



**FONDAZIONE
GIUSEPPE OCCHIALINI**

Studio e previsioni dello stato del sistema

*Federico Porcù (federico.porcu@unibo.it)
Dipartimento di Fisica e Astronomia
Università di Bologna*

un esempio di interazione tra sottosistemi: El nino

forzanti sul sistema climatico (GHG)

proiezioni climatiche

meccanismi di retroazione (feed back)

una forzatura su una componente del sistema produce un effetto che modifica l'impatto della forzatura

feed back positivo: l'impatto aumenta
instabilità

feed back negativo: l'impatto diminuisce
stabilità

feed back negativo

aumento di T \Rightarrow aumento di wv \Rightarrow aumento di copertura
nubi \Rightarrow aumento albedo planetaria \Rightarrow diminuzione di T

feed back positivo

aumento di T \Rightarrow aumento di wv \Rightarrow
aumento effetto serra \Rightarrow aumento di T

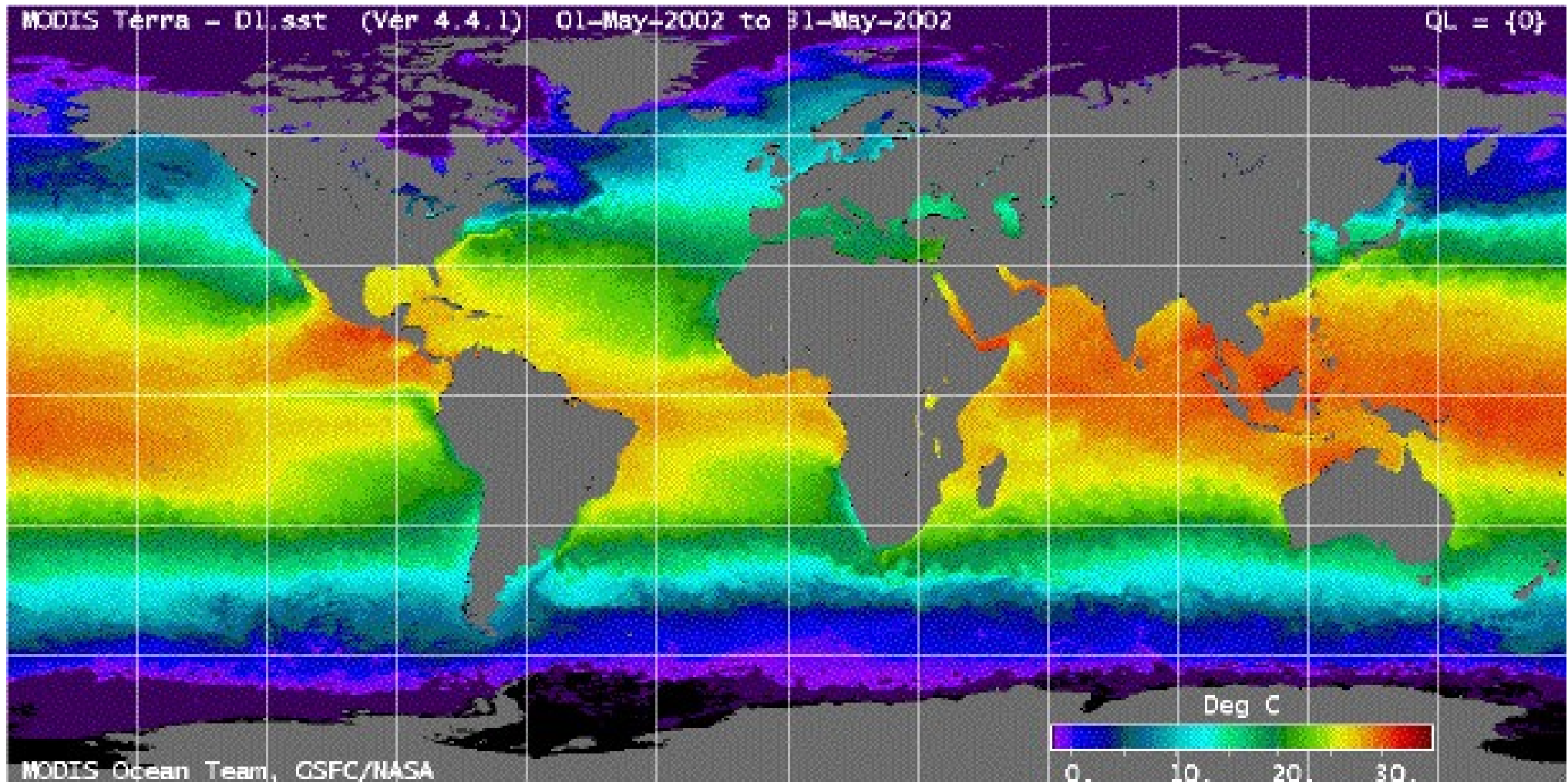
diminuzione di T \Rightarrow aumento ghiaccio superficiale \Rightarrow
aumento di albedo planetaria \Rightarrow diminuzione di T

Interazione Atmosfera/Oceano

- l'atmosfera influenza l'oceano principalmente a causa dello stress del vento superficiale;**

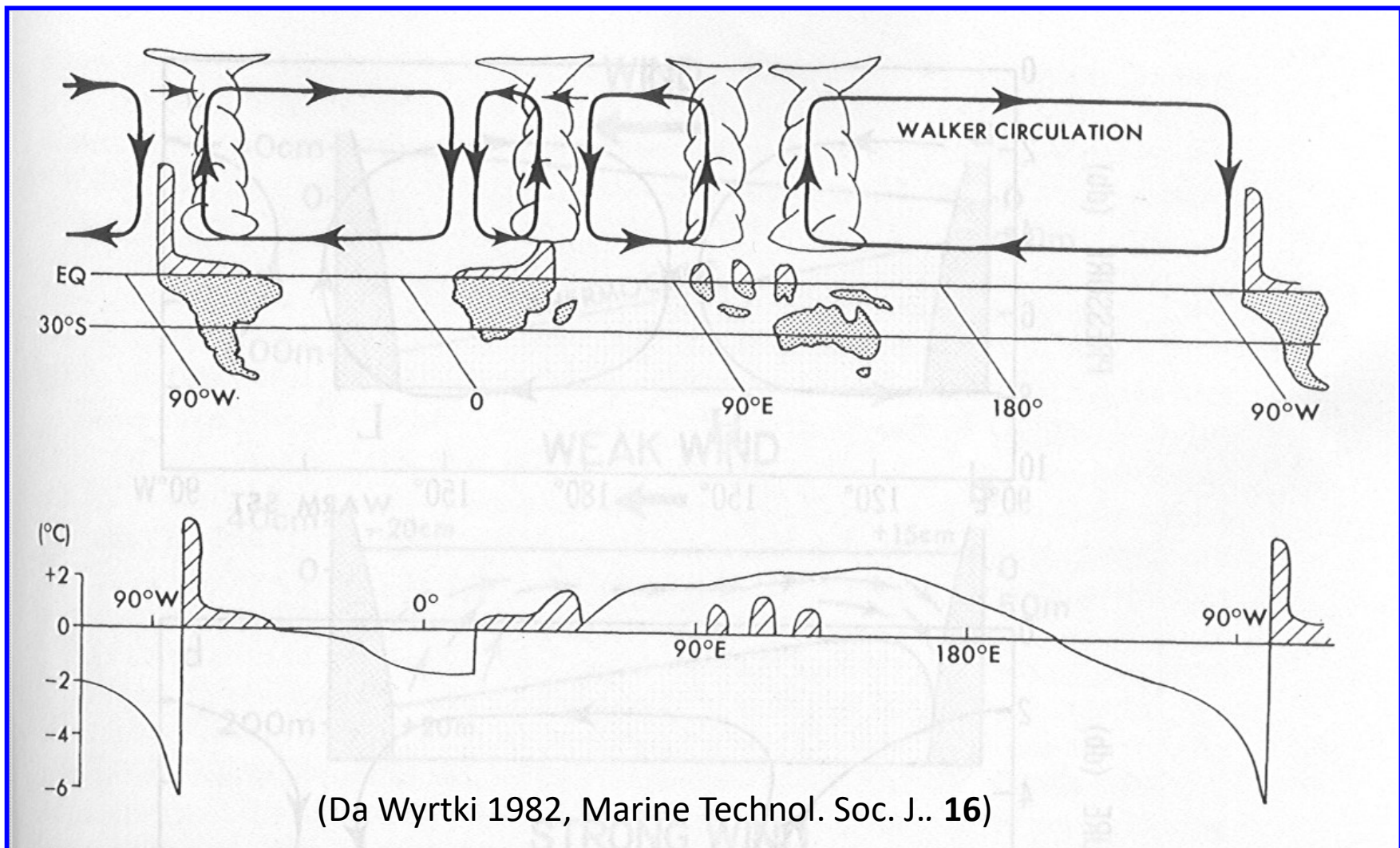
- l'oceano influenza l'atmosfera principalmente a causa di anomalie nella temperatura della sua superficie (*Sea Surface Temperature SST*) e del conseguente flusso verticale di calore sensibile e latente.**

temperatura media oceanica



Circolazione Atmosferica Equatoriale

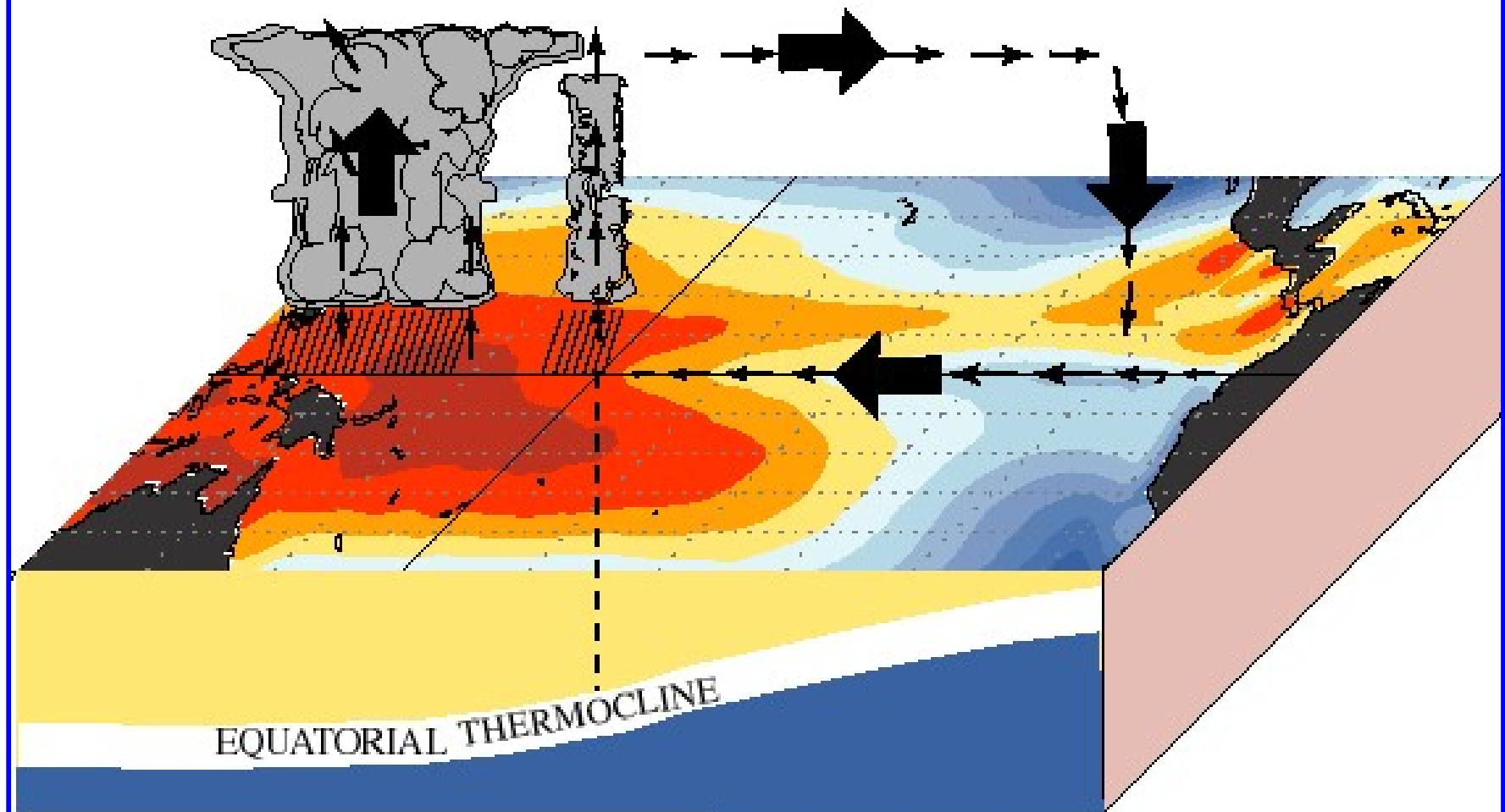
Schema della normale circolazione di Walker lungo l'equatore. Risalita di aria e pioggia insistente sul Indonesia, Pacifico occidentale, Africa sud orientale e Amazzonia, mentre condizioni di scarsa precipitazione nel Pacifico orientale e nell'Africa sud-occidentale. Il grafico in basso mostra inoltre il profilo dell'anomalia di temperatura lungo l'equatore.



