Session 02 Weather & climate data sources

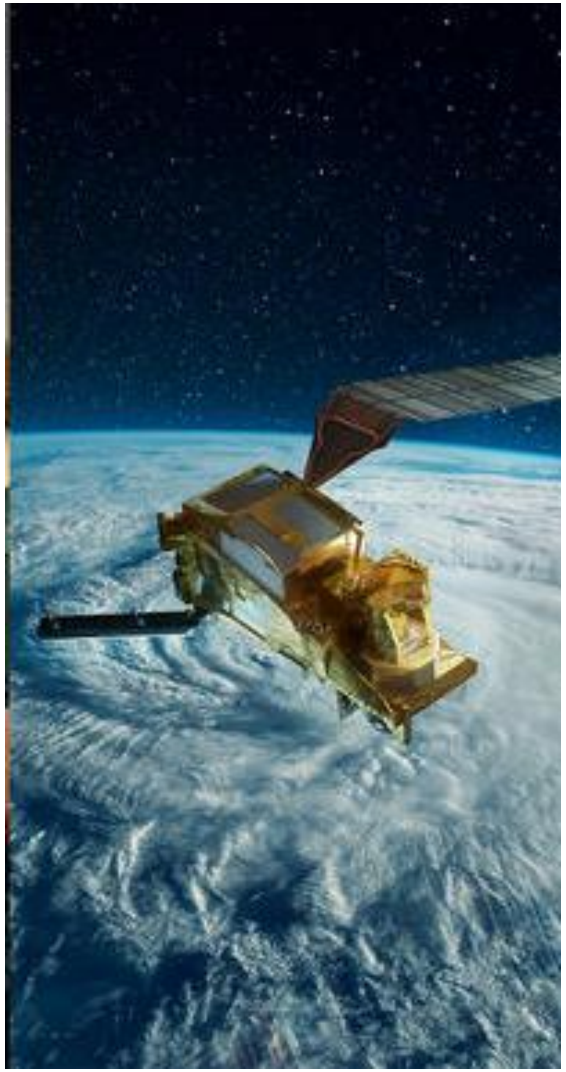
Proyectos en ingeniería de datos e inteligencia artificial

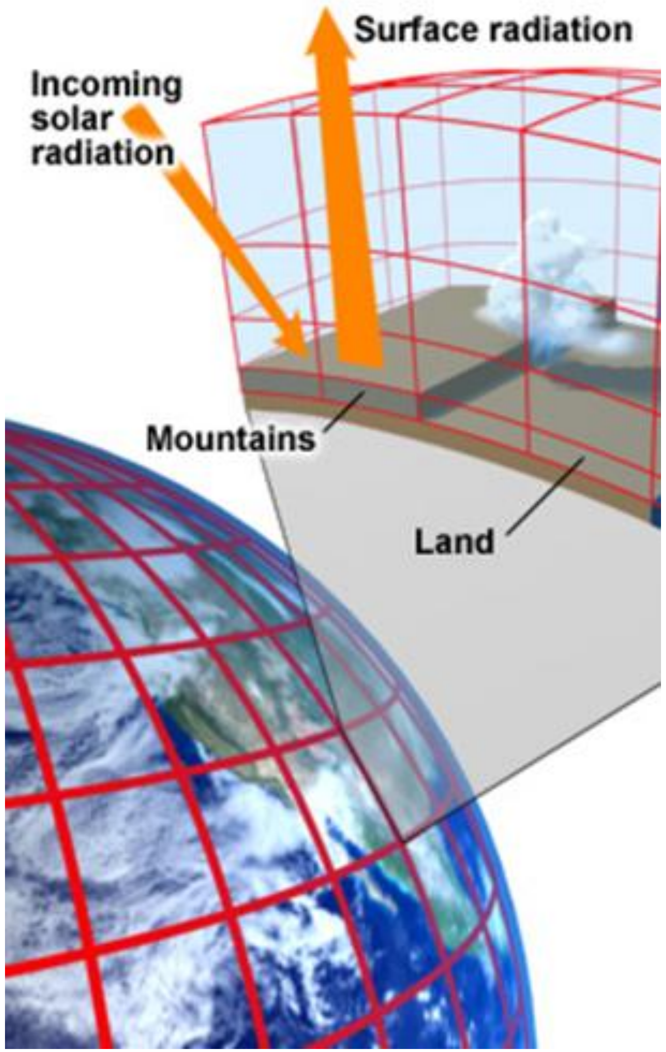
What you will learn

In this session, you will explore the vast amount of data derived from weather and climate analysis. Topics will include observations, models, and reanalysis. You will also learn some key concepts that are essential for working with weather/climate data.

Weather vs **Climate**

“Climate is what you expect; the weather is what you get”

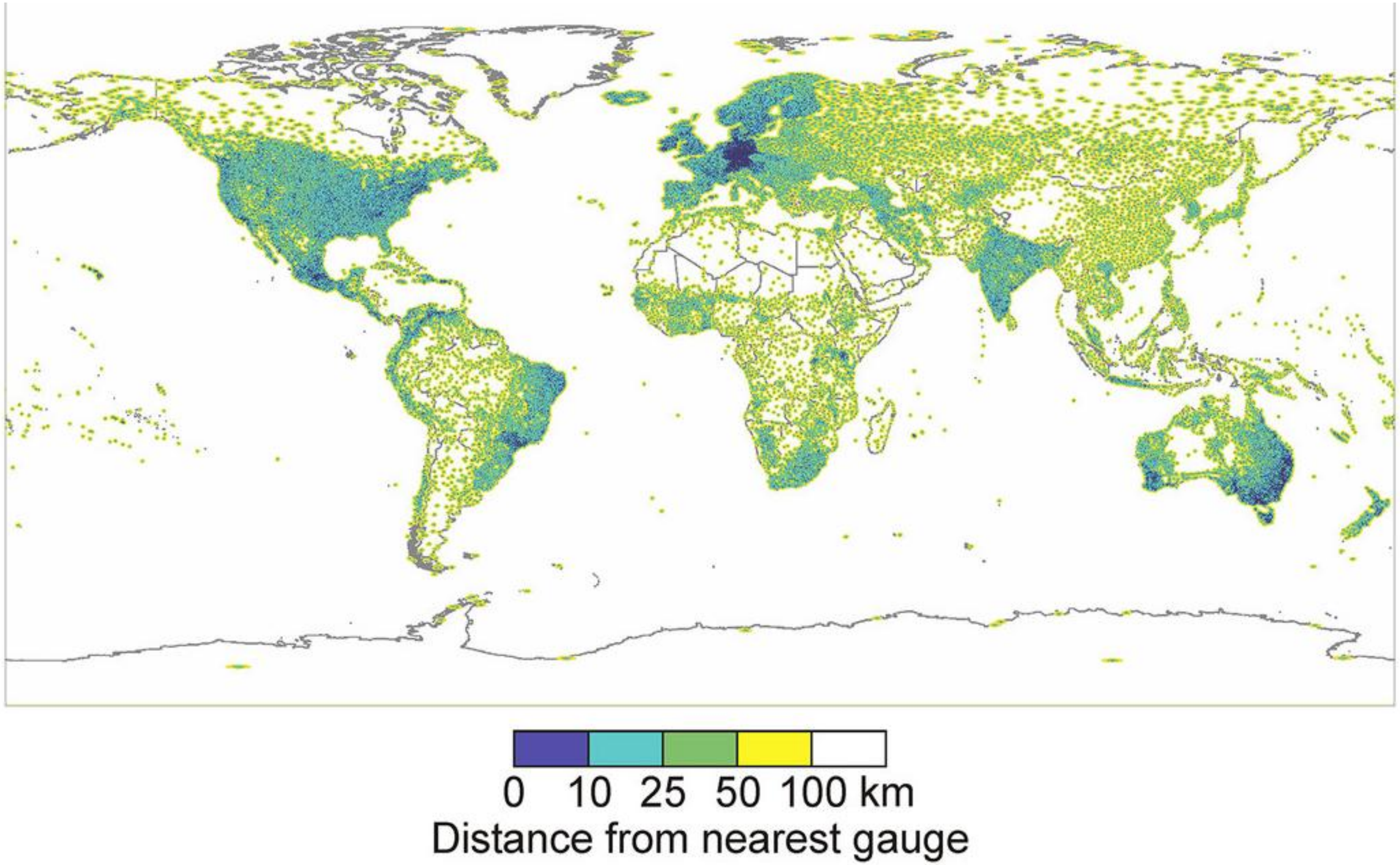


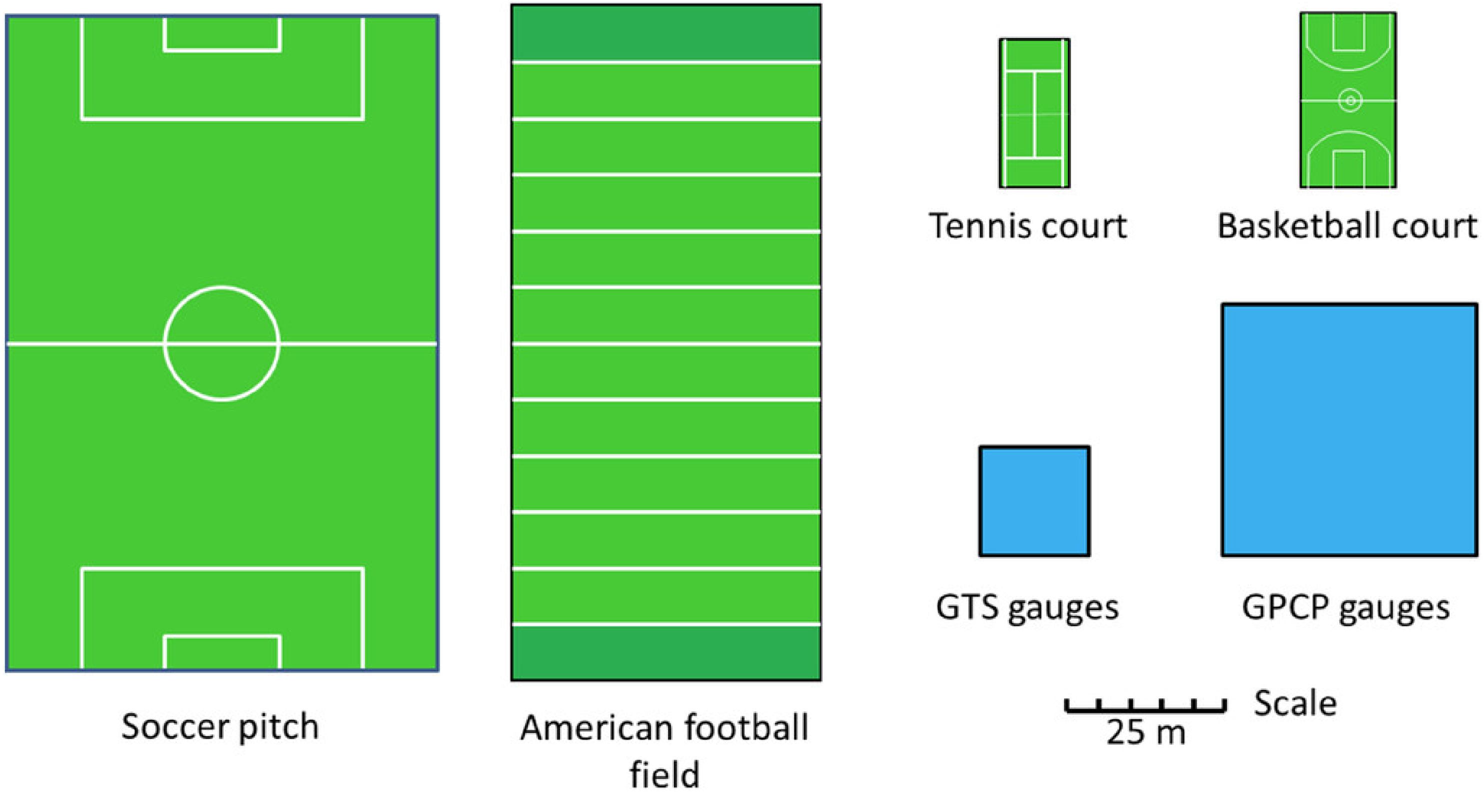


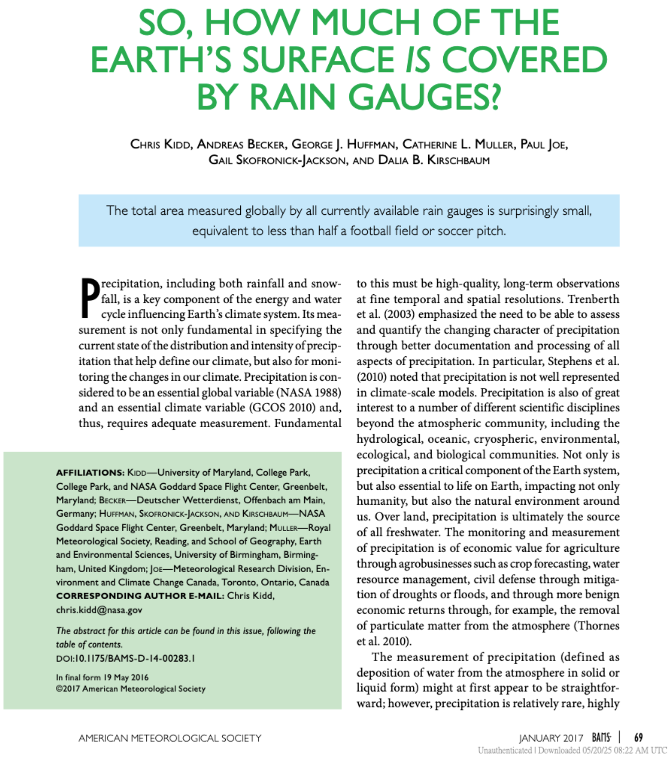
Types of data

- Observations
- Models
- Reanalysis

Ground-based Observations







SO, HOW MUCH OF THE EARTH'S SURFACE *IS* COVERED BY RAIN GAUGES?

Chris Kidd, Andreas Becker, George J. Huffman, Catherine L. Muller, Paul Joe, Gail Skofronick-Jackson, and Dalia B. Kirschbaum

The total area measured globally by all currently available rain gauges is surprisingly small, equivalent to less than half a football field or soccer pitch.

Precipitation, including both rainfall and snowfall, is a key component of the energy and water cycle influencing Earth's climate system. Its measurement is not only fundamental in specifying the current state of the distribution and intensity of precipitation that help define our climate, but also for monitoring the changes in our climate. Precipitation is considered to be an essential global variable (NASA 1988) and an essential climate variable (GCOS 2010) and, thus, requires adequate measurement. Fundamental to this must be high-quality, long-term observations at fine temporal and spatial resolutions. Trenberth et al. (2003) emphasized the need to be able to assess and quantify the changing character of precipitation through better documentation and processing of all aspects of precipitation. In particular, Stephens et al. (2010) noted that precipitation is not well represented in climate-scale models. Precipitation is also of great interest to a number of different scientific disciplines beyond the atmospheric community, including the hydrological, oceanic, cryospheric, environmental, ecological, and biological communities. Not only is precipitation a critical component of the Earth system, but also essential to life on Earth, impacting not only humanity, but also the natural environment around us. Over land, precipitation is ultimately the source of all freshwater. The monitoring and measurement of precipitation is of economic value for agriculture through agrobusinesses such as crop forecasting, water resource management, civil defense through mitigation of droughts or floods, and through more benign economic returns through, for example, the removal of particulate matter from the atmosphere (Thornes et al. 2010).

