# Introduction to
Global Climate Models & their outputs

Sylvie Joussaume
CNRS, IPSL, coordinator of IS-ENES3
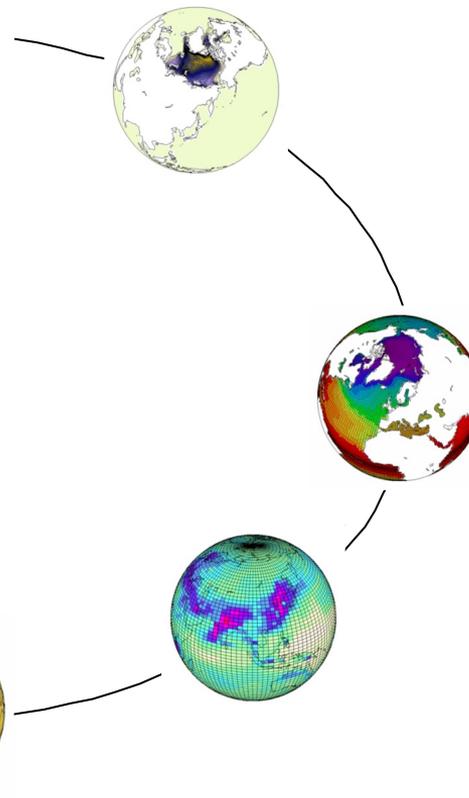
Modelling the Earth's climate system

Understand & Predict Climate Variability and Changes

Atmosphere

Oceans

Continents

Natural & Anthropogenic
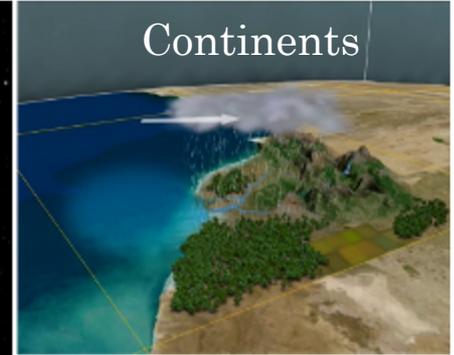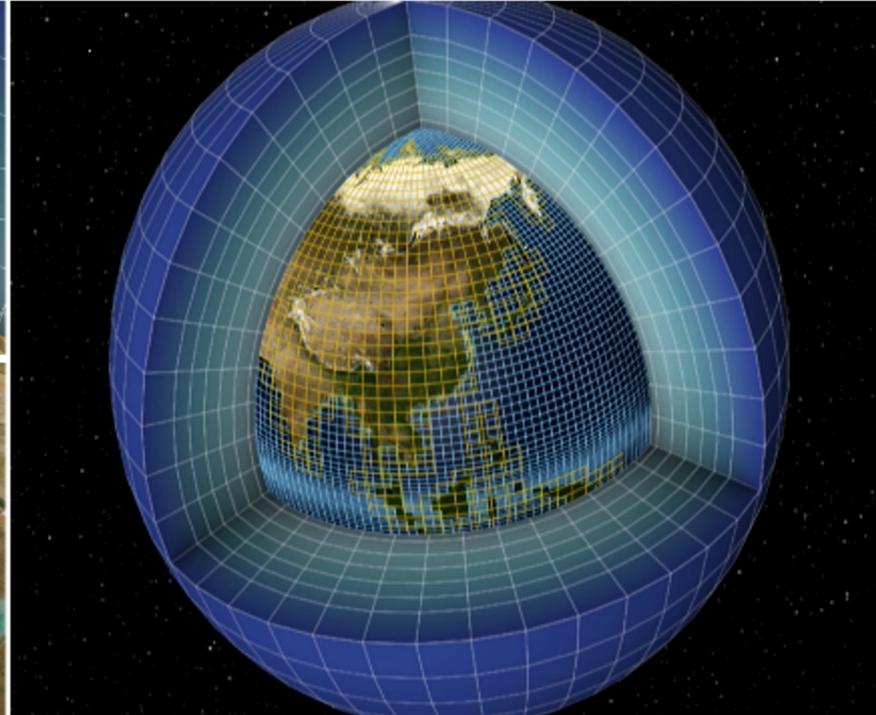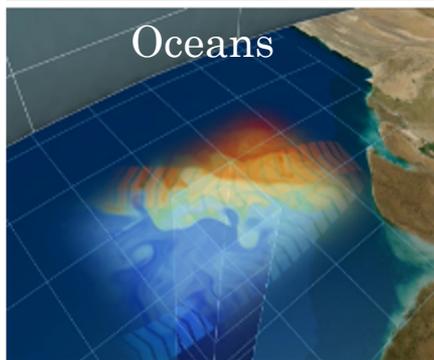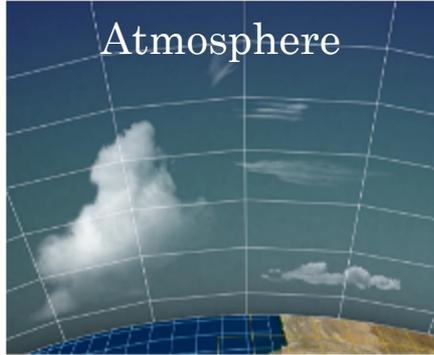
Evolution of climate models
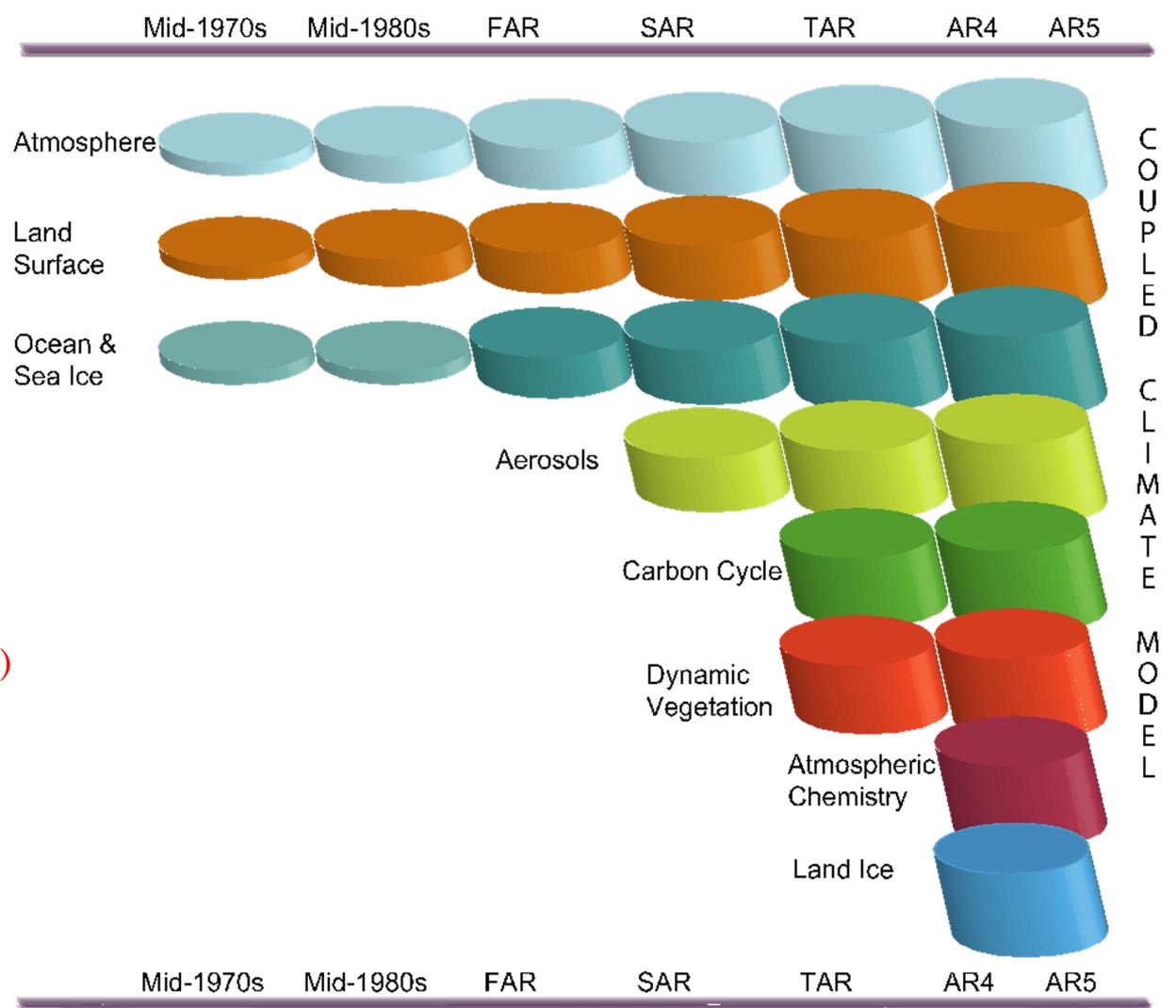
IPCC AR5, WGI, Chap 1 (2013)

