



Guide to the Science of Climate Change in the 21st Century

Chapter 17 Climate Models

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2020

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Chapter 17.0 Climate Models

17.1 Introduction

Computer simulation models of global climate exist. They are providing the ability to assess the potential impacts of climate change and guide adaptation and mitigation efforts. A recent NASA report, by Alan Buis, January 9, 2020, titled ‘Study Confirms Climate Models are Getting Future Warming Projections Right’ emphasizes this conclusion.

Computer models are the only approach to synthesizing the science of climate change as discussed in previous chapters to generate actionable projections. The models and the computers that run them have been under development for more than thirty years and have provided input to the First Assessment Report on Climate Change prepared by the Intergovernmental Panel on Climate Change in 1990 (See

https://www.ipcc.ch/site/assets/uploads/2018/03/ipcc_far_wg_I_full_report.pdf.)

Considerable progress has been made since then as reported in the Fifth Assessment Report in 2013 (See <https://www.ipcc.ch/report/ar5/wg1/>.) The Sixth Assessment Report is in final stages of preparation.

There are many intense ongoing efforts to improve climate models as the science is better understood and more and higher quality data is being collected to support the science. With improved science comes growing complexity, the need for better computational methods, need for improved data management and strategies to use the ever more powerful computers.

17.2 Climate models

The utility of the climate models is more than just their ability to forecast. They:

1. Advance the understanding of complex systems,
2. Guide future research – theoretical and physical,
3. Guide development of data collection systems, and
4. Improve interpretation of data.

Climate models are always improving. There are several organizations around the world which have developed their own models using their own approach. They each have advantages and disadvantages but tend to be complimentary. Most of the climate models are used.

The objectives of all models are to determine how natural and man-made forcings might influence temperature and precipitation.

Some of the steps in the development and use of computer models include:

1. System identification. Identify all of the elements that might affect the behavior of the system. (Energy budget, carbon cycle, hydrological cycle, atmosphere circulation, ocean current, biosphere and anything else that is relevant.)
2. Collection and development of relevant science.

3. Collection and identification of data requirements for input to model and required to calibrate and test models.
4. Develop computer programs.
5. Calibrate model and modify model as required. (May also require additional data.)
6. Test model against different data sets.
7. Use model:
 1. With 'real' data.
 2. With generated data that reflects 'chaos' or statistical characteristics of real data.

Figure 17.1 provides guidance on the type of information that is required to run the climate models. Satellites are meeting this need.



Figure 17.1 Subsystems included in climate models.

<https://www.ipcc.ch/report/ar5/wg1/>

Figures 17.2 and 17.3 illustrate how the surface of the Earth is divided into a grid and how the grid is extended into the atmosphere and ocean to produce a 3-D model of the type that would be used in atmosphere-land surface-ocean and sea ice models used in IPCC Assessment Report 5.

Figure 17.4 shows how the amount of detail in climate models has increased in recent years, largely because of the calculation power provided by newer supercomputers. In the 1990s, high-resolution *global climate models* operated on the T42 resolution scheme (upper left). At this resolution, temperature, moisture, and other features were tracked in grid boxes that each spanned about 200 by 300 kilometers at midlatitudes. In the modelling that led up to the 2007 IPCC Working Group I report, the NCAR-based Community Climate System Model (CCSM) routinely operated at T85 resolution (upper right), with midlatitude grid points of about 100 by 150 km (60 x 90 miles). The finest grid, T340, is now routinely used by climate models.

Figure 17.5 show how the surface grids extend vertically in the ocean. It is apparent that decreasing horizontal and vertical dimensions by fifty per cent would increase the number of computational elements by a factor of eight and the computational power would need to increase by at least this amount.

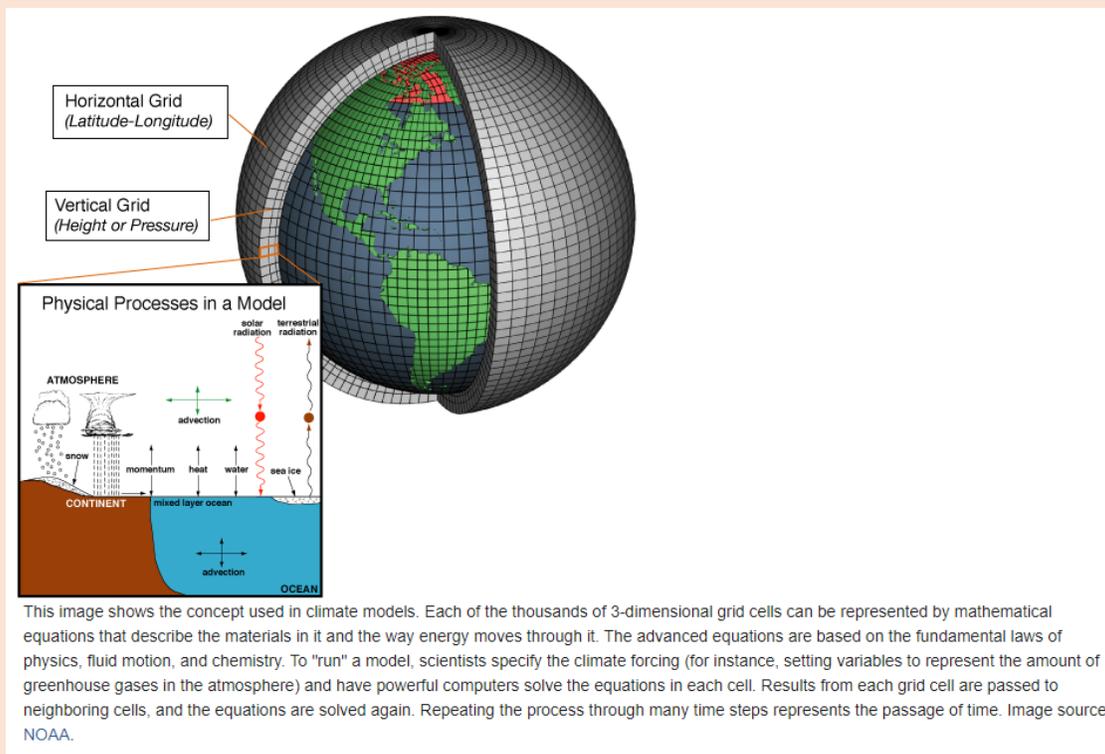


Figure 17.2 Modelling concept used in atmosphere-ocean general circulation climate models, AOGCM's and earth system models, ESM's.

