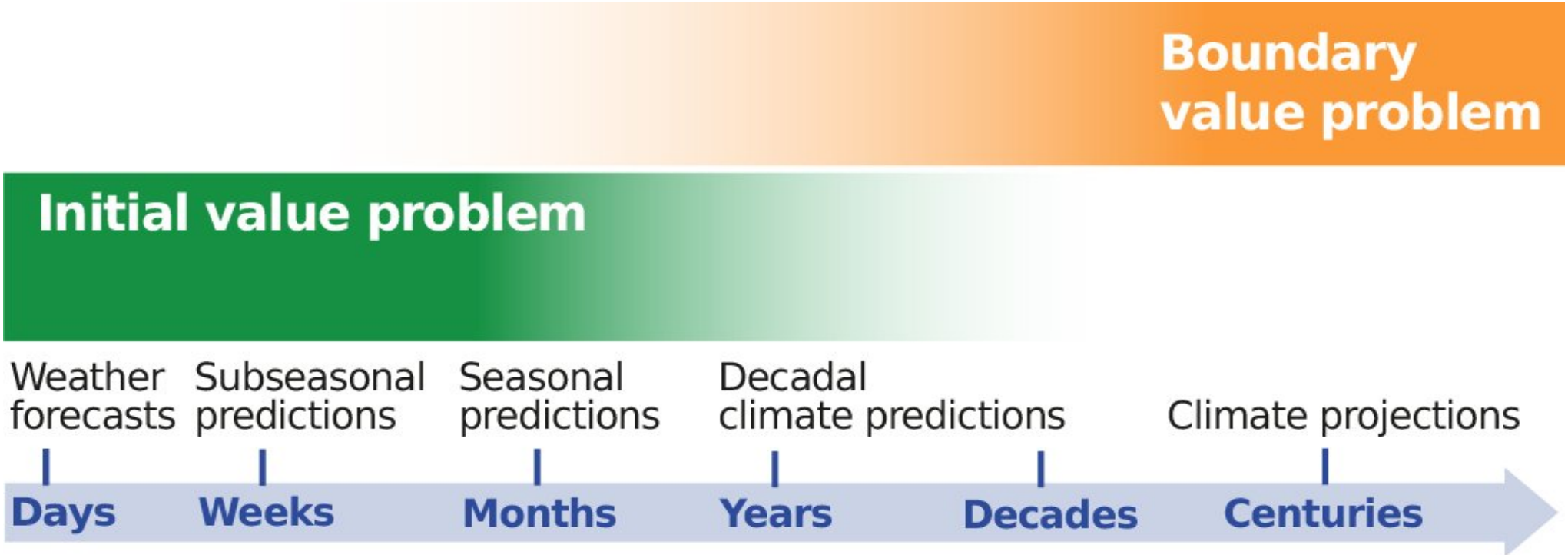
Fizyka procesów klimatycznych
Wykład 07

prof. dr hab. Szymon Malinowski
Instytut Geofizyki, Wydział Fizyki
Uniwersytet Warszawski
malina@igf.fuw.edu.pl

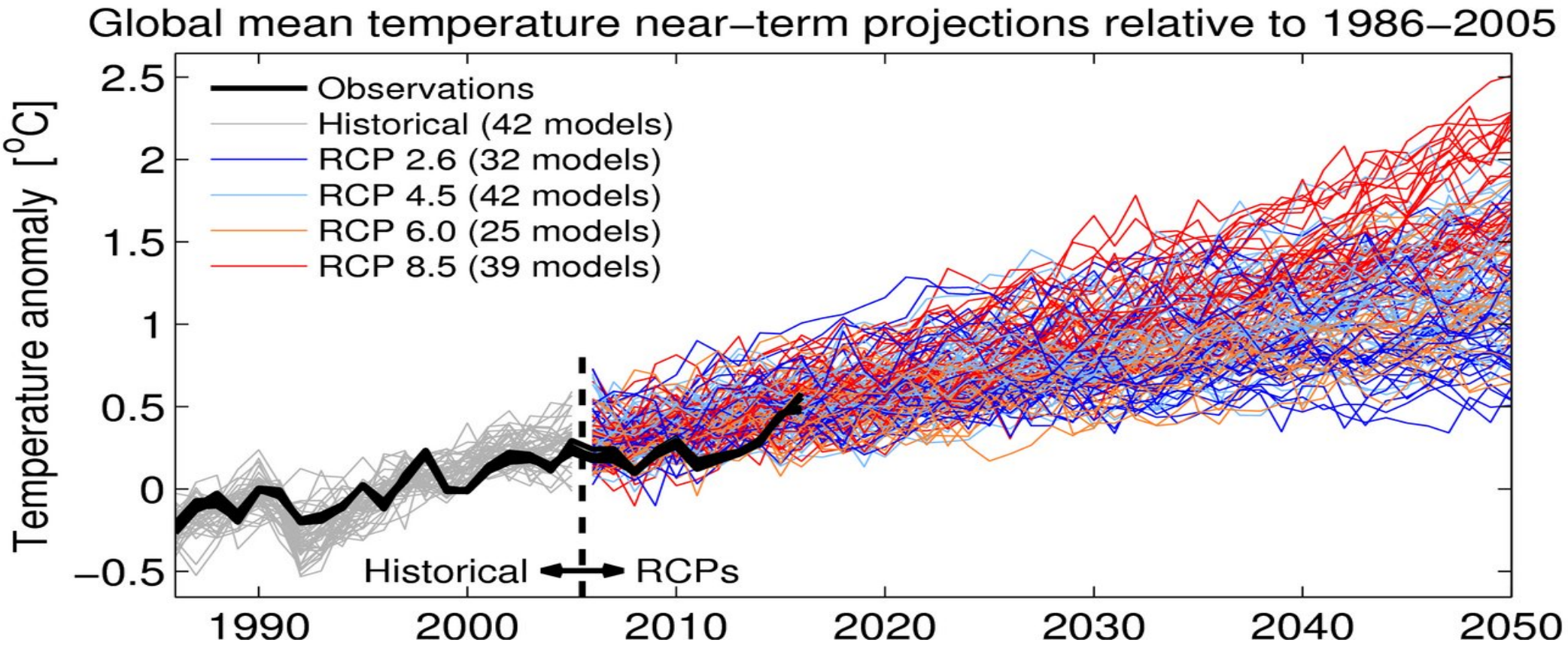
dr hab. Krzysztof Markowicz
Instytut Geofizyki, Wydział Fizyki
Uniwersytet Warszawski
kmark@igf.fuw.edu.pl



szczegóły przepływów - bilans energii
procesy „szybkie” - procesy „wolne”

oddziaływania między procesami lokalnymi i szybkimi
a globalnymi i wolnymi

Przewidywalność klimatu: symulacje różnymi modelami



CMIP Overview

On this Page
What is CMIP?
History
CMIP Data

CMIP is a project of the World Climate Research Programme (WCRP). Members of the **CMIP Core Panel** are currently working on developing the design of CMIP phase 7 (CMIP7). **Task teams** have been created to bring in expertise from across the climate science community, each tackling a different aspect of the design. **Click here** for updates on CMIP7 and for the pages on the **CMIP7 task teams**. The data output for CMIP phase 6 (CMIP6) is available on the Earth System Grid Federation (ESGF). For more information on CMIP6, **click here**.

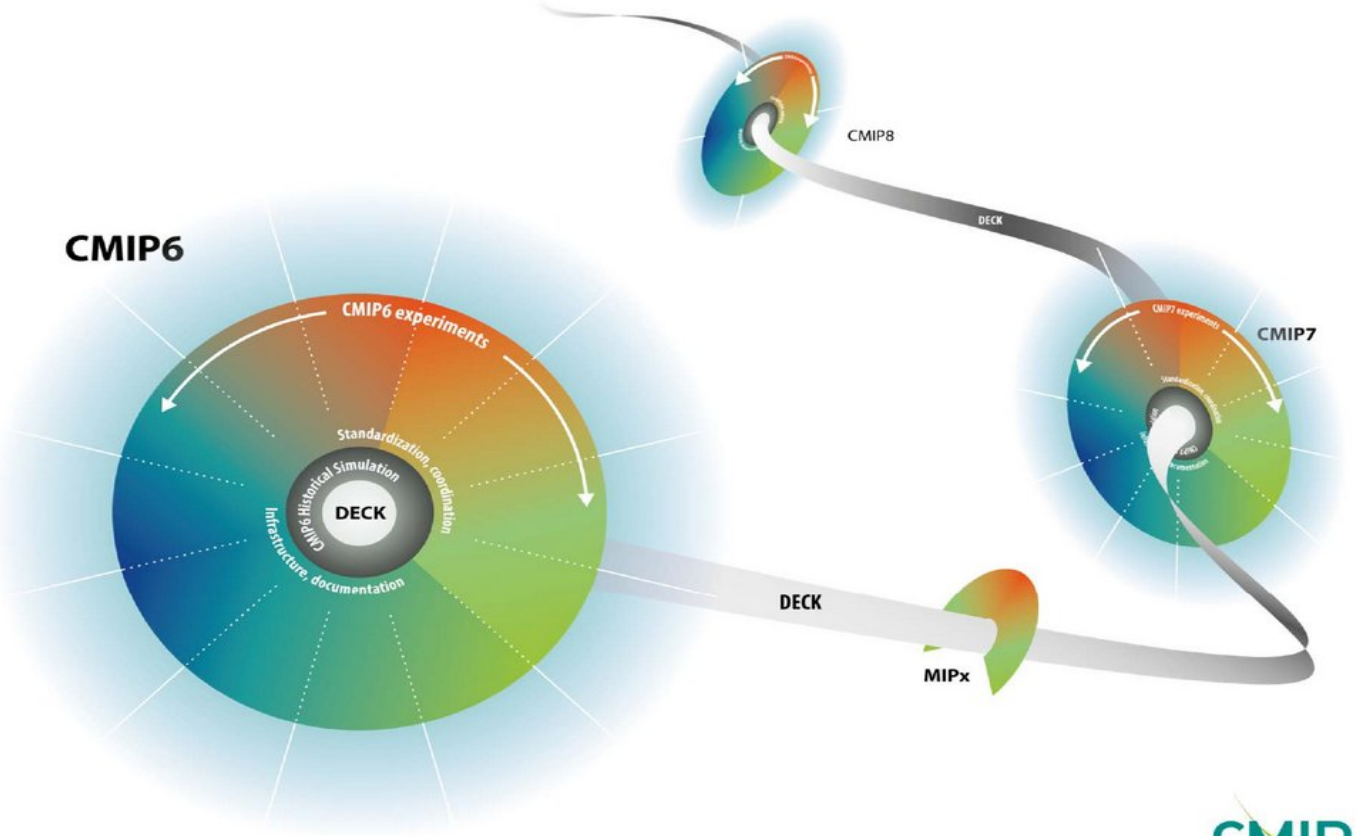
What is CMIP?

The Coupled Model Intercomparison Project (CMIP) is an international climate modelling project, designed to better understand past, present and future changes in the climate. A climate model is a complex computer code that creates a digital analogue to Earth. This model digitises the processes and interactions between parts of Earth's climate system: the atmosphere, ocean, land surface, cryosphere and biosphere. We use models to experiment how future changes in human activities will impact the Earth's future climate, how much it warms, how floods, droughts and other extremes will change. However, many processes in our climate occur on such small scales, that models are not able to exactly represent them in models, and therefore some simplifications are required. How we simplify the climate system is unique to each model. Therefore comparing simulations from different models is useful for understanding which results are consistent across models, and which results are less agreed upon. Since 1995, CMIP has been coordinating this model intercomparison across the climate science community. This multi-model approach helps to evaluate climate models, leads to improvements in the model simulations and provides a better understanding of past, present and future climates. One additional strength of CMIP lies in its global infrastructure which has gathered the data and gives open access for a growing global research community. CMIP has grown from a modest scientific research initiative in the early nineties to become a global enterprise: more than 50 modelling centres around the world are participating in the sixth phase of CMIP, CMIP6. Many hundreds of scientific papers have already been published and the results are taken into account for policy decisions. CMIP has been organised in different phases, each with new and improved climate model experiment protocols, standards, and data distribution mechanisms. **CMIP6** is the most recent phase to release its modelling output data for general use, whilst the latest phase, **CMIP7** is in its earliest organisational stages. CMIP is a project of the World Climate Researcher Programme (WCRP), providing climate projections to understand past, present, and future climate changes. It is part of the WCRP Earth System Modelling and Observations (ESMO) Core Project, which was formed to coordinate all modelling, data, and observation activities across WCRP and its key partners. Under the guidance and at the direction of the **Working Group on Coupled Modelling (WGCM)**, CMIP activities are overseen by a coordinated pair of subcommittees: the **CMIP Panel** and the **WGCM Infrastructure Panel (WIP)**. This continued collaboration of climate scientists has resulted in CMIP knowledge being extended across the world. As such, this website brings this together to provide a one-stop shop for key resources, events, news, and information for the CMIP community. If there is any information you cannot find on these webpages, please see our **FAQs** and **community-led Q&A forum**.

