上海交通大学 SHANGHAI JIAO TONG UNIVERSITY

上海交通大学海洋学院

气候学与全球变化
Climate and Global Change

2022.05.20

SCHOOL OF OCEANOGRAPHY
SHANGHAI JIAO TONG UNIVERSITY
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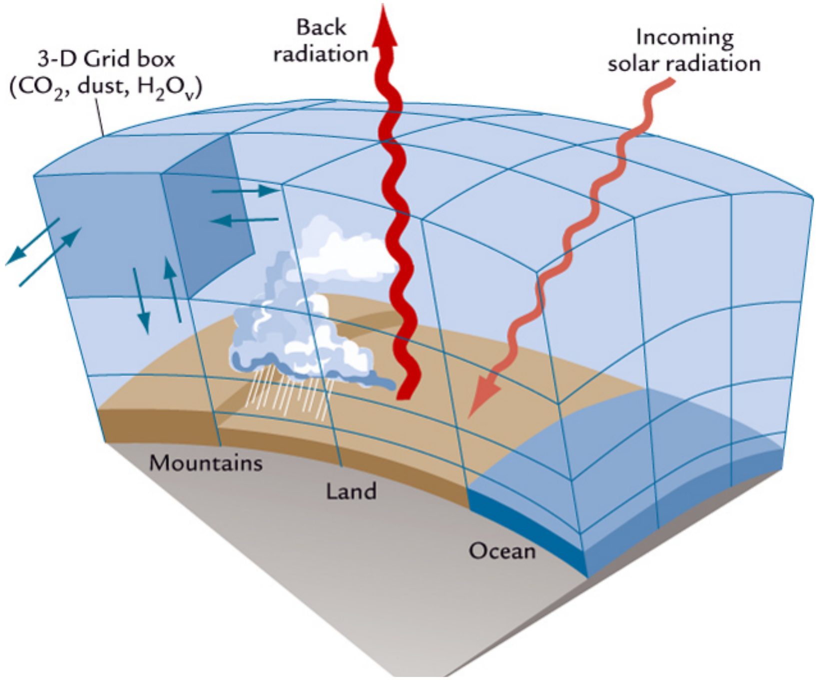
Challenges in Climate Model

- **Parameterization**

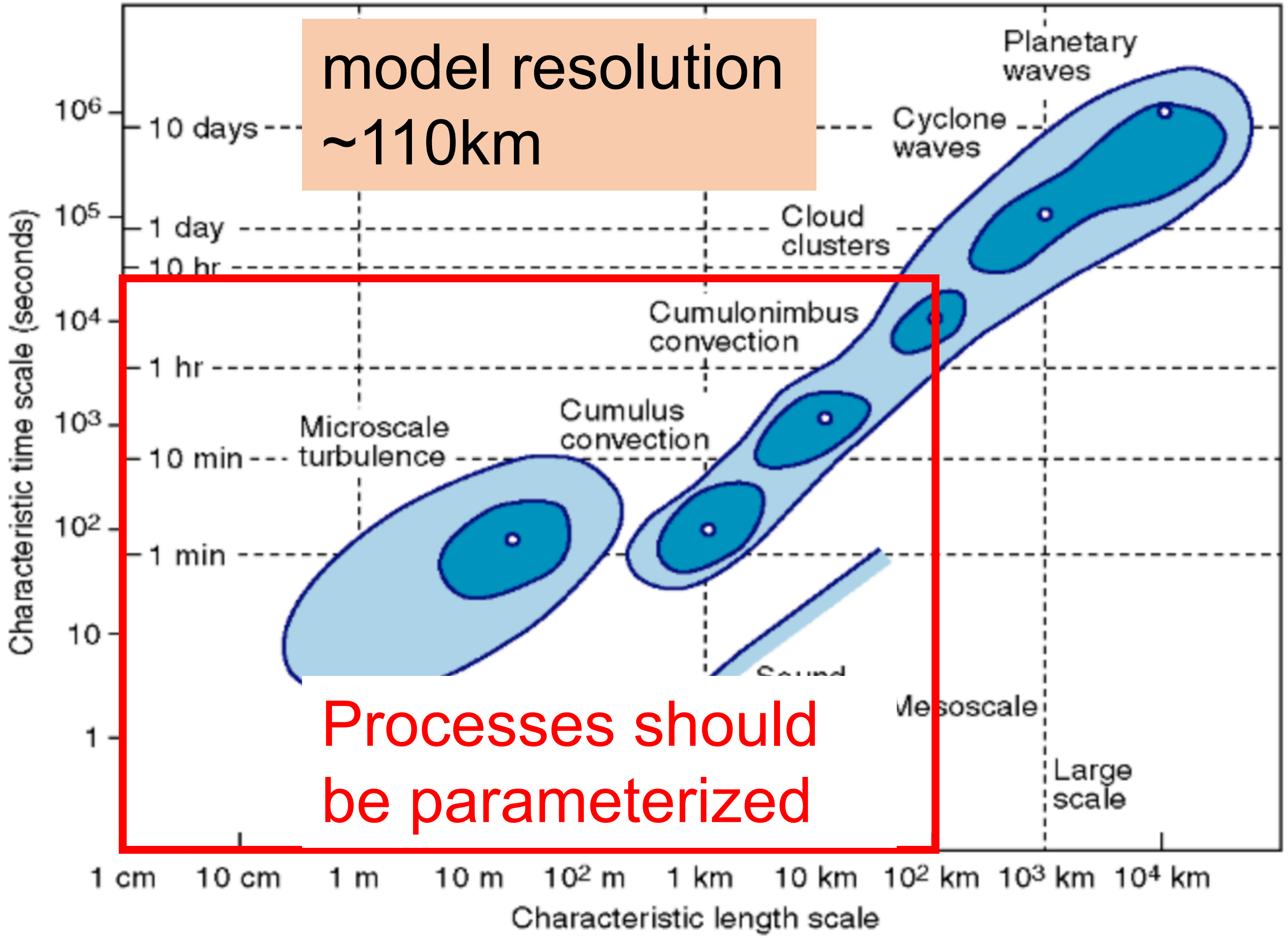


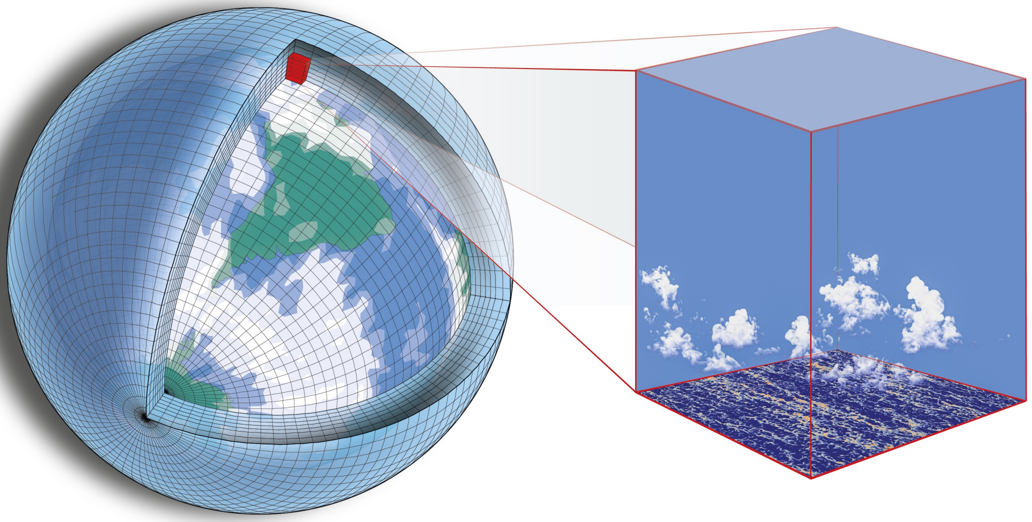
Discretization divides processes between scales:

- **Resolved or grid-scale processes** are those that are large enough that they can be effectively described by the average over a grid box. For example, large-scale transport and planetary waves.
- **Unresolved or sub-grid-scale processes** are those that occur on finer scales within a grid box. Assumptions are needed about the statistics of these properties as a function of the resolved-scale information. These are handled via **parameterizations**.

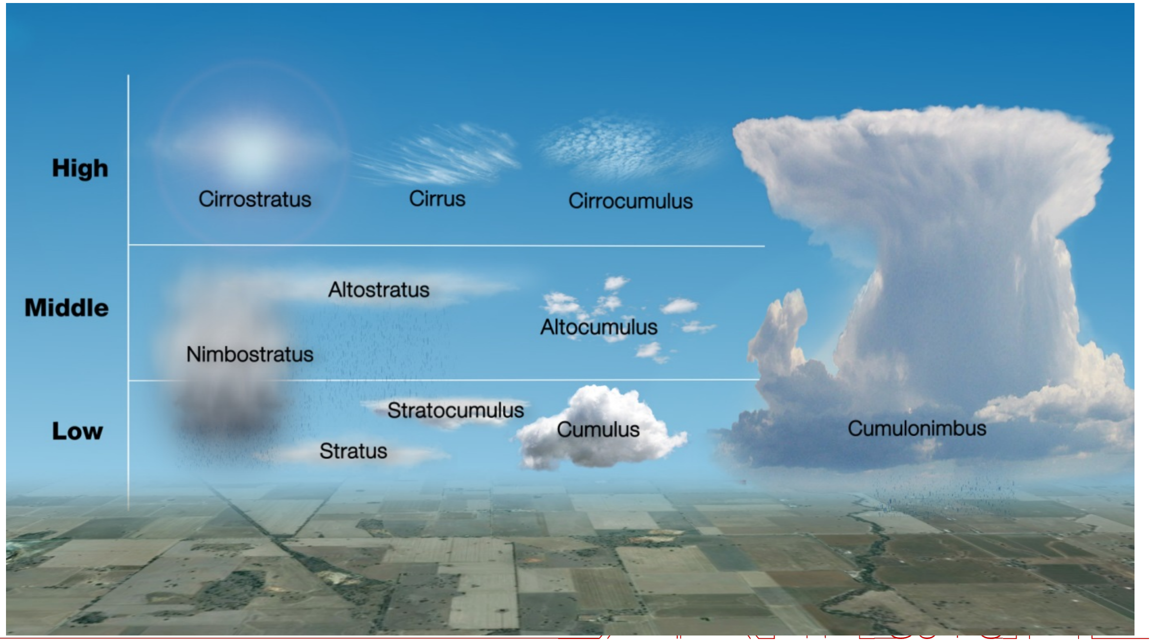
Challenges in Climate Model

- **Parameterization**





Main types of cloud



Challenges in Climate Model

- **Parameterization**

Ocean Mesoscale eddies

Isopycnal Mixing in Ocean Circulation Models†

PETER R. GENT AND JAMES C. MCWILLIAMS

National Center for Atmospheric Research, Boulder, Colorado*

20 March 1989 and 14 August 1989

ABSTRACT

A subgrid-scale form for mesoscale eddy mixing on isopycnal surfaces is proposed for use in non-eddy-resolving ocean circulation models. The mixing is applied in isopycnal coordinates to isopycnal layer thickness, or inverse density gradient, as well as to passive scalars, temperature and salinity. The transformation of these mixing forms to physical coordinates is also presented.