The measurement of precipitation (defined as deposition of water from the atmosphere in solid or liquid form) might at first appear to be straightforward; however, precipitation is relatively rare, highly

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The abstract for this article can be found in this issue, following the table of contents.

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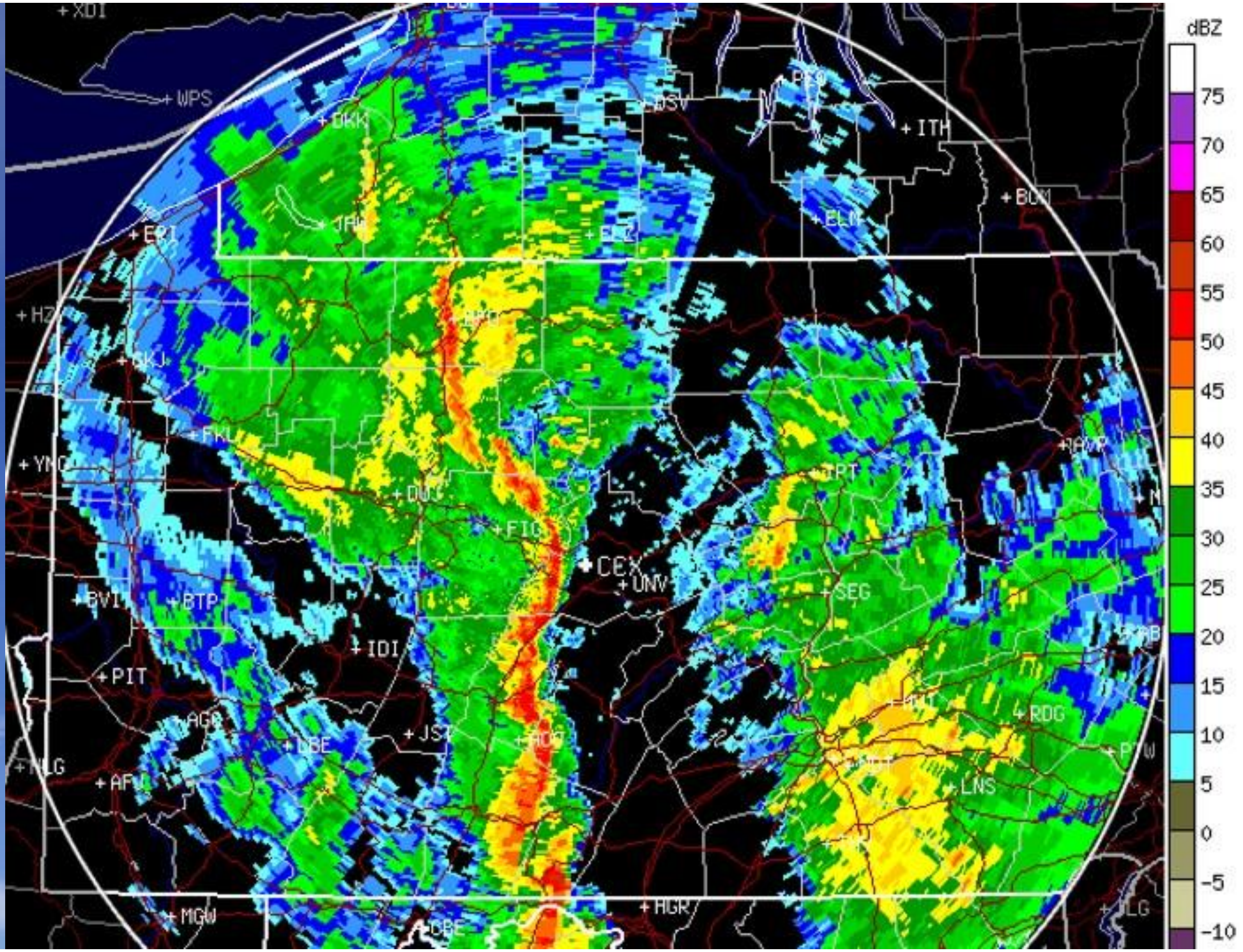
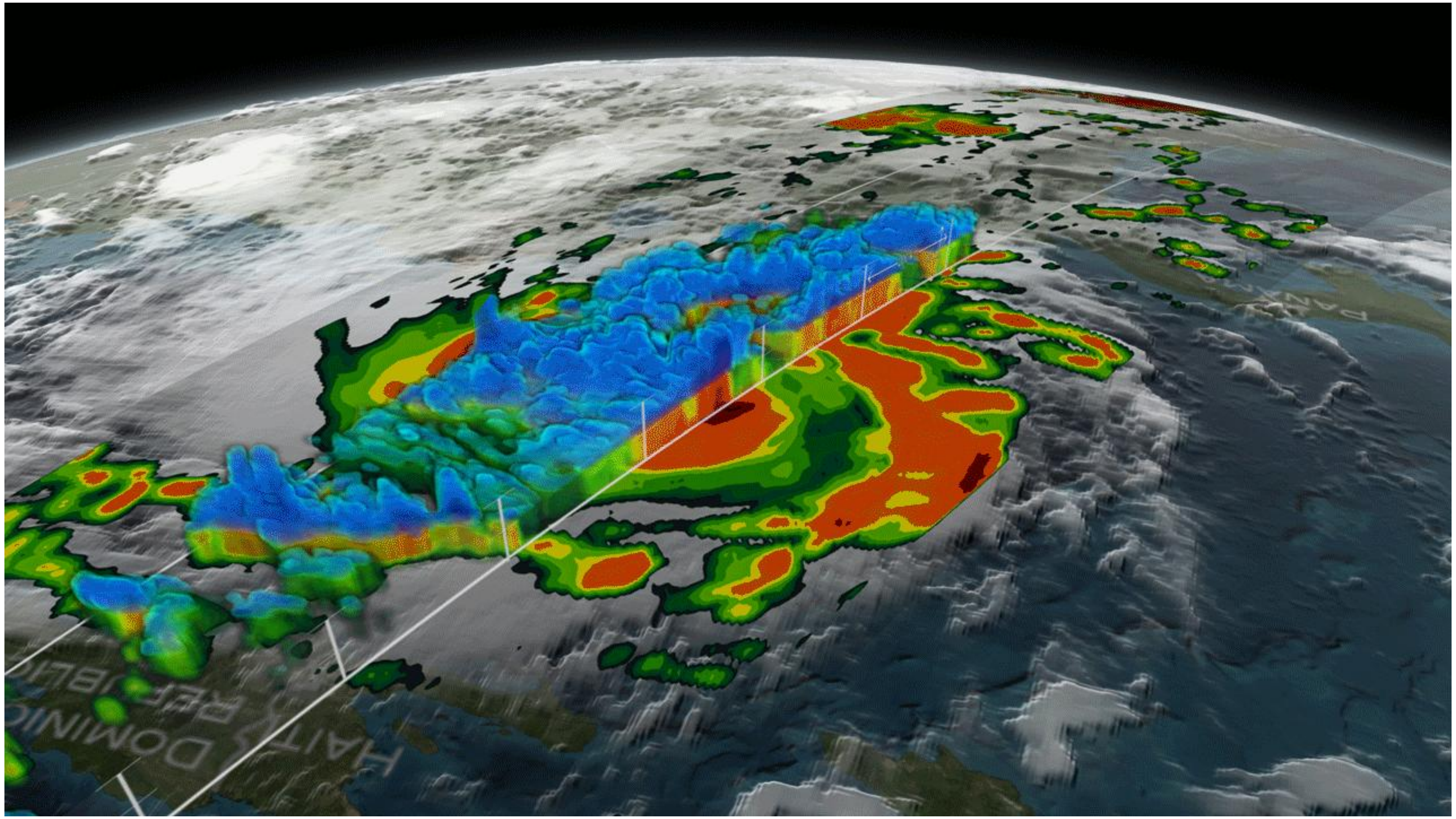
In final form 19 May 2016

Kidd, C., A. Becker, G. J. Huffman, C. L. Muller, P. Joe, G. Skofronick-Jackson, and D. B. Kirschbaum, 2017: So, How Much of the Earth's Surface Is Covered by Rain Gauges?. Bull. Amer. Meteor. Soc., 98, 69–78, https://doi.org/10.1175/BAMS-D-14-00283.1

Ground-based Observations





BAMS Article

The Global Satellite Precipitation Constellation

Current Status and Future Requirements

Chris Kidd, George Huffman, Viviana Maggioni, Philippe Chambon, and Riko Oki

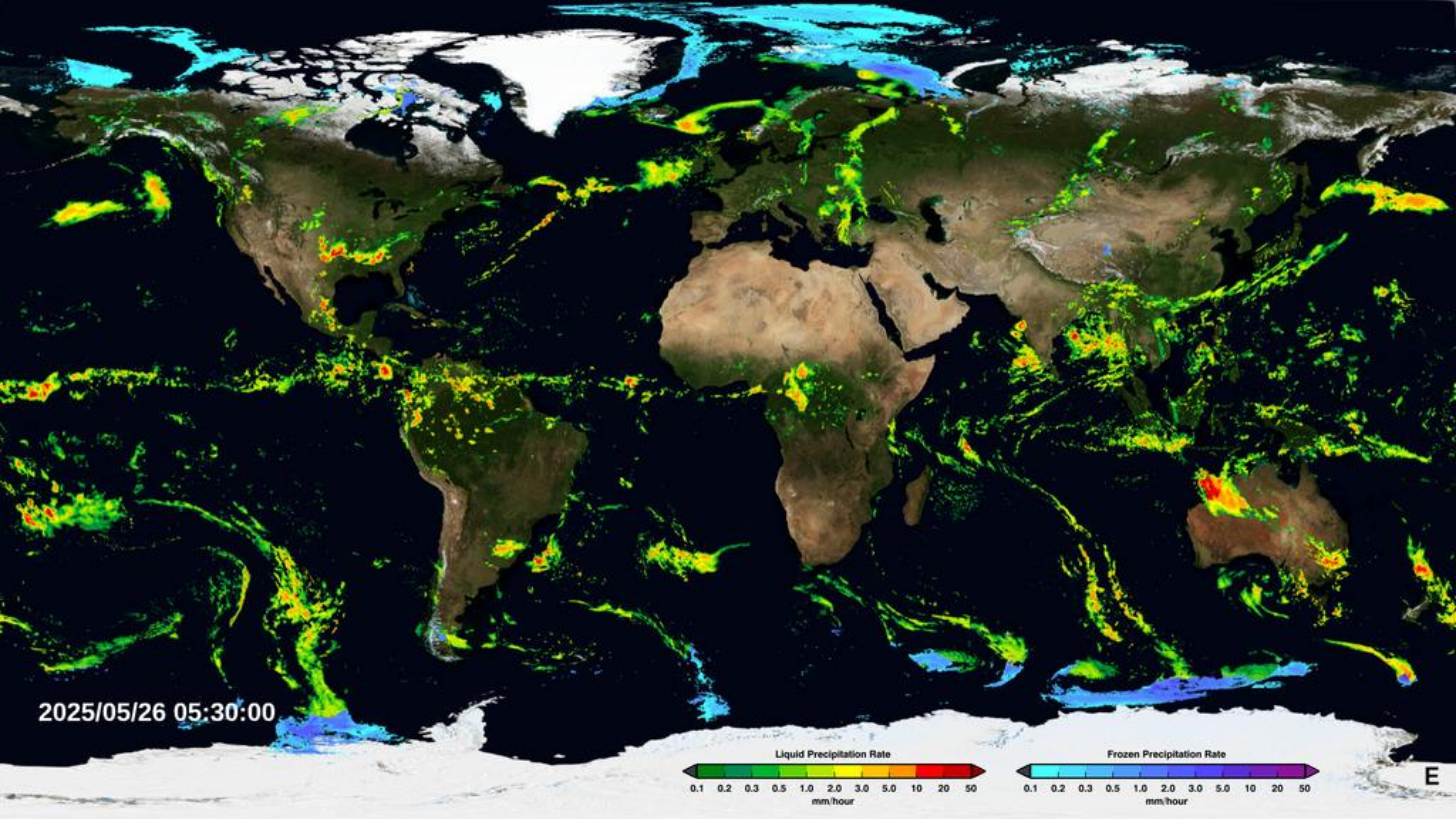
ABSTRACT: To address the need to map precipitation on a global scale, a collection of satellites carrying passive microwave (PMW) radiometers has grown over the last 20 years to form a constellation of about 10–12 sensors at any one time. Over the same period, a broad range of science and user communities has become increasingly dependent on the precipitation products provided by these sensors. The constellation presently consists of both conical and cross-track-scanning precipitation-capable multichannel instruments, many of which are beyond their operational and design lifetime but continue to operate through the cooperation of the responsible agencies. The Group on Earth Observations and the Coordinating Group for Meteorological Satellites (CGMS), among other groups, have raised the issue of how a robust, future precipitation constellation should be constructed. The key issues of current and future requirements for the mapping of global precipitation from satellite sensors can be summarized as providing 1) sufficiently fine spatial resolutions to capture precipitation-scale systems and reduce the beam-filling effects of the observations; 2) a wide channel diversity for each sensor to cover the range of precipitation types, characteristics, and intensities observed across the globe; 3) an observation interval that provides temporal sampling commensurate with the variability of precipitation; and 4) precipitation radars and radiometers in low-inclination orbit to provide a consistent calibration source, as demonstrated by the first two spaceborne radar–radiometer combinations on the Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Measurement (GPM) mission *Core Observatory*. These issues are critical in determining the direction of future constellation requirements while preserving the continuity of the existing constellation necessary for long-term climate-scale studies.

KEYWORDS: Precipitation; Rainfall; Snowfall; Satellite observations; Microwave observations; Instrumentation/sensors

https://doi.org/10.1175/BAMS-D-20-0299.1
Corresponding author: Chris Kidd, chris.kidd@nasa.gov
In final form 12 May 2021

Space-based Observations

Kidd, C., G. Huffman, V. Maggioni, P. Chambon, R. Oki, 2021: The Global Satellite Precipitation Constellation: Current Status and Future Requirements. Bull. Amer. Meteor. Soc., 102, E1844–E1861, https://doi.org/10.1175/BAMS-D-20-0299.1


2025/05/26 05:30:00
Liquid Precipitation Rate
0.1 0.2 0.3 0.5 1.0 2.0 3.0 5.0 10 20 50
mm/hour
Frozen Precipitation Rate
0.1 0.2 0.3 0.5 1.0 2.0 3.0 5.0 10 20 50
mm/hour
E

Point measurements vs gridded data

A single point precipitation measurement is quite often not representative of the volume of precipitation falling over a given catchment area.