On this Page ↑

CMIP Continuity

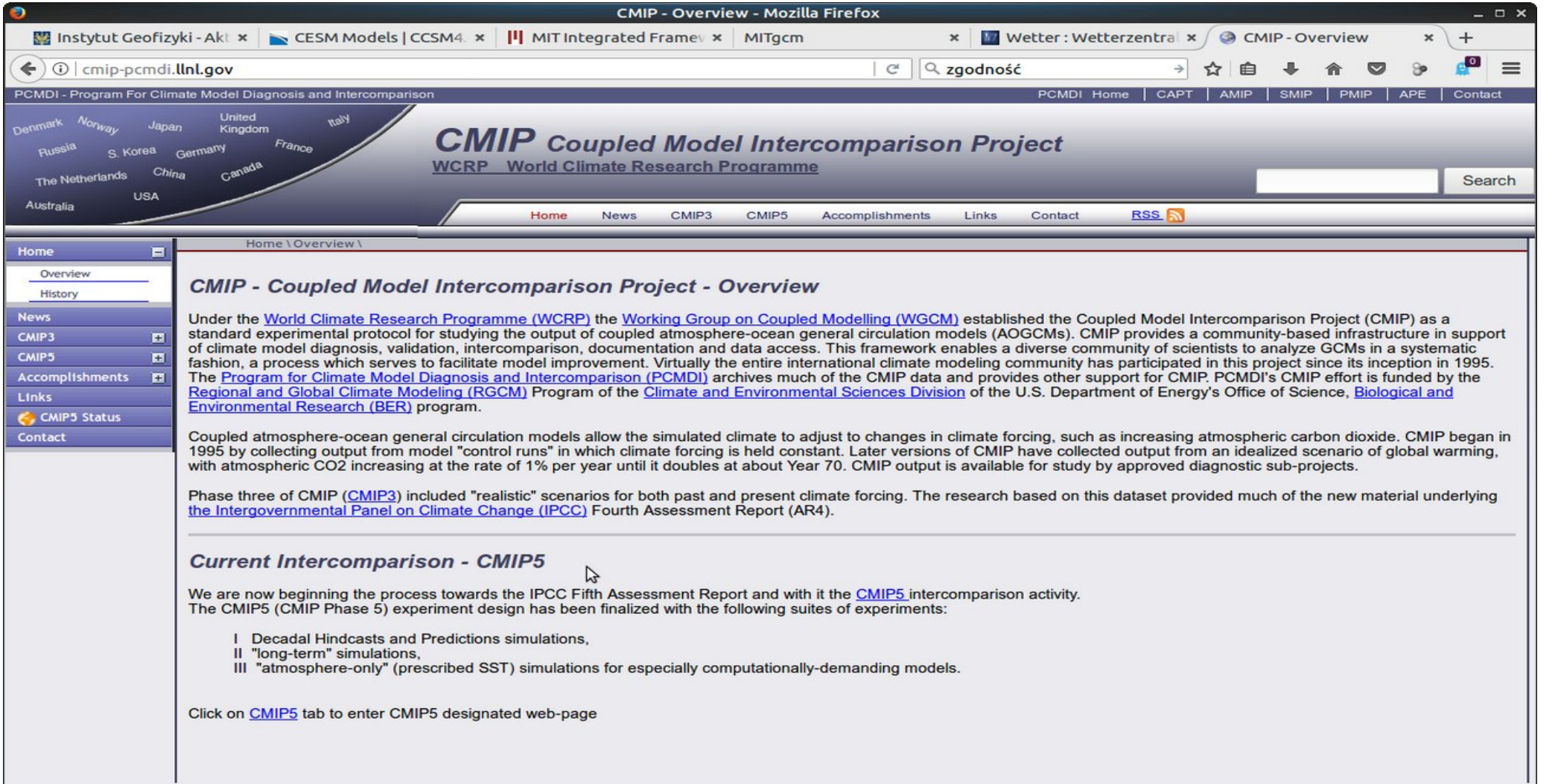
A common suite of experiments for each phase of CMIP provides an opportunity to construct a multi-model ensemble using model output from various phases of CMIP



Eyring et al., CMIP6 Experimental Design and Organization, GMD, 2016

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

Dostęp do wyników symulacji modelami klimatu jest otwarty



Coupled Model Intercomparison Project (CMIP)

- Understanding past, present and future climate -

- CMIP is a project of the World Climate Research Programme (**WCRP**)'s Working Group of Coupled Modelling (**WGCM**).
- Since 1995, **CMIP** has coordinated climate model experiments involving multiple international modeling teams worldwide.
- CMIP has led to a better understanding of past, present and future climate change and variability in a **multi-model framework.**
- CMIP defines **common experiment protocols, forcings and output.**
- CMIP has developed in phases, with the simulations of the fifth phase, CMIP5, now completed, and the planning of the sixth phase, i.e. CMIP6, well underway.

- CMIP's central goal is to advance scientific understanding of the Earth system.
- CMIP model simulations have also been regularly assessed as part of the IPCC Climate Assessments Reports and various national assessments.

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

CMIP6 Design: Scientific Focus

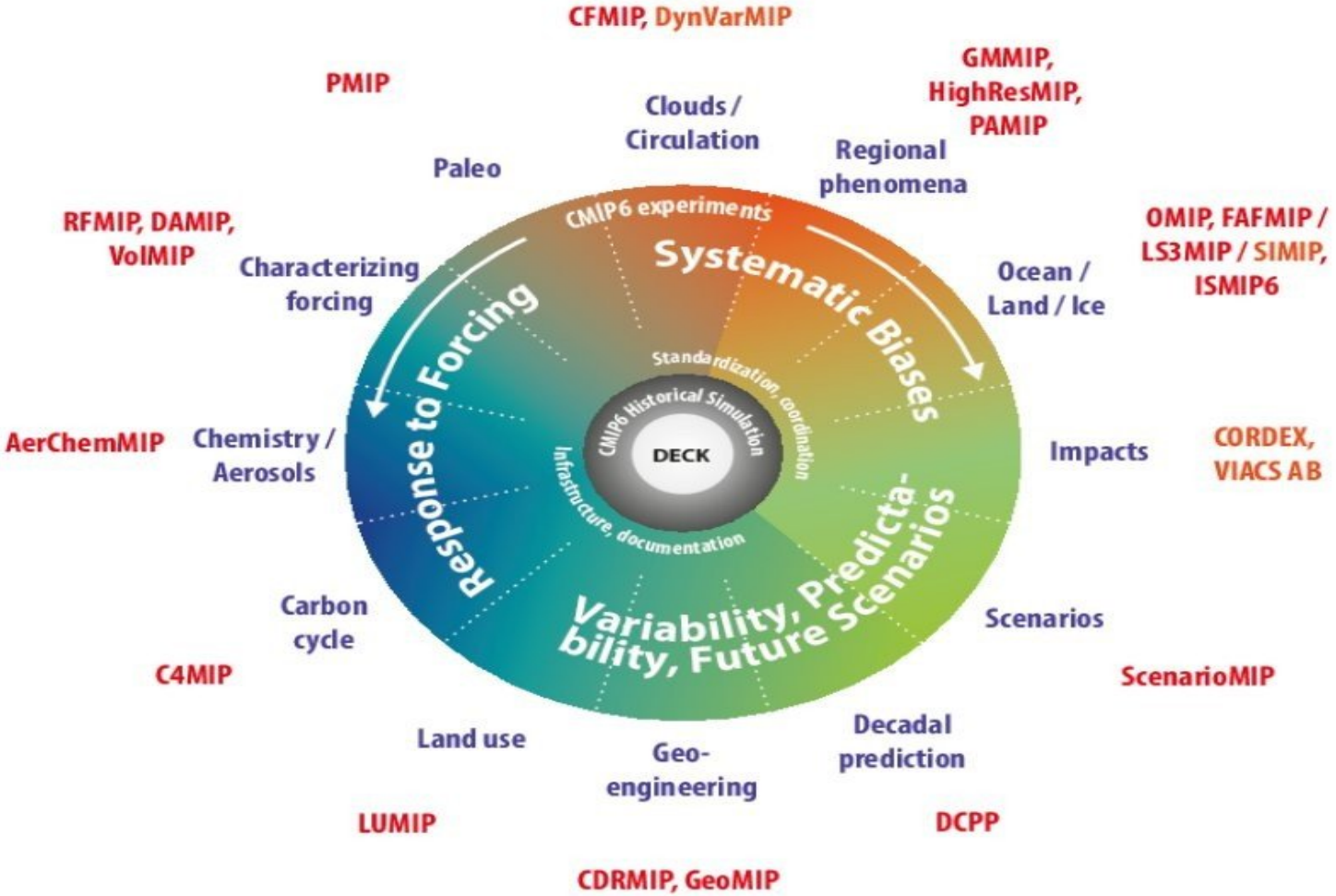
- The **scientific backdrop** for CMIP6 is the **WCRP Grand Science Challenges**:
  1. Clouds, Circulation and Climate Sensitivity
  2. Changes in Cryosphere
  3. Climate Extremes
  4. Regional Sea-level Rise
  5. Water Availability
  6. Near-Term Climate Prediction
  7. Biogeochemical Cycles and Climate Change
- The specific experimental design is focused on **three broad scientific questions**:
  1. How does the Earth System respond to forcing?
  2. What are the origins and consequences of systematic model biases?
  3. How can we assess future climate changes given climate variability, predictability and uncertainties in scenarios?

Eyring et al., GMD, 2016

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

23 CMIP6-Endorsed MIPs

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



CMIP6: Participating Model Groups

	Institution	Country		Institution	Country		Institution	Country
1	AWI	Germany	12	DOE	USA	23	MRI	Japan
2	BCC	China	13	EC-Earth-Cons	Europe	24	NASA-GISS	USA
3	BNU	China	14	FGOALS	China	25	NCAR	USA
4	CAMS	China	15	FIO-RONM	China	26	NCC	Norway
5	CasESM	China	16	INM	Russia	27	NERC	UK
6	CCCma	Canada	17	INPE	Brazil	28	NIMS-KMA	Republic of Korea
7	CCCR-IITM	India	18	IPSL	France	29	NOAA-GFDL	USA
8	CMCC	Italy	19	MESSY-Cons	Germany	30	NUIST	China
9	CNRM	France	20	MIROC	Japan	31	TaiESM	Taiwan, China
10	CSIR-CSIRO	South Africa	21	MOHC	UK	32	THU	China
11	CSIRO-BOM	Australia	22	MPI-M	Germany	33	Seoul Nat.Uni	Republic of Korea

New in CMIP:

2 new model groups from Germany (AWI, MESSY-Consortium)
4 new model groups from China (CAMS, CasESM, NUIST, THU)
1 new model group from Brazil (INPE)
1 new model group from India (CCCR-IITM)
1 new model group from Taiwan, China (TaiESM)
1 new model group from USA (DOE)
2 new model group from Republic of Korea (NIMS-KMA, SAM0-UNICON)
1 new model group from South Africa / Australia (CSIR-CSIRO)
==========

