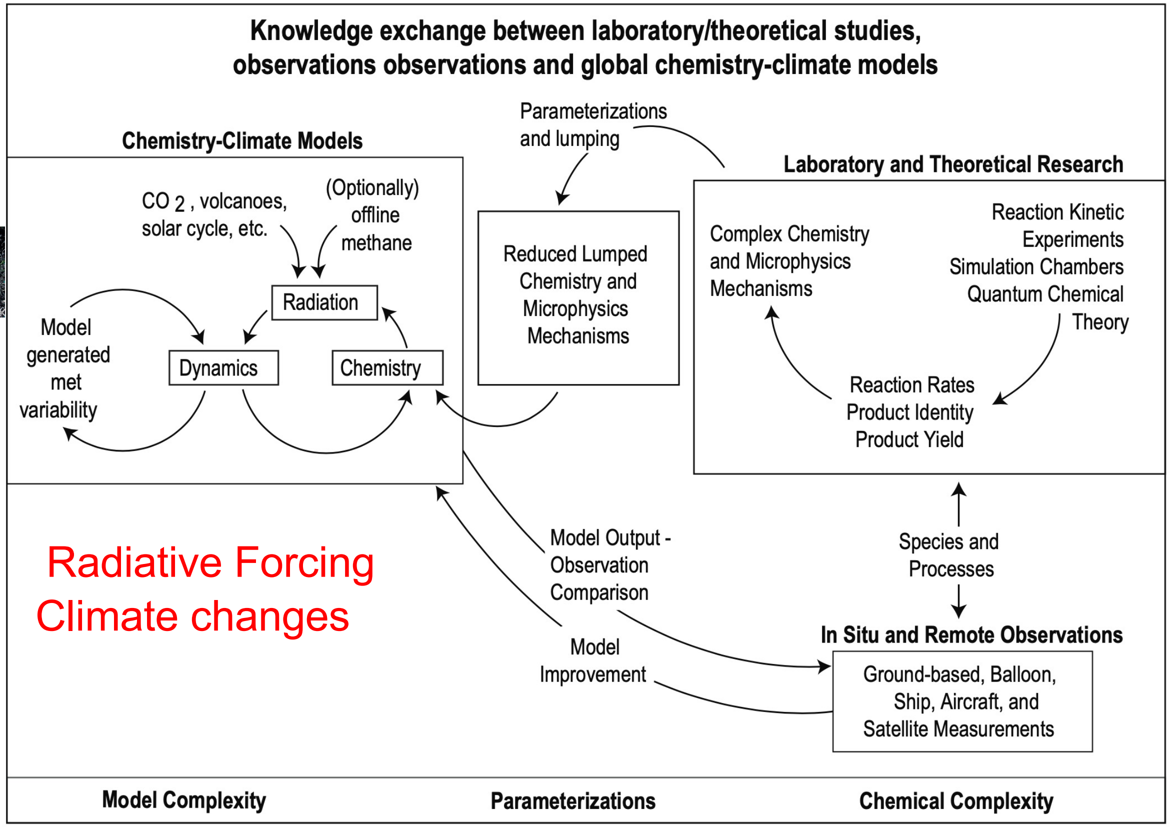
How do we study SLCFs and assess their climate effects?



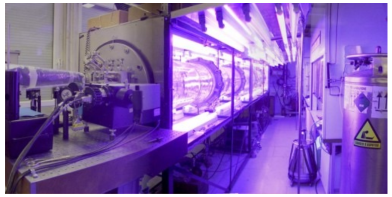
From emissions to climate effects

How do we study SLCFs?





Radiative Forcing
Climate changes



Concentrations

Transformations

Des sources différentes par polluant

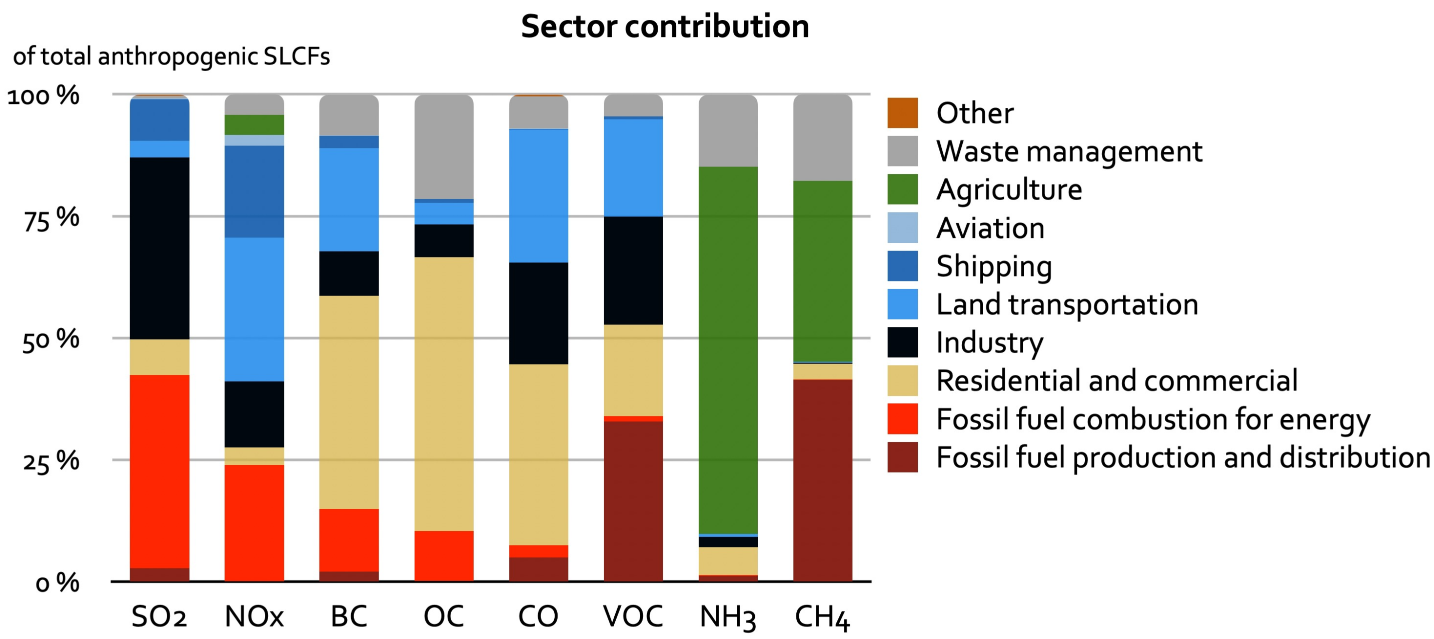


Figure 6.3 | Relative sectoral and regional contributions to the present day (year 2014) anthropogenic emissions of SLCFs

Des sources différentes par régions

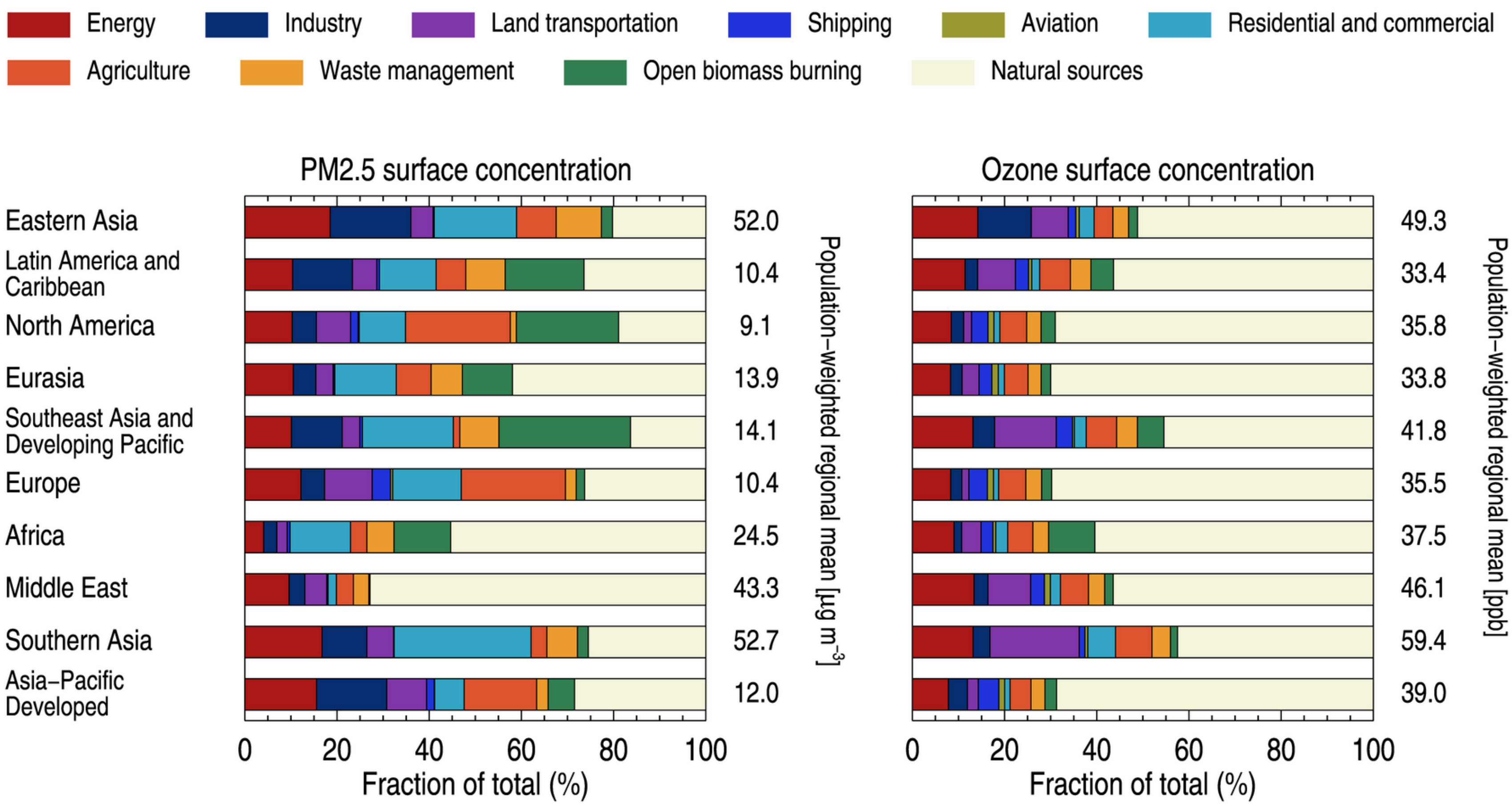
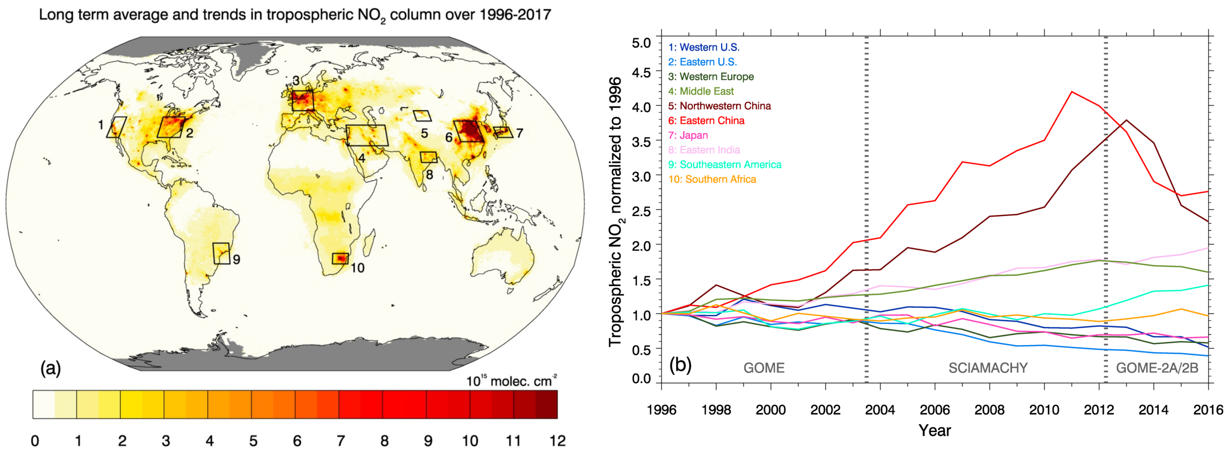


Figure 6.17 | Emission source-sector attribution of regional population weighted mean concentrations of $PM_{2.5}$ and O_3 for present day emissions

Des distributions très hétérogènes

From Figure 6.6 / Long term climatological mean (a) and time evolution (b) of tropospheric NO_2 vertical column density



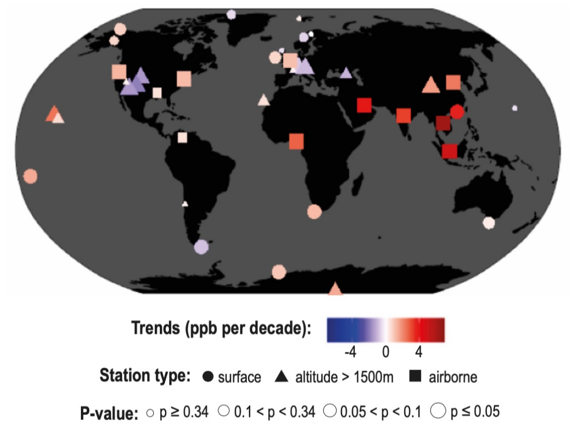


Figure 6.5 | Decadal tropospheric ozone trends since 1994

Des tendances d'évolution qui varient dans d'une région et d'un composé à l'autre

Changes in emissions since preindustrial

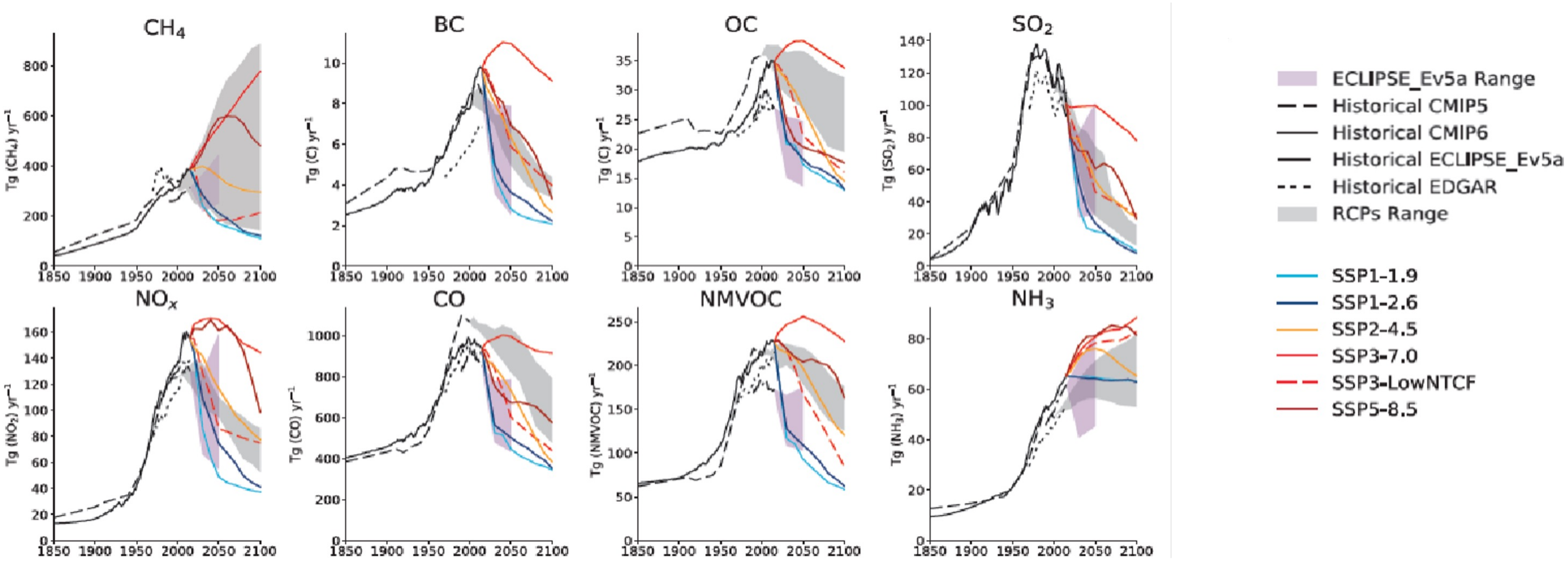
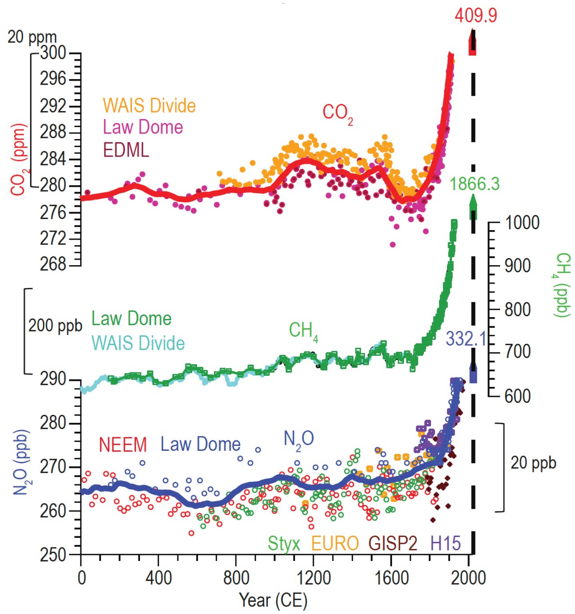


Figure 6.18 | **Global anthropogenic and biomass burning SLCFs (except HFCs) emissions from 1850 to 2000**

Les variations sur de longues échelles de temps

Changes in atmospheric composition since preindustrial



since 1750, CH_4 increased by 156%

Figure 2.4 | Atmospheric well-mixed GHG concentrations from ice-cores

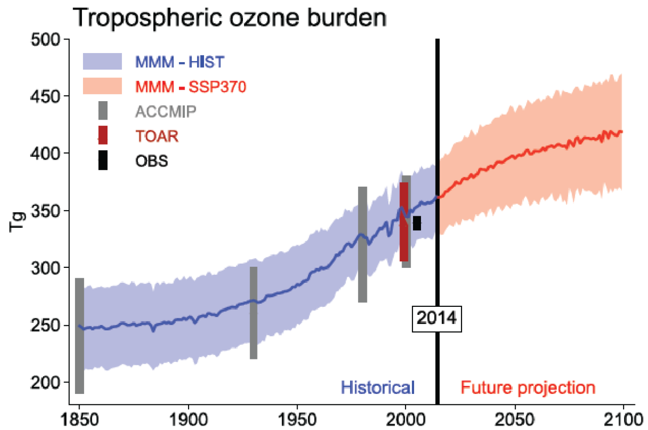


Figure 6.4 | Evolution of global annual mean tropospheric ozone burden (in Tg)

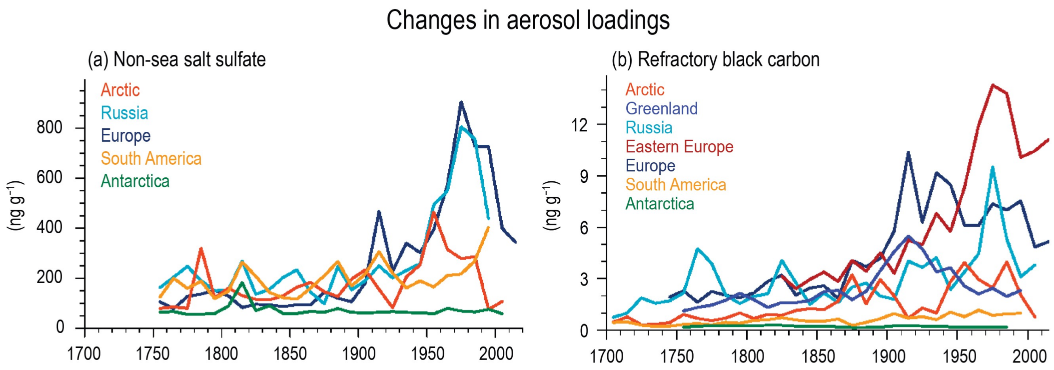


Figure 2.9 | Aerosol evolution from ice-core measurements

Comment le changement climatique affecte-t-il la pollution (i.e. ozone et particules et leurs précurseurs)?

Ozone: baisse dans les régions éloignées des sources de pollution
augmentation de quelques ppb dans les régions polluées (d'autant plus qu'elles sont polluées.

Particules fines: effets mixtes (+ et -) mais faibles sur les moyennes mondiales, même s'il est impossible d'exclure des effets forts localement dans certaines régions du monde.

Encore beaucoup d'incertitude dans les réponses au changement climatique future des processus liés aux systèmes naturels et qui agissent sur qualité de l'air (e.g., échange depuis la stratosphère, émissions de précurseurs naturels (comme COV), feux, éclairs)

[Credit: © UNICEF/Roger LeMoyne]

Le changement climatique a des effets mitigés sur la pollution atmosphérique et le principal moteur de l'évolution de la pollution atmosphérique mondiale sera le changement des émissions (c'est-à-dire le niveau des politiques environnementales et potentiellement les changements dans les émissions naturelles).

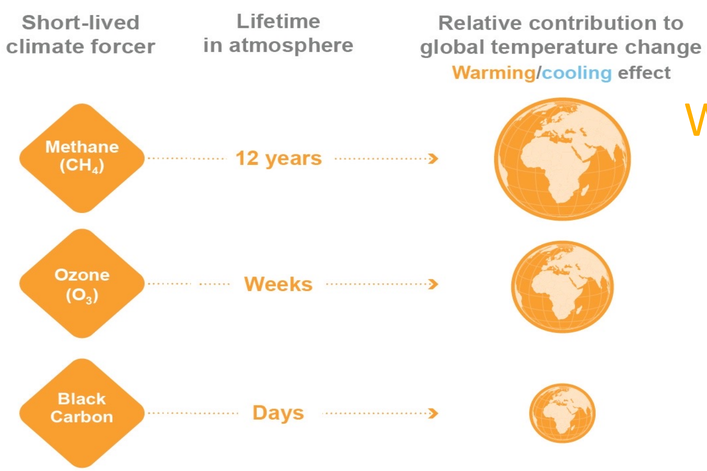
INTERGOVERNMENTAL PANEL ON climate change

ipcc

WMO UNEP

Comment la pollution affecte-t-elle le climat?

How do air pollutants act on climate?

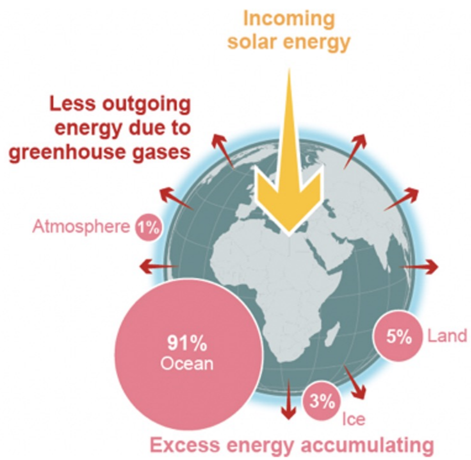


Adapted from FAQ 6.1, Figure 1

WARMING

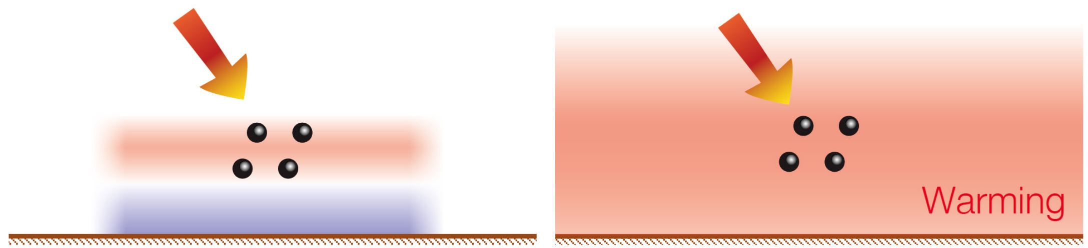
Increases in GHG levels have led to more of the emitted thermal radiation being absorbed by the atmosphere, instead of being released to space

+ dark aerosols absorbing solar radiation



from WGI AR6 FAQ 7.1

Absorbing aerosols



Aerosols absorb solar radiation. This heats the aerosol layer but the surface, which receives less solar radiation, can cool locally.

