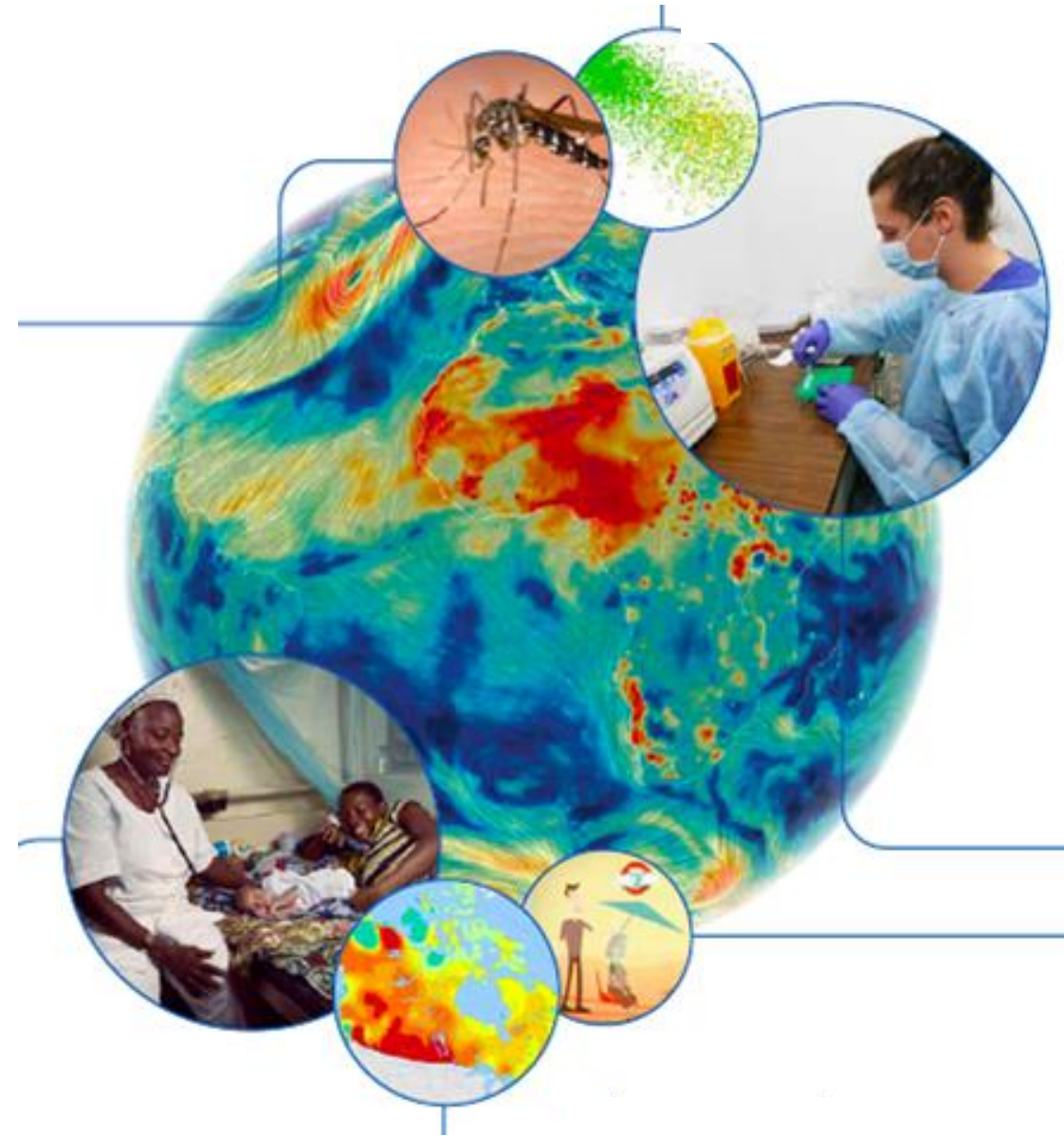


Part 1

FOUNDATIONS FOR INTEGRATING CLIMATE INFORMATION

Improving public health decision-making
in a new climate



Part 1 - FOUNDATIONS FOR INTEGRATING CLIMATE INFORMATION

Section 1.0 – 1.2 Weather & climate information for public health

1.0 Weather and climate information 1: weather and climate observations

1. Weather vs. climate: key terms and terminology
2. Examples of essential climate variables with health impacts– Temperature, precipitation, humidity, wind speed, and direction
3. Observed changes in climate-hazards and impacts on health

1.1 Weather and climate information 2: weather and climate forecasts

1. Types and uses of weather forecasts/predictions
2. Uncertainty in weather and climate forecasts/predictions

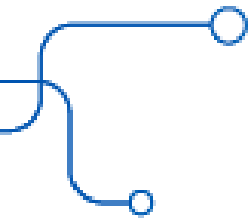
1.2 Weather and climate information 3: climate change projections

1. Global climate models
2. The Coupled Model Intercomparison Project (CMIP)
3. Shared Socioeconomic Pathways (SSPs)
4. Climate change scenarios from the IPCC AR6
 - Observations
 - Projections
5. Downscaling climate change scenarios

Section 1.3 Health-tailored climate services

1.3 Climate services and health

1. Climate and weather information that is useful to practitioners
2. Climate and weather services for health
3. Global framework for climate services and health
4. 6-step approach for co-designing climate services for health
 1. Create an enabling environment
 2. Building capacity for climate services
 3. Research to inform climate services
 4. Applied climate product and service development
 5. Applications
 6. Evaluations



Section 1.0 - 1.2

Weather & climate information for public health

1.0 weather & climate observations | 1.1 forecasts | 1.2 climate change projections

Learning objective:

To understand the **difference between weather and climate**, and how climate observations, forecasts, and projections can be used in public health decision-making across multiple time scales, including hours, days, months, seasons, and decades.

Case study:

[Climate information for public health: the role of the IRI climate data library in an integrated knowledge system \(2014\)](#)

Further reading:

- [On the reliability of seasonal climate forecasts](#)
- [Climate Information for Public Health Action](#)
- [Climate Variability and Change Data and Information for Global Public Health](#)
- [Climate Services for Health Fundamentals and Case Studies for improving public health decision-making in a new climate](#)

Resources:

- [Red Cross Red Crescent Climate Centre: Seasonal forecast game](#)
- [Lancet Countdown](#)

INTRODUCTION

- According to the Intergovernmental Panel on Climate Change, Sixth Assessment Report, climate change has adversely affected the physical health of people globally and their mental health. In 2019, the global magnitude of climate-sensitive diseases was estimated at 39,503,684 deaths and 1,530,630,442 disability-adjusted life years (DALYs). Climate change and related extreme events will significantly increase ill health and premature deaths in the near and long term.
- In order to tackle these challenges, [public health needs to utilize climate information in its analyses](#). Integrated climate services are an indispensable tool for [surveillance, outbreak investigations, risk assessments, health service delivery, research, long-term planning, and decision-making](#).
- Climate services have been successfully integrated into the [National Adaptation Plan \(NAP\)](#) process, which addresses the impacts of climate change on public health. As part of this process, integrated [health vulnerability and adaptation](#) are conducted to advance climate change resilience in the health sector. Climate services have also been used for selected forecasting tools, integrated [climate-health surveillance, health observatories, climate-related disaster forecasting](#) (floods, heat waves), and [early warning systems \(EWS\)](#) for vector-borne diseases and heat and cold waves.
- This module will illustrate how weather and climate observations are collected and how they are used to generate forecasts and projections for public health purposes.

1.0 - Weather and Climate Observations



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1.0 WEATHER AND CLIMATE OBSERVATIONS – Key terms

WEATHER: consists of short-term (minutes to months) changes in the atmosphere with respect to variables such as temperature, humidity, precipitation, cloudiness, brightness, visibility, wind, and atmospheric pressure (e.g., high and low pressure).