Point measurements vs gridded data

Feature	Pointwise [Gauges]	Grid-Based [Radar/Satellites]
Location	Fixed, specific point	Defined area
Spatial resolution	Very high	Variable [depends on sensor]
Coverage	Limited	Broad [regional & global]
Applications	Local studies, validation	Weather forecasting & climate modeling

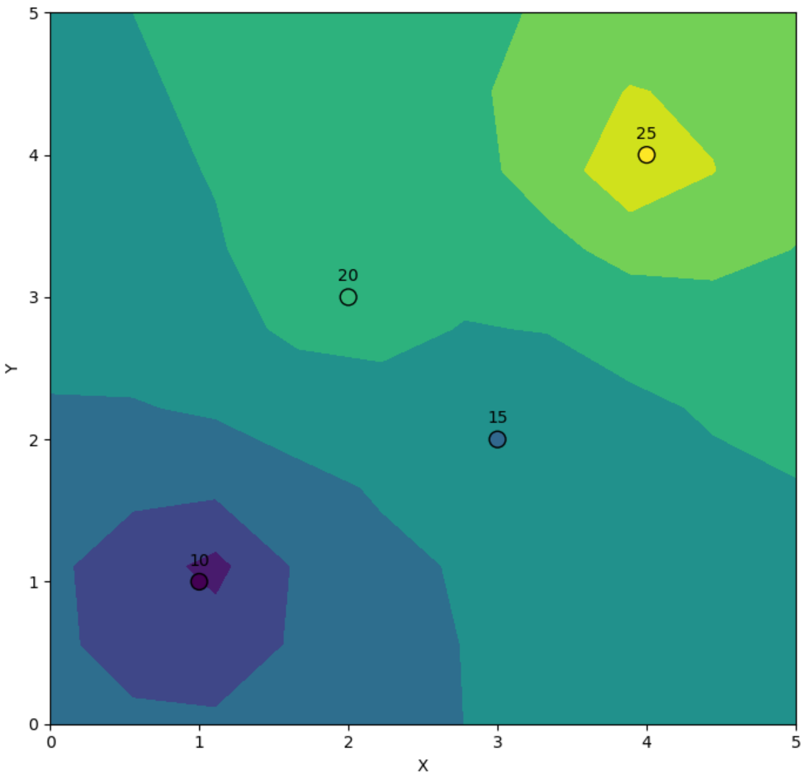
From point measurements to gridded data

Assumption. Tobler's First Law of Geography.

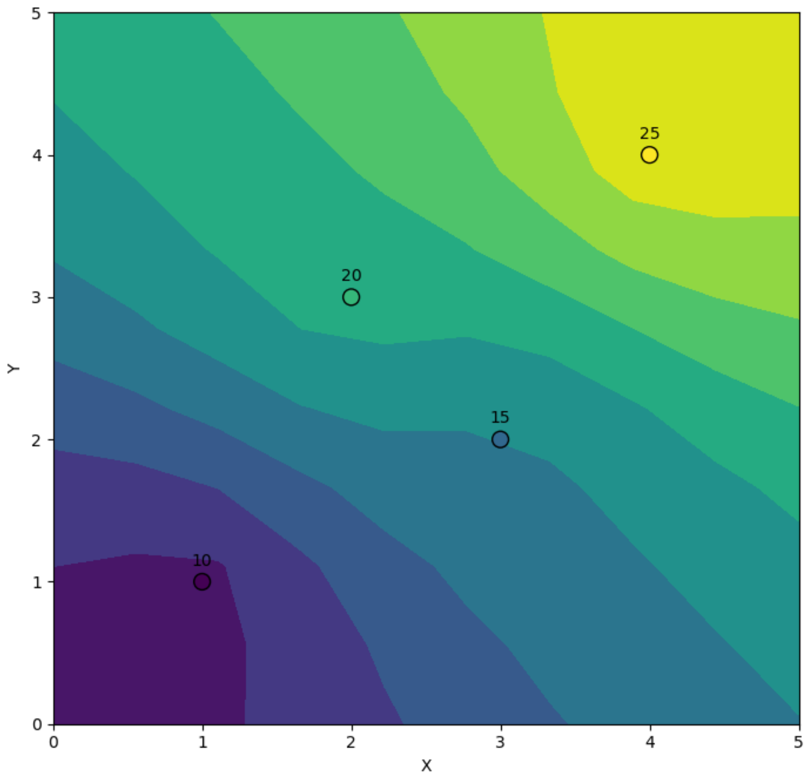
Things that are close are more related than things that are further apart.

From point measurements to gridded data

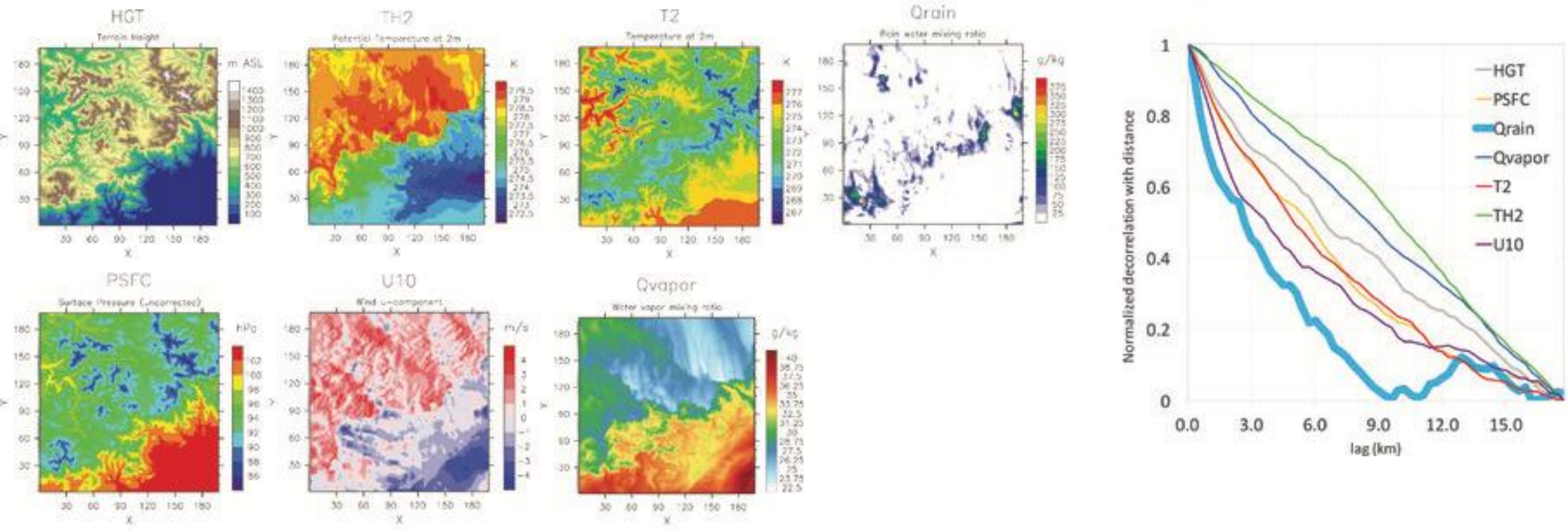
IDW interpolation



Kriging interpolation



Some variables are inherently difficult to interpolate...



Tapiador, F. J., R. Roca, A. Del Genio, B. Dewitte, W. Petersen, and F. Zhang, 2019: Is Precipitation a Good Metric for Model Performance?. *Bull. Amer. Meteor. Soc.*, **100**, 223–233, https://doi.org/10.1175/BAMS-D-17-0218.1.

What is a model?


F-16


F-16

A definition

A representation of a process or object, by necessity simplified in some way from the original.

Why using models in meteorology & climatology?

Why using models in meteorology & climatology?

- Make predictions about the future
- Improve our understanding on the system
- Test hypotheses
- Support decision-making

NWP

Numerical **W**eather **P**rediction model (NWP)

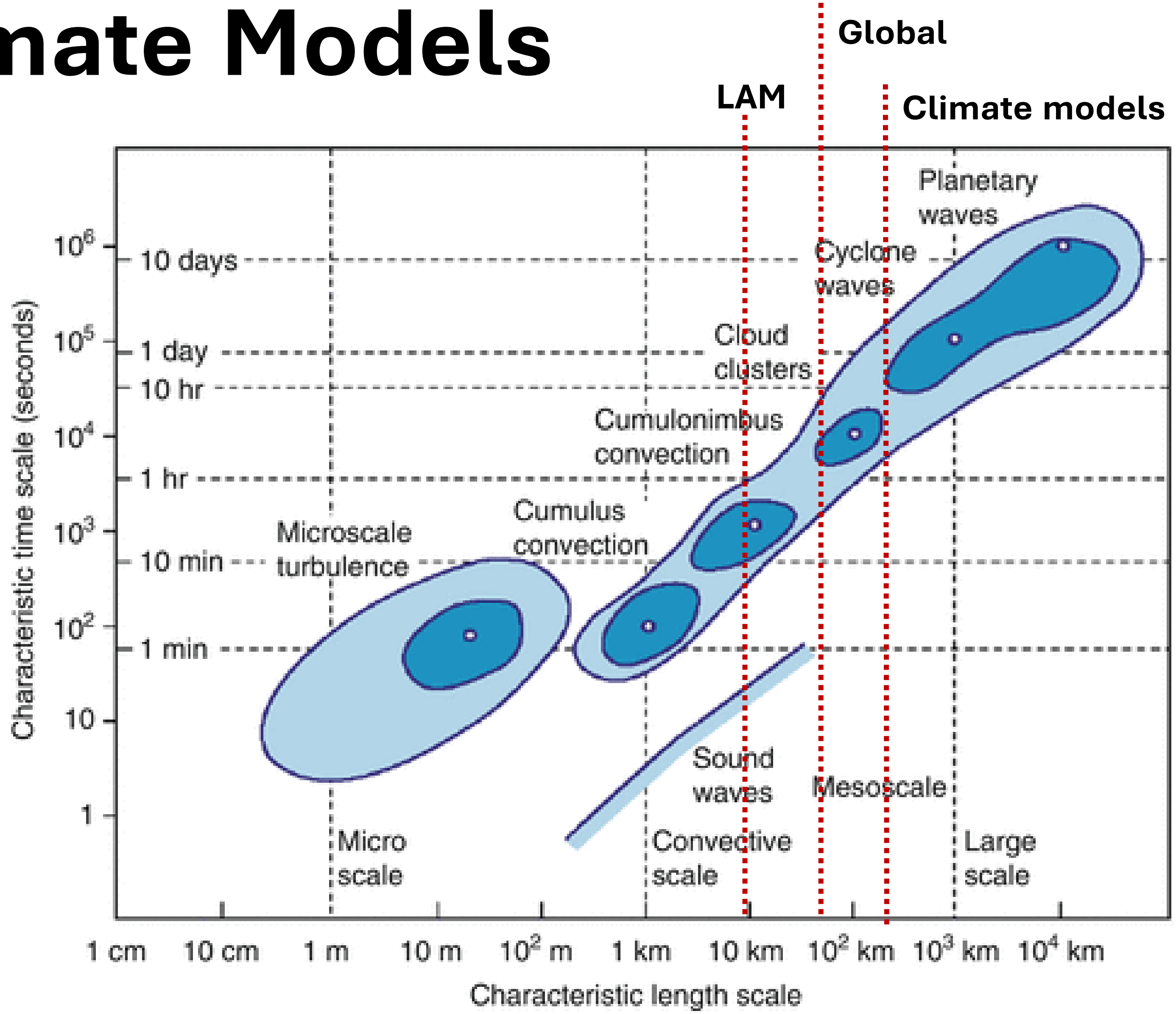
A numerical model used to predict the future state of the atmosphere. More formally, NWP models integrate the hydrodynamical equations with numerical methods subject to specified initial conditions for a particular time.

Domain Size	Model	Description	URL
Global	GFS (USA)	Global Forecast System by NOAA/NCEP. Medium-range forecasts.	https://www.ncei.noaa.gov/products/weather-climate-models/global-forecast
Global	IFS (ECMWF, Europe)	European Centre for Medium-Range Weather Forecasts. High accuracy.	https://www.ecmwf.int/
Global	UM (UKMO, UK)	Unified Model by the UK Met Office. Global and regional forecasts.	https://www.metoffice.gov.uk/research/approach/modelling-systems/unified-model/weather-forecasting
Global	ICON (Germany)	Icosahedral Nonhydrostatic model by DWD. Global and regional.	https://doi.org/10.1002/qj.2378
Global	JMA GSM (Japan)	Global Spectral Model by Japan Meteorological Agency.	https://www.wis-jma.go.jp/cms/gsm/
LAM	WRF (USA)	Weather Research and Forecasting model. Widely used for regional domains.	https://www.mmm.ucar.edu/models/wrf
Global/LAM	ARPEGE/AROME (France)	ARPEGE is global; AROME is high-resolution regional by Météo-France.	https://doi.org/10.1175/2010MWR3425.1
LAM	HARMONIE-AROME	High-resolution model used in Spain and many other European countries.	https://doi.org/10.1175/MWR-D-16-0417.1

NWP & Climate Models

- Same physical laws
- Different processes and complexity
- Different timescales
- Different purposes

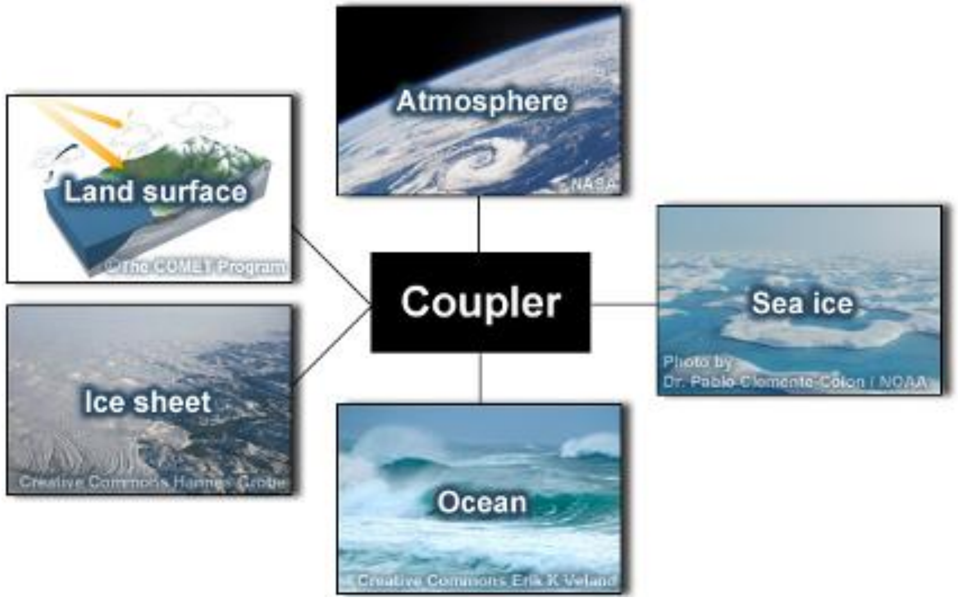
NWP & Climate Models



GCMs

Global **C**limate **M**odel (GCM)

A GCM is a numerical model representing physical processes in the atmosphere, ocean, cryosphere and land surface.