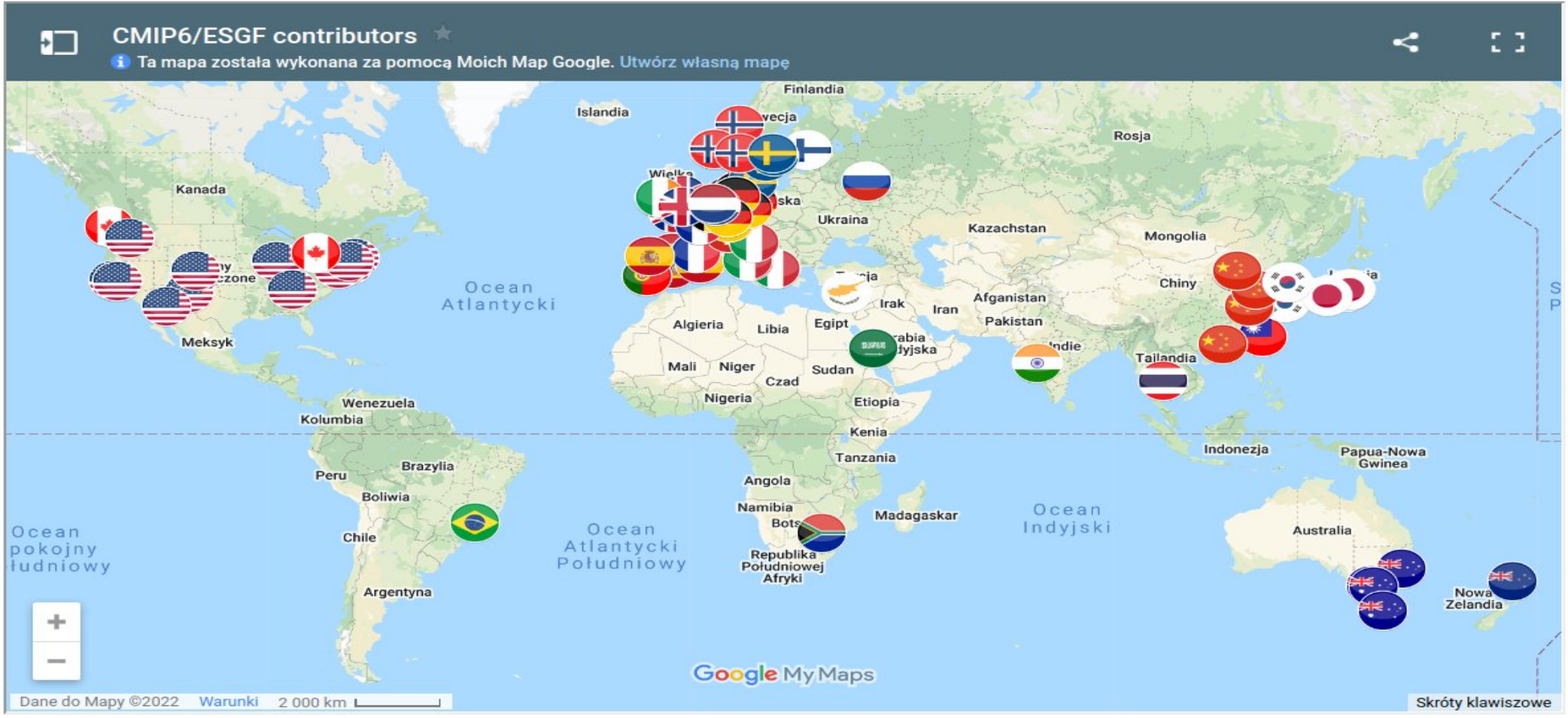
⇒ **13 new model groups so far**

More models (>70)
New models
More complex models
Higher resolution models

* Other models can join providing DECK and historical simulations are submitted

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

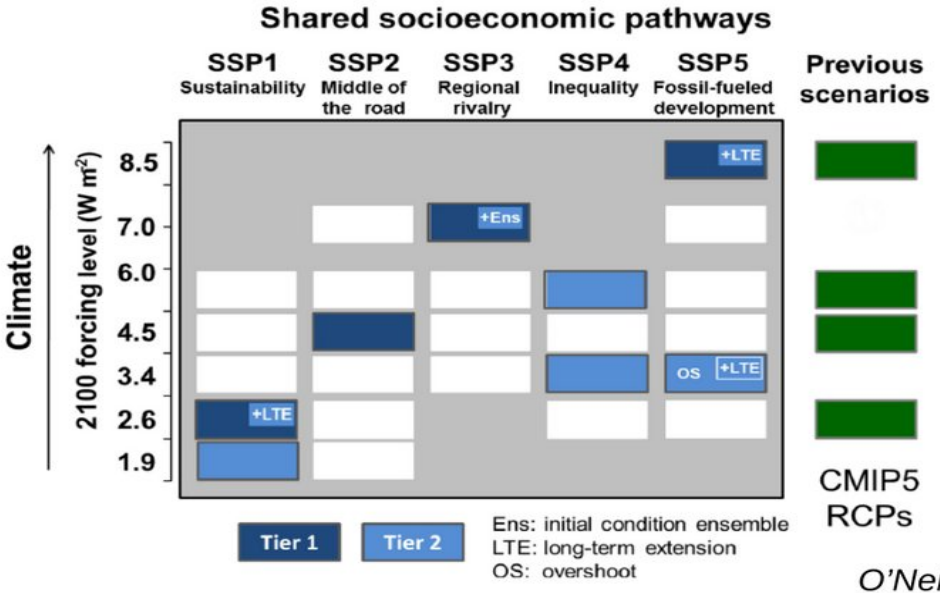
CMIP6 Modeling Groups (click on flags to reveal identity)

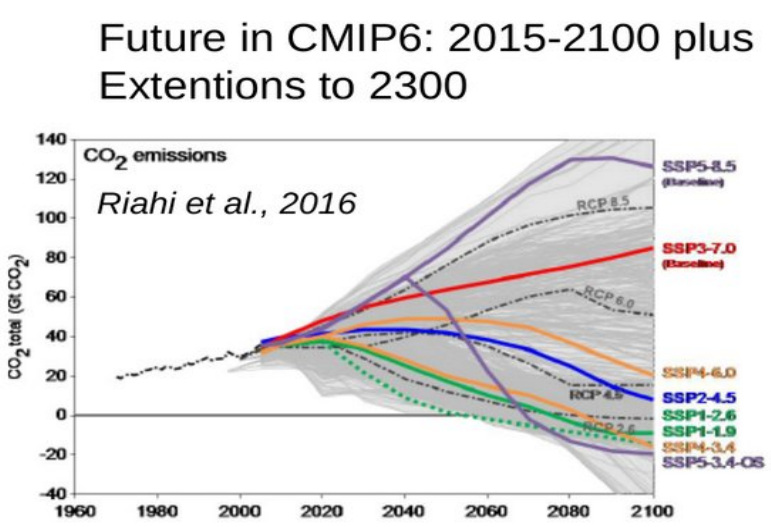


Document version: 13 February 2019

Key Messages: Model Projections / Predictions (2)

SSPs: set of baselines, with future developments in absence of new climate policies beyond those in place today





O'Neill et al., ScenarioMIP for CMIP6, GMD, 2016

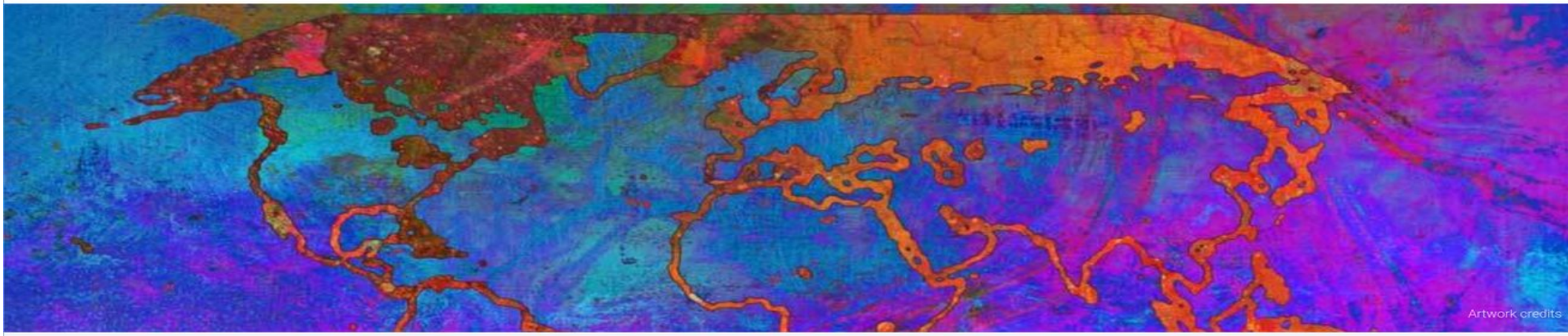
ScenarioMIP: New scenarios span a similar range as the RCPs, but fill critical gaps, including

- Role of specific forcings such as land use and short-lived species (air quality)
- The effect of a peak and decline in forcing,
- The consequences of scenarios that limit warming to below 2 °C,

DCPP: Improvements in models, reanalysis, methods of initialization and ensemble generation, and data analysis will provide extended comprehensive decadal predictions

IPCC Sixth Assessment Report
Working Group 1: The Physical Science Basis

ABOUT ▸ REPORT ▸ RESOURCES ▸ DOWNLOAD ▸ ipcc



Climate Change 2021: The Physical Science Basis

The Working Group I contribution to the Sixth Assessment Report addresses the most up-to-date physical understanding of the climate system and climate change, bringing together the latest advances in climate science.

Summary for Policymakers

The Summary for Policymakers provides a high-level summary of the current state of the climate, how it is changing, the role of human influence, and possible climate futures.

EXPLORE DOWNLOADS FIGURES

Technical Summary

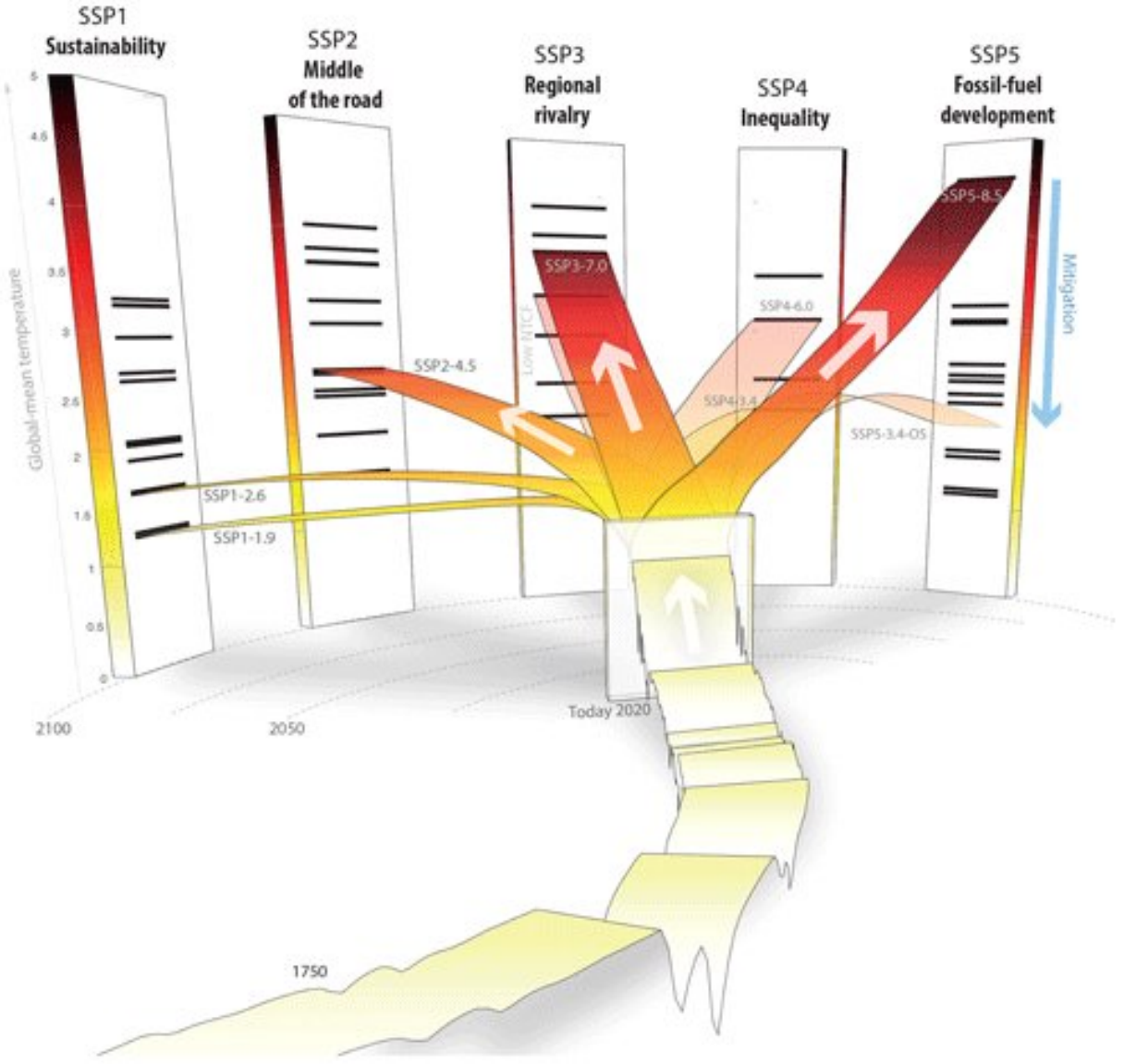
The Technical Summary provides a synthesis of the key findings of the Report and serves as a bridge between the Summary for Policymakers and the chapters of the full report.