<https://www.climate.gov/maps-data/primer/climate-models>

<https://socom.princeton.edu/content/what-earth-system-model-esm>

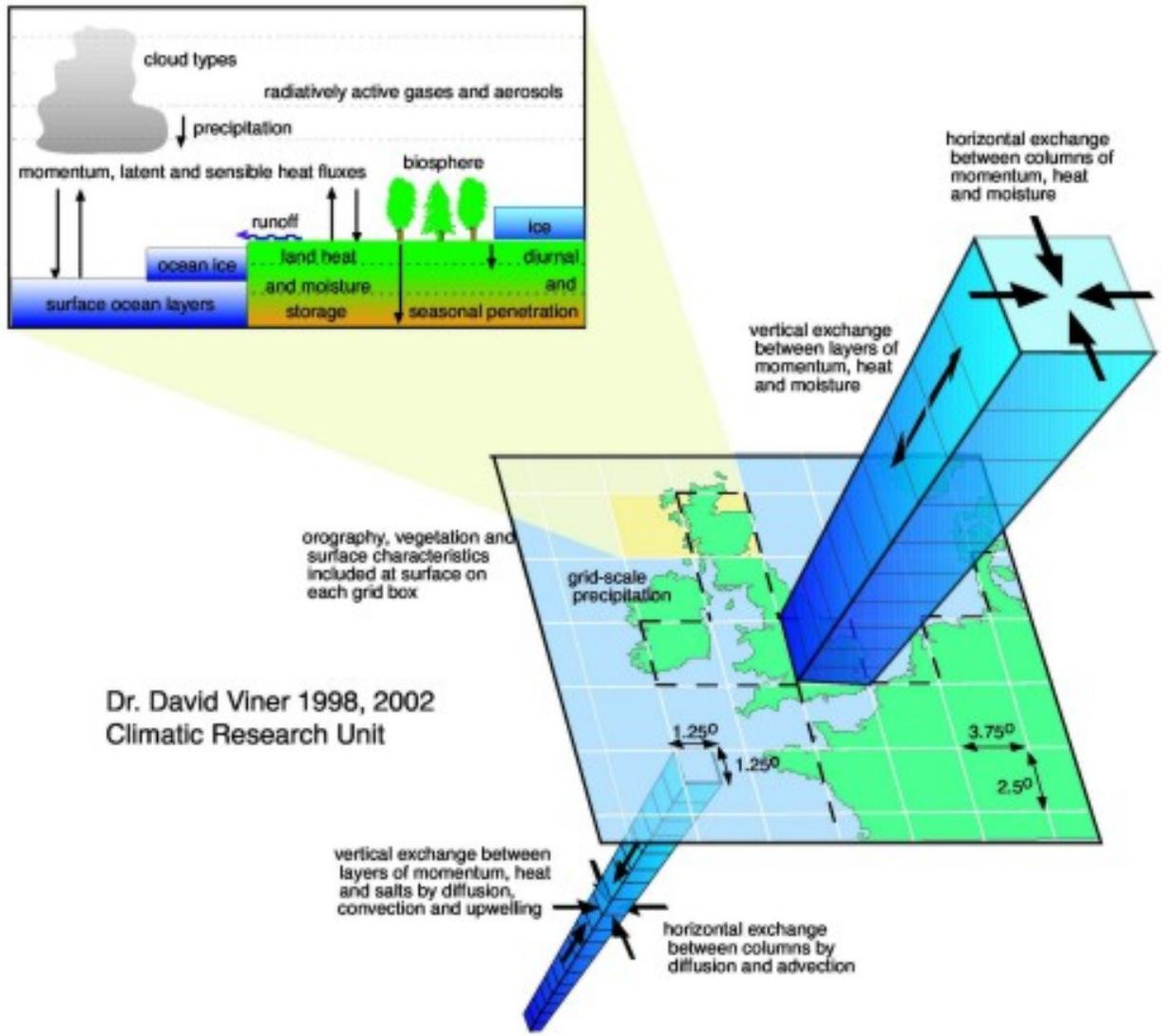
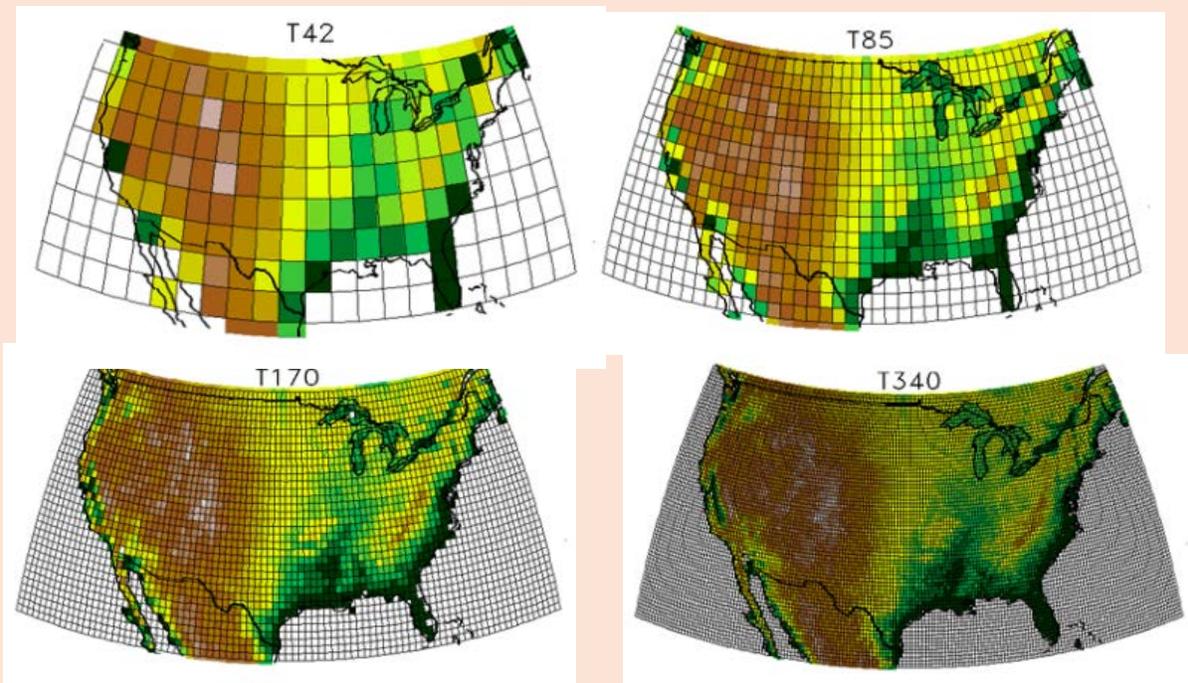


Figure 17.3 Concept used in climate models showing vertical column extending into the oceans.



Resolution:

1. T42 – 200 x 300 km
2. T85 – 100 x 150 km
3. T170 and T340 – regional models much finer resolution – interpolation techniques.
4. Today – 87.5 km x 87.5 km and 30 km x 30 km

Figure 17.4 Comparison of grids used in climate models since they were first being developed for use in IPCC Assessment Report 1 to Assessment Report 5.

<https://scied.ucar.edu/longcontent/climate-modeling>

https://eo.ucar.edu/staff/russell/climate/modeling/climate_model_resolution.html

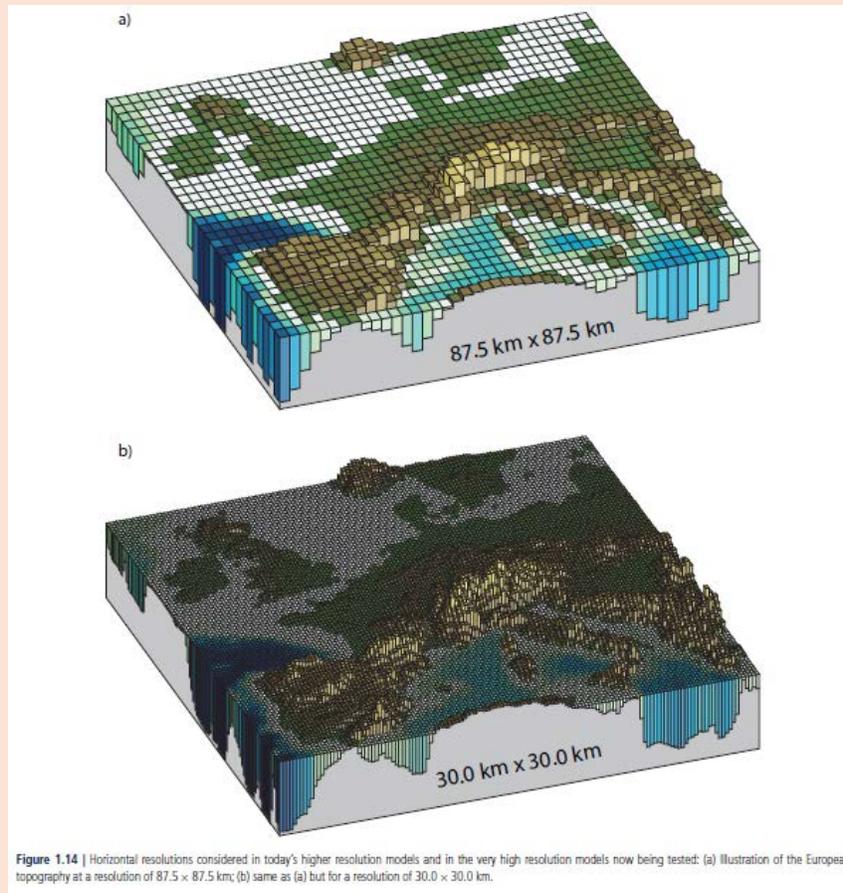


Figure 17.5 Computational elements used in climate models.

<https://www.ipcc.ch/report/ar5/wg1/>

Figure 17.7 illustrates how climate models have increased in complexity since the 1970's. The most complete climate models used in AR5 include:

- Atmosphere
- Land surface
- Ocean and sea ice
- Aerosols
- Carbon cycle
- Dynamic vegetation (consider how the vegetation changes with climate)
- Atmospheric chemistry, and
- Land ice.

The objective is to accurately represent the energy budget, carbon cycle, hydrological cycle, atmospheric circulation, ocean water circulation, and any relevant biochemical reactions and dynamic physical phenomena (such as deforestation due to wildfires, melting permafrost and others).