GCMs

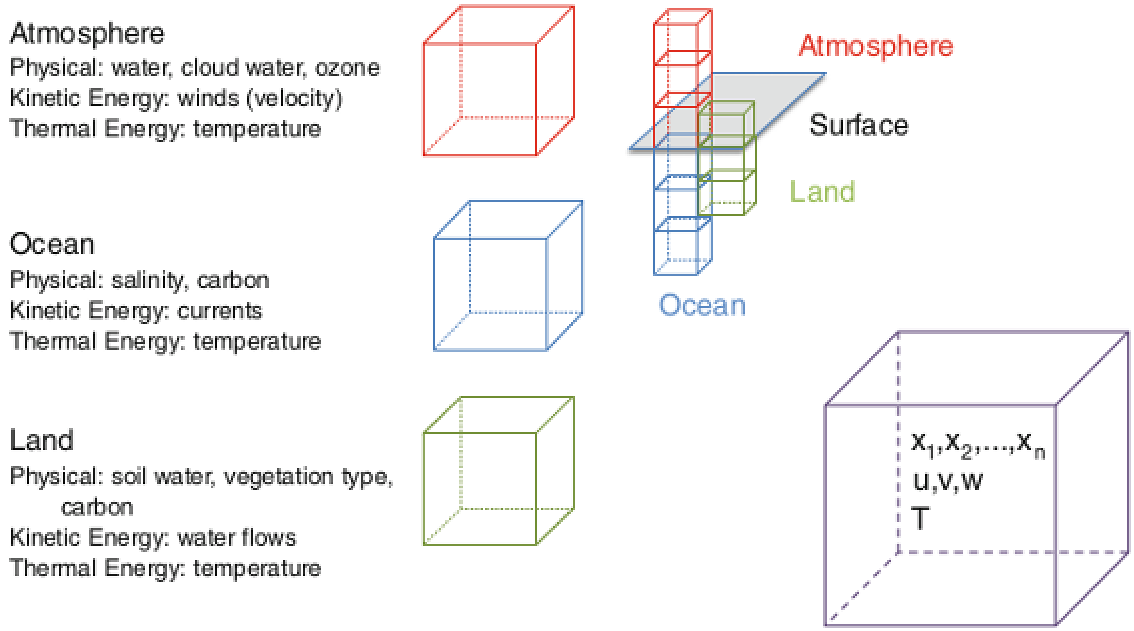
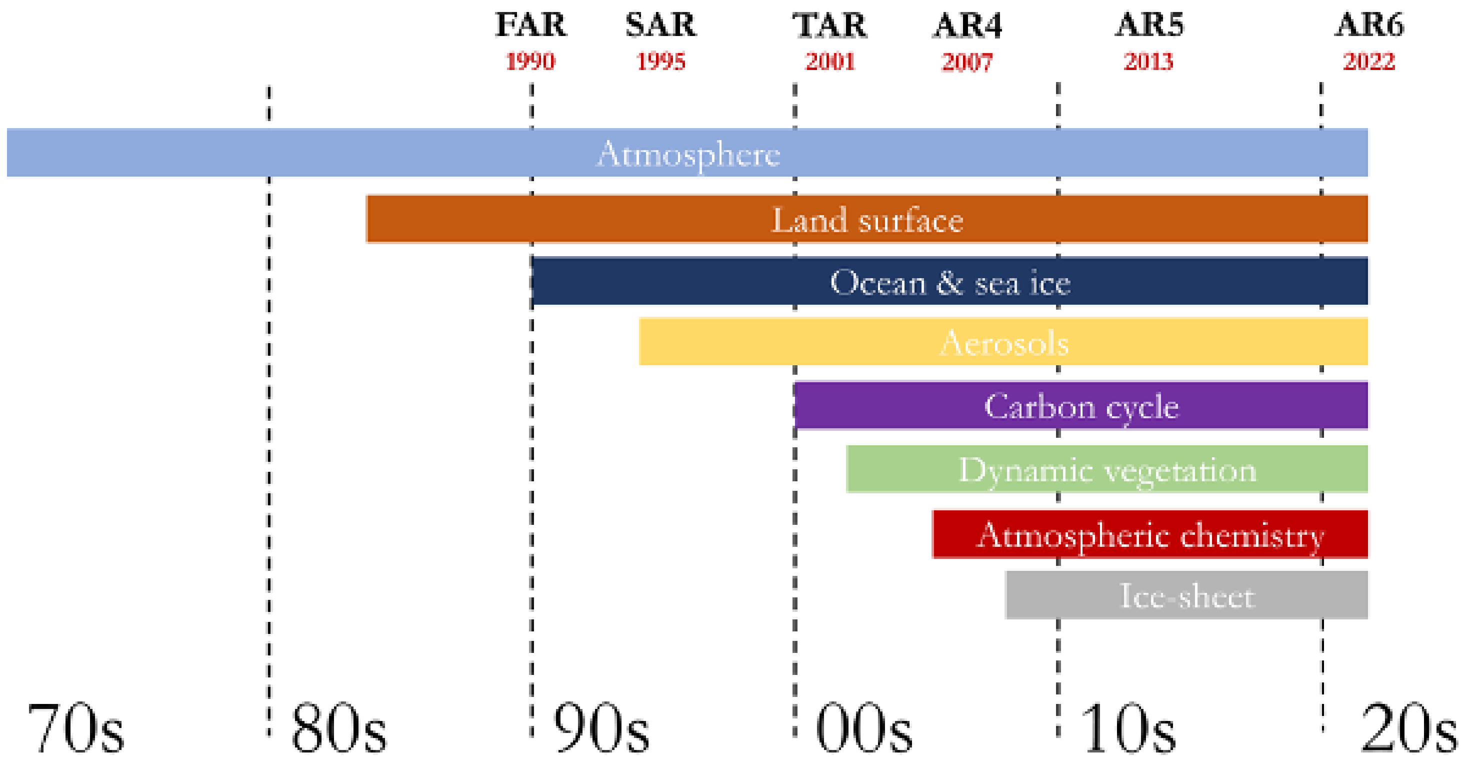


Fig. 4.4 State of the system. Different grid columns for the atmosphere (*red*), ocean (*blue*) and land (*green*) with description of contents. Also a grid box (*purple*) with a 'state' vector of temperature (T), wind in 3 dimensions (U, V for *horizontal* wind and W for *vertical* wind) and the mass fraction of compounds like water (X_n)

- GCMs depict the climate using a 3D grid over the globe.
- Different GCMs may simulate quite different responses to the same GHG emission scenarios, simply because of the way certain processes and feedbacks are modelled.

GCMs & ESMs



Over time CMs have increased in complexity, as separate components have been merged to form coupled systems.

GCMs and **ESMs**

- **Global Climate Models** (GCMs) = Major climate system components (atmosphere, land surface, ocean, and sea ice), and their interactions.
- **Earth System Models** (ESMs)= GCM + Biogeochemistry

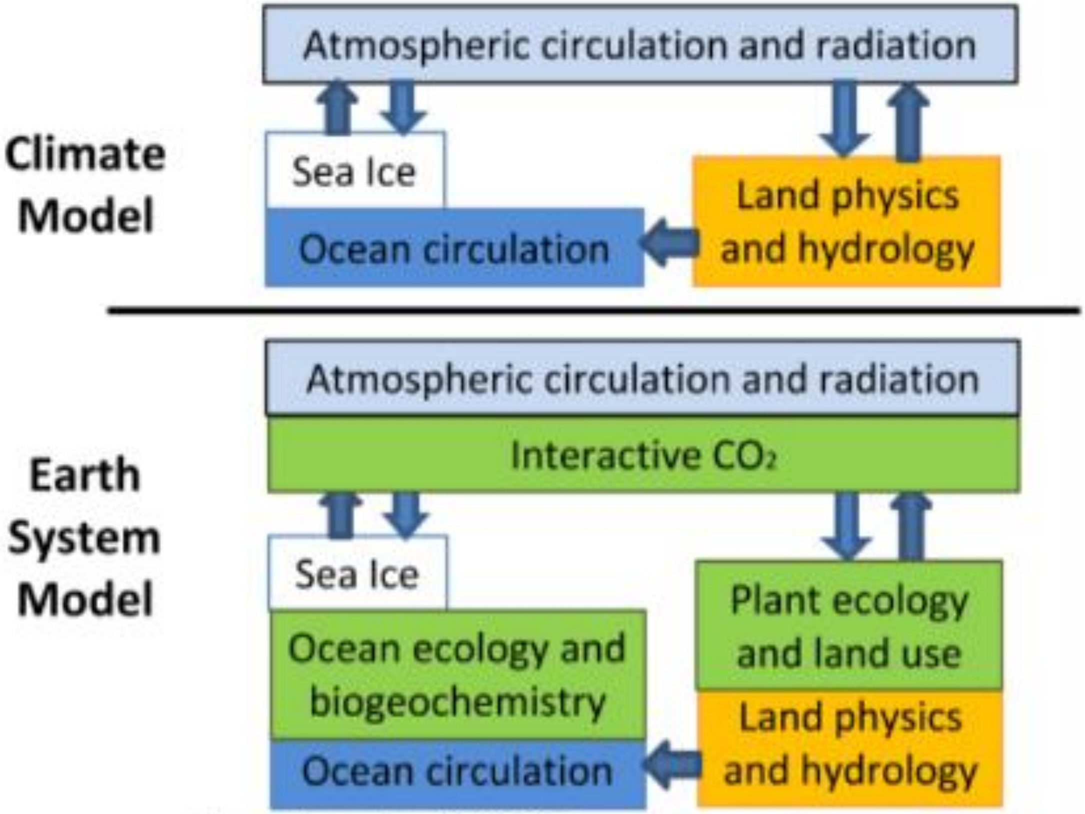


Figure based on SOCCOM

The **C**oupled **M**odel **I**ntercomparison **P**roject (CMIP) is an international effort that aims to improve climate model simulations and projections by facilitating the comparison of different climate models. CMIP **provides a standardized framework** for climate modeling groups around the world to share their results, which **helps in understanding the strengths and weaknesses of models**, thereby advancing climate science as a whole.

https://pcmdi.llnl.gov/CMIP6/Guide/dataUsers.html

GCMs/ESMs: a big family

Model	Institution	Reference
ACCESS-CM2	Commonwealth Scientific and Industrial Research Organisation; Australian Research Council Centre of Excellence for Climate System Science (CSIRO-ARCCSS)	(Bi et al 2020)
ACCESS-ESM1-5	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	(Law et al 2017)
AWI-CM-1-1-MR	Alfred Wegner Institute (AWI)	(Rackow et al 2018; Sidorenko et al 2015)
AWI-ESM-1-1-LR		
BCC-CSM2-MR	Beijing Climate Center (BCC)	(Wu et al 2019)
BCC-ESM1		(Wu et al 2020)
CAMS-CSM1-0	Chinese Academy of Meteorological Sciences (CAMS)	(Rong et al 2019)
CanESM5	Canadian Centre for Climate Modelling and Analysis, Environment and Climate Change (CCCma)	(Swart et al 2019)
CanESM5-CanOE		
CAS-ESM2-0	Chinese Academy of Sciences (CAS)	(Zhou et al 2020)
CESM2	National Center for Atmospheric Research, Climate and Global Dynamics Laboratory (NCAR)	(Danabasoglu et al 2020)
CESM2-FV2		
CESM2-WACCM		
CESM2-WACCM-FV2		
CIESM	Tsinghua University. Department of Earth System Science. (TSU)	(Lin et al 2020)
CMCC-CM2-SR5	Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC)	(Cherchi et al 2019)
CNRM-CM6-1	Centre National de Recherches Meteorologiques; Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique (CNRM-CERFACS)	(Voldoire et al 2019)
CNRM-CM6-1-HR		
CNRM-ESM2-1		(Séférian et al 2019)
E3SM-1-0	E3SM-Project. Lawrence Livermore National Laboratory (LLNL); Argonne National Laboratory, Argonne (ANL); Brookhaven National Laboratory (BNL); Los Alamos National Laboratory (LANL); Lawrence Berkeley National Laboratory (LBNL); Oak Ridge National Laboratory (ORNL); Pacific Northwest National Laboratory (PNNL); Sandia National Laboratories (SNL).	(Golaz et al 2019)
E3SM-1-1		
E3SM-1-1-ECA		
EC-Earth3	EC-Earth Consortium	(Döscher et al 2021; Wyser et al 2020)
EC-Earth3-Veg		
EC-Earth3-Veg-LR		