EXPLORE DOWNLOADS FIGURES

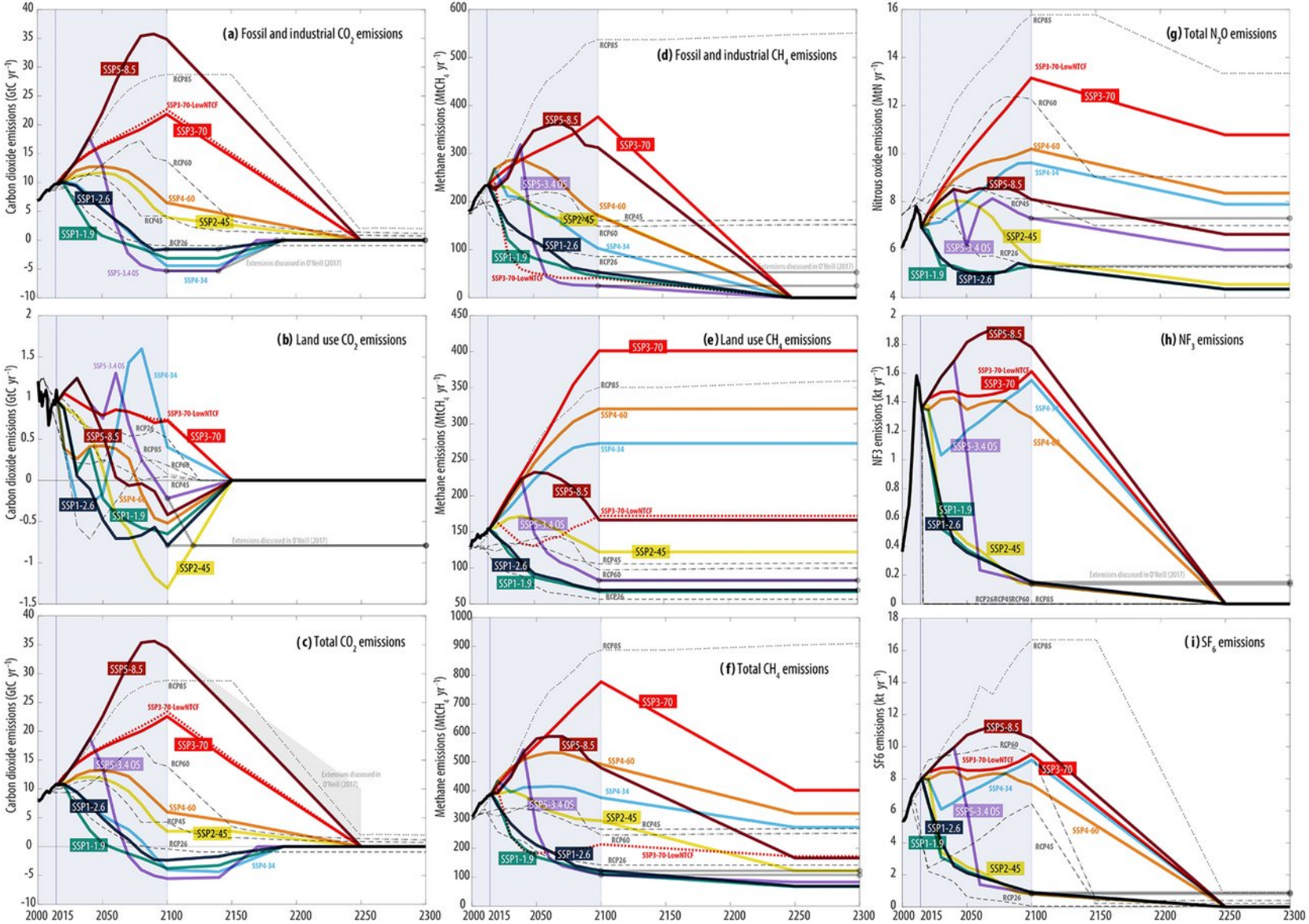
Full Report

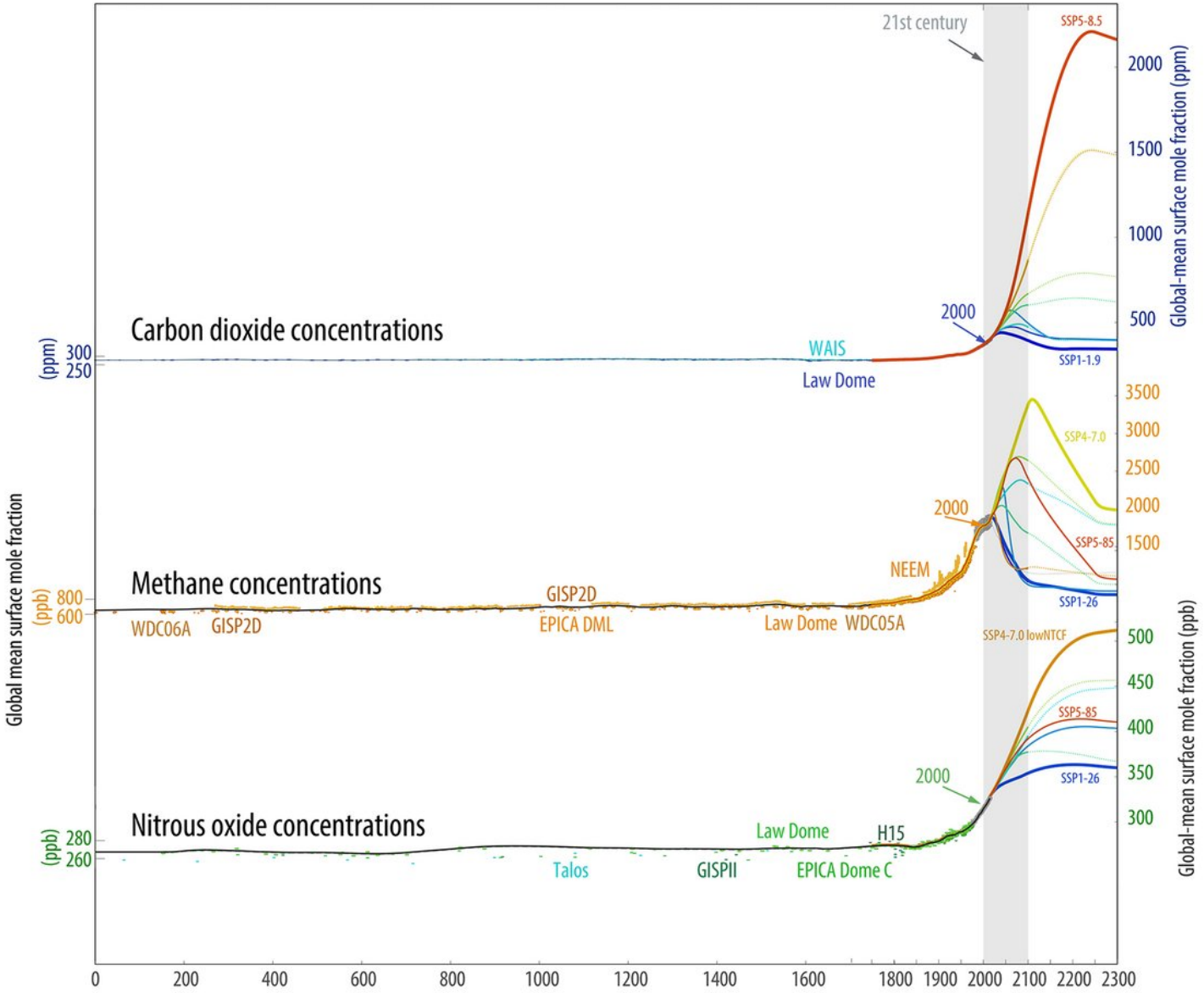
The 13 chapters of the Working Group I report provide a comprehensive assessment of the current evidence on the physical science of climate change.