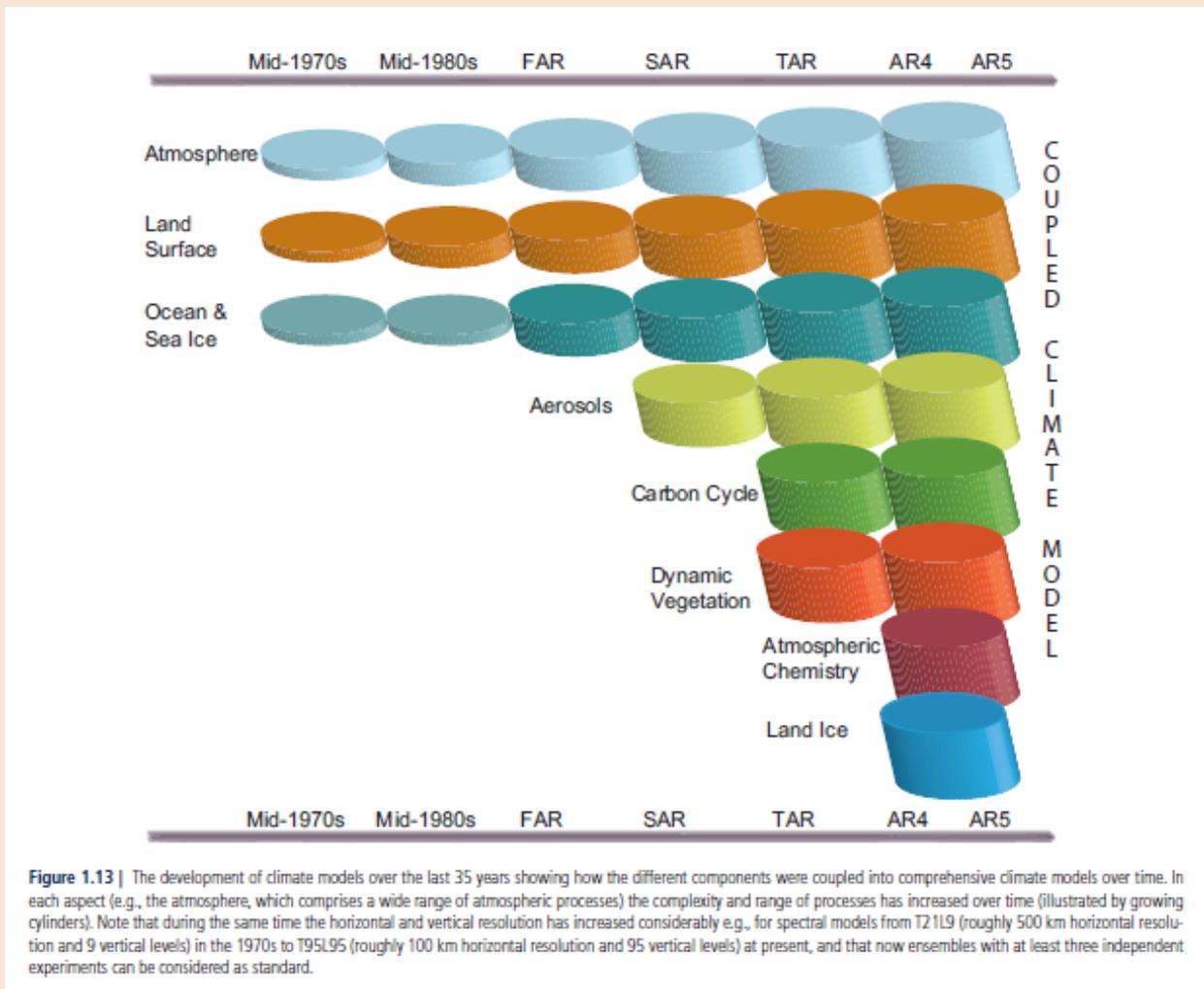


Figure 1.13 | The development of climate models over the last 35 years showing how the different components were coupled into comprehensive climate models over time. In each aspect (e.g., the atmosphere, which comprises a wide range of atmospheric processes) the complexity and range of processes has increased over time (illustrated by growing cylinders). Note that during the same time the horizontal and vertical resolution has increased considerably e.g., for spectral models from T21L9 (roughly 500 km horizontal resolution and 9 vertical levels) in the 1970s to T95L95 (roughly 100 km horizontal resolution and 95 vertical levels) at present, and that now ensembles with at least three independent experiments can be considered as standard.

Figure 17.6 Increase in climate model complexity since the 1970's.

<https://www.ipcc.ch/report/ar5/wg1/>

17.3 Data available for climate models

Most of the data needs required by climate models is obtained by satellites. Land, sea and airborne instrumentation provide data that is used for calibrating (also known as ground truthing) satellite scanners and to obtain data that can't as yet be obtained by satellites such as ocean bottom morphology, biology and chemistry. An example of the extent of satellite acquired information, by NASA alone, is illustrated in Figure 17.7. NASA has an extensive fleet of space-based platforms as shown in Figure 14.12. There are many more satellites and space-based platforms operated by other agencies in the United States and many more operated by several agencies around the world (European Union, Japan, Canada, China and others). Most of this information is shared on a cost-recovery basis. Satellite technology has become sufficiently affordable that the private sector is providing data acquisition services and competing with or complimenting government agencies.

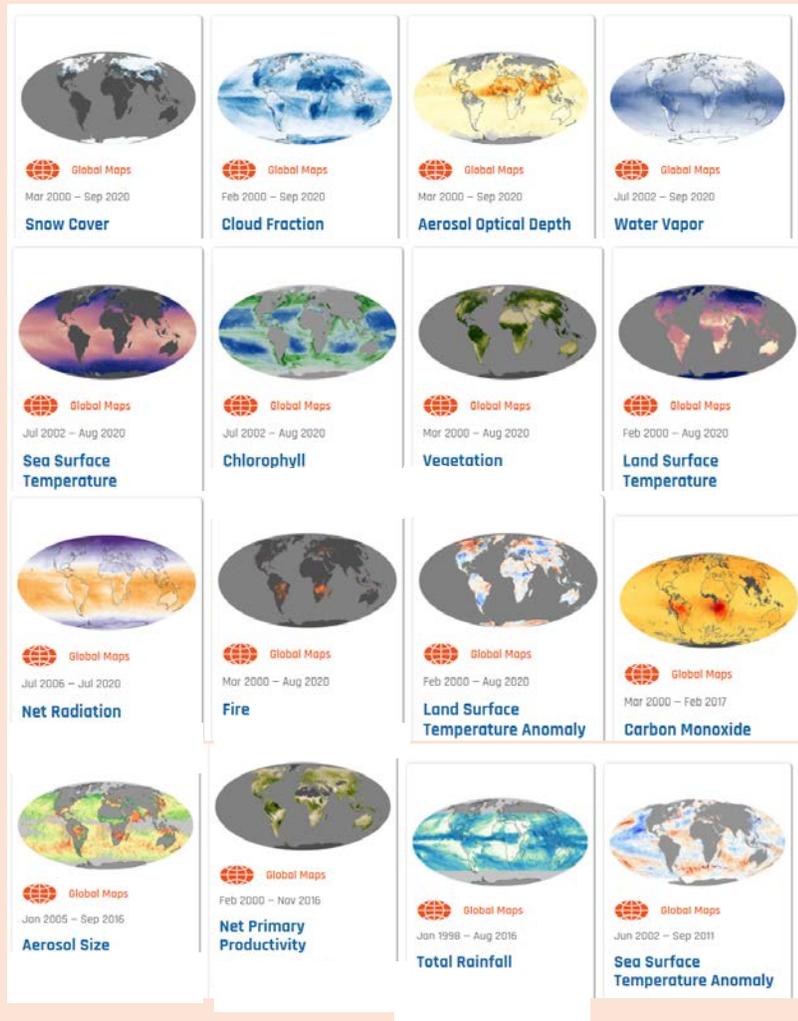


Figure 17.7 NASA Earth Observatory global maps. https://earthobservatory.nasa.gov/global-maps?utm_campaign=nav20&utm_source=topnav&utm_medium=globalmaps

Another good example of the data acquisition utility of satellites is their ability to supply data that can be used to accurately map global vegetation including ocean plankton. Figure 17.8 shows a map of global vegetative biomass capable of converting CO₂ to plant tissue. Figure 17.9 shows ocean chlorophyll concentrations. Figure 17.9 shows land use including vegetative cover (available for fifty years).

This information is being enhanced with additional space-based platforms that are capable of mapping ice cover, Figure 17.11, space weather, Figure 17.12 and the Global Ecosystem Dynamics Investigation instrument (GEDI) that is mounted on the International Space Station. GEDI produces the first high resolution laser ranging observations of the 3D structure of the Earth. It makes precise measurements of forest canopy height, canopy

vertical structure, and surface elevation. GEDI radically improves our ability to characterize important carbon and water cycling processes, biodiversity, and habitat.