Earth system models (ESM)

EARTH SYSTEM MODELS

Basic physical laws
Based on Navier-Stokes
Conservation of:
energy,
mass (air, water, carbon)
&
Parameterisations
clouds, radiation, surface fluxes
subgrid-scale processes
(eddies, bound. layer turbulence)

each ESM
> 1000 man years:
strong legacy
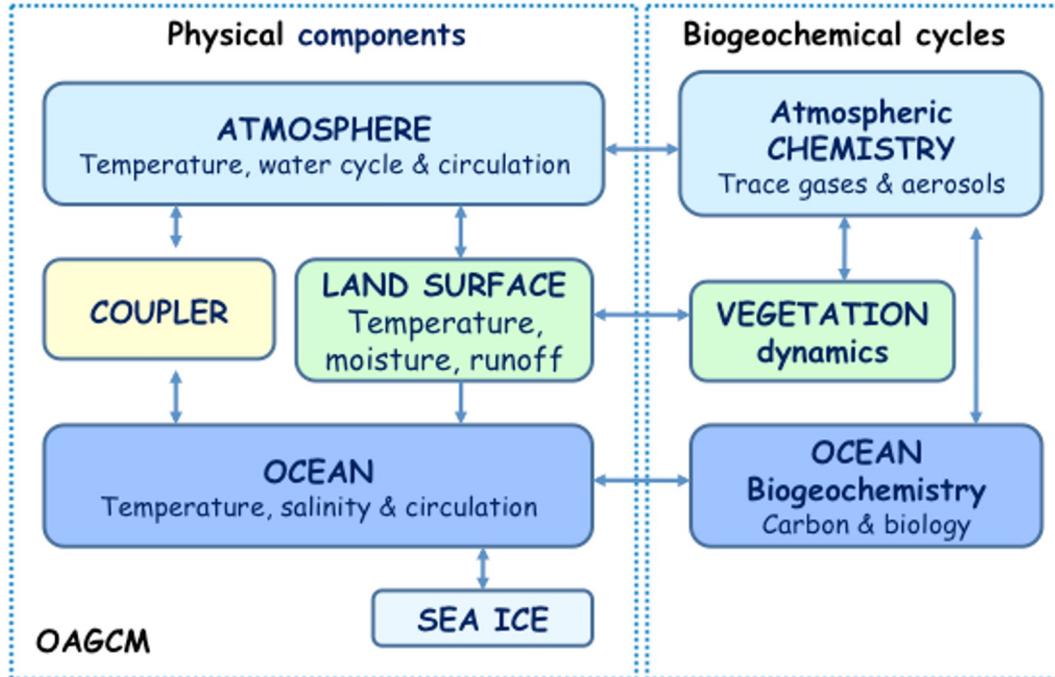
GCM: originally « General Circulation Models »