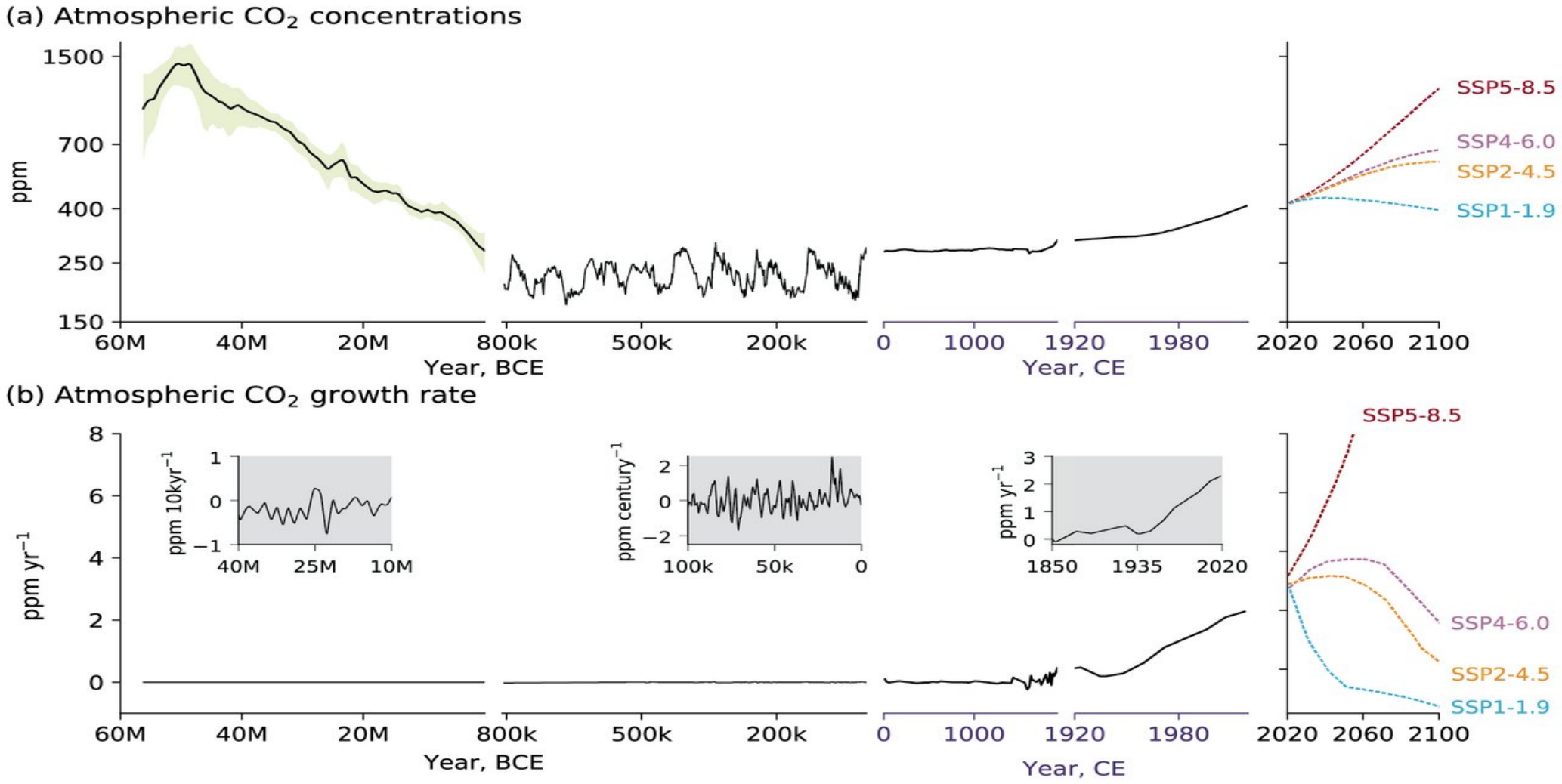
DOWNLOADS

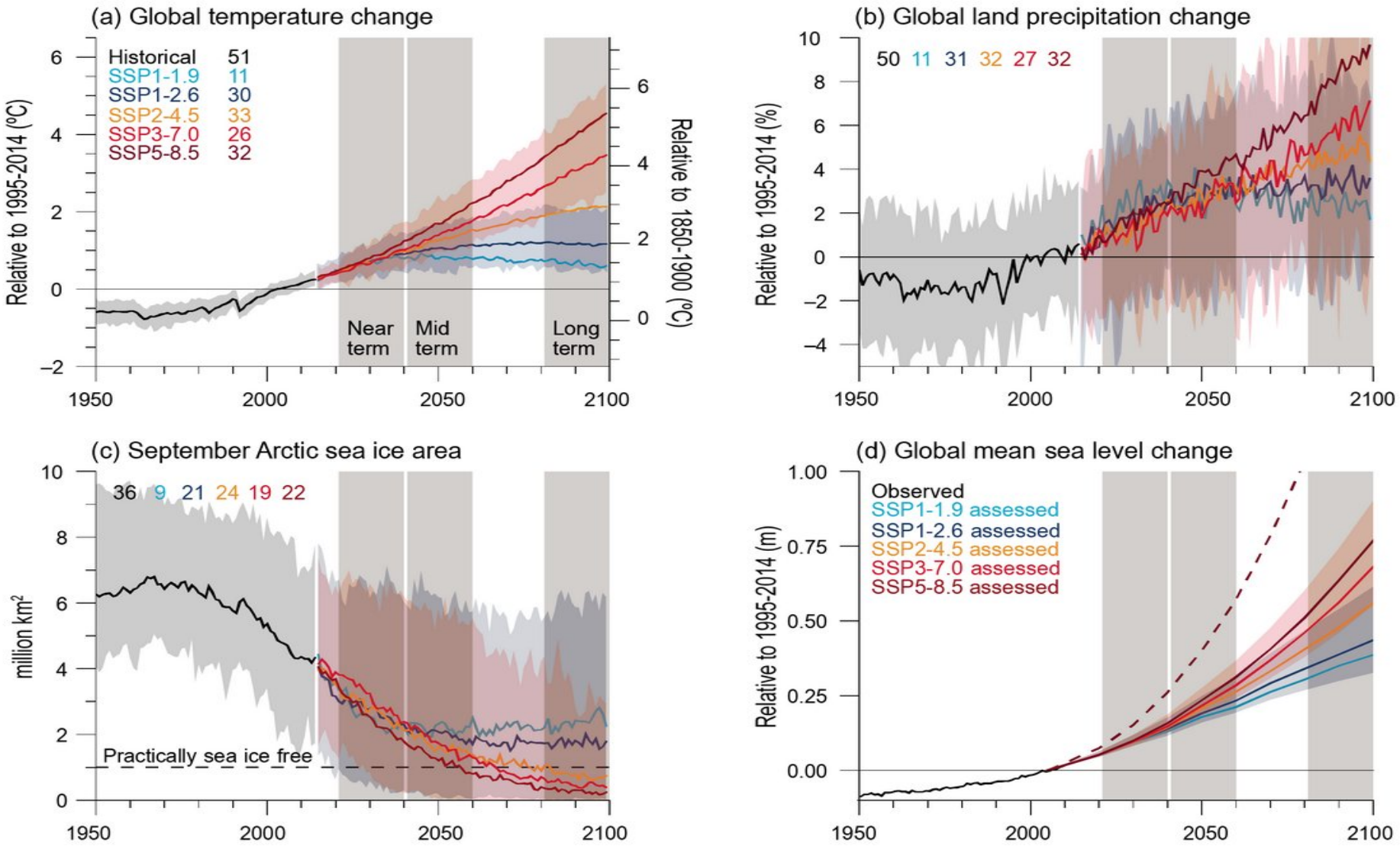


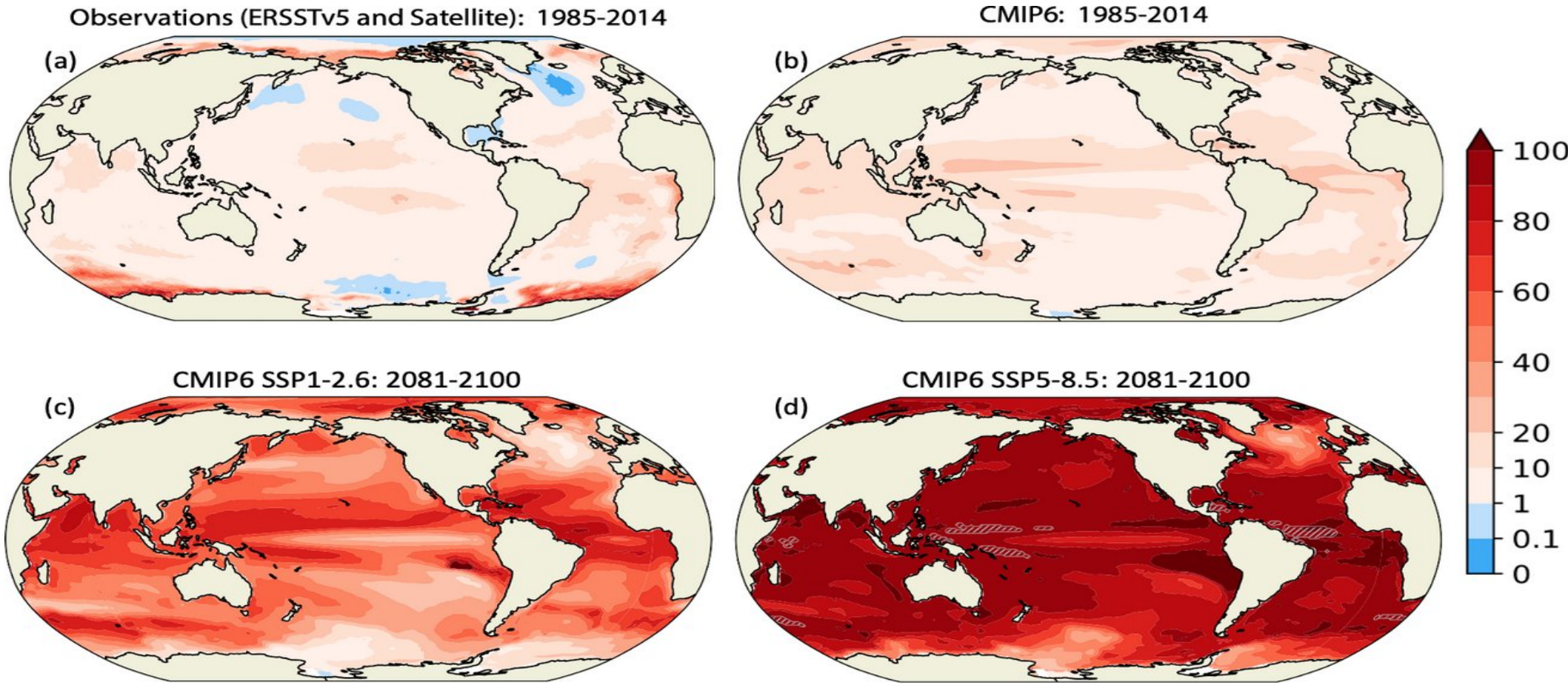
https://doi.org/10.5194/gmd-13-3571-2020


(a) Fossil and industrial CO_2 emissions
Carbon dioxide emissions (GtC yr^{-1})
(b) Land use CO_2 emissions
Carbon dioxide emissions (GtC yr^{-1})
(c) Total CO_2 emissions
Carbon dioxide emissions (GtC yr^{-1})
(d) Fossil and industrial CH_4 emissions
Methane emissions (MtCH$_4$ yr^{-1})
(e) Land use CH_4 emissions
Methane emissions (MtCH$_4$ yr^{-1})
(f) Total CH_4 emissions
Methane emissions (MtCH$_4$ yr^{-1})
(g) Total N_2O emissions
Nitrous oxide emissions (MtN yr^{-1})
(h) NF_3 emissions
NF3 emissions (kt yr^{-1})
(i) SF_6 emissions
SF6 emissions (kt yr^{-1})
SSP5-8.5
SSP3-70-LowNTCF
SSP3-70
SSP5-3.4OS
SSP4-60
SSP4-34
SSP2-45
SSP1-2.6
SSP1-1.9
RCP85
RCP60
RCP45
RCP26
Extensions discussed in O'Neill (2017)
2000 2015 2050 2100 2150 2200 2250 2300


21st century
SSP5-8.5
2000
1500
1000
500
Global-mean surface mole fraction (ppm)
Carbon dioxide concentrations
(ppm)
300
250
WAIS
Law Dome
2000
SSP1-1.9
3500
3000
2500
2000
1500
SSP4-7.0
SSP5-85
SSP1-26
Methane concentrations
(ppb)
800
600
WDC06A
GISP2D
GISP2D
EPICA DML
NEEM
Law Dome
WDC05A
2000
SSP4-7.0 lowNTCF
500
450
400
350
300
SSP5-85
SSP1-26
Nitrous oxide concentrations
(ppb)
280
260
Talos
GISPII
Law Dome
H15
EPICA Dome C
2000
Global mean surface mole fraction
Global-mean surface mole fraction (ppb)
0
200
400
600
800
1000
1200
1400
1600
1800
1900
2000
2100
2200
2300

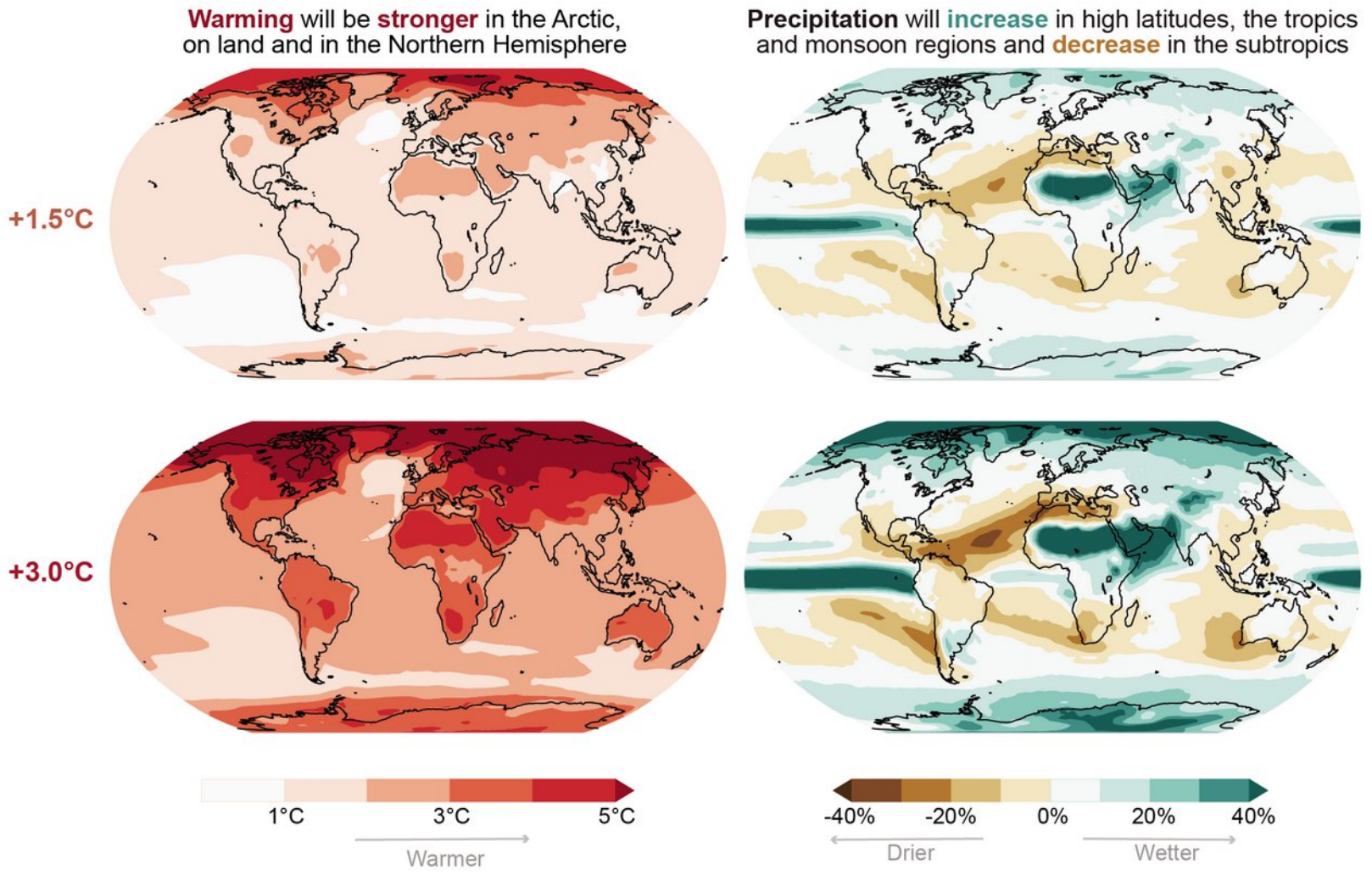

(a) Atmospheric CO_2 concentrations
ppm
1500
700
400
250
150
60M
40M
20M
800k
500k
200k
0
1000
1920
1980
2020
2060
2100
Year, BCE
Year, CE
SSP5-8.5
SSP4-6.0
SSP2-4.5
SSP1-1.9
(b) Atmospheric CO_2 growth rate
ppm yr^{-1}
ppm 10kyr^{-1}
ppm century^{-1}
ppm yr^{-1}
40M
25M
10M
100k
50k
1850
1935
2020
Year, BCE
Year, CE
SSP5-8.5
SSP4-6.0
SSP2-4.5
SSP1-1.9