CLIMATE: is defined as the measurement of the mean and variability of relevant quantities of certain variables (such as temperature, precipitation, or wind) over a period of time, ranging from **months to thousands or millions of years**. **The classical period is 30 years**, as defined by the World Meteorological Organization (WMO). Climate, in a wider sense, is the state, including a statistical description, of the climate system.

**“Climate is what you expect,
weather is what you get”**



© WHO/Yoshi Shimizu

WEATHER

What is
happening



© WHO/Alexandra McPhedran

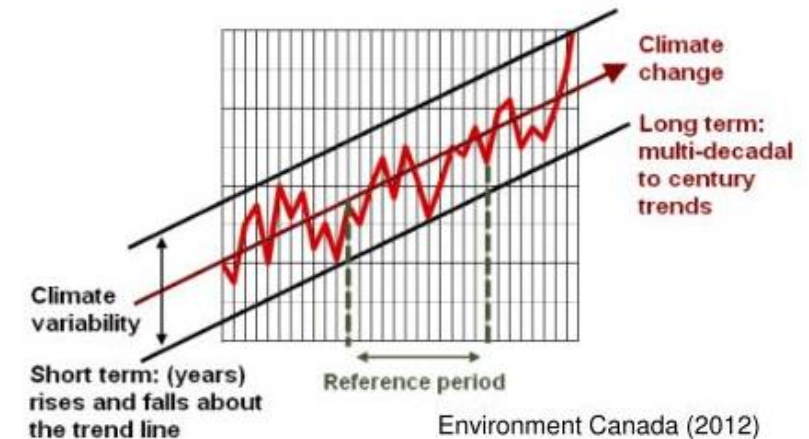
CLIMATE

Average
weather

1.0 WEATHER AND CLIMATE OBSERVATIONS – Key terms

CLIMATE VARIABILITY: Variations in the average state and other statistics of the climate on all temporal and spatial scales beyond individual weather events. The term is often used to denote **deviations in climatic statistics over a given period (e.g., a month, season, or year) when compared with** long-term statistics for the same calendar period. Climate variability is measured by these deviations, which are usually referred to as **anomalies**. Variability may be due to natural internal processes within the climate system (**internal variability**), or to variations in natural or anthropogenic external factors (**external variability**).

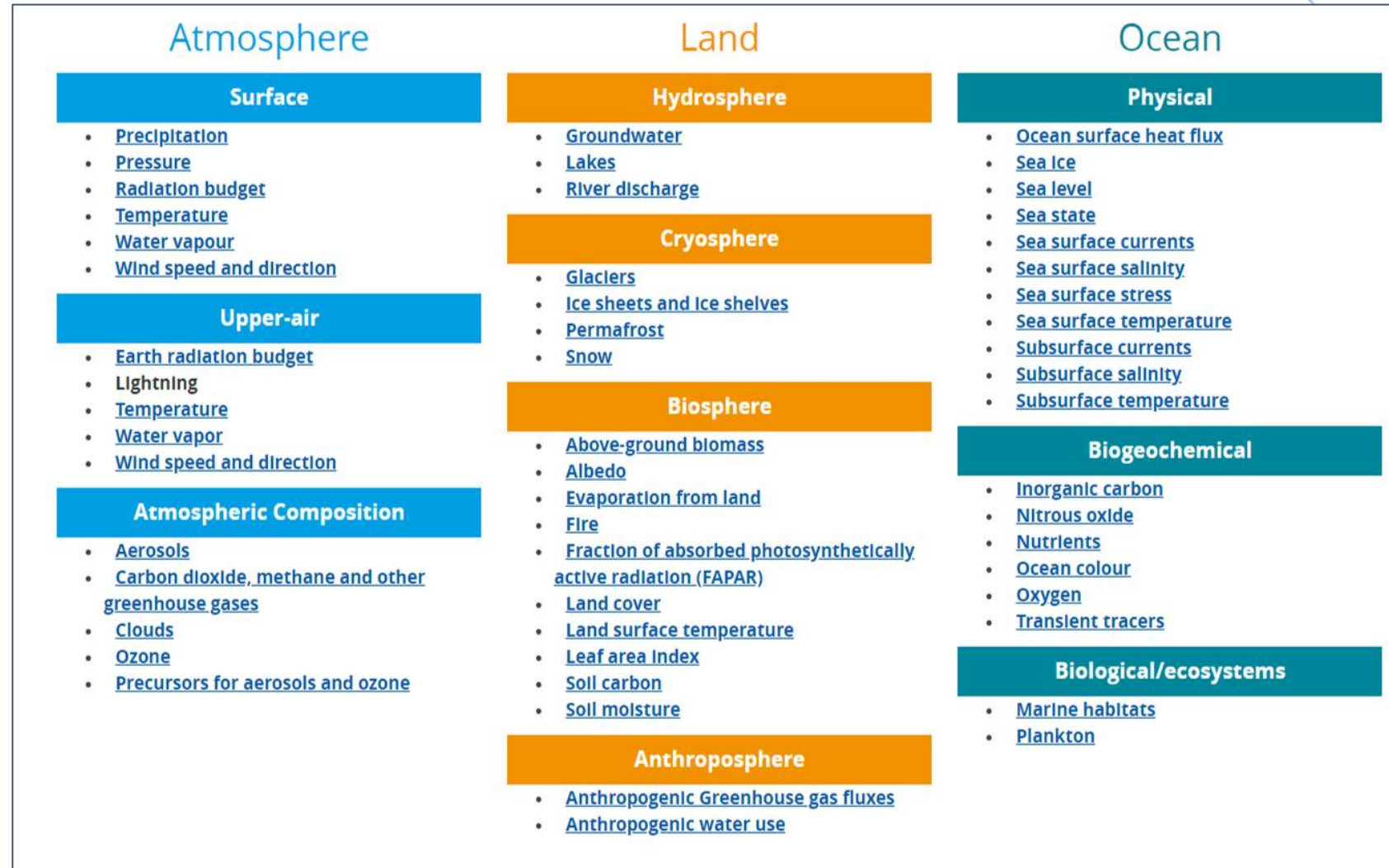
CLIMATE CHANGE: refers to a **statistically significant variation** in either the mean state of the climate or in its variability, **persisting for an extended period (typically decades or longer)**. Climate change may be due to natural internal processes or external factors, such as persistent changes in the atmosphere or in land use.



1.0 WEATHER AND CLIMATE OBSERVATIONS – Key terms

54 essential climate variables (ECV) are used to describe and measure the state of the climate.

Related to **HEALTH impacts**, mainly four climate variables are considered as potential climate hazards to health: 1) Temperature, 2) Precipitation, 3) Humidity, and 4) Wind speed and direction.



1.0 WEATHER AND CLIMATE OBSERVATIONS – Essential climate variables with impacts for health



Temperature: Air Temperature, or how hot or cold the air is

Temperature is one of the most important climate variables for health because of its direct impact on the human body (e.g., heat waves and extreme cold periods) and many indirect impacts, such as its effects on disease transmission.

Air temperatures are commonly reported as a maximum, a minimum, and/or a mean over a 24-hour period.

Our subjective sense of how hot or cold (the air) is depends on the humidity and/or wind chill (e.g., a breeze) and possibly other current weather conditions.



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Chapter 4: Climate Basics. Connecting Climate Information with Health Outcomes. In “Climate Information for Public Health Action”, Eds. Thomson, M.C. & Mason, S.J. Routledge, London, UK

1.0 WEATHER AND CLIMATE OBSERVATIONS – Essential climate variables with impacts for health



Precipitation: Rain, snow, hail, and sleet (a mix of rain and snow) are the main forms in which water falls to Earth’s surface is either liquid or solid. Collectively, these forms are called ‘precipitation’.