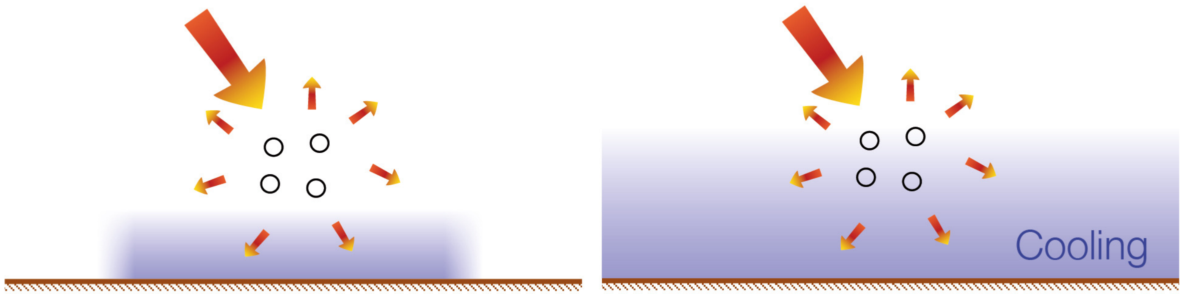
At the larger scale there is a net warming of the surface and atmosphere because the atmospheric circulation and mixing processes redistribute the thermal energy.

from WG1 AR5 FAQ 7.1

How do air pollutants act on climate?

Aerosol-radiation interactions

Scattering aerosols



Aerosols scatter solar radiation. Less solar radiation reaches the surface, which leads to a localised cooling.

The atmospheric circulation and mixing processes spread the cooling regionally and in the vertical.

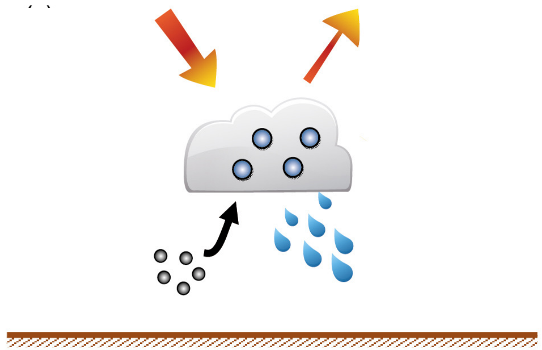
Adapted from FAQ 6.1, Figure 1

COOLING

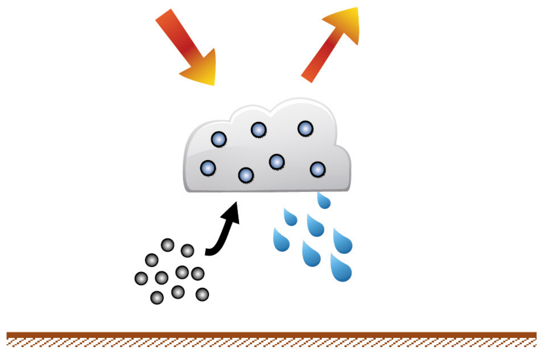
Increases in aerosols such as sulphates in the atmosphere

=> more incoming sunlight being reflected away, by the aerosols + formation of more **cloud** drops, which increases the reflectivity of clouds

Aerosol-cloud interactions

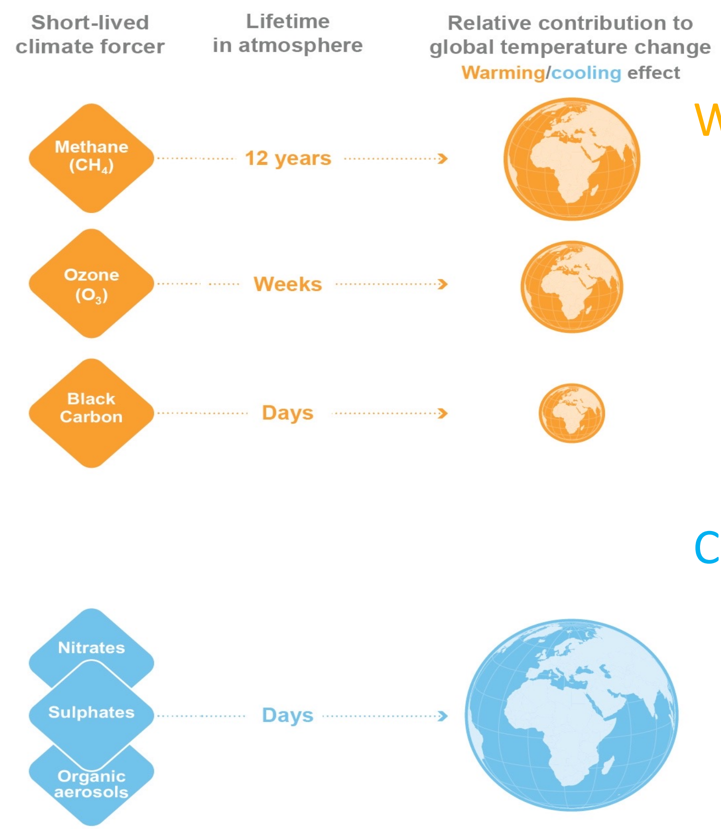


Aerosols serve as cloud condensation nuclei upon which liquid droplets can form.



More aerosols result in a larger concentration of smaller droplets, leading to a brighter cloud. However there are many other possible aerosol–cloud–precipitation processes which may amplify or dampen this effect.

How do air pollutants act on climate?



Adapted from FAQ 6.1, Figure 1

WARMING

Increases in GHG levels have led to more of the emitted thermal radiation being absorbed by the atmosphere, instead of being released to space

+ dark aerosols absorbing solar radiation

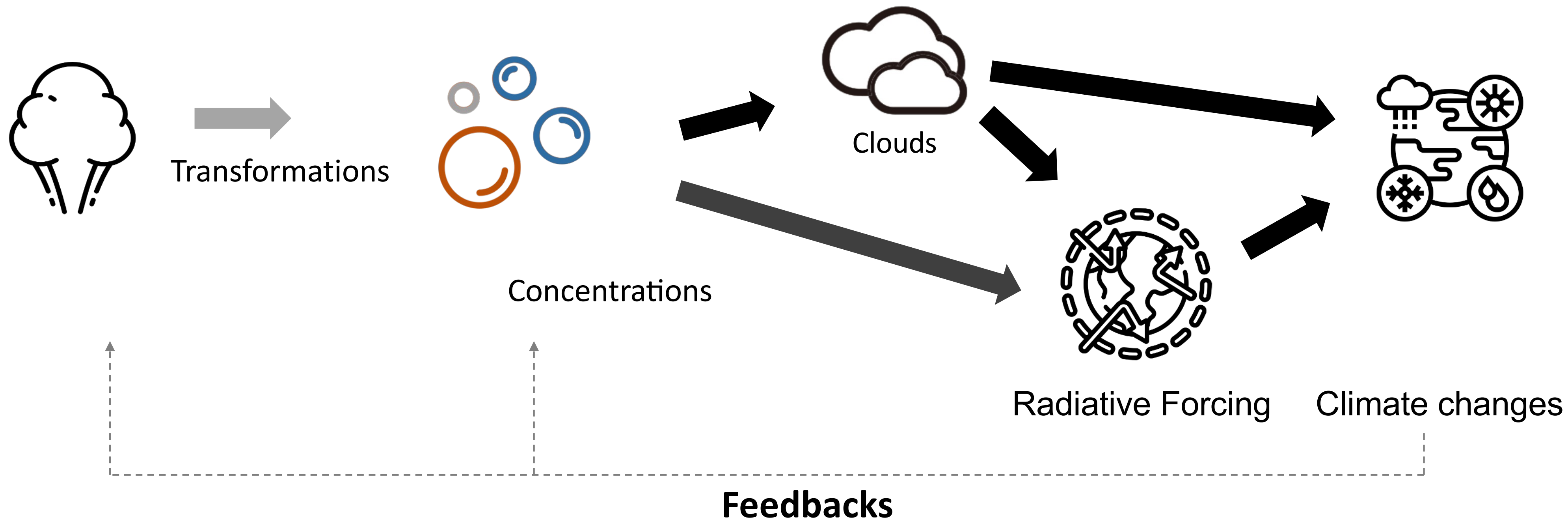
COOLING

Increases in aerosols such as sulphates in the atmosphere

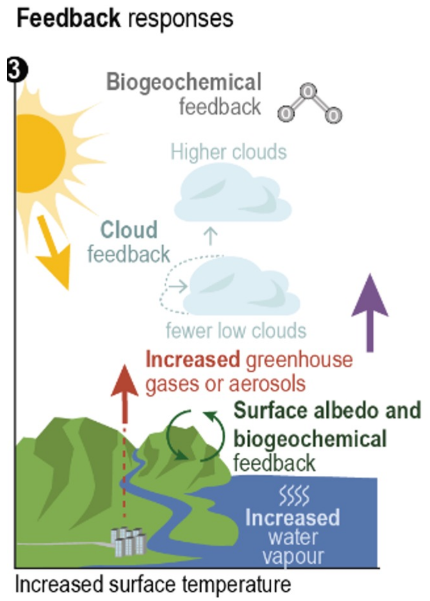
=> more incoming sunlight being reflected away, by the aerosols + formation of more **cloud** drops, which increases the reflectivity of clouds

Note: Some are formed through (non-linear) chemical processes => thus precursors (CO, NOx, VOC are also considered as climate forcers)

Feedbacks


Transformations
Clouds
Concentrations
Radiative Forcing
Climate changes
Feedbacks

Feedbacks involving SLCFs



IPCC AR6 Figure TS.14

Feedbacks involving SLCFs: if T ↗ =>

Permafrost extent ↘ + T wetlands ↗ => CH_4 emissions

SST ↗ + sea-ice extent ↘ + changes in winds => sea-salt emissions ↗

SST ↗ + sea-ice extent ↘ + changes in winds + pH ↘ => DMS emissions ↘

Aridity ↗ + changes in winds => changes dust emissions

Changes in vertical circulation+ water wapor ↗ => changes in ozone distribution

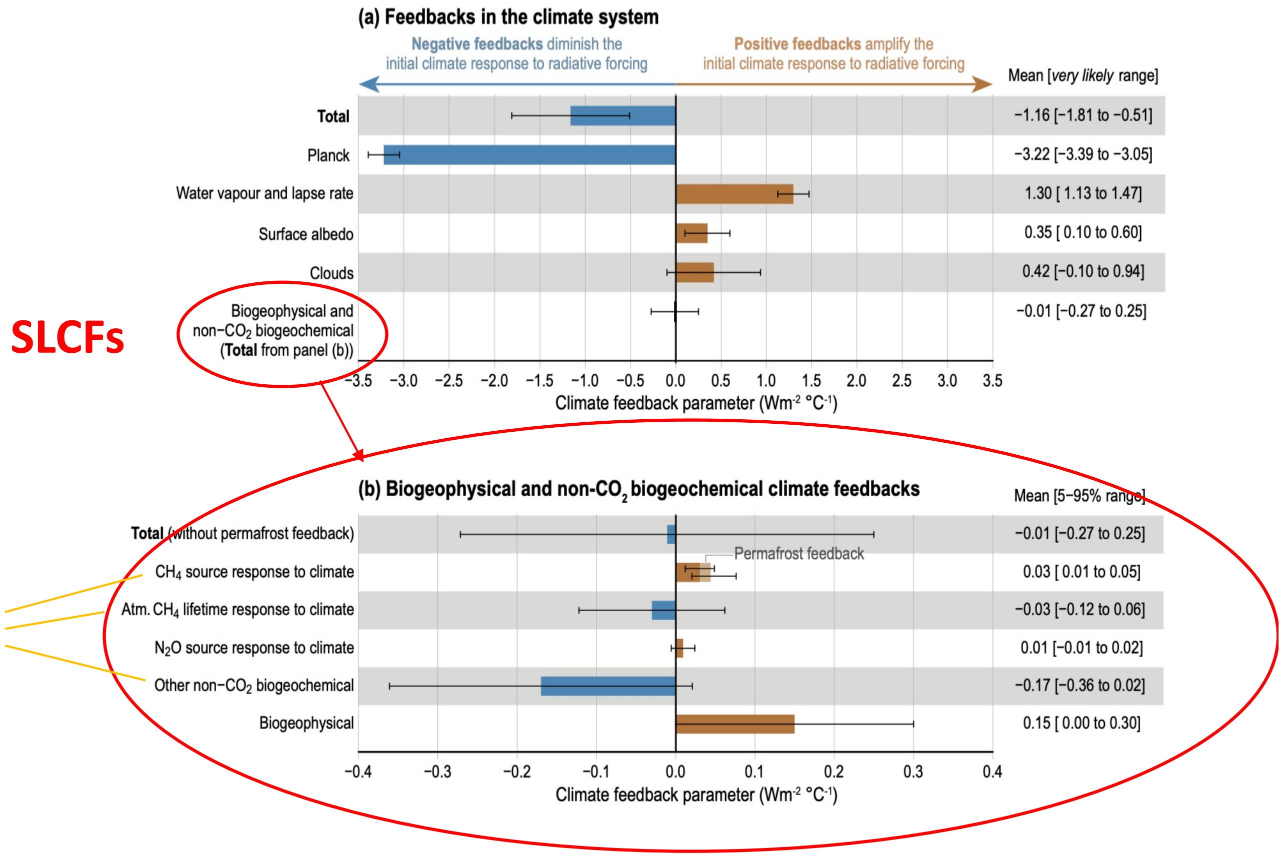
T ↗ + CO_2 ↗ => biogenic organic compounds emissions ↗ (?) => organic aerosols ↗ + Ozone ↗ + CH_4 lifetime ↗

Changes in lightning => change in NOx emissions ??

T ↗ + in water wapor ↗ => ↗ OH => ↗ CH_4 destruction

Changes in Fire ? => changes in CH_4, aerosol and ozone precursors emissions

Feedbacks involving SLCFs



Small but **very** uncertain

Le réchauffement observé est dû aux émissions des activités humaines, le réchauffement des gaz à effet de serre étant partiellement masqué par le refroidissement des aérosols

+1.1°C

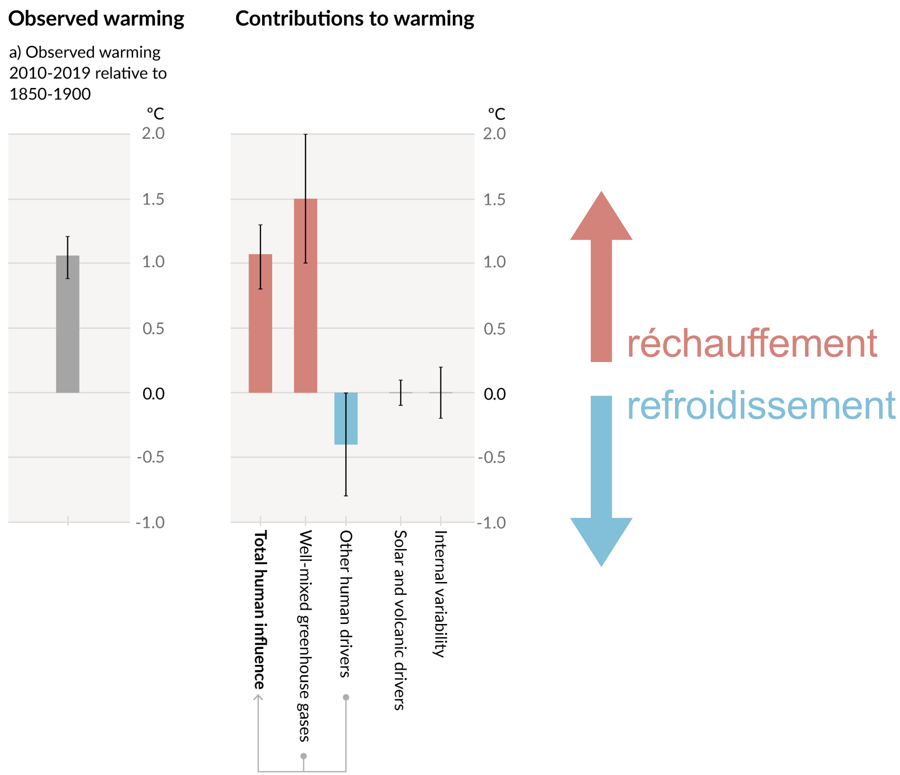


Figure SPM.2

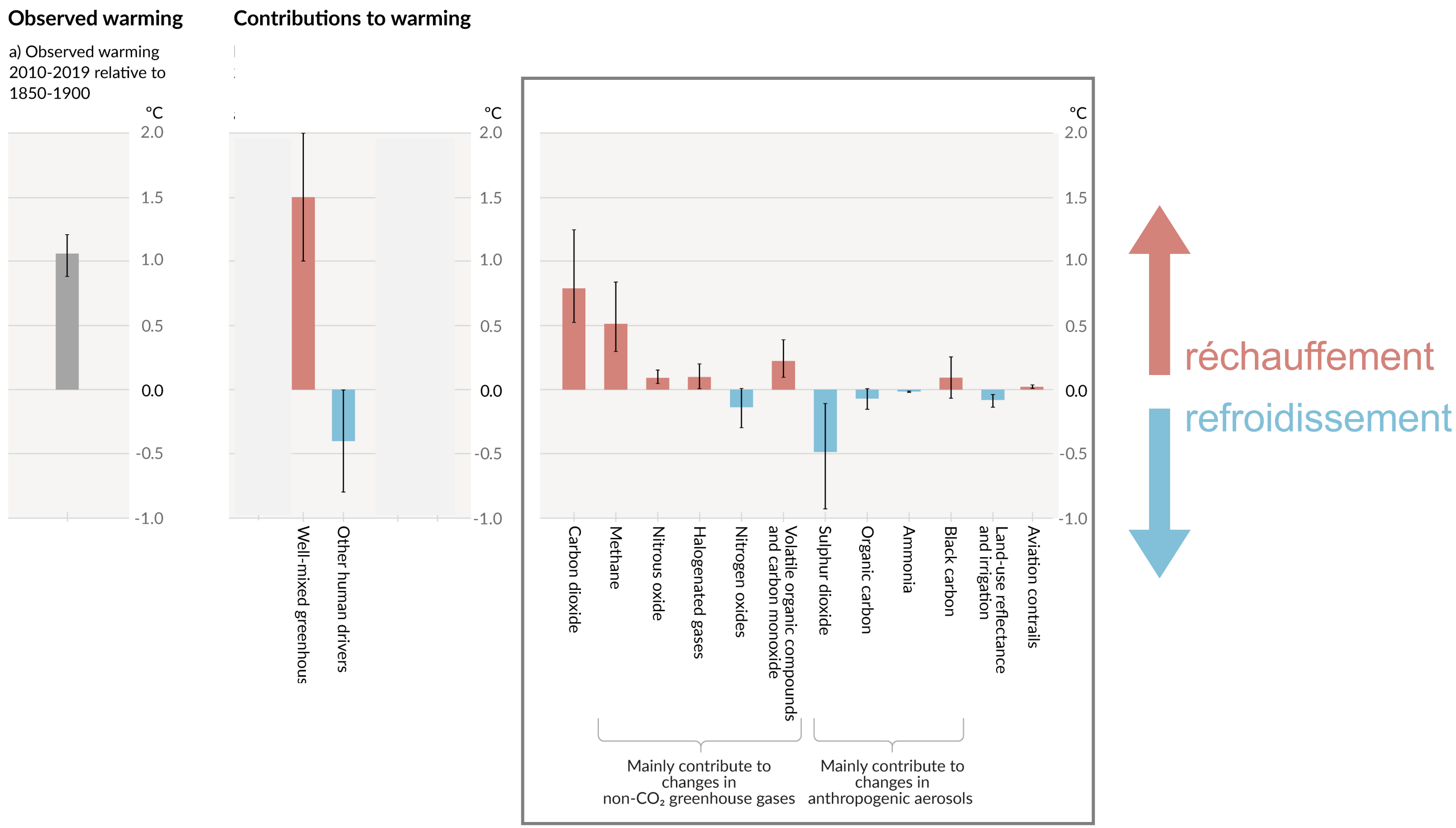

Observed warming
Contributions to warming
a) Observed warming
2010-2019 relative to
1850-1900
°C
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
Well-mixed greenhous
Other human drivers
Carbon dioxide
Methane
Nitrous oxide
Halogenated gases
Nitrogen oxides
Volatile organic compounds
and carbon monoxide
Sulphur dioxide
Organic carbon
Ammonia
Black carbon
Land-use reflectance
and irrigation
Aviation contrails
Mainly contribute to
changes in
non-CO_2 greenhouse gases
Mainly contribute to
changes in
anthropogenic aerosols
réchauffement
refroidissement

Figure SPM.2

CO_2 :

Énergies fossiles (80-90%)
Changements d'usages des terres

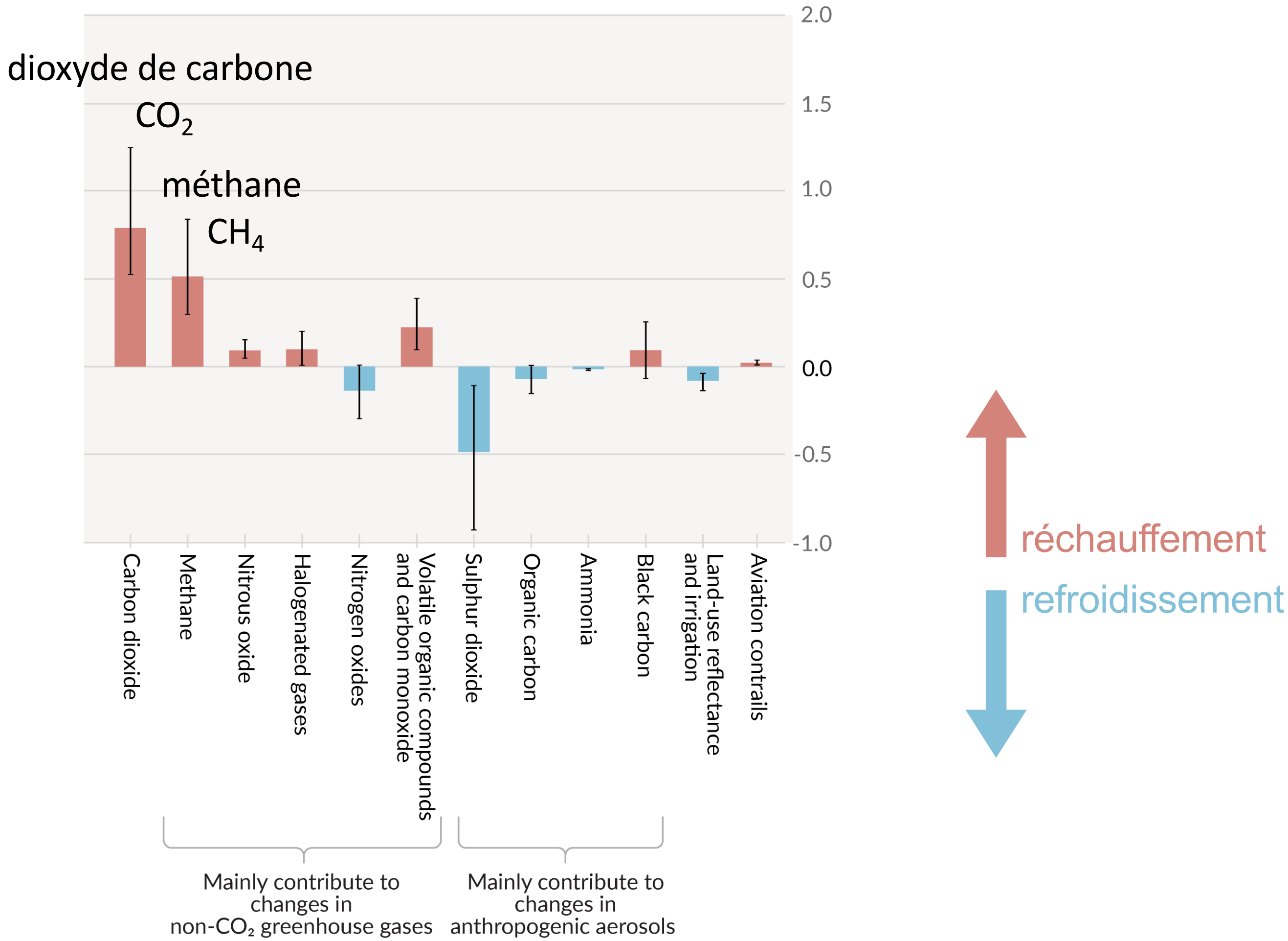
56% des émissions absorbées par l'océan (acidification), la végétation et les sols

