Introduction to climate modelling

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04/11/2020

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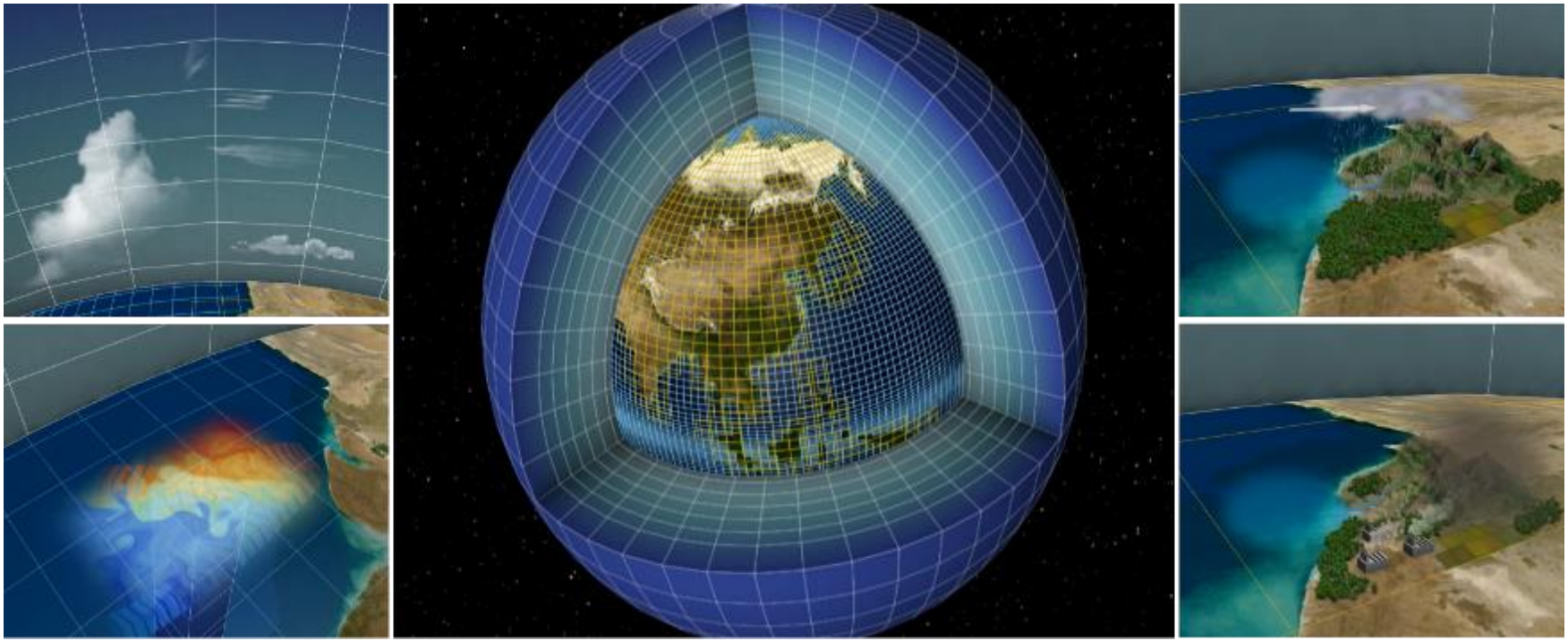
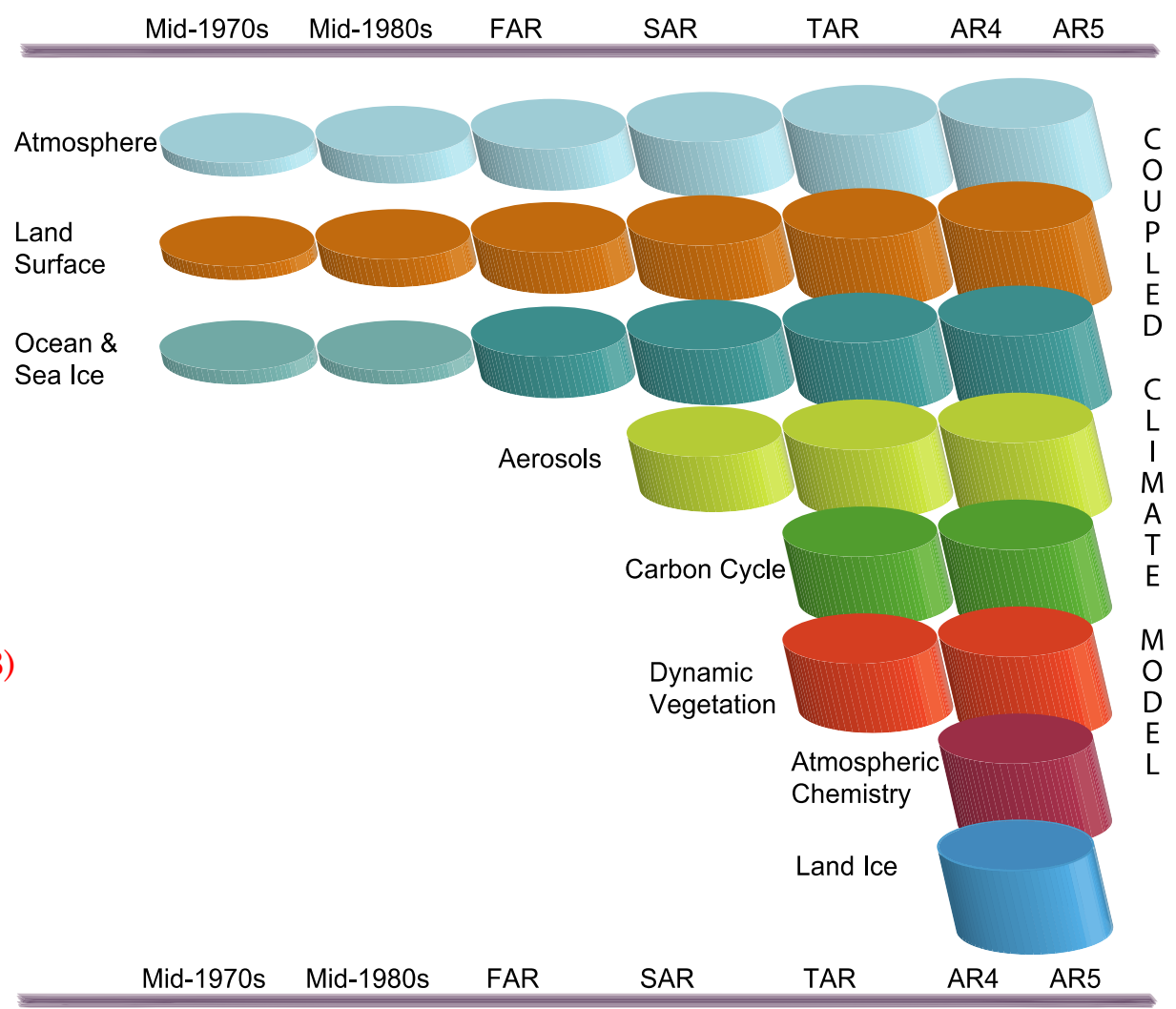
Modelling the Earth's climate system