Spatial resolution

IN THE ATMOSPHERIC COLUMN
Wind vectors
Humidity
Clouds
Temperature
Height

Vertical exchange between levels

AT THE SURFACE
Ground temperature, water and energy fluxes

Horizontal exchange between columns

Time step ~30 minutes   Grid spacing ~3° x 3°

TAR 2001

~180 km (T63)

AR4 2007

~110 km (T106)

Common range

AR5 2013

87.5 km x 87.5 km
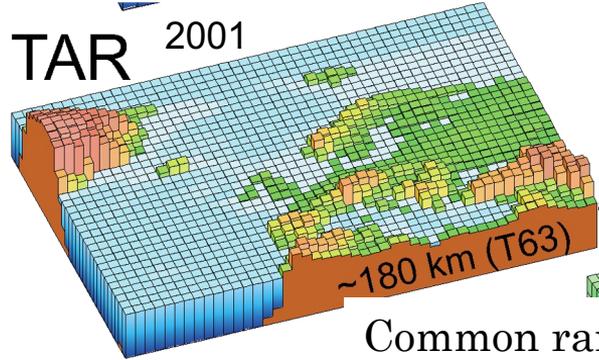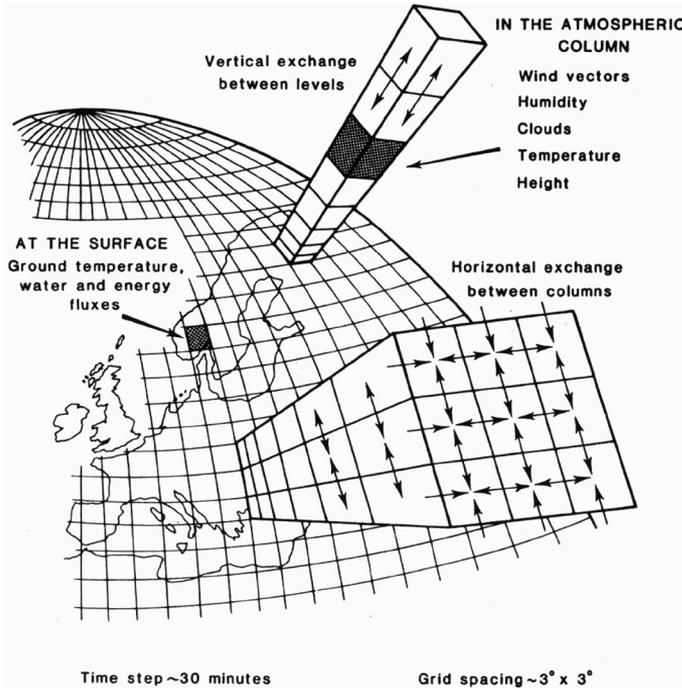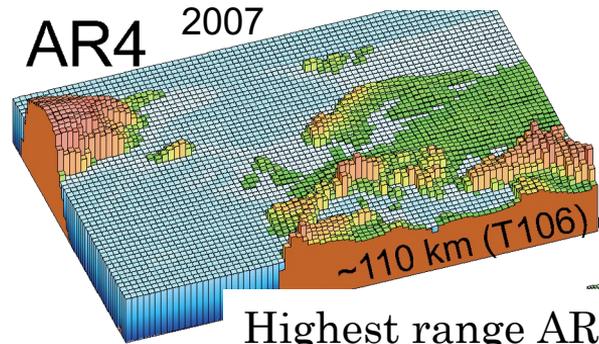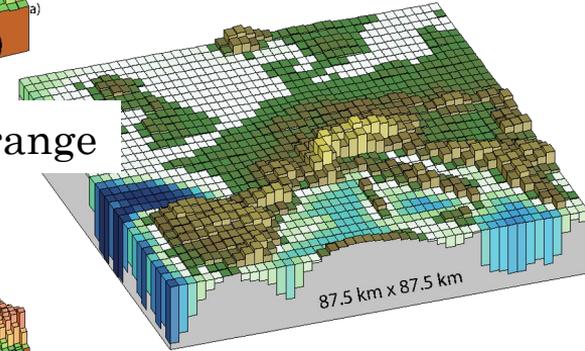
Highest range AR6

2021

30.0 km x 30.0 km
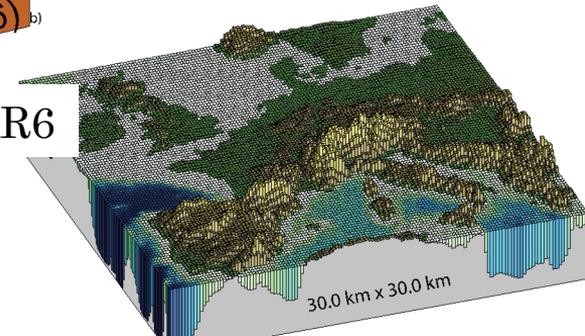
Evaluation of climate models with observations