Effet cumulatif, dominant

CH_4 :

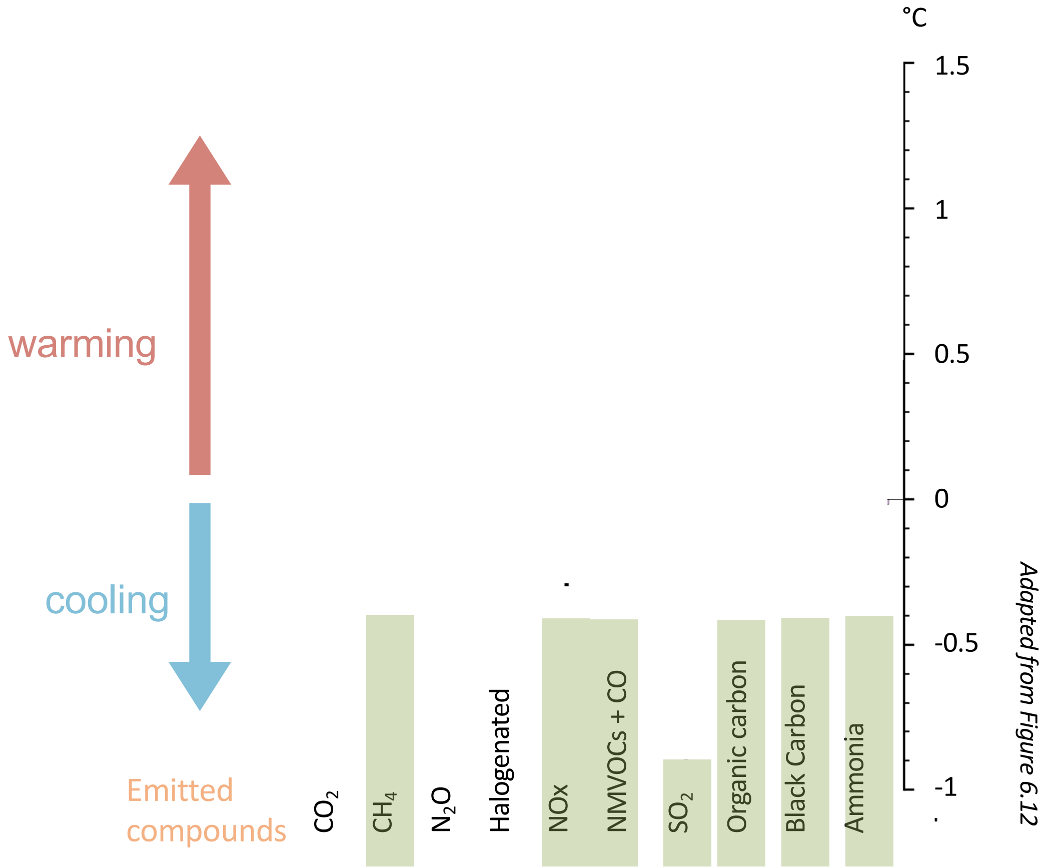
Énergies fossiles
Activités agricoles (élevage)

Durée de vie courte (10 ans)
Affecte la qualité de l'air

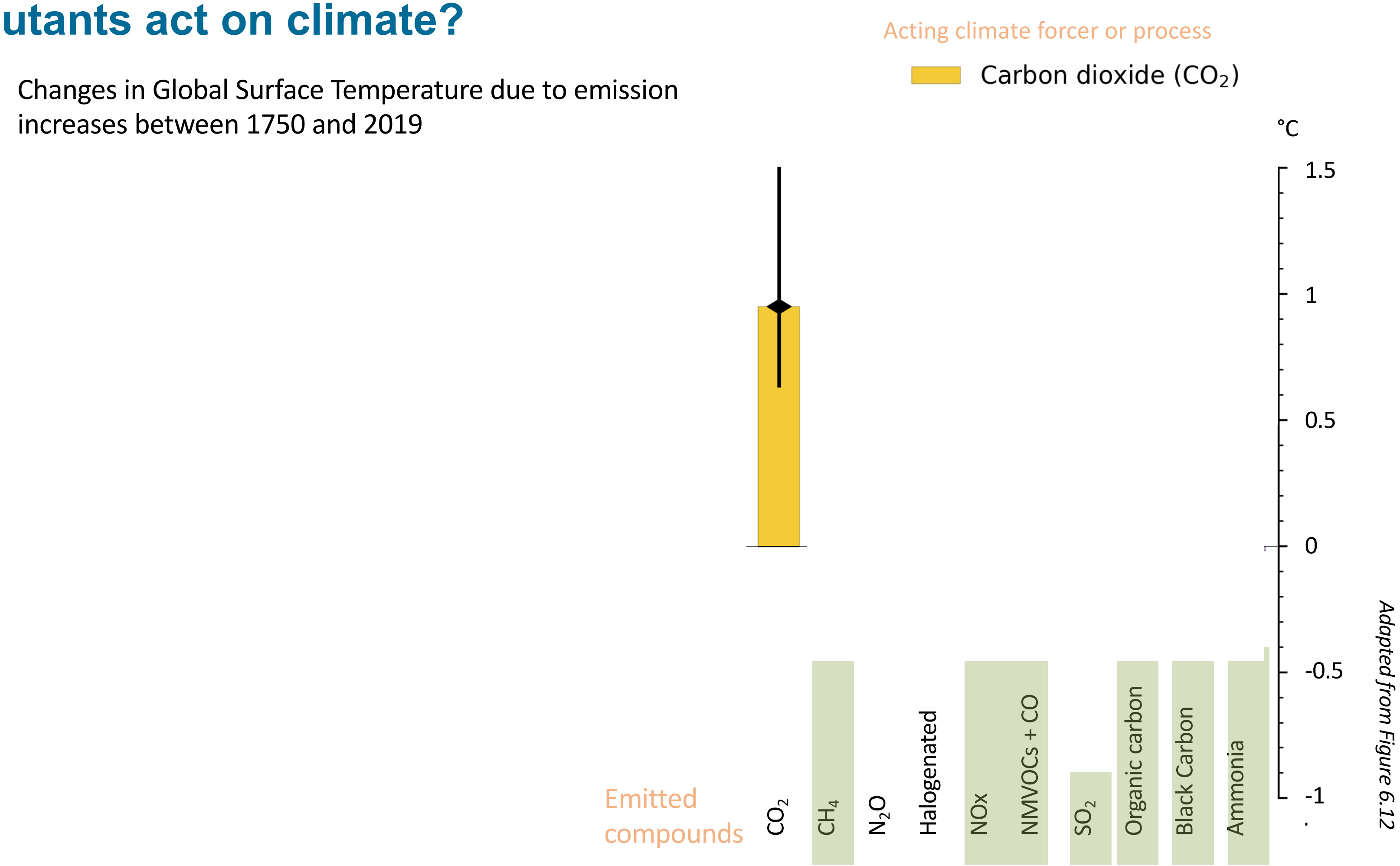


How do air pollutants act on climate?

Changes in Surface Temperature due to emission increases between 1750 and 2019



How do air pollutants act on climate?



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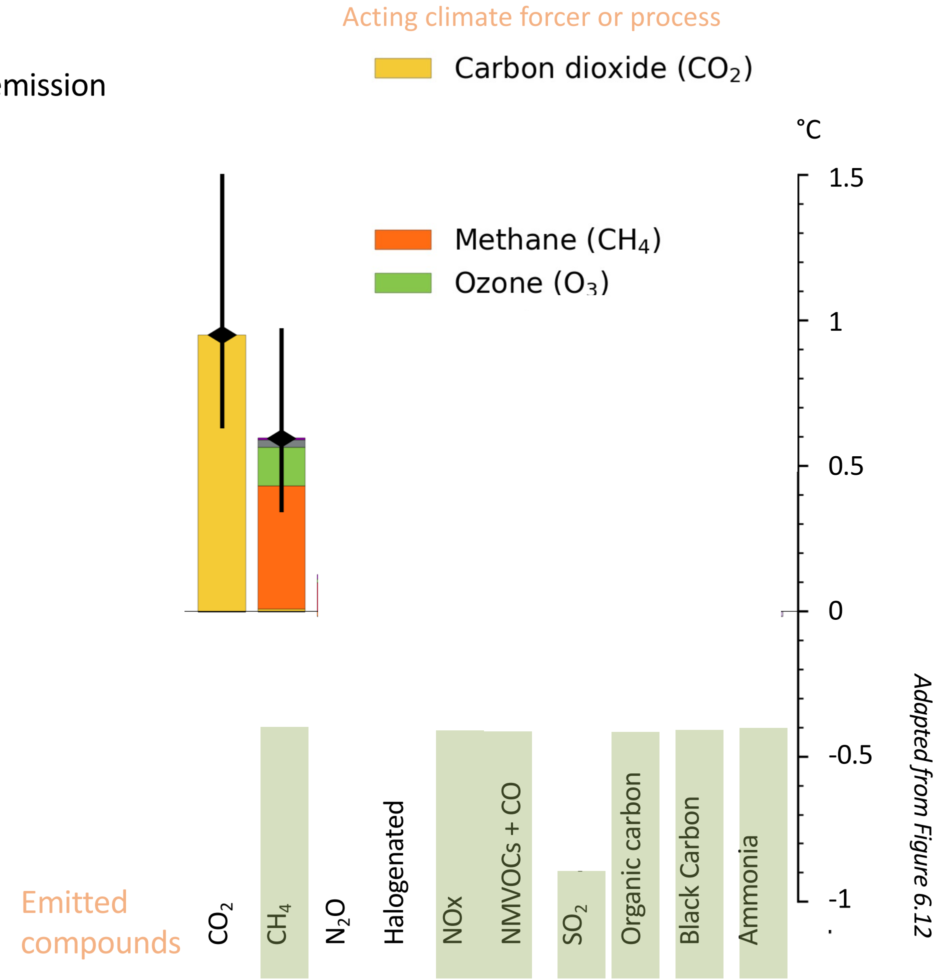

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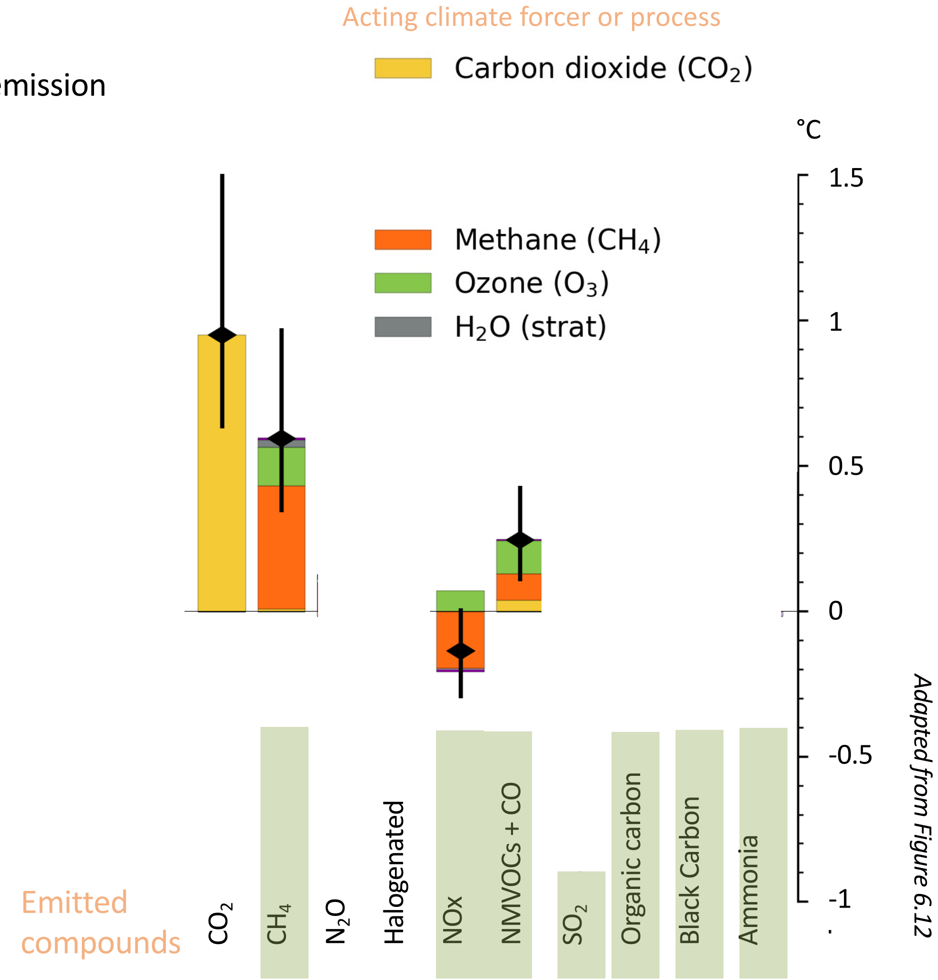

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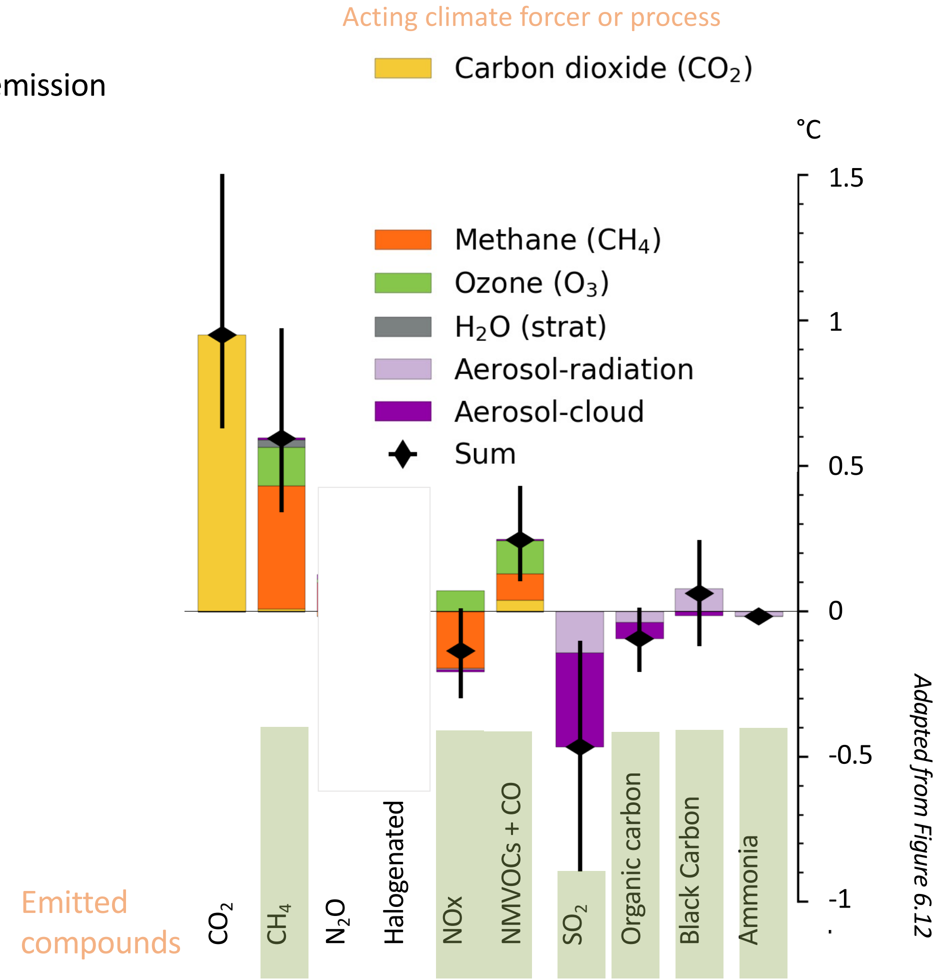
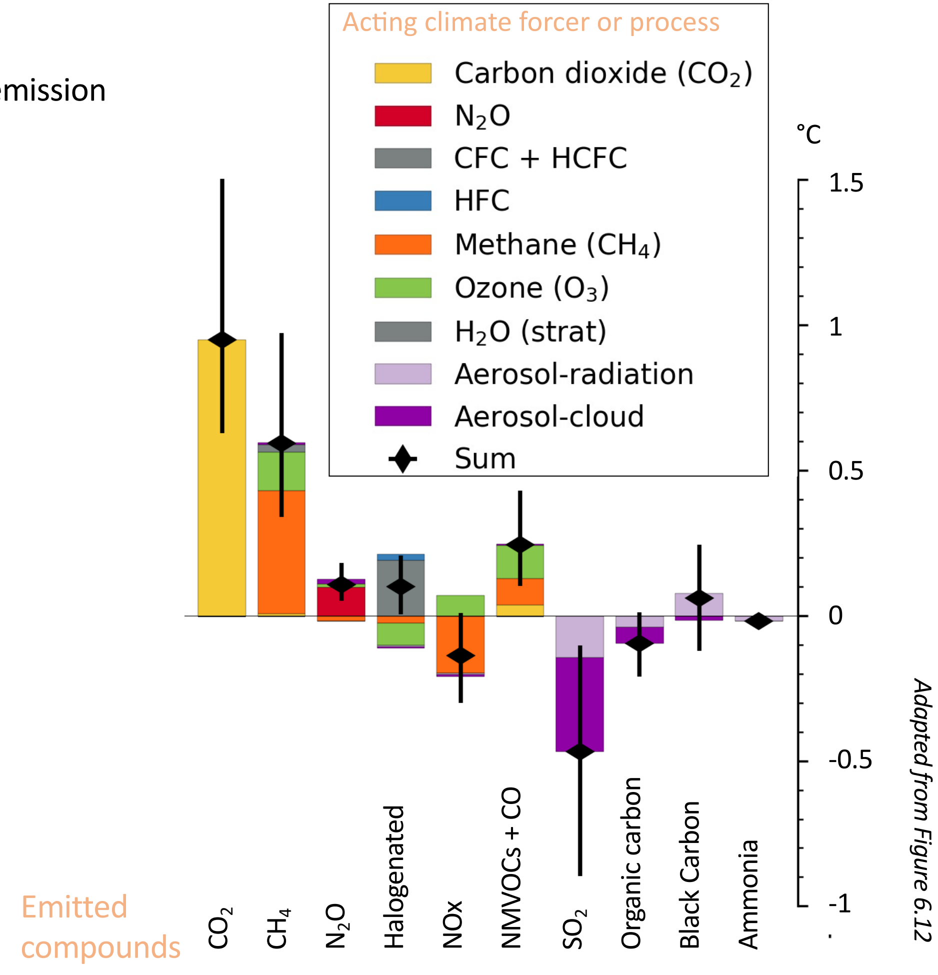
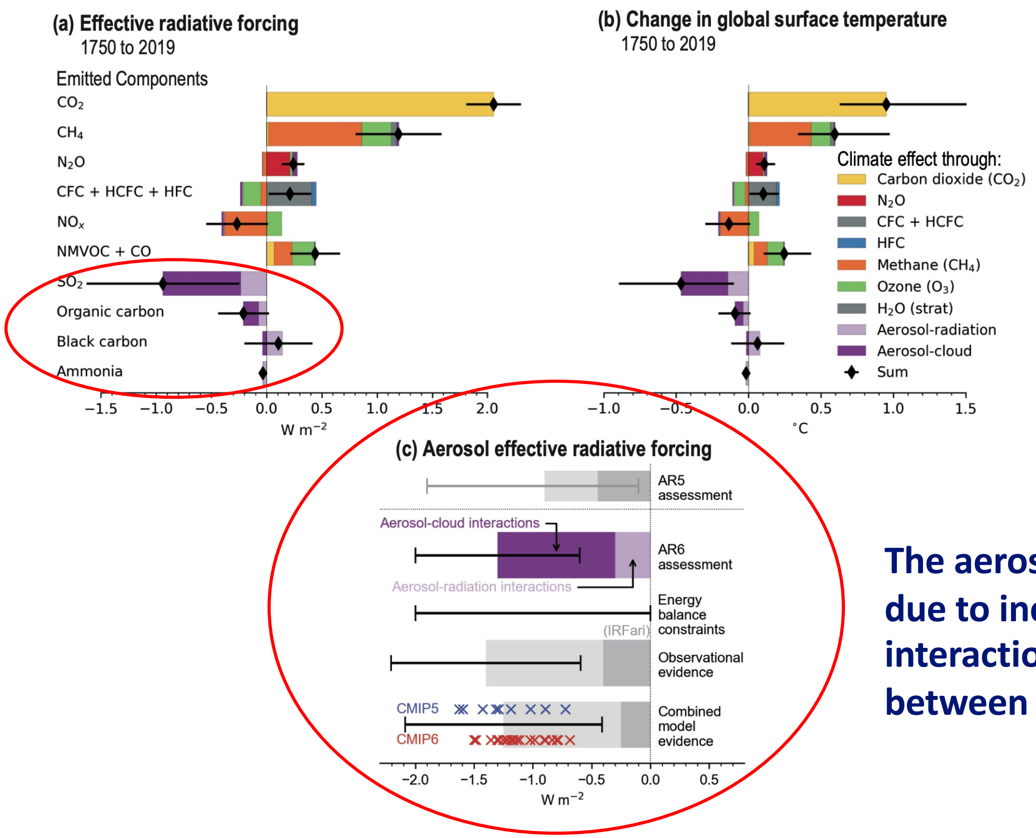


How do air pollutants act on climate?