Understand & Predict Climate Variability and Changes

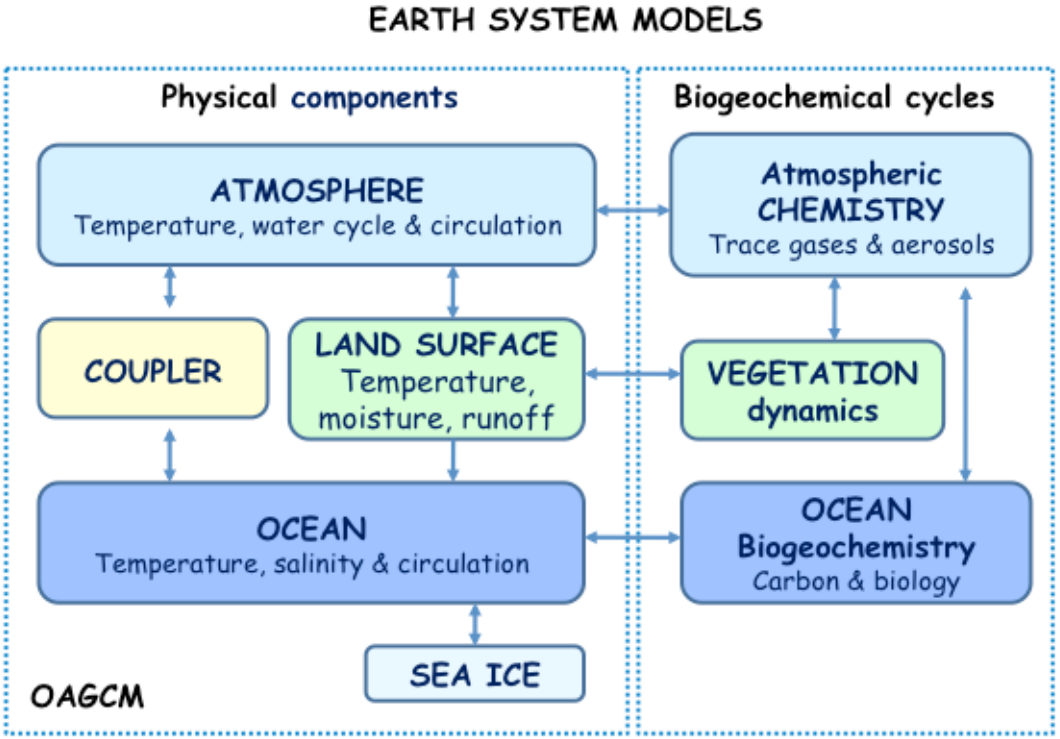


Evolution of climate models



IPCC AR5, WGI, Chap 1 (2013)

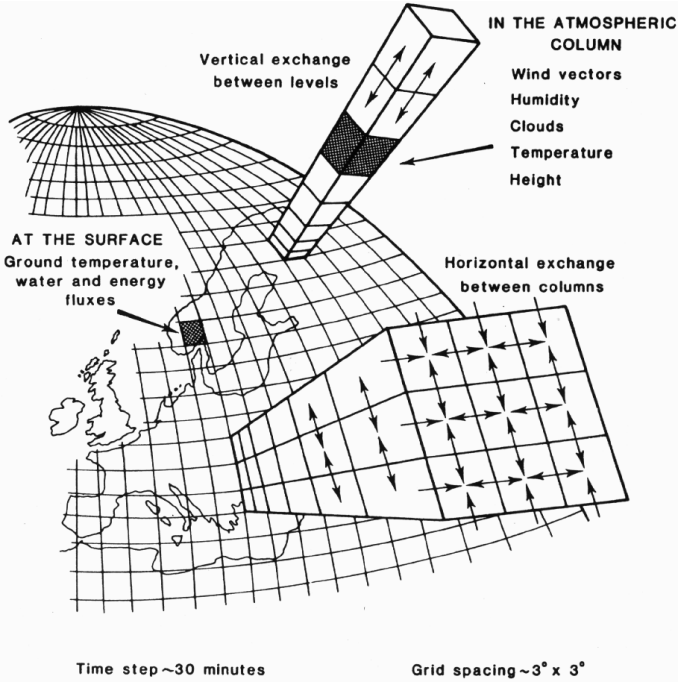
Earth system models (ESM)

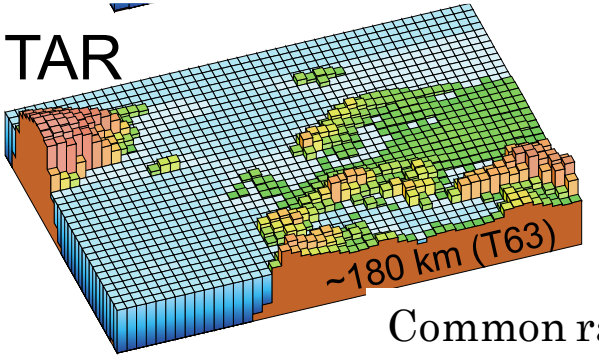


Basic physical laws
Based on Navier-Stokes
Conservation of:
energy,
mass (air, water, carbon)
&
Parameterisations
clouds, radiation, surface fluxes
subgrid-scale processes
(eddies, bound. layer turbulence)

each ESM
> 1000 man years:
strong legacy

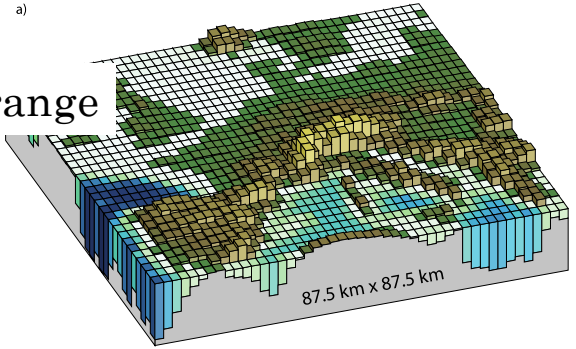
Spatial resolution

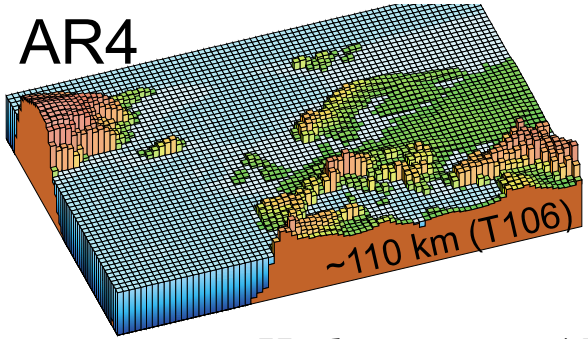




a)

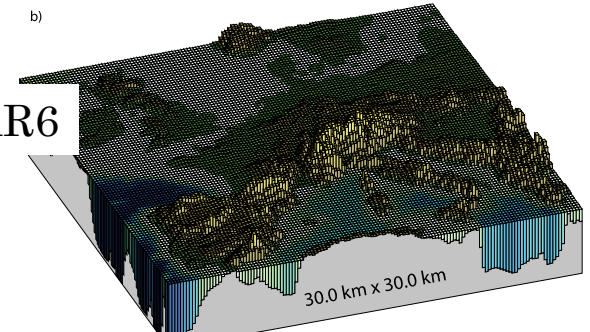
Common range



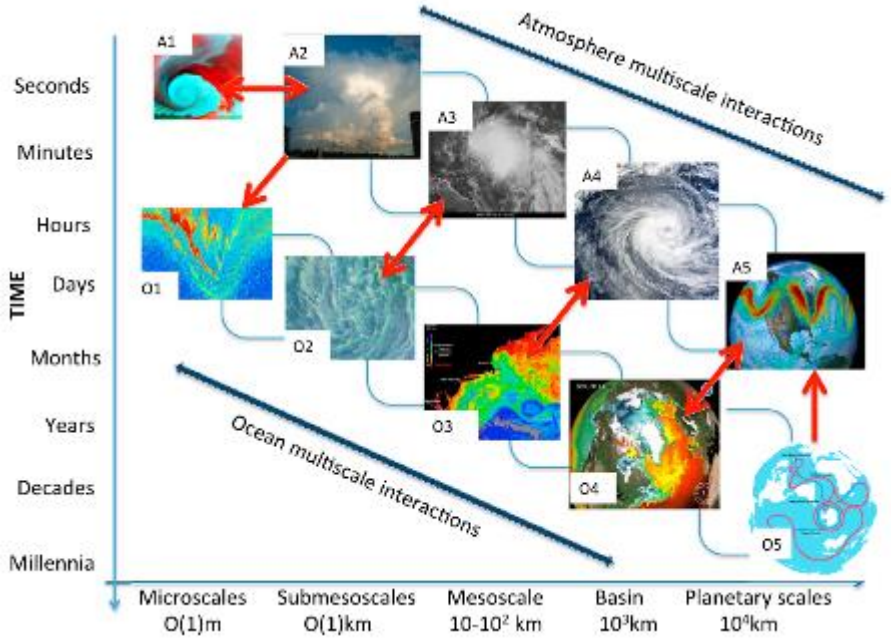


b)