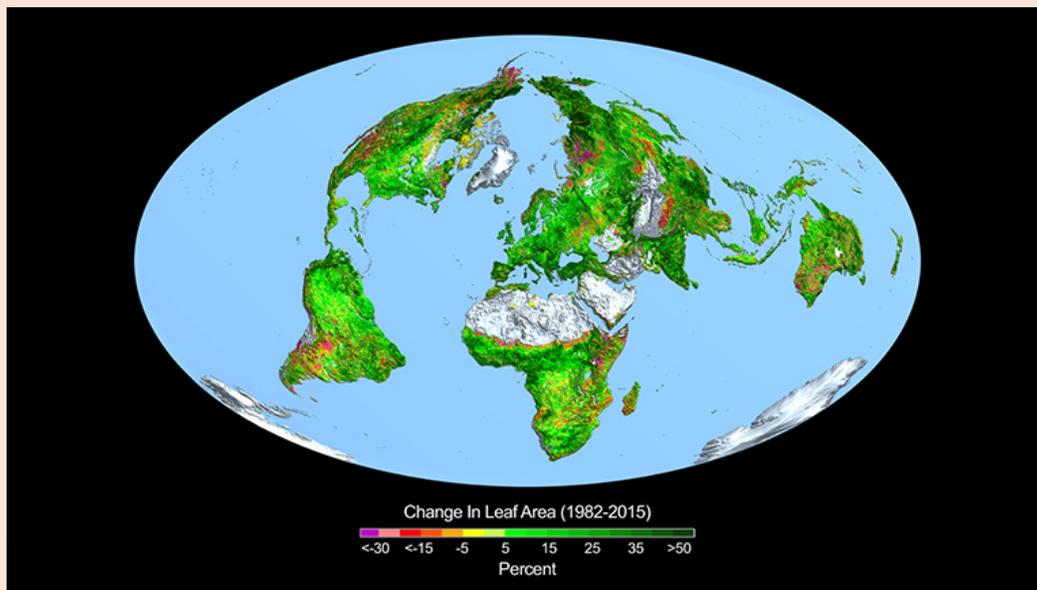


Figure 17.8 Assessment of global vegetative biomass capable of converting CO_2 to plant tissue using satellite carbon dioxide data. <https://climate.nasa.gov/news/2436/co2-is-making-earth-greenerfor-now/>

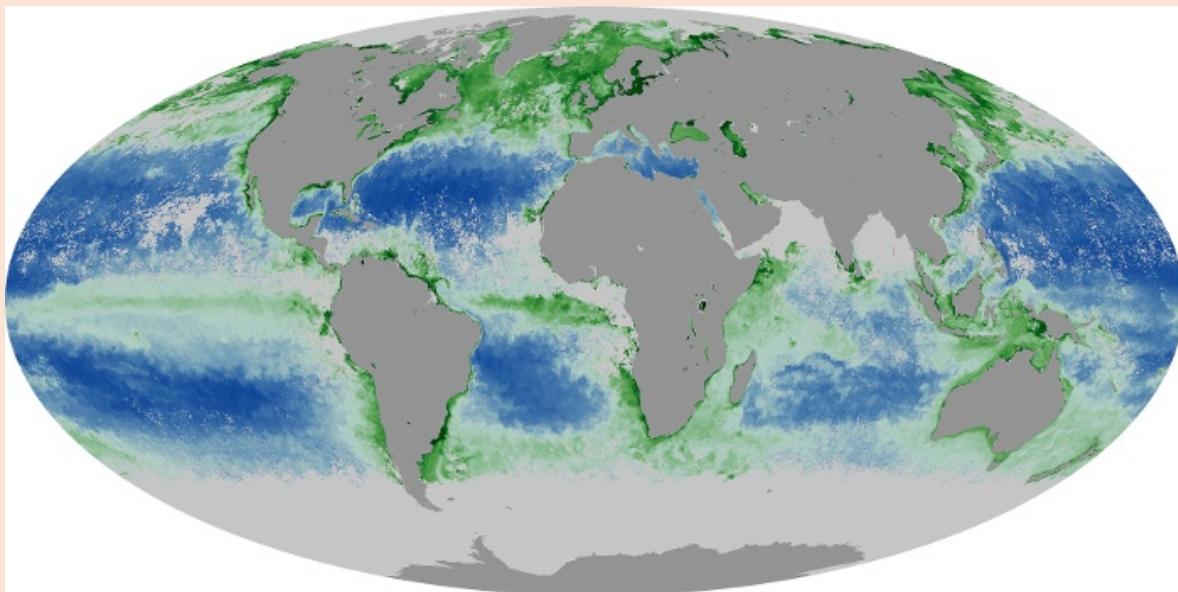
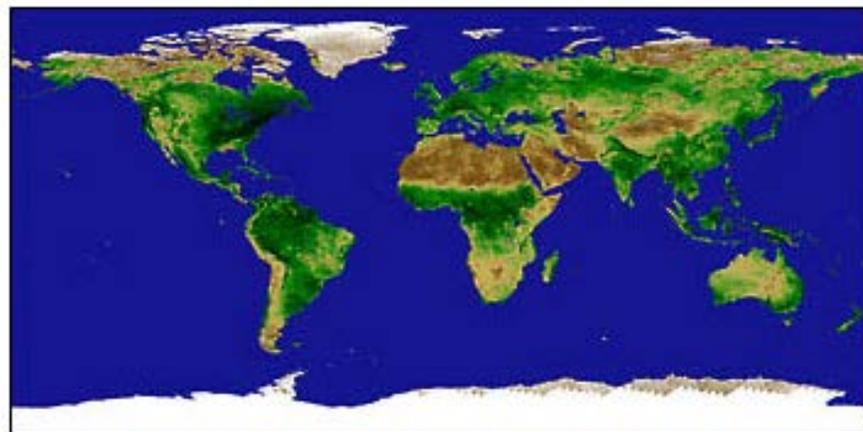


Figure 17.9 Ocean chlorophyll concentrations. https://earthobservatory.nasa.gov/global-maps/MY1DMM_CHLORA



Normalized Differential Vegetation Index, Sept. 21–31, 1992 This is one of the simplest types of land cover classification maps, showing only the amount of green vegetation. Heavily vegetated areas are dark green, moderate vegetation is light green, sand, rock, snow, and ice are shown as tan and white.

Figure 17.10 Land use including vegetation and type of vegetative cover. https://earthobservatory.nasa.gov/features/LandCover/land_cover_3.php

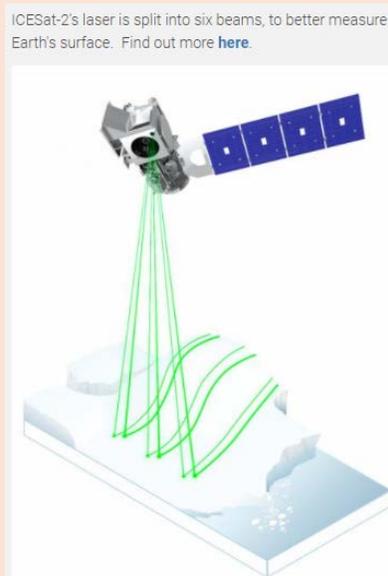


Figure 17.11 Ice thickness. <https://icesat-2.gsfc.nasa.gov/>



Figure 17.12 Space weather satellite.

<https://www.spaceweatherlive.com/en/news/view/399/20191209-welcome-goes-16.html>

GEDI's data on surface structure are also of immense value for weather forecasting, forest management, glacier and snowpack monitoring, and the generation of more accurate digital elevation models. GEDI provides the missing piece – 3D structure – in NASA's observational assets which enables us to better understand how the Earth behaves as a system, and guides the actions we can take to sustain critical resources.

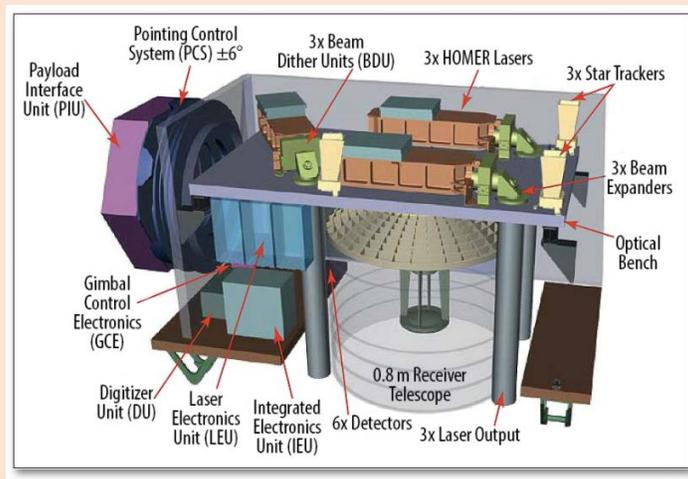


Figure 17.13 GEDI instrument showing lasers, optical paths, detectors and digitizers.

<https://gedi.umd.edu/instrument/instrument-overview/>



Figure 17.14 GEDI, shown in gold, as mounted on the International Space Station.

17.4 Climate models

There are basically three classes of models:

1. General circulation (atmosphere - ocean) models, AOGCM's or GCM's used in AR4 and also AR5.
2. AR5 also uses Earth System Models or ESMs that include various biochemical cycles, (carbon, sulphur, ozone).
3. Regional climate change (circulation) models or RCM's. High resolution regional climate models are known as convection permitting models or CPM's.

A very good description is provided by IPCC fifth assessment report, AR5, Chapter 9, Working Group 1 (scientific basis). Each of these model classes are important on their own, require different resources to run and meet different modelling needs.