(Da Wyrтки 1982, Marine Technol. Soc. J.. 16)

Circolazione Atmosferica Equatoriale

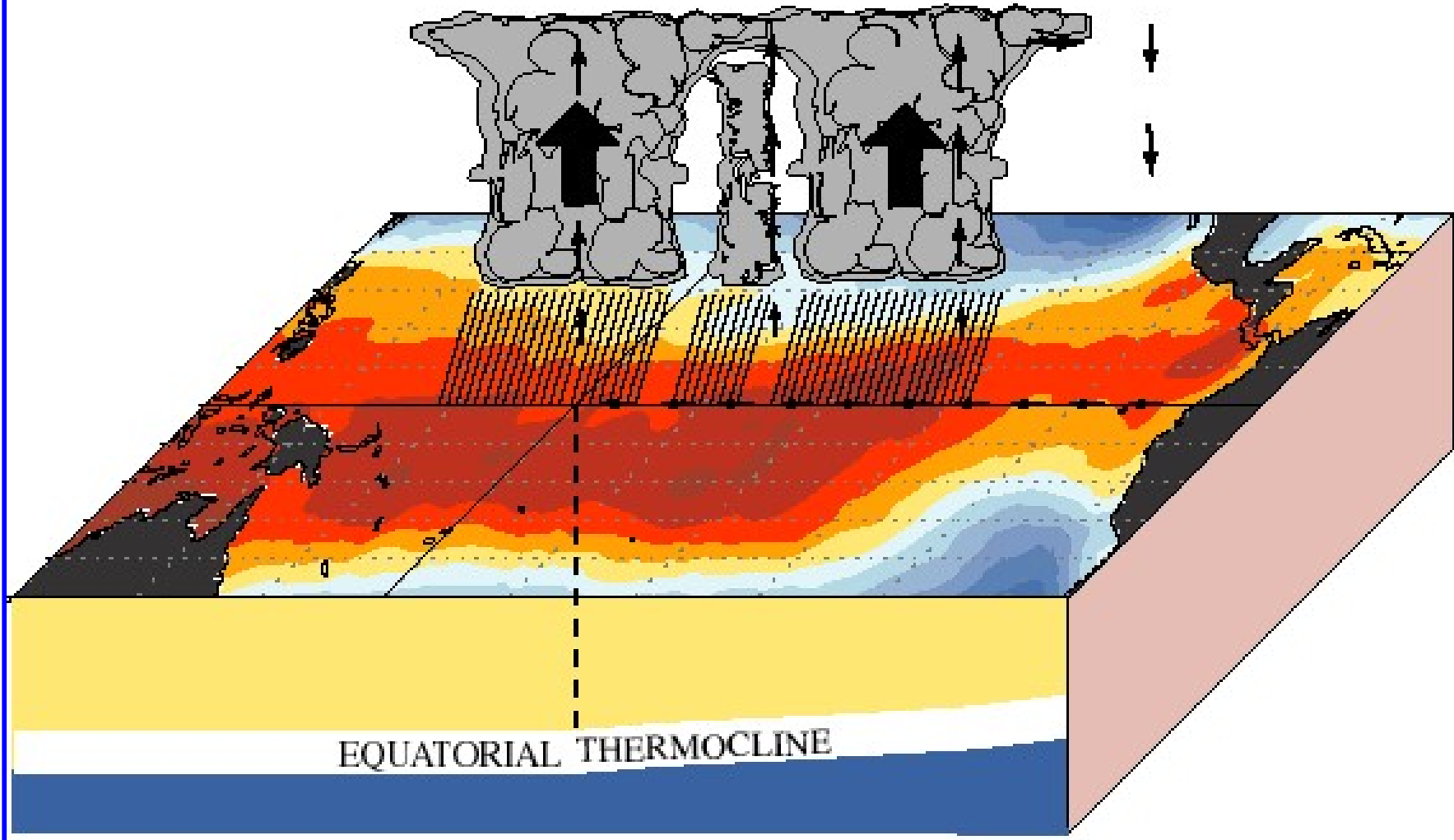
December - February Normal Conditions



Circolazione Atmosferica Equatoriale

Condizione ENSO – El Niño

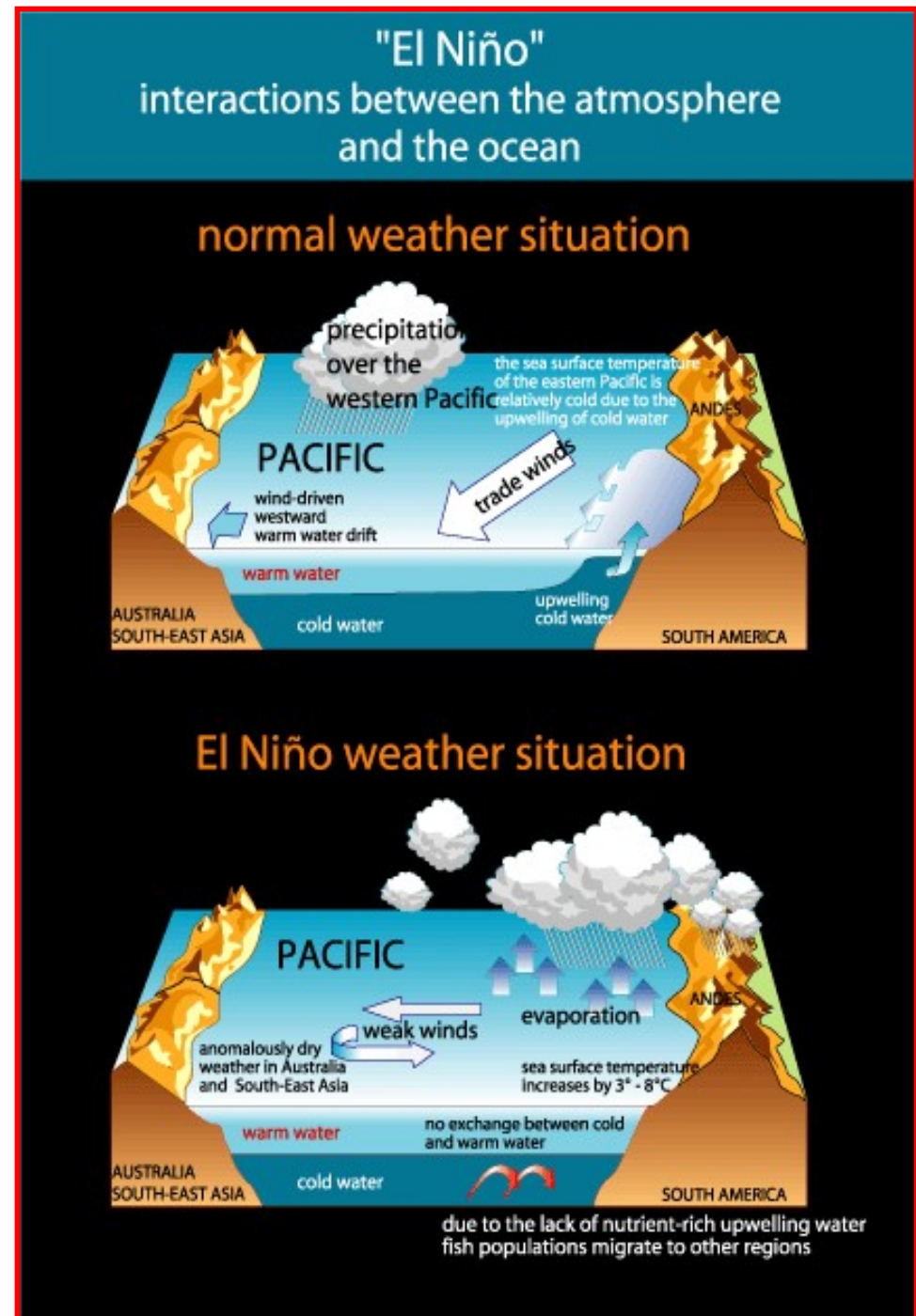
December - February El Niño Conditions



Circolazione Atmosferica Equatoriale - Condizione ENSO

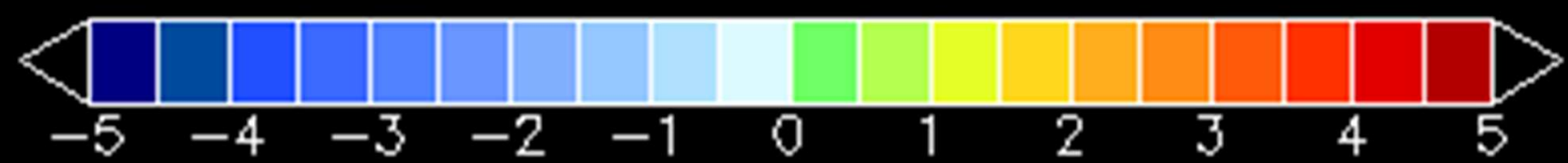
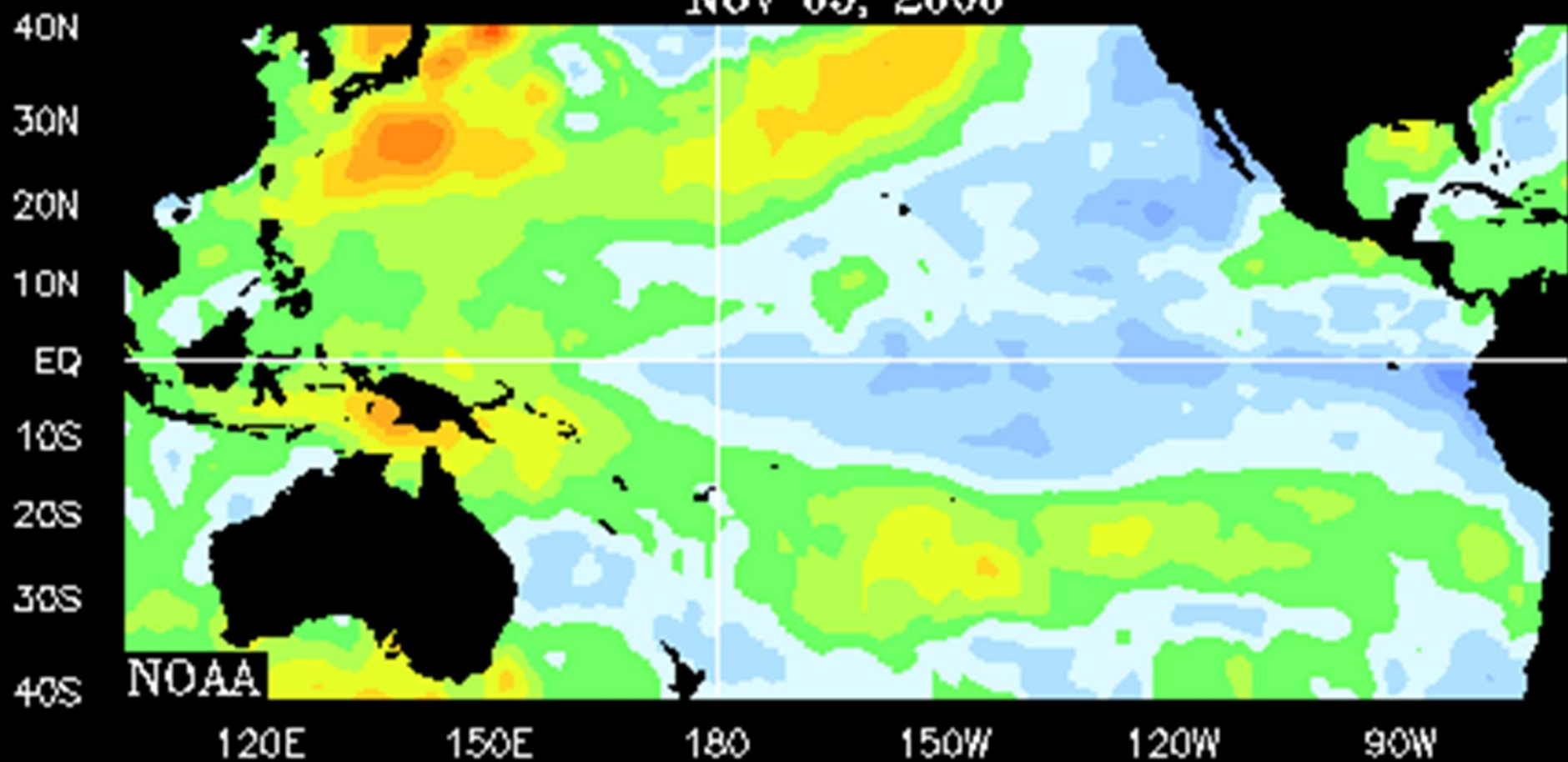
Negli anni “normali” il forte gradiente di temperatura superficiale (freddo a est caldo a ovest) nel Pacifico equatoriale è accompagnato da **forti venti alisei** che spingono le acque superficiali verso ovest permettendo a quelle più fredde e profonde di risalire in superficie. La **risalita delle acque** rafforza a sua volta il gradiente di temperatura superficiale mantenendo gli alisei.