Water, largely obtained from rainfall, is vital to every living organism; it provides the water that plants and animals, including humans, need to thrive. In addition, there are hazards posed by the physical properties of falling hail and by rain and snow on the ground.

Daily precipitation is measured as an accumulation in mm over a 24-hour period (the starting time of day varies by location). Precipitation is measured as the depth of water (snow and hail are first melted to get an equivalent amount of rainfall) that has fallen to the surface.

The most common method of measuring precipitation is to capture it in a specially designed bucket, known as a rain gauge.

1.0 WEATHER AND CLIMATE OBSERVATIONS – Essential climate variables with impacts for health



Humidity: Amount of water vapour in the air

The humidity of air near the surface of the Earth affects the comfort and health of humans, livestock and wildlife, the swarming behaviour of insects, and the occurrence of plant disease.

Among the impacts are those stemming from the formation of fog. Along with temperature and wind, near-surface water vapour influences the surface fluxes of moisture and thus plays a role in the energy and hydrological cycles.

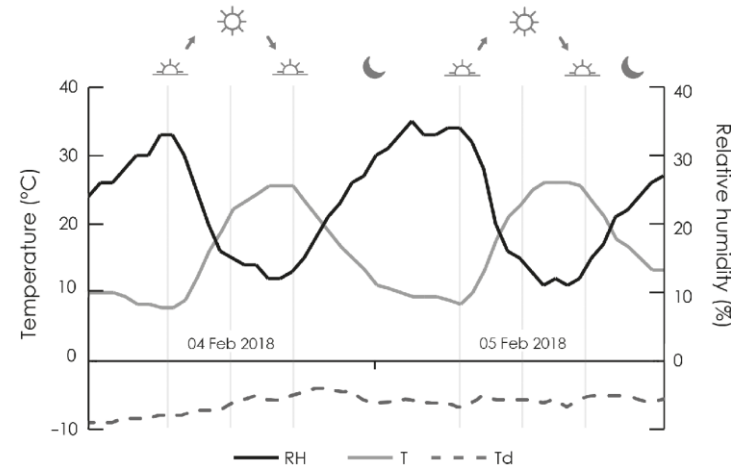
There are **three ways to measure humidity**:

- ***Absolute humidity:** Mass of water vapour per cubic metre of air. Because air expands as its temperature increases, a cubic metre contains more air if it is cold than if it is hot. Absolute humidity is likely to be unsuitable for most analyses of health effects.*
- ***Specific humidity**, also known as the “moisture content”, is a measure of how much water vapour there is in relation to the total mass of water vapour and air combined. Thus, it corrects for the problem with absolute humidity.*
- ***Relative humidity** is the most commonly reported measure of humidity because it measures the amount of water vapour in the air as a fraction of the amount in ‘saturated’ air of the same temperature. ‘Saturated’ means that the air is holding as much moisture as it can; further increases in humidity or decreases in temperature would lead to condensation.*

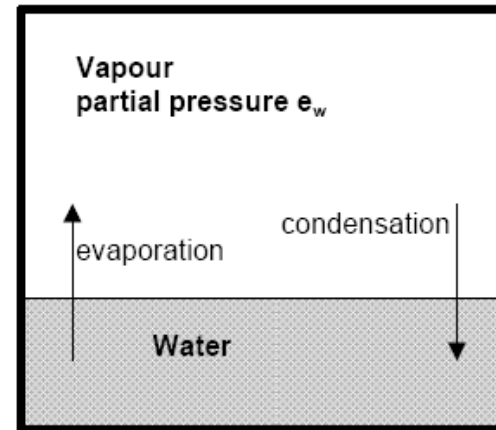
1.0 WEATHER AND CLIMATE OBSERVATIONS – Essential climate variables with impacts for health



- The figure indicates that relative humidity is sensitive to temperature and thus can vary significantly depending on when the measurement is taken. The relative humidity drops with rising temperature because at higher temperatures, saturated air contains more moisture (as warmer air can hold more water vapour; the denominator becomes larger)
- Thus, for health analyses, the co-variability of RH with temperature must be accounted for adequately.
- The relative humidity is measured as a percent of atmospheric capacity, from slightly above 0 percent to 100 percent. These measurements are made by a thin-film capacitive humidity sensor and reported as 5-minute averages.



Hourly temperature (T; thin grey line), dew-point temperature (Td; dashed line), and relative humidity (RH; thick black line) in Tucson, AZ, USA, for 4 and 5 February 2018. The times of sunrise, high noon, and sunset are shown by the symbols and thin vertical lines. The correlation between the temperature and the relative humidity is – 0.97.



RH is the ratio of the actual water vapour pressure to the saturation water vapour pressure over a plane (=flat/level) liquid water surface at the same temperature. For the actual water vapour pressure e and the saturation water vapour pressure e_s ,

$$RH \text{ (in \%)} = e/e_s \times 100$$

Condensation occurs when the RH reaches 100%. Conversely, when RH is low, there is more capacity for additional water vapour in the air, allowing for faster evaporation.

1.0 WEATHER AND CLIMATE OBSERVATIONS – Essential climate variables with impacts for health



Wind: Flow of air, measured in terms of its direction and speed

Strong winds pose an obvious health risk due to the physical hazards they create from flying and falling objects. The potential for wind damage increases by a factor of 4 for every doubling of **wind speed**, but the risk is further exacerbated when wind is combined with **rain or snow**. Hence, **strong tropical or winter storms** can be particularly devastating.

Winds affect our perception of temperature and humidity by altering exposure and evaporation rates, and they transport and disperse **dust, pollution, pathogens, and insect vectors**.

Wind speeds are highly variable, and so a distinction is sometimes made between **gusts** and **sustained winds**.

Sustained wind speeds are calculated over two-minute periods, while gusts are instantaneous speeds and are recorded only if they exceed the sustained winds by more than 10 knots ($19 \text{ km}\cdot\text{h}^{-1}$).



Wind direction is measured by a vane consisting of a thin horizontal arm carrying a vertical flat plate at one end and a balance weight at the other, serving as a pointer. The arm is carried on a vertical spindle mounted on bearings, allowing it to turn freely in the wind. The anemometer and wind vane are each attached to a horizontal supporting arm at the top of a 10 m mast.

Each station uses an anemometer to measure wind speed at a height of approximately 1.5 meters above the surface. Every five minutes, the datalogger averages two-second pulse counts to derive a 5-minute average wind speed in meters per second (m/s).