Highest range AR6



Multiscale interactions



From Stammer et al. 2018

High-performance computing
Ca > 5 Simulated Years per Day

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

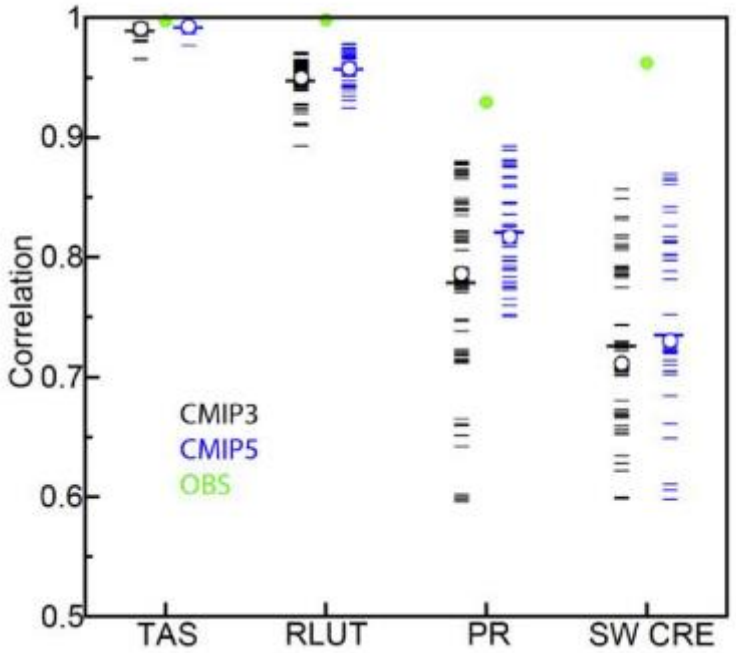
Model evaluation: comparisons with observations

Pattern correlations between models and observations
Annual 1980-1999

Ensemble mean

Median

IPCC AR5 WGI, Ch 9



Surface air temperature

Precipitation

LW outgoing radiation

SW cloud radiative effect

Models ca 2005
CMIP3

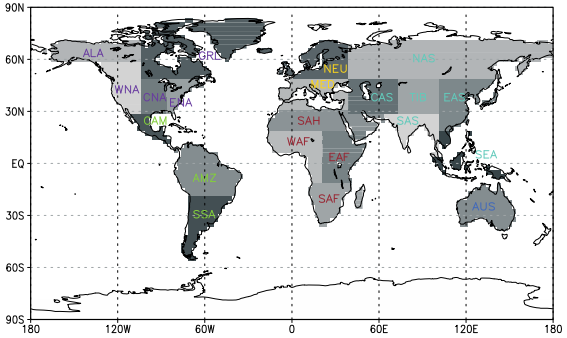
Models ca 2012
CMIP5

OBS other set of observations

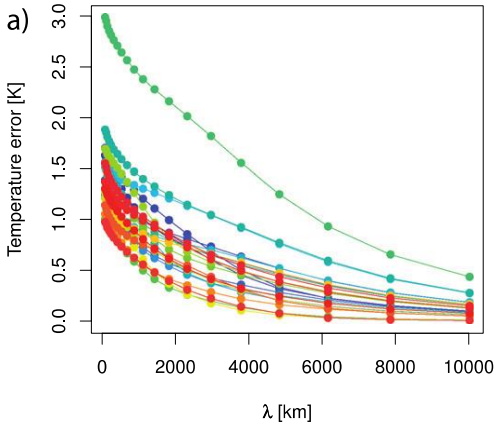
Good performance at large regional scale/ weak at smaller scale

Sillmann et al, JGR, 2013

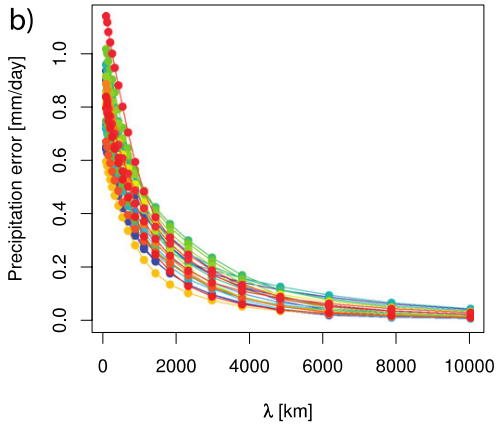
CMIP3 & CMIP5
1981-2000

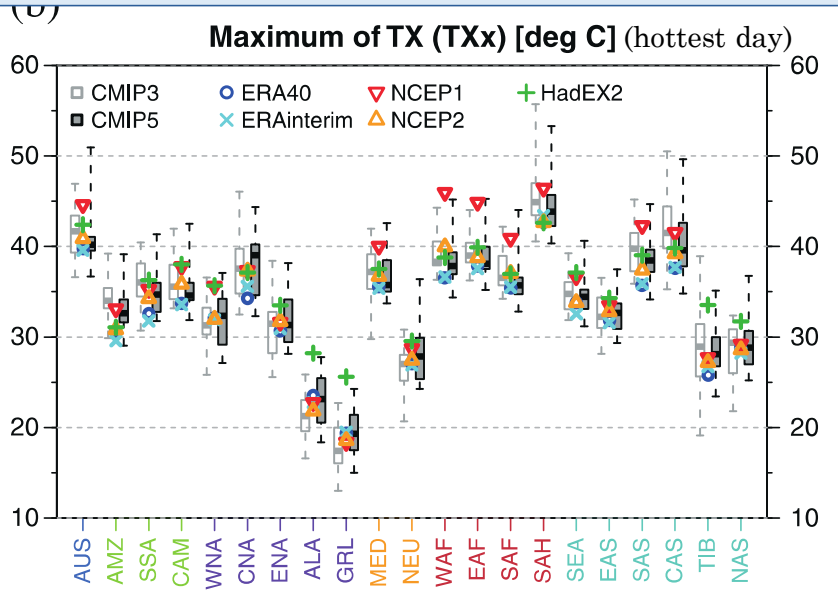


Temperature error



Precipitation error



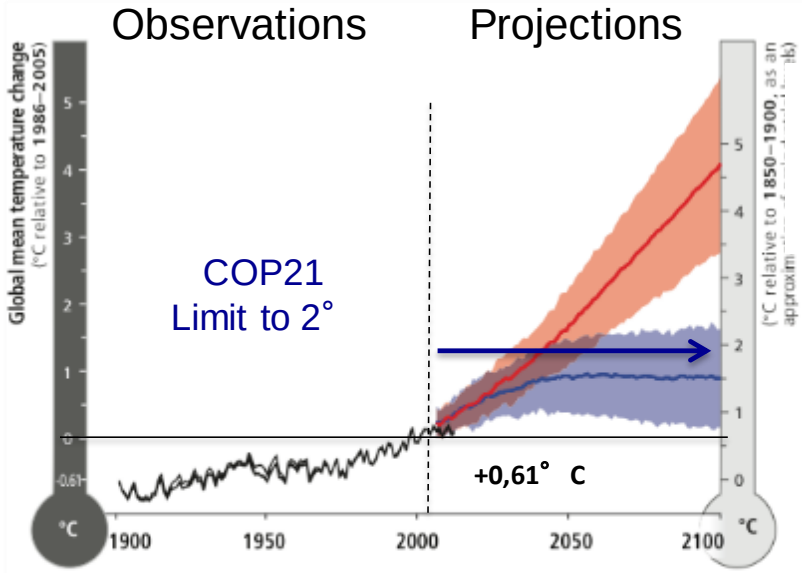


Masson & Knutti, J. Clim. (2011)