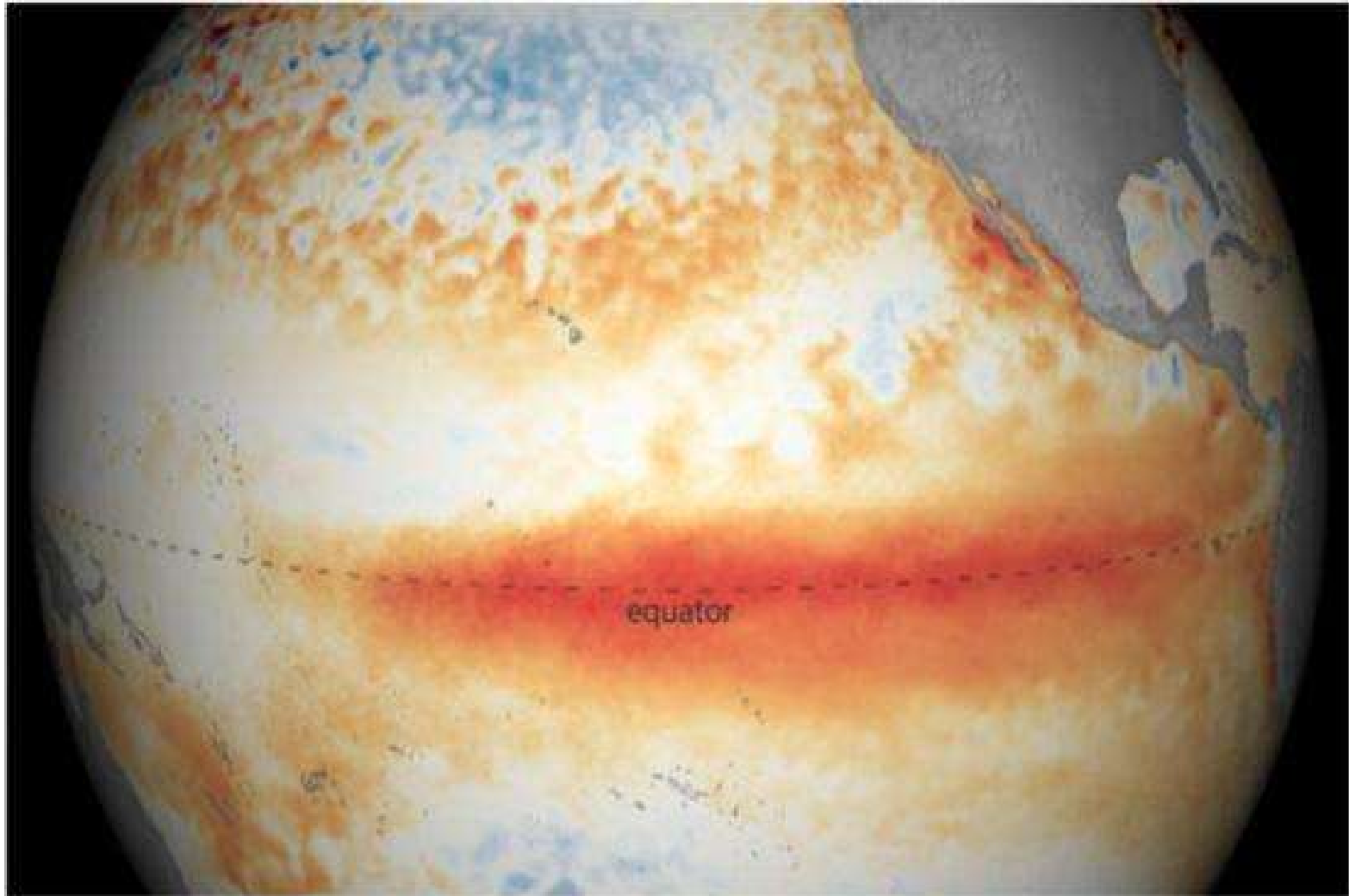
Un **indebolimento degli alisei** nel Pacifico centrale **indebolisce l'upwelling** e fa aumentare la temperatura del Pacifico orientale. Questo fenomeno contribuisce a indebolire ulteriormente gli alisei. Il rafforzarsi vicendevole di questi effetti contribuisce all'instaurarsi di un El Niño.



SST ANOMALIES °C

NOV 05, 2000



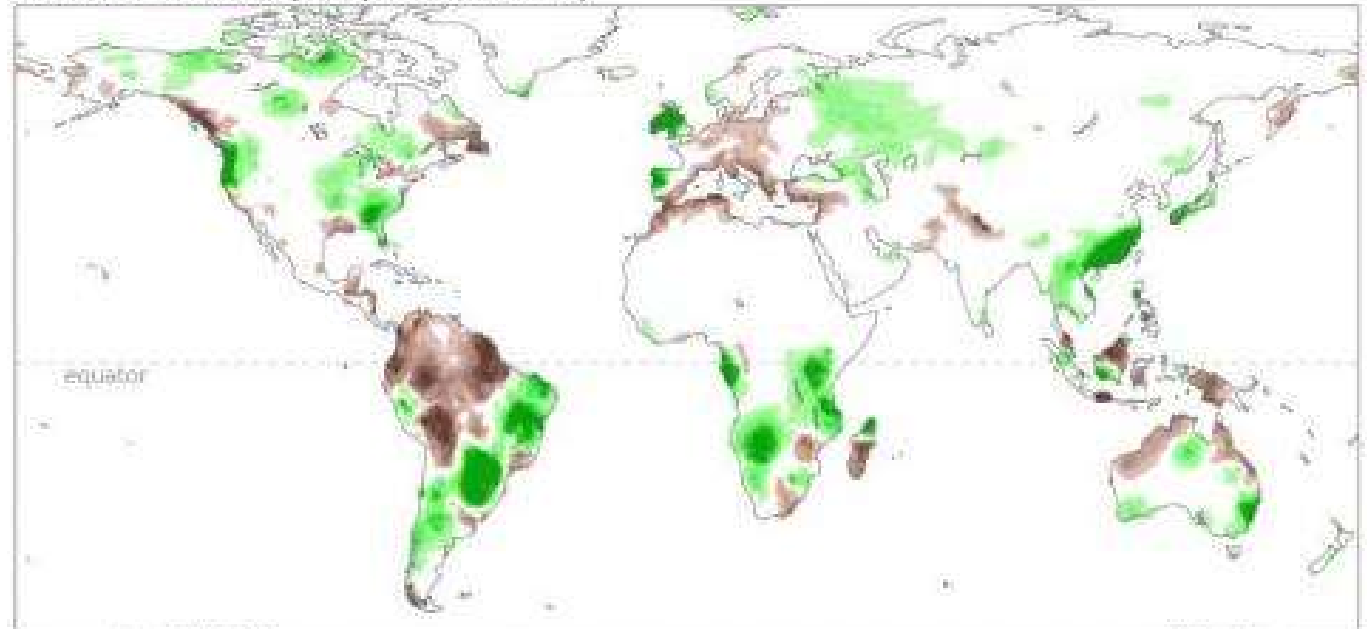


February 2016
compared to 1981-2010



Climate.gov/NNVL
Data: Geo-Polar SST

Dec 2015–Feb 2016 precipitation anomaly



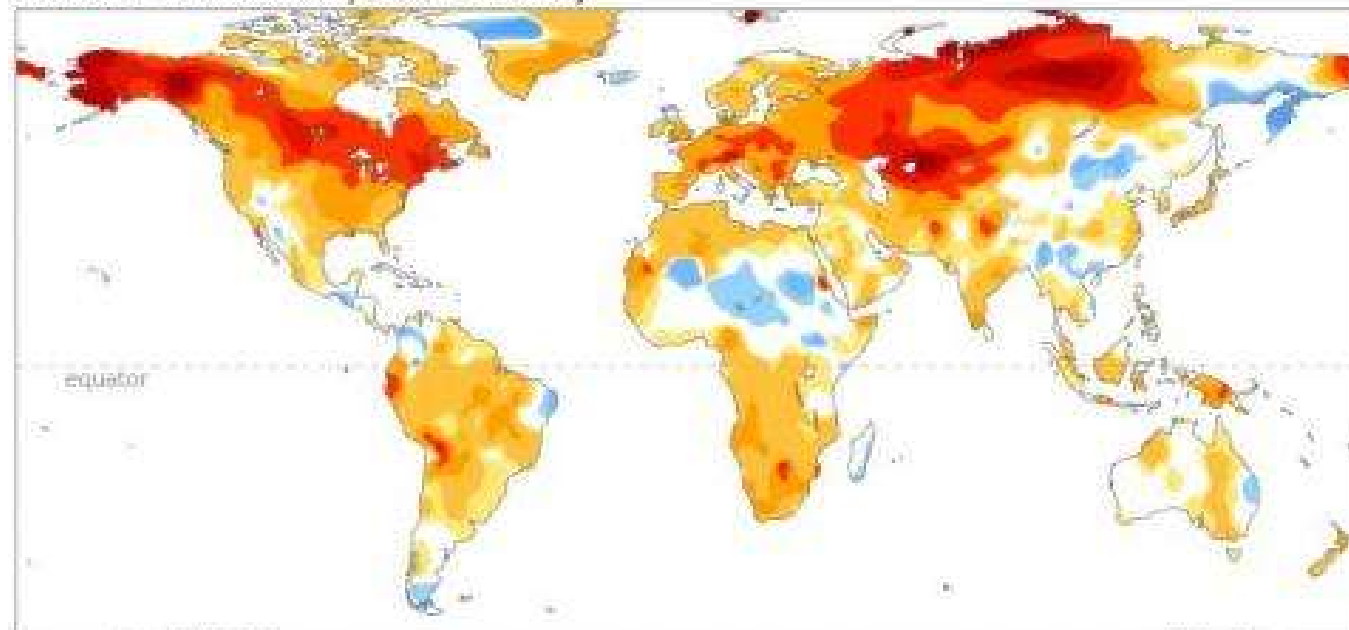
Compared to 1981–2010

NOAA Climate.gov
Data: CPC

Difference from average (mm)

-2.0 -1.5 -1.25 -1.0 -0.75 -0.5 -0.25 0.25 0.5 0.75 1.0 1.25 1.5 2.0

Dec 2015–Feb 2016 temperature anomaly



Compared to 1981–2010

NOAA Climate.gov
Data: CPC

Difference from average temperature (°C)

-2 -1 -0.5 0.5 1 2 3 4 5 6

FORZANTI NATURALI

VARIAZIONE DELLA RADIAZIONE SOLARE

Diretta



Attività Solare

Indiretta



Milankovitch

INTERAZIONI TRA DIVERSE COMPONENTI

El Niño

ERUZIONI VULCANICHE

DERIVA DEI CONTINENTI

FORZANTI ANTROPICHE

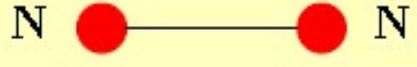
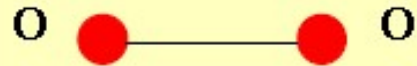
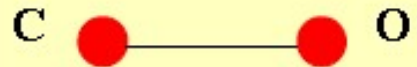
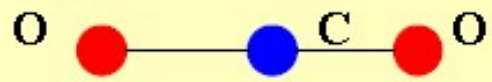
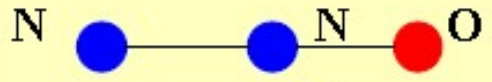
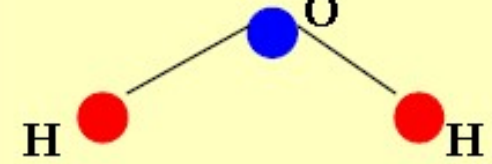
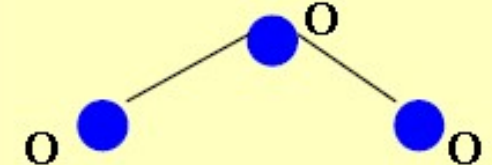
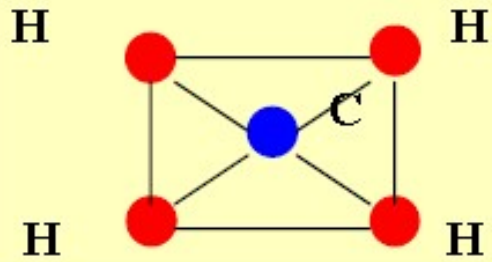
IMMISSIONE DI GAS IN ATMOSFERA