17.4.1 Atmosphere-ocean general circulation models (AOGCM)

Atmosphere-ocean general circulation models (AOGCM) combine atmospheric general circulation models (AGCM) discussed in Chapter 7 and ocean general circulation models (OGCM) discussed in Chapter 8. Sub-models to consider other hydrological elements such as sea ice, evapotranspiration discussed in Chapter 6 and other elements of the energy budget (such as GHG emissions, clouds, etc.) discussed in Chapter 4 to provide full climate models. See Figures 17.2 and 17.3.

17.4.2 Earth System Models (ESM)

An Earth System Model (ESM) is a coupled climate model that also models the movement of carbon (and other substances) through the earth system. They are the current state-of-the-art models. They may expand on AOGCMs to include the carbon cycle, aerosols, methane cycle and permafrost, global vegetation and wildfires, effects of land use, chemistry-climate interactions, land ice sheets, penetration of solar radiation into the ocean (phytoplankton) and more. Figure 17.15 illustrates the relationship between AOGCMs and ESMs. These models challenge computational resources. This issue is partly resolved using Earth System Models of Intermediate Complexity (EMICs) which reduce computational demands by using lower resolution, coarser computational grid.

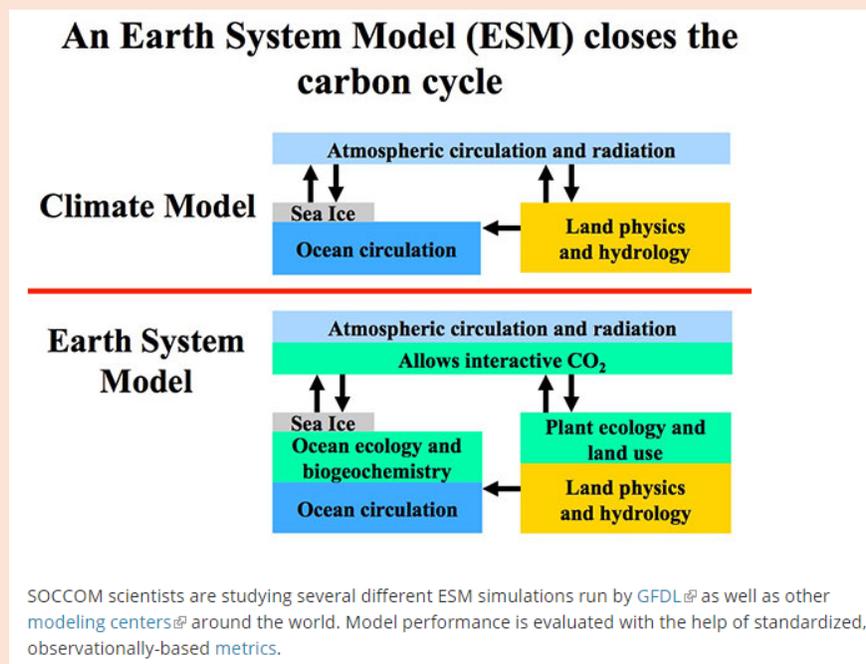


Figure 17.15 Comparison between a climate model and an earth system model
<https://socc.com.princeton.edu/content/what-earth-system-model-esm>

17.4.3 Regional climate models

Regional climate models (RCMs) are limited-area models. These models are used to downscale the global model simulations for a particular geographical region of interest to provide more

detailed information (higher resolution) on climate variation throughout the region. The global model simulations provide the boundary conditions for the RCMs.

For example, an RCM might want to use more detailed topographic information to be able to consider the effects of mountains. T340 may be considered too coarse a resolution (30km by 30km grid) and an RCM might try to take this down to 5km by 5km or less to provide a better idea as to how climate varies at the local level.

High resolution regional models (https://www.carbonbrief.org/guest-post-how-high-resolution-climate-models-will-help-europe-plan-for-extreme-weather?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20210413&utm_medium=email&utm_source=Revue%20Daily and <https://link.springer.com/article/10.1007/s00382-021-05708-w>) that use horizontal grid spacing of approximately 3 km are considered to produce improved estimates mean precipitation, precipitation intensity and frequency and heavy precipitation on daily and hourly timescales (convective storms). These models are known as convection permitting models or CPM's. A discussion on what is actually being modelled is reported in <https://www.carbonbrief.org/guest-post-why-climate-change-could-mean-heavier-bouts-of-summer-rain-in-the-uk> .

17.4.4 Coupled model intercomparison project, CMIP5

The IPCC reports evaluations of several climate models developed and supported by organizations around the world that were used to assess impacts of future climate change. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter09_FINAL.pdf. The models used in AR5, CMIP5, are listed in Table 17.1. The models used in AR4, CMIP3, are listed in Table 17.2. This table shows the features of each model and the resolution with which each feature is considered. Further details may be found in <https://pcmdi.llnl.gov/index.html> .

Table 17.3 lists and describes several EMICs which were also compared. The results of these comparisons are detailed in the report.

As one might expect the various models demonstrated different strengths and weaknesses. This information is relevant when selecting a model or models for a particular study.

Table 9.1 | Main features of the Atmosphere–Ocean General Circulation Models (AOGCMs) and Earth System Models (ESMs) participating in Coupled Model Intercomparison Project Phase 5 (CMIP5), and a comparison with Coupled Model Intercomparison Project Phase 3 (CMIP3), including components and resolution of the atmosphere and the ocean models. Detailed CMIP5 model description can be found in Table 9.A.1 (* refers to Table 9.A.1 for more details). Official CMIP model names are used. HT stands for High-Top atmosphere, which has a fully resolved stratosphere with a model top above the stratopause. AMIP stands for models with atmosphere and land surface only, using observed sea surface temperature and sea ice extent. A component is coloured when it includes at least a physically based prognostic equation and at least a two-way coupling with another component, allowing climate feedbacks. For aerosols, lighter shading means 'semi-interactive' and darker shading means 'fully interactive'. The resolution of the land surface usually follows that of the atmosphere, and the resolution of the sea ice follows that of the ocean. In moving from CMIP3 to CMIP5, note the increased complexity and resolution as well as the absence of artificial flux correction (FC) used in some CMIP3 models.

	Model name	AOGCM				FC	ESM			
		Atmos	Land Surface	Ocean	Sea-Ice		Aerosol	Atmos Chem	Land Carbon	Ocean BGC
CMIP5	ACCESS1.0, ACCESS1.3	Australia								
	BCC-CSM1.1, BCC-CSM1.1(m)	China								
	BNU-ESM	China								
	CanCM4	Canada								
	CanESM2	Canada								
	CCSM4									
	CESM1 (BGC)									
	CESM1 (WACCM)	USA	HT							
	CESM1 (FASTCHEM)									
	CESM1 (CAM5)									
	CESM1 (CAM5.1-FV2)	USA								
	CMCC-CM, CMCC-CMS	Italy	HT							
	CMCC-CESM		HT							
	CNRM-CM5	France								
	CSIRO-Mk3.6.0	Australia								
	EC-EARTH	Europe								
	FGOALS-g2	China								
	FGOALS-s2	China								
	FIO-ESM v1.0	China								
	GFDL-ESM2M, GFDL-ESM2G									
	GFDL-CM2.1	USA								
	GFDL-CM3		HT							
	GISS-E2-R, GISS-E2-H	USA	HT					p2, p3*	p2, p3*	
	GISS-E2-R-CC, GISS-E2-H-CC		HT					p2, p3*	p2, p3*	
	HadGEM2-ES									
	HadGEM2-CC	UK	HT							
	HadCM3									
	HadGEM2-AO	Korea								
INM-CM4	Russia									
IPSL-CM5A-LR / -CM5A-MR / -CM5B-LR	France	HT								
MIROC4h, MIROC5		HT								
MIROC-ESM	Japan	HT								
MIROC-ESM-CHEM		HT								
MPI-ESM-LR / -ESM-MR / -ESM-P	Germany	HT								
MRI-ESM1	Japan	HT								
MRI-CGCM3		HT								
NCEP-CFSv2	USA									
NorESM1-M										
NorESM1-ME	Norway									
AMIP	GFDL-HIRAM C180 / -HIRAM C360	USA								
	MRI-AGCM3.2S / -AGCM3.2H	Japan								

Table 17.1 Comparison of AOGMs and ESMs, CMIP5. <https://pcmdi.llnl.gov/index.html> and https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter09_FINAL.pdf