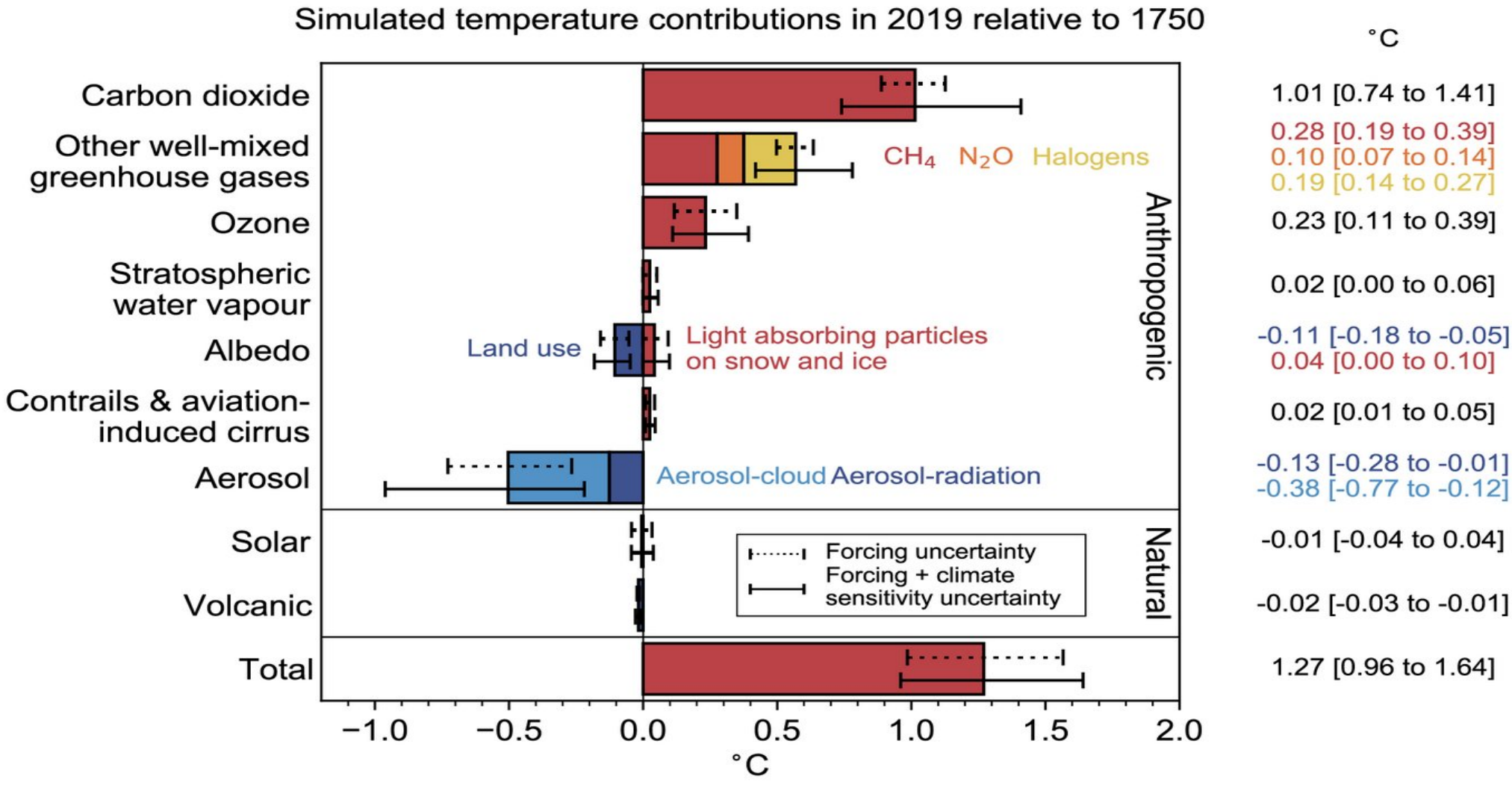

(a) Global temperature change
Historical 51
SSP1-1.9 11
SSP1-2.6 30
SSP2-4.5 33
SSP3-7.0 26
SSP5-8.5 32
Relative to 1995-2014 (°C)
Relative to 1850-1900 (°C)
Near term
Mid term
Long term
(b) Global land precipitation change
50 11 31 32 27 32
Relative to 1995-2014 (%)
(c) September Arctic sea ice area
36 9 21 24 19 22
million km²
Practically sea ice free
(d) Global mean sea level change
Observed
SSP1-1.9 assessed
SSP1-2.6 assessed
SSP2-4.5 assessed
SSP3-7.0 assessed
SSP5-8.5 assessed
Relative to 1995-2014 (m)
1950
2000
2050
2100


Observations (ERSSTv5 and Satellite): 1985-2014
(a)
CMIP6: 1985-2014
(b)
CMIP6 SSP1-2.6: 2081-2100
(c)
CMIP6 SSP5-8.5: 2081-2100
(d)
100
80
60
40
20
10
1
0.1
0

FAQ 4.3: **Climate change and regional patterns**

Climate change is not uniform and proportional to the level of global warming.




Simulated temperature contributions in 2019 relative to 1750
°C
Carbon dioxide
Other well-mixed greenhouse gases
Ozone
Stratospheric water vapour
Albedo
Contrails & aviation-induced cirrus
Aerosol
Solar
Volcanic
Total
CH4 N2O Halogens
Land use
Light absorbing particles on snow and ice
Aerosol-cloud Aerosol-radiation
Anthropogenic
Natural
Forcing uncertainty
Forcing + climate sensitivity uncertainty
1.01 [0.74 to 1.41]
0.28 [0.19 to 0.39]
0.10 [0.07 to 0.14]
0.19 [0.14 to 0.27]
0.23 [0.11 to 0.39]
0.02 [0.00 to 0.06]
-0.11 [-0.18 to -0.05]
0.04 [0.00 to 0.10]
0.02 [0.01 to 0.05]
-0.13 [-0.28 to -0.01]
-0.38 [-0.77 to -0.12]
-0.01 [-0.04 to 0.04]
-0.02 [-0.03 to -0.01]
1.27 [0.96 to 1.64]
−1.0 −0.5 0.0 0.5 1.0 1.5 2.0
°C

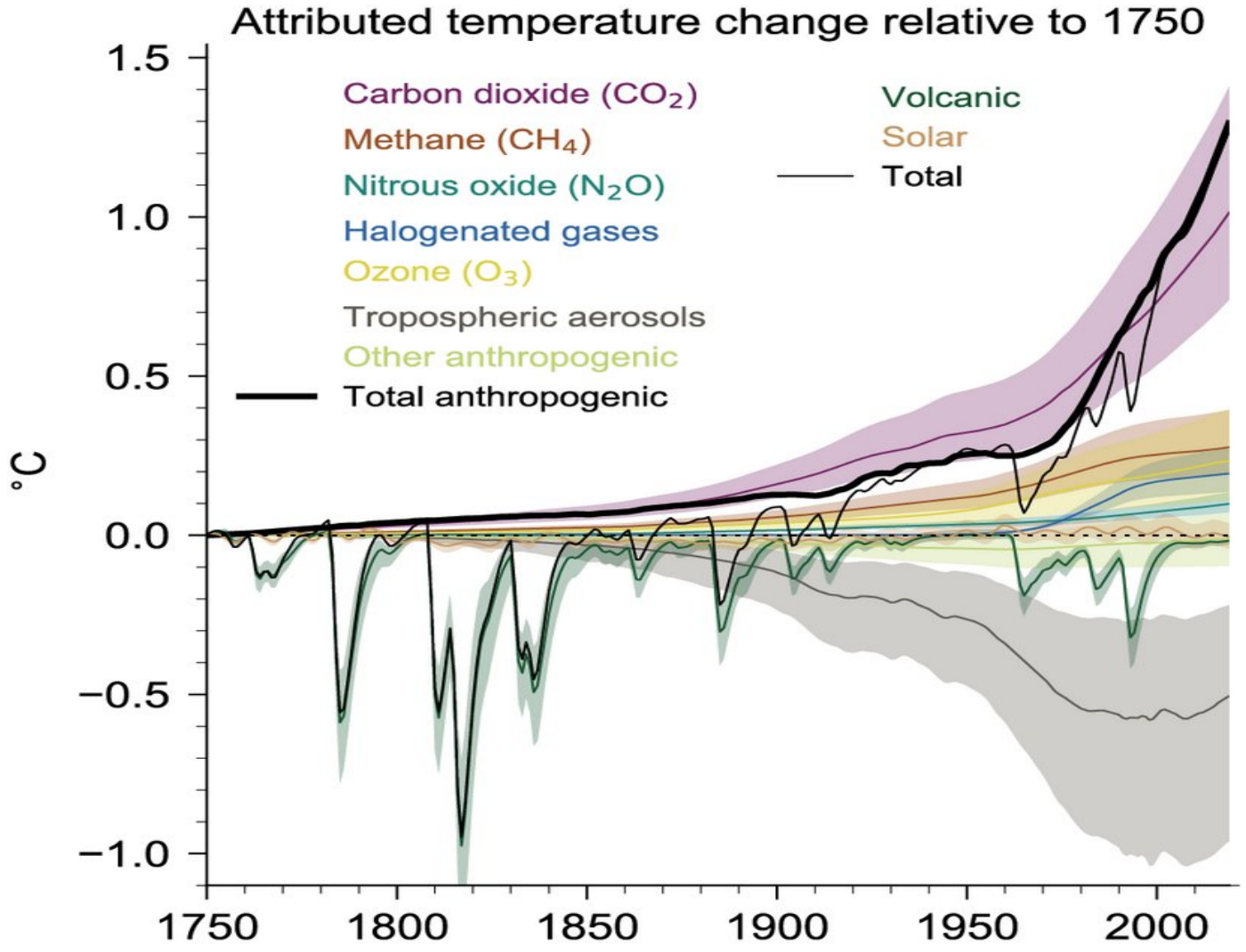
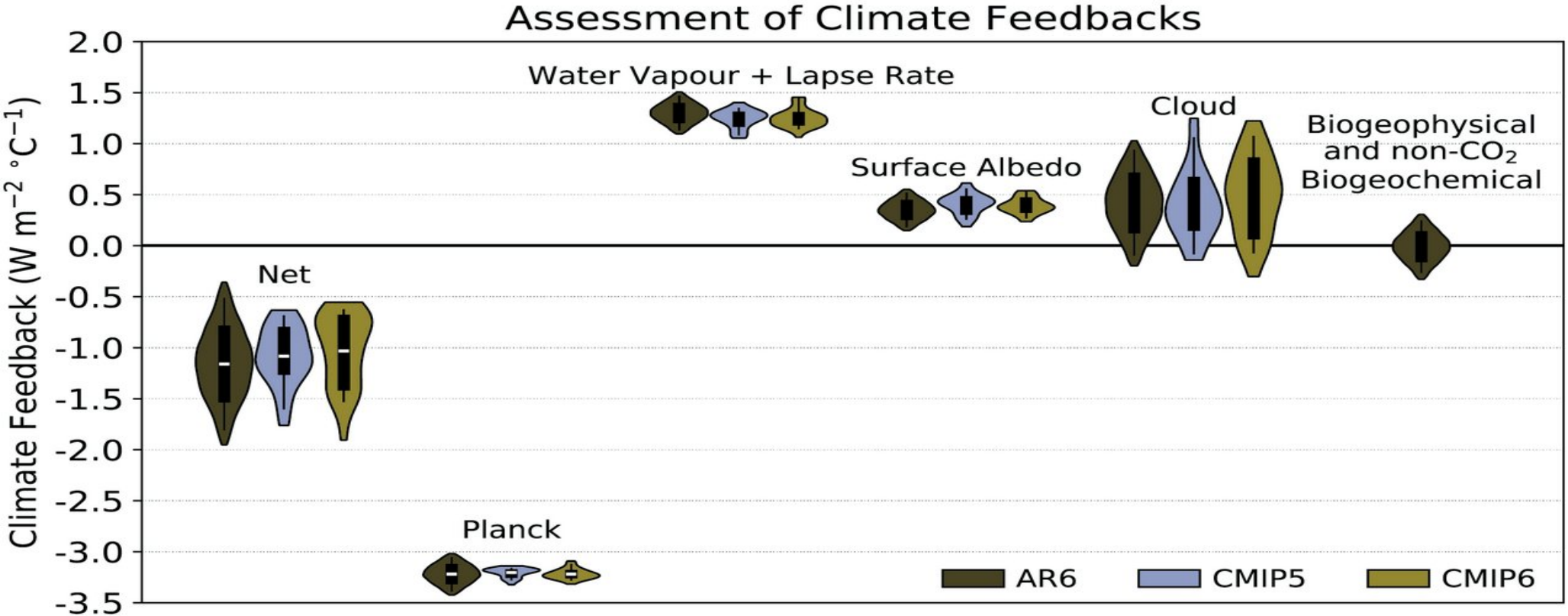
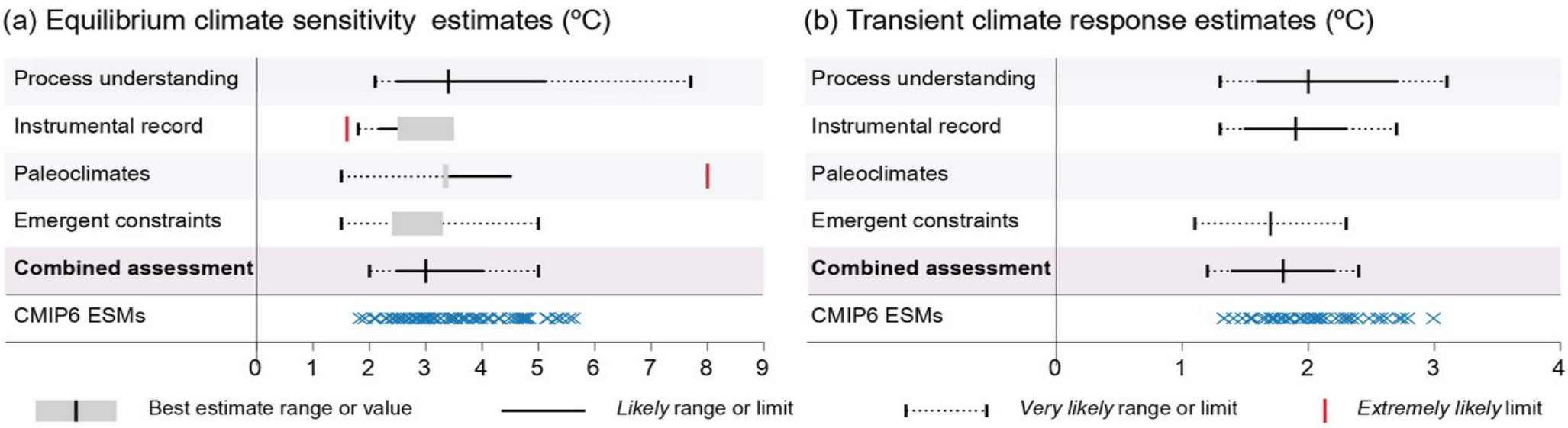