IMMISSIONE DI AEROSOL IN ATMOSFERA

SFRUTTAMENTO DEL TERRENO

forzanti - GHG I

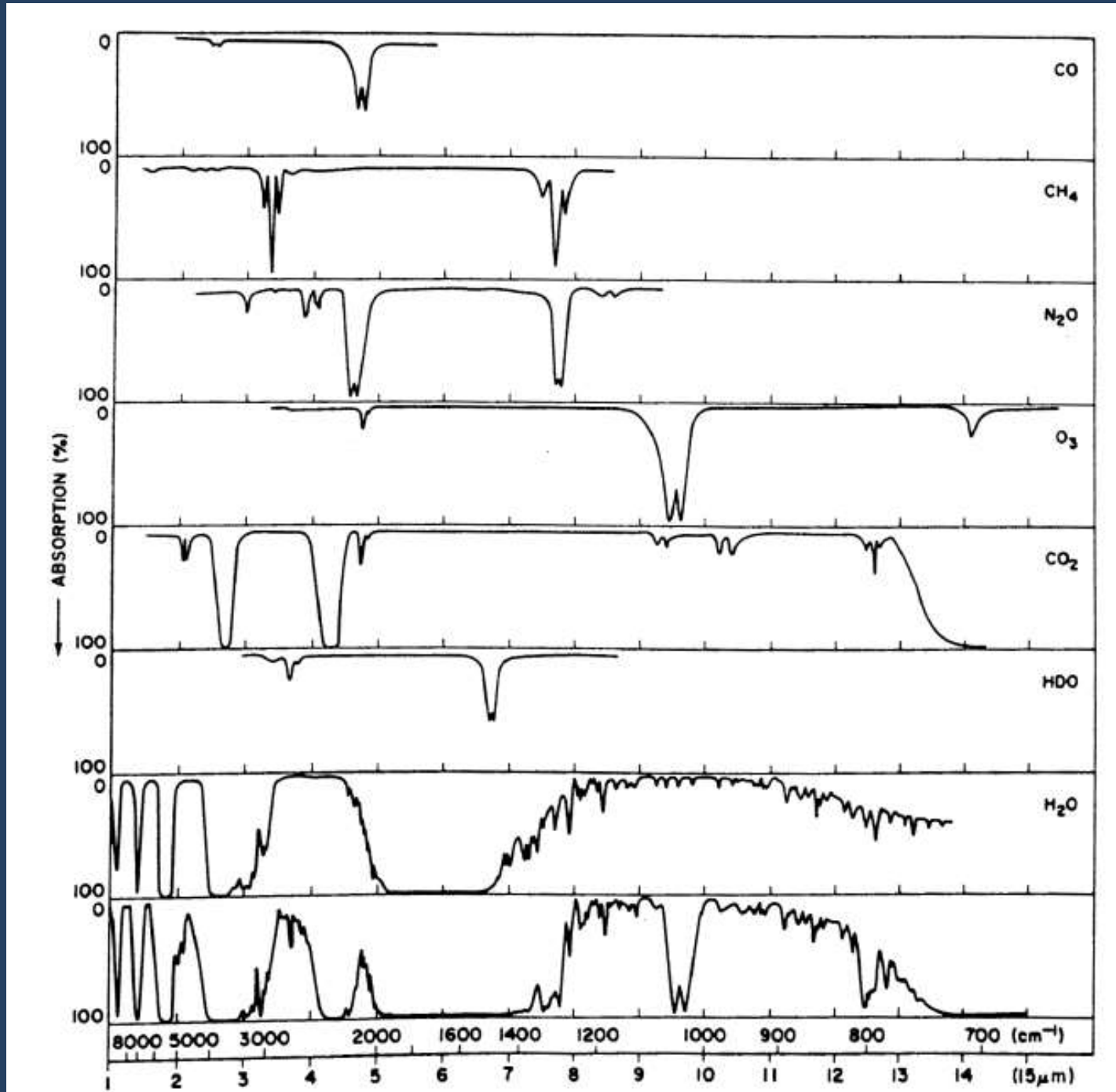
interazione tra radiazione e costituenti atmosferici

Molecule	Structure	Permanent dipole moment	May acquire dipole moment
N_2		No	No
O_2		No	No
CO		Yes	Yes
CO_2		No	Yes (in two vibrational modes)
N_2O		Yes	Yes
H_2O		Yes	Yes
O_3		Yes	Yes
CH_4		No	Yes (in two vibrational modes)

Peixoto and Oort (1998)

forzanti - GHG II

spettri di assorbimento dei gas atmosferici

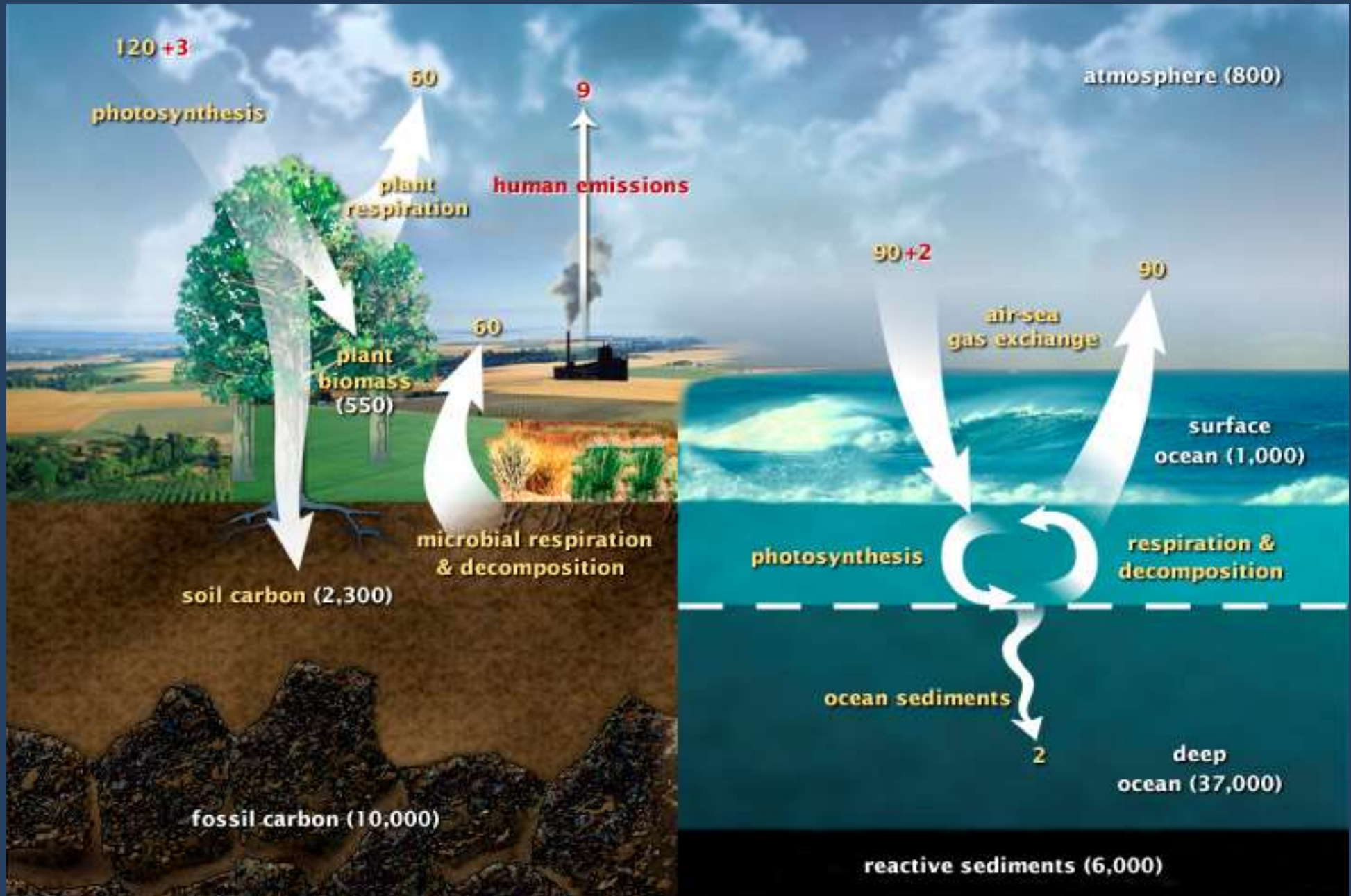


(Valley, 1965)

forzanti - GHG III

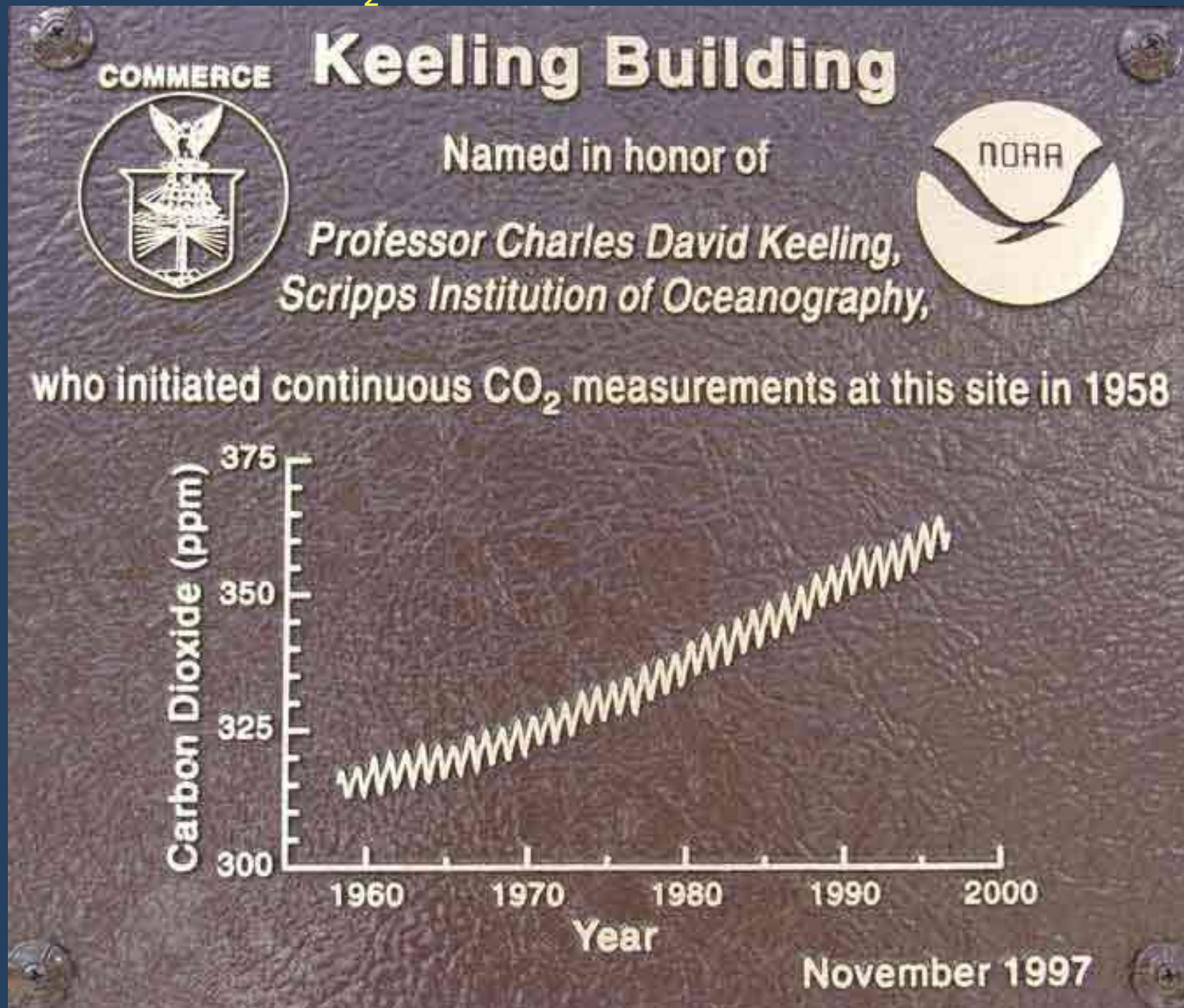
ciclo veloce del carbonio

flussi naturali (GtC/anno) flussi antropici (GtC/anno) riserve (GtC)