CMIP3
Versus ERA 40/CMAP
1980-1999 annual means

Smoothing scale

Simulations of future climate change under different scenarios

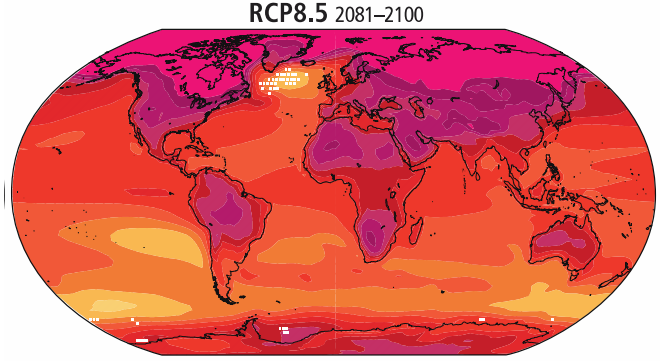


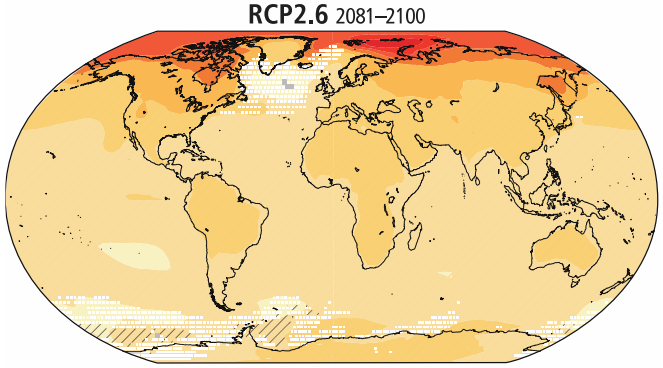
4,8° C

2,6° C

1,7° C

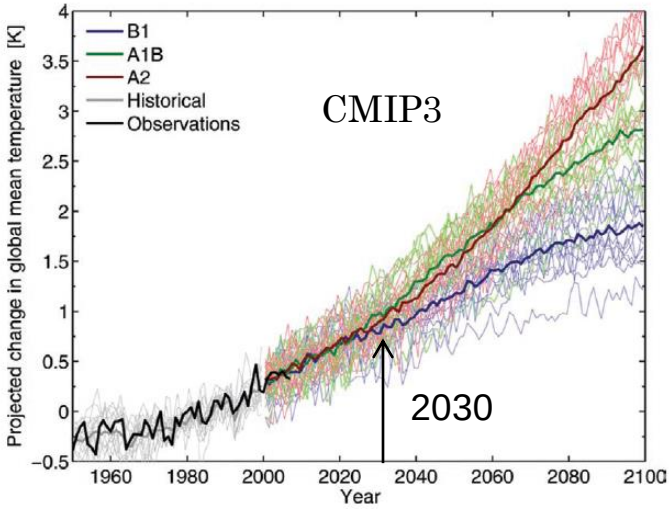
0,3° C





IPCC AR5 (2013)

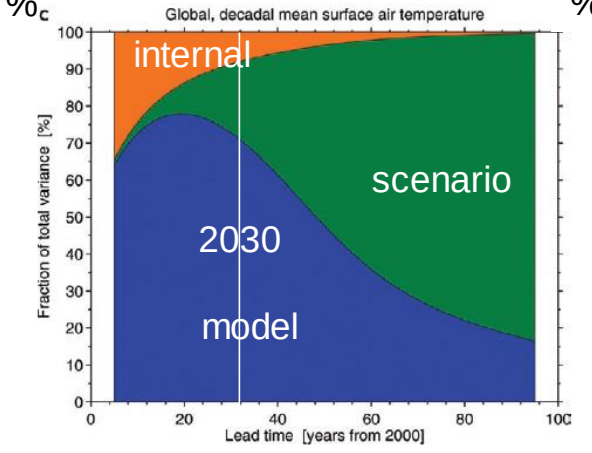
Model projections: Sources of uncertainties



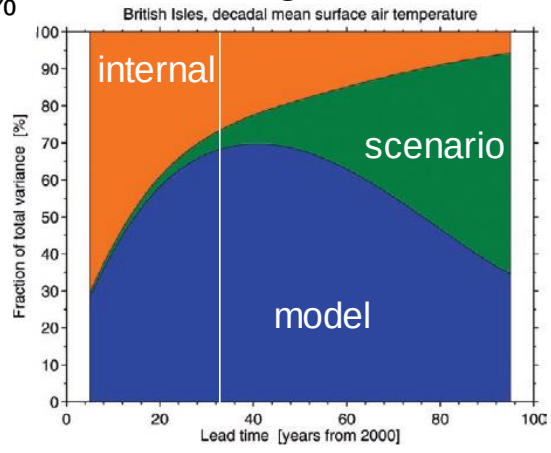
Internal variability
Socio-economic scenarios
Models

Hawkins and Sutton, BAMS, 2009

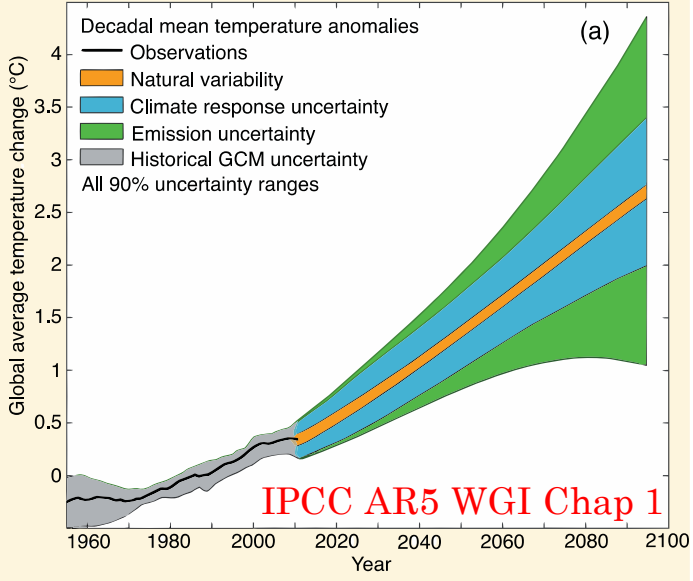
Global



Regional



Schematic diagram



Climate sensitivity and cloud feedbacks

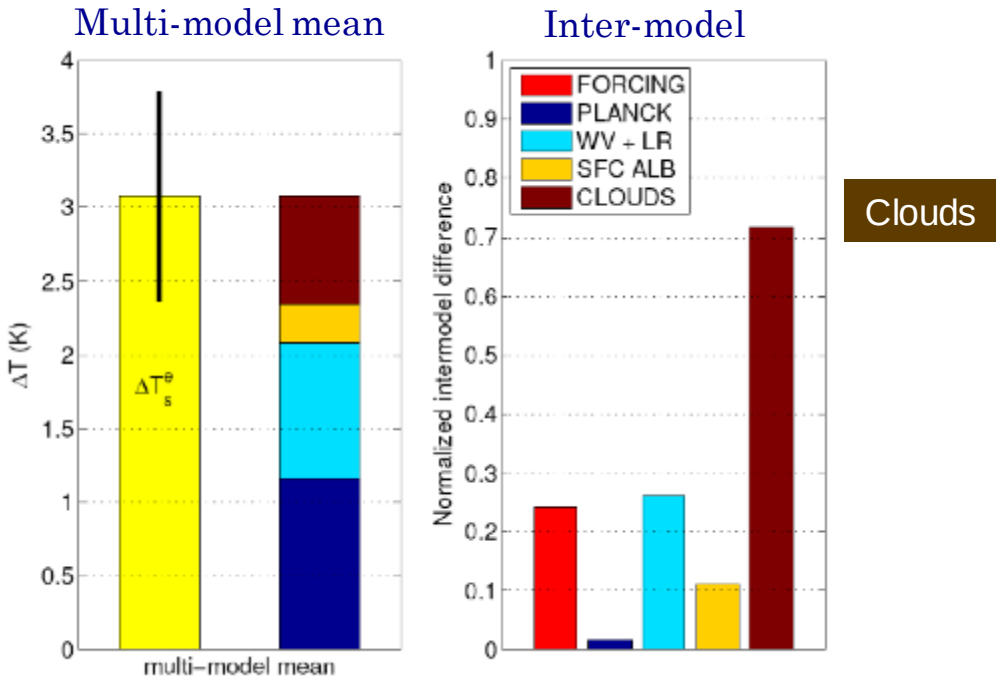
CMIP3 (AR4)