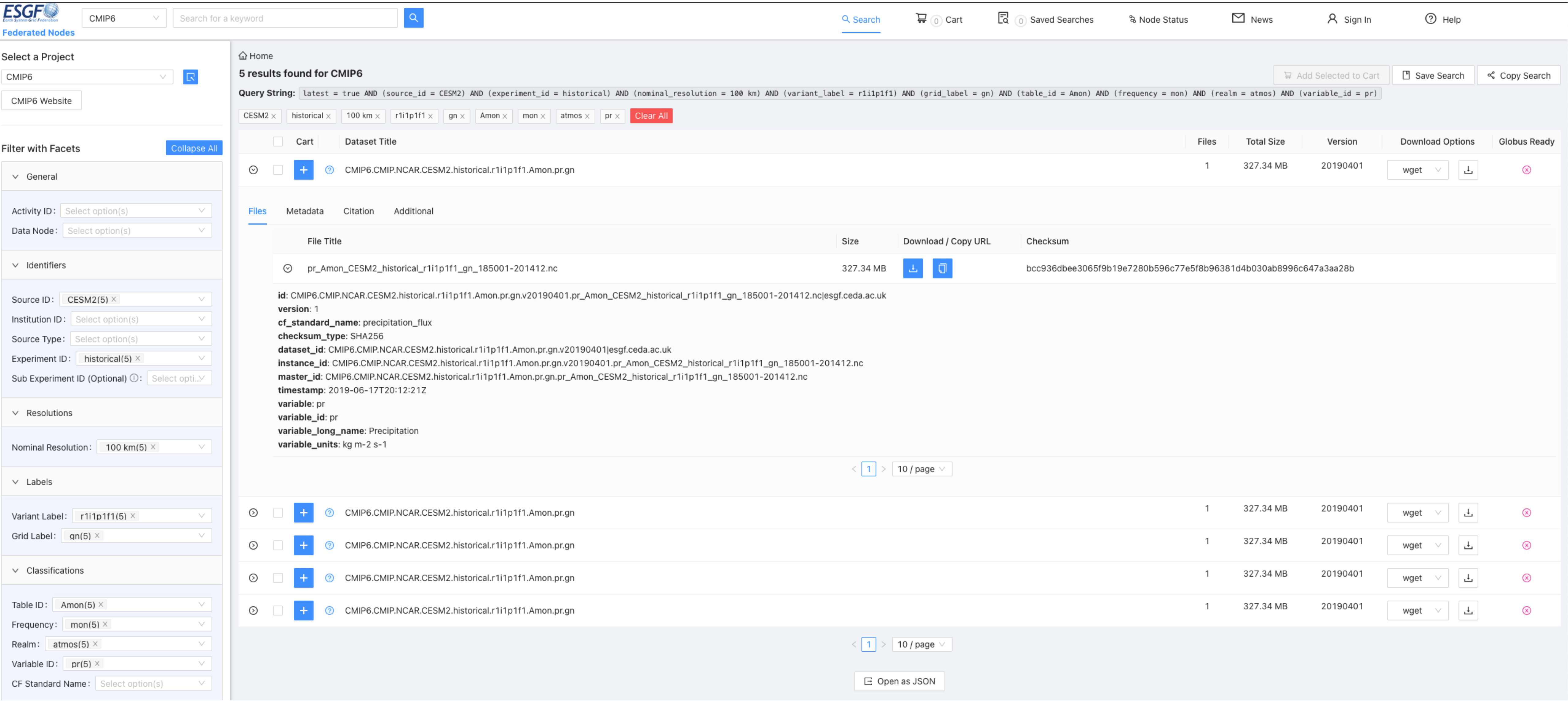
GCMs/ESMs: a big family

WCRP CMIP6
World Climate Research Programme

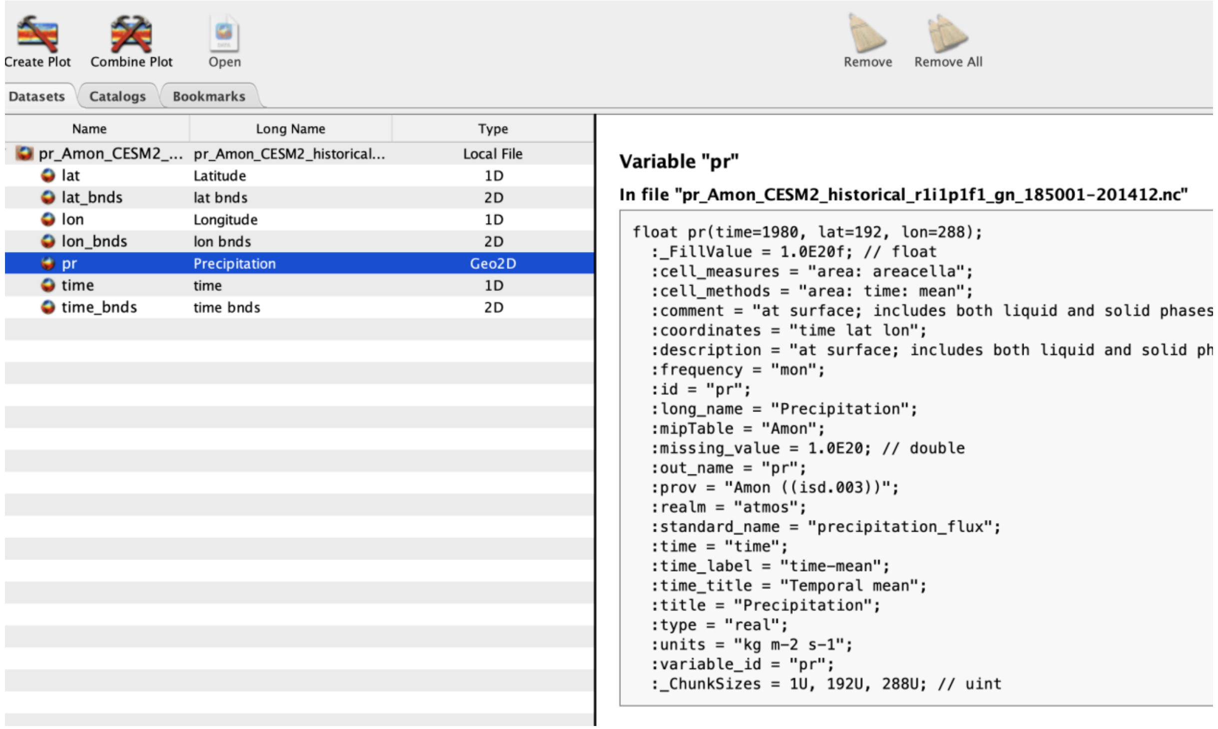
Model	Institution	Reference
GFDL-ESM4	National Oceanic and Atmospheric Administration; Geophysical Fluid Dynamics Laboratory (NOAA-GFDL)	(Dunne et al 2020)
GISS-E2-1-G	Goddard Institute for Space Studies (NASA-GISS).	(Kelley et al 2020)
GISS-E2-1-CC		
GISS-E2-1-H		
HadGEM3-GC31-LL	Met Office Hadley Centre (MOHC)	(Kuhlbrodt et al 2018)
HadGEM3-GC31-MM		(Andrews et al 2020)
INM-CM4-8	Institute for Numerical Mathematics (INM)	(Volodin et al 2018)
INM-CM5-0		(Volodin and Gritsun 2018)
IPSL-CM6A-LR	Institut Pierre Simon Laplace (IPSL)	(Boucher et al 2020)
KACE-1-0-G	National Institute of Meteorological Sciences/Korea Meteorological Administration (NIMS-KMA)	(J. Lee et al 2020)
MCM-UA-1-0	Department of Geosciences, University of Arizona (UA)	(Delworth et al 2002)
MIROC6	Japan Agency for Marine-Earth Science and Technology (JAMSTEC); Atmosphere and Ocean Research Institute (AORI); National Institute for Environmental Studies (NIES); RIKEN Center for Computational Science (R-CCS)	(Tatebe et al 2019)
MIROC-ES2L		(Hajima et al 2020)
MPI-ESM-1-2-HAM	HAMMOZ-Consortium	(Neubauer et al 2019)
MPI-ESM1-2-HR	Max Planck Institute for Meteorology (MPI-M)	(Müller et al 2018)
MPI-ESM1-2-LR		(Mauritsen et al 2019)
MRI-ESM2-0	Meteorological Research Institute (MRI)	(Yukimoto et al 2019)
NESM3	Nanjing University of Information Science and Technology (NUIST)	(Cao et al 2018)
NorCPM1	NorESM Climate modeling Consortium (NCC)	(Bethke et al 2021)
NorESM2-LM		(Seland et al 2020)
NorESM2-MM		
SAM0-UNICON	Seoul National University (SNU)	(Park et al 2019)
TaiESM1	Research Center for Environmental Changes, Academia Sinica (AS-RCEC)	(W.-L. Lee et al 2020)
UKESM1-0-LL	Natural Environment Research Council; Met Office Hadley Centre (NERC-MOHC)	(Sellar et al 2019)

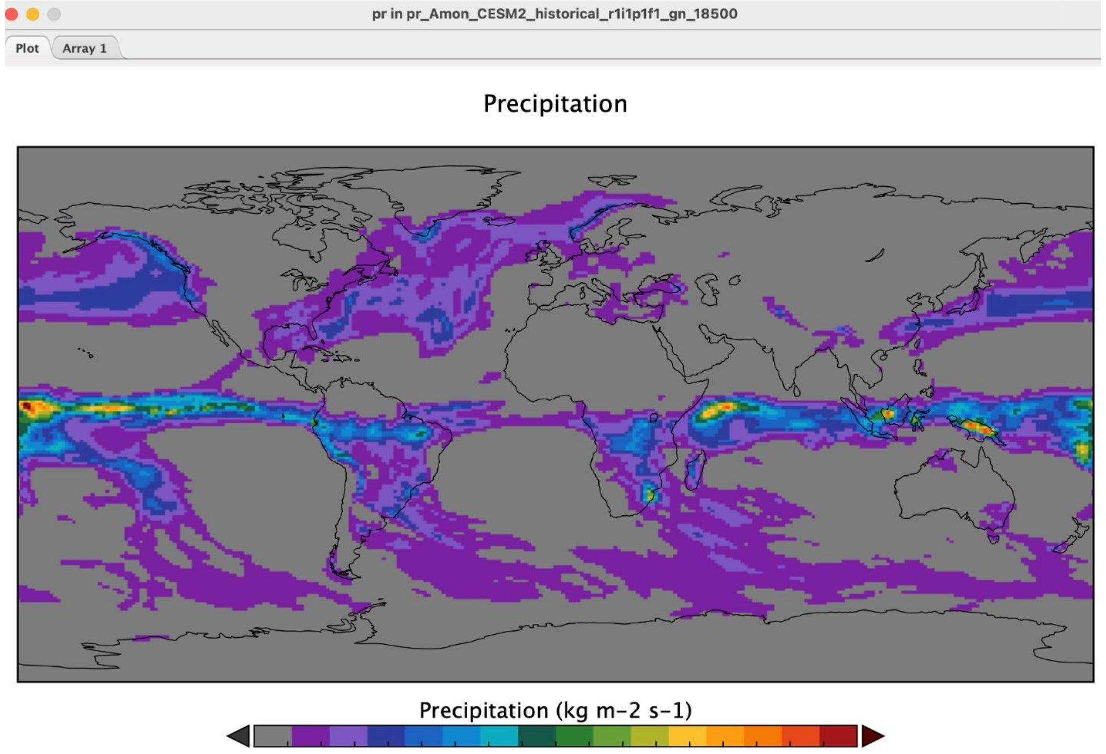
[redacted]

WCRP CMIP6
World Climate Research Programme



https://esgf-metagrid.cloud.dkrz.de/search





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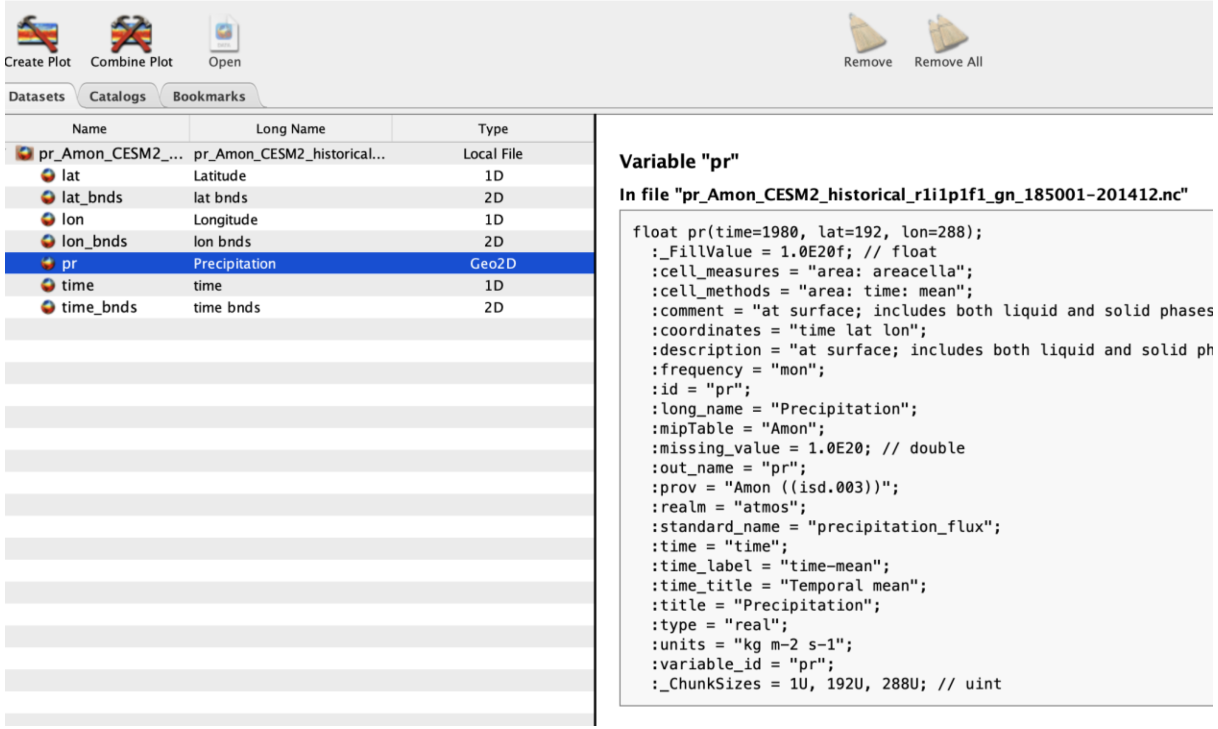
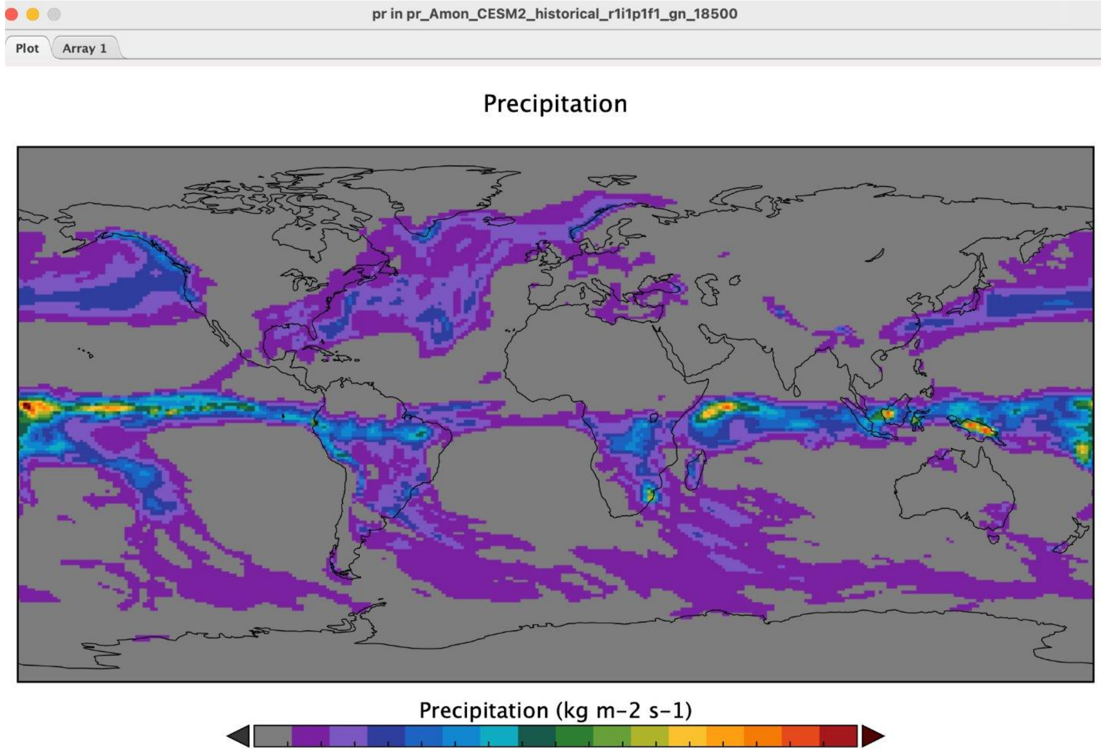




pr_Amon_CESM2_historical_r1i1p1f1_gn_185001-201412.nc

Var_ID *Table_ID* *Model* *Experiment* *Variant_label* *Grid* *Period*

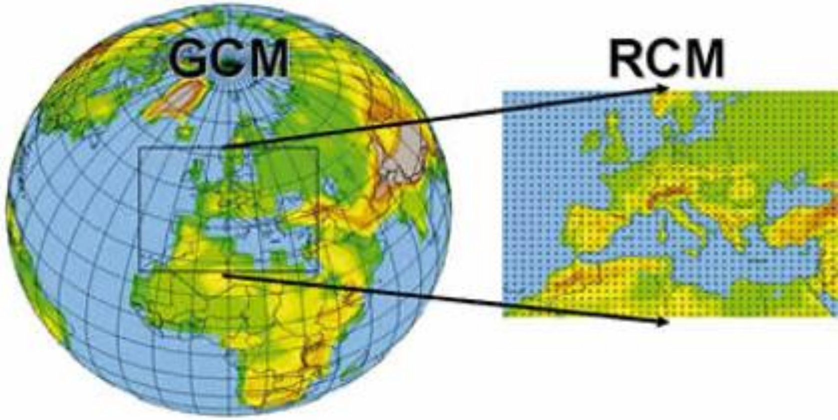
https://pcmdi.llnl.gov/CMIP6/Guide/modelers.html

https://clipc-services.ceda.ac.uk/dreq/index.html pr_Amon_CESM2_historical_r1i1p1f1_gn_185001-201412.nc

Var_ID *Table_ID* *Model* *Experiment* *Variant_label* *Grid* *Period*

Variable	Values	Description
Var_ID	pr	Precipitation flux [$kg \cdot m^{-2} \cdot s^{-1}$]
	t2	Mean air Temperature [K]
Table_ID	Amon	Monthly atmospheric data
	Odec	Decadal ocean data
Model	Cesm2	Community Earth System Model, version 2
	NorCPM1	Norwean Climate Prediction Model, version 1
Experiment	historical	Simulation of recent past (1850 to 2014). Impose changing conditions (consistent with observations)
	ssp585	SSP-based RCP scenario with high radiative forcing by the end of the century (8.5 W/m^2)
Variant_ID	r1i1p1f1	r: realization (i.e. ensemble member); i: initialization method; p: physics; f: forcing.
	r3i1p1f1	r: realization (i.e. ensemble member); i: initialization method; p: physics; f: forcing.
Grid_label	gn	Native grid.
	gr	Regridded data.