Changes in Global Surface Temperature due to emission increases between 1750 and 2019

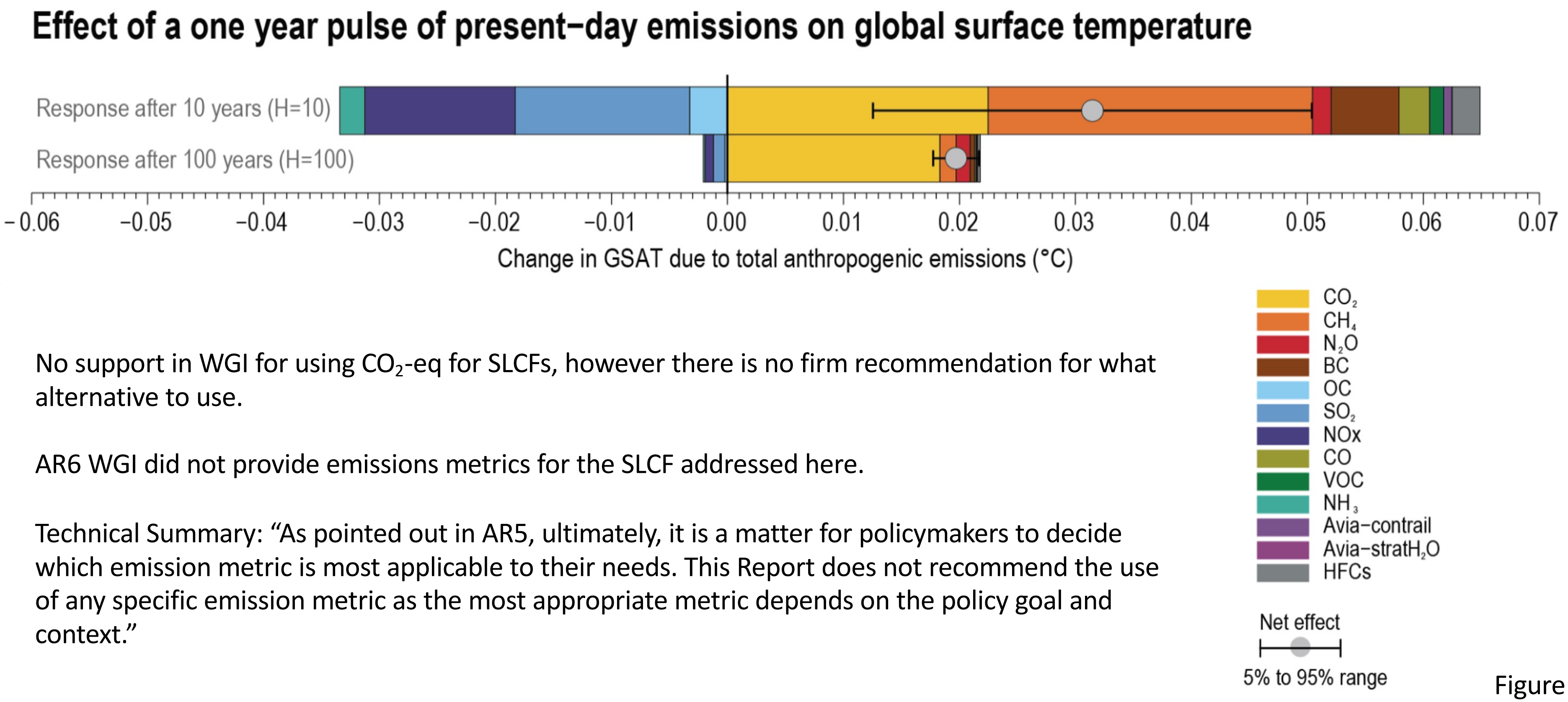




The aerosol ERF has been revised since AR5. This is due to increased understanding of aerosol–cloud interactions and is supported by improved agreement between different lines of evidence.

Figure TS 15

Which metrics to use for SLCFs? Very dependent on time horizon



- No support in WGI for using CO_2-eq for SLCFs, however there is no firm recommendation for what alternative to use.
- AR6 WGI did not provide emissions metrics for the SLCF addressed here.
- Technical Summary: "As pointed out in AR5, ultimately, it is a matter for policymakers to decide which emission metric is most applicable to their needs. This Report does not recommend the use of any specific emission metric as the most appropriate metric depends on the policy goal and context."

Figure 6.16

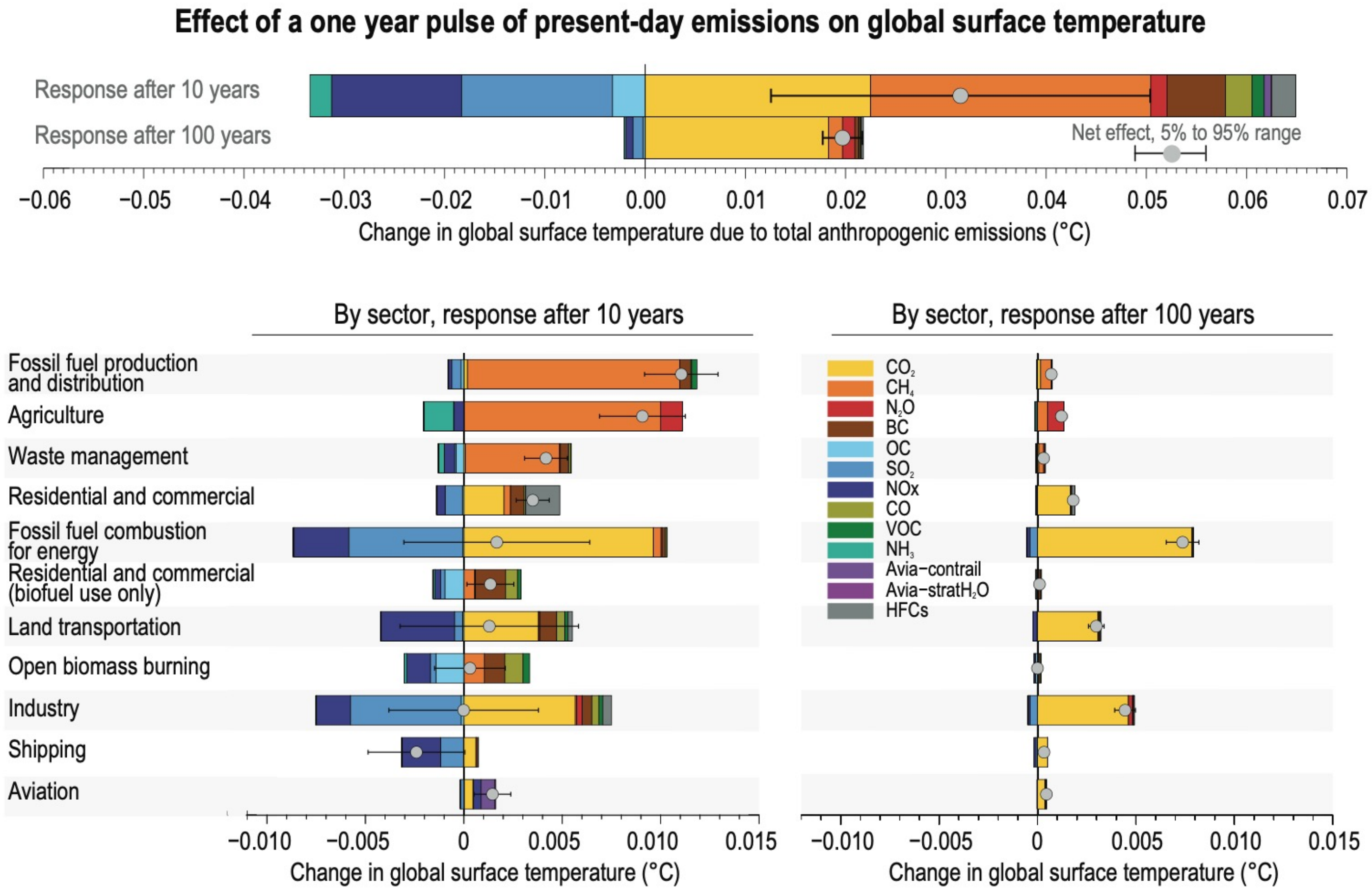


Figure 6.16 | GSAT response 10 and 100 years following one year of present day emissions

Aerosols also affect Precipitation (assessed in Chapter 8)

The overall effect of anthropogenic **aerosols** is to **reduce global precipitation and alter large-scale atmospheric circulation patterns** (*high confidence*).

Cooling in the Northern Hemisphere by **sulphate aerosols explained a southward shift in the tropical rain belt** and **contributed to the Sahel drought from the 1970s to the 1980s** (*high confidence*).

Decreases in global land monsoon precipitation from the 1950s to the 1980s are partly attributed to human-caused **Northern Hemisphere aerosol emissions**, but increases since then have resulted from rising GHG concentrations and decadal to multi-decadal internal variability (*medium confidence*).

Over South Asia, East Asia and West Africa increases in monsoon precipitation due to warming from GHG emissions were counteracted by **decreases in monsoon precipitation due to cooling from human-caused aerosol emissions** over the 20th century (*high confidence*).

Photo Courtesy: Top: Wikimedia commons: Bottom: Deborah Lee Soltez

[Credit: evgeny-nelmin.]

Interactions entre régulations pour la qualité de l'air et régulations pour le climat?

INTERGOVERNMENTAL PANEL ON climate change

WMO UNEP

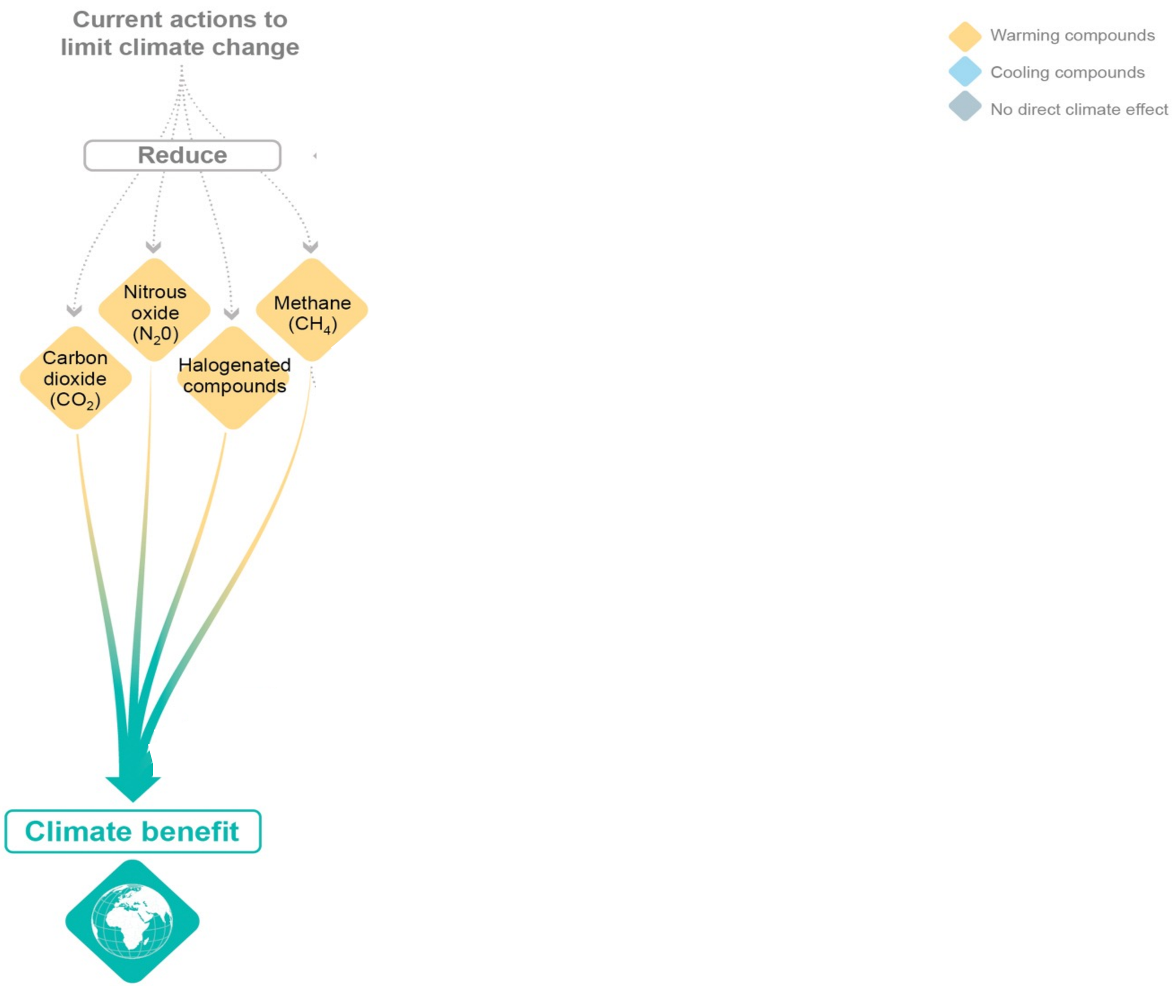


Figure FAQ 6.2

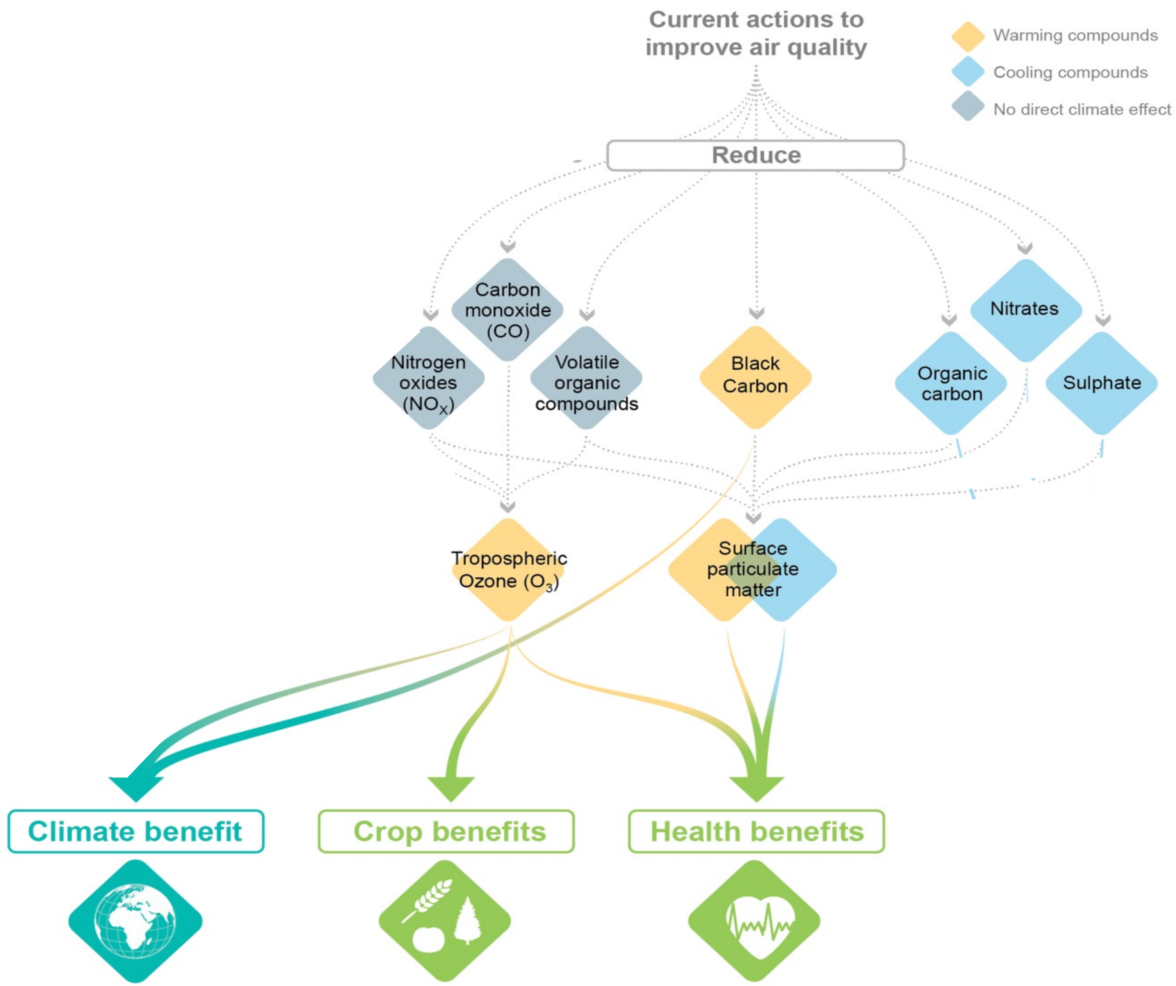


Figure FAQ 6.2

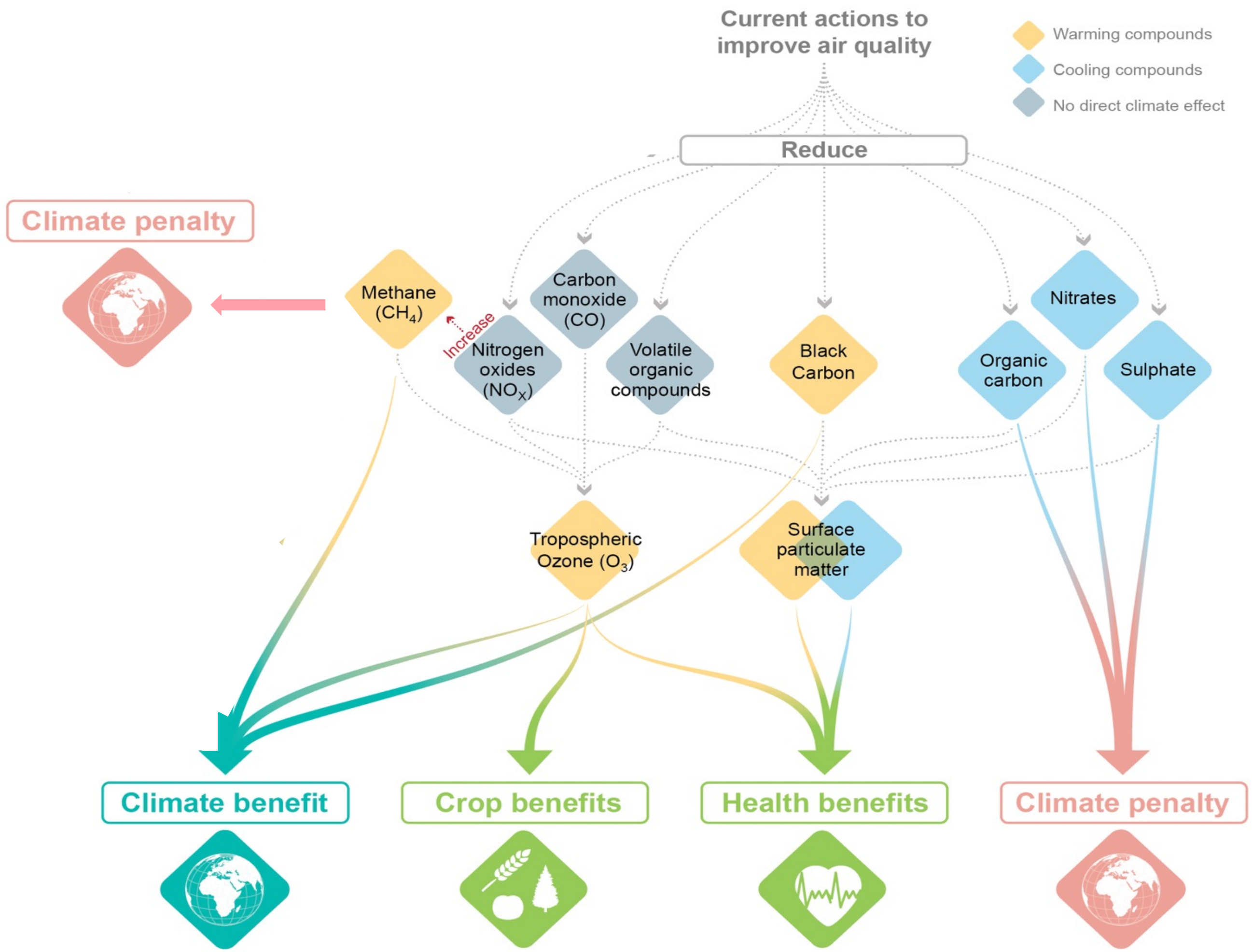


Figure FAQ 6.2

Synergies et Antagonismes

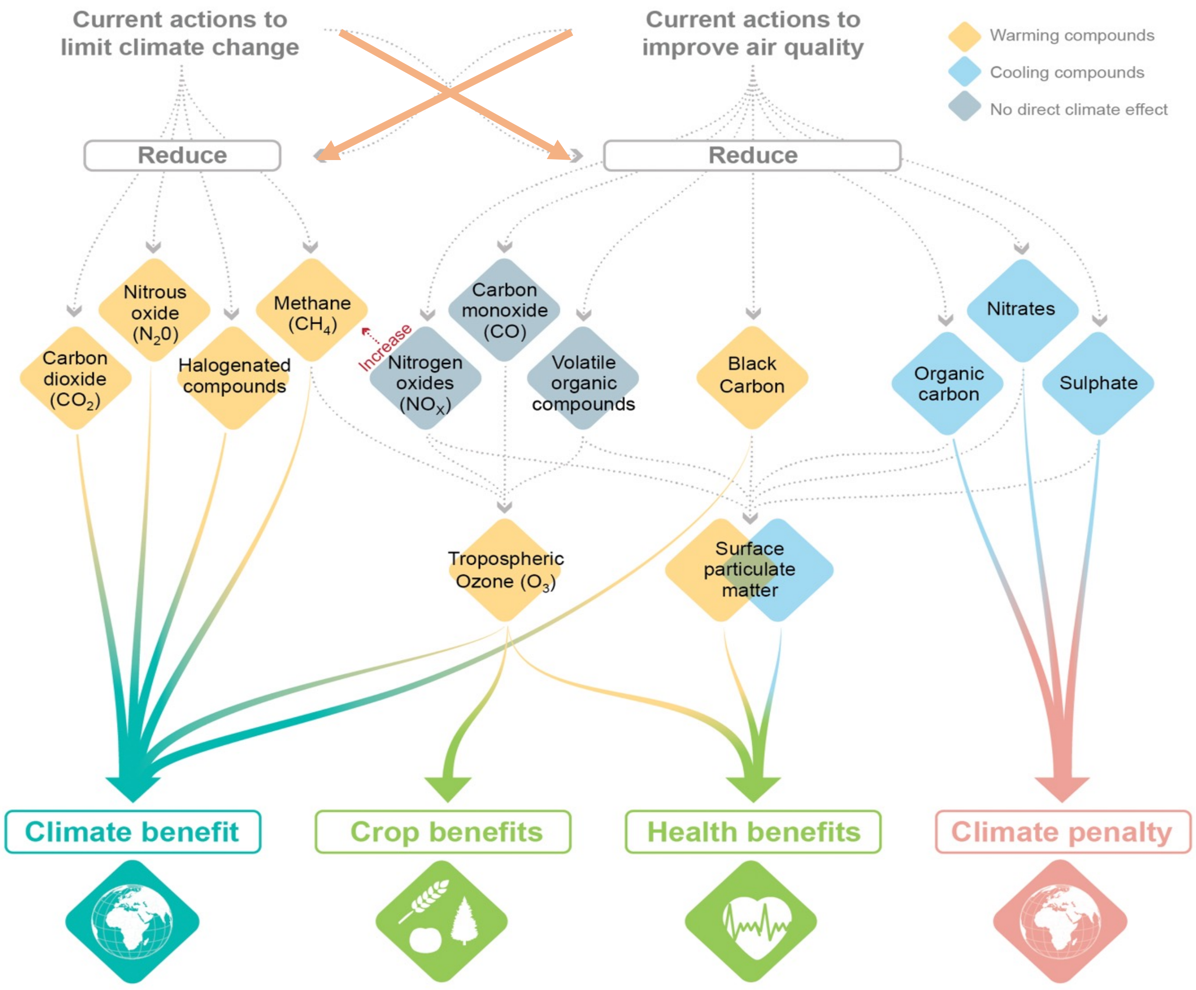


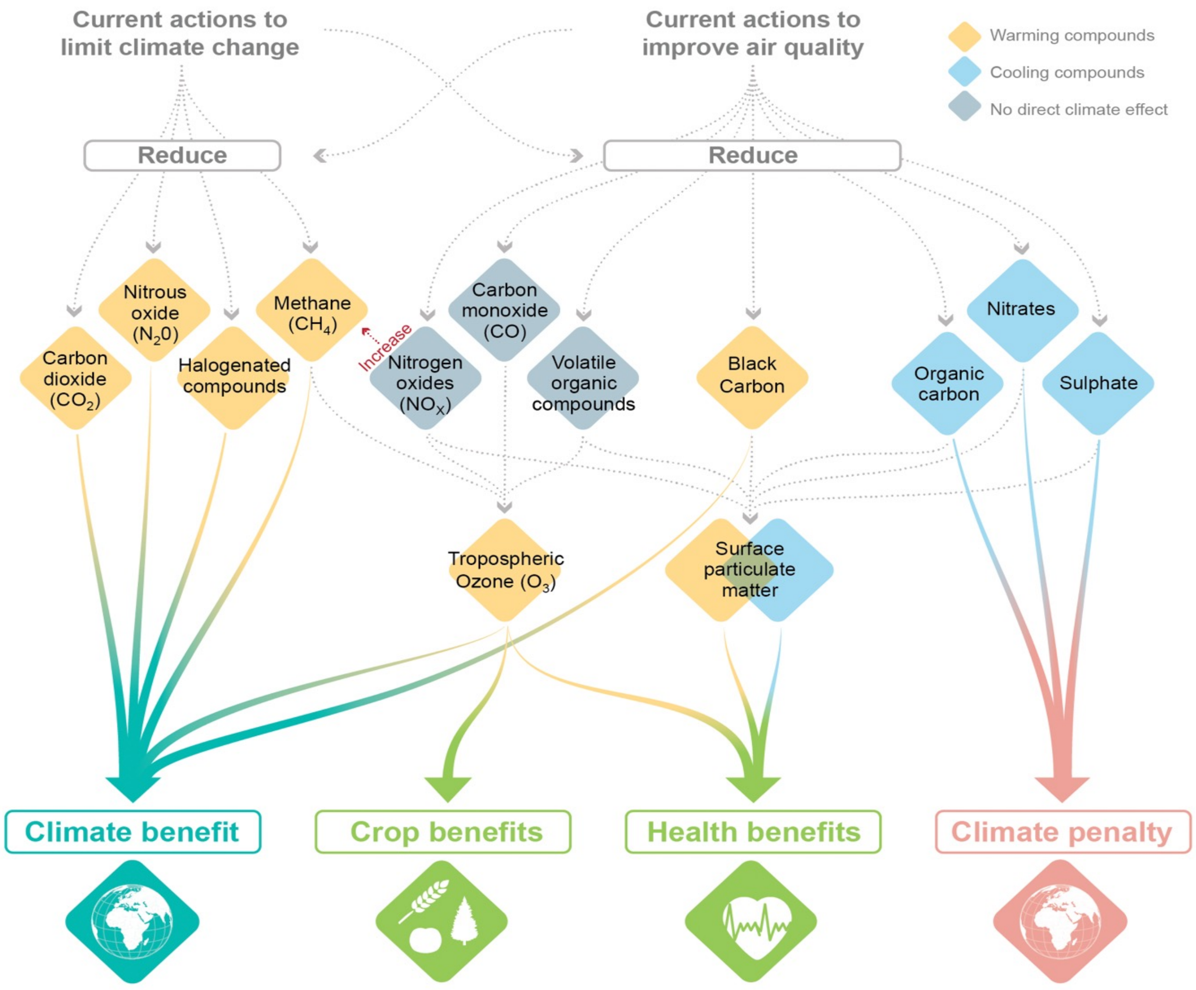
Figure FAQ 6.2

La décarbonation nécessite une transformation à grande échelle et en profondeur dans :