Mean: **3° C**

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

Dufresne & Bony, J. Climate, 2008

Temperature change to 2 x CO_2



CMIP
Coupled Model Intercomparison Project

1995 WCRP creation of the Working Group on Coupled Modelling

Foster the development and review of coupled models

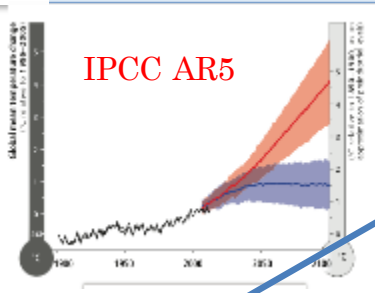
CMIP Launched in 1995 - Mainly control runs
CMIP2: Launched in 1997 – Idealised experiment 1%/year increased CO2
0.5 TB - Data accessible only on subproject basis - IPCC TAR (2001)

CMIP3: more realistic past (20th) and future simulations (scenarios) **- IPCC AR4 (2007)**
36 TB of data at PCMDI – open and free non commercial
Limitations: different model versions for CMIP and other MIPs (eg Paleoclimates PMIP)

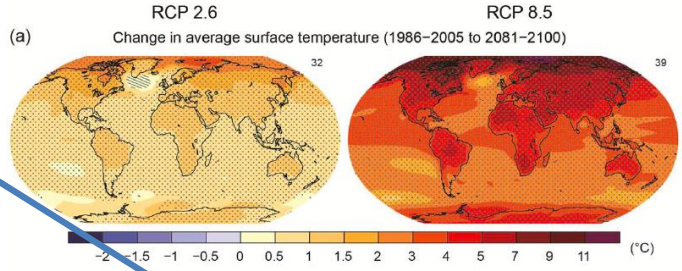
CMIP5 (2008-2013): consistent set for all experiments - **IPCC AR5 (2013)**
1.5 PB of data – ESGF – open data (very few closed for non commercial)
Difficulties: all experiments with same model version / very heavy

CMIP6 (2014-2019) common core simulations and more independent MIPs **- IPCC AR6 (2020)**
New approach: Allows a better involvement of the community in the design
9 PB of data – ESGF – open data