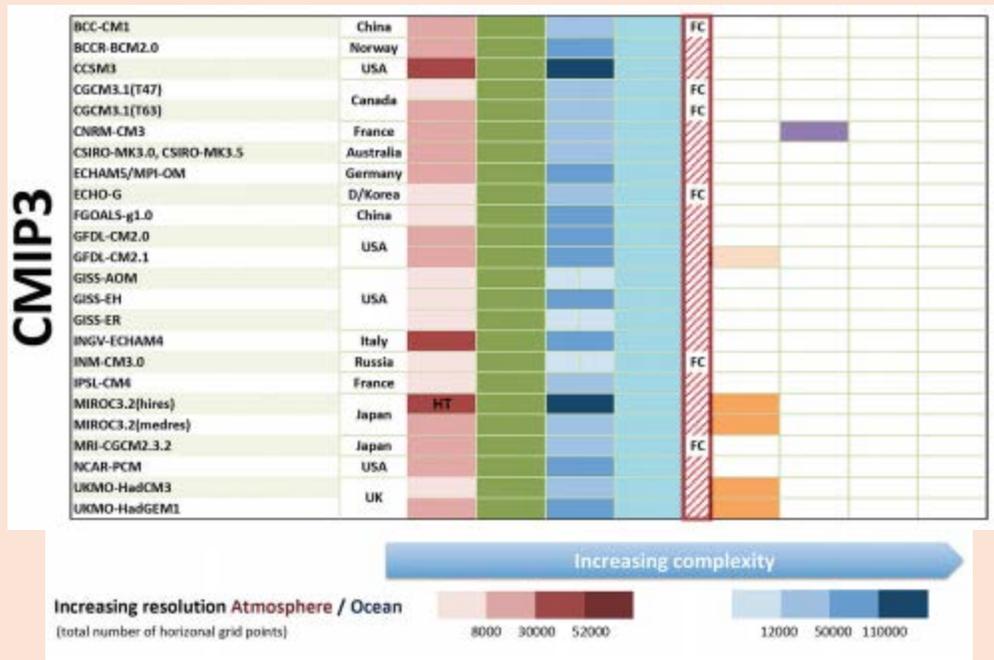


Table 17.2 Comparison of AOGMs and ESMs, CMIP3. <https://pcmdi.llnl.gov/index.html> and https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter09_FINAL.pdf

Table 9.2 | Main features of the EMICs assessed in the AR5, including components and complexity of the models. Model complexity for four components is indicated by colour shading. Further detailed descriptions of the models are contained in Table 9.A.2.

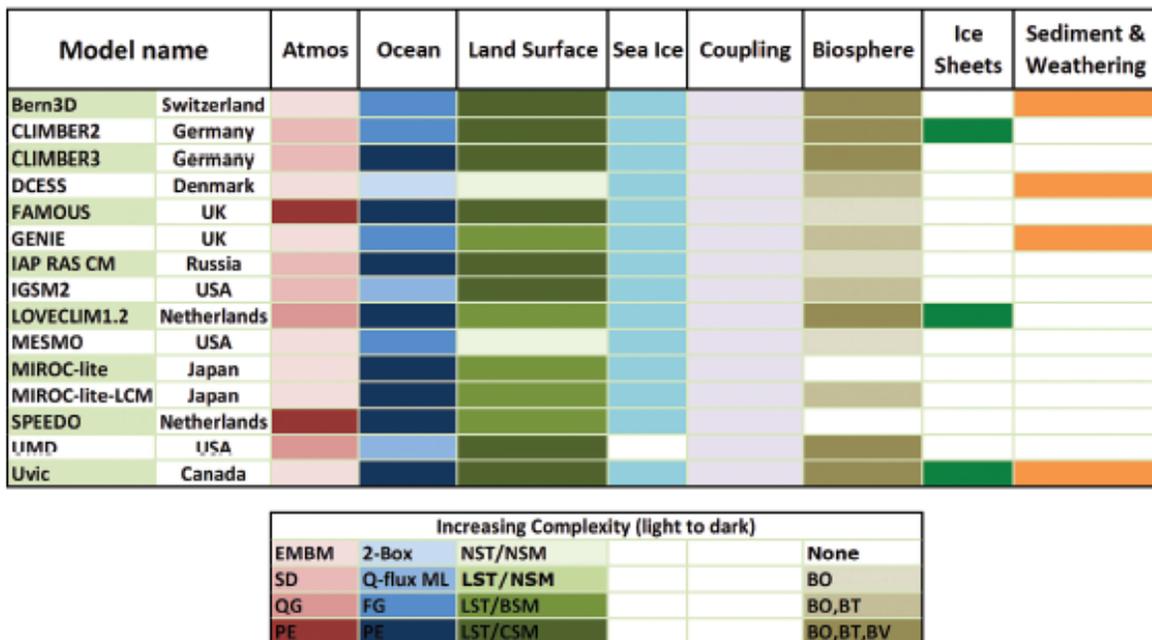


Table 17.3 Comparison of EMICs. <https://pcmdi.llnl.gov/index.html> and https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter09_FINAL.pdf

17.5 Model predictions of surface temperature change compared to observed

The only data set that is available with which to evaluate model predictions is the temperature data between 1850 to present, the instrumental period. Several comparisons are made.

Both CMIP3 and CMIP5 models were compared to observed global temperature as shown in Figure 17.16 (a), (b) and (c). The observed global temperature set used for comparison is an average of three data sets shown in the small graph in the upper left corner of Figure 17.16 (b) similar to that shown in Figure 14.1. When both anthropogenic forcings and natural forcings were used, Figure 17.16 (a), model results compare reasonably to observed temperature. When only natural forcings were used, Figure 17.16 (b) model results did not match observed temperature. When only anthropogenic forcings were used, Figure 17.16 (c), model results did not match observed temperature. Clearly, both anthropogenic and natural forcings must be considered for models to predict observed global temperature which they do quite well.

Figure 17.17 shows a comparison of model predictions using natural forcings only and using both natural and anthropogenic forcings to observed temperature on each of the continents and oceans. The agreement between model predictions and observed temperatures is very good when both natural and anthropogenic forcings are used.

Figure 17.18 shows a comparison of model predictions using natural forcings only and using both natural and anthropogenic forcings to observed global ocean, land, and land and ocean temperature. The agreement between model predictions and observed temperatures is very good when both natural and anthropogenic forcings are used. A similar comparison was made on prediction of ocean heat content which again demonstrated very good agreement between model predictions and observed when both natural and anthropogenic forcings are used.

Chapter 10 of AR5 provides an extensive discussion on detection and attribution of a wide variety of climate features of interest and the confidence that climate models can be used to assess them. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter10_FINAL.pdf

The results shown in Figures 17.16, 17.17 and 17.18 provide considerable confidence, at the intuitive level, that the climate models used by IPCC are predicting PAST changes well enough to be used for PREDICATION PURPOSES.