Challenges in Climate Model

- **Parameterization**

Parameterization example: 1-D temperature equation

1D heat flux:
F = K∂T/∂x
K is diffusivity (parameter)
transport heat down-gradient

Advection-diffusion Equation

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} = \frac{\partial}{\partial x}\left(K\frac{\partial T}{\partial x}\right)$$

Challenges in Climate Model

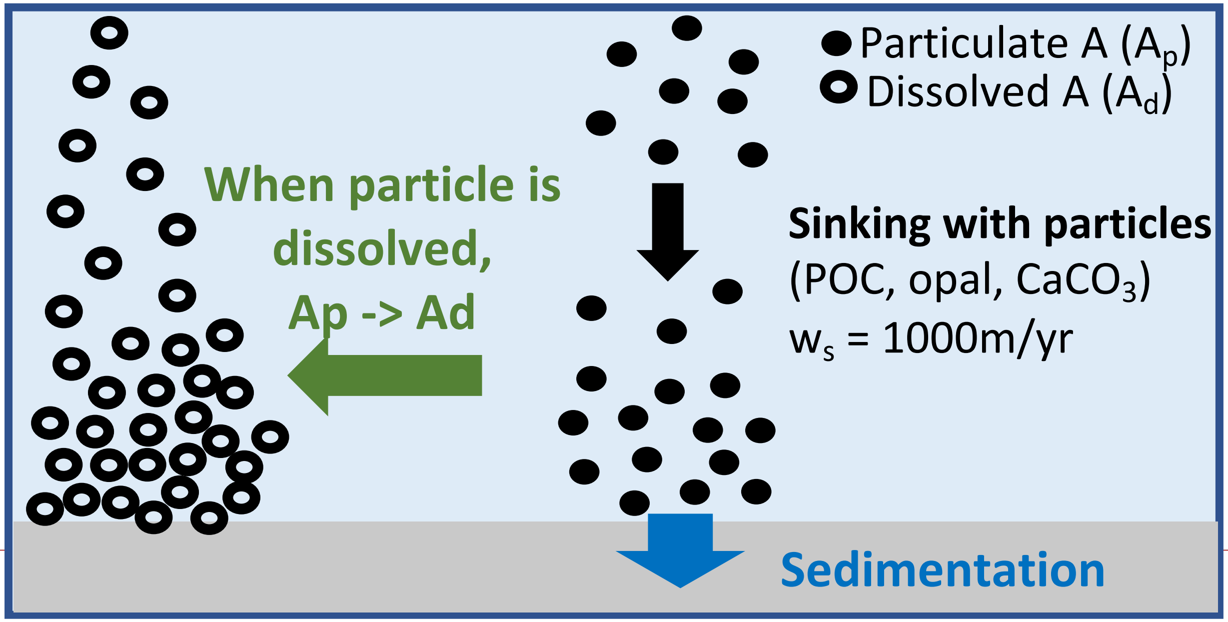
- **Parameterization**

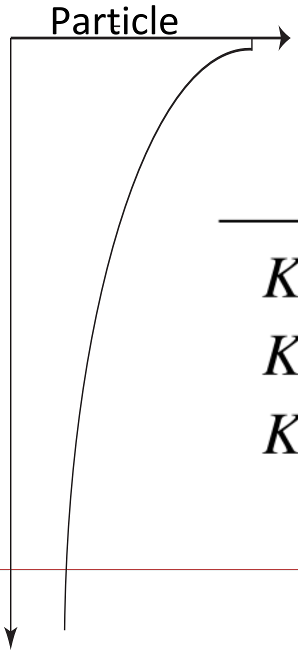
Reversible Scavenging (Bacon&Anderson, 1982):

adsorption of isotopes onto sinking particles and desorption after the dissolution of particles

$[A] = [A]_d + [A]_p$, A: ^{231}Pa, ^{230}Th

$\frac{[A]_p}{[A]_d} = K_i * R_i, i = POC, opal, Calcite$, $\mathrm{R} = \frac{particle\ concentration}{density\ of\ seawater}$, ***K* : partition coefficient**





	^{231}Pa	^{230}Th
K_{CaCO_3}	2.5×10^5	1.0×10^7
K_{opal}	1.67×10^6	5×10^5
K_{POC}	1.0×10^7	1.0×10^7

Chase et al., 2002

Challenges in Climate Model

- **Increasing Resolution**

spatial: more grids
temporal: smaller timestep

Very expensive for high resolution modeling!

JAMES Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE
10.1029/2020MS002298

Key Points:

- An unprecedented set of multi-century high-resolution Community Earth System Model (CESM) simulations is described
- High-resolution CESM simulations reveal a potential role of Southern Ocean polynyas in multidecadal climate variability
- High-resolution CESM exhibits significantly improved simulations of extreme events, such as tropical cyclones and atmospheric rivers

An Unprecedented Set of High-Resolution Earth System Simulations for Understanding Multiscale Interactions in Climate Variability and Change

Ping Chang[1,2,3], Shaoqing Zhang[1,4,5], Gokhan Danabasoglu[1,6], Stephen G. Yeager[1,6], Haohuan Fu[1,7,8], Hong Wang[1,4,5], Frederic S. Castruccio[1,6], Yuhu Chen[9], James Edwards[1,6], Dan Fu[1,2], Yinglai Jia[1,5], Lucas C. Laurindo[1,6], Xue Liu[1,2], Nan Rosenbloom[1,6], R. Justin Small[1,6], Gaopeng Xu[1,2], Yunhui Zeng[10], Qiuying Zhang[1,2], Julio Bacmeister[1,6], David A. Bailey[1,6], Xiaohui Duan[8,11], Alice K. DuVivier[1,6], Dapeng Li[1,2], Yuxuan Li[11], Richard Neale[6], Achim Stössel[1,2], Li Wang[10], Yuan Zhuang[10], Allison Baker[1,6], Susan Bates[6], John Dennis[6], Xiliang Diao[1,2], Bolan Gan[1,4,5], Abishek Gopal[1,2], Dongning Jia[9], Zhao Jing[1,4,5], Xiaohui Ma[1,4,5], R. Saravanan[1,3], Warren G. Strand[6], Jian Tao[1,12], Haiyuan Yang[1,4,5], Xiaoqi Wang[1,2], Zhiqiang Wei[9], and Lixin Wu[4,5]

- atmosphere 0.25°
- ocean 0.1°,~11km

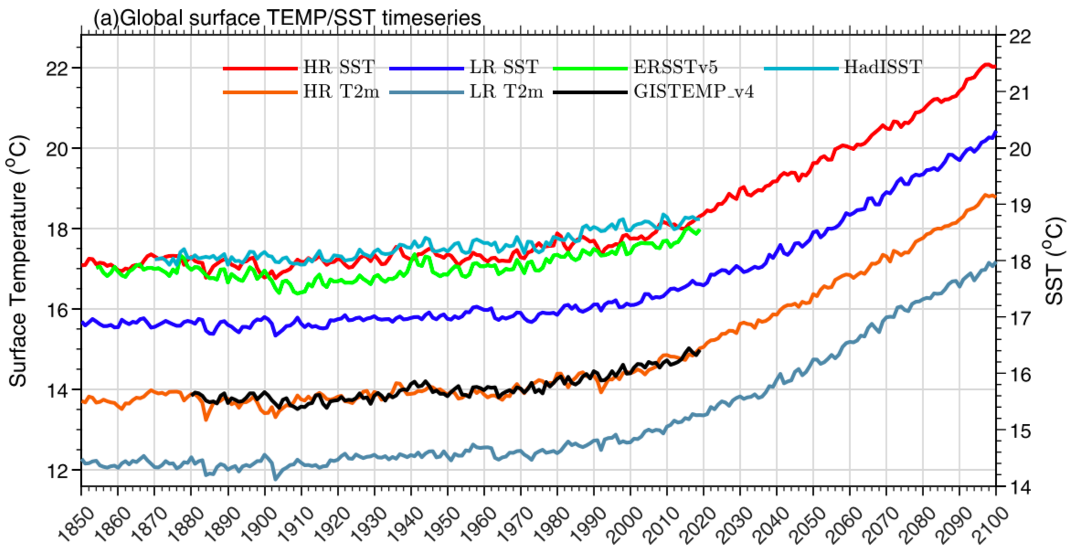
eddy resolving!