From IPCC AR4 to AR6
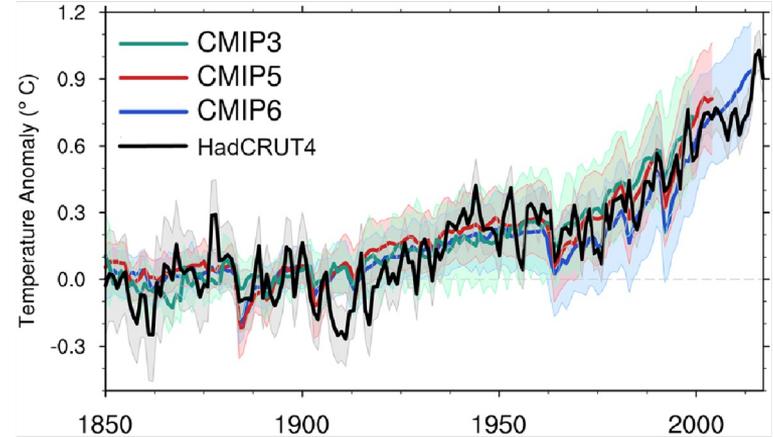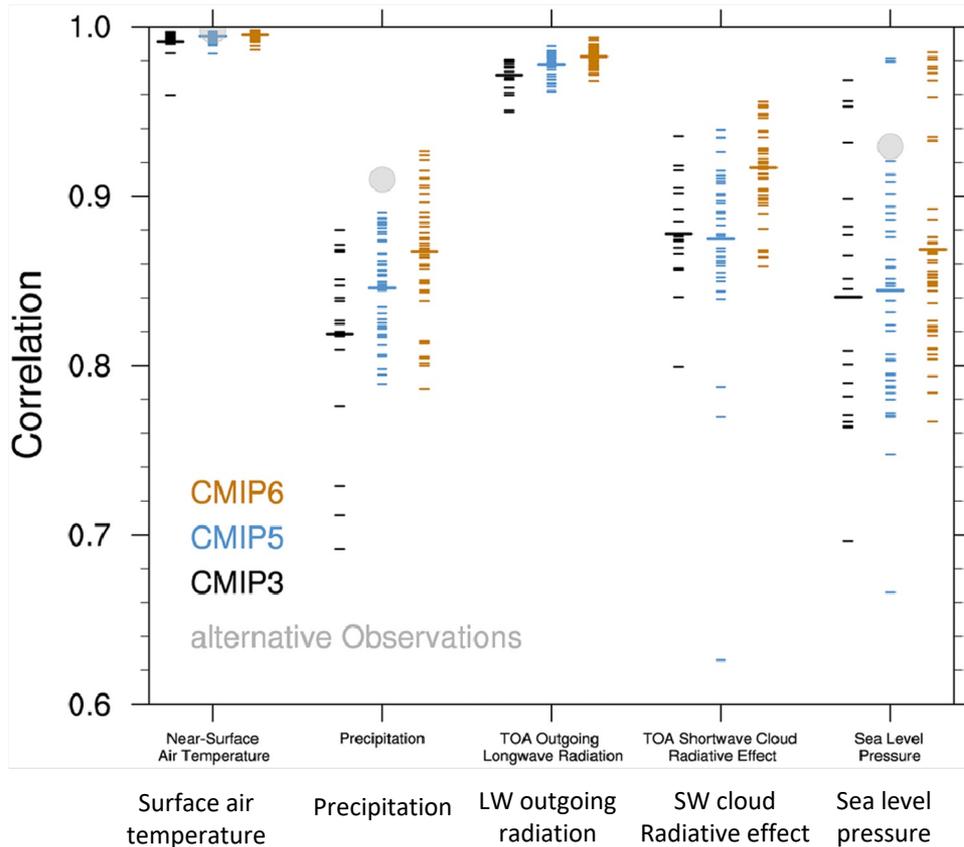
Bock et al., JGR (2020)

**Better at large scale / weaker at smaller scale**

"It is unequivocal that human influence has warmed the atmosphere, ocean and land"

IPCC AR6 SPM (2021)
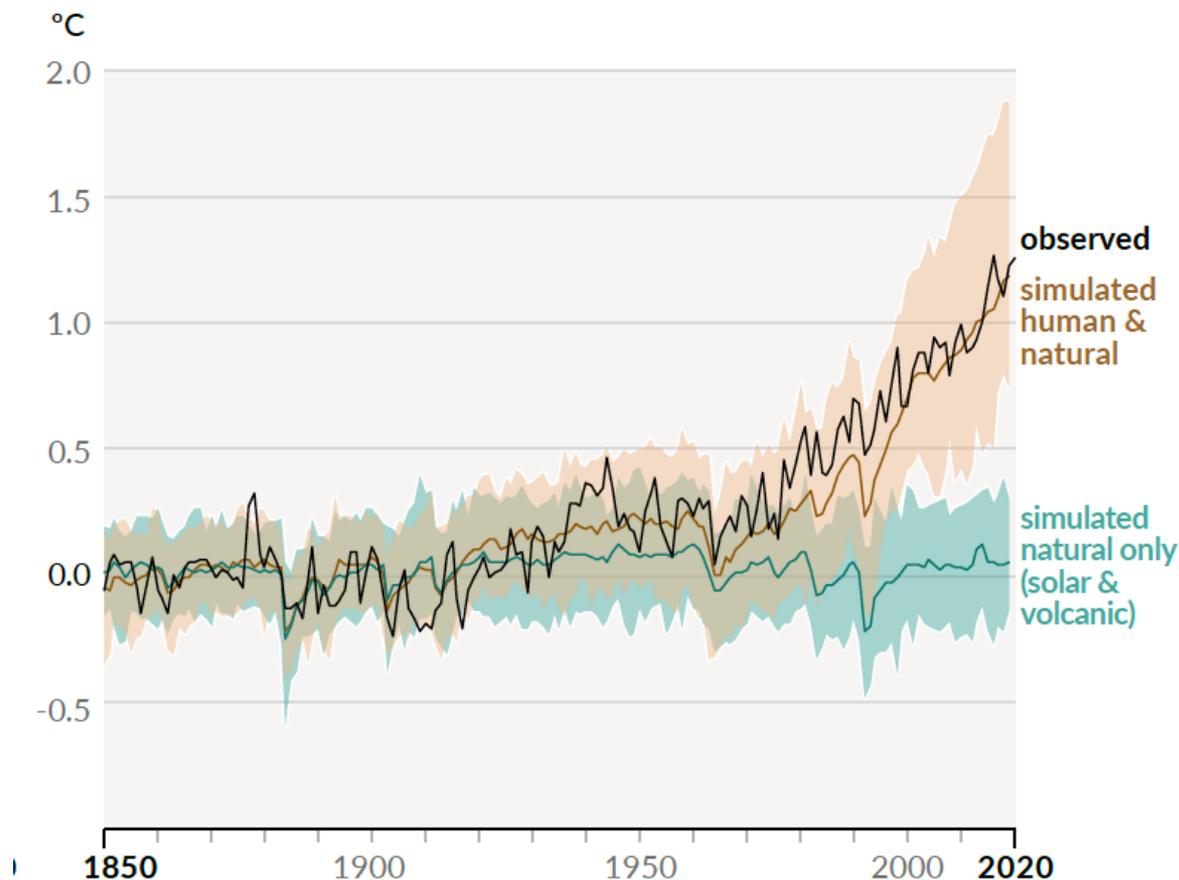
Simulations of future climate change under different scenarios