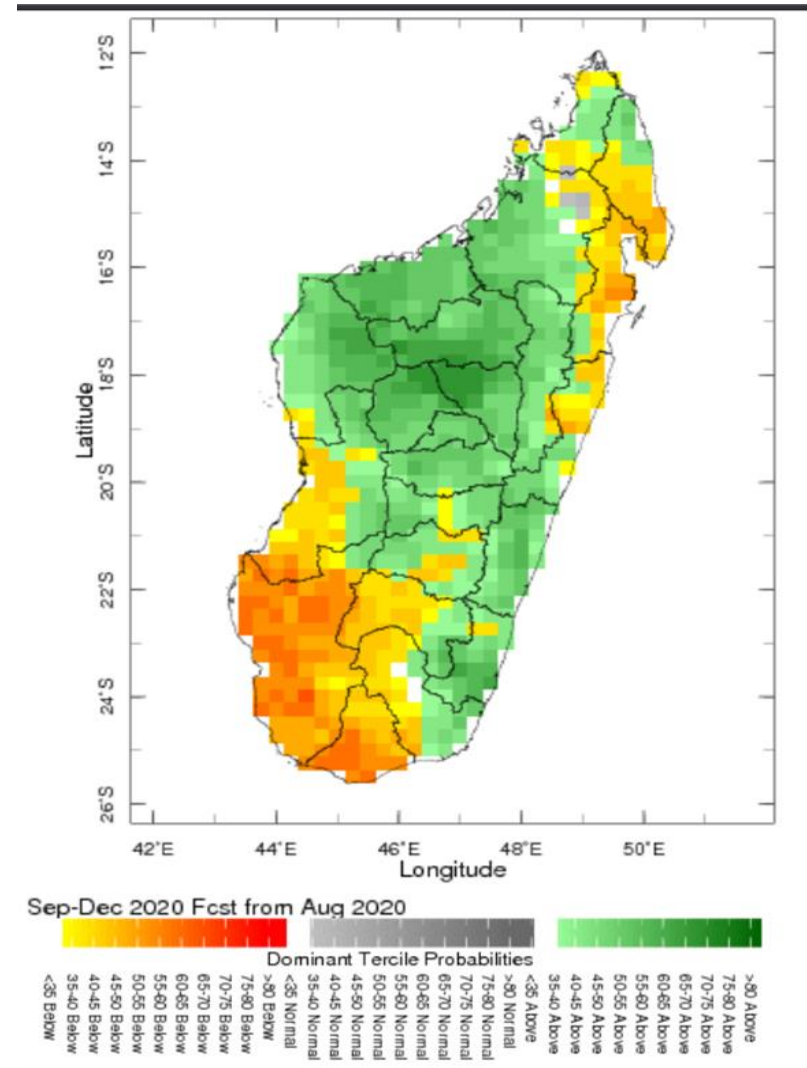


Because wind varies rapidly over very short periods of time, it is sampled at high frequency (every 0.25 sec) to capture the intensity of gusts, or short-lived peaks in speed, which inflict the greatest damage in storms.



1.0 WEATHER AND CLIMATE OBSERVATIONS – Changes in climate-hazards and impacts on health

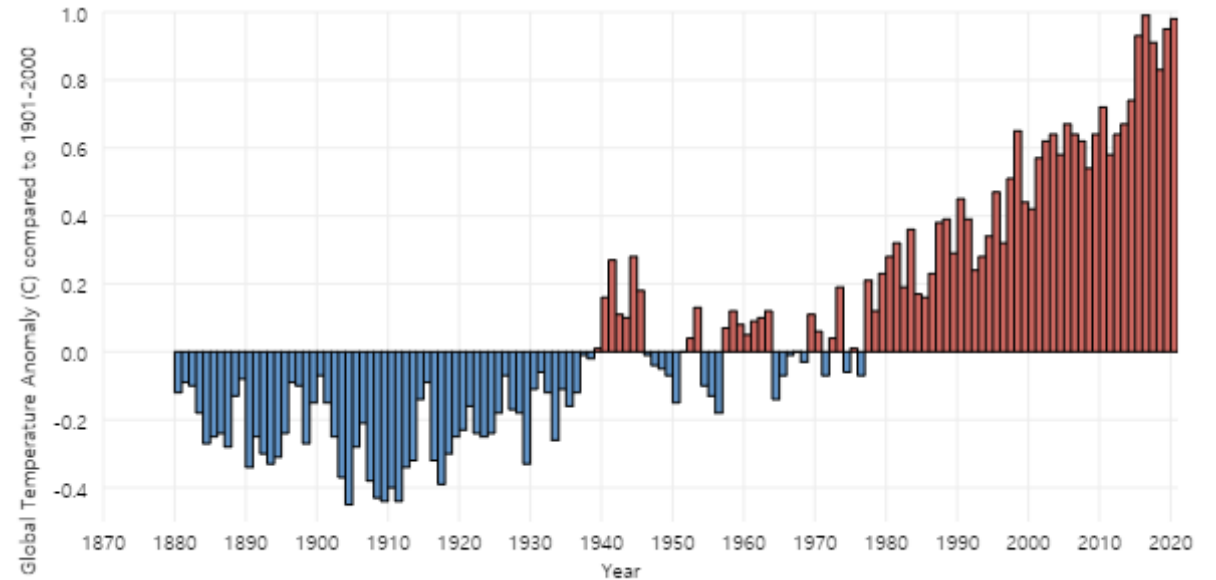
- **Climate normals** are three-decade averages of climatological variables, including temperature and precipitation. This establishes the “normal” conditions expected for a season and location.
- **Climate anomalies**, or extreme conditions, are identified as deviations from the “normal” climatology of a location
- **Tercile forecasts** provide the probability or likelihood that conditions will be below-, near-, or above-normal rainfall
 - *Example: There is a 30% chance of below-normal rainfall, a 40% chance of near-normal rainfall, and a 30% chance of above-normal rainfall*



1.0 WEATHER AND CLIMATE OBSERVATIONS – Changes in climate-hazards and impacts on health

Climate is changing: Temperature

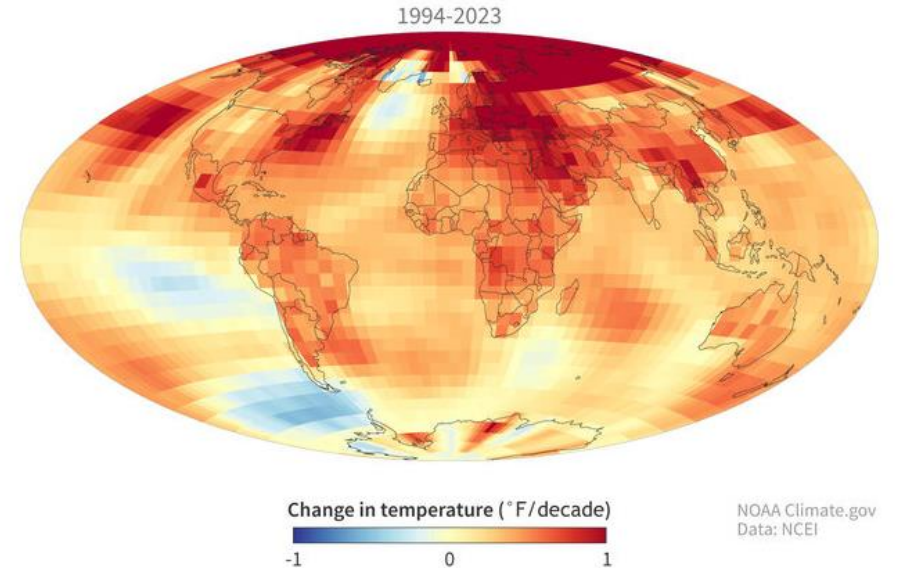
- Given the size and tremendous heat capacity of the global oceans, it takes a massive amount of heat energy to raise Earth's average yearly surface temperature even a small amount. The **~1-degree Celsius increase in global average surface temperature** since the pre-industrial era (1880-1900) might seem small, but it represents a significant increase in accumulated heat.
- That extra heat is driving regional and seasonal temperature extremes, reducing snow cover and sea ice, intensifying heavy rainfall, and changing habitat ranges for plants and animals, expanding some and shrinking others.
- The combined land and ocean temperature has increased at an average rate of **0.06°C per decade** since 1850; however, the **rate of warming since 1982 is more than three times as fast: 0.20° C per decade.**



1.0 WEATHER AND CLIMATE OBSERVATIONS – Changes in climate-hazards and impacts on health

Climate is changing: Temperature

- The year 2023 stands out as the warmest year on record by a significant margin due to a combination of long-term climate change, El Niño, and other factors, with trends continuing in 2024.
- June 2024 was the 13th consecutive month to break global temperature records.
- The latest projection warns that at least one of the next five years will be the warmest on record, beating 2023.
- According to the IPCC (AR6), there is “high confidence” that Central and South America, southern Europe, Southern and Southeast Asia, and Africa will be the most affected by climate change in terms of **heat-related mortality** by 2100, based on 1.5°C, 2°C, and 3°C increases in the global temperature.