Attributed temperature change relative to 1750
Carbon dioxide (CO_2)
Methane (CH_4)
Nitrous oxide (N_2O)
Halogenated gases
Ozone (O_3)
Tropospheric aerosols
Other anthropogenic
Total anthropogenic
Volcanic
Solar
Total
°C
1.5
1.0
0.5
0.0
−0.5
−1.0
1750
1800
1850
1900
1950
2000

Table 7.10 | Synthesis assessment of climate feedbacks (central estimate shown in bold). The mean values and their 90% ranges in CMIP5/6 models, derived using multiple radiative kernels (Zelinka et al., 2020) are also presented for comparison.

Feedback Parameter α x($W\ m^{-2}\ °C^{-1}$)	CMIP5 GCMs	CMIP6 ESMs	AR6 Assessed Ranges			
	Mean and 5–95% Interval	Mean and 5–95% Interval	Central Estimate	*Very likely* Interval	*Likely* Interval	Level of Confidence
Planck	−3.20 [−3.3 to −3.1]	−3.22 [−3.3 to −3.1]	**−3.22**	−3.4 to −3.0	−3.3 to −3.1	*high*
WV+LR	1.24 [1.08 to 1.35]	1.25 [1.14 to 1.45]	**1.30**	1.1 to 1.5	1.2 to 1.4	*high*
Surface albedo	0.41 [0.25 to 0.56]	0.39 [0.26 to 0.53]	**0.35**	0.10 to 0.60	0.25 to 0.45	*medium*
Clouds	0.41 [−0.09 to 1.1]	0.49 [−0.08 to 1.1]	**0.42**	−0.10 to 0.94	0.12 to 0.72	*high*
Biogeophysical and non-CO_2 biogeochemical	Not evaluated	Not evaluated	**−0.01**	−0.27 to 0.25	−0.16 to 0.14	*low*
Residual of kernel estimates	0.06 [−0.17 to 0.29]	0.05 [−0.18 to 0.28]				
Net (i.e., relevant for ECS)	−1.08 [−1.61 to −0.68]	−1.03 [−1.54 to −0.62]	**−1.16**	−1.81 to −0.51	−1.54 to −0.78	*medium*
Long-term ice-sheet feedbacks (millennial scale)				>0.0		*high*

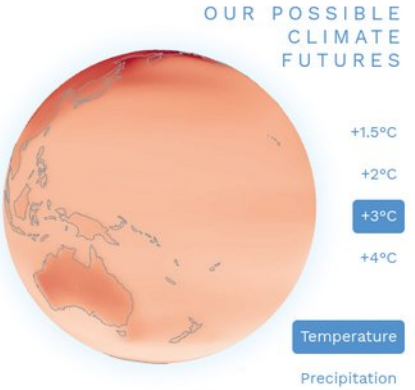

Assessment of Climate Feedbacks
Climate Feedback (W m^{-2} °C^{-1})
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
Net
Planck
Water Vapour + Lapse Rate
Surface Albedo
Cloud
Biogeophysical and non-CO_2 Biogeochemical
AR6
CMIP5
CMIP6


(a) Equilibrium climate sensitivity estimates (ºC)
Process understanding
Instrumental record
Paleoclimates
Emergent constraints
Combined assessment
CMIP6 ESMs
0
1
2
3
4
5
6
7
8
9
Best estimate range or value
Likely range or limit
(b) Transient climate response estimates (ºC)
Process understanding
Instrumental record
Paleoclimates
Emergent constraints
Combined assessment
CMIP6 ESMs
0
1
2
3
4
Very likely range or limit
Extremely likely limit

IPCC WGI Interactive Atlas

A novel tool for flexible spatial and temporal analyses of much of the observed and projected climate change information underpinning the Working Group I contribution to the Sixth Assessment Report, including regional synthesis for Climatic Impact-Drivers (CIDs).

Errata and problem reporting | License, data and citation | Contact



REGIONAL INFORMATION

REGIONAL SYNTHESIS

DOCUMENTATION

Copernicus Interactive Climate Atlas

Mean temperature (°C) - CMIP6 - Change - rel. to 1850-1900 - Warming 2°C - Annual

Mean temperature | CMIP6

Climatology and Changes | Global warming levels

1961-1990 1981-2010 1991-2020 2°C 4°C
1850-1900 1986-2005 1995-2014 1.5°C 3°C
PAST FUTURE

Quantity
Change

Season
Annual

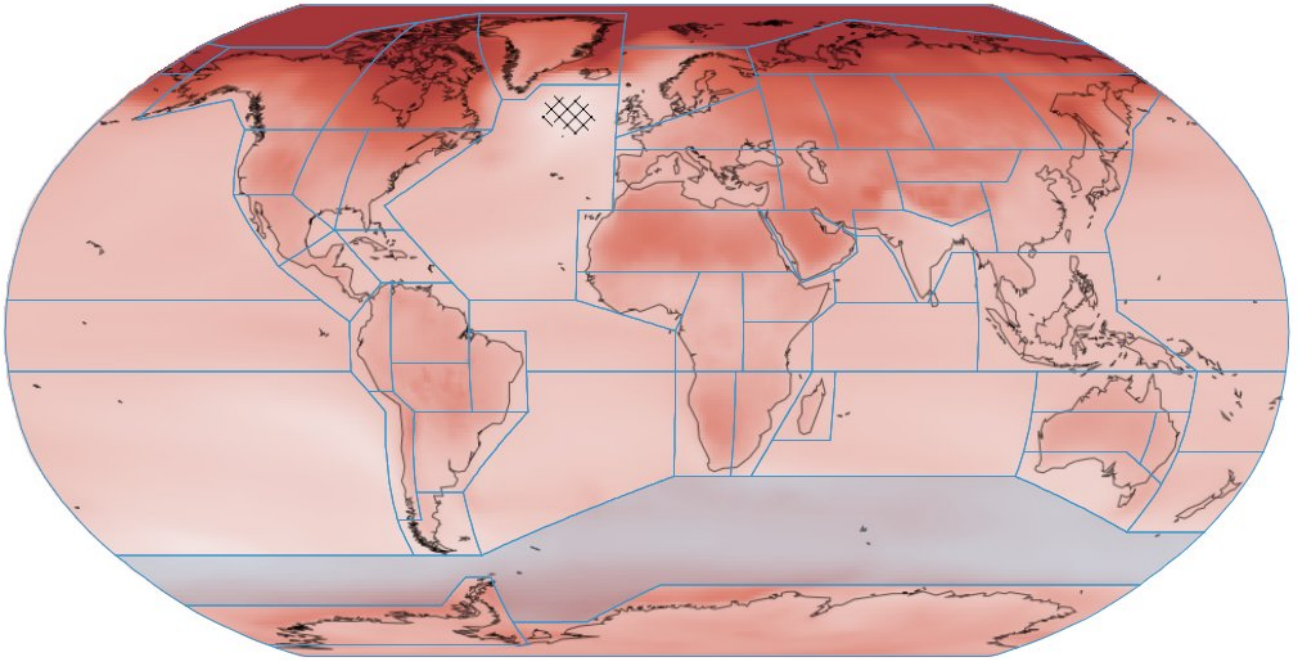
6 5 4 3 2 1 0 -1 -2 -3 -4 -5 -6

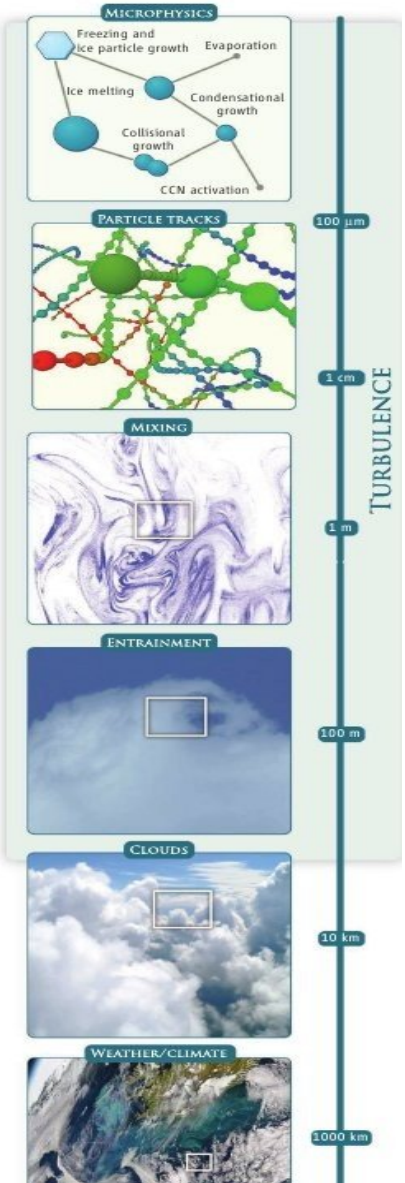
Units: °C

Robustness:
- Robust signal (original color)
- No change or no robust signal
- Conflicting signals

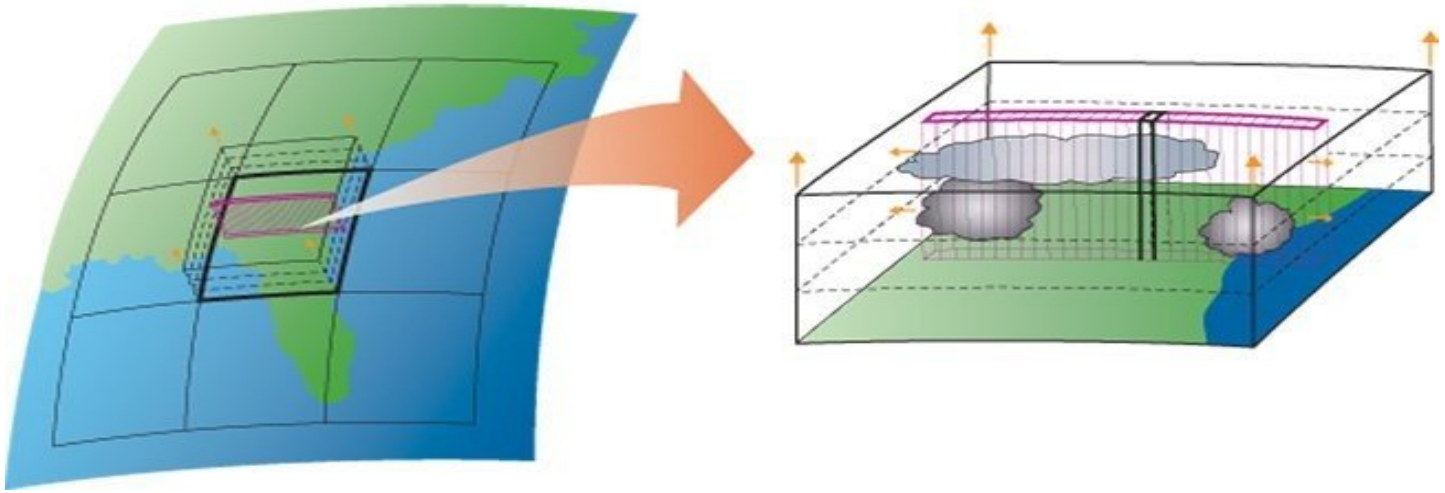
Palette Autofit Reset

AR6 Regions





Jak sobie radzimy z problemami?
„Multiscale modeling” - modelowanie wieloskalowe, superparametryzacje, GIGA-LES, ILES, explicit cloud-resolving....