International coordinated experiments CMIP



Projections & Predictions



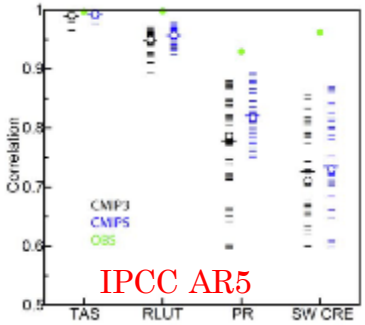
CMIP

Evaluation

Mechanisms

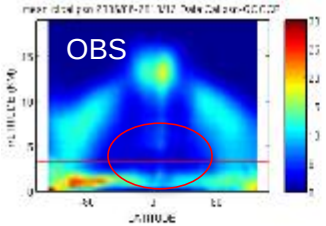
obs4MIP
ana4MIP

Pattern correlation with observations

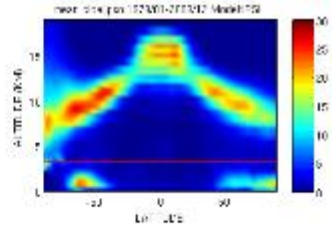


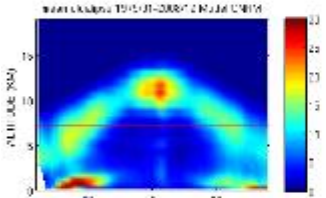
Observations
CALIPSO-GOCCP

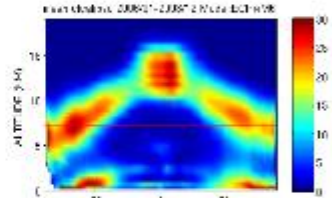
CFMIP



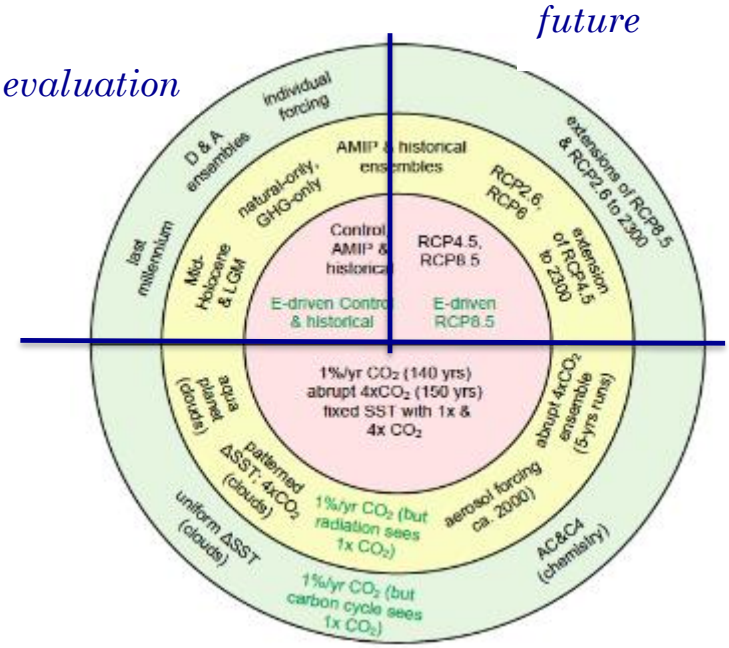
Models





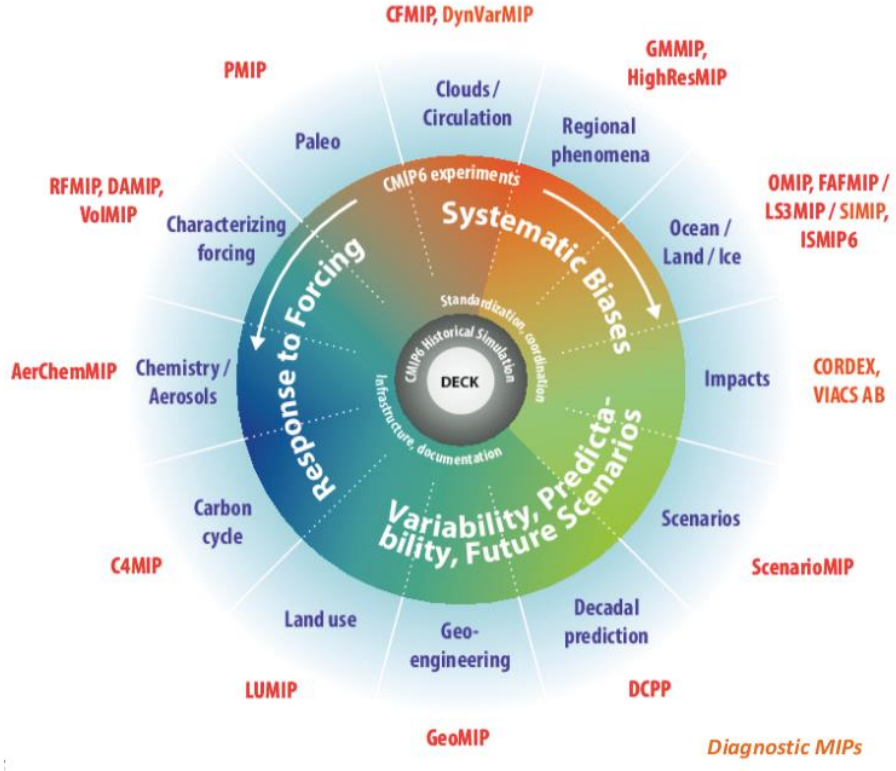


CMIP5
Basis for AR5



Projections and near-term predictions

21 CMIP6-Endorsed MIPs



Meehl et al., EOS, 2014

Status of CMIP5 experiments

28 modelling groups
61 models

1 Canada

CCCma	CanAM4 CanCM4 CanESM2
NSF-DOE-NCAR	CESM1(BGC) CESM1(CAM5) CESM1(CAM5.1, FV2) CESM1(FAST CHEM) CESM1(WACCM)
NCAR	CCSM4
NOAA GFDL	GFDL-CM2.1 GFDL-CM3 GFDL-ESM2G GFDL-ESM2M GFDL-HIRAM-C180 GFDL-HIRAM-C360
NASA GMAO	GEOS-5
NASA GISS	GISS-E2-H GISS-E2-H-CC GISS-E2-R GISS-E2-R-CC
COLA & NCEP	CFSv2-2011

6 USA

1 Brazil (with UK)

NCC	NorESM1-M NorESM1-ME
MPI-M	MPI-ESM-LR MPI-ESM-MR MPI-ESM-P
MOHC (with INPE)	HadCM3 Hadcm3Q HadGEM2-A HadGEM2-CC HadGEM2-ES
EC-EARTH	EC-EARTH
IPSL	IPSL-CM5A-LR IPSL-CM5A-MR IPSL-CM5B-LR
CNRM-CERFACS	CNRM-CM5 CNRS-CM5-2
CMCC	CMCC-CESM CMCC-CM CMCC-CMS
INM	INM-CM4

7 in Europe

1 Russia

4 Japan

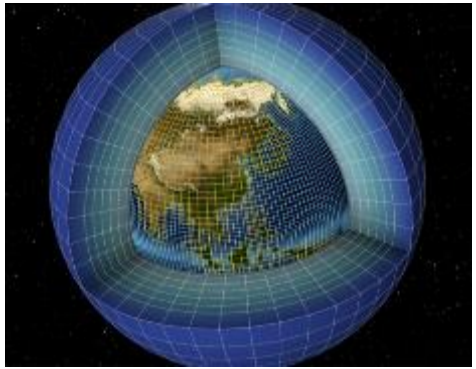
2 Australia

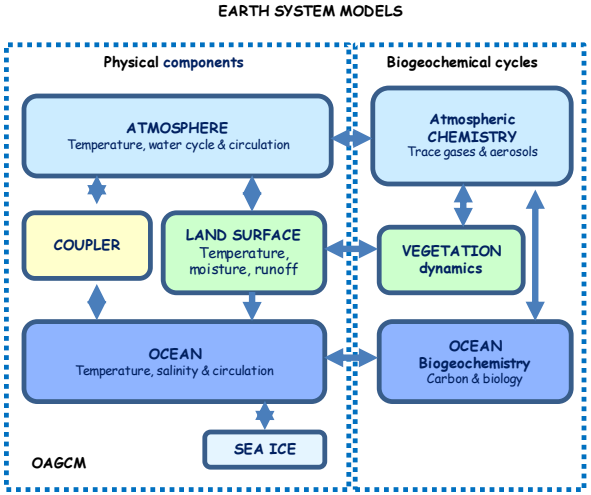
5 China / 1 Korea

LASG-IAP	FGOALS-gl FGOALS-s2
LASG-CESS	FGOALS-g2
GCESS	BNU-ESM
FIO	FIO-ESM
BCC	BCC-CSM1.1(m) BCC-CSM1.1
NIMR/KMA	HadGEM2-AO
NICAM	NICAM.09
MRI	MRI-AGCM3.2H MRI-AGCM3.2S MRI-CGCM3 MRI-ESM1
MIROC	MIROC-ESM MIROC-ESM-CHEM
MIROC	MIROC4h MIROC5
CSIRO-QCCCE	CSIRO-Mk3.6.0
CSIRO-BOM	ACCESS1.0 ACCESS1.3