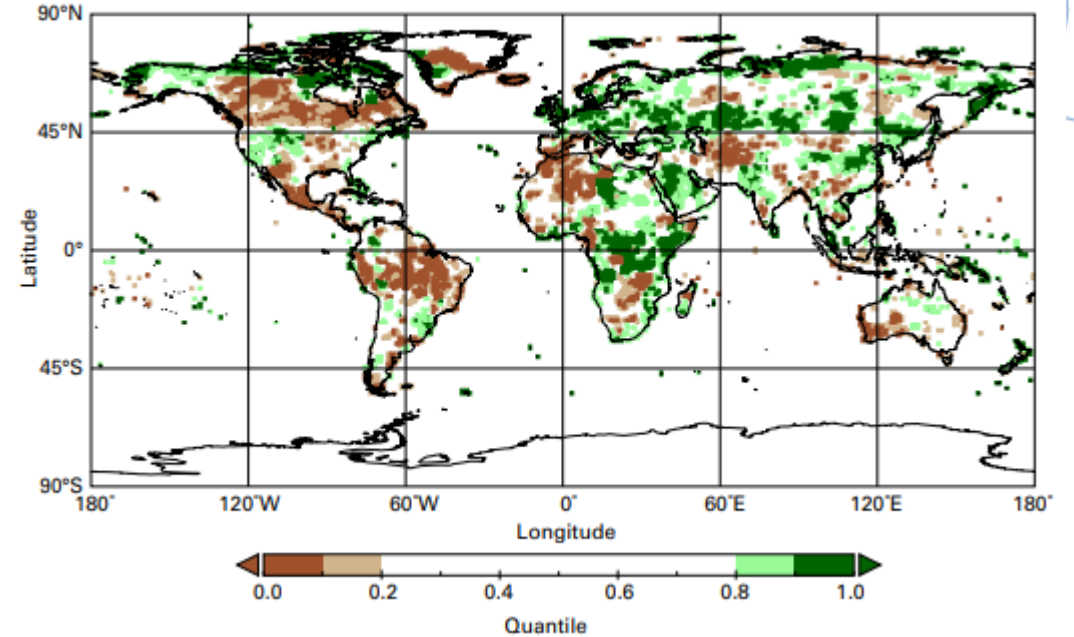


Changes in global average surface temperature from 1994-2023. Places that warmed by up to 1° Fahrenheit over the past 30 years are red, places that have cooled by up to 1° F are blue, and places where we don't have enough observations to calculate a trend are light gray. NOAA Climate.gov map, based on NCEI data.

1.0 WEATHER AND CLIMATE OBSERVATIONS – Changes in climate-hazards and impacts on health

Climate is changing: Precipitation

- The figure shows **increasing precipitation** accumulated totals in 2023 in some regions, and **marked deficits** in others.
- **Long-term drought** persisted in north-western Africa, parts of the Iberian Peninsula, parts of central and southwest Asia, and intensified in many parts of Central America, northern South America, and the southern United States. For instance, in Uruguay, water storage reached critically low levels, badly affecting the quality of supplies to major centres.
- **Flooding associated with extreme rainfall** from Mediterranean Cyclone Daniel affected Greece, Bulgaria, Türkiye, and Libya, with particularly heavy loss of life in Libya.
- The Greater Horn of Africa region, which had been experiencing **long-term drought**, suffered **substantial flooding** in 2023, particularly later in the year following heavy rains associated with El Niño and the positive Indian Ocean Dipole (Short-term climate drivers).

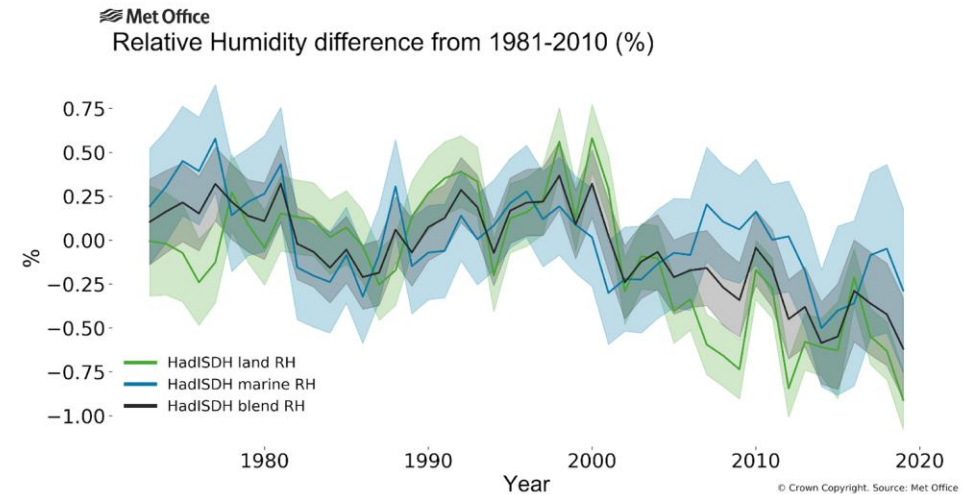
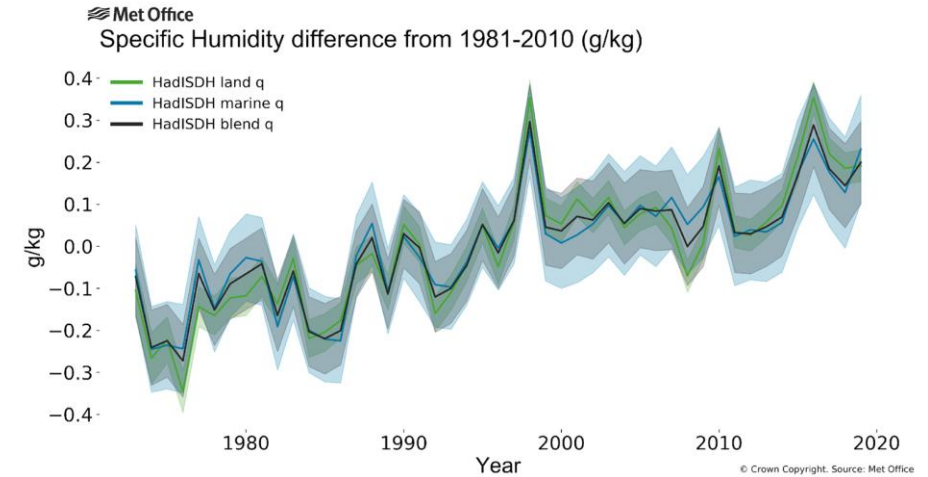


Total precipitation in 2023, expressed as a quantile of the 1991–2020 reference period, for areas that would have been in the driest 20% (brown) and wettest 20% (green) of years during the reference period, with darker shades of brown and green indicating the driest and wettest 10%, respectively. Source: Global Precipitation Climatology Centre (GPCC), Deutscher Wetterdienst, Germany.