RCPs Representative Concentration Pathways
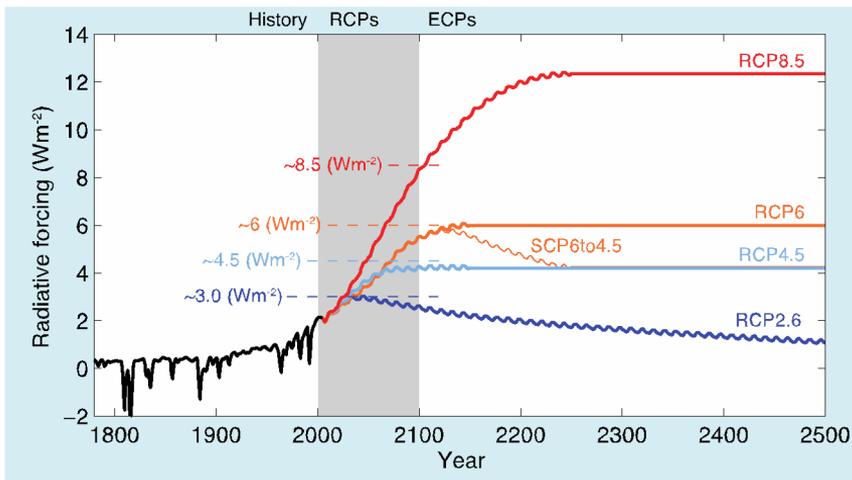
CMIP5 / IPCC AR5 (2013)

Adding SSPs
"Shared Socioeconomic Pathways »
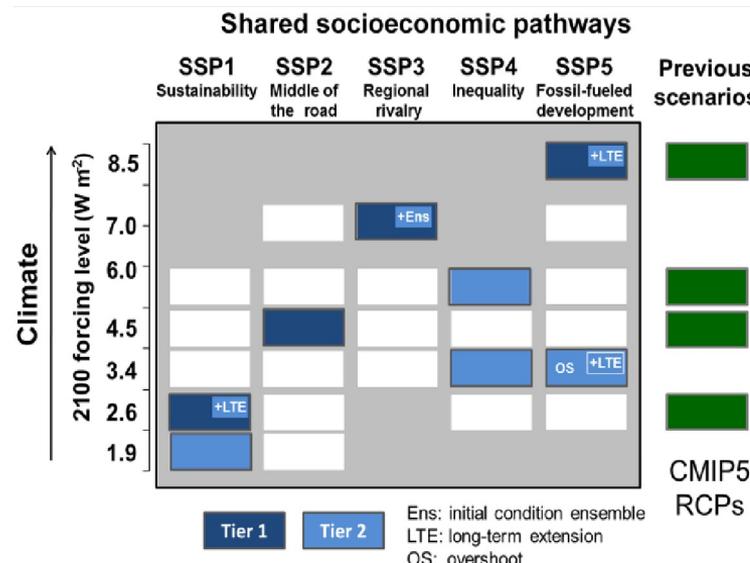
CMIP6 / IPCC AR6 (2021)

O'Neill et al., GMD (2016)

Simulations of future climate change under different scenarios

IPCC AR6 SPM (2021)

a) Global surface temperature change relative to 1850-1900

COP21 Limit to 2°

SSP5-8.5
SSP3-7.0
SSP2-4.5
SSP1-2.6
SSP1-1.9

Simulated change at **4 °C** global warming
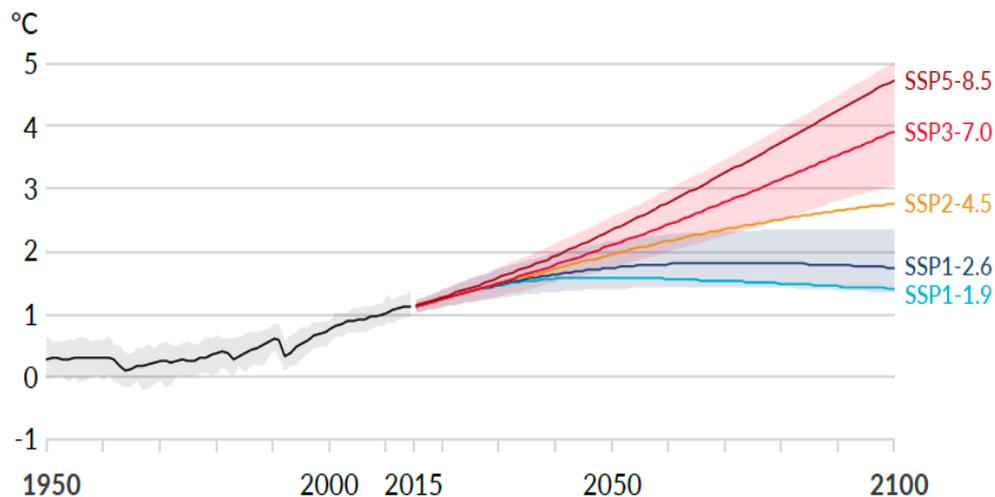
4.4°C
3.3 - 5.7