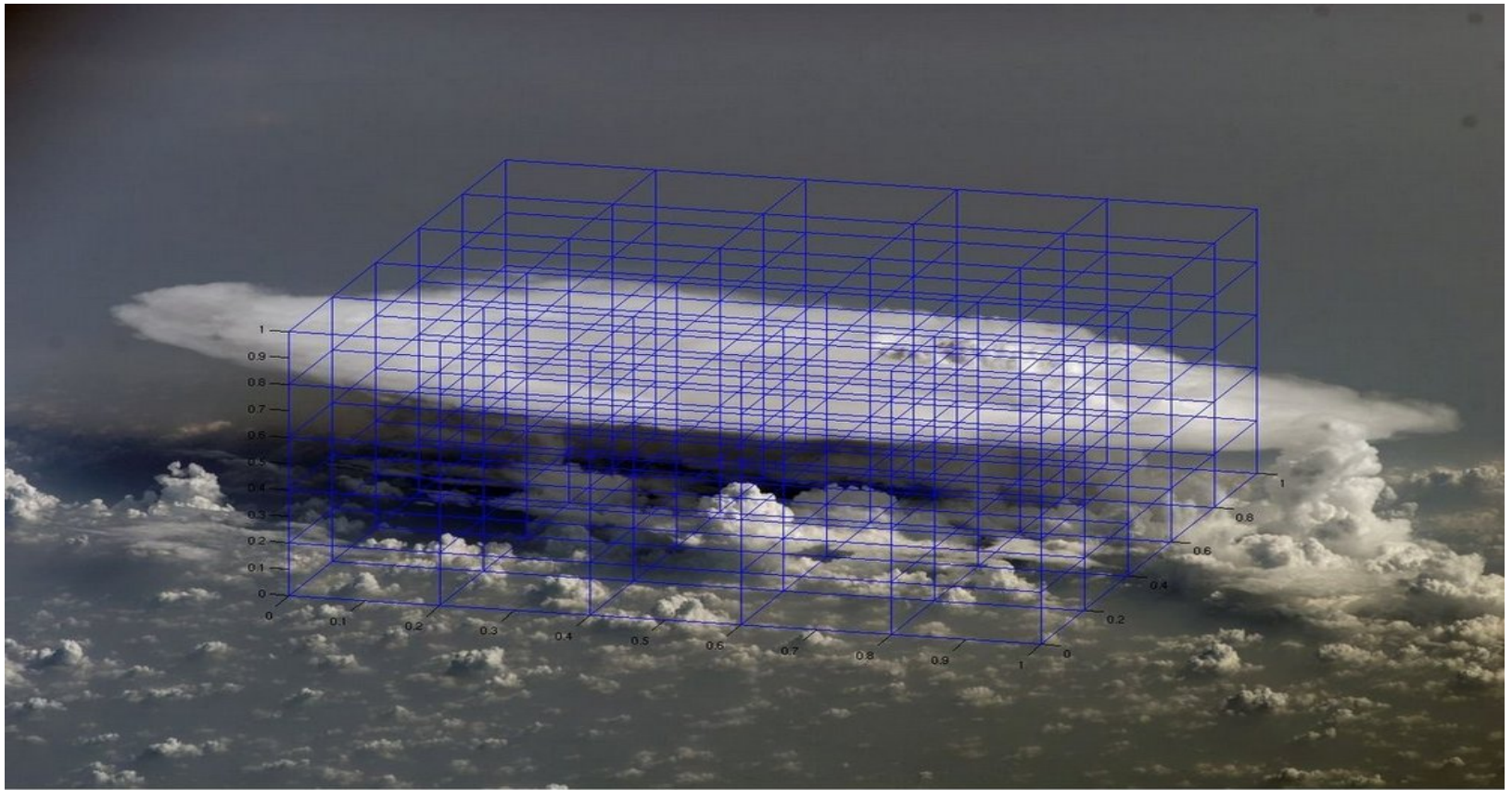
Bodenschatz, E., S.P. Malinowski, R.A. Shaw, F. Stratmann, 2010: Can We Understand Clouds without Turbulence? *Science,* **327**, 970 – 971.

Randall D.A, Khairoutdinov M, Arakawa A, Grabowski W.W., 2003: Breaking the cloud parameterization deadlock . Bull. Amer. Meteorol. Soc., **84**, 1547-1564.

I wiele wiele innych.....

Jakie problemy napotyka modelowanie prognozy pogody i klimatu?

Najważniejszy to wielkoskalowość przepływów w atmosferze i oceanie i konieczność parametryzacji procesów podskalowych (o rozmiarach mniejszych niż oczko siatki i zachodzących szybciej niż krok czasowy obliczeń)

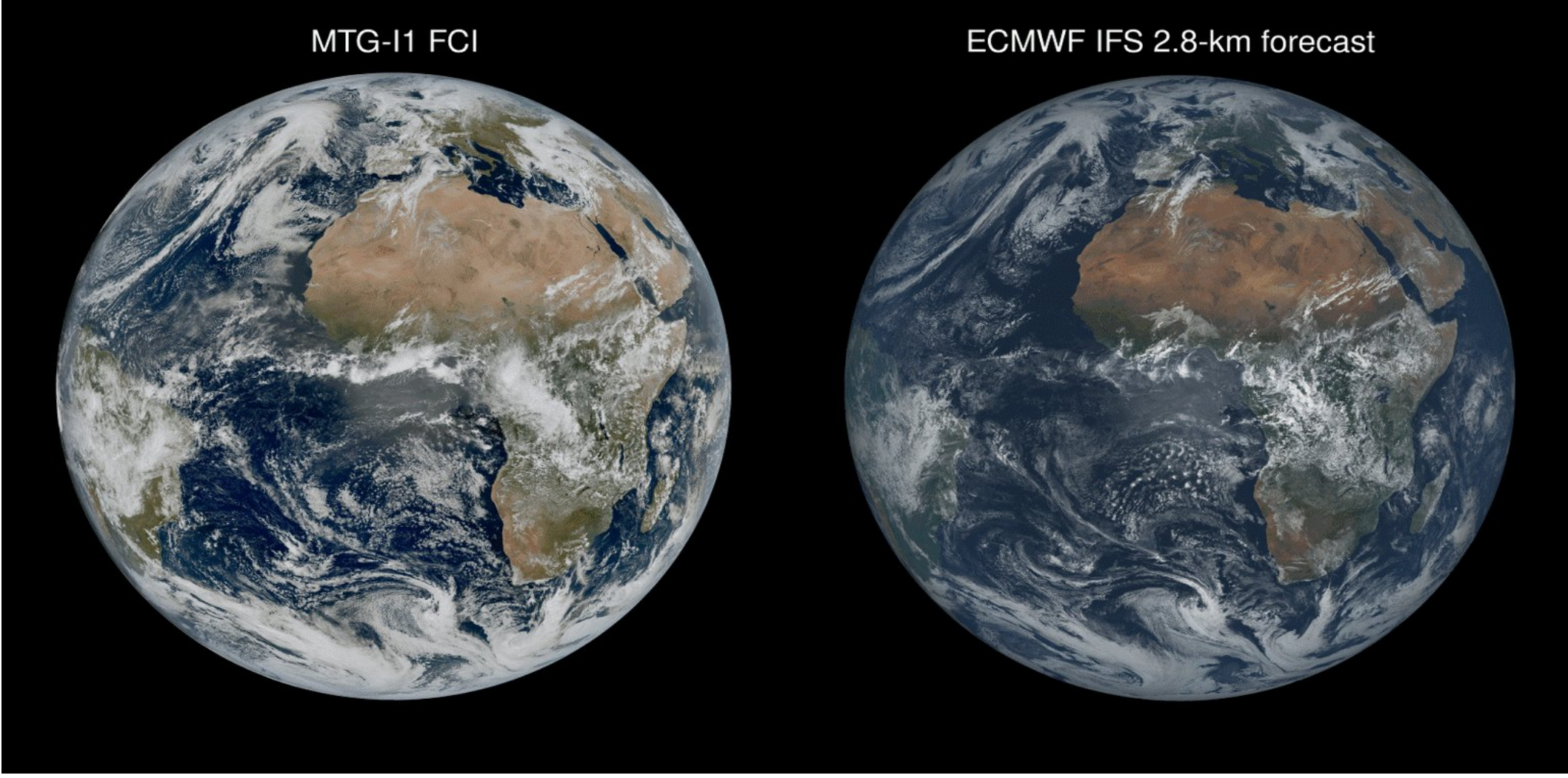


About the Project

nextGEMS is a collaborative European project. Funded by the EU's Horizon 2020 programme, it will tap expertise from fourteen European Nations to develop two next generation (storm-resolving) Earth-system Models. Through breakthroughs in simulation realism, these models will allow us to understand and reliably quantify how the climate will change on a global and regional scale, and how the weather, including its extreme events, will look like in the future.

nextGEMS is a Horizon 2020 project funded by the European Commission. It is coordinated by Bjorn Stevens at the Max Planck Institute for Meteorology and Irina Sandu at the ECMWF. The nextGEMS consortium is made up of 26 institutes:

- Max Planck Institute for Meteorology (MPI-M), Germany
- European Centre for Medium-Range Weather Forecasts (ECMWF)
- Alfred-Wegener-Institut (AWI), Germany
- University of Bergen (UiB), Norway
- University of Copenhagen (UCPH), Denmark
- French National Centre for Scientific Research (CNRS), France
- Stockholm University (SU), Sweden
- University of Warsaw (UW), Poland
- University of Oxford (UOXF), UK
- Helmholtz Centre for Ocean Research Kiel (GEOMAR), Germany
- Barcelona Supercomputing Center (BSC), Spain
- University of Reading (UREAD), UK
- Wageningen University (WU), The Netherlands
- Eidgenössische Technische Hochschule Zürich (ETHZ), Switzerland
- Universität Bern (UBERN), Switzerland
- Instituto Português do Mar e da Atmosfera IP (IPMA), Portugal
- University of Helsinki (UH), Finland
- University of Trento (UNITN), Italy
- Deutsches Klimarechenzentrum GmbH (DKRZ), Germany
- Universidad Complutense de Madrid (UCM), Spain
- French National Institute for Sustainable Development (IRD), France
- Iberdrola Renovables Energía S.A.U. (IBE), Spain
- Institut Sénégalais de Recherches Agricoles (ISRA), Senegal
- Latest Thinking GmbH (LT), Germany
- Karlsruhe Institut of Technology (KIT), Germany
- University of Hamburg (UHH), Germany



Pierwszy oficjalny obraz w świetle widzialnym z satelity MTG-FCI z EUMETSAT (po lewej) i 12-godzinna symulacja przy użyciu Zintegrowanego Systemu Prognozowania (IFS) ECMWF w rozdzielczości 2,8 km (po prawej), ważna na dzień 18 marca 2023 r. o godzinie 12:00 UTC. Źródło: EUMETSAT/ECMWF

Technika prognozowania klimatu : multimodel ensemble – pozwala a priori na ocenę prawdopodobieństwa sprawdzenia prognozy – podejście bayesowkie.

Dlaczego możemy (w ograniczonym stopniu) ufać prognozom klimatu:

1) modele bazują na podstawowych powszechnych prawach fizyki: zasadach zachowania energii, pędu, momentu pędu, masy....
2) w „wirtualnej rzeczywistości" modeli wielkości fizyczne i ich statystki zachowują się w sposób rozsądny, a kolejne ulepszenia prowadzą do poprawy zachowań modeli zgodnie z naszym doświadczeniem i oczekiwaniami;
3) modele odtwarzają trendy i obserwowany rozkład przestrzenny wielu zmiennych;
4) testy modeli na przeszłych stanach atmosfery (w tym tych sytuacjach paleo, dla których mamy odpowiednie dane) stanowią dodatkowe, niezależne źródło weryfikacji;
5) różnorodne modele dają zgodne (w spodziewanych granicach) wyniki symulacji na tych samych danych;
6) prognozy nowej generacji modeli są zgodne ze starszymi;
7) potrafimy zinterpretować wyniki symulacji w sensie zrozumienia procesów fizycznych i sprzężeń.

R Knutti, 2008: Should we believe model predictions of future climate change? Phil. Trans. R. Soc. A 366, 4647–4664 doi:10.1098/rsta.2008.0169

Odnośniki do kilku wybranych modeli klimatu:

http://www.cesm.ucar.edu/models/ccsm4.0/

https://www.mpimet.mpg.de/en/science/models/icon-esm/

https://geos5.org/wiki/index.php?title=GEOS_GCM_Documentation_and_Access

http://web.mit.edu/globalchange/www/climate.html

https://cds.climate.copernicus.eu/cdsapp#!/toolbox