1.0 WEATHER AND CLIMATE OBSERVATIONS – Changes in climate-hazards and impacts on health

Climate is changing: Humidity

- Humidity paradox: **Specific humidity** – or the amount of water vapour – has **increased**. Yet, at the same time, **relative humidity** – or saturation – over many regions has **declined** (for more on why, see this [article](#))
- Higher levels of moisture in the air can lead to more rainfall. Extreme events, such as hurricanes, can already be devastating to society and the environment, so increased rainfall makes them even more dangerous. In addition, higher humidity can also raise the **risk of heat stress** on very warm days.
- The implications of a **decrease in relative humidity** are less obvious. Decreasing saturation will affect something called the vapour pressure deficit. This is basically a measure of how much extra water vapour the atmosphere could hold at that temperature. When the **vapour pressure deficit is high**, plants may need to close their stomata to avoid too much moisture loss. In these **dry conditions**, **wildfires can start more easily and spread more easily**.



Global time series of annual average specific humidity (top) and relative humidity (bottom) for the land (green line), ocean (blue) and global average (dark blue), relative to 1981-2010. The two-standard deviation ranges for uncertainty are shown combining the observation, sampling and coverage uncertainty

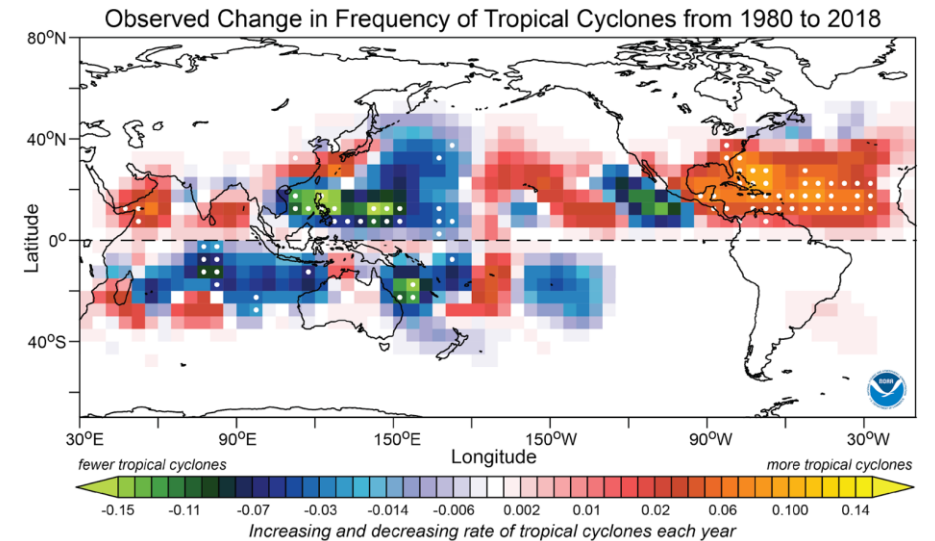
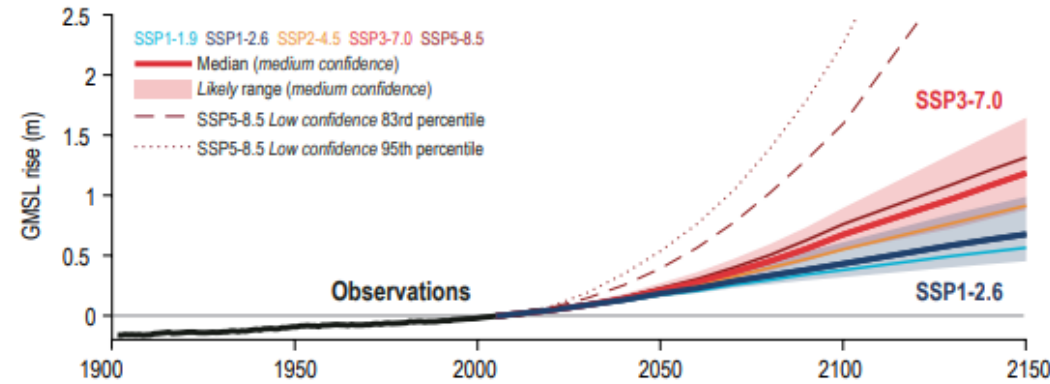
1.0 WEATHER AND CLIMATE OBSERVATIONS – Changes in climate-hazards and impacts on health

Climate is changing: Climate impacts

- **Sea level rise** – for which human activities were very likely the main driver since 1971– is very likely to be virtually certain (depending on the region) to continue during the 21st century, contributing to **increased coastal flooding** in low-lying areas and **coastal erosion** along most sandy coasts. Sea level will continue to rise beyond 2100.
- Water cycle variability and related extremes are projected to increase faster than mean changes in most regions of the world (high confidence). A warmer climate increases moisture transport into weather systems, intensifying wet seasons and extreme events (high confidence). The average and maximum **rain-rates associated with tropical and extratropical cyclones, atmospheric rivers, and severe convective storms** will therefore increase with future warming (high confidence). In some regions, there is medium confidence that peak tropical cyclone rain rates will increase by more than 7% per 1°C of warming due to increased low-level moisture convergence driven by stronger winds.
- The proportion of **tropical cyclones that are intense** is expected to increase (high confidence), but the total global number of tropical cyclones is expected to decrease or remain unchanged (medium confidence).

https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_TS.pdf

(a) Global mean sea level rise from 1900–2150



This graphic depicts the global pattern of where the frequency of tropical cyclones has increased and where it has decreased around the world from 1980 to 2018. New NOAA research shows that while the global annual average number of tropical cyclones has remained at 86, climate change has influenced the location of where tropical cyclones have become more frequent, or less frequent.

<https://www.noaa.gov/news/study-climate-change-has-been-influencing-where-tropical-cyclones-rage>

1.1 – Weather and climate forecasts



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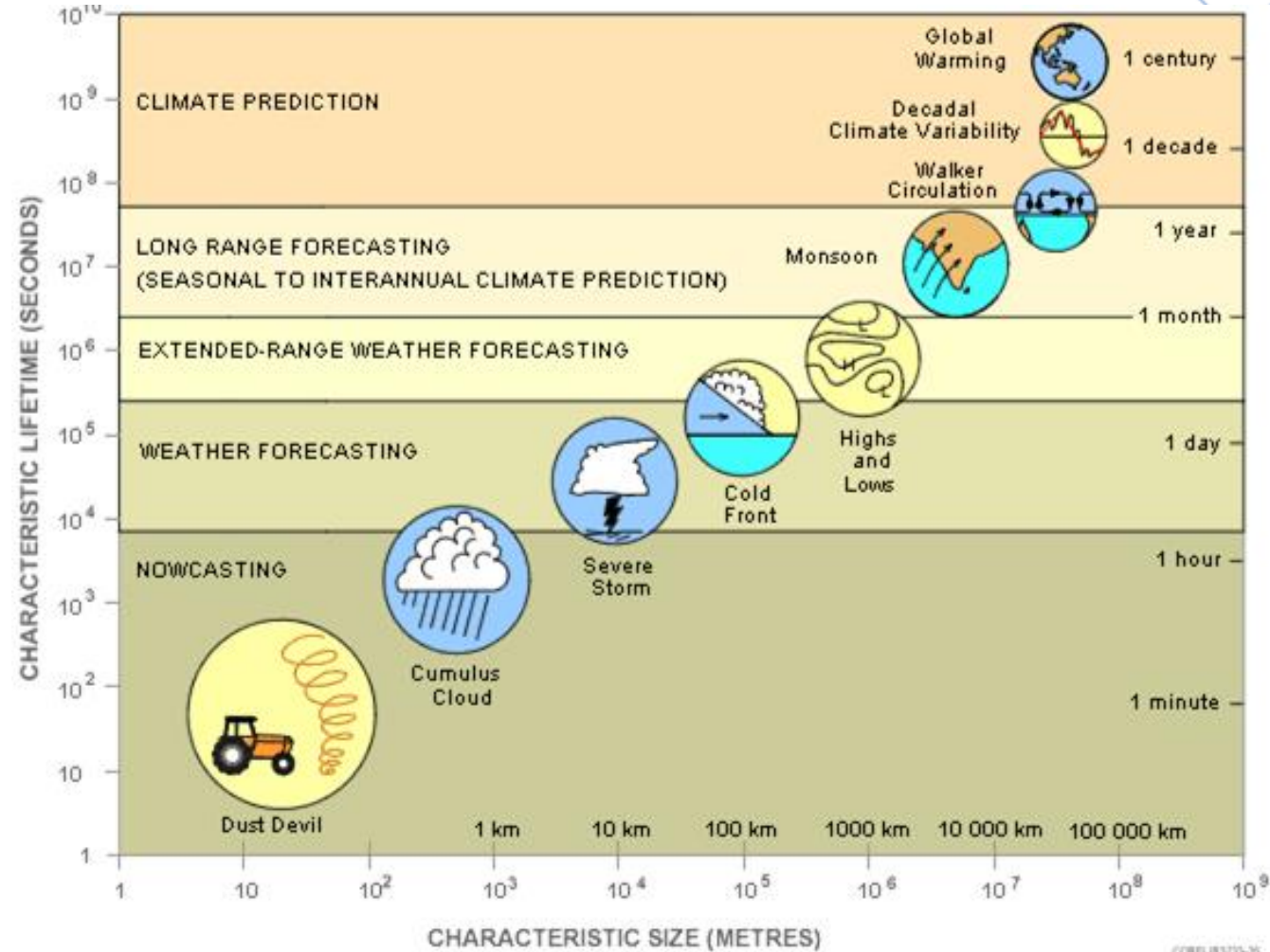