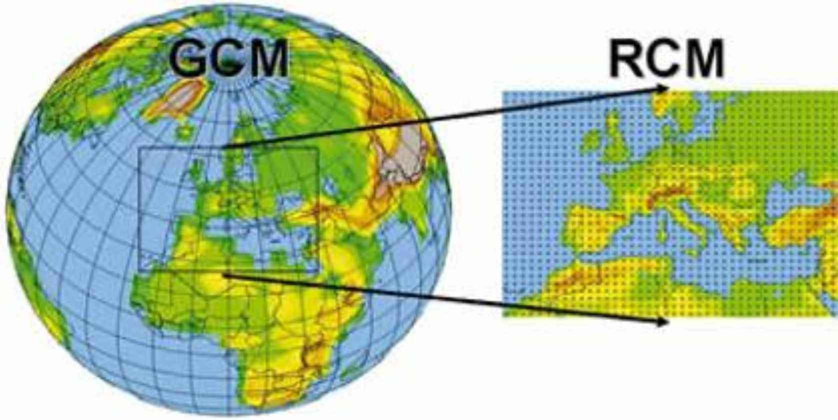
GCMs and **RCMs**



Regional **C**limate **M**odel (RCM)

A numerical climate prediction model forced by specified lateral and ocean conditions from a general circulation model (GCM) or observation-based dataset that simulates atmospheric and land surface processes, while accounting for high-resolution topographical data, land-sea contrasts, surface characteristics, and other components of the Earth-system.

GCMs and **RCMs**



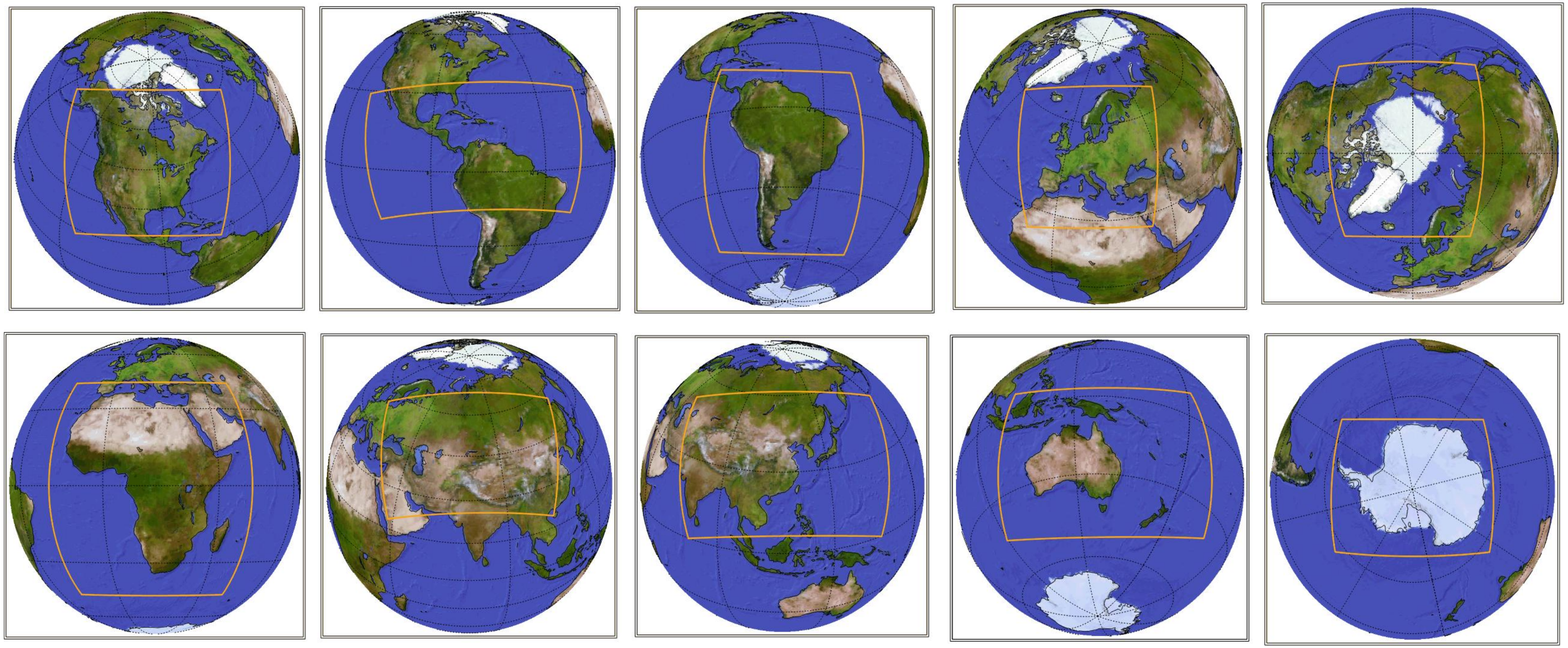
- The inception of RCMs in 1989 was motivated by computational constraints.
- Two main theoretical limitations
    - Effects of systematic errors in the driving fields provided by GCMs
    - Lack of two-way interactions between RCM and GCM, which causes inconsistencies in the physics of the simulations.

GCMs and **RCMs**

It is now possible to run GCMs/ESMs with small grid spacing

- High resolution → 0.25° atm/land + 1° (or 0.1°) ocean/ice (e.g. High-res CESM)
- Better resolve processes that we've previously had to parameterize (convection, ocean eddies…)
- Better resolve topographic features: dynamics and precipitation.
- Detect highly localized storms: tropical cyclones, mid-latitude storms, tornadoes…

Coordinated Regional Climate Downscaling Experiment (CORDEX)



https://cordex.org/

Models & Uncertainties

Key Concept

The noncorrectable or unknown part of the inaccuracy of a model. Uncertainty represents the limit of the forecast precision.

Models & **Uncertainties**

Types

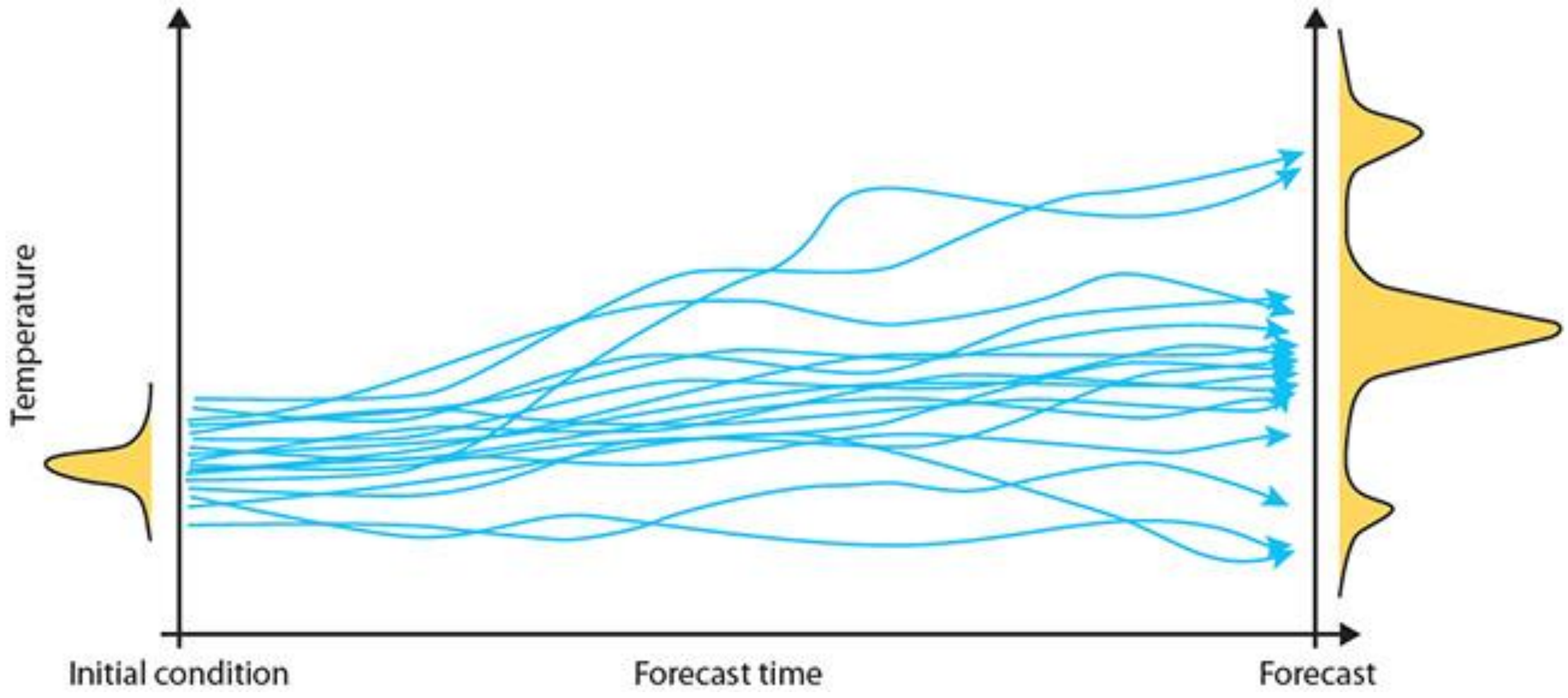
- Initial conditions
- Model uncertainties
- Scenario uncertainties
- Natural variability / Climate variability

Initial conditions

The uncertainty in a projection, prediction or forecast due to uncertainties in the initial input conditions of the state of the system.

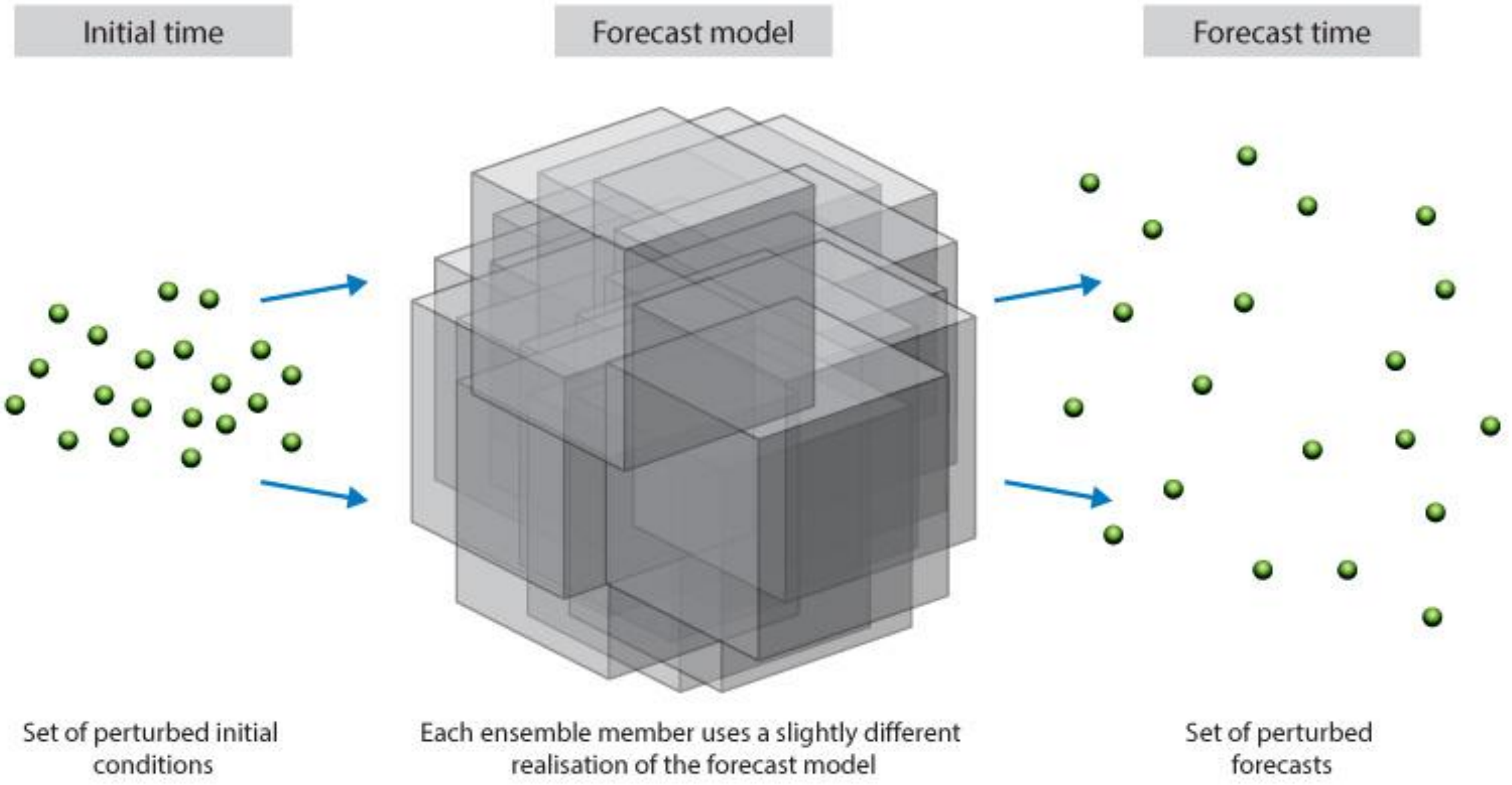
Initial conditions

Slingo J, Palmer T. Uncertainty in weather and climate prediction. Philos Trans A Math Phys Eng Sci. 2011 Dec 13;369(1956):4751-67. 10.1098/rsta.2011.0161