2.7°C
$2.1 - 3.5$

1.4°C
1.0 - 1.8
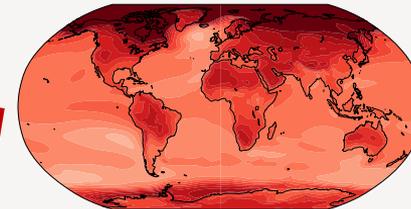
Simulated change at **1.5 °C** global warming

0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 --->

Change (°C)   Warmer
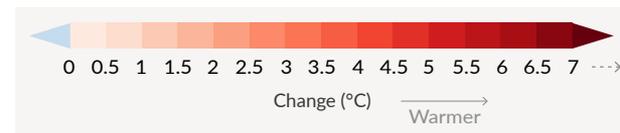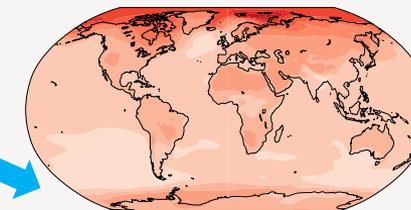
Change in surface temperature of the Earth

Change in surface temperature of the Earth
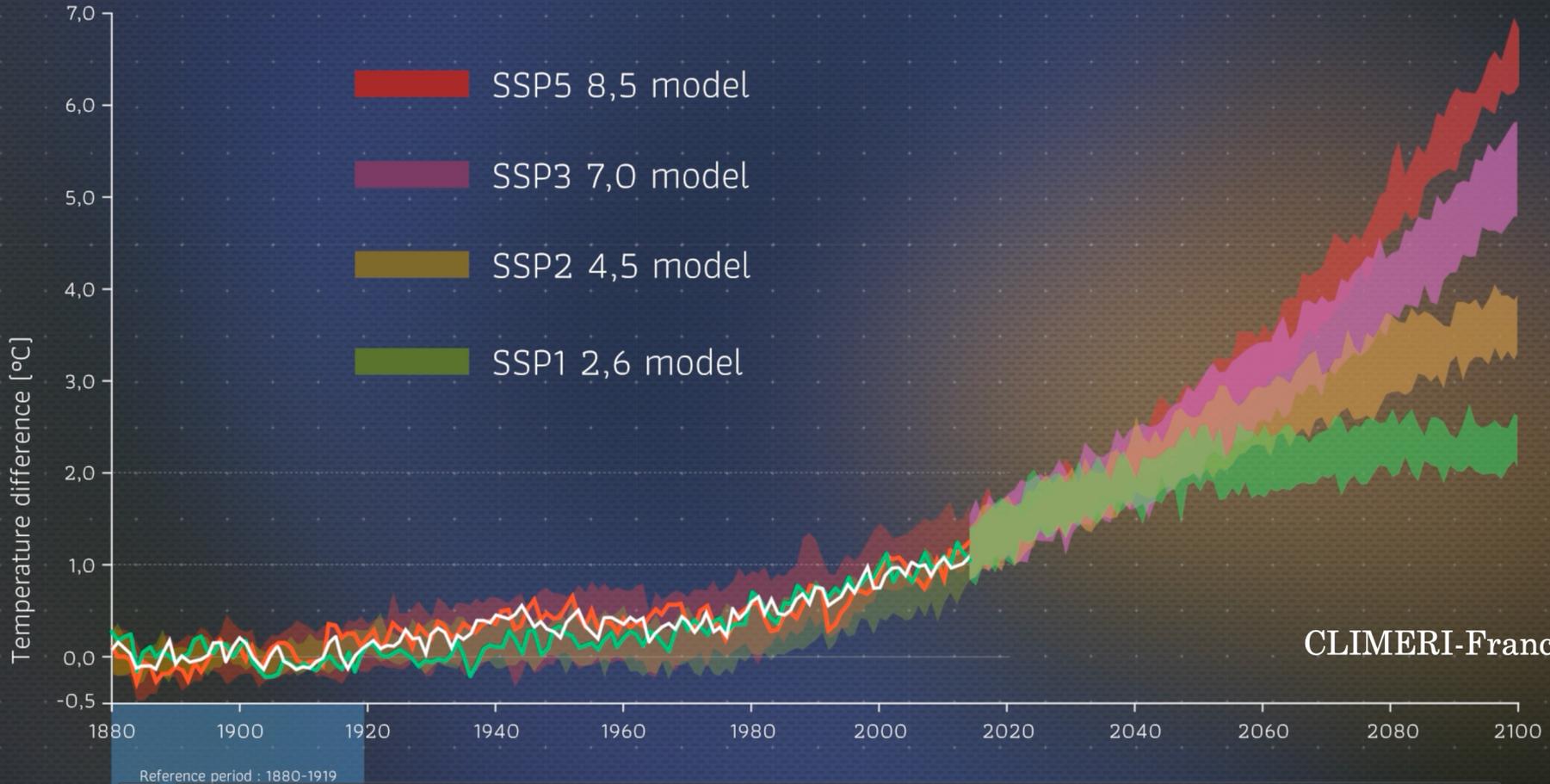
Accounting for uncertainties

Emission scenarios **Internal variability**

Model uncertainties
Structural (resolution, physics)
Parametric (parameters)