1.1 WEATHER AND CLIMATE FORECASTS – Types and uses of weather forecasts/predictions

Future weather is forecast, and future climate is projected using a range of techniques.

Numerical Weather Prediction is the most frequently used method, which involves using current weather observations and processing them with computer models to forecast the future state of the weather for minutes to days ahead.

- **Weather**
- **Sub-Seasonal**
- **Long-range Forecasting (Seasonal to multi-annual)**
- **Climate Prediction**

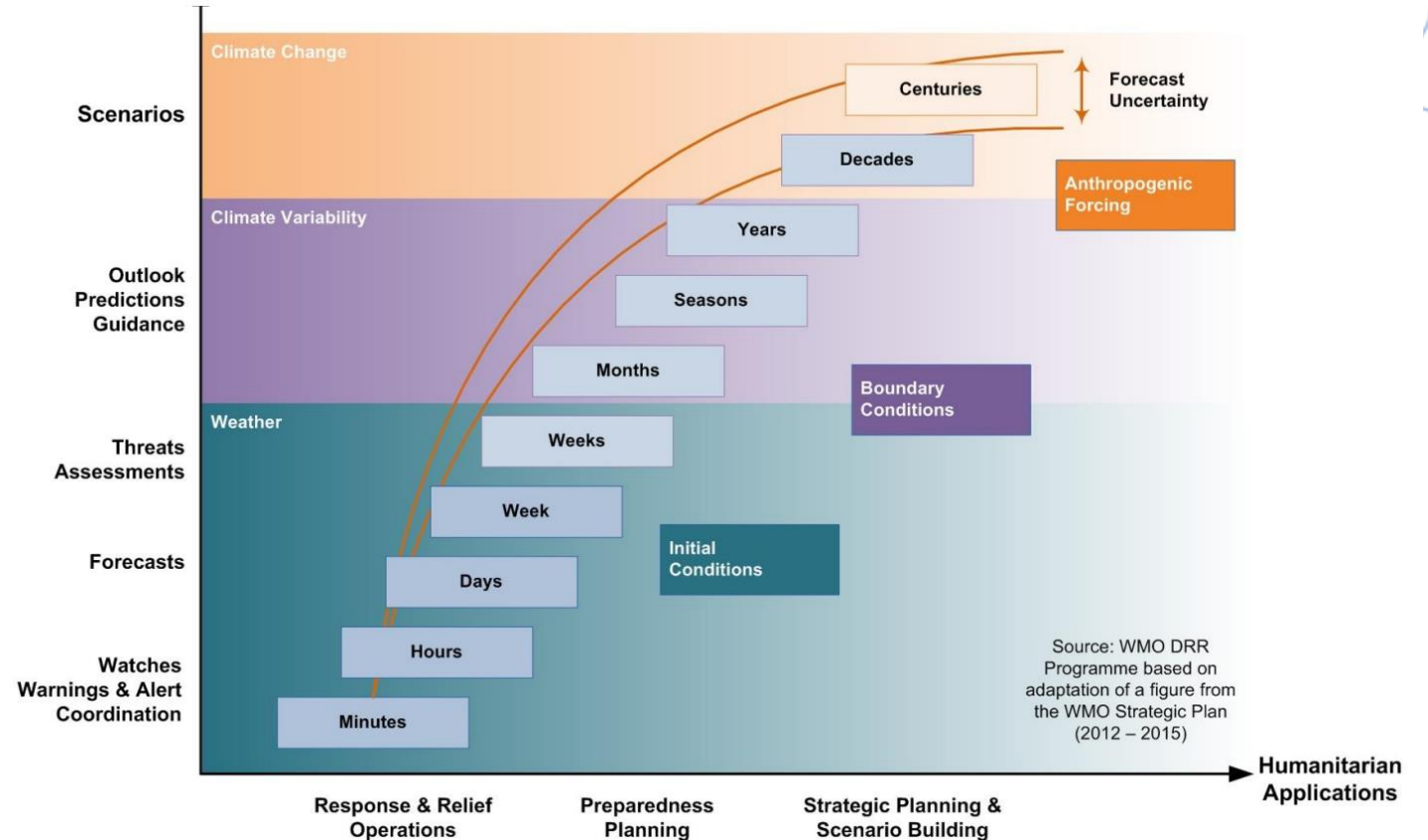


1.1 WEATHER AND CLIMATE FORECASTS – Types and uses of weather forecasts/predictions

Weather/climate data should be used in an appropriate timescale that fits the user’s needs.

Example: Humanitarian context

- Short-term: weather-based data covering current conditions, extending out to a few weeks, will be most helpful in ensuring that the negative impacts of weather on operations are minimized.
- Medium-term preparedness: Information on climate variability outlook and predictions in the coming months, seasons, and years can inform the location of camps for displaced populations or the establishment of natural resource-based livelihoods (e.g., agriculture).
- Long-term programming: Development programming can benefit from the integration of climate risks to ensure that the work is resilient to climate change.