Initial conditions

Slingo J, Palmer T. Uncertainty in weather and climate prediction. Philos Trans A Math Phys Eng Sci. 2011 Dec 13;369(1956):4751-67. 10.1098/rsta.2011.0161

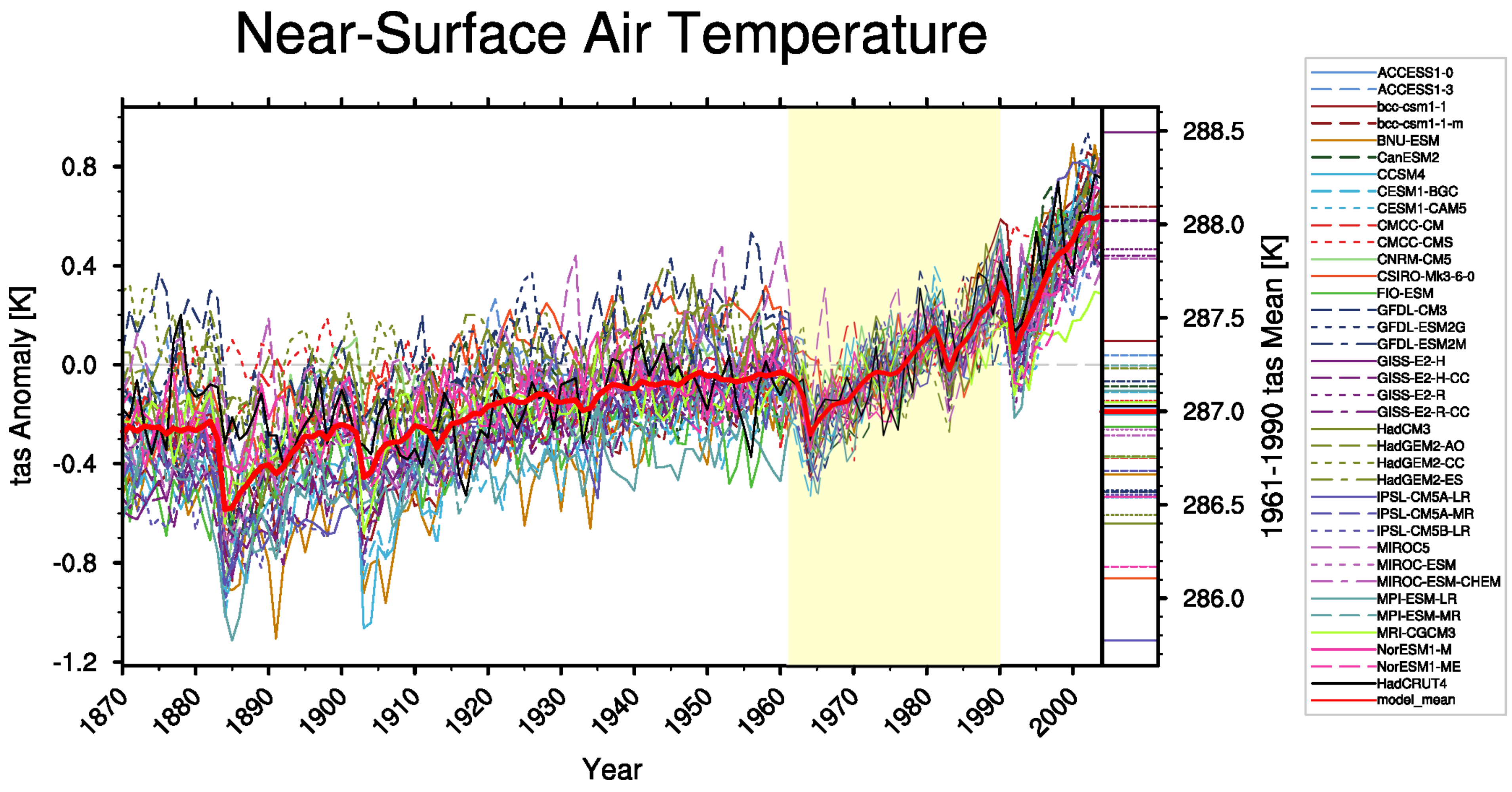


To model uncertainty in the forecasting system, each ensemble member uses a slightly different stochastic realisation of the model as well as a slightly different set of initial conditions.

Model uncertainties

Model uncertainty results from imperfect representations of different processes and their interactions.

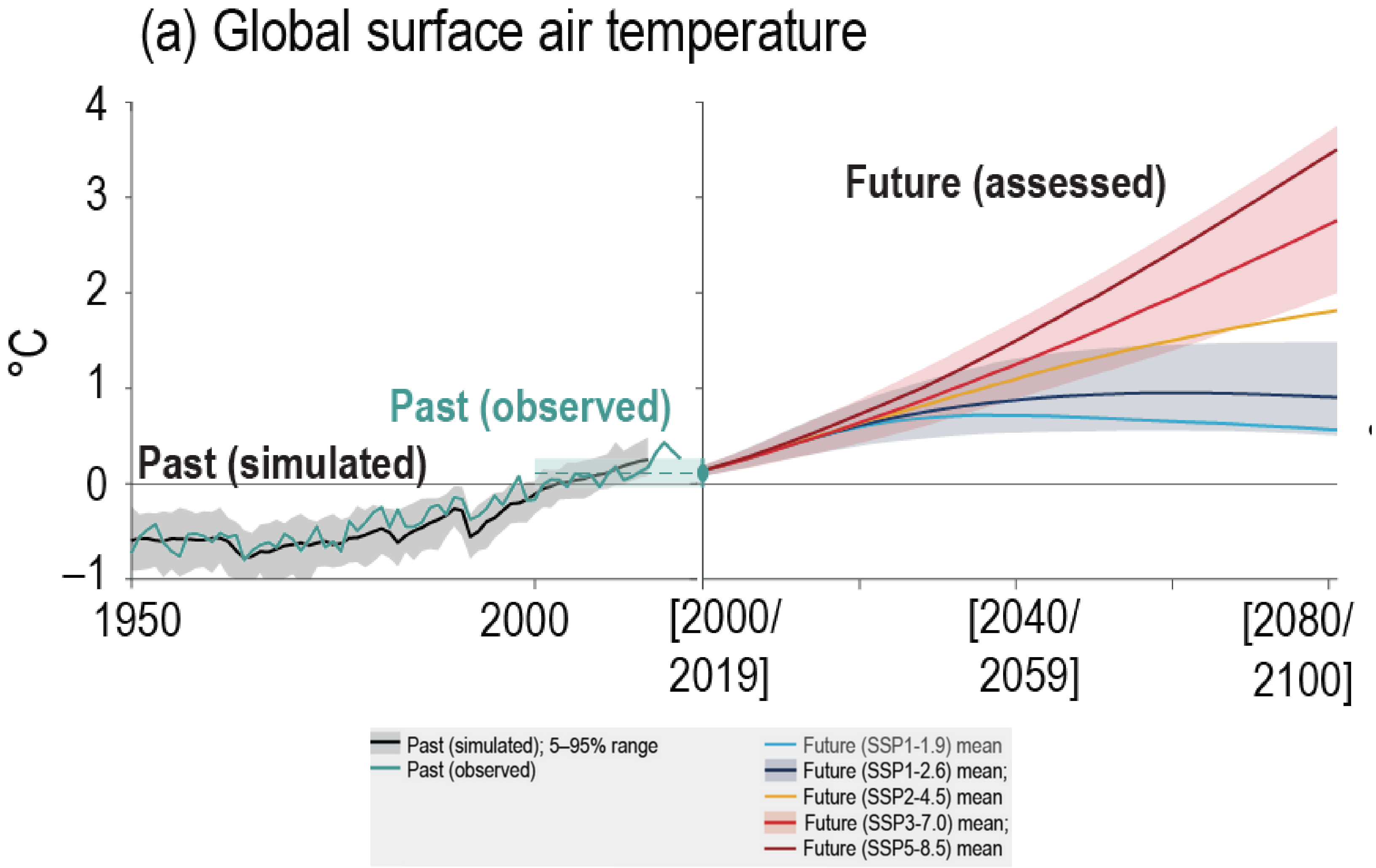
Model uncertainties



Scenario uncertainties

The uncertainty in a projection or prediction of the future due to uncertainties in inputs (boundary conditions) to a model over time.

Scenario uncertainties



Natural variability

Natural refers to exogenous factors such as volcanic eruptions and solar and orbital cycles and intrinsic fluctuations of the climate system caused by the chaotic dynamics of the atmosphere and oceans.

https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2020EF001854

Natural variability

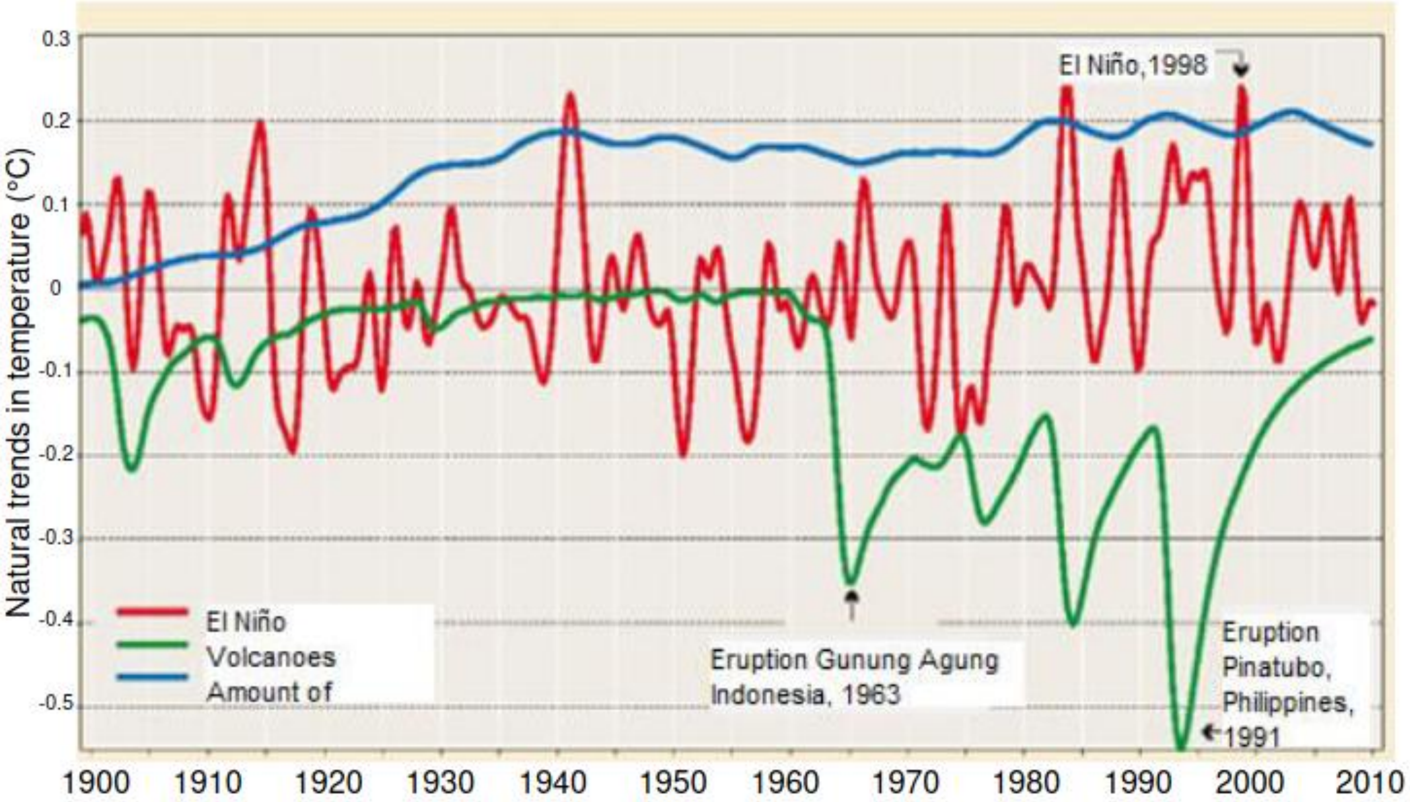
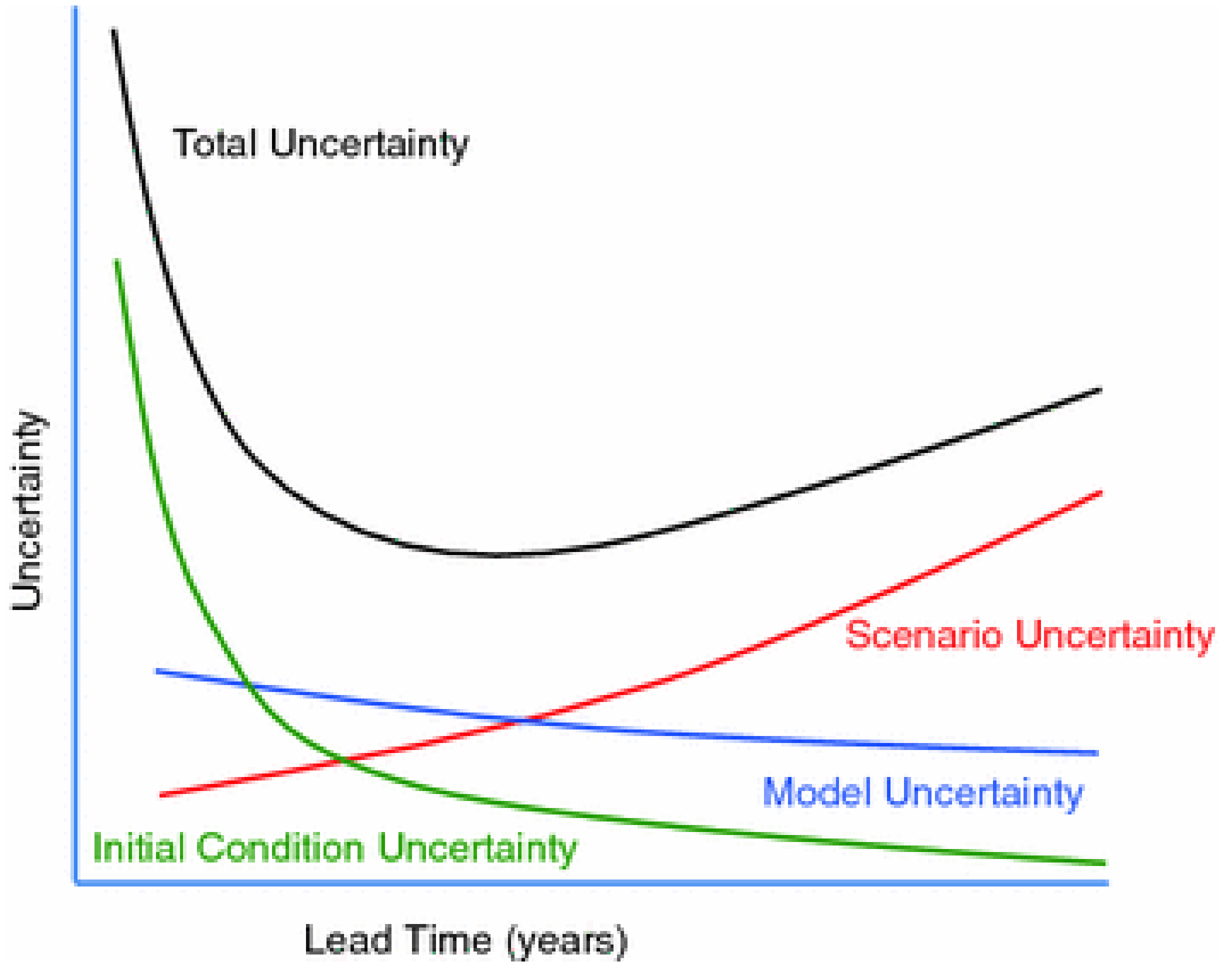