1. Impacts (possible/probable).
2. Adaptation (if desired).
3. Mitigation (if desired).

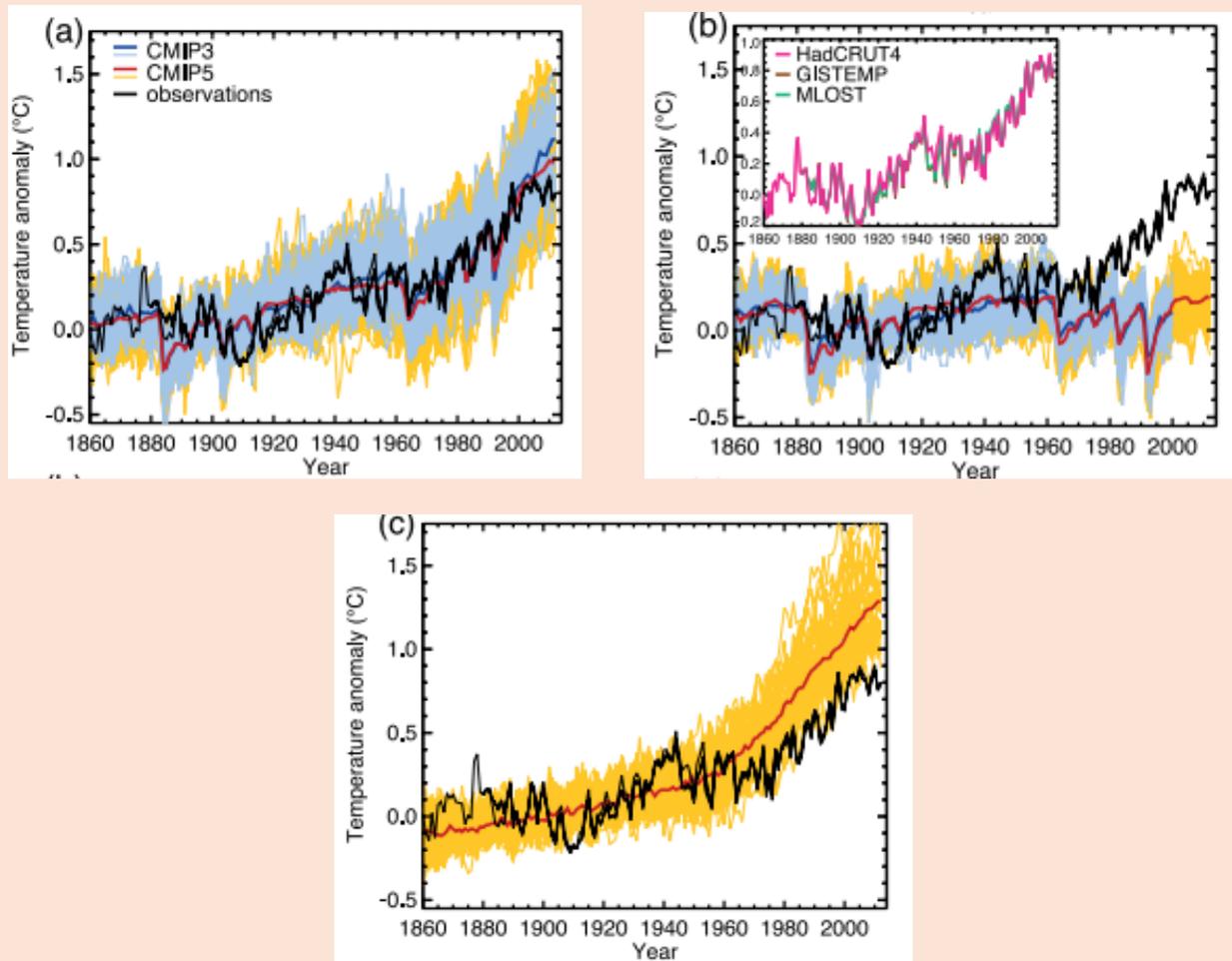


Figure 17.16 Estimates of global mean surface temperature (GMST) using averages of CMIP3(blue) and CMIP5(yellow) models using (a) both anthropogenic and natural forcings; (b) only natural forcings; and (c) only anthropogenic forcings compared to observed temperatures from 1850 to present. The red line is an average of CMIP5 predictions. CMIP3 models were not available for (c).

https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter10_FINAL.pdf

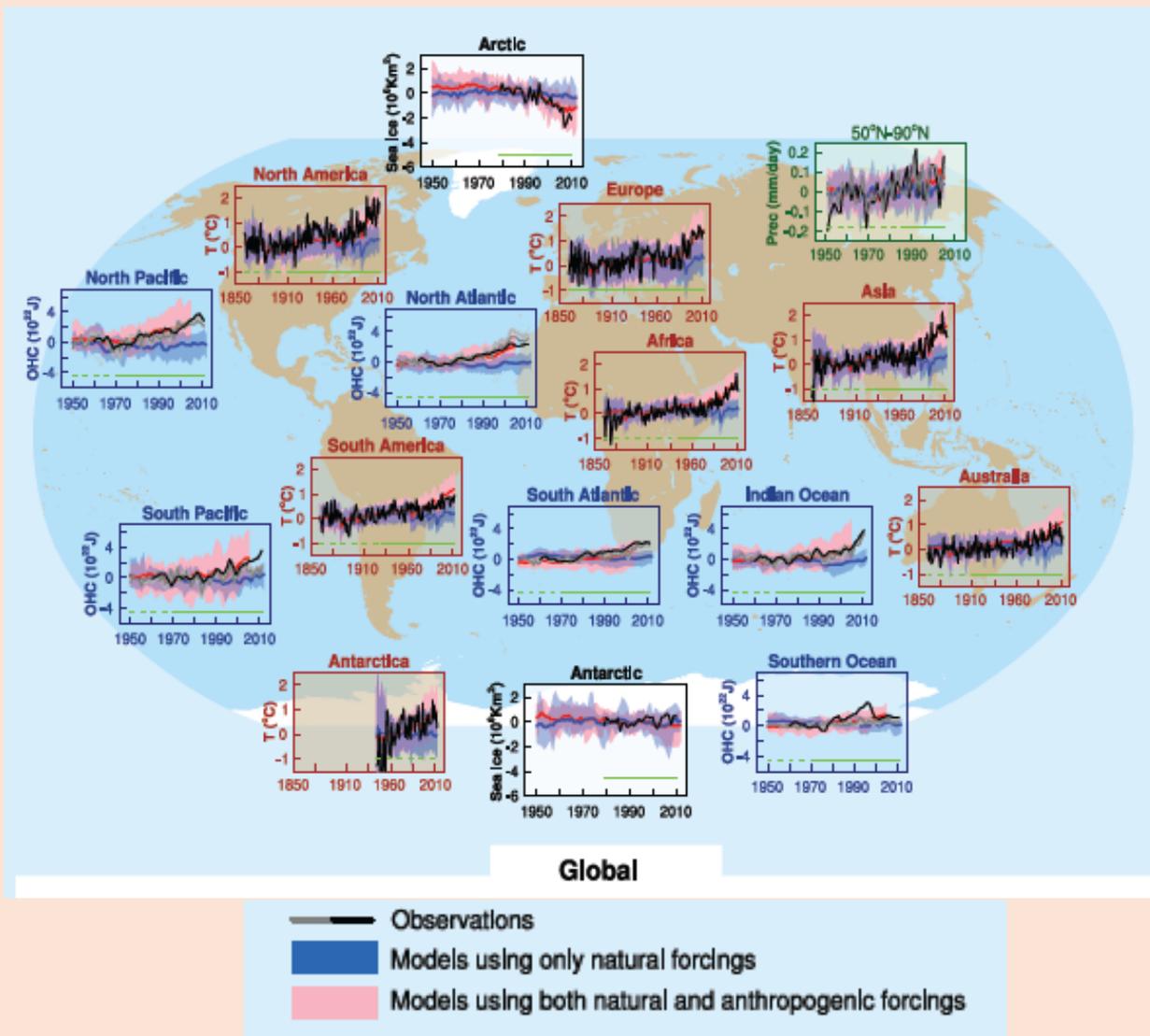


Figure 17.17 Comparison of model predictions to observed temperature on each of the continents.

https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter10_FINAL.pdf

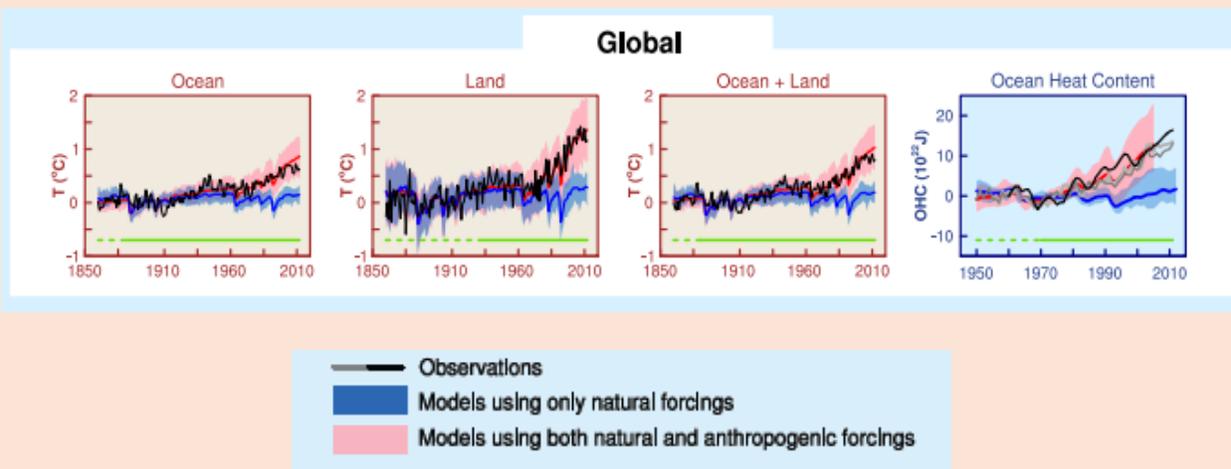


Figure 17.18 Comparison of model results when performed with only natural forcings and using both natural and anthropogenic forcings to observed global temperature of the ocean, land, ocean and land and ocean heat content.

https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter10_FINAL.pdf

17.6 Assessment of model predictions

Predictions using climate models, of any type, are assessed using qualitative descriptors.

Table 17.4 lists the meaning of confidence terms.

Table 17.5 provides guidance as to how to use confidence terms.

Table 17.6 lists the meaning likelihood terms used in old IPCC reports.

Table 17.7 summary of IPCC usage of calibrated language.