IPCC AR5 WGI Chap 1

Bock et al., JGR (2020)
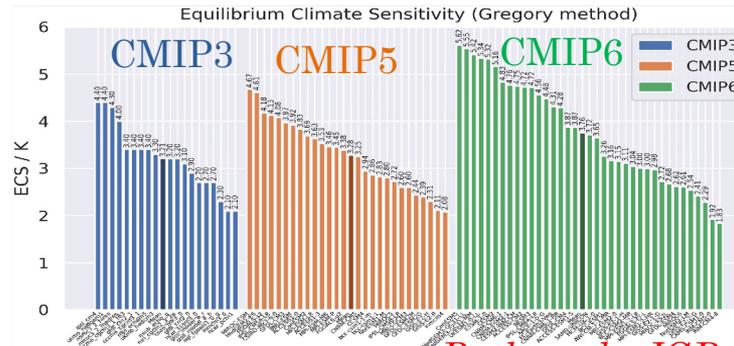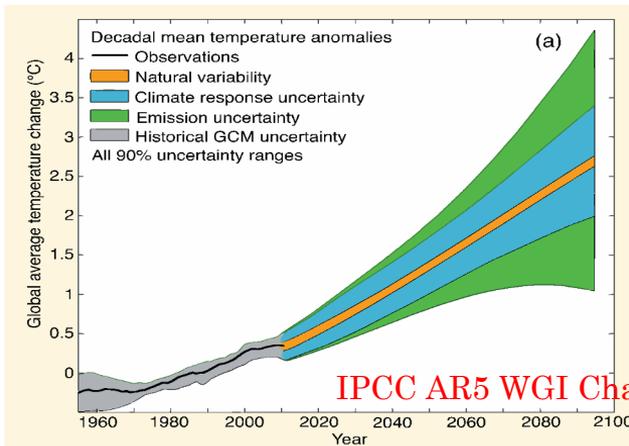
& also
Missing components/feedbacks

IPCC AR6 SPM (2021)
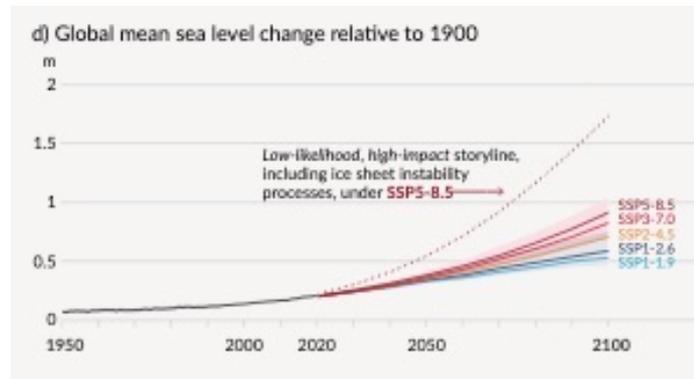
Climate sensitivity and cloud feedbacks

Temperature change to 2 x CO_2

CMIP3 (AR4)

Mean: **3°C**

Uncertainty range of
Equilibrium Climate Sensitivity:
2°to 4.5 °C
Mainly due to cloud feedbacks

Dufresne & Bony, J. Climate, 2008

Multi-model mean
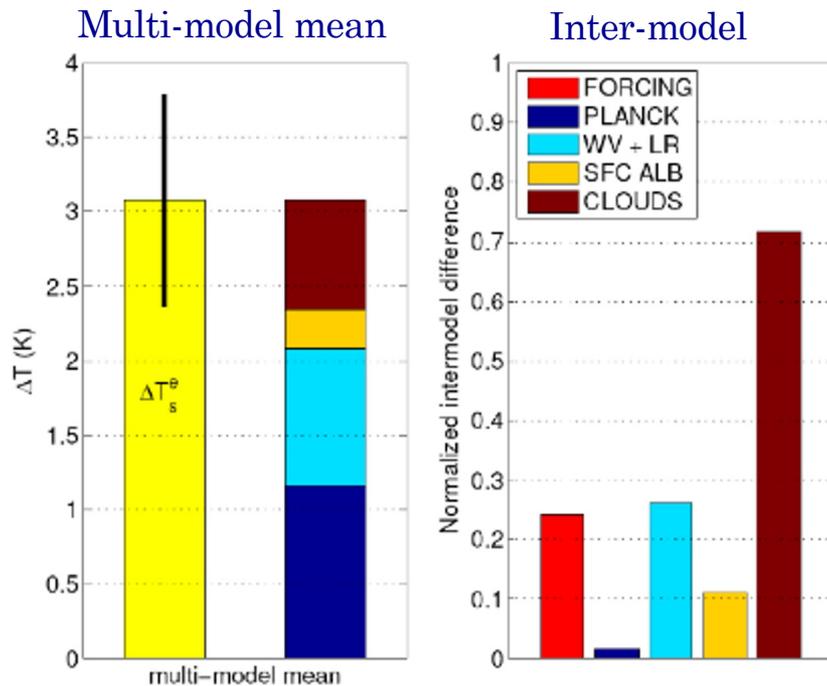
Inter-model

Clouds

World Climate Research Program:

Coupled Model Intercomparison Project, Phase 6 (CMIP6)

CMIP6
(Eyring et al., GMD, 2016)

23 endorsed MIPs
Model Intercomparison Projects

Deck: 30 modelling groups (59 models)