- énergie
- utilisation des terres/agriculture/alimentation
- villes et infrastructures
- industrie

Bénéfique pour AQ sauf quelques mesures spécifiques (e.g. chauffage bois si sans précaution, diesel)

Figure FAQ 6.2



Future Projections of SLCFs on their effects on Air Quality and GSATs

INTERGOVERNMENTAL PANEL ON climate change

WMO UNEP

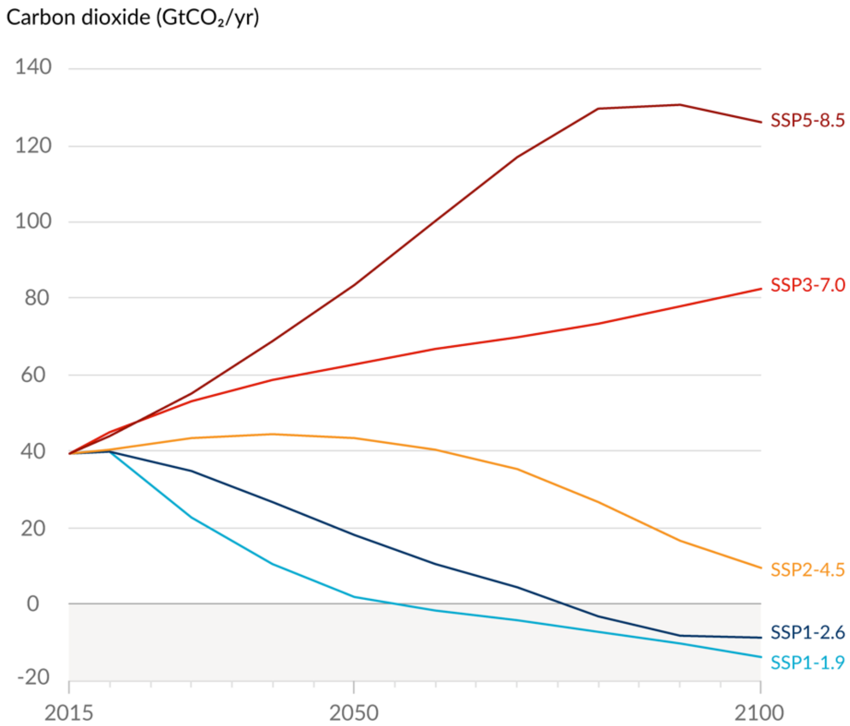
Assumptions differ for GHGs and air pollutants in emissions scenarios used in IPCC WGI

Emissions vary depending on socio-economic assumptions, levels of climate change mitigation and, for aerosols and non-methane ozone precursors, air pollution controls.

Assumptions differ for GHGs and air pollutants in emissions scenarios used in IPCC WGI

Emissions vary depending on socio-economic assumptions, levels of climate change mitigation and, for aerosols and non-methane ozone precursors, air pollution controls.

Emissions of

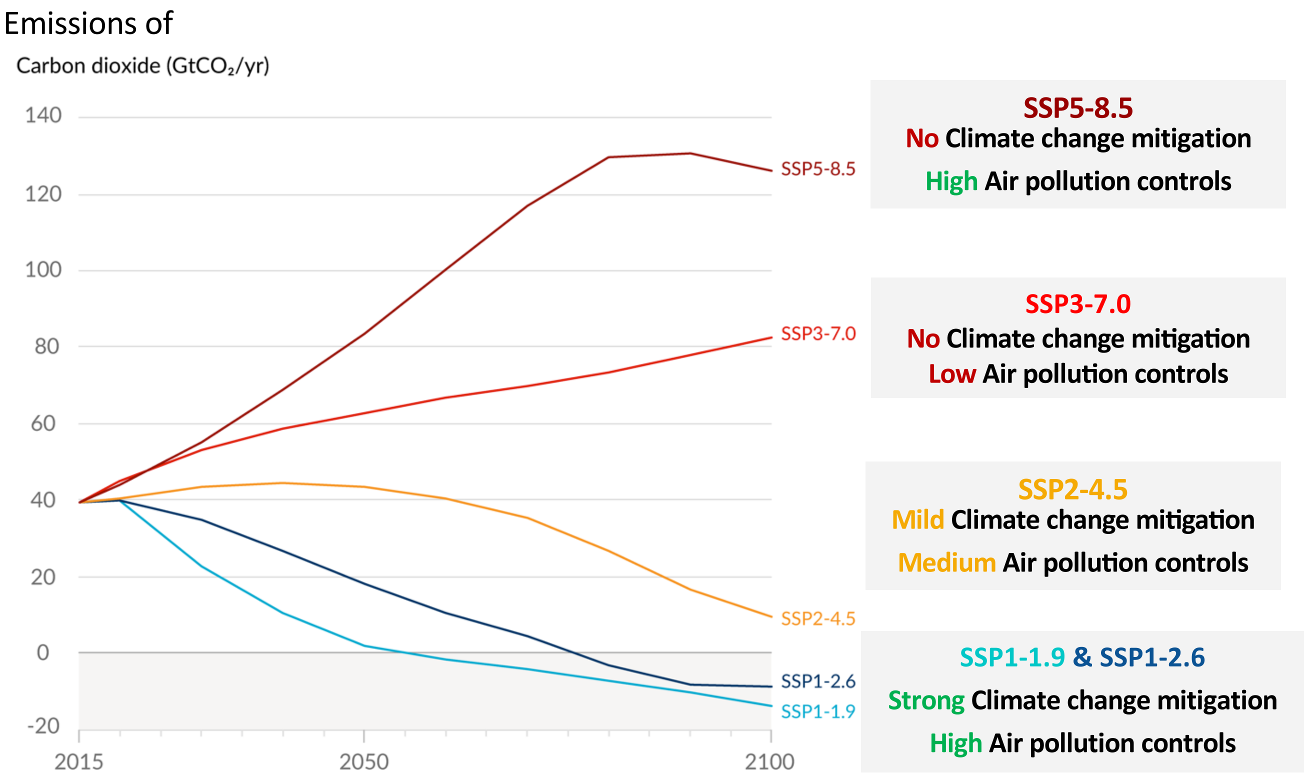


SSP3-7.0
No Climate change mitigation
Low Air pollution controls

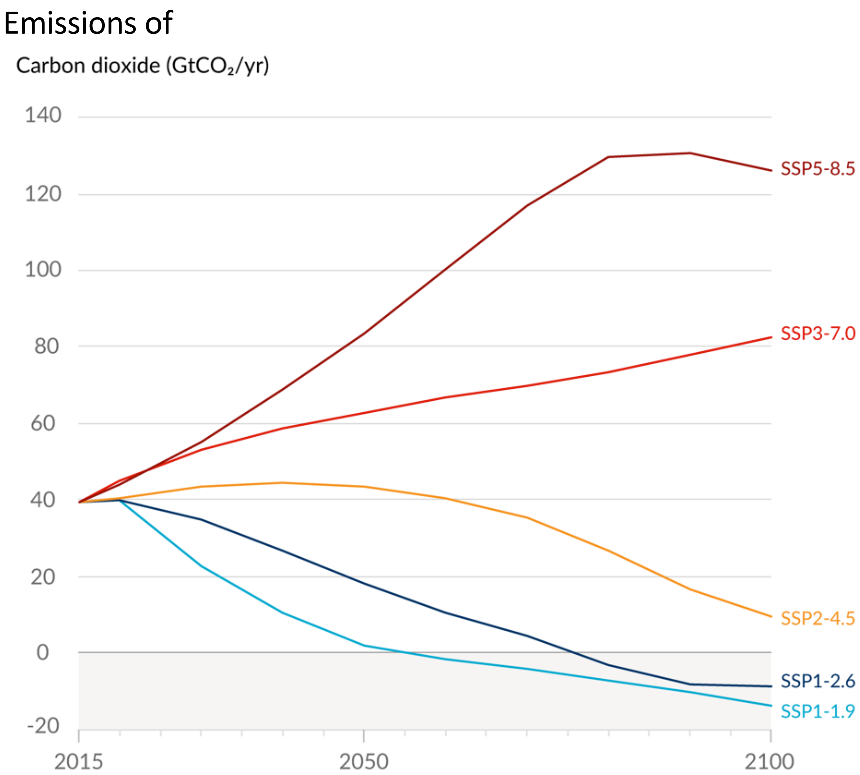
SSP2-4.5
Mild Climate change mitigation
Medium Air pollution controls

SSP1-1.9 & SSP1-2.6
Strong Climate change mitigation
High Air pollution controls

Assumptions differ for GHGs and air pollutants in emissions scenarios used in IPCC WGI



Emission trajectories differ for GHG and air pollutants

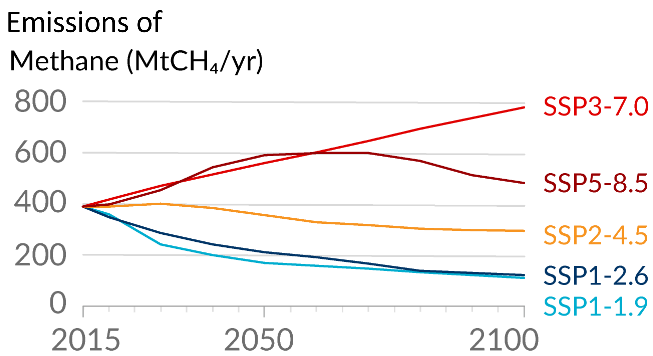


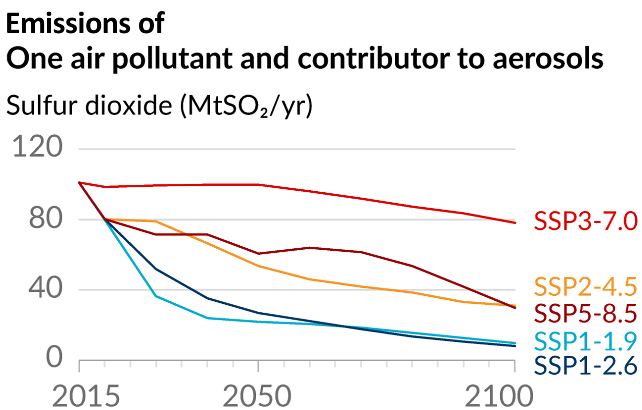
SSP5-8.5
No Climate change mitigation
High Air pollution controls

SSP3-7.0
No Climate change mitigation
Low Air pollution controls

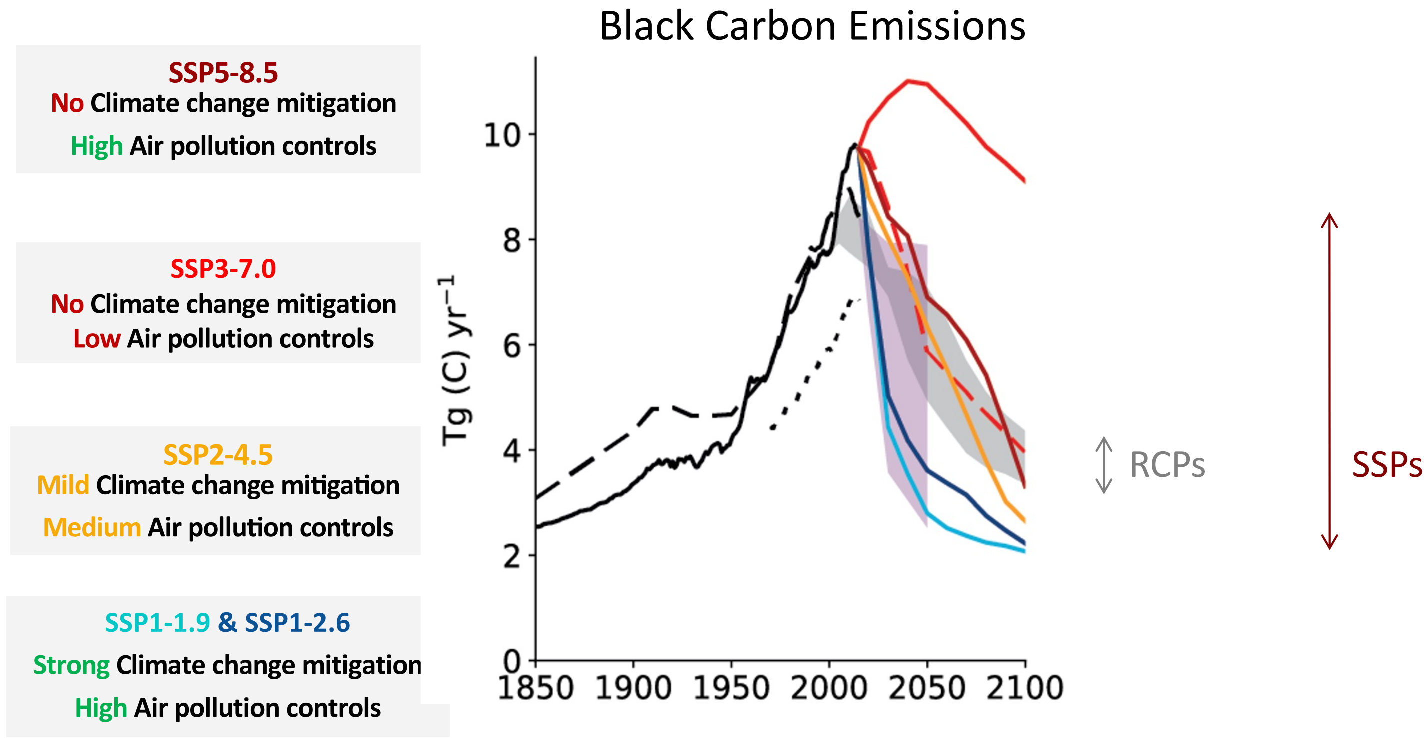
SSP2-4.5
Mild Climate change mitigation
Medium Air pollution controls

SSP1-1.9 & SSP1-2.6
Strong Climate change mitigation
High Air pollution controls



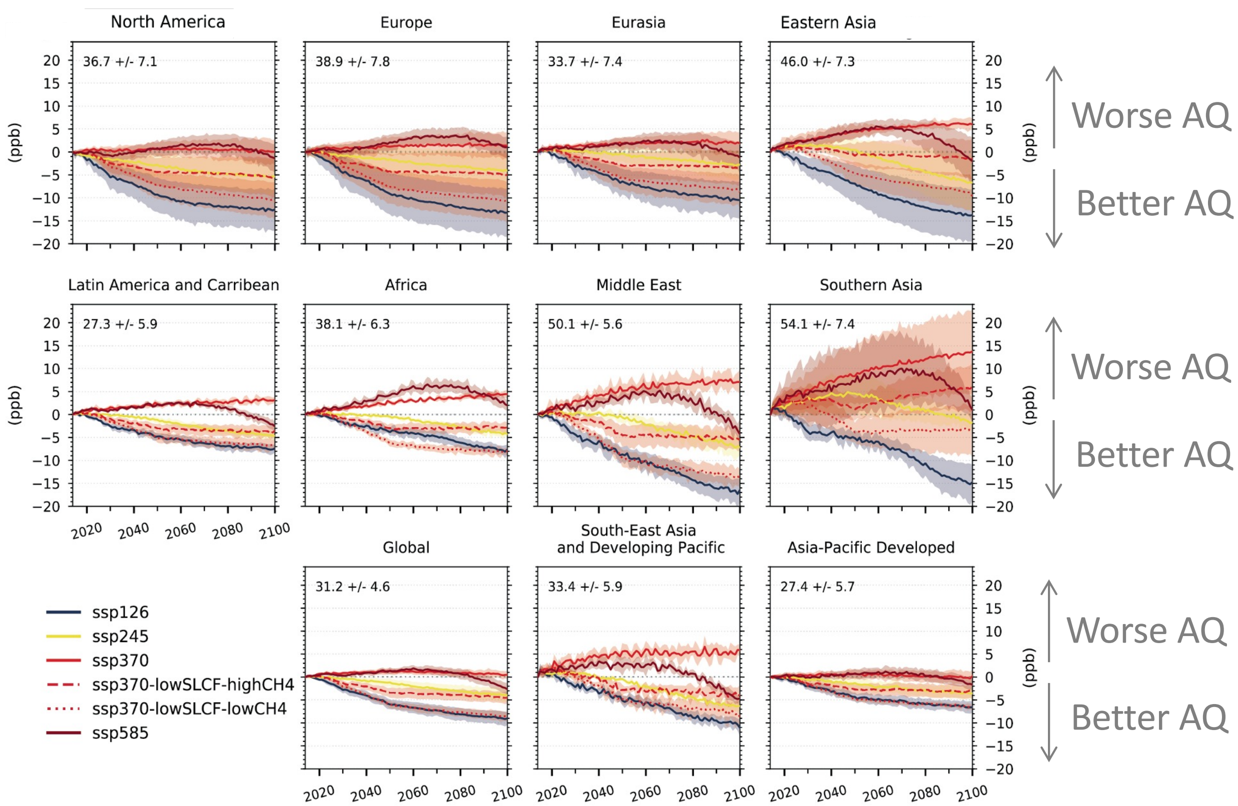


The SSPs span a wider range of SLCF emissions than the RCPs and better cover the diversity of future options in air pollution management



Future air quality on global to local scales will be primarily driven by changes in precursor emissions

Projected Changes in surface O_3 from 2015 to 2100



Strong reduction in surface O_3 in scenarios with combined climate change and air pollution mitigation (SSP1-2.6)

Strong increases in surface O_3 in scenarios with no climate change and air pollution mitigation (SSP3-7.0)

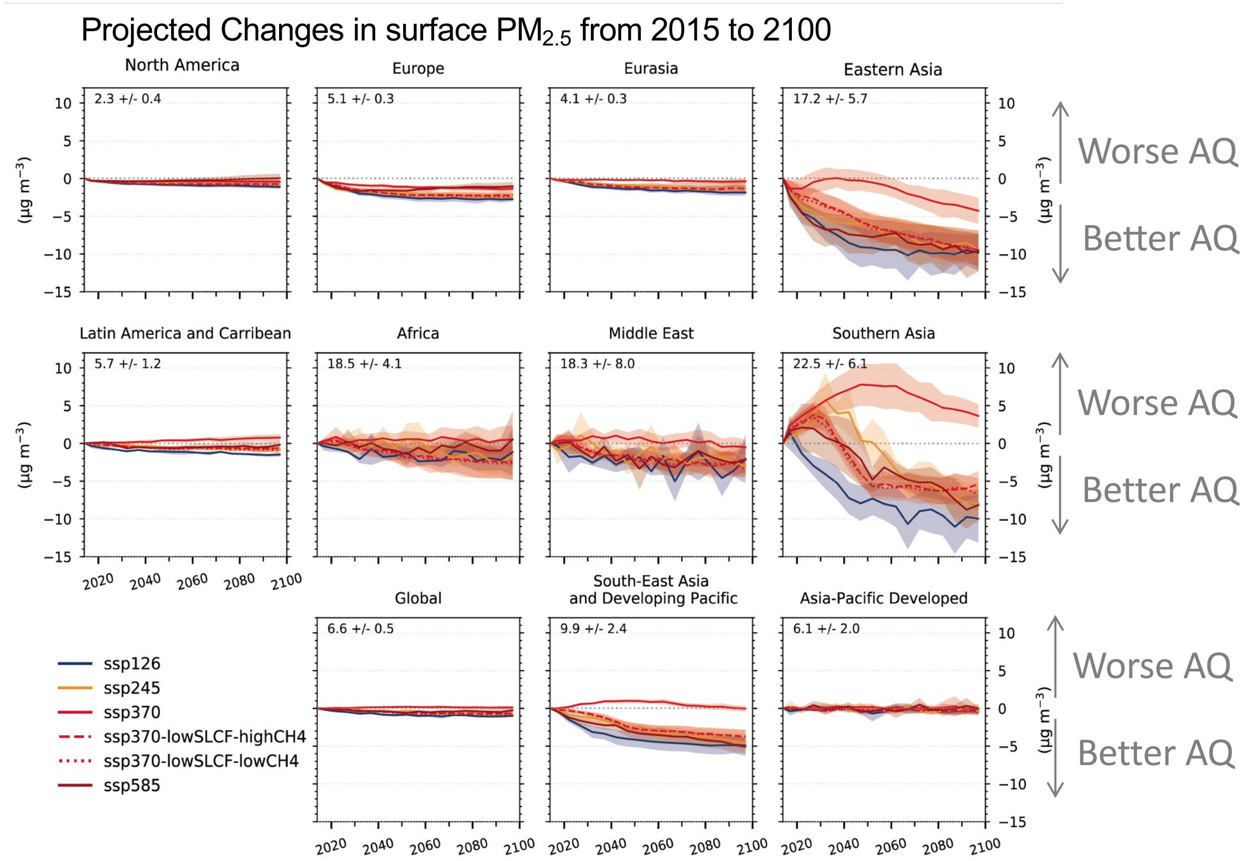
Increases in surface O_3 in scenarios with stringent air pollution controls but without climate change mitigation driven by high methane (SSP5-8.5)