forzanti - GHG IV

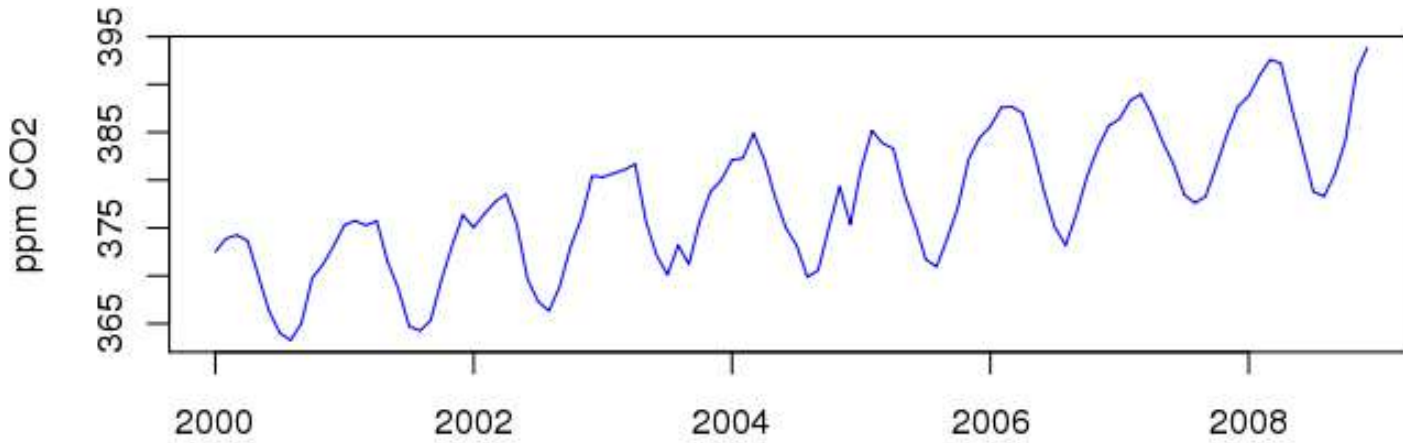
misure di contenuto di CO₂



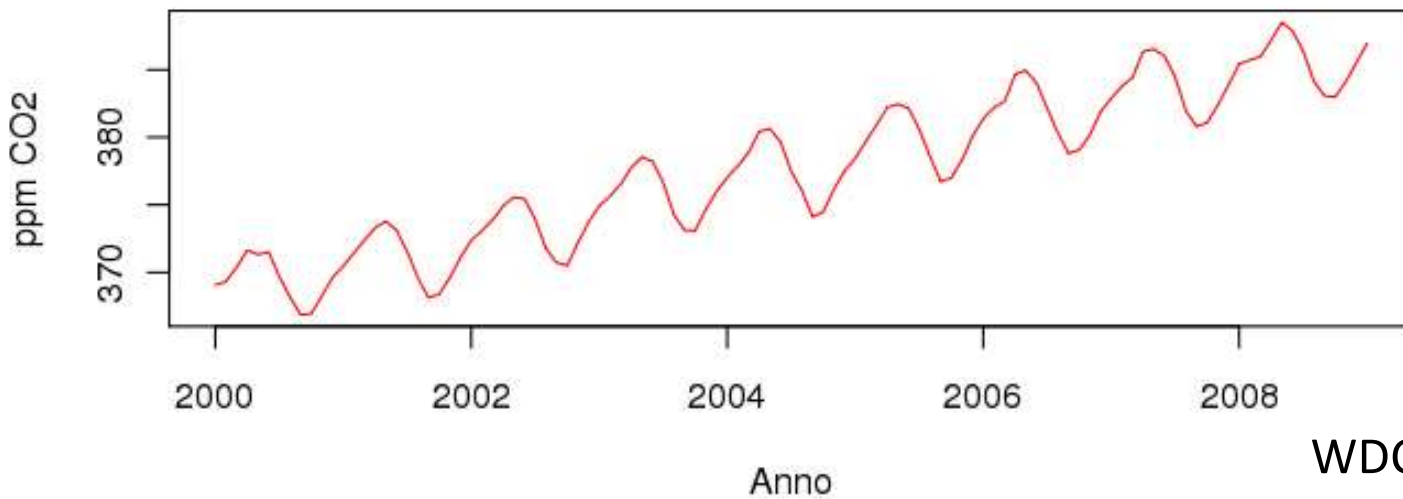
forzanti - GHG V

misure di contenuto di CO₂

CO2 - Monte Cimone



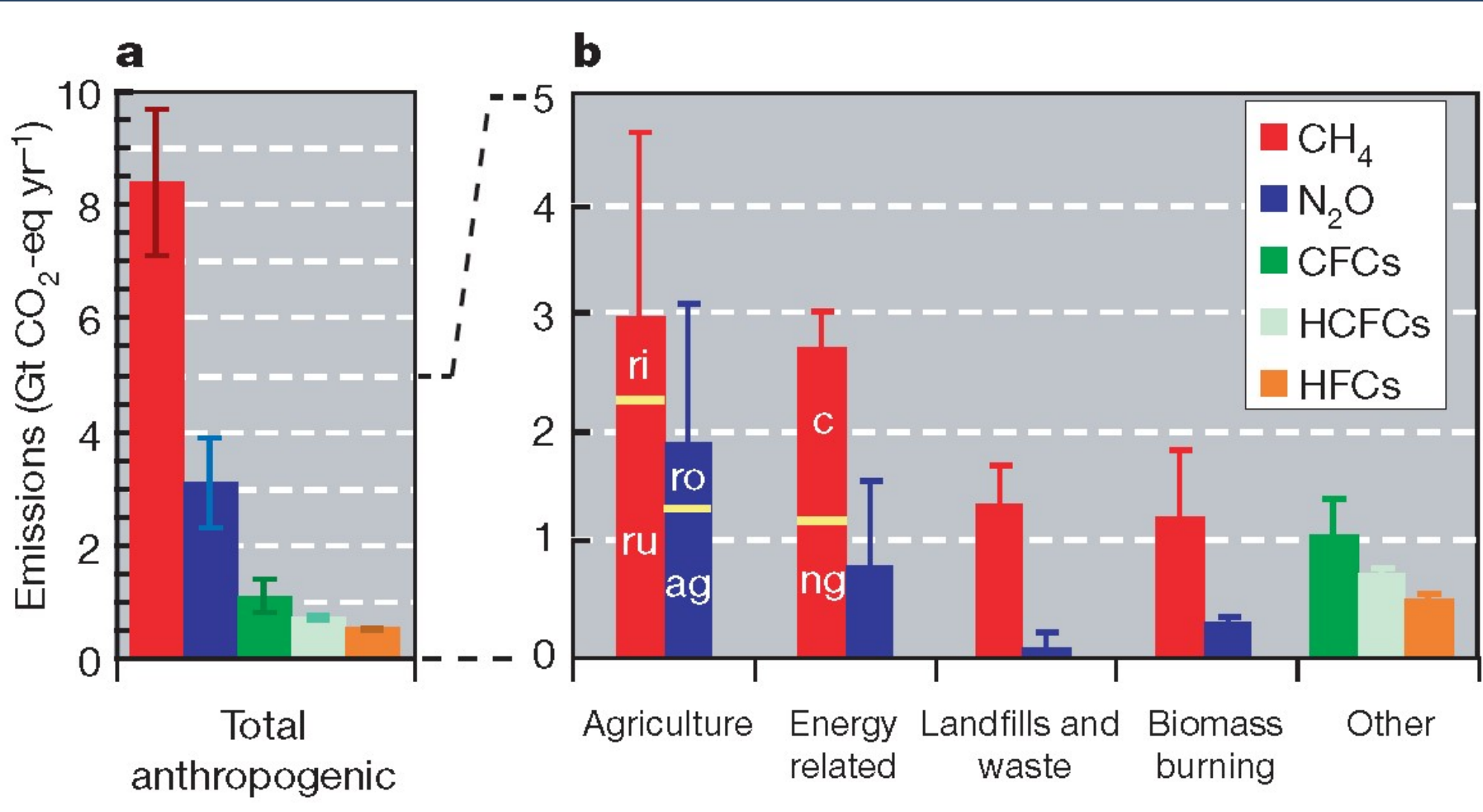
CO2 - Mauna Loa



forzanti - GHG VI

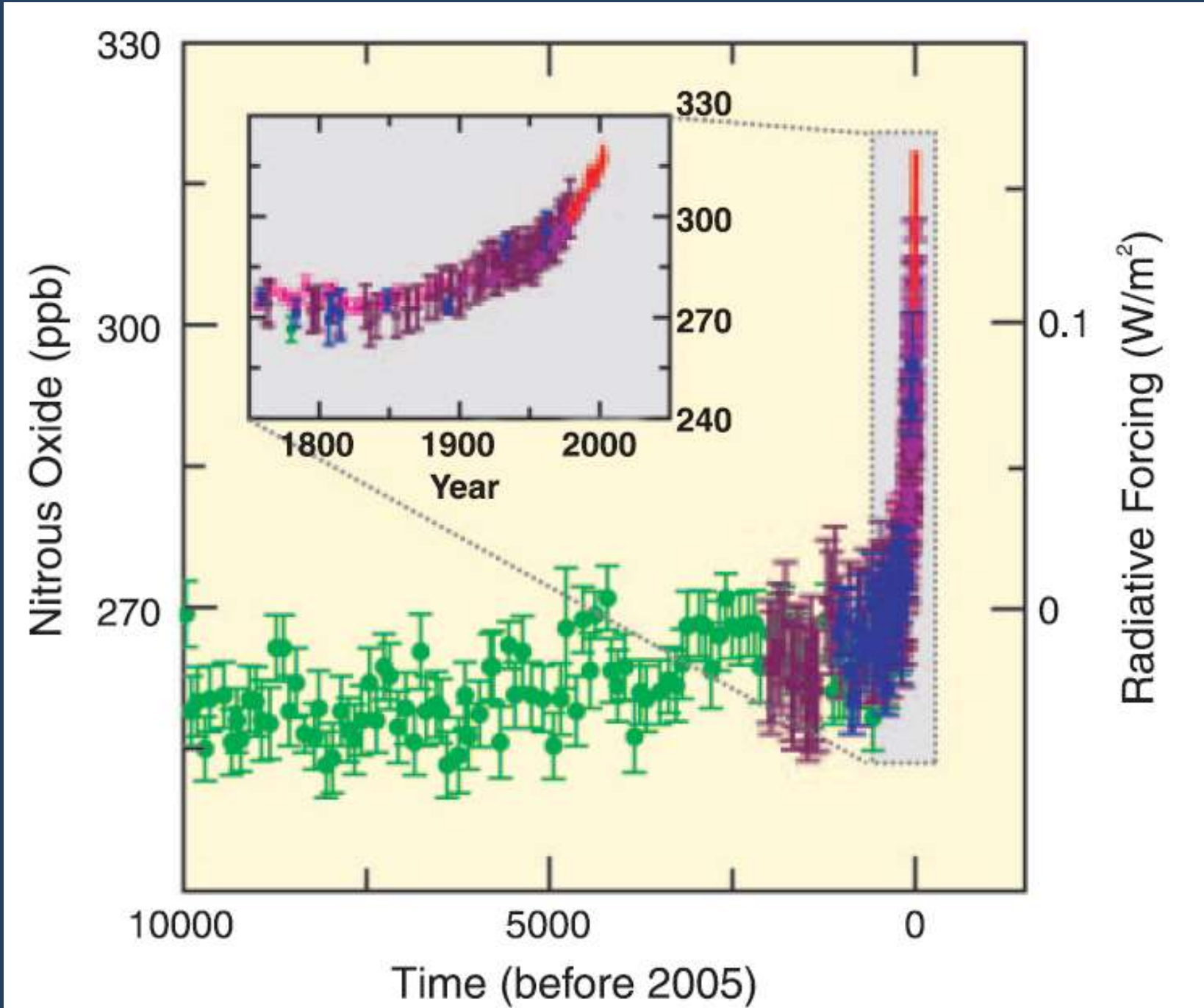
meccanismi di produzione e distruzione di altri GHG

ri: coltivazione del riso; ru: ruminanti; ng: gas naturali; c: miniere
ro: run-off; ag: agricoltura



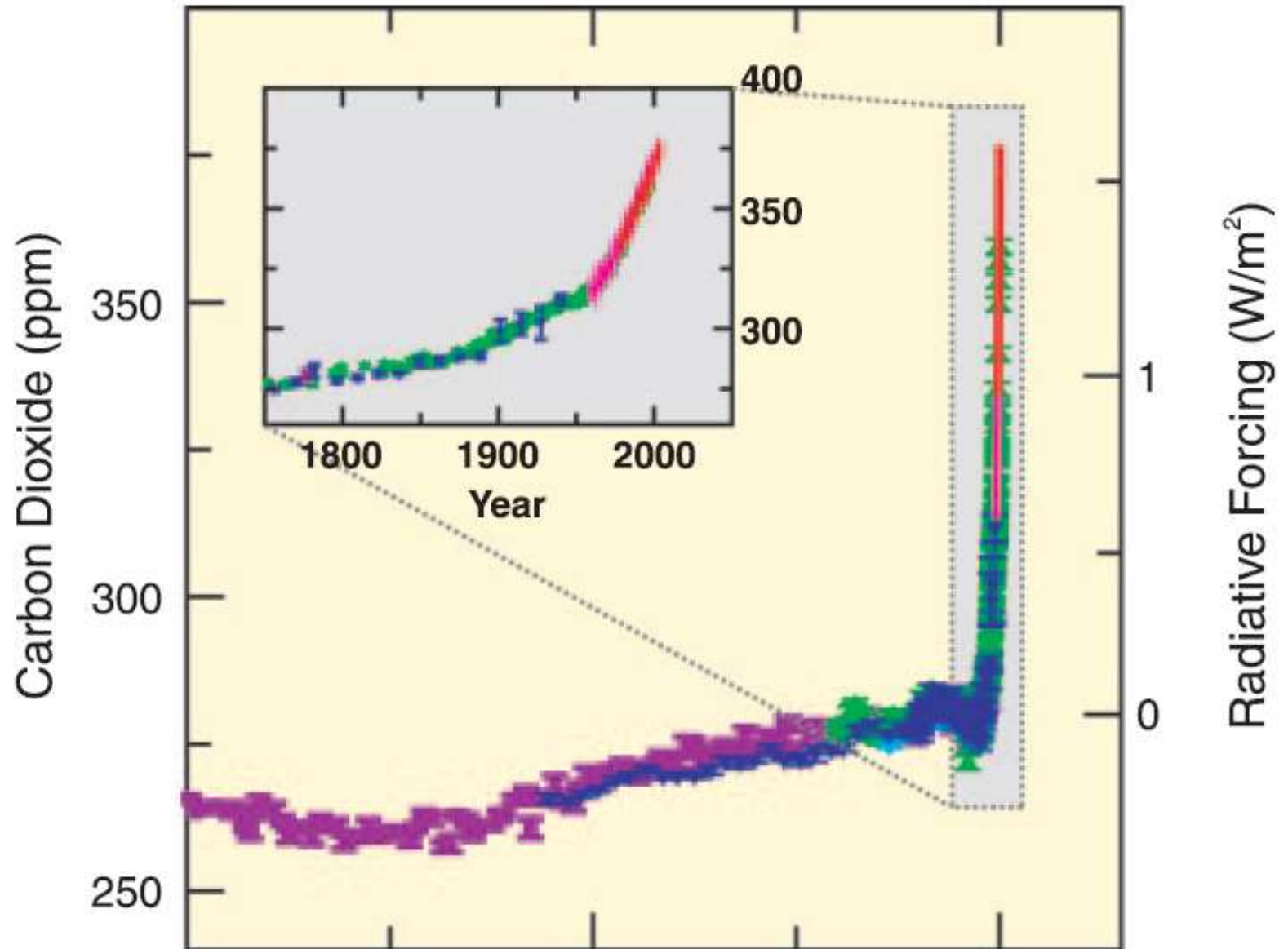
(Montzka et al, 2011)

forzanti - GHG VII
record storici (ice cores)