Per model:
20 to 50 000 simulated years
HPC: 100s Mh
Data: 1 – 10 PB produced

Input to IPCC AR6 2021

Evaluate

Understand

Predict/Project

Status of CMIP6 experiments
(CMIP deck)
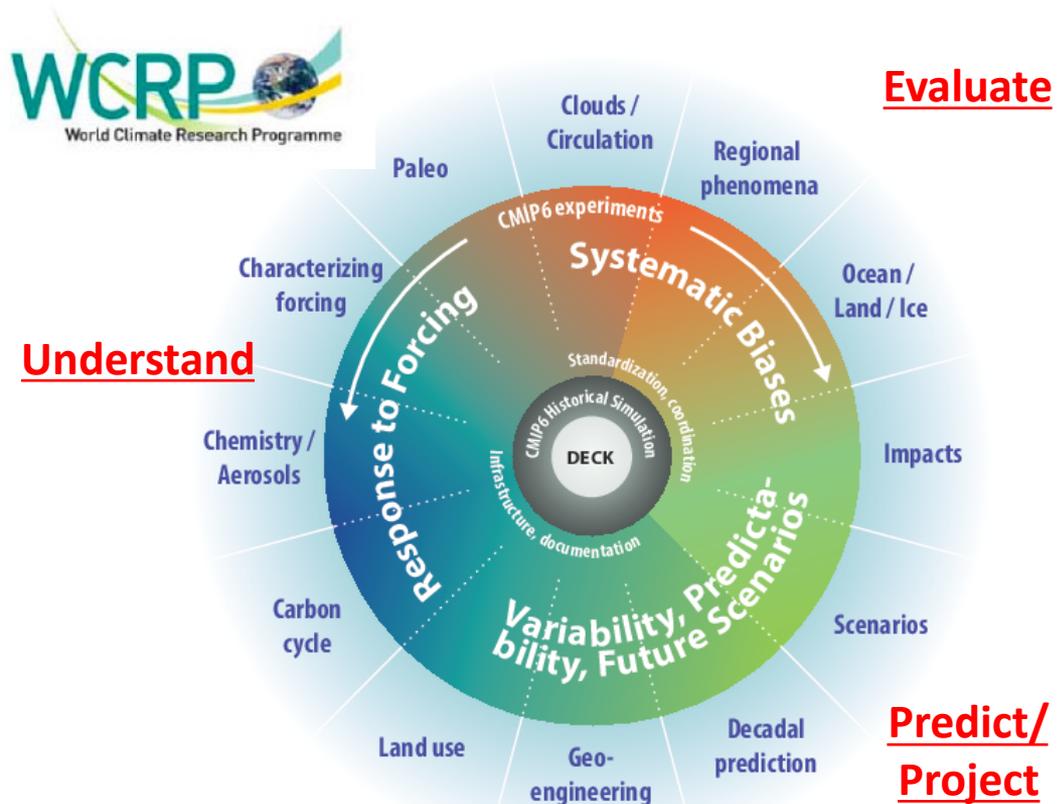
30 modelling groups
59 models
All: 38/100

1 Canada

Canada	CAN	CanESM5
		CanESM5-CanOE
USA	NCAR	CESM2
		CESM2-FV2
		CESM2-WACCM
		CESM2-WACCM-FV2
USA	E3SM	E3SM-1-0
		E3SM-1-1
		E3SM-1-1-ECA
USA	GFDL	GFDL-AM4
		GFDL-CM4
		GFDL-ESM4
USA	GISS	GISS-E2-1-G
		GISS-E2-1-G-CC
		GISS-E2-1-H
		GISS-E2-2-G
USA	MCM	MCM-UA-1-0

5 USA

|		
DE	MPI	MPI-ESM-1-2-HAM
		MPI-ESM1-2-HR
		MPI-ESM1-2-LR
DE	AWI	AWI-CM-1-1-MR
		AWI-ESM-1-1-LR
FR	CNRM	CNRM-CM6-1
		CNRM-CM6-1-HR
		CNRM-ESM2-1
FR	IPSL	IPSL-CM6A-LR
IT	CMCC	CMCC-CM2-HR4
		CMCC-CM2-SR5
UK	HADLEY/UKESM	HadGEM3-GC31-LL
		HadGEM3-GC31-MM
		UKESM1-0-LL
NO	NorESM	NorCPM1
		NorESM1-F
		NorESM2-LM
		NorESM2-MM
EC-Earth	EC-Earth	EC-Earth3
		EC-Earth3-LR
		EC-Earth3-Veg
		EC-Earth3-Veg-LR
Russie	INM	INM-CM4-8
		INM-CM5-0

8 in Europe

7 China / 1 Taïwan/ 3 Korea

2 Japan

Chine	BCC	BCC-CSM2-MR
		BCC-ESM1
Chine	CAMS	CAMS-CSM1-0
Chine	CAS	CAS-ESM2-0
Chine	CIESM	CIESM
Chine	FGOALS	FGOALS-f3-L
		FGOALS-g3
Chine	FIO	FIO-ESM-2-0
Chine	NESM	NESM3
Taiwan	TaiESM	TaiESM1
Korea	KACE	KACE-1-0-G
Korea	KIOST	KIOST-ESM
Korea	SNU	SAM0-UNICON
JP	MIROC	MIROC-ES2L
		MIROC6
JP	MRI	MRI-ESM2-0
Inde	IITM	IITM-ESM
AU	ACCESS	ACCESS-CM2

1 Russia

1 Australia

is-enes
INFRASTRUCTURE FOR THE EUROPEAN NETWORK
FOR EARTH SYSTEM MODELLING

WCRP
World Climate Research Programme

Earth system grid federation: A common data infrastructure

GA 824084
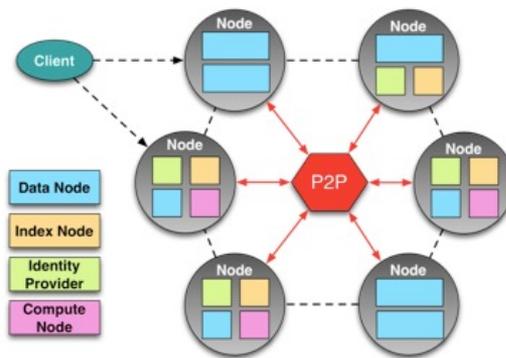
Dashboard stat
ESGF: 13 M datasets
31.8 PB

CMIP6: 12 M datasets
22.6 PB (w/o replica 12.2)
CMIP5: 5.3 PB (1.5)

ca 15 000 registered users

FAIR data
Open access, common data and metadata standards
Multi-agencies support: *DOE, NOAA, NASA, IS-ENES, NCI*

Climate projections
@ climate data store

Conclusions

- Climate models are key tools to understand mechanisms and predict possible future changes

- **CMIP cycles**: key reference set of simulations, with improvements at each cycle

- Europe a key player in the international landscape (models and infrastructure). IS-ENES a resource for accessing and analysing climate model data

- **From GCM to impacts** : downscaling, bias corrections and forcing for impact models

    Climate models are at the core of climate information for society