Large reductions in surface O_3 are possible across all regions for scenarios that contain **strong climate and air pollutant mitigation measures, including those targeting CH_4**

Projected changes in regional annual mean surface ozone (ppb) from 2015 to 2100 in different SSPs | Figure 6.20

Air pollution projections range from strong reductions in global surface ozone and PM to no improvement and even degradation (*high confidence*)

+ Strong regional heterogeneities

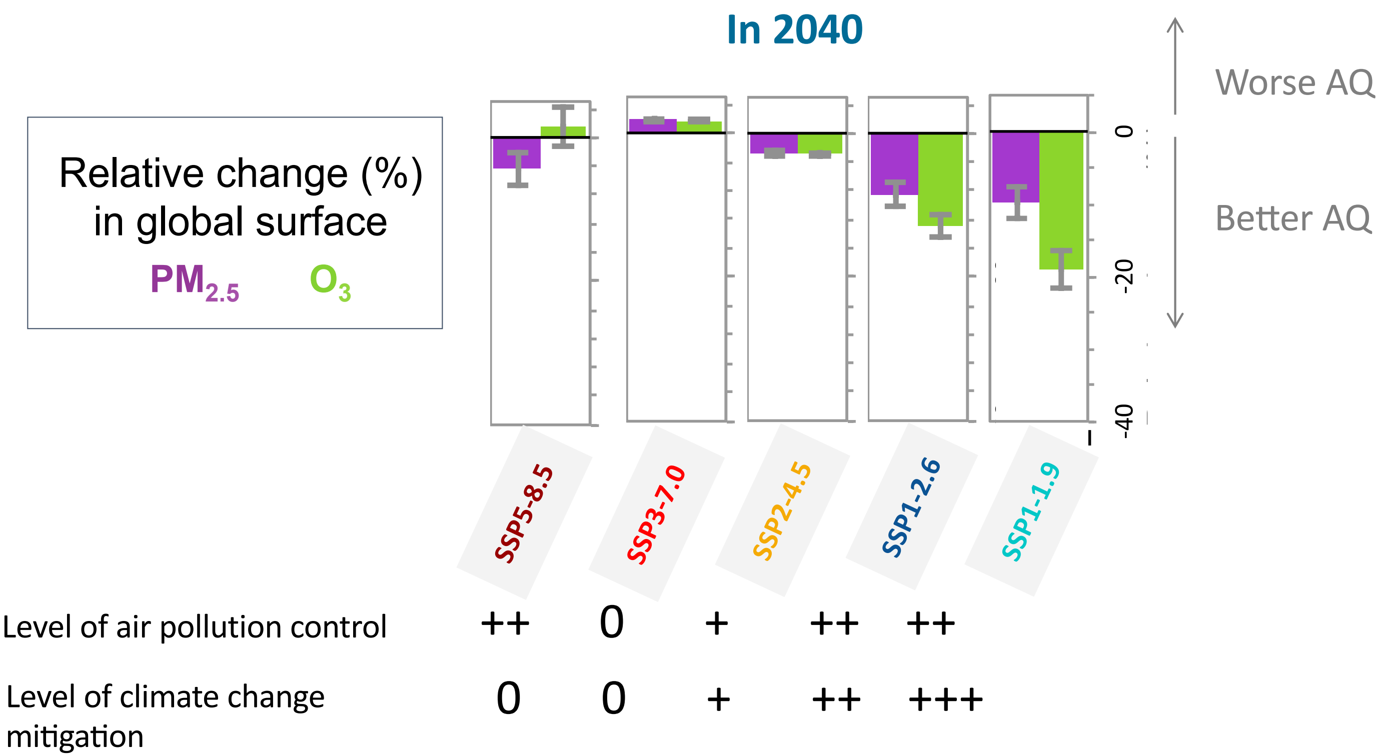


Strong reduction in surface $PM_{2.5}$ in scenarios with combined climate change and air pollution mitigation (SSP1-2.6)

Stringent air pollution controls would ensure declining $PM_{2.5}$ despite no climate change mitigation (SSP5-8.5)

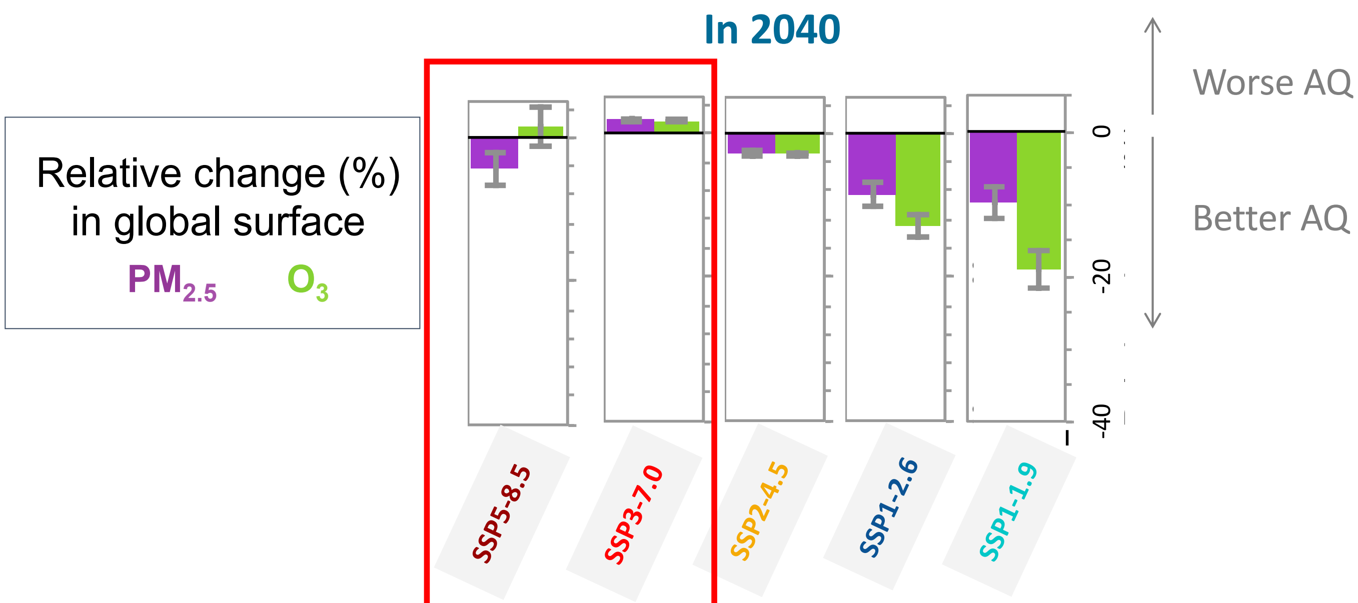
Strong increases in surface $PM_{2.5}$ in scenarios with no climate change and air pollution mitigation (SSP3-7.0), over large parts of Asia

Projected changes in regional annual mean surface ozone (ppb) from 2015 to 2100 in different SSPs | Figure 6.21



Changes in air pollution across the WG1 core set SSPs | From Box TS.7, Figure 1

In a world with increasing consumption of fossil fuel and agriculture => Low improvements or worsening of AQ (even with strong air pollution control)

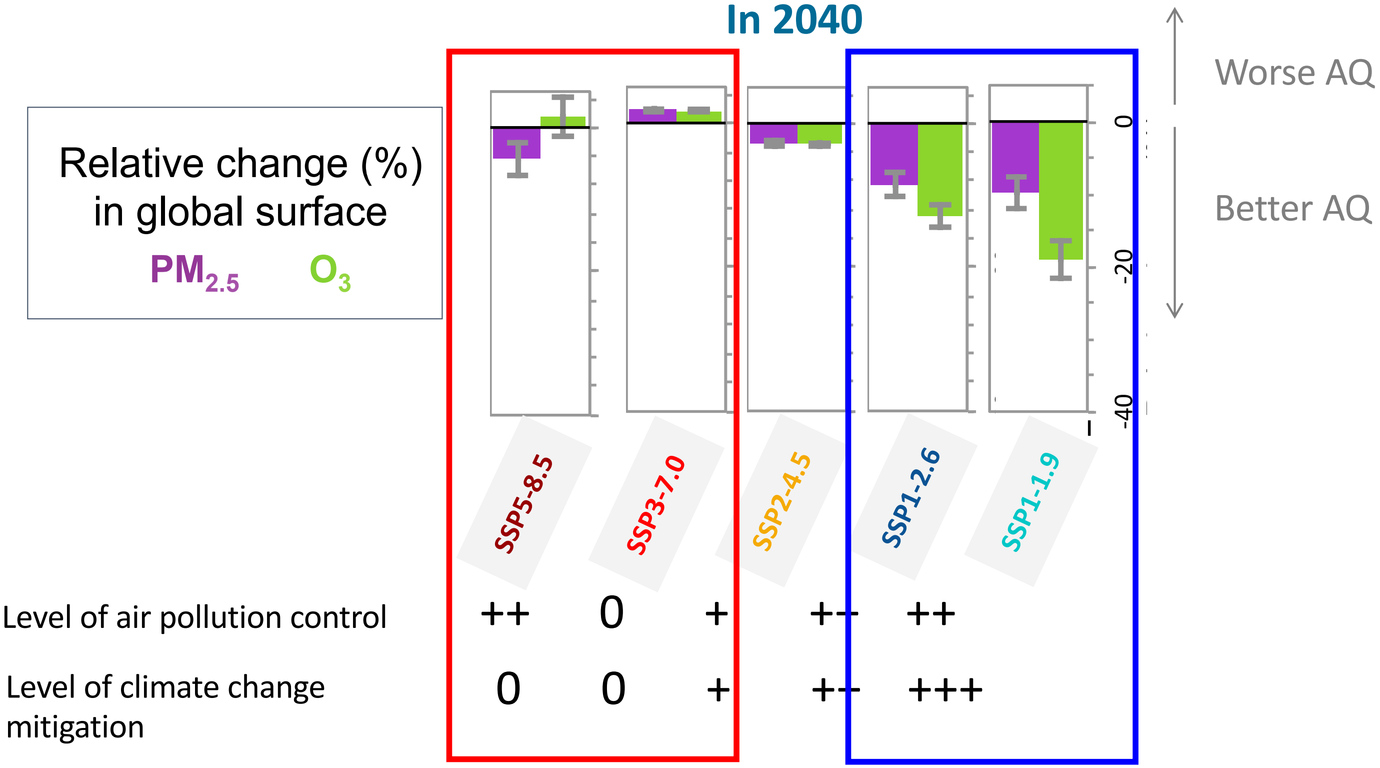


Level of air pollution control	++	0	+	++	++
Level of climate change mitigation	0	0	+	++	+++

Changes in air pollution across the WG1 core set SSPs | From Box TS.7, Figure 1

In a world with increasing consumption of fossil fuel and agriculture => Low improvements or worsening of AQ (even with strong air pollution control)

Best AQ improvements are obtained by combining strong air pollution control and decarbonisation



Changes in air pollution across the WG1 core set SSPs | From Box TS.7, Figure 1

In a world with increasing consumption of fossil fuel and agriculture => Low improvements or worsening of AQ (even with strong air pollution control)

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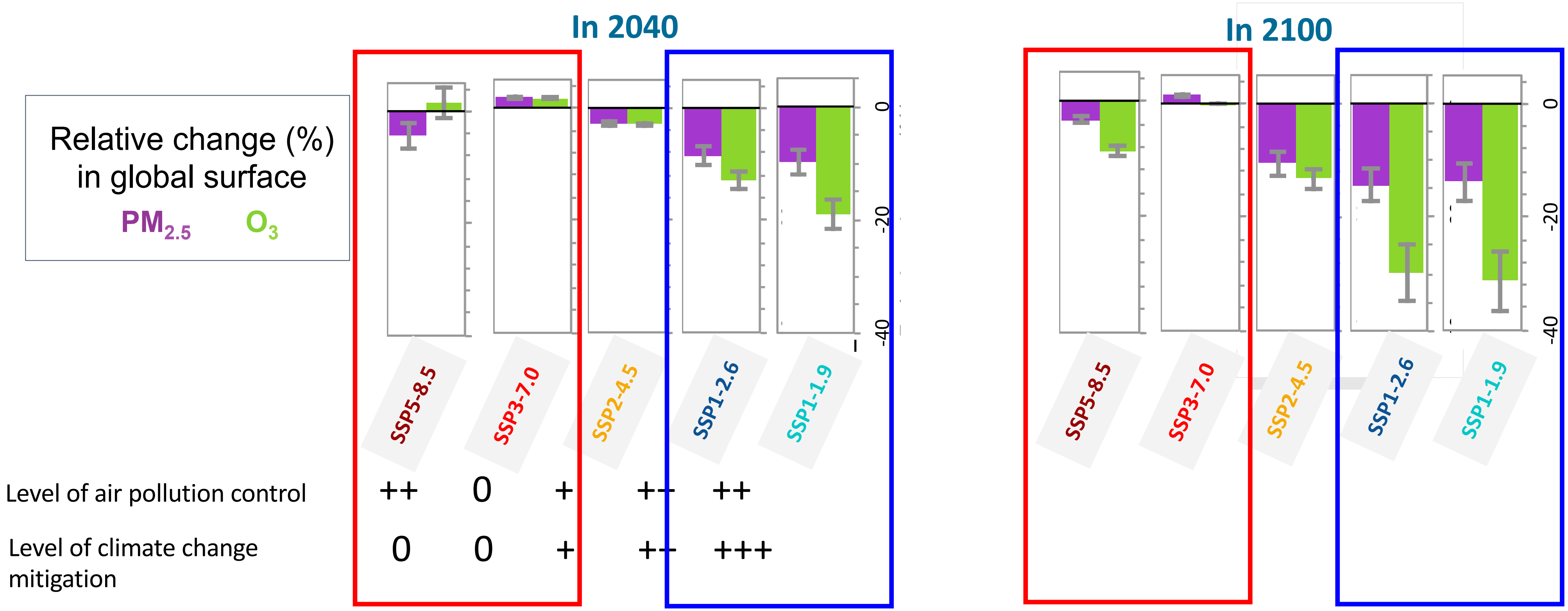
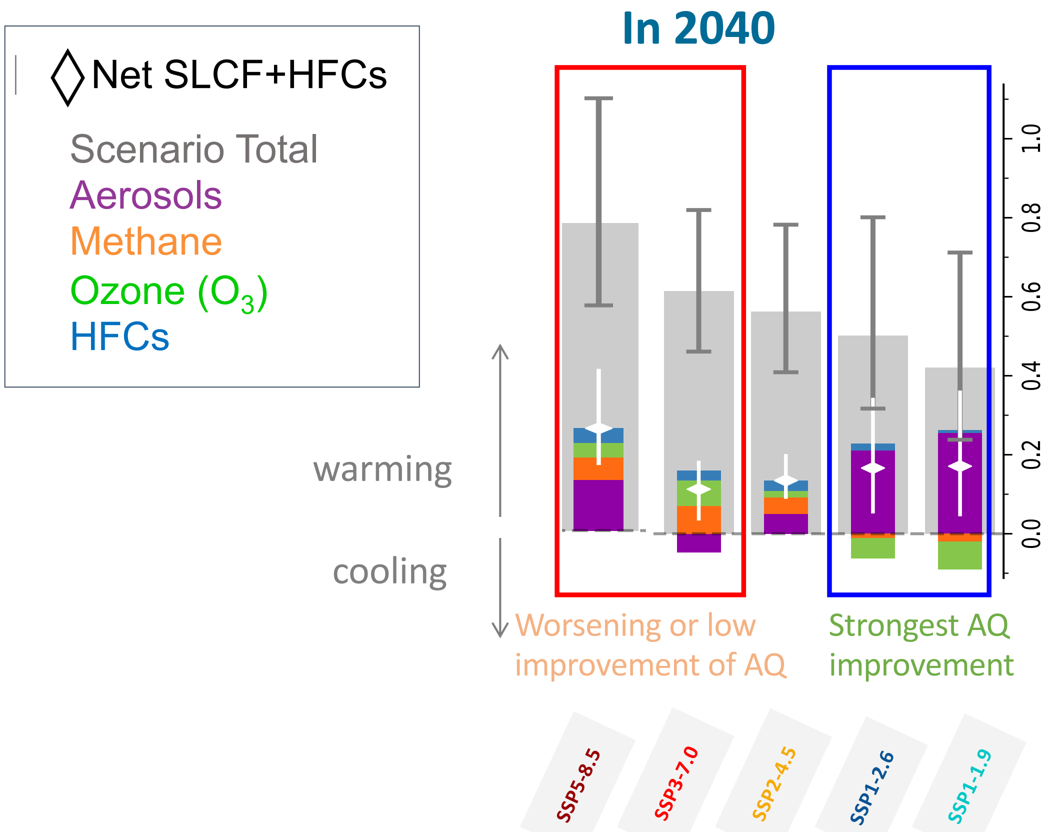


Changes in air pollution across the WG1 core set SSPs | From Box TS.7, Figure 1

The changes in SLCFs cause an additional warming (compared to 2019)



driven by:

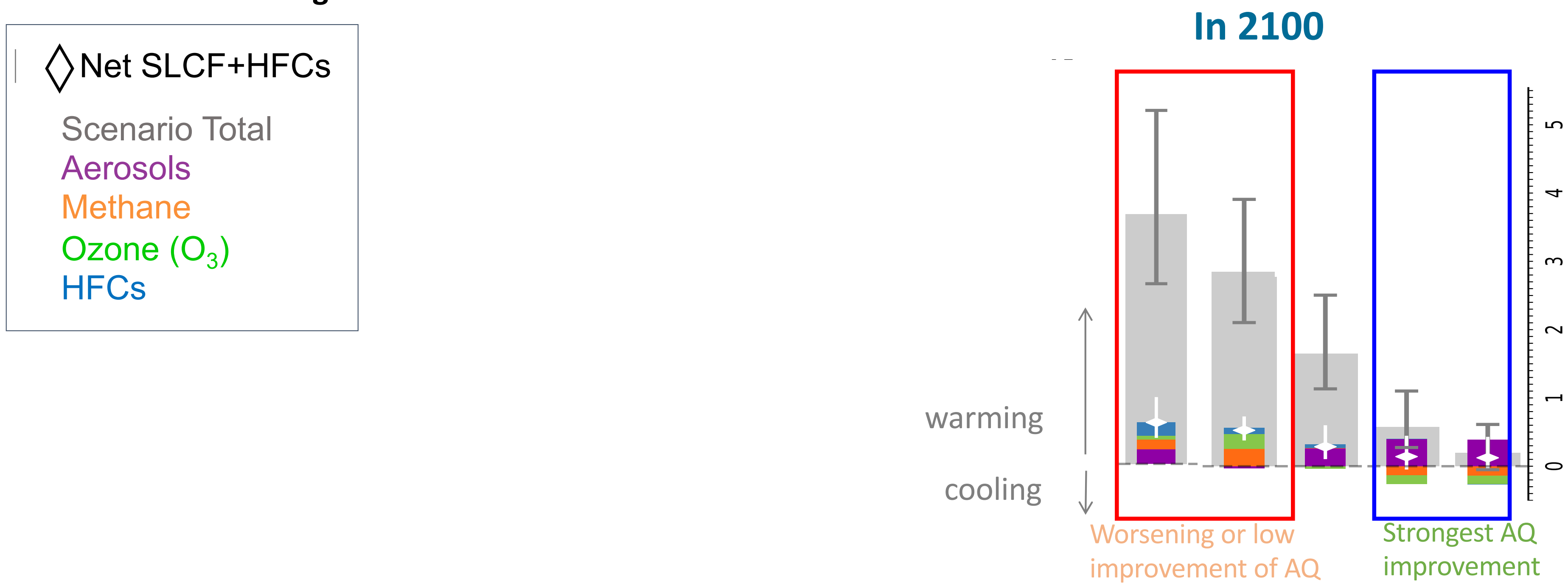
- **the decrease of the cooling aerosols (strong air pollution control)**

or

- **the increase of ozone and methane (no/mild climate change mitigation)**

Effects of SLCFs on global surface temperature across the WG1 core set of SSPs | From Box TS.7, Figure 1

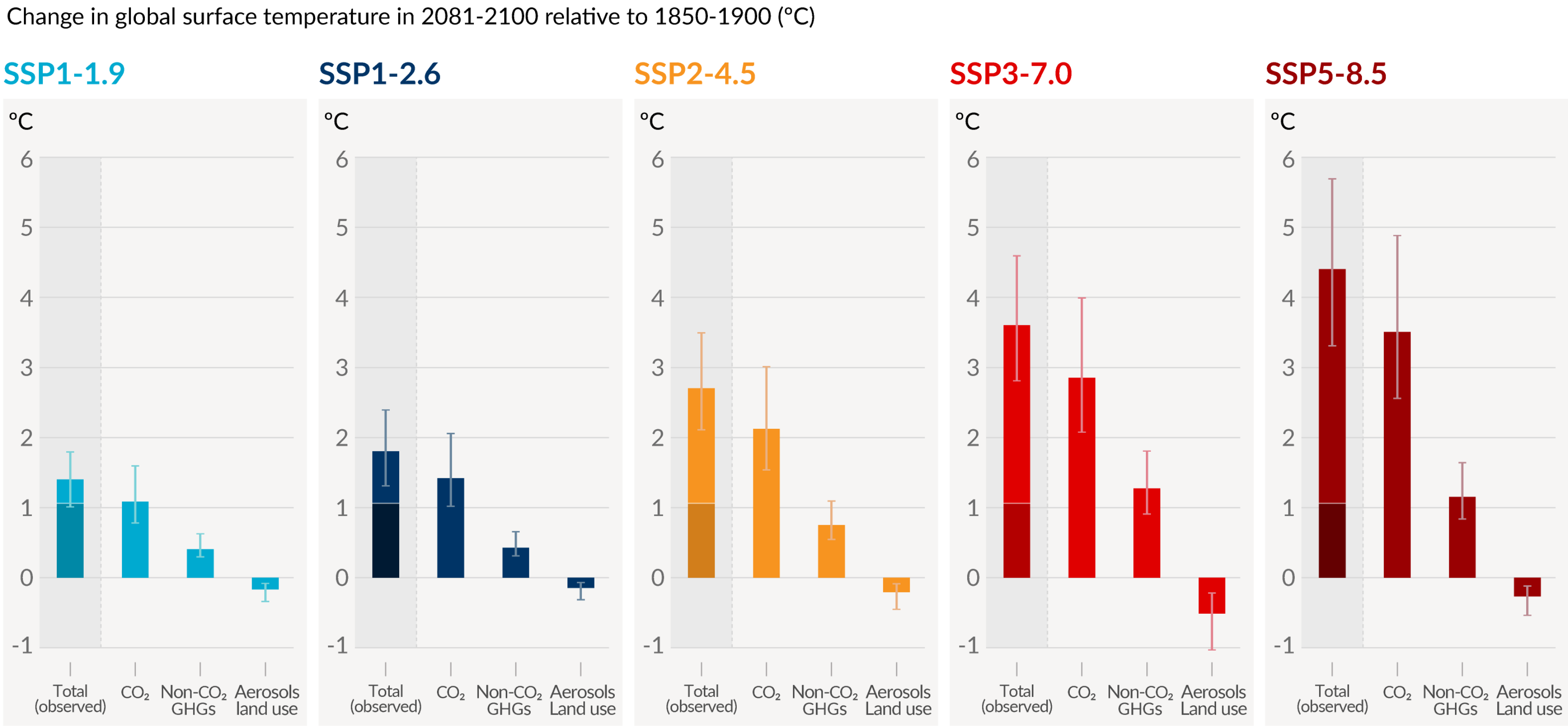
In the long term, this net warming is lower in scenarios leading to lower global air pollution as long as methane emissions are also mitigated



Effects of SLCFs on global surface temperature across the WG1 core set of SSPs | From Box TS.7, Figure 1

But keep in mind the dominant role of CO_2 emissions for future additional warming

Figure SPM.4



La décarbonisation nécessite de forts changements systémiques dans tous les secteurs qui conduiraient à des améliorations de la qualité de l'air, mais ne sont pas suffisants pour atteindre les directives de l'OMS dans de nombreuses régions.