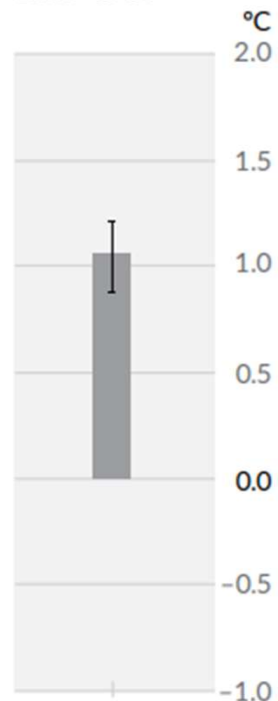
forzanti - GHG VII

record storici (ice cores)



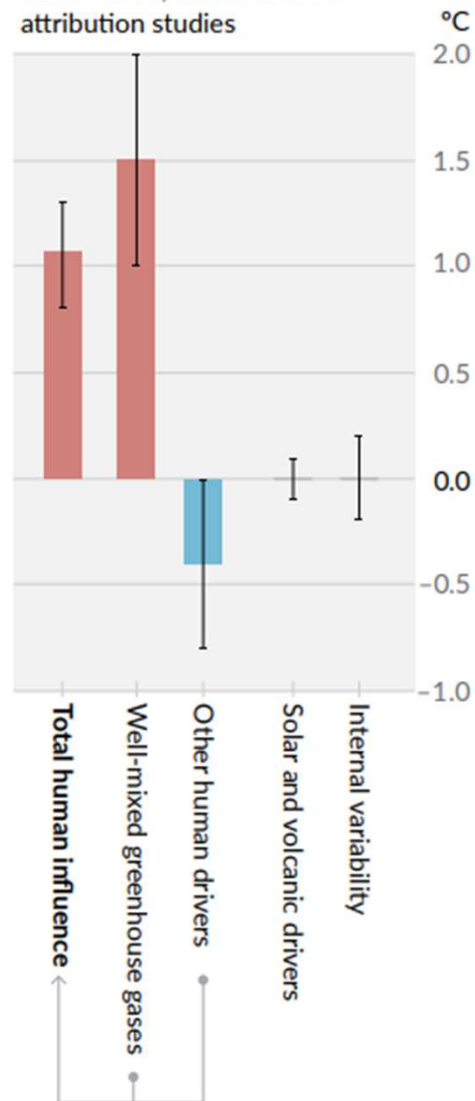
Observed warming

(a) Observed warming 2010–2019 relative to 1850–1900

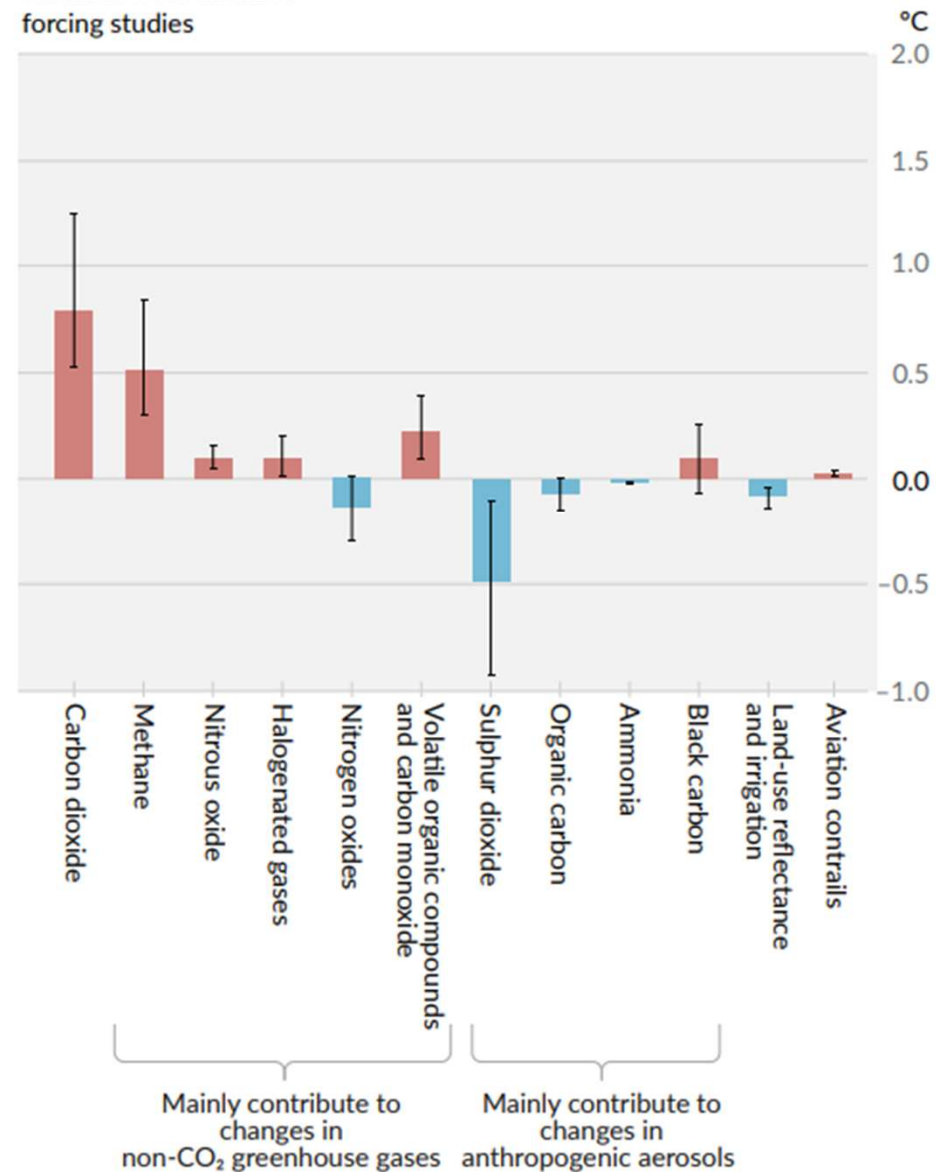


Contributions to warming based on two complementary approaches

(b) Aggregated contributions to 2010–2019 warming relative to 1850–1900, assessed from attribution studies



(c) Contributions to 2010–2019 warming relative to 1850–1900, assessed from radiative forcing studies



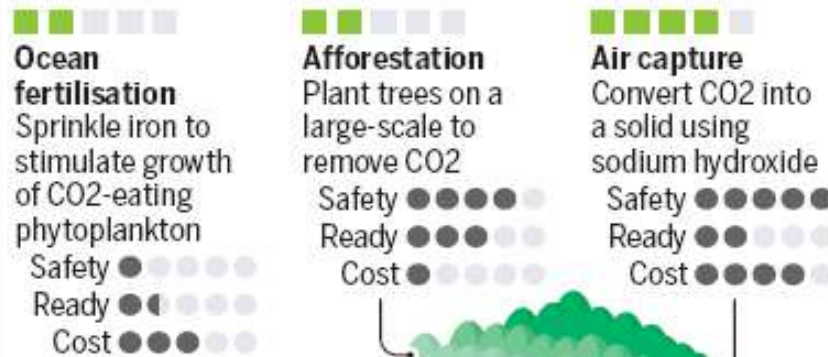
GEOENGINEERING TECHNIQUES

Geoengineering is the large-scale intervention in the Earth system to counteract human-induced climate change. There are two basic approaches to intervention:



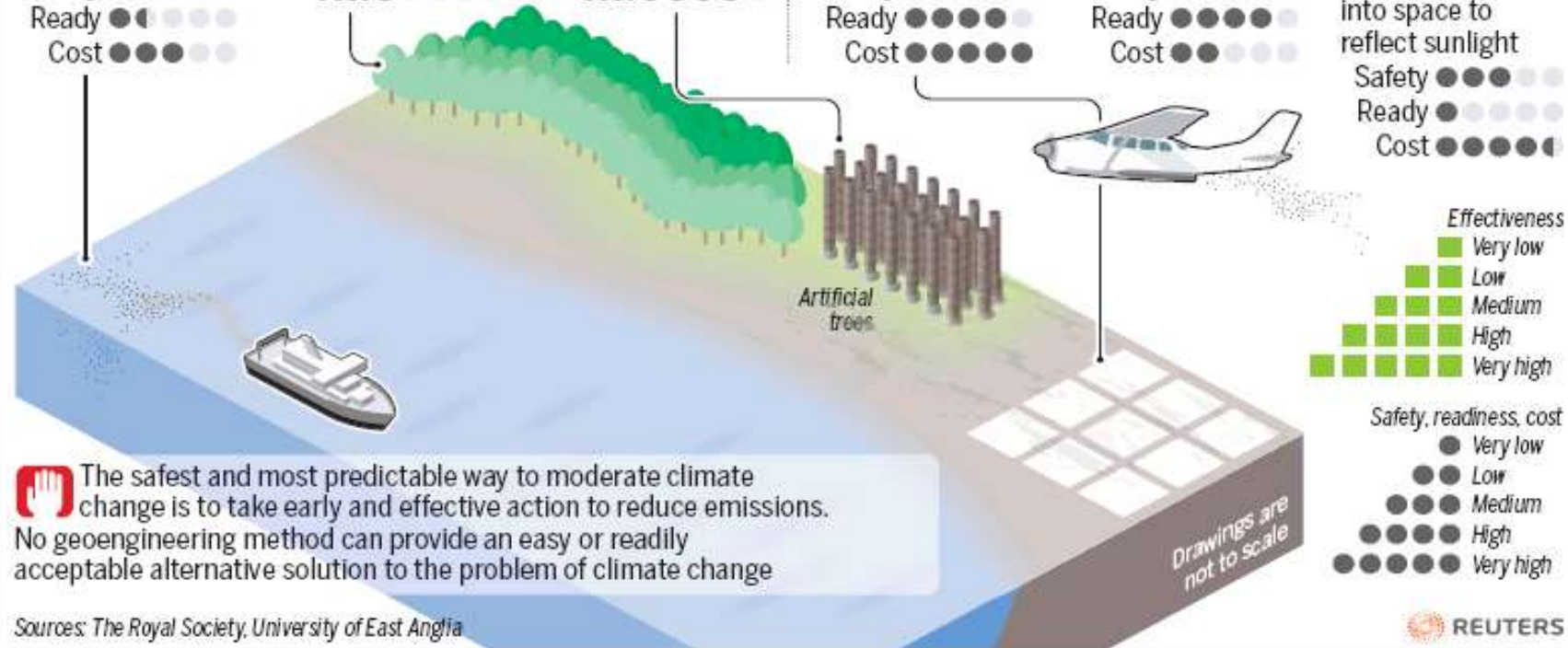
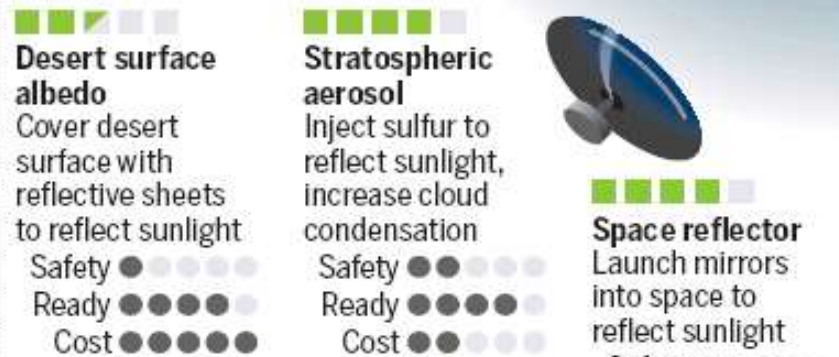
CARBON DIOXIDE REMOVAL

Removes carbon dioxide (CO₂) from the atmosphere and storing it for a long time. Techniques include:



SOLAR RADIATION MANAGEMENT

Counteracts global warming by reflecting some sunlight back to space. Techniques include:



The safest and most predictable way to moderate climate change is to take early and effective action to reduce emissions. No geoengineering method can provide an easy or readily acceptable alternative solution to the problem of climate change

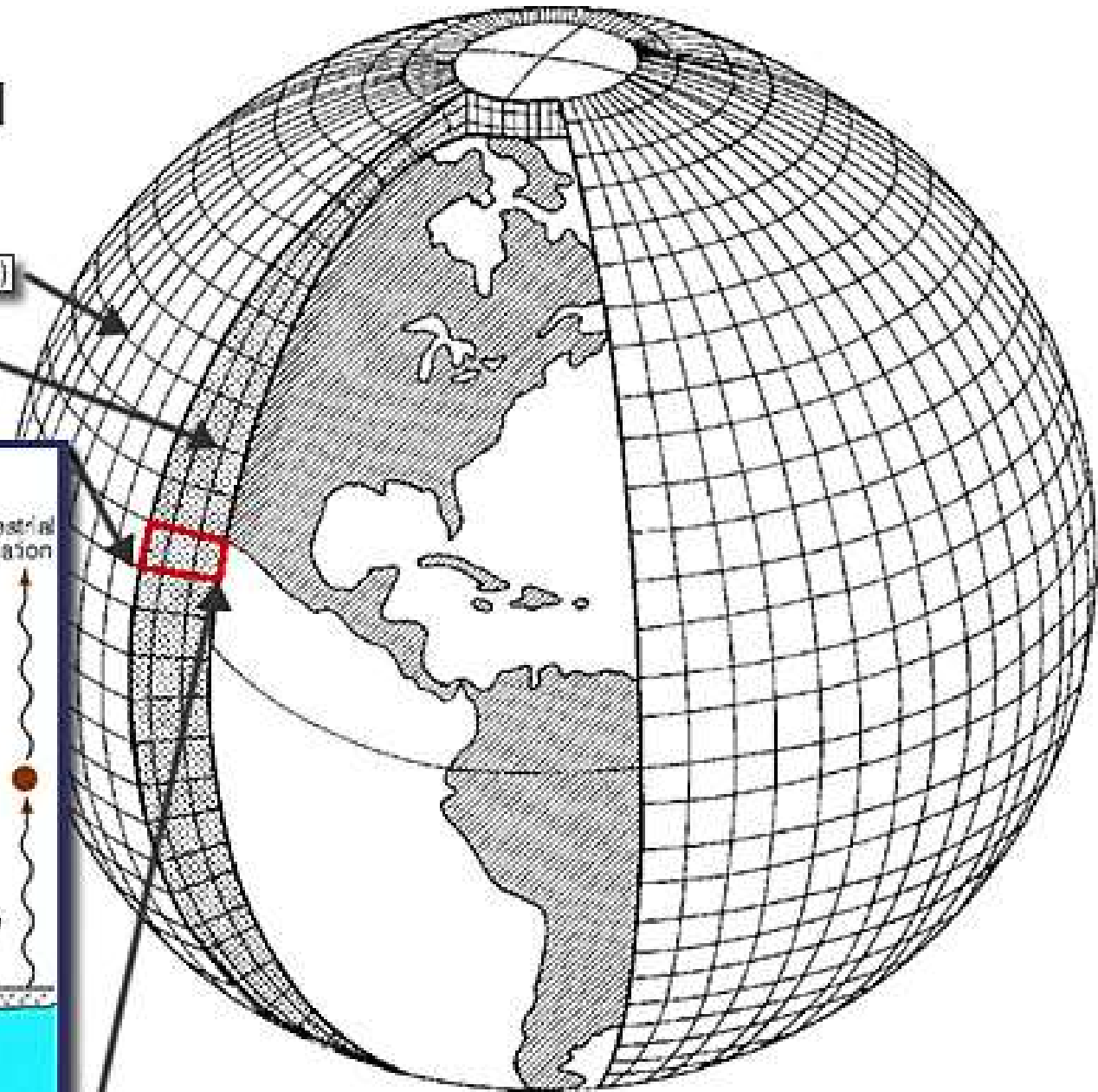
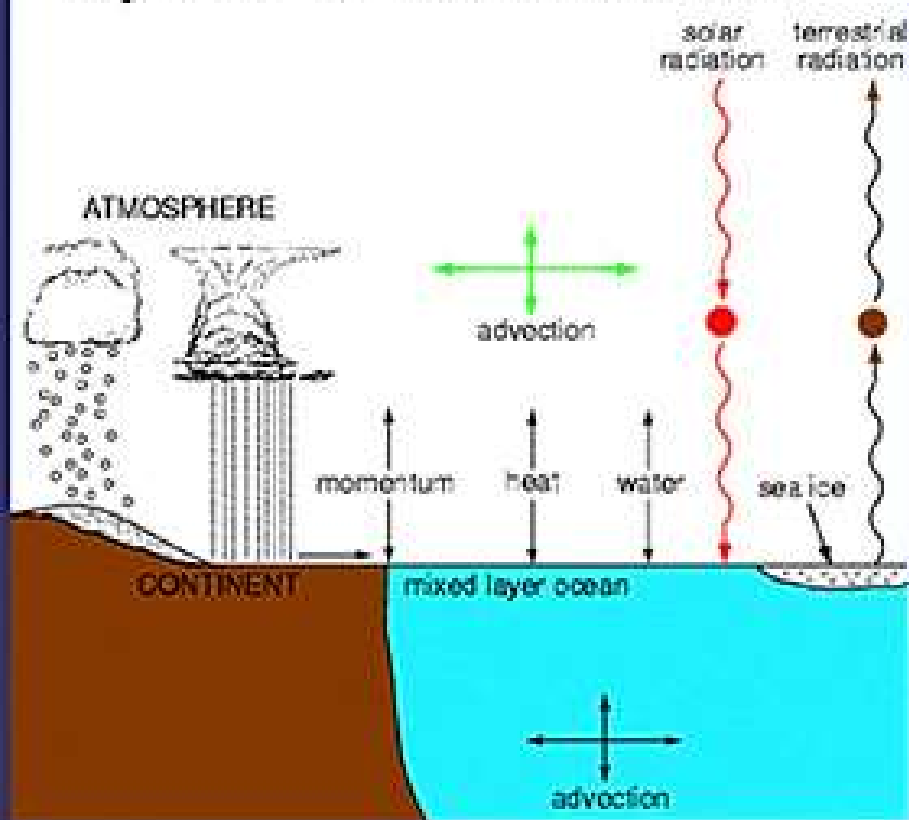
Sources: The Royal Society, University of East Anglia

Schematic for Global Atmospheric Model

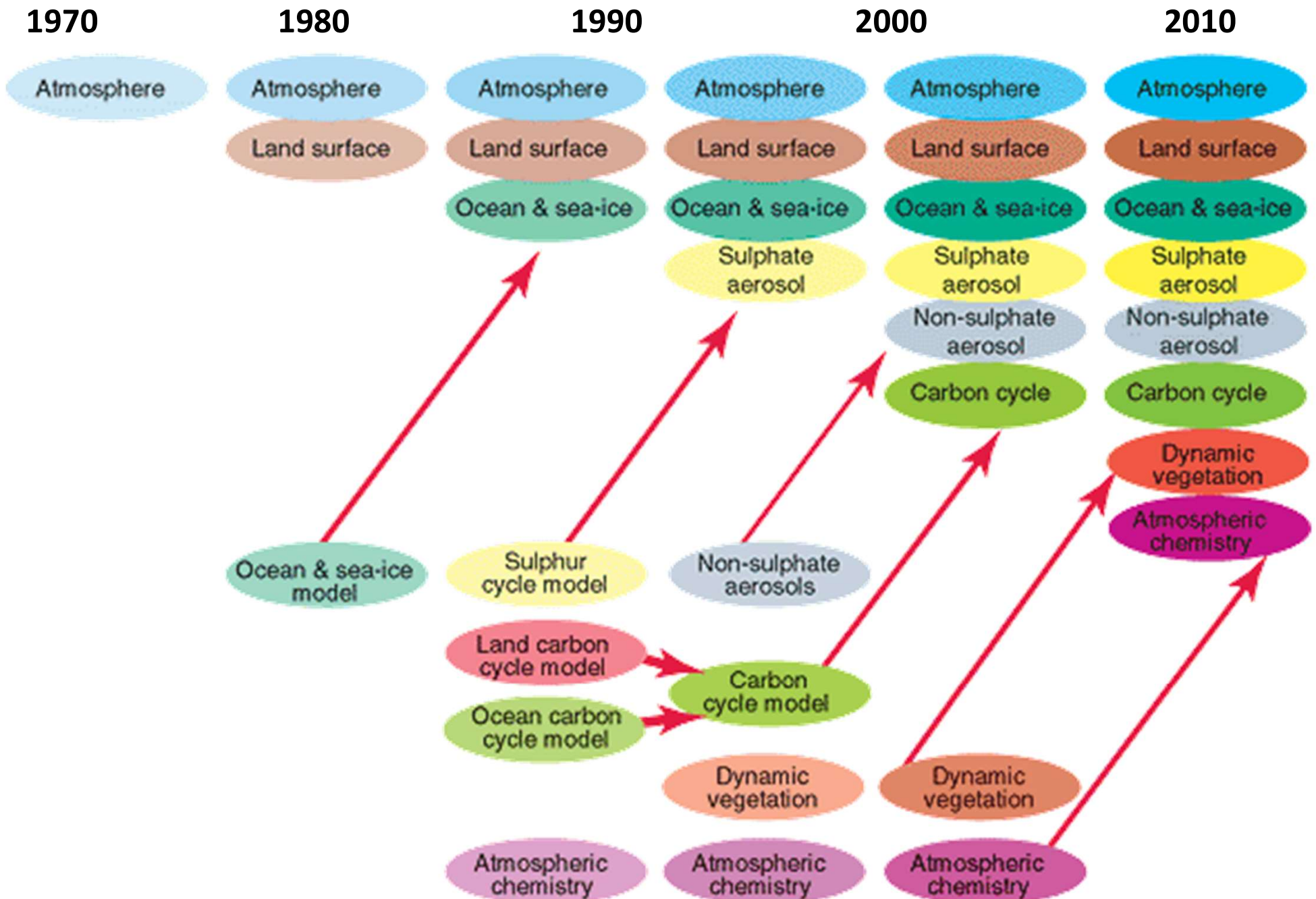
Horizontal Grid (latitude - longitude)

Vertical Grid (height or pressure)