Chang et al., 2020,JAMES

Challenges in Climate Model

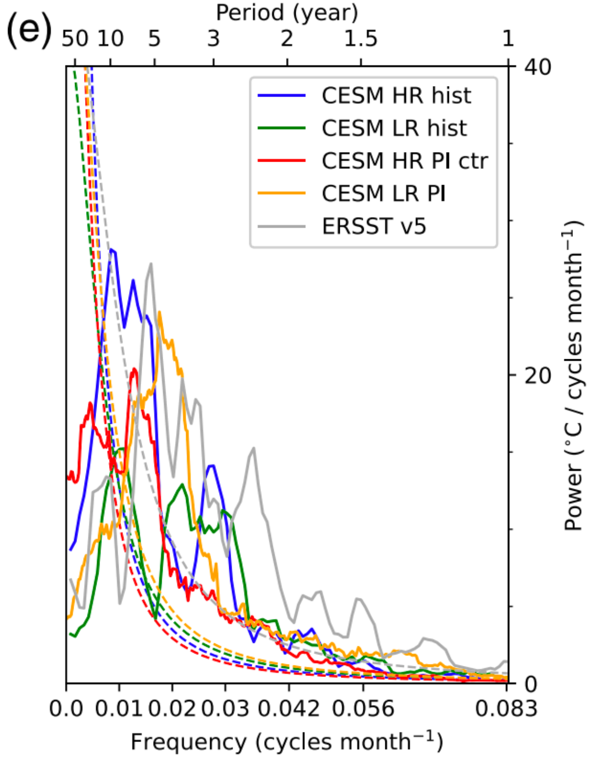
- **Increasing Resolution**

Global Mean Surface Temperature

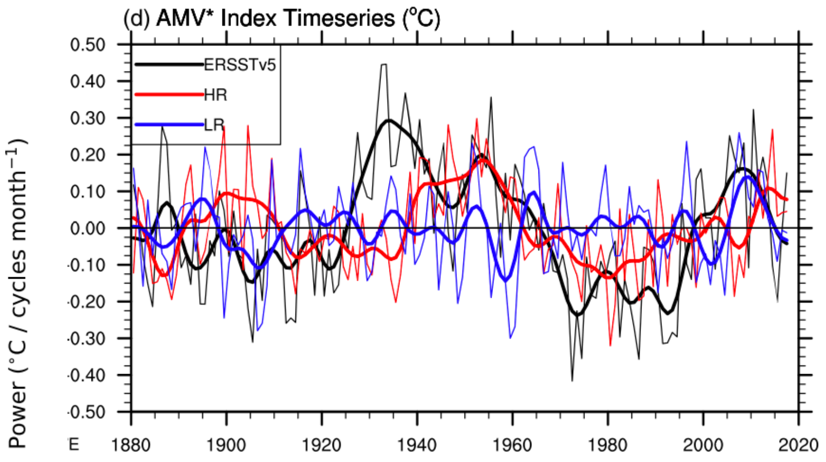


Climate Variabiltiy

ENSO



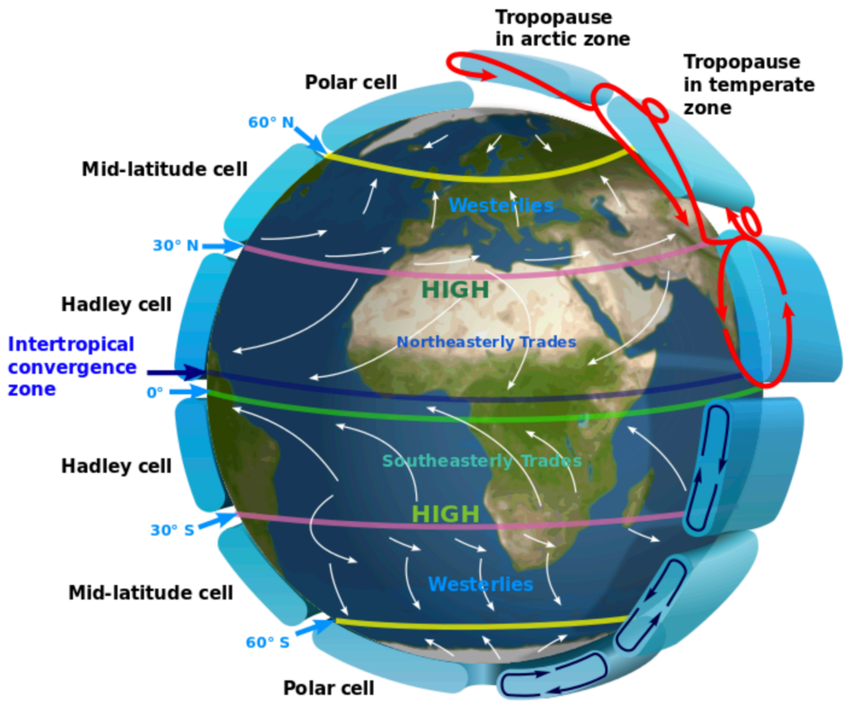
AMV

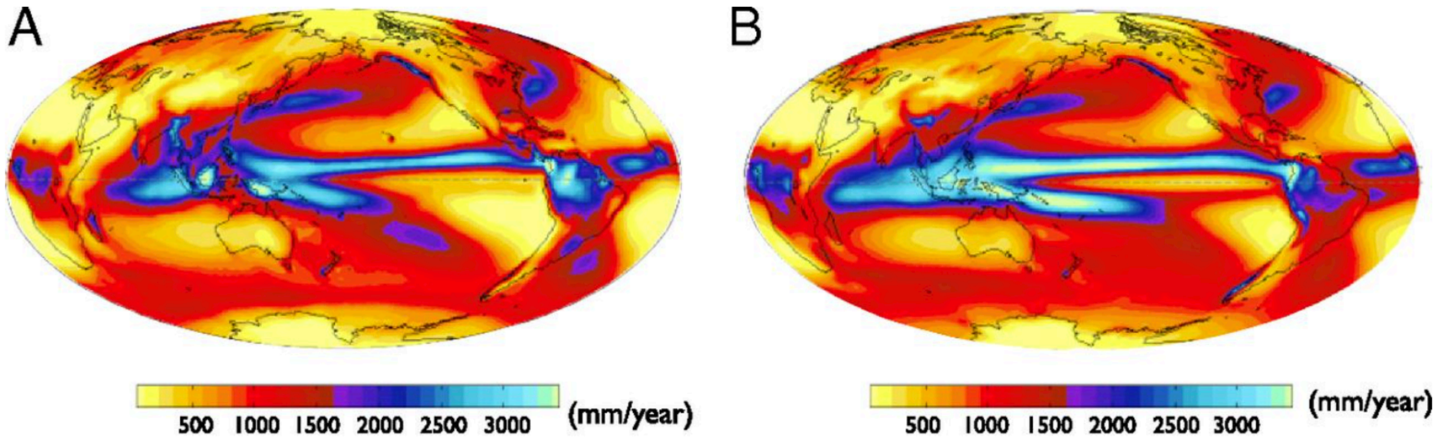


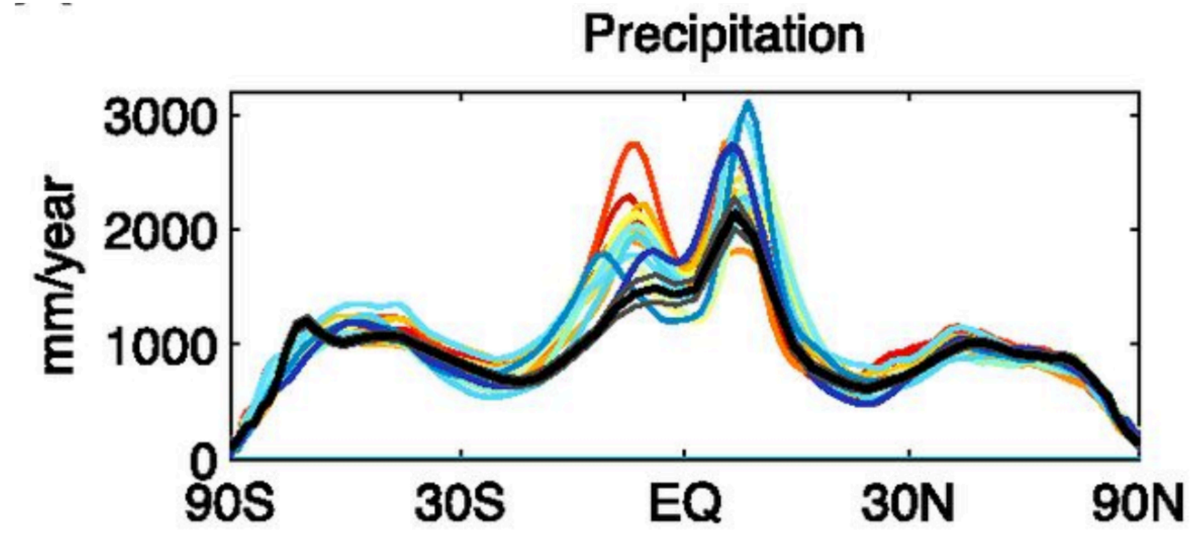
Challenges in Climate Model

- **Model biases**

Double ITCZ



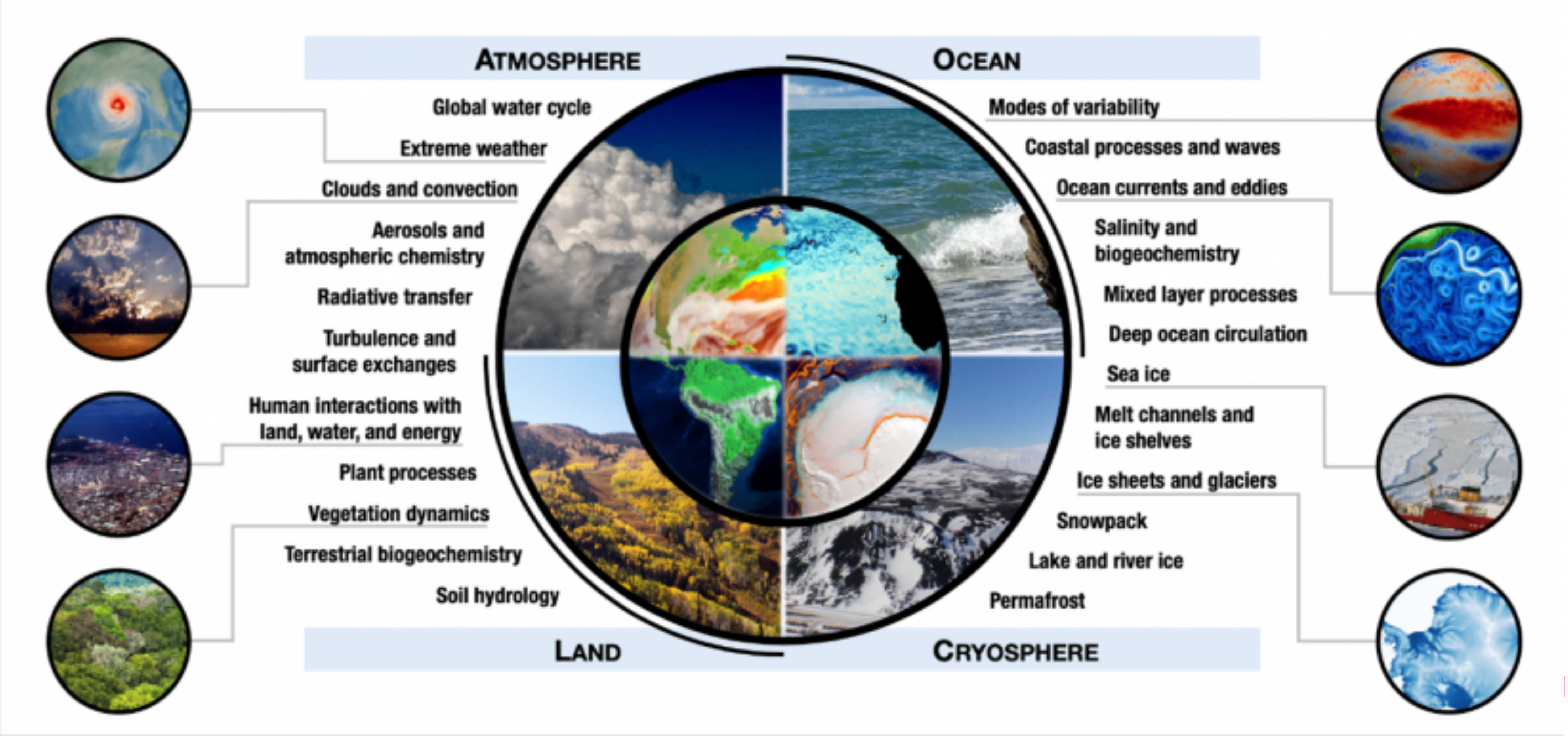




Hwang et al., 2013, PNAS

Challenges in Climate Model

- Earth System Modeling requires Interdisciplinary Interaction



Applications in Climate Science ?

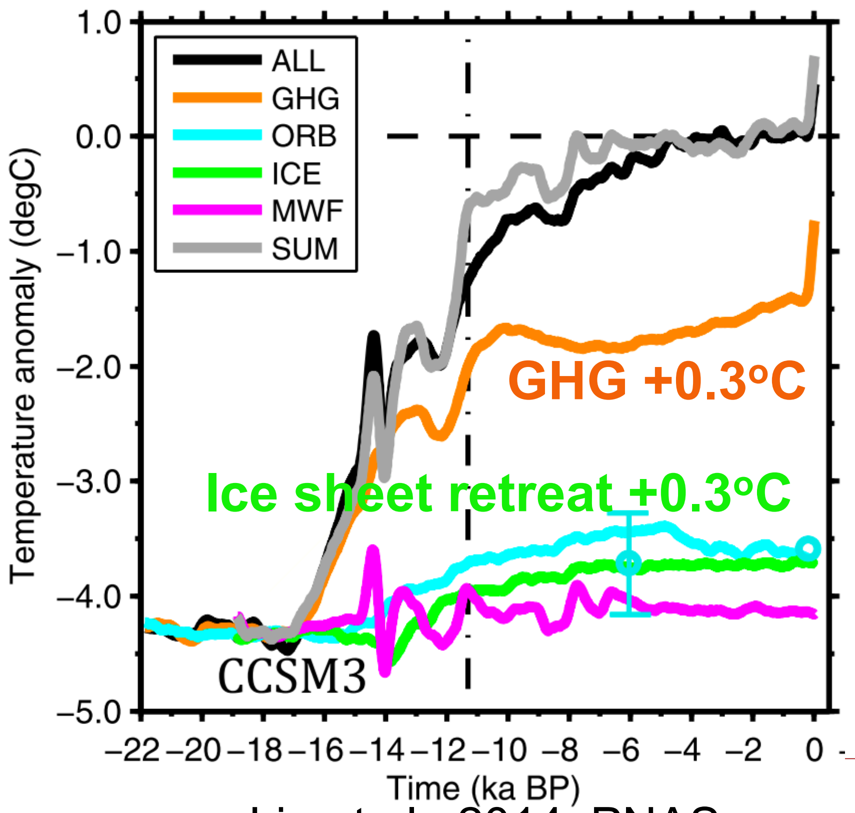
- Paleoclimate model studies;
- Detection and attribution studies;
- Future projections.

Applications in Climate Science？

- Paleoclimate model studies

A better understanding of past climate changes

Holocene Temperature Increase?



Liu et al., 2014, PNAS

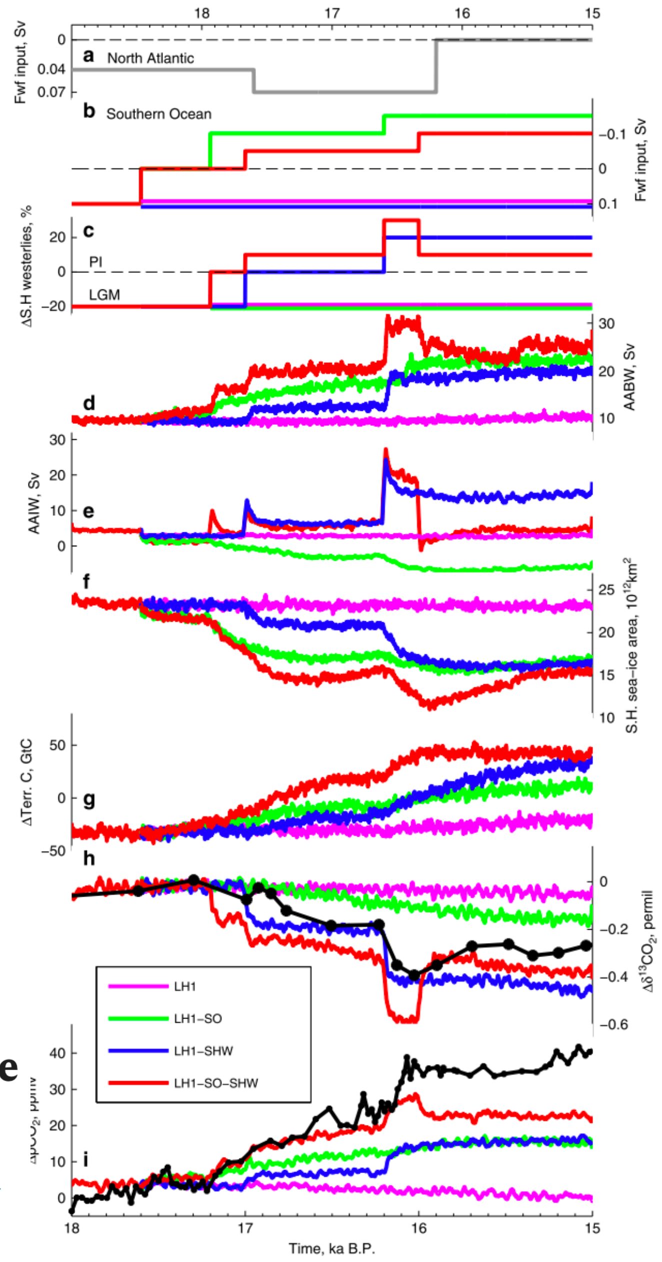
Sensitivity experiments:

- LH1: NA + freshwater.
- LH1-SO (buoyancy forcing): NA+freshwater &SO+salt
- LH1-SHW (dynamic forcing): NA+freshwater&SO+westerlies
- LH1-SO-SHW: NA + freshwater & SO+salt & SO+westerlies

Southern Hemisphere westerlies as a driver of the early deglacial atmospheric CO_2 rise

L. Menviel, P. Spence, J. Yu, M. A. Chamberlain, R. J. Matear, K. J. Meissner & M. H. England

Nature Communications **9**, Article number: 2503 (2018) | Cite this article



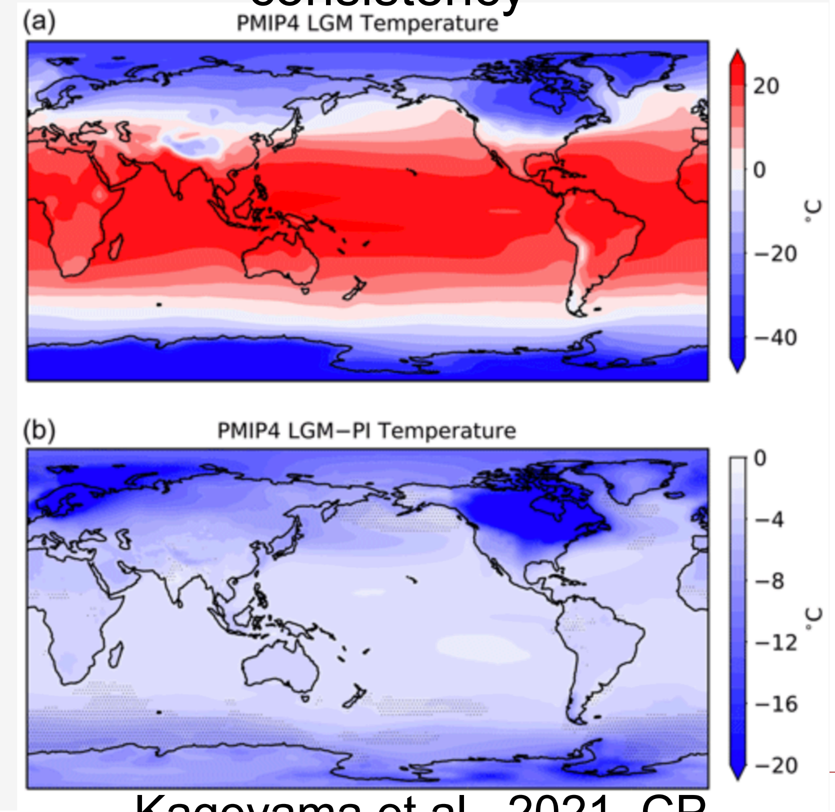
Applications in Climate Science ?

- Paleoclimate model studies

Evaluate the models

LGM simulation

consistency



Kageyama et al., 2021, CP

inconsistency

Table 1. Maximum Transport and Depth of the AMOC at 25°N Calculated by PMIP3 Models, in Their PIC and LGM Simulations, and Percentage of Increment Between the Two Periods[a]

Model	PIC (Sv)	LGM (Sv)	Change (%)	PIC Depth (m)	LGM Depth (m)	Change (%)
CCSM4	19.69	21.53	9	2608	2333	−10
GISS	16.92	22.32	32	2055	2273	11
CNRM	13.03	22.74	74	1735	3230	86
MPI	18.19	21.37	17	1963	1993	01
MIROC	13.56	22.07	63	1795	2745	53
MRI	14.82	21.76	47	2193	3363	53
FGOALS	23.02	31.64	37	1965	2940	50
IPSL	12.64	23.04	82	2238	2980	78
Mean	16.48	23.31	41	2069	2732	32

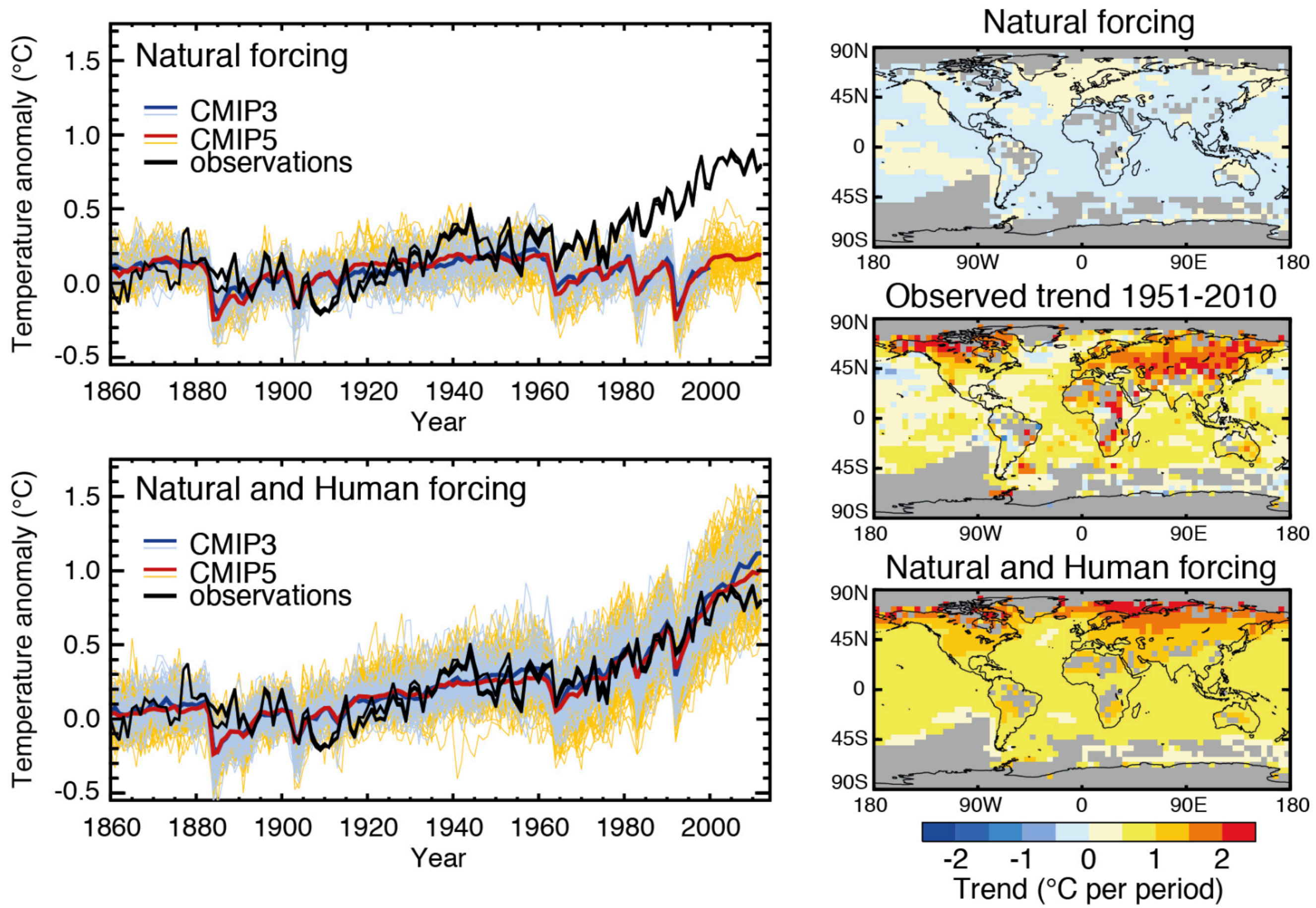
Muglia et al., 2015, GRL

Applications in Climate Science ?

- Detection and attribution studies

Detection: determine which observed climate changes are unusual;

Attribution: what are its causes;



Applications in Climate Science ?

- Future projections

IPCC: The Intergovernmental Panel on Climate Change

1990 First IPCC Assessment Report (FAR)

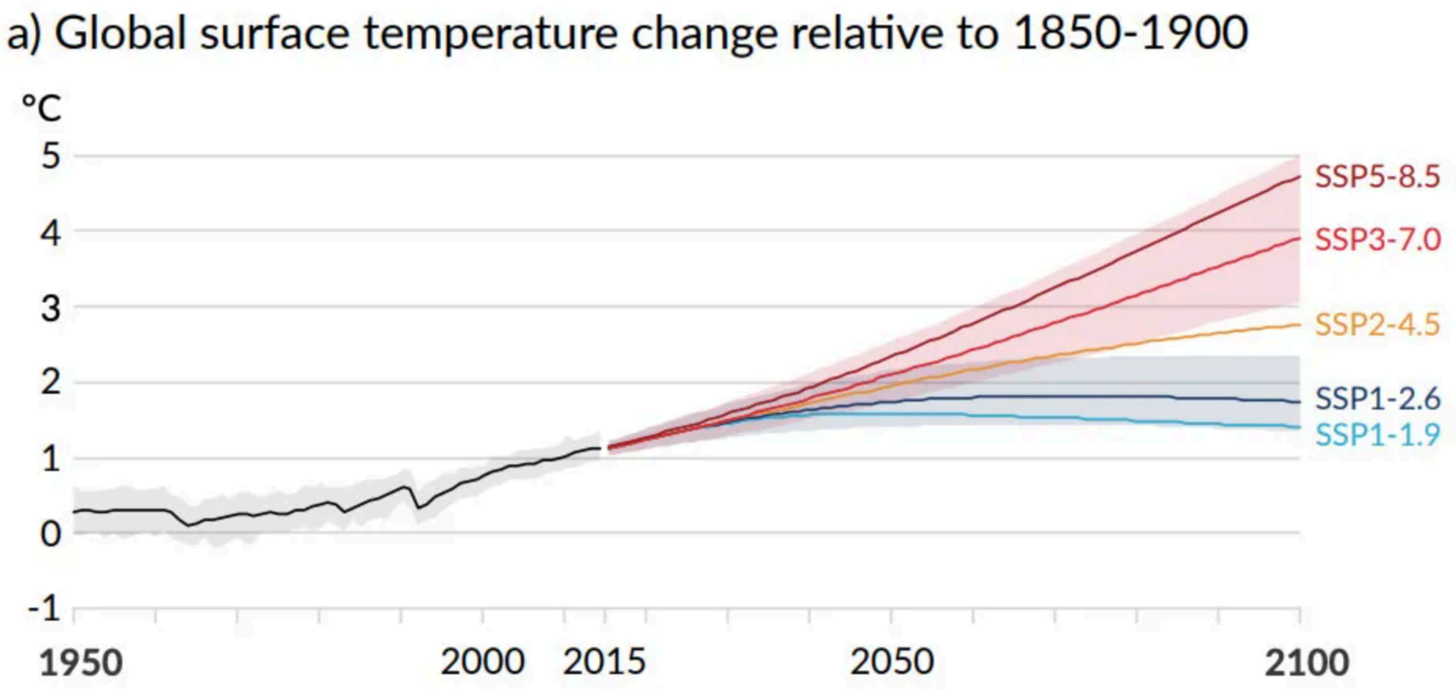
1995 Second IPCC Assessment Report (SAR)