Les politiques dédiées à la pollution de l'air permettent d'atteindre plus rapidement l'amélioration de l'AQ.

Des politiques supplémentaires (par exemple, l'accès à une énergie propre, la gestion des déchets) envisagées pour atteindre les objectifs de développement durable (ODD) apportent une réduction complémentaire de la pollution atmosphérique.


[Credit: © Getty / Kevin Frayer]

La réduction de la pollution de l'air entraîne un léger réchauffement supplémentaire dû à la diminution des aérosols (mais le climat n'est pas seulement T et les aérosols affectent également la circulation et les précipitations).

Mais le réchauffement induit par les modifications des polluants atmosphériques et de leurs précurseurs peut être pire à long terme dans des scénarios où l'environnement est négligé en raison de l'augmentation de l'ozone et du méthane.

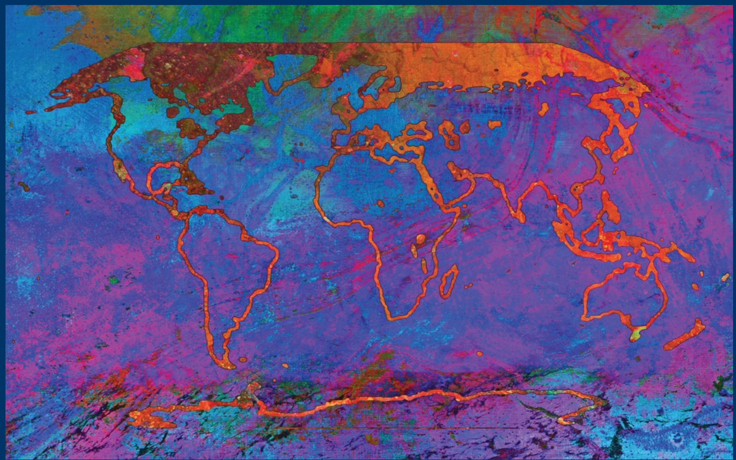
INTERGOVERNMENTAL PANEL ON climate change

[Credit: Evgeny Nelmin | Unsplash]

Pour limiter le réchauffement climatique, des réductions fortes, rapides et soutenues du CO_2, du méthane et des autres gaz à effet de serre sont nécessaires.

Le **méthane** a un rôle central : l'atténuation durable du méthane, où qu'elle se produise, se présente comme une option qui combine des gains à court et à long terme sur la température de surface et conduit à un bénéfice sur la pollution de l'air en réduisant globalement le niveau d'ozone en surface

ipcc
INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP



Conclusion

S'attaquer à la qualité de l'air ne peut pas résoudre le problème climatique, mais s'attaquer au changement climatique ne peut pas non plus résoudre totalement le problème de la qualité de l’air.

⇒ Des politiques intégrées sont nécessaires pour produire de multiples avantages d'atténuation du changement climatique, d'amélioration de la qualité de l'air, de protection de la santé humaine et d'atteinte de plusieurs objectifs de développement durable

⇒ La réduction du méthane est une stratégie gagnant-gagnant

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INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP

Deep, rapid, and sustained reductions in greenhouse gas emissions would lead to a discernible slowdown in global warming within around two decades, and also to discernible changes in atmospheric composition within a few years (*high confidence*). … discernible effects would emerge within years for GHG concentrations, and sooner for air quality improvements, due to the combined targeted air pollution controls and strong and sustained methane emissions reductions. Targeted reductions of air pollutant emissions lead to more rapid improvements in air quality within years compared to reductions in GHG emissions only, but in the long term, further improvements are projected in scenarios that combine efforts to reduce air pollutants as well as GHG emissions. (*high confidence*)

Many mitigation actions would have benefits for health through **lower air pollution**, active mobility (e.g., walking, cycling), and shifts to sustainable healthy diets. **Strong, rapid and sustained reductions in methane emissions can limit near-term warming and improve air quality by reducing global surface ozone**. (*high confidence*)

The **economic benefits for human health from air quality improvement** arising from mitigation action can be of the same order of magnitude as mitigation costs, and potentially even larger (*medium confidence)*

B.1.2 Discernible differences in trends of global surface temperature between contrasting GHG emissions scenarios would begin to emerge from natural variability within around 20 years. Under these contrasting scenarios, discernible effects would emerge within years for GHG concentrations, and sooner for air quality improvements, due to the combined targeted air pollution controls and strong and sustained methane emissions reductions. Targeted reductions of air pollutant emissions lead to more rapid improvements in air quality within years compared to reductions in GHG emissions only, but in the long term, further improvements are projected in scenarios that combine efforts to reduce air pollutants as well as GHG emissions. (*high confidence*) {3.1.1} (Box SPM.1)

C.2 Deep, rapid and sustained mitigation and accelerated implementation of adaptation actions in this decade would reduce projected losses and damages for humans and ecosystems (*very high confidence*), and deliver many co-benefits, especially for air quality and health (*high confidence*). Delayed mitigation and adaptation action would lock-in high-emissions infrastructure, raise risks of stranded assets and cost-escalation, reduce feasibility, and increase losses and damages (*high confidence*). Near-term actions involve high up-front investments and potentially disruptive changes that can be lessened by a range of enabling policies (*high confidence*). {2.1, 2.2, 3.1, 3.2, 3.3, 3.4, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8}

C.2.3 Accelerated climate action can also provide co-benefits (see also C.4). Many mitigation actions would have benefits for health through lower air pollution, active mobility (e.g., walking, cycling), and shifts to sustainable healthy diets. Strong, rapid and sustained reductions in methane emissions can limit near-term warming and improve air quality by reducing global surface ozone. (*high confidence*) Adaptation can generate multiple additional benefits such as improving agricultural productivity, innovation, health and wellbeing, food security, livelihood, and biodiversity conservation (*very high confidence*). {4.2, 4.5.4, 4.5.5, 4.6}

C.2.4 Cost-benefit analysis remains limited in its ability to represent all avoided damages from climate change (*high confidence*). The economic benefits for human health from air quality improvement arising from mitigation action can be of the same order of magnitude as mitigation costs, and potentially even larger (*medium confidence*). Even without accounting for all the benefits of avoiding potential damages the global economic and social benefit of limiting global warming to 2°C exceeds the cost of mitigation in most of the assessed literature (*medium confidence*). More rapid climate change mitigation, with emissions peaking earlier, increases co-benefits and reduces feasibility risks and costs in the long-term, but requires higher up-front investments (*high confidence*). {3.4.1, 4.2}

C.4.3 Implementing both mitigation and adaptation actions together and taking trade-offs into account supports co-benefits and synergies for human health and well-being. For example, improved access to clean energy sources and technologies generate health benefits especially for women and children; electrification combined with low-GHG energy, and shifts to active mobility and public transport can enhance air quality, health, employment, and can elicit energy security and deliver equity. (*high confidence*) {4.2, 4.5.3, 4.5.5, 4.6, 4.9}

Future Projections of SLCFs and their effects on Air Quality and GSATs

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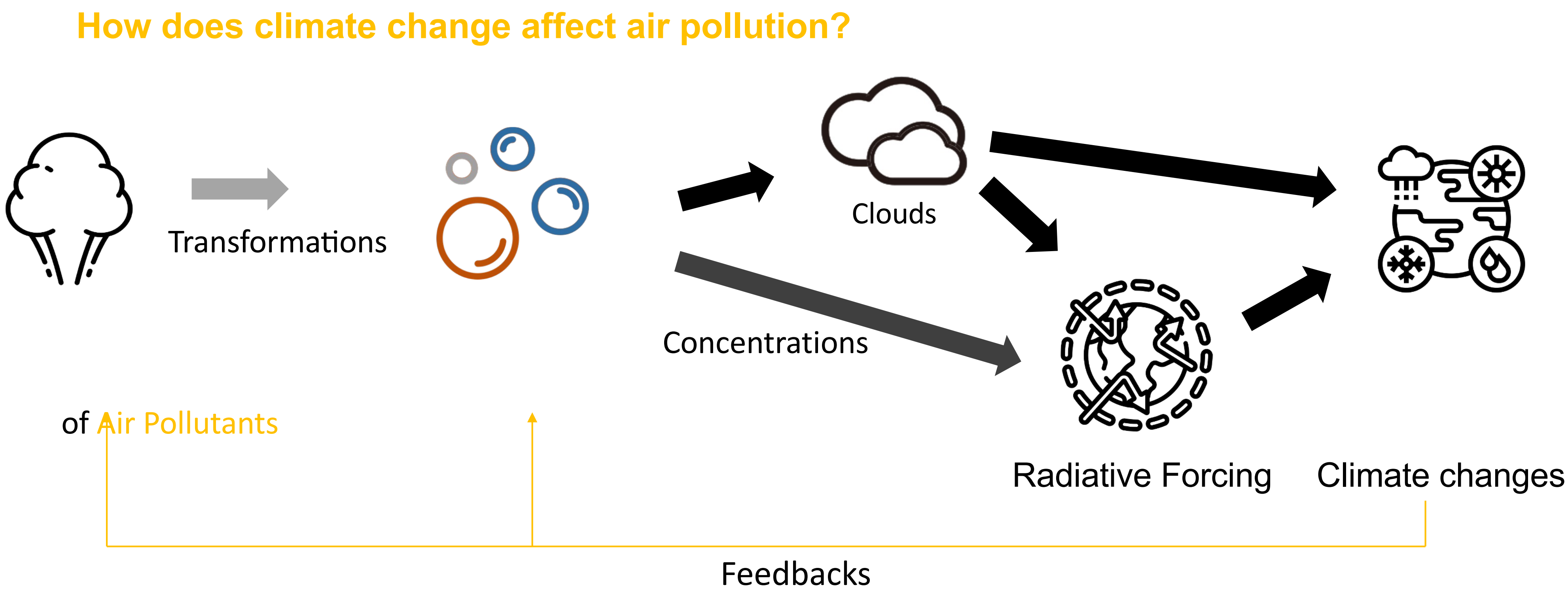
Future air quality on global to local scales will be primarily driven by changes in precursor emissions as opposed to climate change (*high confidence*)



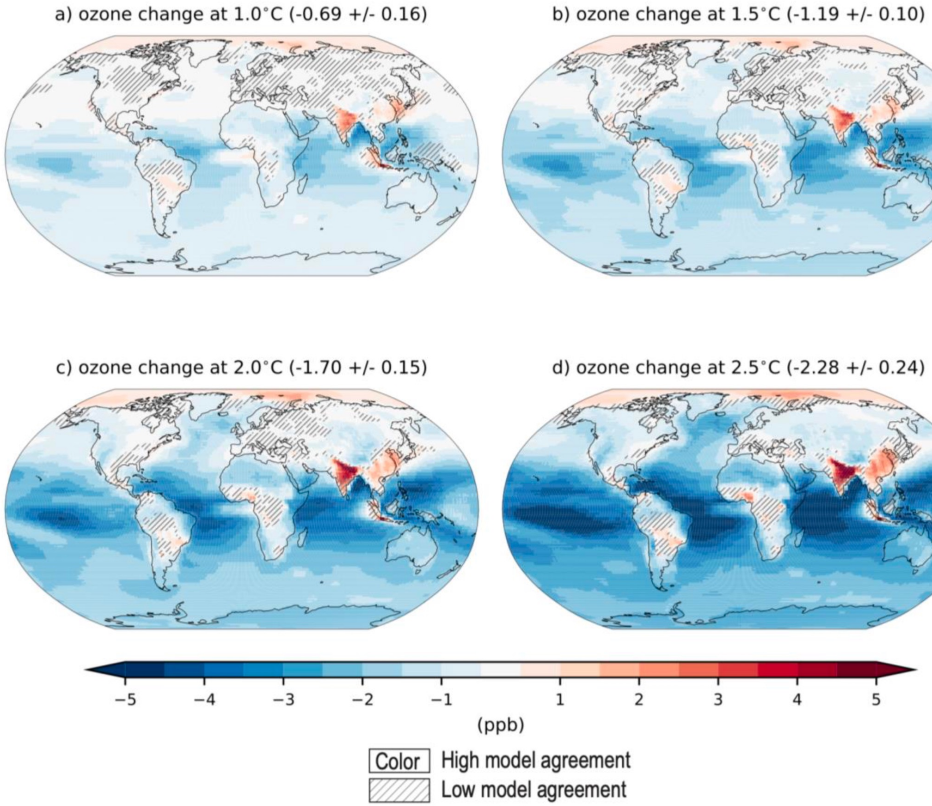


Figure 6.14 | Multi-model annual mean change in surface O_3 (ppb) concentrations at different warming levels

How does climate change affect air pollution?

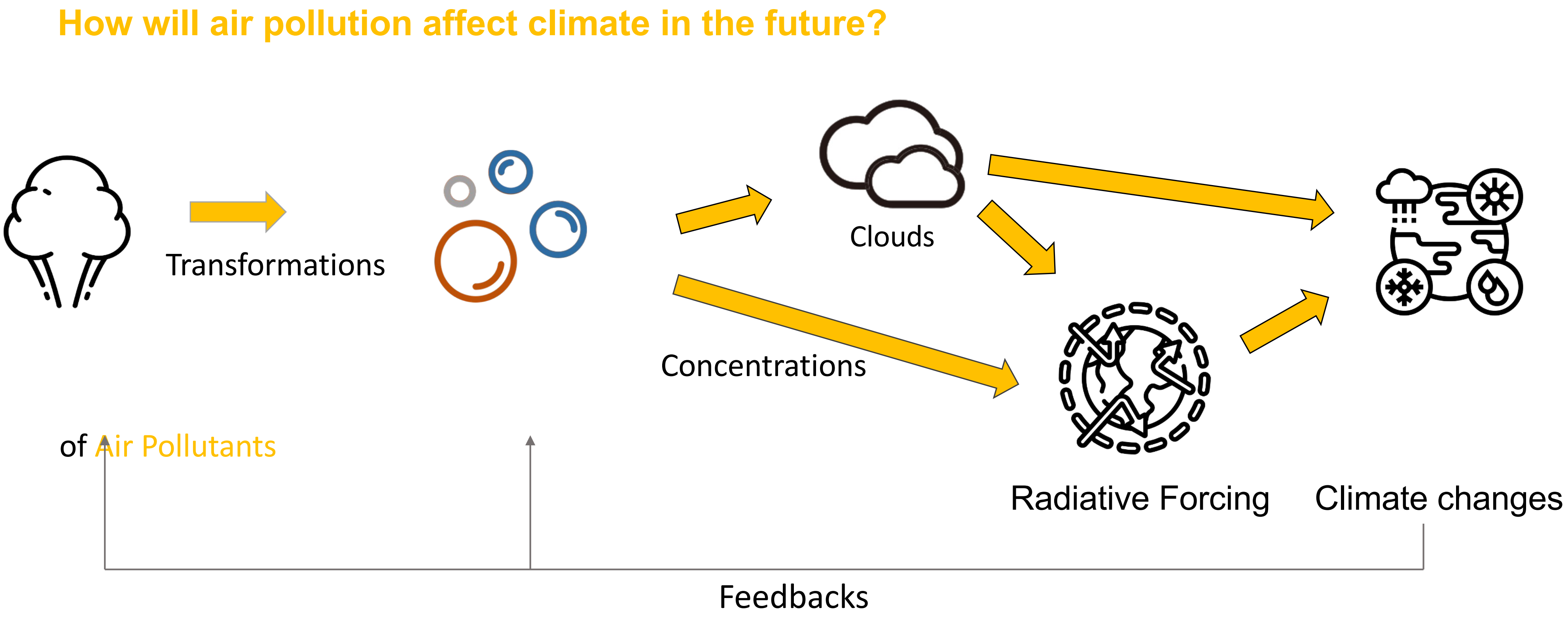
Climate change is expected to have mixed effects on future air quality (*high confidence*)

Warmer climate is expected to ↓ surface O_3 in regions remote from pollution sources (*high confidence*) but to ↑ it by a few ppb over polluted regions (*medium to high confidence*).

Future climate change is expected to have mixed effects, + or -, with an overall low effect on global surface PM and more generally on the aerosol global burden (*medium confidence*), but stronger effects are not excluded locally in regions prone to specific meteorological conditions (*low confidence*).

But *low confidence* in the response of AQ to future climate change due to the uncertainty in the response of the processes in the natural system to climate change.

Future air quality on global to local scales will be primarily driven by changes in precursor emissions as opposed to climate change (*high confidence*)




[Credit: evgeny-nelmin.]

Mitigation

Air pollution control vs Climate change mitigation

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Links between actions aiming to limit climate change and actions to improve air quality

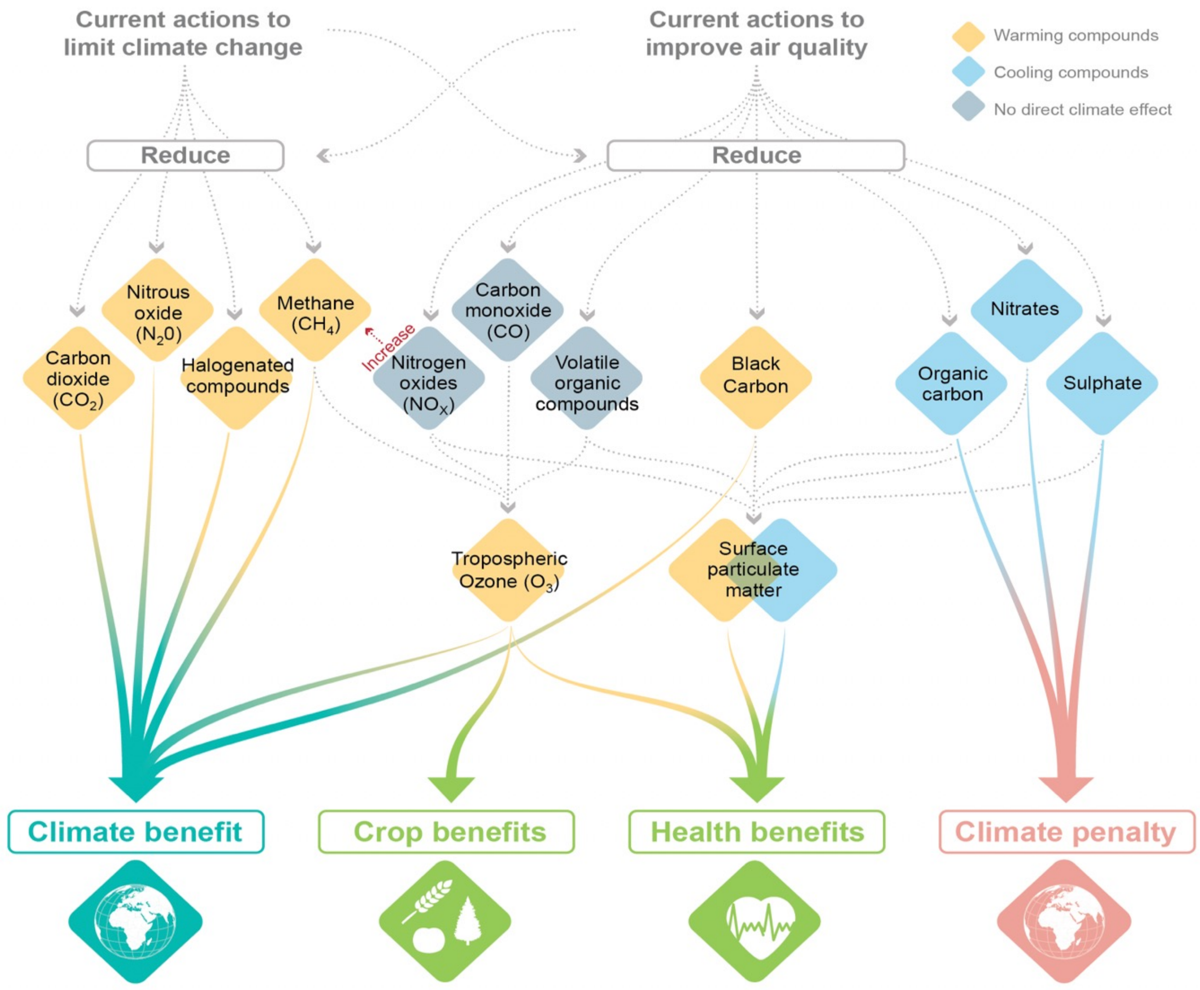


Figure FAQ 6.2

Links between actions aiming to limit climate change and actions to improve air quality

According to SR1.5 and >G3 reports, decarbonisation requires large scale and in depth transformation in :

- energy
- landuse/ agriculture / food
- cities and infrastructures
- industry

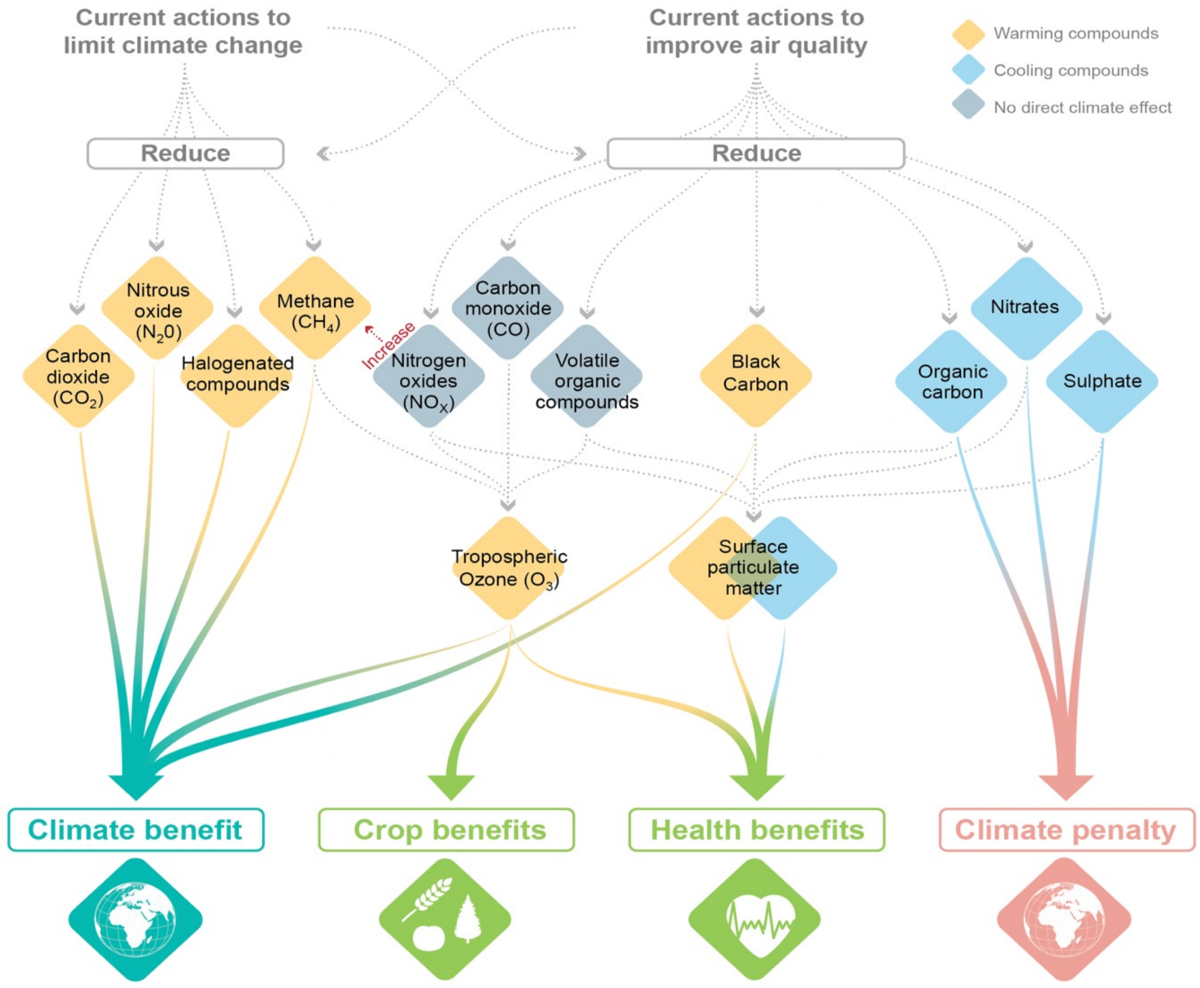


Figure FAQ 6.2

WGII Chapter 5 (Food, Fibre and Other Ecosystem Products)
ES

Climate change impacts are stressing agriculture, forestry, fisheries and aquaculture, increasingly hindering efforts to meet human needs (*high confidence*1). Human-induced warming has slowed growth of agricultural productivity over the past 50 years in mid and low latitudes (*medium confidence*). Crop yields are compromised by surface ozone (*high confidence*). Methane emissions have negatively impacted crop yields by increasing temperatures and surface ozone concentrations (*medium confidence*). Warming is negatively affecting crop and grassland quality and harvest stability (*high confidence*). Warmer and drier conditions have increased tree mortality and forest disturbances in many temperate and boreal biomes (*high confidence*), negatively impacting provisioning services (*medium confidence*). Ocean warming has decreased sustainable yields of some wild fish populations (*high confidence*). Ocean acidification and warming have already affected farmed aquatic species (*high confidence*).