Fig. 2. Natural causes of global temperature variations since the beginning of the 20th century (Source: KNMI/Noordhoff, 2011)

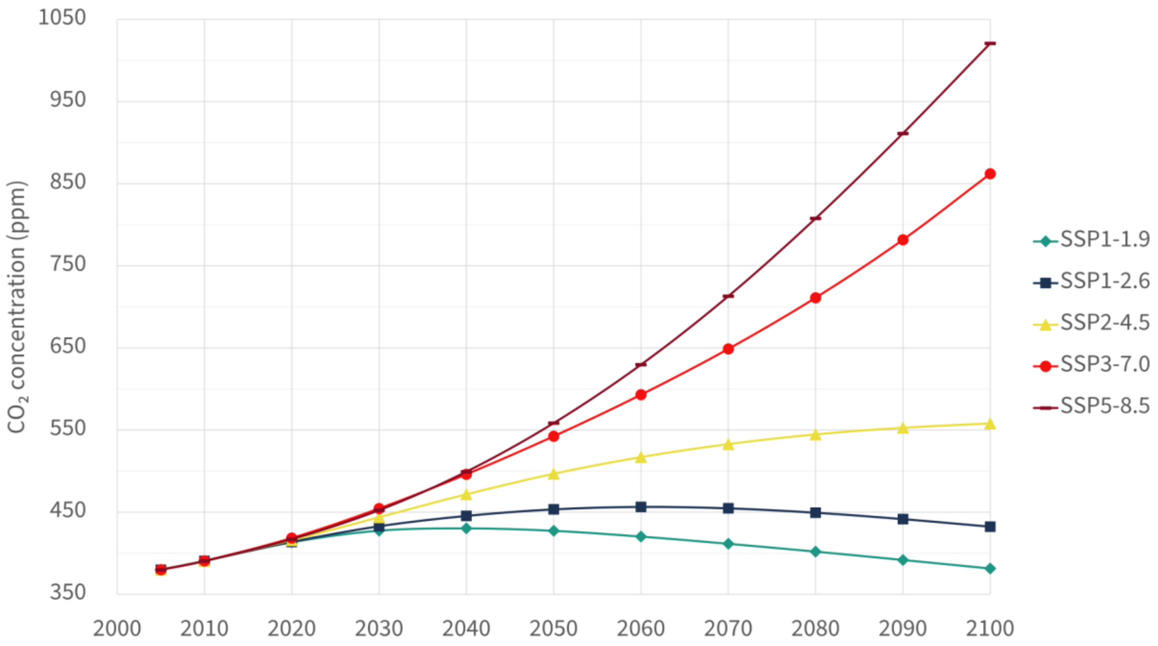
Total uncertainty



Key differences: Forecast vs Projection

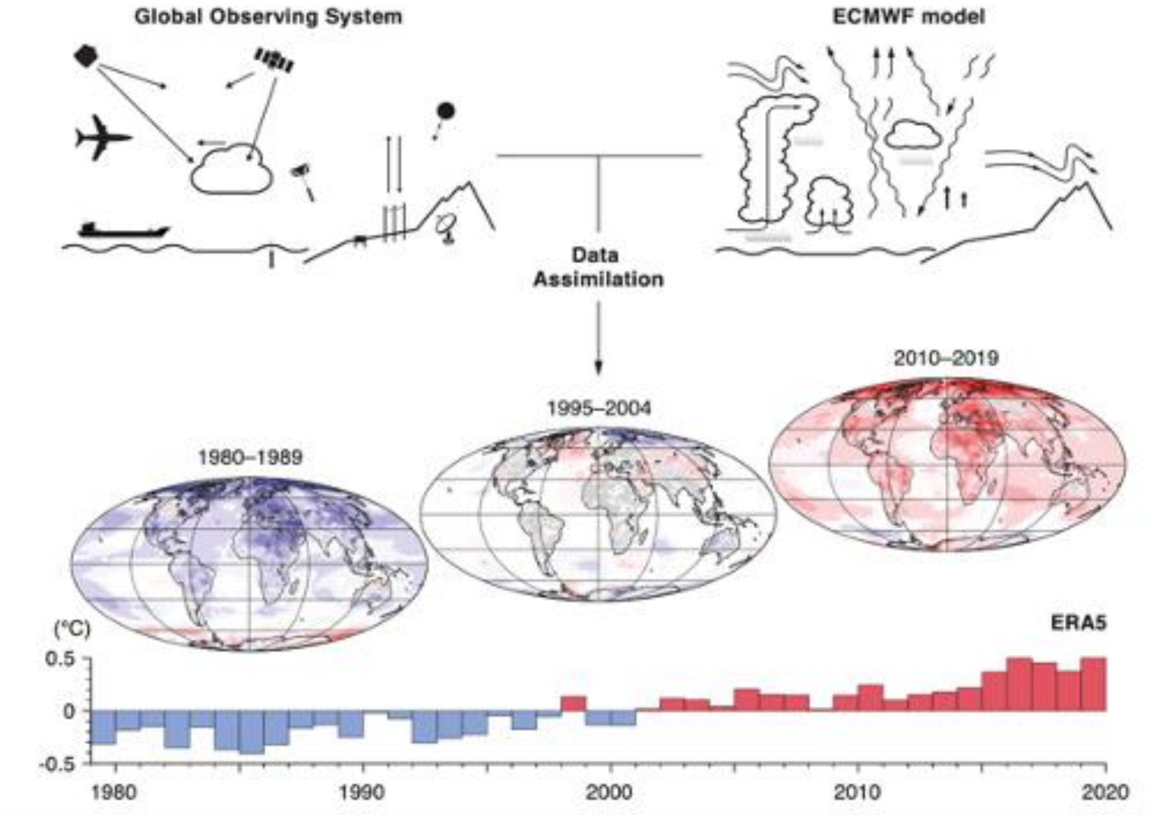
A **projection** is usually dependent on **things that we do not know about the future**. For a **weather forecast**, we can assume **we know all the important things** that can force the weather on the scale of a few days (measured as probability).

Models & Scenarios



A special case: Reanalyses

A scientific method for developing a comprehensive record of how weather and climate are changing over time. In it, observations and a numerical model that simulates one or more aspects of the Earth system are combined objectively to generate a synthesized estimate of the state of the system.



Current / State-of-the-art:

ASR | COSMO-REA | CERA-20C | ERA5 | ERA-20C| ERA-20CM | ERA-Interim | JRA-55, JRA-55C, JRA-55AMIP | MERRA-2 | NCEP CFSR | NOAA-CIRES 20CRv2c | NOAA-CIRES-DOE 20CRv3

- Reanalyses **fill the gaps in the observational record**, and they do so in a **way that is consistent in time**, thus minimising any spurious signals of change.
- Reanalysis **combines** past short-range weather **forecasts with observations** throughdata assimilation.

https://climate.copernicus.eu/climate-reanalysis

ECMWF ERA5: 1940-present

ERA5 is the latest climate reanalysis produced by ECMWF, providing hourly data on many atmospheric, land-surface and sea-state parameters together with estimates of uncertainty. ERA5 data are available on regular latitude-longitude grids at 0.25o x 0.25o resolution, with atmospheric parameters on 37 pressure levels. Recently, 1940-1978 has been added.

Data Access: Copernicus | NCAR | ECMWF

https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/

NASA Modern Era Reanalysis for Research and Applications Version-2 (MERRA-2): 1980-present

MERRA-2 is a NASA reanalysis for the satellite era using a major new version of the Goddard Earth Observing System Data Assimilation System Version 5 (GEOS-5) produced by the NASA GSFC Global Modeling and Assimilation Office (GMAO). MERRA-2 assimilates observations not available to MERRA during the 2010s, and therefore, will continue processing in real time longer than MERRA. There are numerous improvements and updates to the data assimilaiton, model and observing system. One notable change is the assimilation of aerosol observations, including black and organic carbon, sulfate and dust. Production began in the spring of 2014 and is presently available for access.

Data Access: GES MDISC | FTP Subsetter

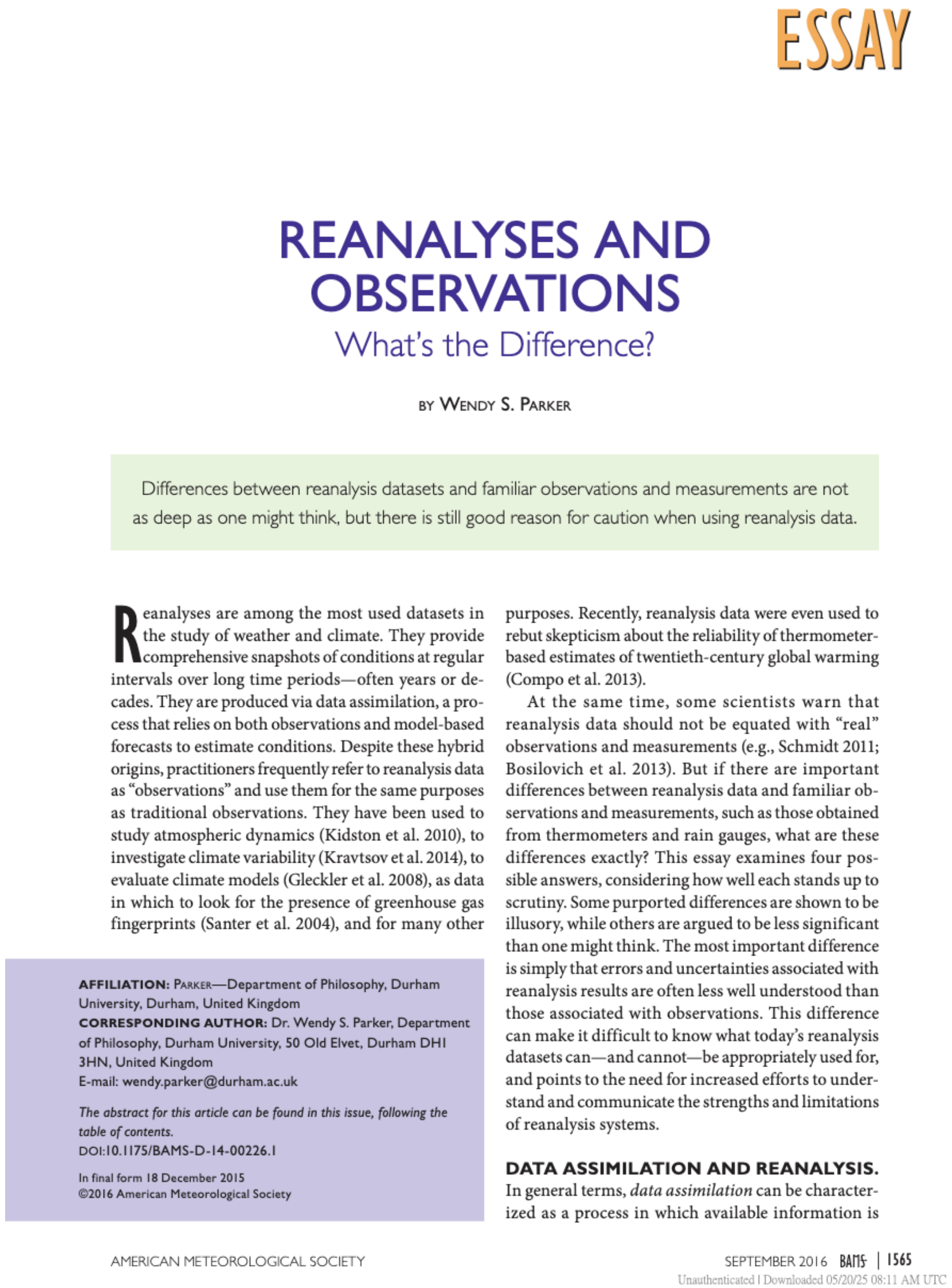
Home Page | File Specification | Documentation | AMS Special Collection

https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.ncdc:C00877

NCEP Climate Forecast System Reanalysis (CFSR): 1979-present

The National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) spans 1979 to present. The CFSR was designed and executed as a global, high resolution, coupled atmosphere-ocean-land surface-sea ice system to provide the best estimate of the state of these coupled domains over this period. The T382 resolution atmospheric data spans 1979 to 2010. The current T574 analysis is an extension of the CFSR as an operational, real time CFSv2 product from 2011 into the future.

Data Access: NCEP | NCDC NOMADS | NCAR (includes real time CFSv2) | ESGF



ESSAY

REANALYSES AND OBSERVATIONS

What's the Difference?

BY WENDY S. PARKER

Differences between reanalysis datasets and familiar observations and measurements are not as deep as one might think, but there is still good reason for caution when using reanalysis data.

Reanalyses are among the most used datasets in the study of weather and climate. They provide comprehensive snapshots of conditions at regular intervals over long time periods—often years or decades. They are produced via data assimilation, a process that relies on both observations and model-based forecasts to estimate conditions. Despite these hybrid origins, practitioners frequently refer to reanalysis data as "observations" and use them for the same purposes as traditional observations. They have been used to study atmospheric dynamics (Kidston et al. 2010), to investigate climate variability (Kravtsov et al. 2014), to evaluate climate models (Gleckler et al. 2008), as data in which to look for the presence of greenhouse gas fingerprints (Santer et al. 2004), and for many other purposes. Recently, reanalysis data were even used to rebut skepticism about the reliability of thermometer-based estimates of twentieth-century global warming (Compo et al. 2013).

At the same time, some scientists warn that reanalysis data should not be equated with "real" observations and measurements (e.g., Schmidt 2011; Bosilovich et al. 2013). But if there are important differences between reanalysis data and familiar observations and measurements, such as those obtained from thermometers and rain gauges, what are these differences exactly? This essay examines four possible answers, considering how well each stands up to scrutiny. Some purported differences are shown to be illusory, while others are argued to be less significant than one might think. The most important difference is simply that errors and uncertainties associated with reanalysis results are often less well understood than those associated with observations. This difference can make it difficult to know what today's reanalysis datasets can—and cannot—be appropriately used for, and points to the need for increased efforts to understand and communicate the strengths and limitations of reanalysis systems.

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In final form 18 December 2015

DATA ASSIMILATION AND REANALYSIS. In general terms, *data assimilation* can be characterized as a process in which available information is

Further Reading...

Parker, W. S., 2016: Reanalyses and Observations: What's the Difference?. *Bull. Amer. Meteor. Soc.*, **97**, 1565–1572, https://doi.org/10.1175/BAMS-D-14-00226.1

The Bible

- Climate products
- Climate Tools
- Climate concepts

https://climatedataguide.ucar.edu/