2001 Third IPCC Assessment Report (TAR)

2007 Fourth IPCC Assessment Report (AR4)

2013 Fifth IPCC Assessment Report (AR5)

2022 Sixth IPCC Assessment Report (AR6)

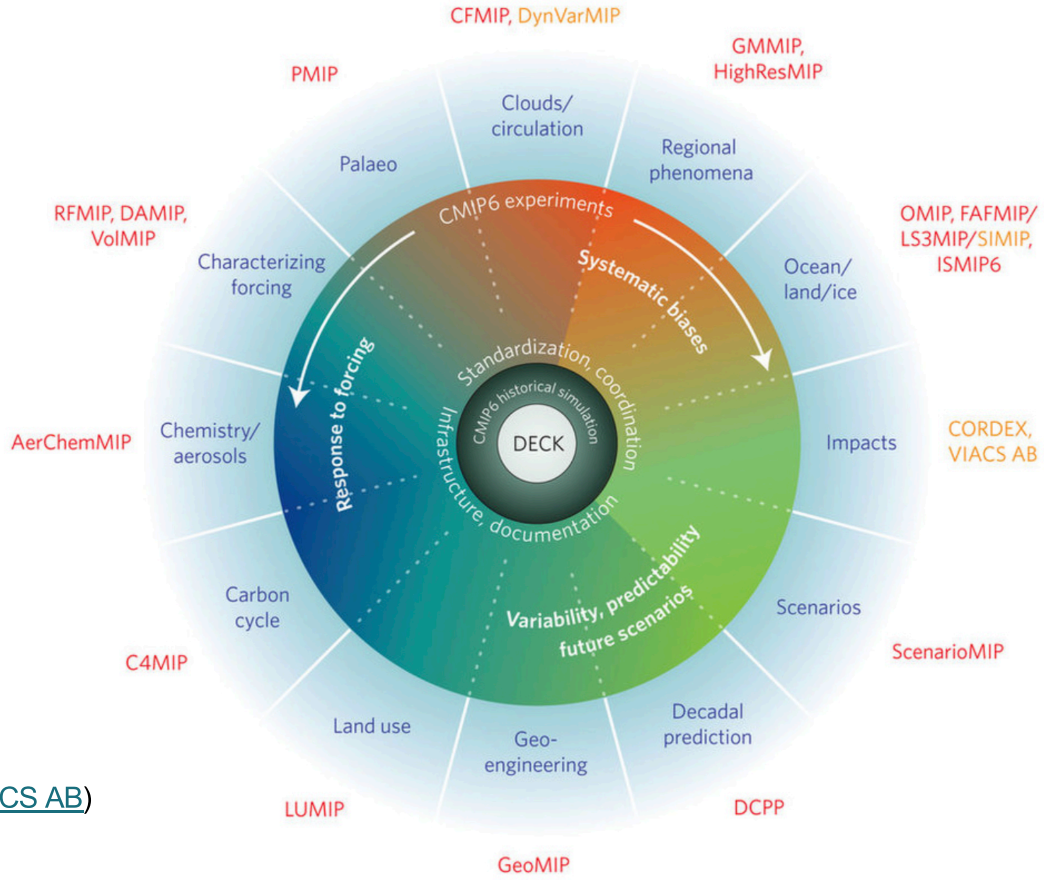


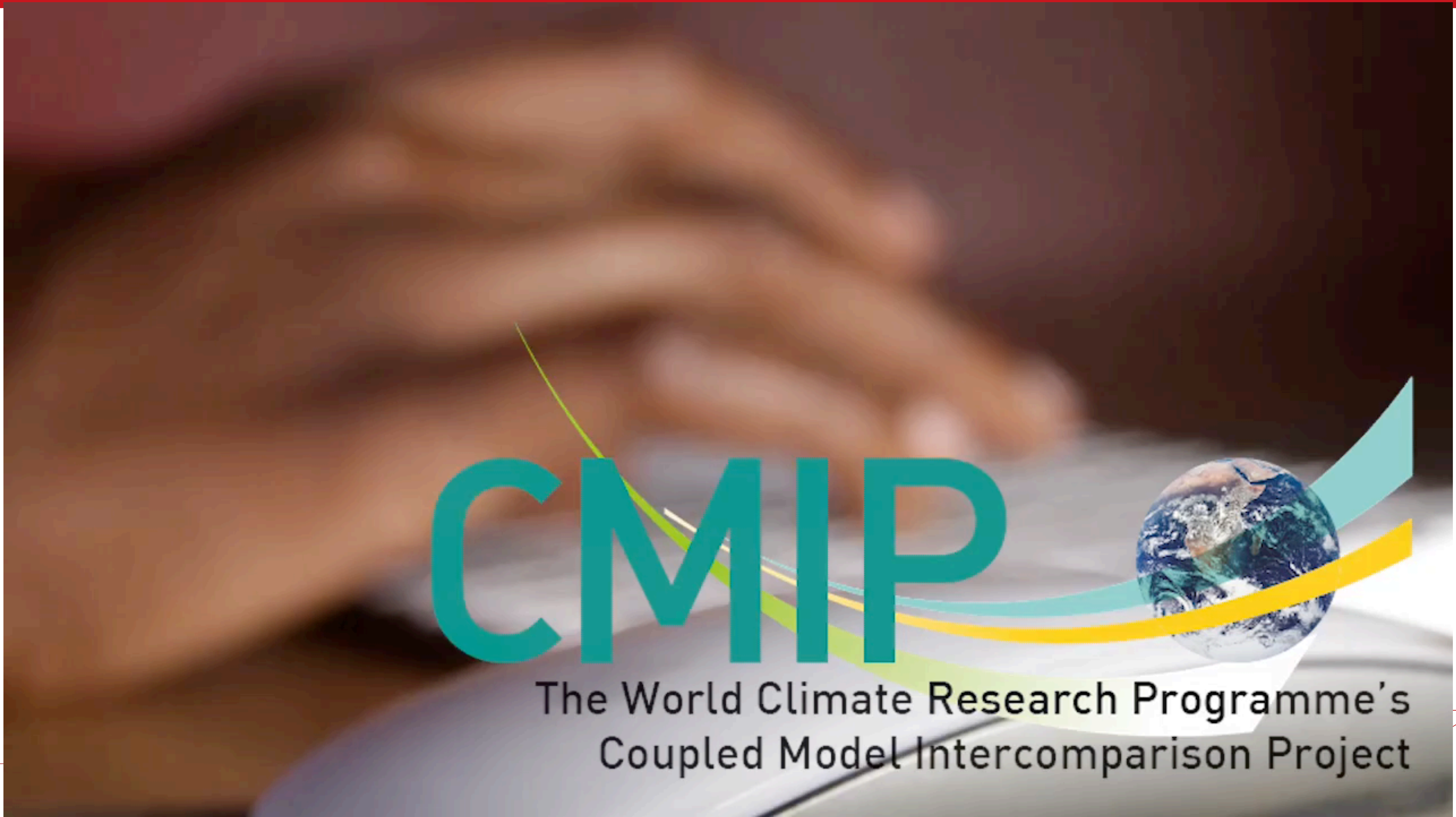
https://www.ipcc.ch/report/ar6/wg1/

Applications in Climate Science ?

Coupled Model Intercomparison Project Phase 6 (CMIP6)

The Aerosols and Chemistry Model Intercomparison Project (AerChemMIP)
Coupled Climate Carbon Cycle Model Intercomparison Project (C^4MIP)
The Carbon Dioxide Removal Model Intercomparison Project (CDRMIP)
Cloud Feedback Model Intercomparison Project (CFMIP)
Detection and Attribution Model Intercomparison Project (DAMIP)
Decadal Climate Prediction Project (DCPP)
Flux-Anomaly-Forced Model Intercomparison Project (FAFMIP)
Geoengineering Model Intercomparison Project (GeoMIP)
Global Monsoons Model Intercomparison Project (GMMIP)
High-Resolution Model Intercomparison Project (HighResMIP)
Ice Sheet Model Intercomparison Project for CMIP6 (ISMIP6)
Land Surface, Snow and Soil Moisture (LS3MIP)
Land-Use Model Intercomparison Project (LUMIP)
Ocean Model Intercomparison Project (OMIP)
Polar Amplification Model Intercomparison Project (PAMIP)
Palaeoclimate Modelling Intercomparison Project (PMIP)
Radiative Forcing Model Intercomparison Project (RFMIP)
Scenario Model Intercomparison Project (ScenarioMIP)
Volcanic Forcings Model Intercomparison Project (VolMIP)
Coordinated Regional Climate Downscaling Experiment (CORDEX)
Dynamics and Variability Model Intercomparison Project (DynVarMIP)
Sea Ice Model Intercomparison Project (SIMIP)
Vulnerability, Impacts, Adaptation and Climate Services Advisory Board (VIACS AB)

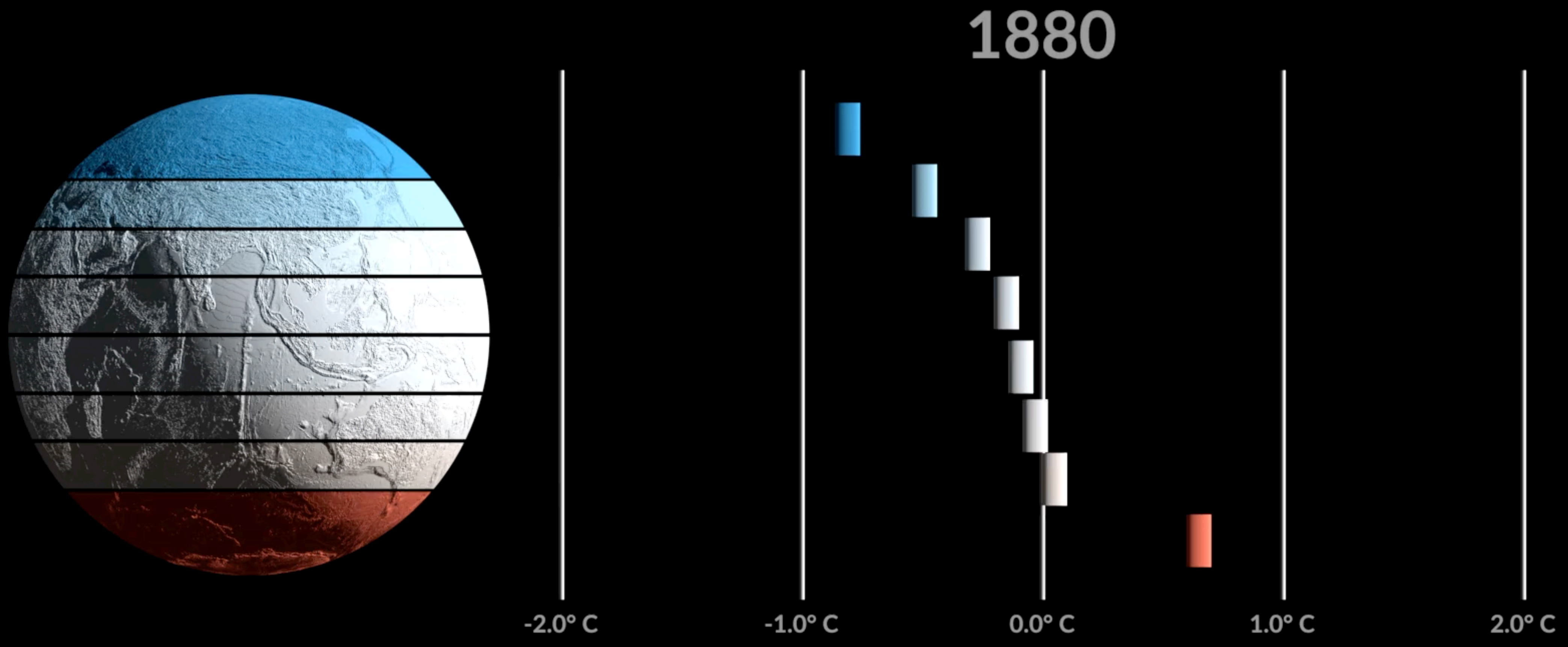



CMIP
The World Climate Research Programme's
Coupled Model Intercomparison Project

总结

- Climate modeling is at the cutting edge of the climate system science (**Interdisciplinary**).
- A wide range of climate models are available (**No perfect model!**).
- Climate models are becoming critical tools for a wide range of applications.
- Evaluation of climate models is increasingly strict and our confidence in them is becoming greater. **But challenges remain.**

Land surface temperature anomaly by latitude



Climate is changing!