Physical Processes in a Model



evoluzione dei modelli climatici



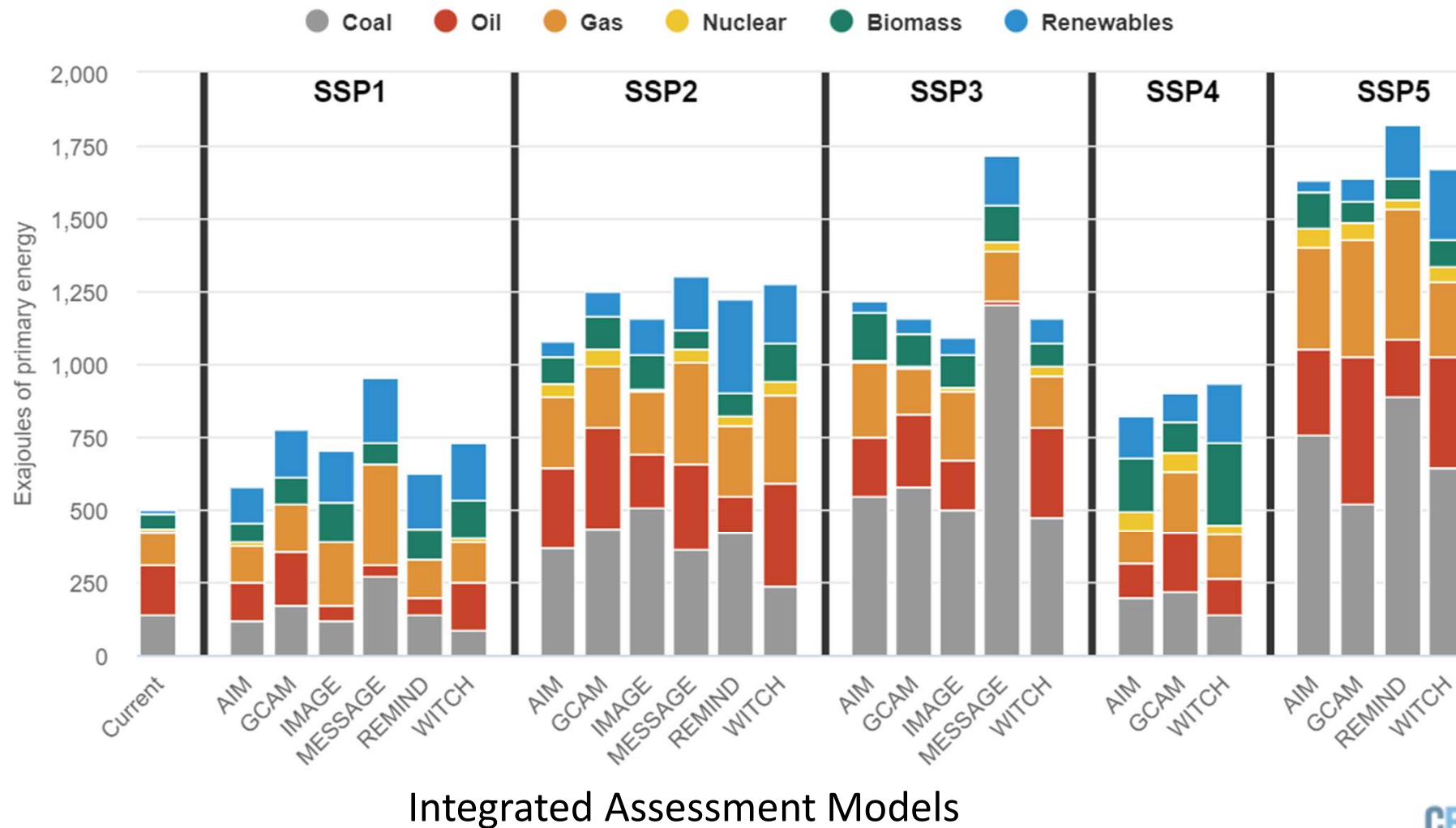
Future Climate Change

Shared Socioeconomic Pathways

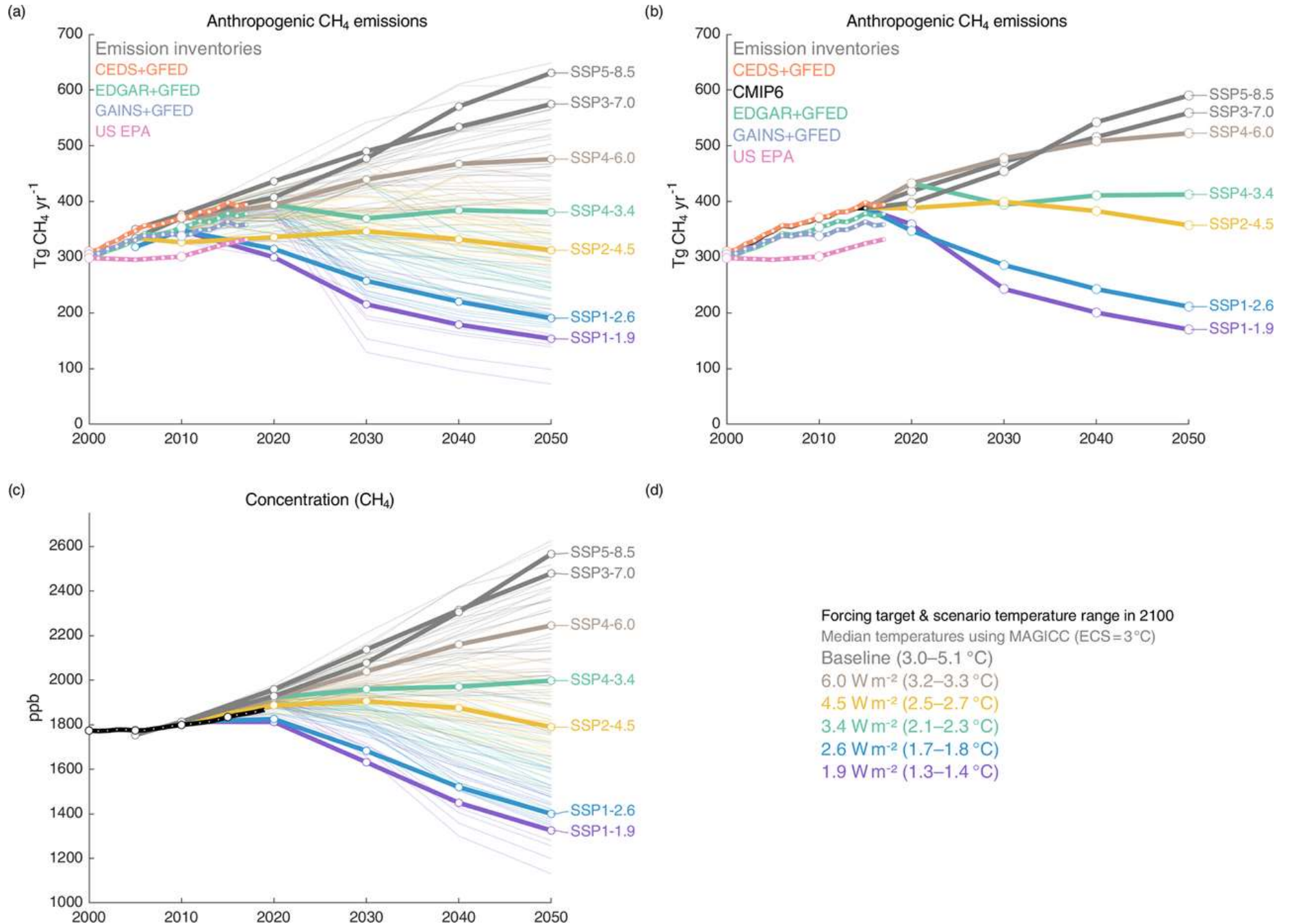


ogni SSP ha una propria tendenza nello sviluppo energetico

Primary energy in 2100 by model for SSP baseline scenarios

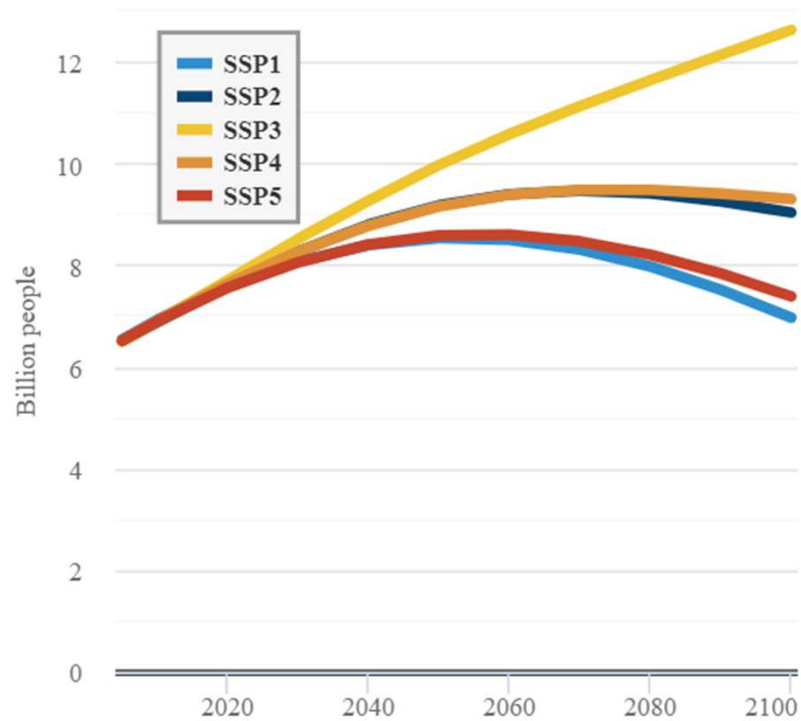


ogni SSP ha una propria tendenza nelle emissioni

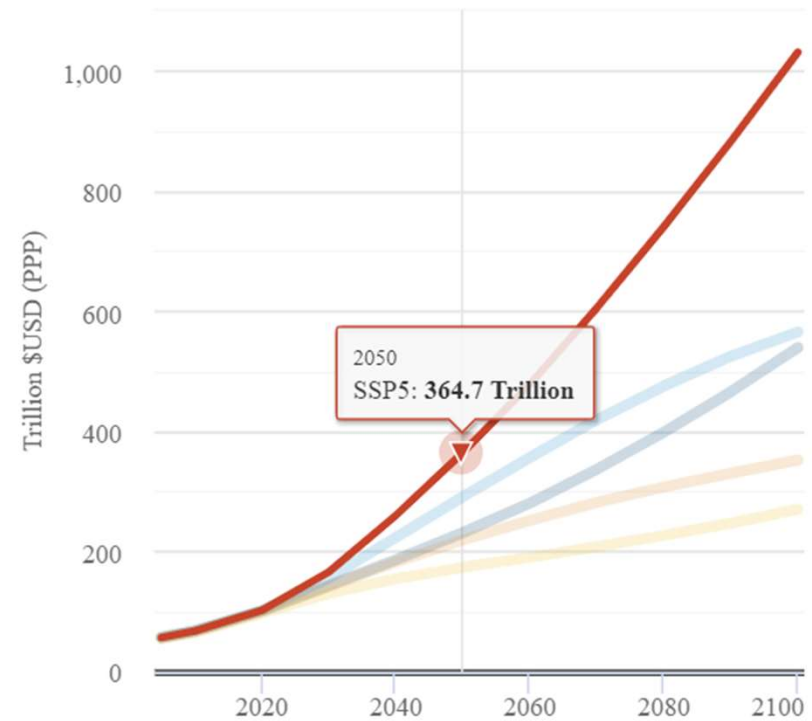


ogni SSP ha una propria tendenza delle condizioni socioeconomiche

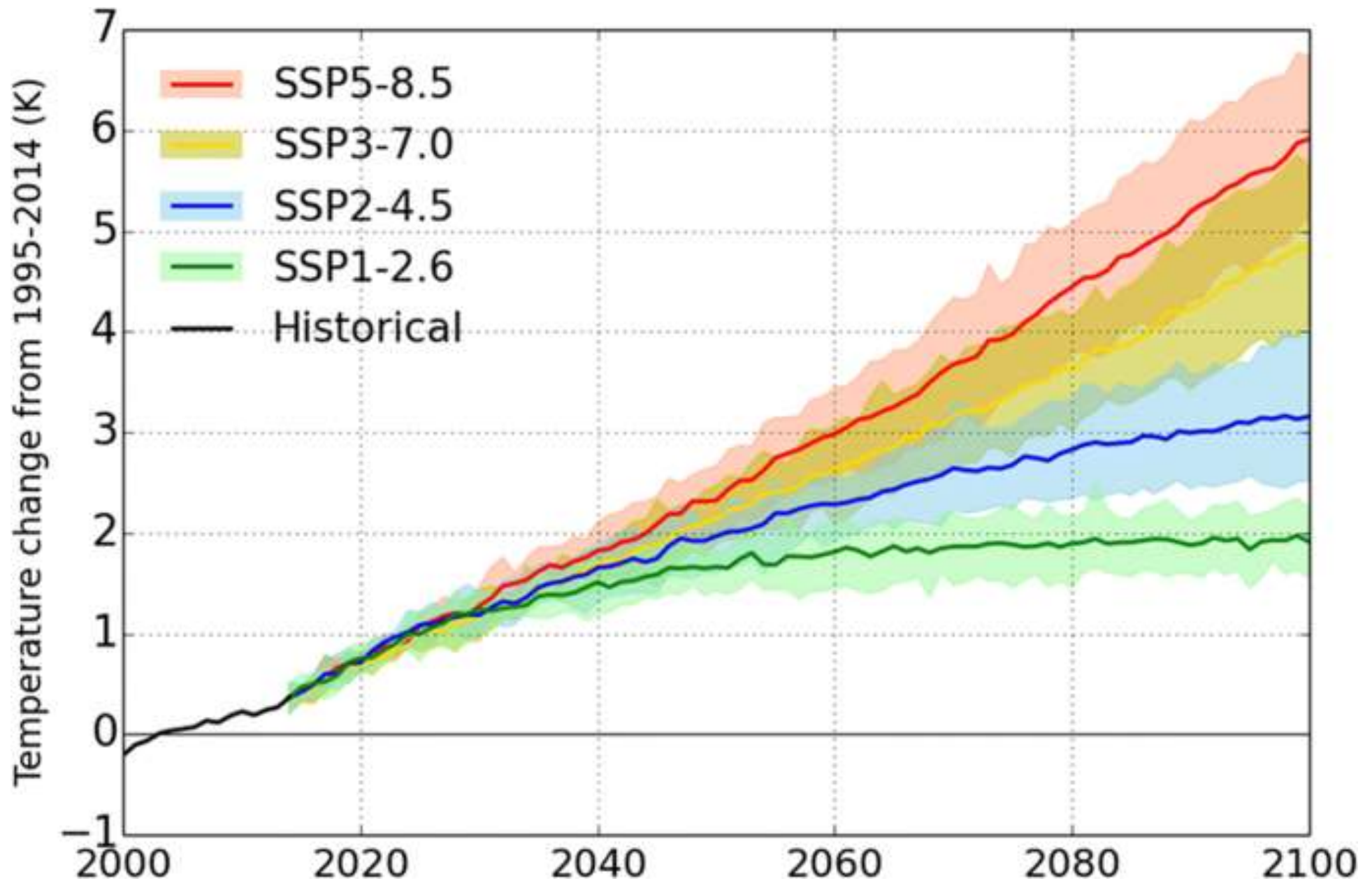
Global population



Global GDP



I modelli climatici vengono inizializzati con i diversi scenari ipotizzati



**Prediction is very
difficult, especially if
it's about the future.**

-Nils Bohr-