Earth System modelling in Europe

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





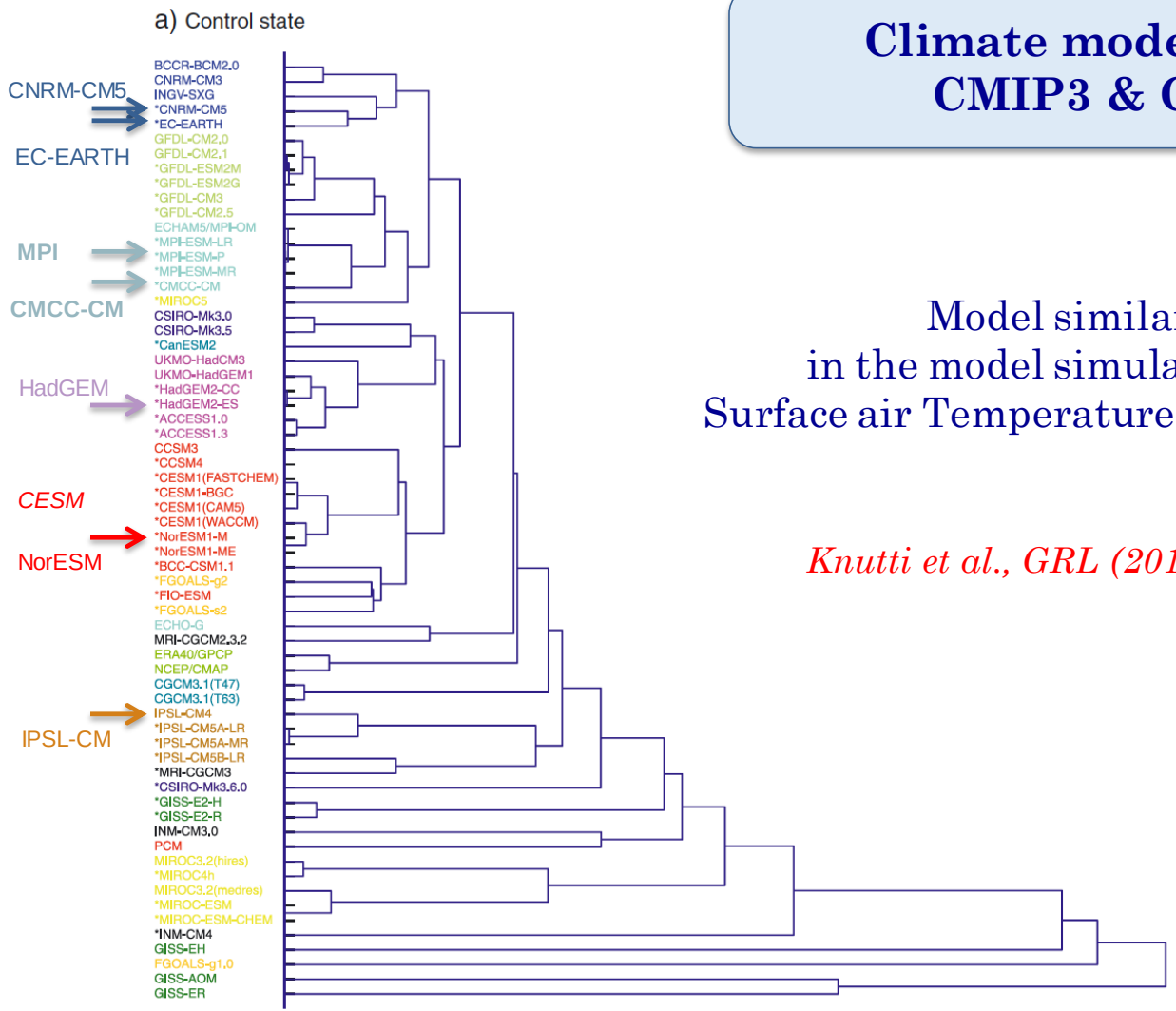
http://enes.org

Status CMIP5 2012

Country	name of model (CMIP5)	Atmosphere	Ocean	Sea Ice	Coupler	Land Surface *Vegetation	Atmospheric Chemistry	Ocean Bio-geochemistry
Consortium	EC-EARTH	IFS	NEMO	LIM	OASIS	HTESSEL	TM5	
France	IPSLCM5	LMDz	NEMO	LIM	OASIS	ORCHIDEE	INCA	PISCES
France	CNRM-Cerfacs	ARPEGE	NEMO	GELATO	OASIS	SURFEX		
Germany	MPI-ESM	ECHAM5	MPIOM	MPIOM	OASIS	JSBACH*	HAM	HAMOCC
Italy	C-ESM	ECHAM5	NEMO	LIM	OASIS	SILVA		PELAGOS
UK	HadGEM2	UM	UM	CICE	OASIS	TRIFFID*	UKCA	diat-HADOCC
Norway	NorESM	NCAR	MICOM	CICE	CPL7	CLM	Chemistry	HAMOCC

EC-Earth Cor Netherlands, Sweden, Ireland, Denmark, Spain, Portugal, Italy, Belgium

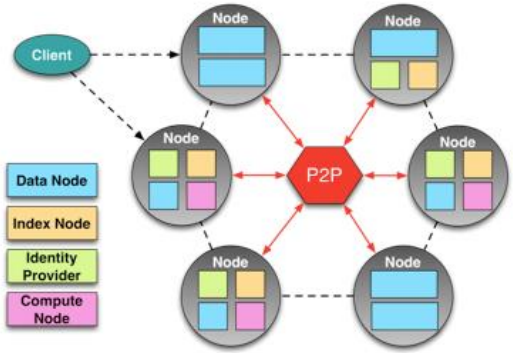
Climate model genealogy
CMIP3 & CMIP5 (*)



Model similarity
in the model simulated fields:
Surface air Temperature & Precipitation

Knutti et al., GRL (2013)

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 source software, common data and metadata standards

International, Community led : GO-ESSP, WIP

Multi-agencies support: *DOE, NOAA, NASA, IS-ENES, NCI*

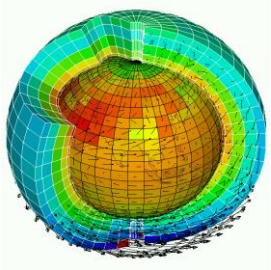
Climate projections @ climate data store

Climate Change Service

opernicus Europe's eyes on Earth

Coordinated Regional Downscaling Experiments
CORDEX (dynamical & statistical)

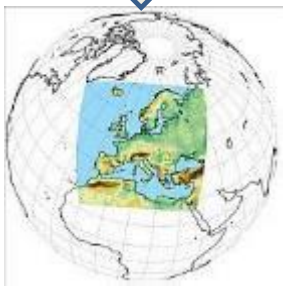
Dynamical downscaling



Global model

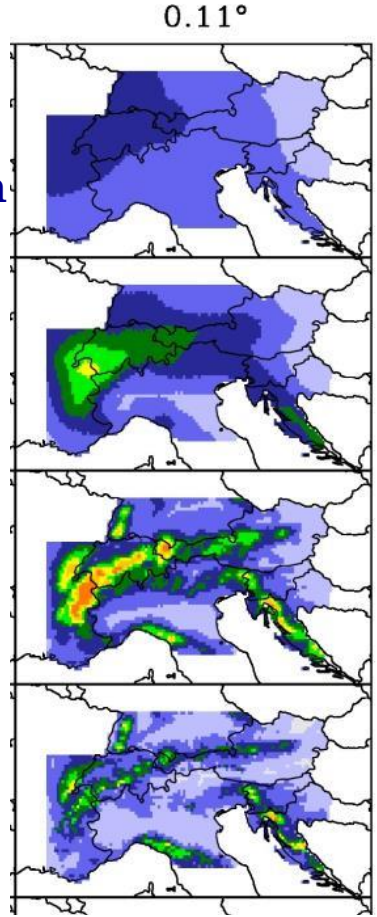
~100-200 km

~44 km



~12 km

Regional climate model



Precipitation
Over the Alps

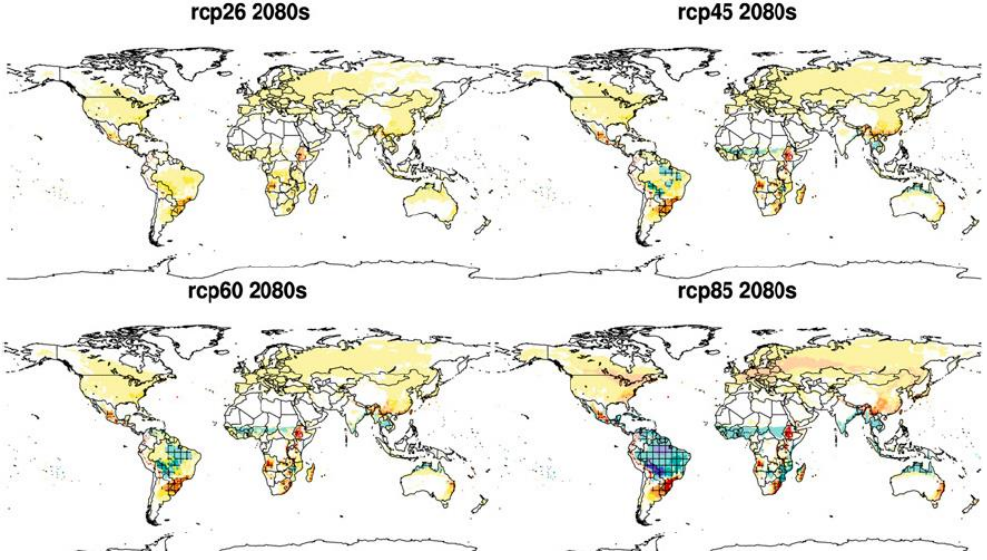
Torma et al., JGR, 2015

Impact models: use of bias corrected GCM simulations

Inter_Sectoral Impact MIP

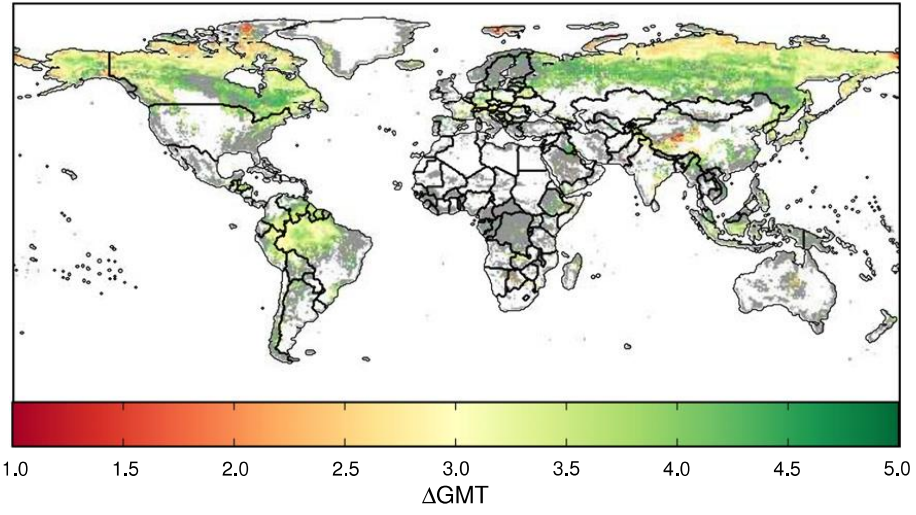
Warszawski et al. ERL (2013)