WGII Chapter 7 (Health)

ES. Several chronic, non-communicable respiratory diseases are climate-sensitive based on their exposure pathways (e.g., heat, cold, dust, small particulates, ozone, fire smoke and allergens) *(high confidence)***, although climate change is not the dominant driver in all cases.** Worldwide, rates of adverse health impacts associated with PM exposure have decreased steadily due to decreasing primary emissions *(very high confidence)*, while rates of adverse health impacts from ozone air pollution exposure have increased *(very high confidence).* Exposure to wildland fires and associated smoke has increased in several regions (*very high confidence*). Spring pollen season start dates in northern mid-latitudes are occurring earlier due to climate change, increasing the risks of allergic respiratory diseases *(high confidence)* {7.2.3.2}.

Opportunities for co-benefits from mitigation actions were identified through such actions as reducing local emissions of short-lived climate pollutants from energy systems *(very high confidence)* and expanding transport systems that promote active travel *(high confidence)*.

Risks of compounding or cascading impacts for vulnerable populations.
For example, many of the long-term impacts of climate change on NCDs and injury are associated with future increases in air temperature and levels of air pollution; in many regions, and especially in large urban centres in Asia and Africa, these particular hazards are already causing substantial increases in morbidity and mortality due to respiratory illnesses (Tong et al., 2016). Climate change can therefore be expected to magnify such health risks over the long term.

There are evidence for synergistic effects of heat and air pollution

Inequal exposure (more exposure of Poor populations and urban populations)

BC Forcing in AR5 and AR6

AR5 (1750-2011)

BC RFari = **+0.40 (+0.05 to +0.80)** Wm^{-2}
(Chapters 7 and 8)

Emission-driven (Figure 8.17):

BC RFari = 0.64 Wm^{-2}

Fossil and Bio Fuel BC RFari = 0.60 Wm^{-2}

BC on snow and ice RFari = + 0.04 Wm^{-2}

Estimates relied on Aerocom models (Myhre et al. 2013) and assessment of Bond et al (2013)

AR6 (1750-2019)

BC ERF = **+ 0.11 (-0.20 to +0.42)** $\mathbf{Wm^{-2}}$
(Chapter 6)

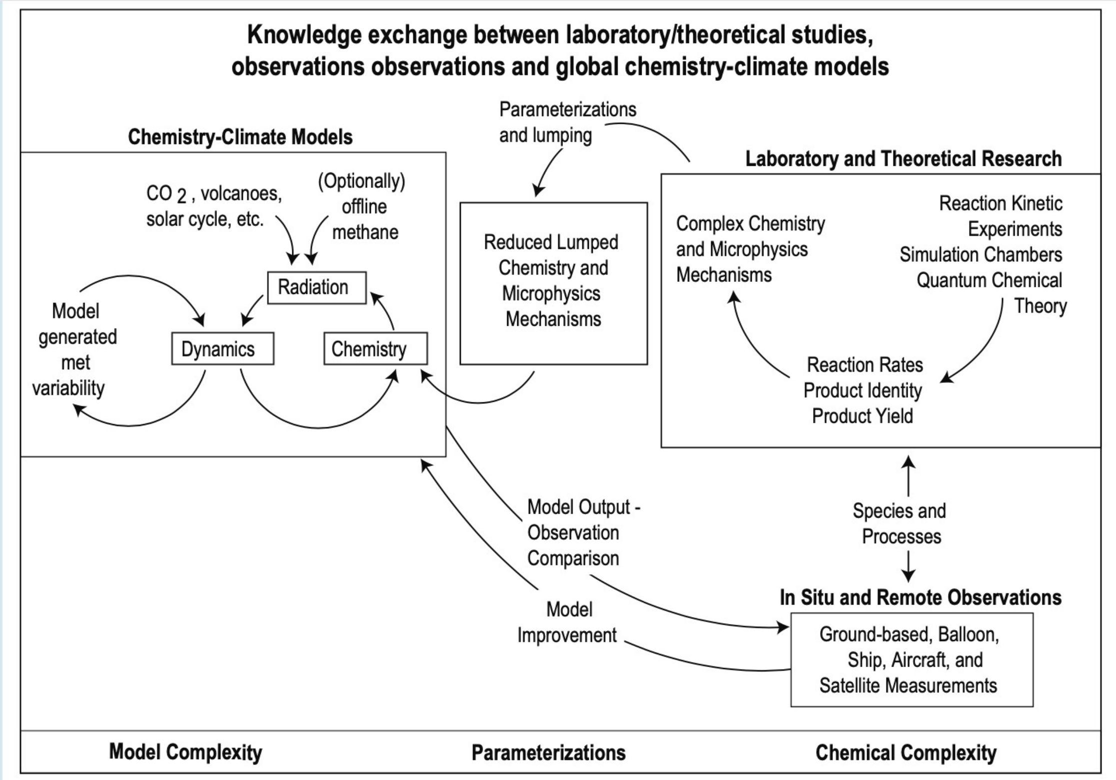
Aerosol-radiation = 0.145 Wm^{-2}

Aerosol-cloud = -0.037 Wm^{-2}

Albedo effect = +0.08 Wm^{-2}
(Chapter 7)

BC ERF incl. albedo effect = **0.18** $\mathbf{Wm^{-2}}$

Estimates rely on AerChemMIP models (Thornhill et al. 2021) and assessment of aerosol-cloud interactions in Chapter 7



But:
Between atmospheric chemistry field and climate field

- Fewer models participating to the intermodel comparisons for aerosols and chemistry

- Full evaluation/comparison of processes missing

- Need a better grid to assess the fit-for-purpose and (maybe) allows weighting in ensemble

Take Home Message #2

[Credit: © UNICEF/Roger LeMoyne]

Air pollution is evolving rapidly with strong regional variations. Climate change has mixed effects on air pollution and the main driver of global air pollution evolution will be the change in emissions (i.e. level of environmental policies and potentially changes in natural emissions).

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[Credit: evgeny-nelmin.]

How does air pollution interact with climate?

How is air pollution evolving and could evolve in the future?

Is fighting climate change good for air pollution?

Is fighting air pollution good for climate change?

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Links between actions aiming to limit climate change and actions to improve air quality

According to SR1.5, decarbonisation requires large scale and in depth transformation in :

- energy
- landuse/ agriculture / food
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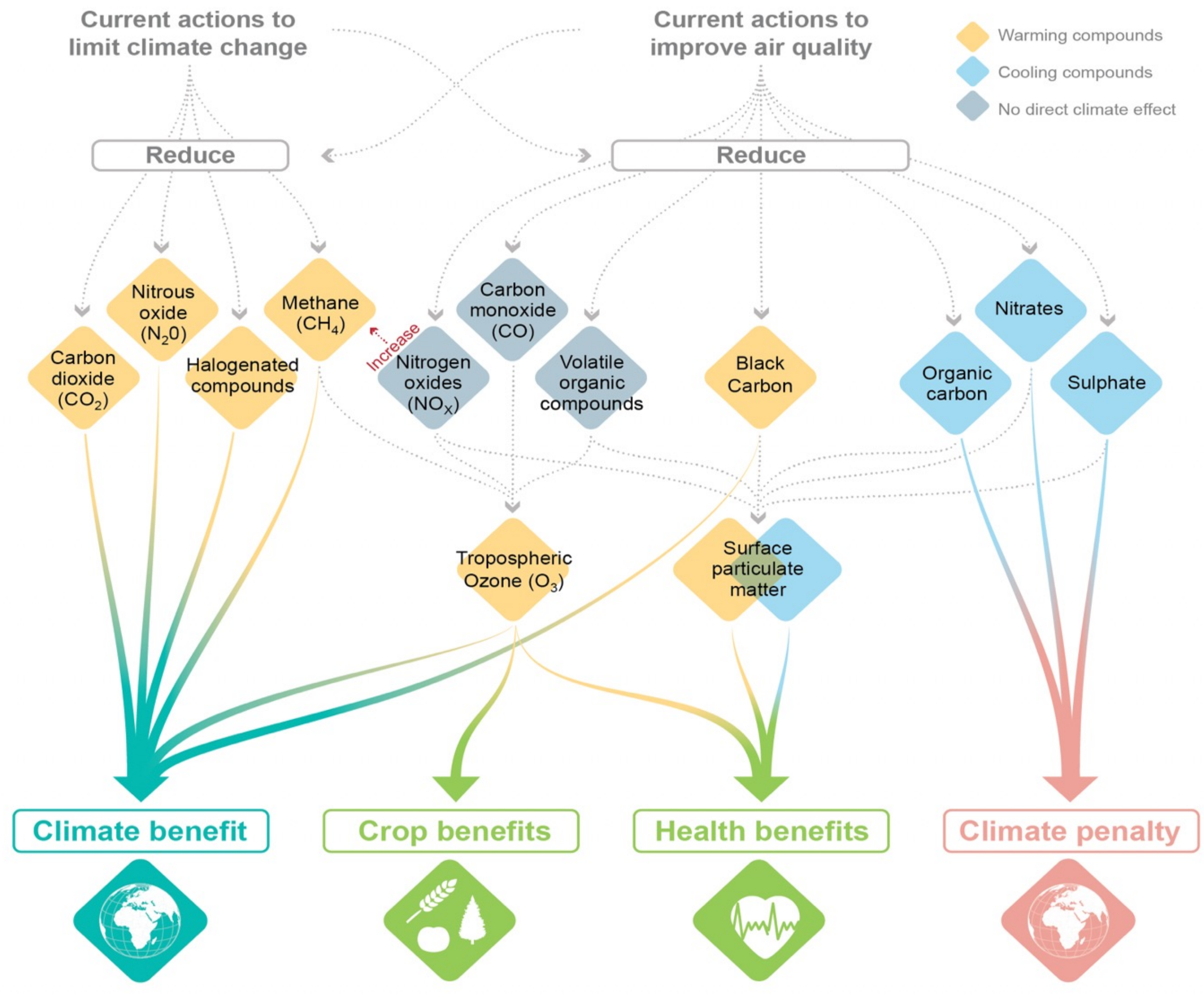
- industry

Figure FAQ 6.2



Take Home Message #4

Decarbonisation requires strong systemic changes in all sectors which would lead to air quality improvements but are not sufficient to reach WHO guidelines in many regions. Air pollution dedicated policies allow to reach AQ improvement more rapidly.

Additional policies (e.g., access to clean energy, waste management) envisaged to attain Sustainable Development Goals (SDG) bring complementary air pollution reduction.

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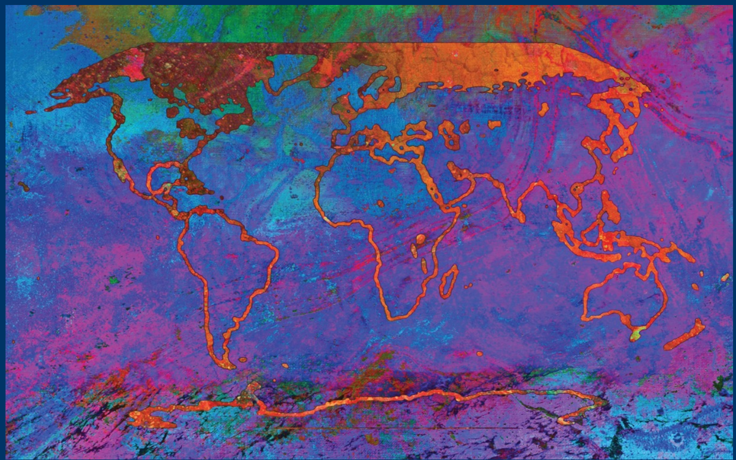

Conclusion

Tackling air quality can't solve the climate issue but tackling climate change can't totally solve the air quality issue either

⇒ **Integrated policies are necessary to yield multiple benefits of mitigating climate change, improving air quality, protecting human health, and achieving several Sustainable Development Goals**

⇒ **Methane reduction is win-win strategy**

SIXTH ASSESSMENT REPORT
Working Group I – The Physical Science Basis

INTERGOVERNMENTAL PANEL ON climate change

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Merci.

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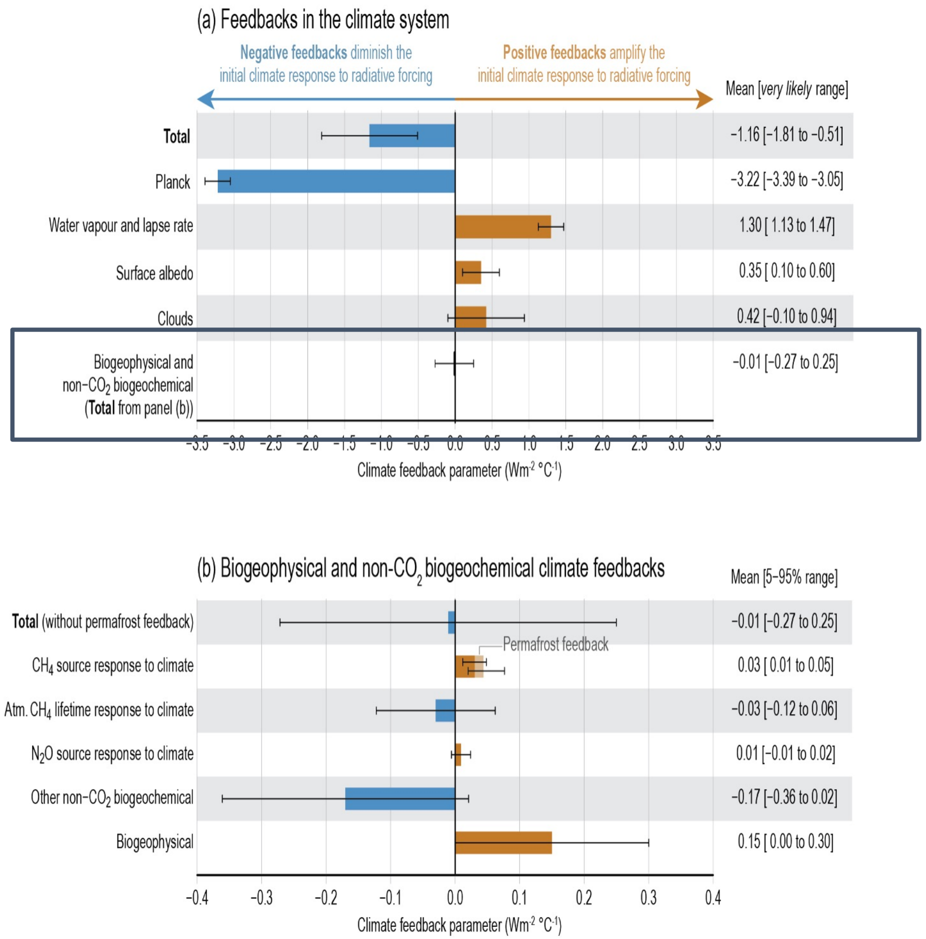
How will climate-induced changes in SLCFs feedback climate?

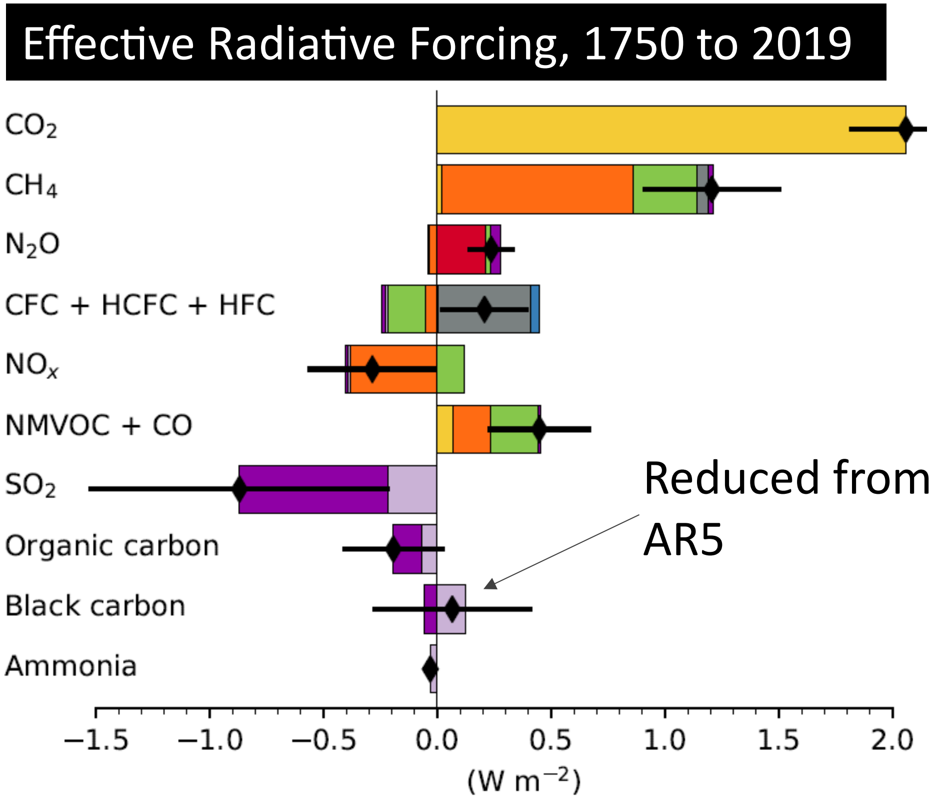
- Climate-induced **changes in atmospheric abundances or lifetime of SLCFs mediated by natural processes (e.g, emissions) or atmospheric chemistry** acting on time scales of years to decades either **diminish** or **amplify** initial climate perturbation
- The **feedback parameter** (α_x) measure of change in net energy flux at the TOA for a given change in surface temperature is **quantified entirely from Earth System Models (ESMs)** that couple the physical climate and atmospheric chemistry to land and ocean biogeochemistry

Non-CO_2 Biogeochemical Feedbacks in Earth System Models are negative (cooling)

Non-CO_2 Biogeochemical Climate Feedback (x)	Number of AerChemMIP Models	Assessed Central Estimate and Very Likely Range of Feedback Parameter (α_x) W m^{-2} °C^{-1}	Published Estimates of α_x W m^{-2} °C^{-1}
Sea salt	6	–0.049 [–0.13 to +0.03]	–0.08 (Paulot et al., 2020)
DMS	3	0.005 [0.0 to 0.01]	–0.02 (Ciais et al., 2013)
Dust	6	–0.004 [–0.02 to +0.01]	–0.04 to +0.02 (Kok et al., 2018)
Ozone	4	–0.064 [–0.08 to -0.04]	–0.015 (Dietmüller et al., 2014), –0.06 (Muthers et al., 2014, stratospheric ozone changes only), –0.01 (Marsh et al., 2016, stratospheric ozone changes only), –0.13 (Nowack et al., 2015, stratospheric ozone and water vapour changes), –0.007 ± 0.009 (Heinze et al., 2019, tropospheric ozone changes only)
BVOC	4	–0.05 [–0.22 to +0.12]	–0.06 (Scott et al., 2017, aerosol effects only), –0.01 (Paasonen et al., 2013; indirect aerosol effects only), 0–0.06 (Ciais et al., 2013)
Lightning	4	–0.010 [–0.04 to +0.02]	
Methane lifetime	4	–0.030 [–0.12 to +0.06]	–0.30 ± 0.01 (Heinze et al., 2019)
Total non-CO_2 Biogeochemical feedbacks assessed in this chapter		–0.200 [–0.41 to +0.01]	0.0 ± 0.15 (Sherwood et al., 2020)

Non-CO_2 BGC feedbacks are much lower than physical climate feedbacks but contribute to uncertainty in climate sensitivity





Effective Radiative Forcing, 1750 to 2019
CO2
CH4
N2O
CFC + HCFC + HFC
NOx
NMVOC + CO
SO2
Organic carbon
Black carbon
Ammonia
Reduced from AR5
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
(W m−2)

Reasons for Differences in BC Forcing between AR5 and AR6

1. AR5 reported radiative forcing due to aerosol-radiation interactions only **(RFari)** where as AR6 reports effective radiative forcing **(ERF)** (*more in Chapter 6*)

2. The inclusion of **rapid adjustments**, mainly caused by **cloud changes** but also by lapse rate and atmospheric water vapor changes, offset the positive instantaneous RF from BC, bringing the net forcing and the BC climate impact down. Rapid adjustments are recognized to be the main reason for low temperature change from BC emissions *(more in Chapter 7*).

3. Improved knowledge of **BC related processes** (e.g., ageing, lifetime), improvements in **models** (e.g., atmospheric absorption, optical parameters)**,** updates in **observational constraints** (e.g., representativeness of Aeronet sites) and in **emissions** (e.g., temporal resolution, updates in CMIP emissions) *(more in Chapters 6 and 7)*

BC Forcing in AR5 and AR6

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BC ERF incl. albedo effect = **0.18** $\mathbf{Wm^{-2}}$

Estimates rely on AerChemMIP models (Thornhill et al. 2021) and assessment of aerosol-cloud interactions in Chapter 7

Effect of SLCFs on Biogeochemical Cycles

Reactive nitrogen, ozone and aerosols affect terrestrial vegetation and carbon cycle through deposition and effects on large scale radiation (*high confidence*). However, the magnitude of these effects on the land carbon sink, ecosystem productivity and indirect CO_2 forcing remain uncertain due to the difficulty in disentangling the complex interactions between the individual effects. As such these effects are assessed to be of second order in comparison to the direct CO_2 forcing (*high confidence*), but effects of ozone on terrestrial vegetation could add a substantial (positive) forcing compared with the direct ozone forcing (*low confidence*). {6.4.5}

Feedbacks induced from changes in emissions, abundances or lifetimes of SLCFs mediated by natural processes or atmospheric chemistry are assessed to have an overall cooling effect, that is, a negative feedback parameter, of-0.20 [-0.41 to +0.01] W m^{-2} °C^{-1}. These non-CO_2 biogeochemical feedbacks are estimated from ESMs, which have advanced since AR5 to include a consistent representation of biogeochemical cycles and atmospheric chemistry. However, process-level understanding of many chemical and biogeochemical feedbacks involving SLCFs, particularly natural emissions, is still emerging, resulting in *low confidence* in the magnitude and sign of most of SLCF climate feedbacks. {6.2.2, 6.4.5}

Figure SPM.2

Observed warming is driven by emissions from human activities, with greenhouse gas warming partly masked by aerosol cooling