Confidence Terminology	Degree of confidence in being correct
<i>Very high confidence</i>	At least 9 out of 10 chance
<i>High confidence</i>	About 8 out of 10 chance
<i>Medium confidence</i>	About 5 out of 10 chance
<i>Low confidence</i>	About 2 out of 10 chance
<i>Very low confidence</i>	Less than 1 out of 10 chance

Table 17.4 Confidence terminology used in IPCC reports.

https://www.ipcc.ch/site/assets/uploads/2017/08/AR5_Uncertainty_Guidance_Note.pdf

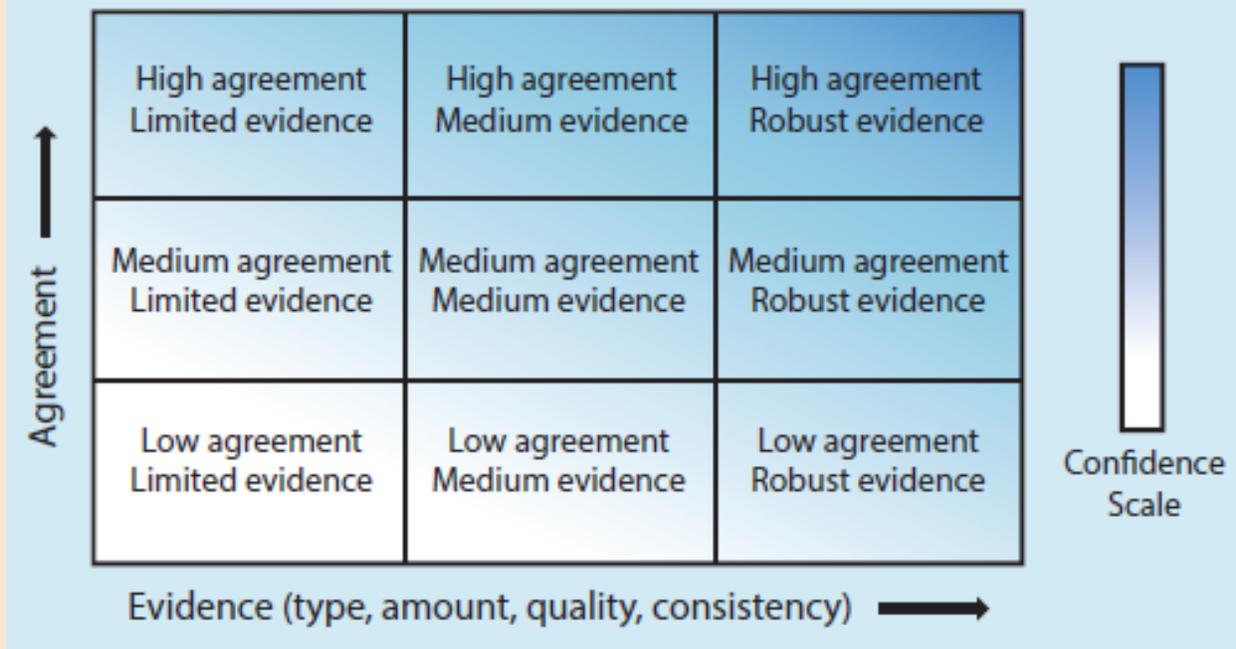


Table 17.5 Agreement-evidence scale used in IPCC reports to aid in use of confidence descriptors.

https://www.ipcc.ch/site/assets/uploads/2017/08/AR5_Uncertainty_Guidance_Note.pdf

Likelihood Terminology	Likelihood of the occurrence/ outcome
<i>Virtually certain</i>	> 99% probability
<i>Extremely likely</i>	> 95% probability
<i>Very likely</i>	> 90% probability
<i>Likely</i>	> 66% probability
<i>More likely than not</i>	> 50% probability
<i>About as likely as not</i>	33 to 66% probability
<i>Unlikely</i>	< 33% probability
<i>Very unlikely</i>	< 10% probability
<i>Extremely unlikely</i>	< 5% probability
<i>Exceptionally unlikely</i>	< 1% probability

Table 17.6 Likelihood terminology used in IPCC reports.

https://www.ipcc.ch/site/assets/uploads/2017/08/AR5_Uncertainty_Guidance_Note.pdf

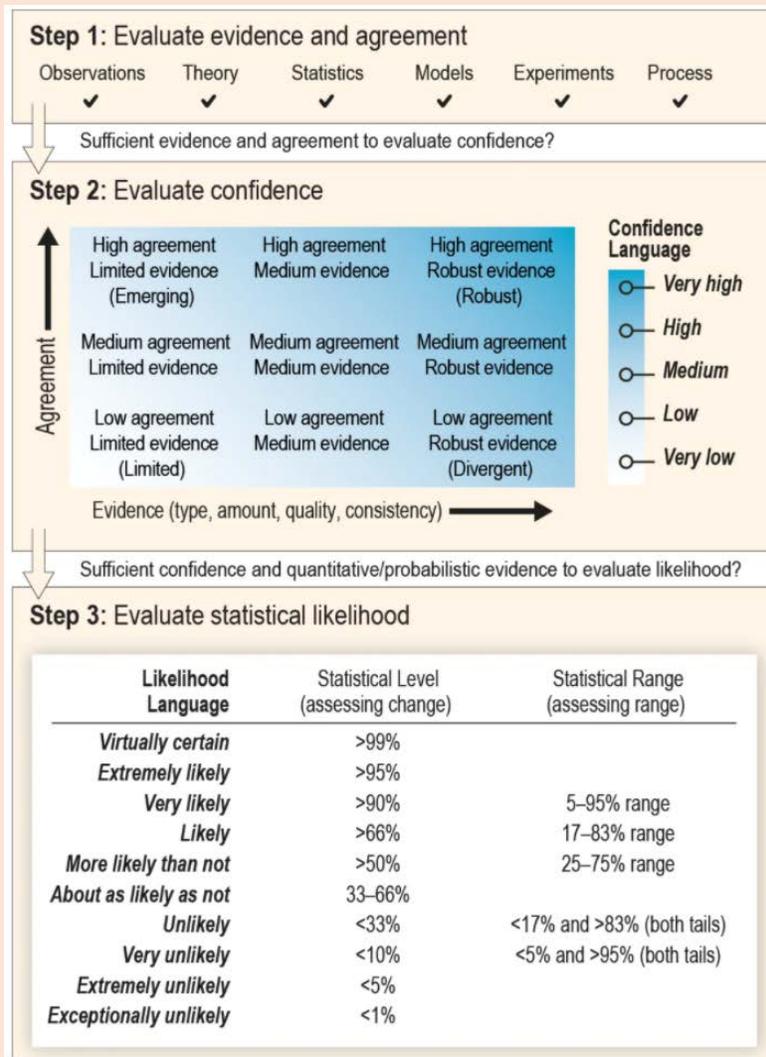


Table 17.7 Method for IPCC usage of calibrated language.

17.7 Information support

Key web sites:

1. Climate models. <https://www.climate.gov/maps-data/primer/climate-models>
2. Early climate modelers got global warming right. <https://news.berkeley.edu/2019/12/04/early-climate-modelers-got-global-warming-right-new-report-finds/>
3. Evaluating the performance of past climate model projections. <https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2019GL085378>
4. Study confirms climate models are getting future warming projections right. <https://climate.nasa.gov/news/2943/study-confirms-climate-models-are-getting-future-warming-projections-right/>
5. Global maps, NASA, Earth observatory. <https://earthobservatory.nasa.gov/global-maps/MYD28M>
6. Climate model diagnosis and intercomparison. <https://pcmdi.llnl.gov/index.html>
7. Evaluation of climate models. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter09_FINAL.pdf
8. Detection and attribution of climate change: global to regional. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter10_FINAL.pdf
9. Climate modelling. <https://scied.ucar.edu/longcontent/climate-modeling>
10. Resolution of climate models. https://eo.ucar.edu/staff/russell/climate/modeling/climate_model_resolution.html
11. Use of models in detection and attribution of climate change. <https://www.geos.ed.ac.uk/~ghegerl/assets/WIRES.pdf>
12. Climate change, the IPCC scientific assessment. https://www.ipcc.ch/site/assets/uploads/2018/03/ipcc_far_wg_1_full_report.pdf
13. NASA Global precipitation measurement mission, GPM. https://www.nasa.gov/mission_pages/GPM/overview/index.html

14. NASA CO2 is making Earth greener for now.
<https://climate.nasa.gov/news/2436/co2-is-making-earth-greenerfor-now/>
15. NASA explore Earth. <https://www.nasa.gov/topics/earth/index.html>
16. IPCC Chapter 1.
https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter1.pdf
17. Earth system model. <https://socom.princeton.edu/content/what-earth-system-model-esm>
18. General circulation model.
https://en.wikipedia.org/wiki/General_circulation_model
19. Earth systems models of intermediate complexity.
https://en.wikipedia.org/wiki/Earth_systems_model_of_intermediate_complexity
20. Atmosphere-ocean general circulation models (AOGCMs).
<https://www.narccap.ucar.edu/about/aogcms.html>
21. Evaluation of climate models.
https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter09_FINAL.pdf
22. Guide for treatment of uncertainties, IPCC.
https://www.ipcc.ch/site/assets/uploads/2017/08/AR5_Uncertainty_Guidance_Note.pdf
23. High resolution regional climate models, Springer Link.
<https://link.springer.com/article/10.1007/s00382-021-05708-w>
24. High resolution regional climate models review, Carbon Brief.
https://www.carbonbrief.org/guest-post-how-high-resolution-climate-models-will-help-europe-plan-for-extreme-weather?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20210413&utm_medium=email&utm_source=Revue%20Daily
25. Development of high resolution regional climate models – convection permitting models, Met Office, UK, Carbon Brief. <https://www.carbonbrief.org/guest-post-why-climate-change-could-mean-heavier-bouts-of-summer-rain-in-the-uk>