Climate Change

Natural Climate Change

- orbit
- solar variations
- volcanic eruptions
- natural aerosols
- ocean currents (e.g., global conveyor belt)
- internal climate variability (e.g., ENSO)

……

Anthropogenic Climate Change

- fossil fuels
- agriculture
- land use (e.g., deforestation)

……

- Emission of greenhouse gases
- Emission of aerosols
- Land cover and land use change
- Future projections
- Impacts of climate change
- Tipping Points
- Solutions

Emission of greenhouse gases

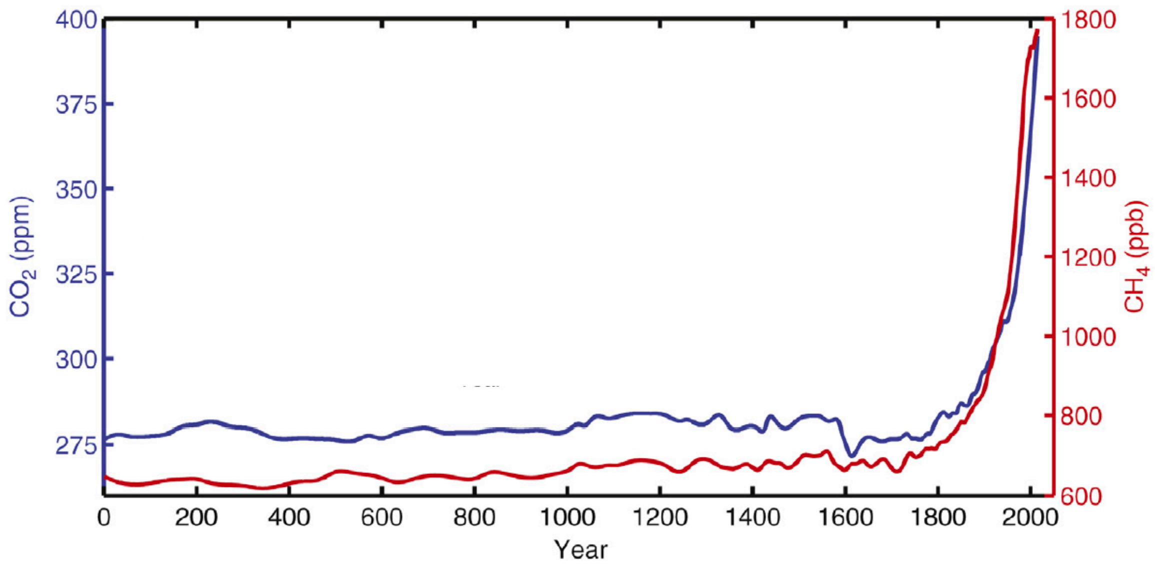
TABLE 13.1 Characteristics of Some Key Greenhouse Gases That are Influenced by Human Activities

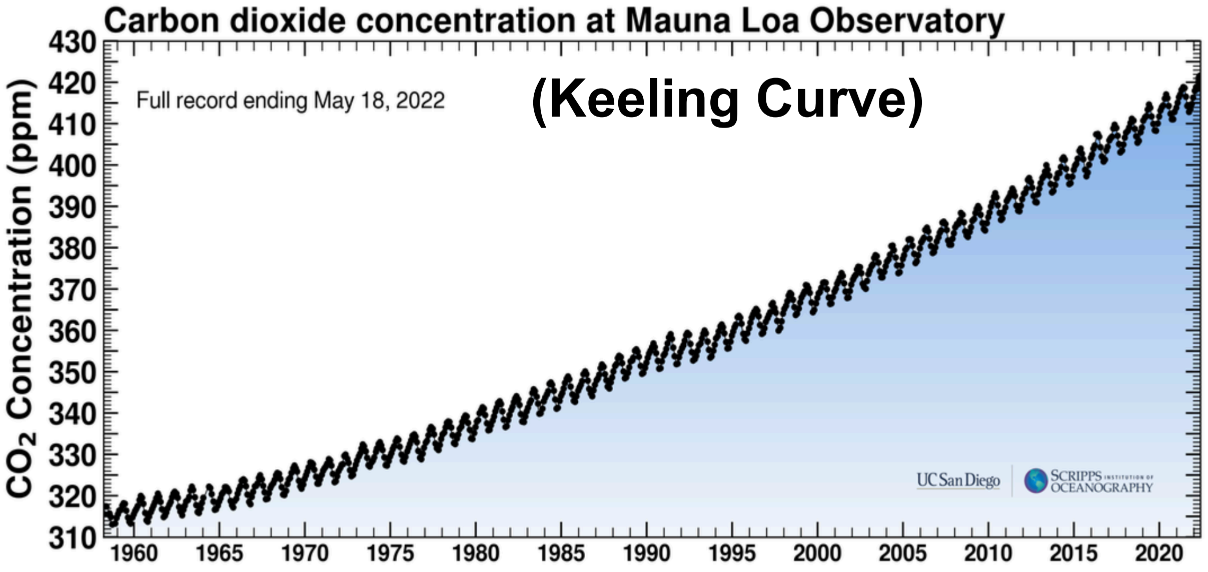
Parameter	CO_2	CH_4	CFC-11	CFC-12	N_2O
Preindustrial atmospheric concentration (1750)	278 ppm	715 ppb	0	0	270 ppb
Current atmospheric concentration (2011)	390 ppm	1803 ppb	238 ppt	527 ppt	324 ppb
Current annual rate of atmospheric accumulation	2.0 ppm (0.5%)	4.8 ppb (0.27%)	−2.25 ppt (−0.93%)	−2.25 ppt (−0.42%)	0.8 ppb (0.25%)
Atmospheric lifetime (years)	(50–200)	10	65	130	150

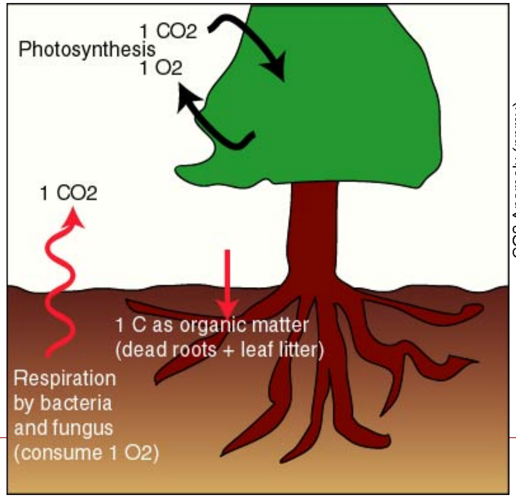
$$\text{lifetime} = \frac{\text{atmospheric content}}{\text{rate of removal}}$$

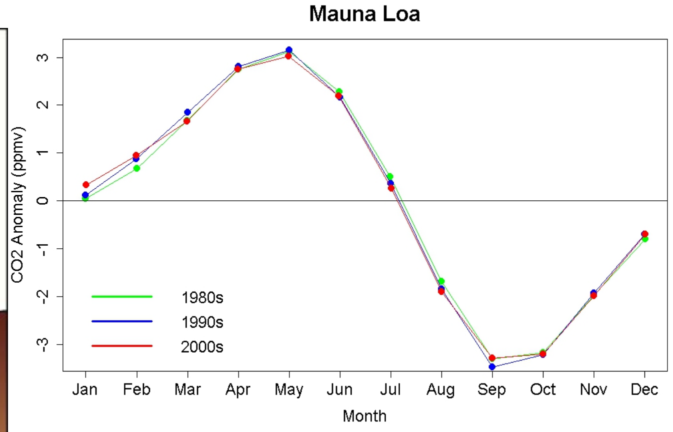
man-made GHG

Emission of greenhouse gases: CO_2



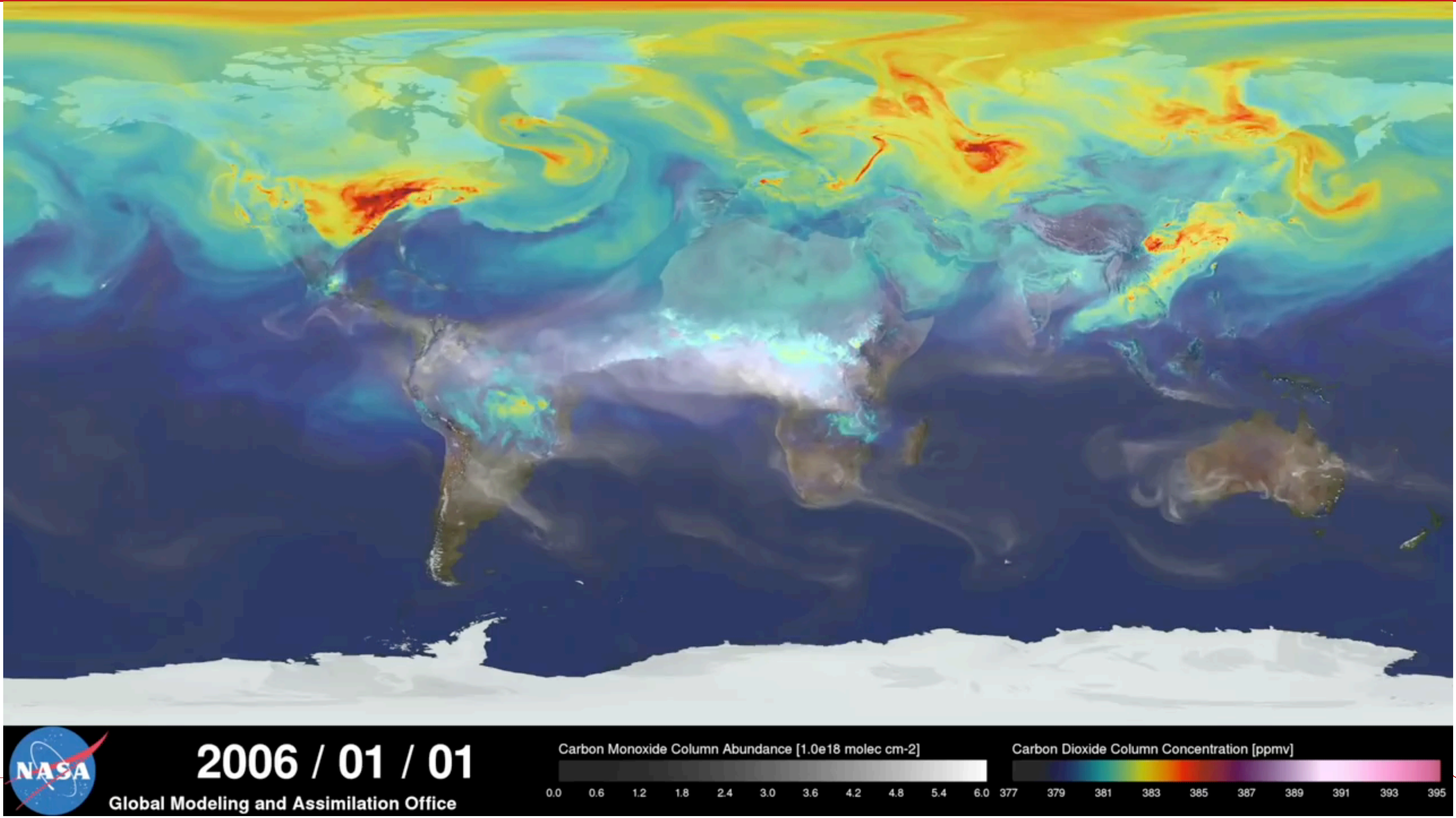




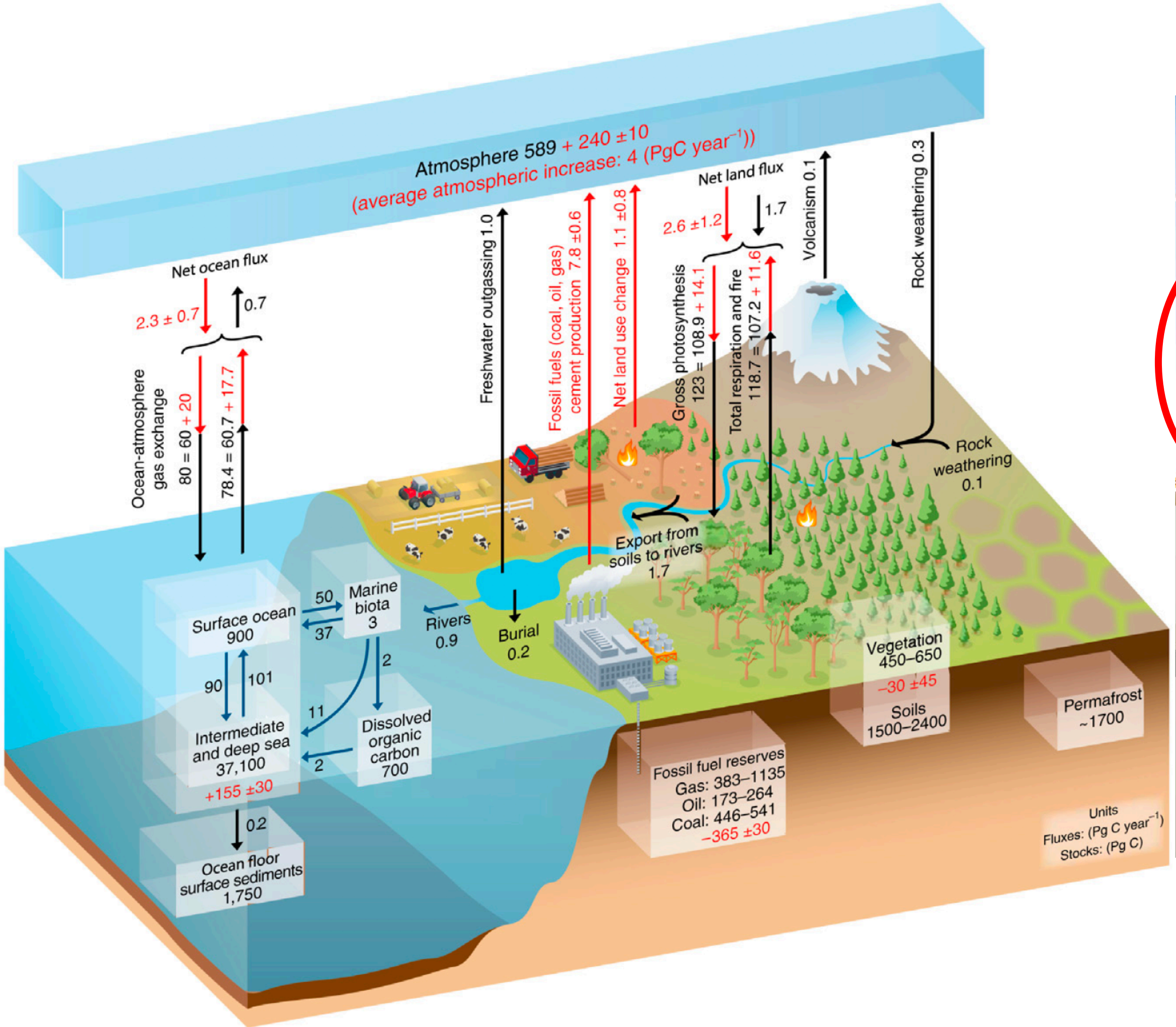


- Long term trend: increasing
- Seasonal cycle: <u>signature of the terrestrial biosphere</u>