Impact on malaria distribution

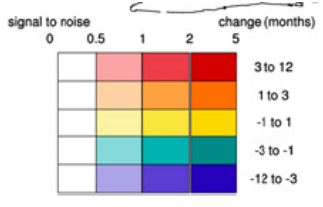


Temperature change at which ecosystems are at severe risk of change

ISIMIP from CMIP5



Caminade et al., PNAS (2013)

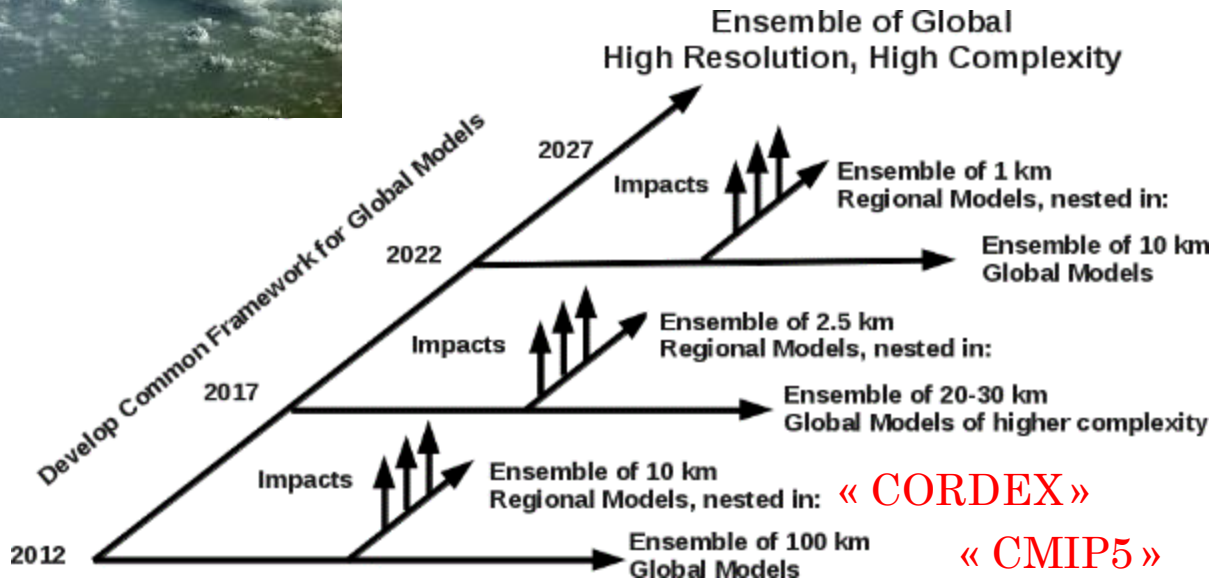


ENES Infrastructure Strategy Roadmap

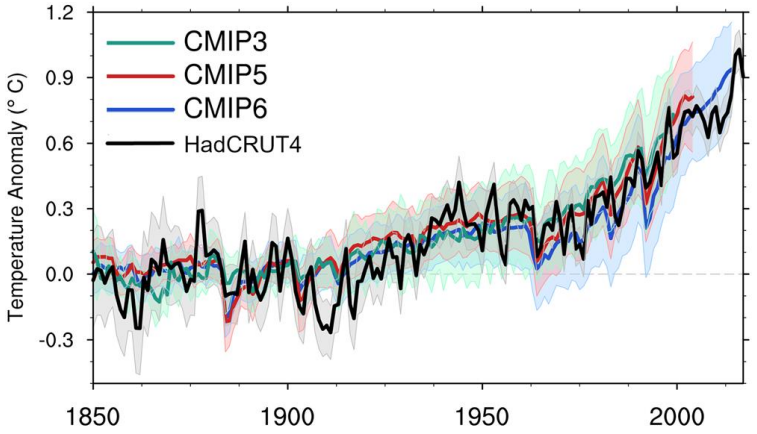
Mitchell et al., 2012; Joussaume et al., 2017

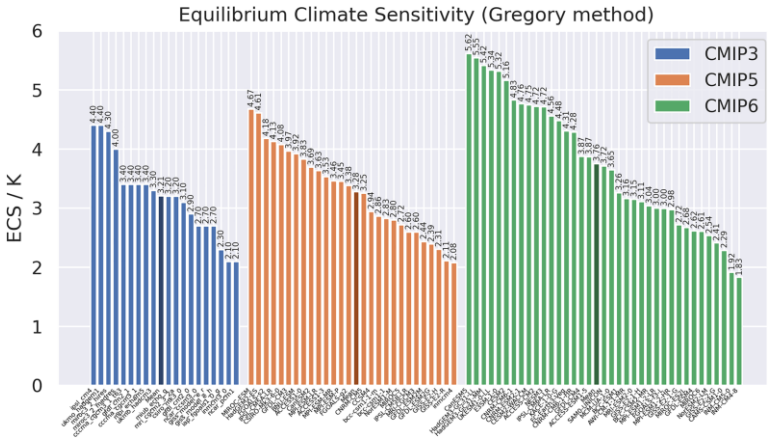
http://enes.org/

A grand challenge :
Towards ≈ 1 km scale for atmosphere
resolving deep convective clouds
in global climate models
Need to accelerate progress
in computing efficiency

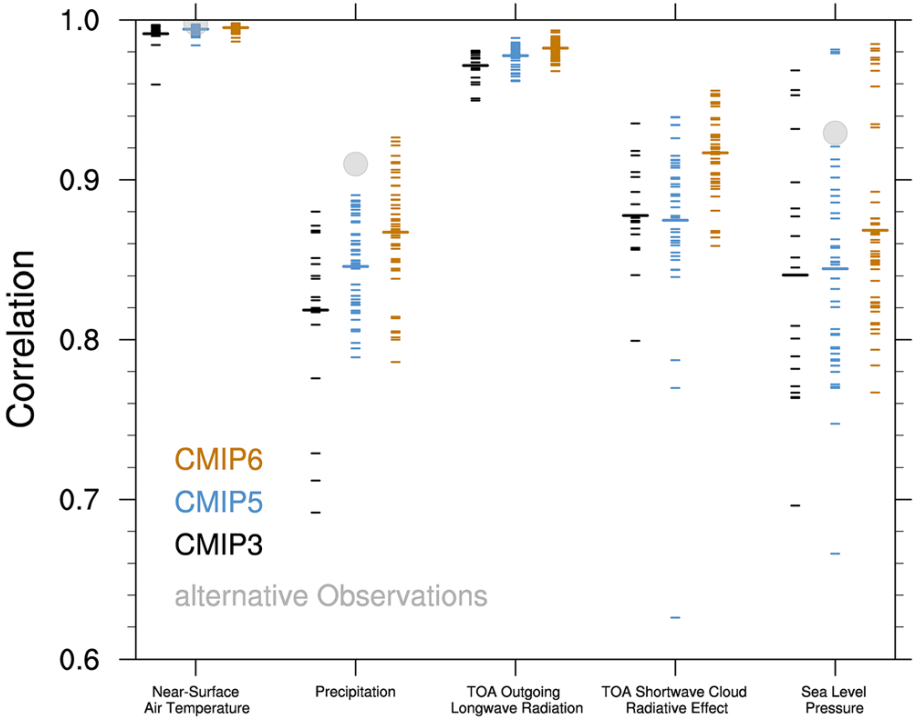


CMIP6 first results





Bock et al., JGR (2020)



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

  CMIP5 very well documented, CMIP6 now available
- Europe a key player in the international landscape (models and infrastructure)
- Grand challenge: towards very high resolution (key for adaptation) but also larger ensembles and better account for complexity

Climate models are at the core of climate information for society

Enjoy the IS-ENES autumn school !