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Modelling Climate Change

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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

2021: +1.11° 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)

COP21
Limit to 2°

4.4°C
3.3 - 5.7

2.7°C
2.1 – 3.5

1.4°C
1.0 - 1.8

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 CO_2 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)

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

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

Downloaded data volume over IS-ENES2 and IS-ENES3 from European ESGF data nodes (Apr 2013 – Feb 2022)

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ca 7000 distinct users/month

IS-ENES2

From dashboard at CMCC

IS-ENES3

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

From understanding to informing society
Modelling & Observations

Multiscale interactions

From Stammer et al. 2018

Climate models
Spatial resolution of 100-200 km
down to 25 km at best for CMIP6

Infrastructure Strategy Roadmap 2012-2022

Mitchell et al., 2012
Joussaume et al., 2017

Resolution:
Resolution x 2 -> Computing x 8

Complexity :
carbon cycle, aerosols, chemistry, biosphere (x 5-10)

Duration: need for long simulations
Multi-decadal to multi-centennial (> 5 SYPD)

Ensemble size: document internal variability, quantify uncertainties (x 10 -30)

Spatial resolution

Key for regional patterns

PRIMAVERA HighResMIP

Bias in precipitation variability
Danubius river

Simulated tropical cyclones
Roberts et al. (2015)

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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
ICON 2.5 km:
6 Simulated Days Per Day on 12,960 cores (2019)
ICON (5 km)
0.66 Simulated Years Per Day on 387 Juwels Booster NVIDIA nodes (2021)

4 August, initialised 1 Aug 2016

Change in surface temperature of the Earth

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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)

Preparing for future complex architectures

Revisiting dynamical cores
e.g. DYNAMICO at IPSL

DSL approach: « Separation of concerns »
DSLs (2 approaches: UK, CH)
e.g. UK Met Office (LFRic project)

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

7th ENES HPC Workshop
9-11 May 2022 at Barcelona Supercomputing Center

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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