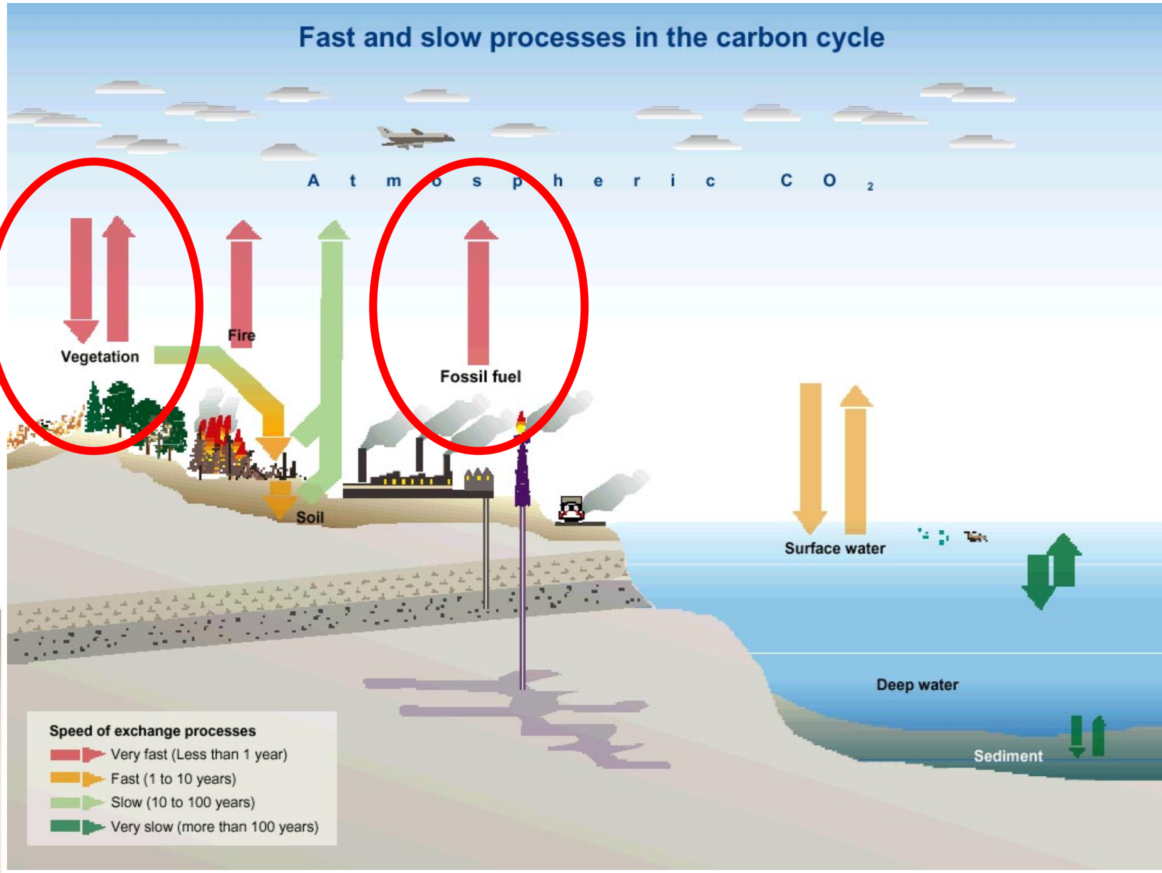
A Year in the Life of Earth's CO2



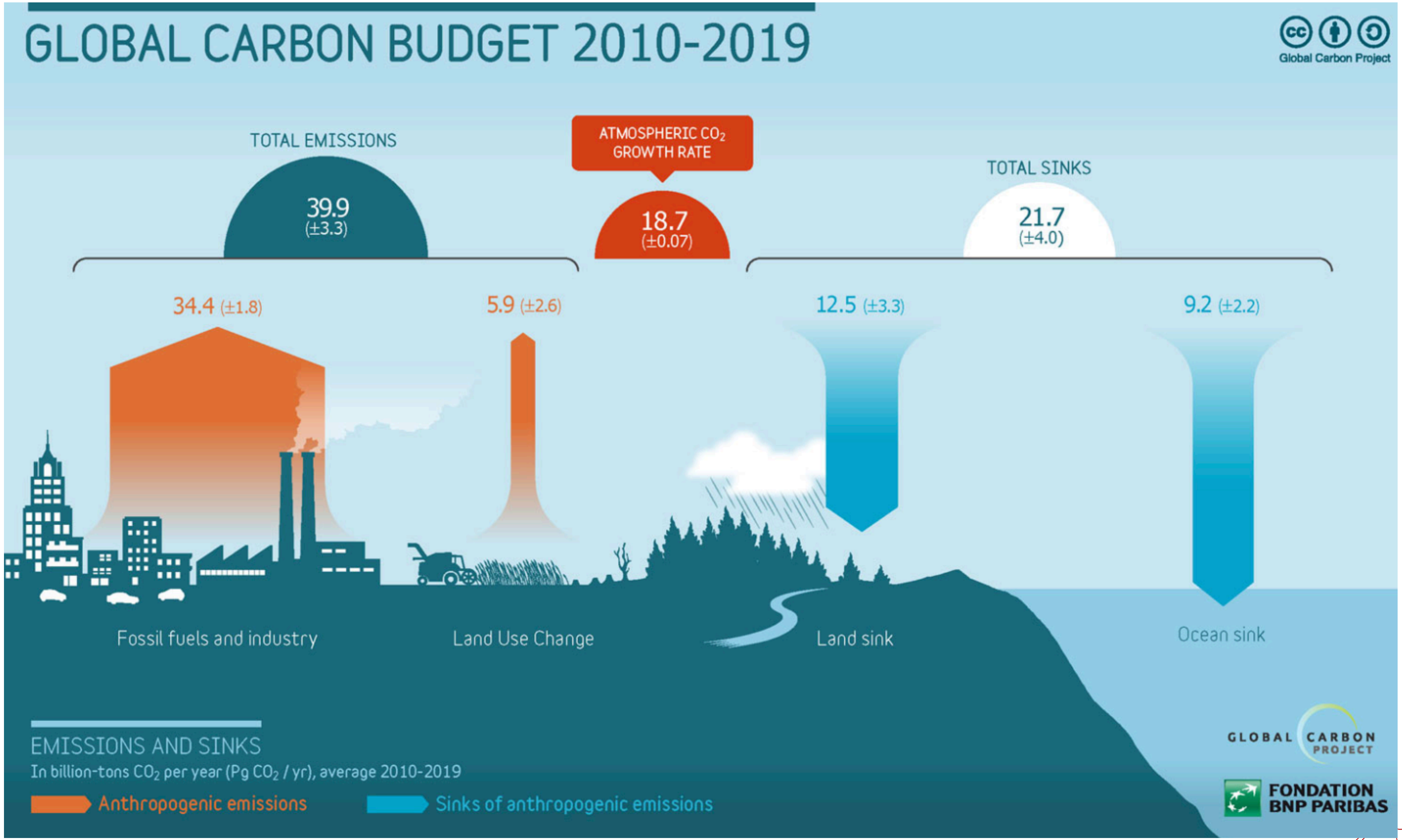
Emission of greenhouse gases: CO_2



Fast and Slow Processes in the Carbon Cycle



Emission of greenhouse gases: CO_2

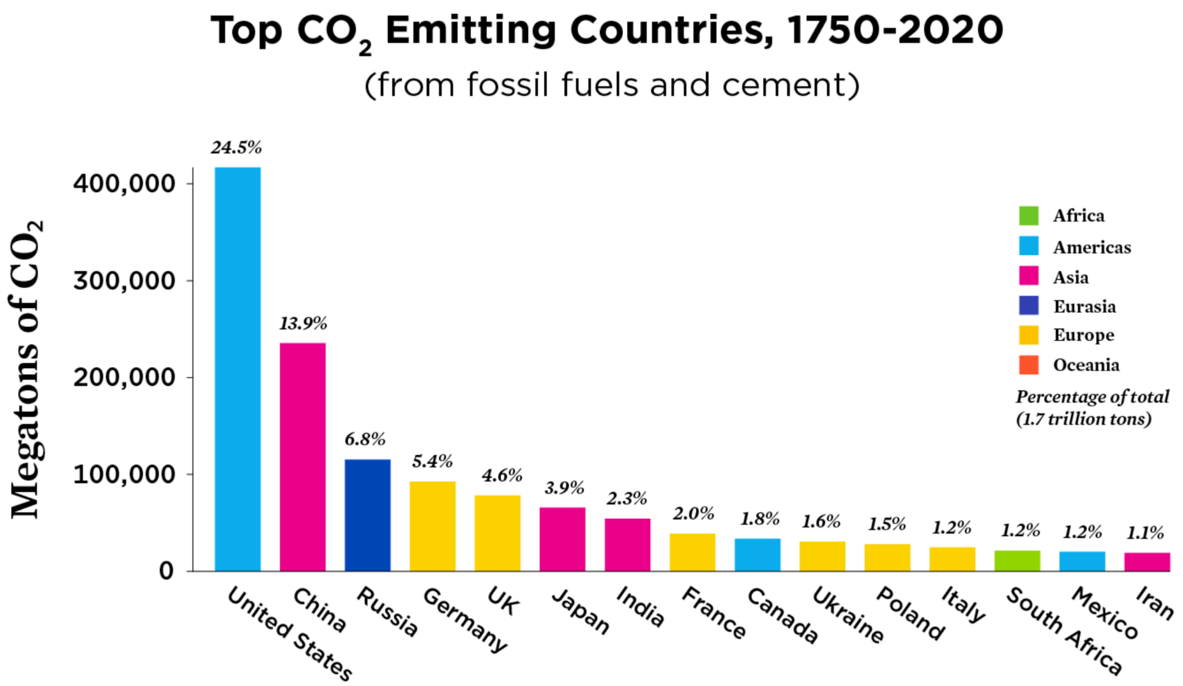


Emission of greenhouse gases: CO_2

Anthropogenic source: fossil fuel

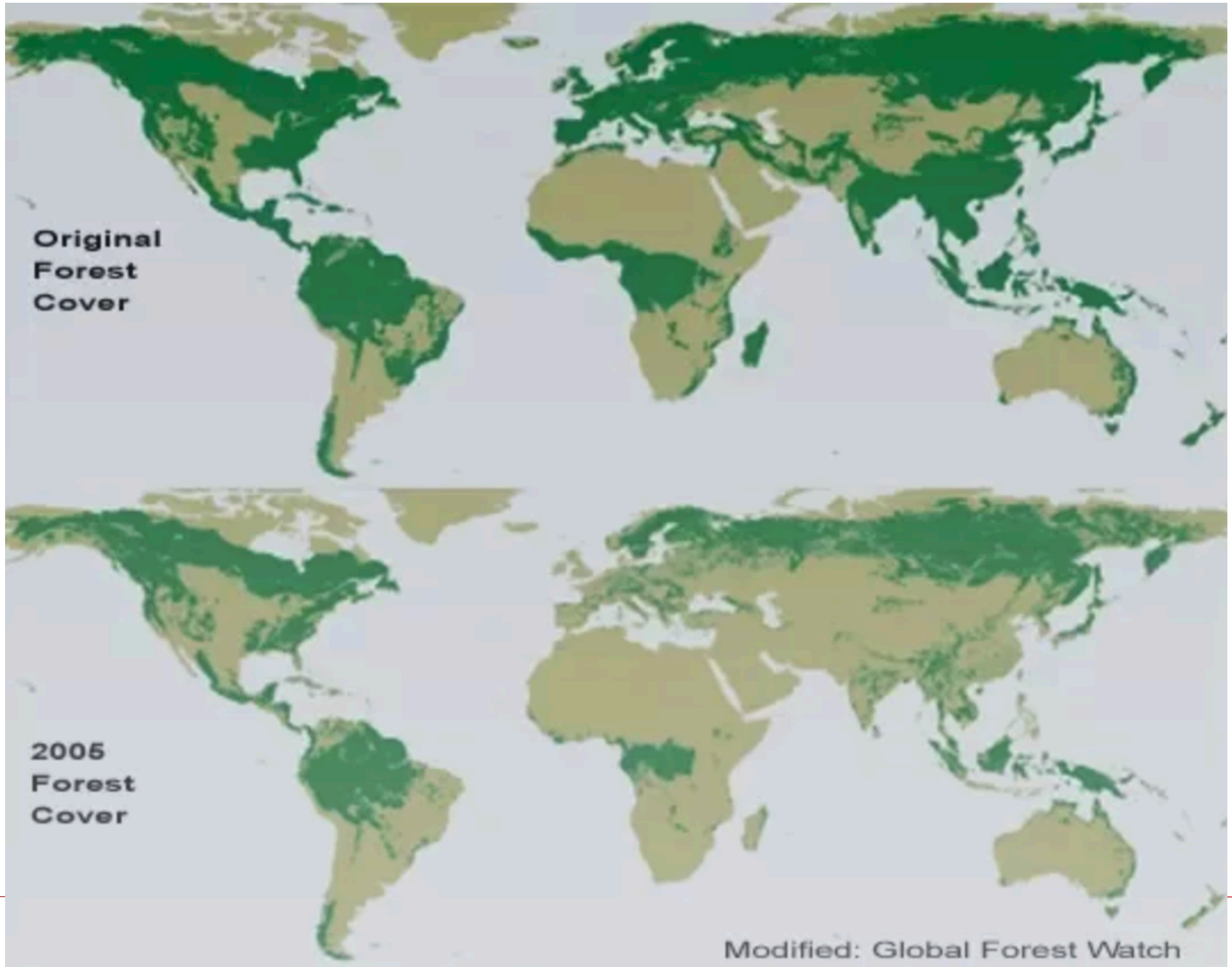
Verify **fossil fuel** as the major source of atmospheric CO2?

