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Climate modelling: computing and data challenges

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1- Climate change and climate modelling

2- Climate models and international landscape

3- Challenges in climate modelling

Conclusions

1- Climate change and climate modelling

Global warming is unequivocal

IPCC AR6 (2021)

Global :

Decade 2011-2020: +1.09 warmer than 1850-1900

Each last 4 decades: warmer than any decade that preceded it since 1850

UK MetOffice

2020: +1,28° C versus 1850-1900

Increase of greenhouse gases: use of fossil fuels and demography

Atmosphere
410 ppm in 2019
+48% since 1750
(277 ppm in 1750)

Unprecedented in 800 000 years

Global Carbon Budget 2020
Friedlingstein et al., 2020

Modelling the Earth's climate system

Understand & Predict Climate Variability and Changes

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“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

IPCC AR6 SPM (2021)

Annual temperature changes relative to 1850-1900

IPCC AR6 SPM (2021)

Annual precipitation changes relative to 1850-1900

IPCC AR6 SPM (2021)

Every tonne of CO_2 emissions adds to global warming

Global surface temperature increase since 1850-1900 (°C) as a function of cumulative CO_2 emissions ($GtCO_2$)

Temperature Change

Cumulative CO2 emissions ($GtCO_2$)

IPCC AR6 SPM (2021)

Future cumulative CO_2 emissions differ across scenarios, and determine how much warming we will experience

2019
2390 $GtCO_2$
emitted

2- Climate models and international landscape

Earth's climate system models

ESM > 1000 man years
Strong legacy

Based on physical laws (navier-stokes, conservation)
& parameterizations (clouds, surface fluxes, radiation, sub-grid scale processes)

Spatial resolution

Common range

Highest range AR6

World Climate Research Program:
Coupled Model Intercomparison Project, Phase 6 (CMIP6)

CMIP6
(Eyring et al., GMD, 2016)

23 endorsed MIPs
Model
Intercomparison
Projects

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

Input to IPCC AR6
2021

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

1 Russia

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 Australia

Earth system grid federation: A common data infrastructure

Dashboard stat

ESGF: 8 M datasets
23,4 PB (w/o replica 12,7)

CMIP6: 7 M datasets
16,1 PB (w/o replica 9,3)
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

Support exploitation of model data

ESGF data statistics from all European ESGF nodes

CMIP6 downloaded data volume (TB)

Evaluation of CMIP6 model results

Correlation with observations

Precipitation

TOA SW

Air Temperature

TOA LW

Sea Level Pressure

Bock et al., JGR (2020)

3- Challenges in climate modelling

WCRP Strategic Plan 2019-2028

Variability and changes in the coupled system

Seasonal to decadal predictions: Adaptation

Uncertainties, feedbacks: Mitigation & Adaptation

Decision-relevant information and knowledge

Multiscale interactions

Stammer et al. 2018

« Storm-resolving » models

Climate models
Spatial resolution of 100-200 km down to 25 km at best

Spatial resolution

Key for regional patterns

130 km

60 km

25 km

Observations

PRIMAVERA **HighResMIP**

Bias in precipitation variability
Danubius river

Simulated tropical cyclones
Roberts et al. (2015)

Resolution and computation

Roberts et al., GMD, 2019

Model name	CMIP6 resolution (atmosphere–ocean) (km)	Initial condition	Total years (spinup years)	Nodes (atmosphere–ocean)	Max turnaround (years per day)	Output per year (TB)
LL	250–100	LL-spinup (30 years)	1130 (30)	12–2	4	0.13
MM	100–25	MM-spinup (30 years)	680 (30)	50–24	1.3	0.73
HM	50–25	MM-spinup (30 years)	117 (0)	90–24	0.5	2.8
MH	100–8	MH-spinup (30 years)	205 (30)	34–171	0.45	2.0
HH	50–8	MH-spinup (30 years)	100 (0)	90–171	0.4	4.5

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Weather and Climate models Prepare for very high resolution "Storm-resolving" models

DYAMOND
intercomparison project
40 day simulations
Stevens et al. (2019)

HPC, e.g. ICON
2 Simulated Days Per Day
On 12,960 cores

4 August, initialised 1 Aug 2016

ExtremeEarth flagship concept

ExtremeEarth will co-design the technological transformation necessary for step changes in the ability of European society to anticipate weather and climate extremes, earthquakes and volcanoes; to collect and integrate Earth system data; and to access and adapt this information to the needs of an expanding user community.

Inspiration for
Destination Earth

Infrastructure Strategy Roadmap 2012-2022

Resolution:
Resolution x 2 > Computing x 8

Complexity :
carbon cycle, aerosols, chemistry, biosphere

Duration: need for long simulations
Multi-decadal to multi-centennial
At least 5-10 SYPD

Ensemble size: document internal variability, quantify uncertainties

Complexity and duration

Carbon cycle feedbacks

AF: Air borne fraction of CO2 emissions

CMIP6: Reduced spread due to inclusion of land nitrogen cycle

Jones and Friedlingstein (ERL, 2020)

Climate of the last 6000 years

Braconnot et al. (GRL, 2019)

Change in surface temperature of the Earth

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Preparing for future complex architectures

Revisiting dynamical cores
e.g. DYNAMICO at IPSL

Low resolution Aquaplanet with full physics

At 1/3°
28 SYPD
184 000 cores

Other approach:
UK Metoffice
« Separation of concerns »
LFRic project

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Multiple Types of Storage & Data Interaction

Multiple Roles, at least:
Model Developer, Model Tinkerer, Expert Data Analyst, Service Provider, Data User

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INFRASTRUCTURE FOR THE EUROPEAN NETWORK FOR EARTH SYSTEM MODELLING

Multi-model analysis platforms

ESGF data nodes

Exabyte before Exaflops !

Overpeck et al. (Science 2011)

Tsengdar Lee, Icas17

Data workflow:

- Parallel IO (e.g. XIOS)
- « on the fly » processing
- Compression
- Reduction of data
- Computing near data

Conclusions

Climate models: at the core of climate information for mitigation and adaptation
But also needed for understanding

A range of model configurations will be needed

From high to very-high resolution

> shorter time scales and high regional information

To lower resolutions with large ensembles, multi-models, complexity, long-term variability

> to address uncertainties and understanding

Both approaches needed and complementary

Data and computing challenges:

HPC: prepare for future architectures although using legacy codes, ensemble of codes, complex workflows and having international production runs

Data: from managing large amounts of data near HPC to ease a wide access to large multi-model ensembles

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