- Δ14C decrease
- δ13C decrease

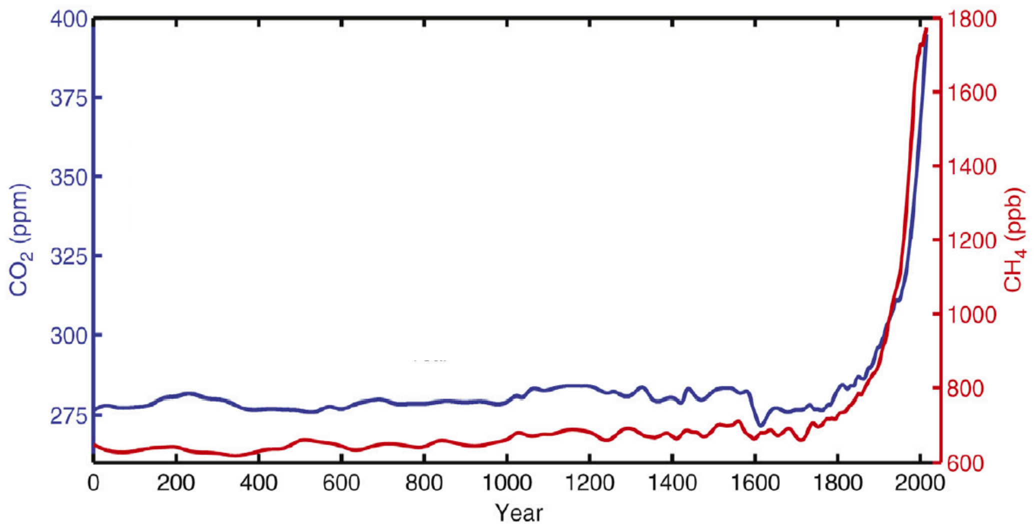


Emission of greenhouse gases: CO_2

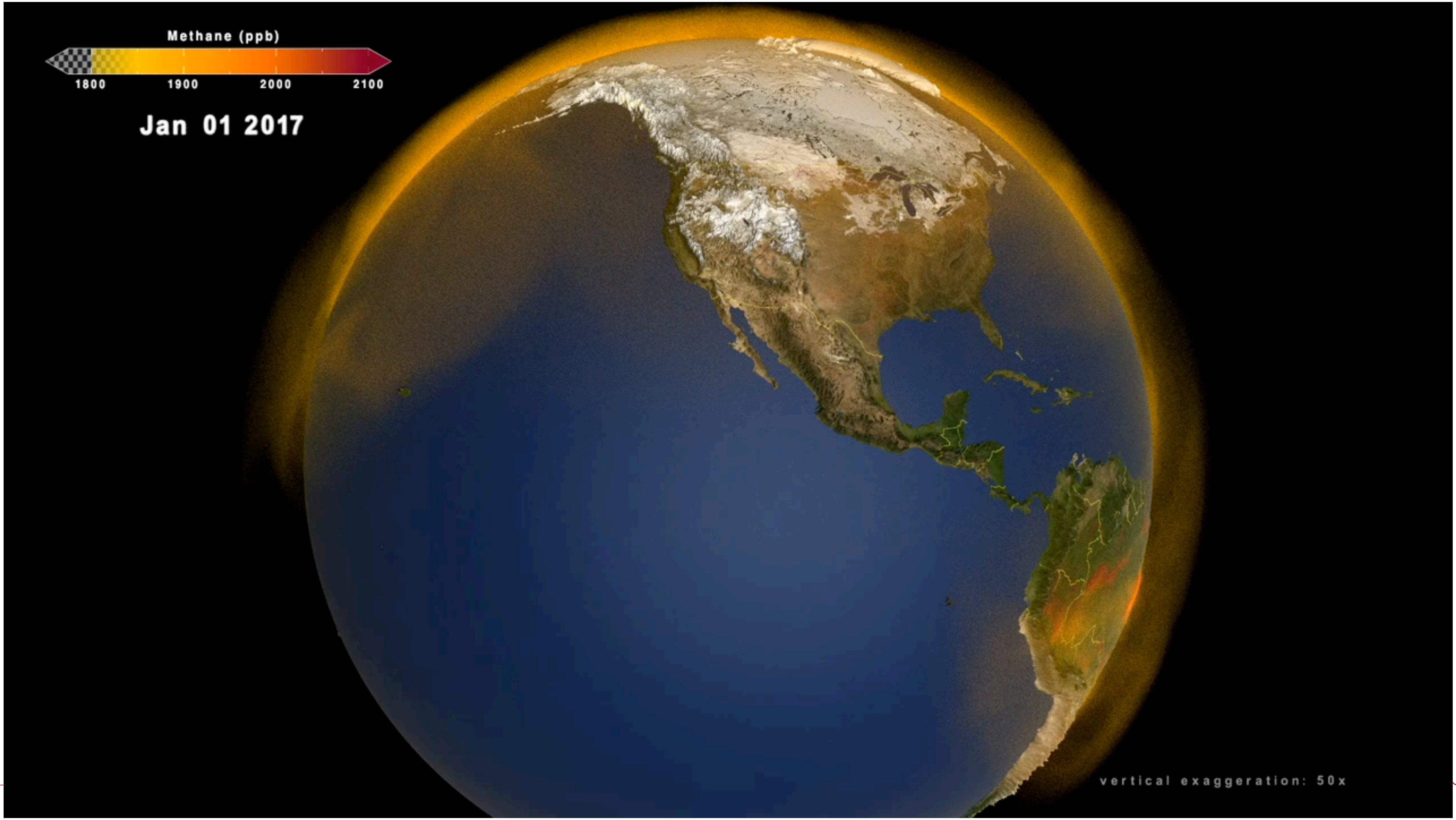
Anthropogenic source: Deforestation



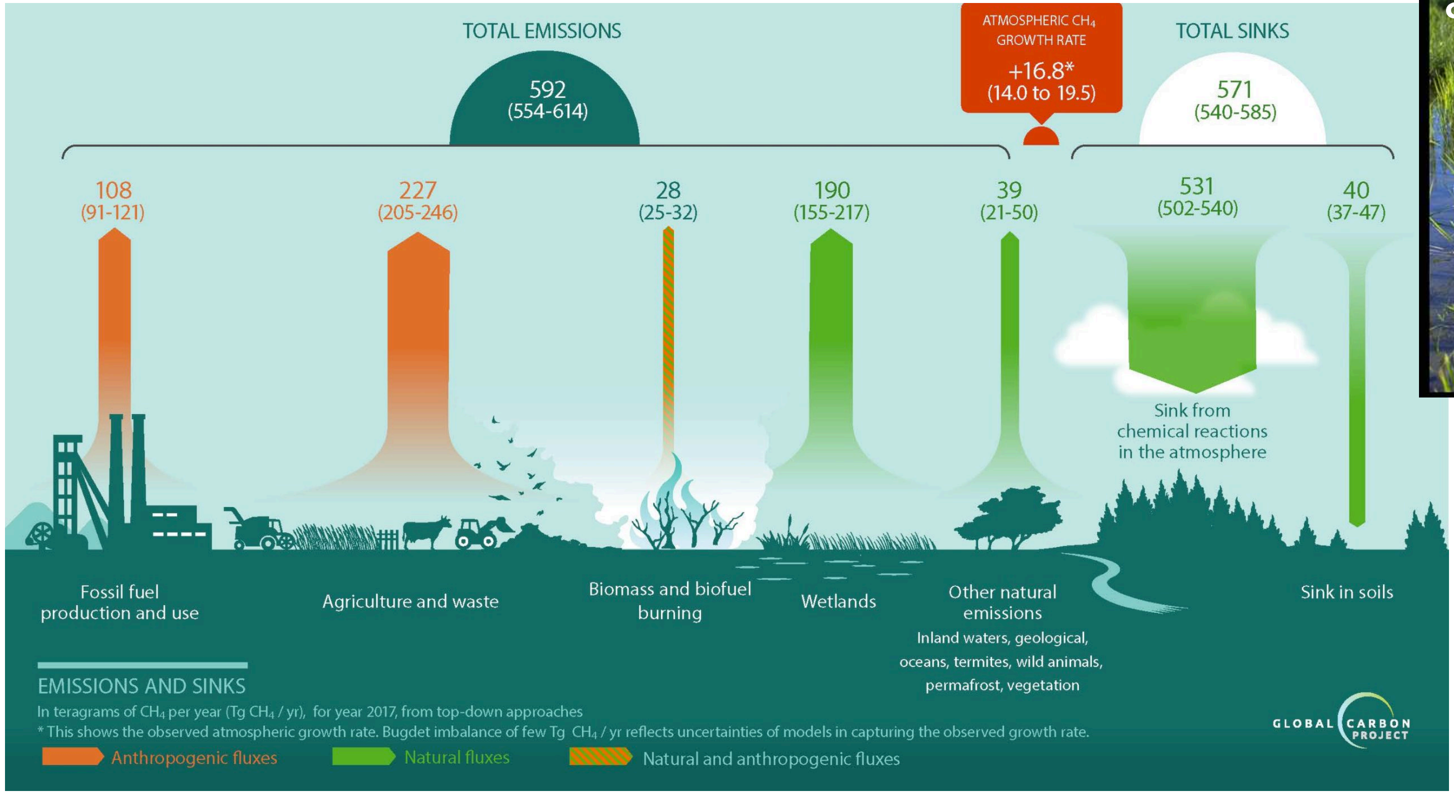
Emission of greenhouse gases: CH_4



Global Atmospheric Methane



Emission of greenhouse gases: CH_4



Lifetime~**10yrs** : If we make big changes in our emissions, methane can be removed relatively quickly.