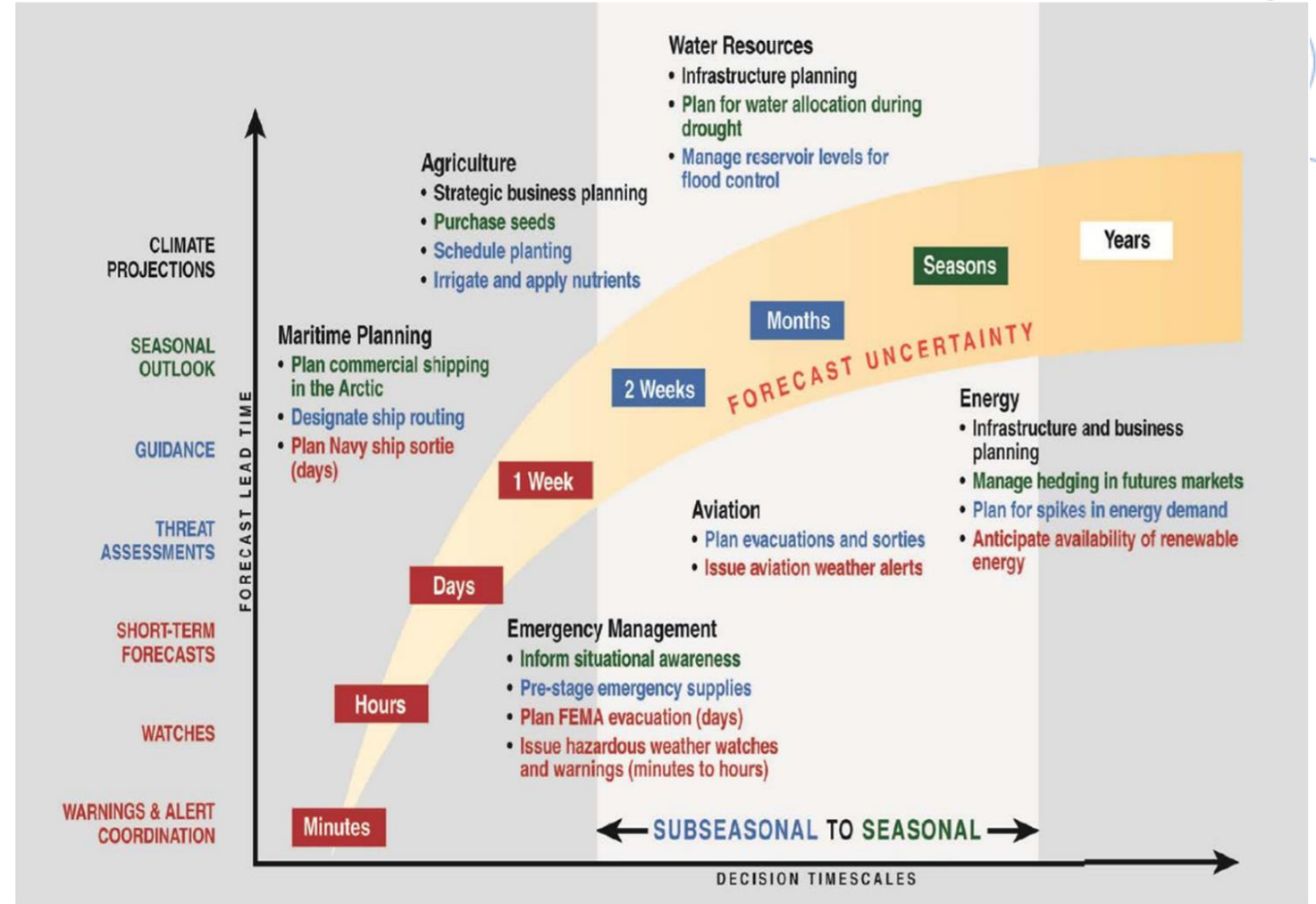


Schematic diagram showing the challenges of developing “seamless” products and services, and the available climate information and gaps (Source: National Oceanic and Atmospheric Administration)



1.1 WEATHER AND CLIMATE FORECASTS – Types and uses of weather forecasts/predictions

Forecasts inform critical decisions across many different sectors

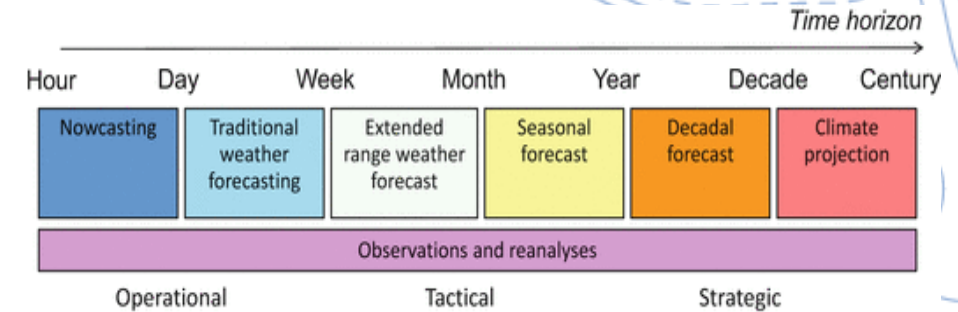


Source: Earth System Prediction Capability Office

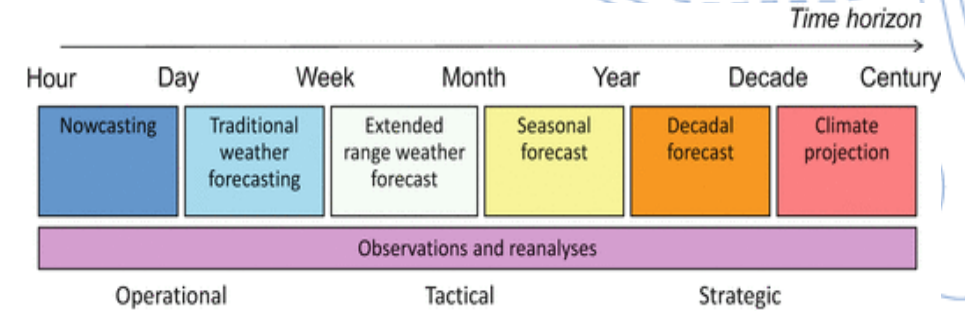


1.1 WEATHER AND CLIMATE FORECASTS – Types and uses of weather forecasts/predictions

- **Nowcasting:** a forecast on a small spatial range (few to several hundred kilometers) on a period of **up to 6 hours** using mainly surface weather stations, wind profilers, and other real-time weather data available.
- **Extended-range forecast:** a forecast beyond **10 days and up to 30 days** describing weather parameters, usually averaged and expressed as a departure from climate values for that period. Examples include 10-day and two-week forecasts, extreme climate event probability forecasts, and three-category (above normal, normal, below normal) probabilistic forecasts of rainfall and temperature.
- **Long-range forecast:** a forecast **from 30 days up to one year** that generally includes
 - **monthly outlooks** providing a description of averaged weather parameters expressed as a departure (deviation, variation, anomaly) from climate values for that month (not necessarily the coming month);
 - **90-day outlooks** that provide a description of averaged weather parameters expressed as a departure from climate values for that period (which is not necessarily the coming three-month or 90-day period);
 - **seasonal outlooks** that provide a description of averaged weather parameters expressed as a departure from climate values for that season. Examples include climate forecasts for variables such as precipitation, surface air temperature, mean sea-level pressure, 500 hPa geopotential height, forecasts of tropical storm activity, and large-scale climate variability phenomena such as El Niño/Southern Oscillation (ENSO) and the Madden-Julian Oscillation (MJO).



1.1 WEATHER AND CLIMATE FORECASTS – Types and uses of weather forecasts/predictions



- **Interannual prediction:** A prediction from one to several years in advance that describes the large-scale climatic state. This prediction is **initialized with indicators of the current climate** to capture the evolution of modes of **internal climate variability**, such as ENSO. Examples include predicting climatic trends in variables such as precipitation, temperature, mean sea-level pressure, and 500 hPa geopotential height.
- **Decadal prediction:** A prediction of fluctuations in the climate system **over the next 10 years**, taking into account **natural variability, as well as human influences**. This is achieved by initializing climate models with observations of the current climate state and by specifying changes in radiative forcing from greenhouse gases, aerosols, and solar variability.
- **Climate projection:** provides statements for the long-term horizon, up to the end of the 21st century, based on different scenarios of future societal development. They can inform current adaptation efforts and increase society's resilience to climate change and variability.

1.1 WEATHER AND CLIMATE FORECASTS – Types and uses of weather forecasts/predictions

Forecasts/predictions are used to create warnings of dangerous conditions, which are **threshold-based** or **impact-based**

Impact-based forecasts: an approach to forecasting severe weather that turns forecasts and warnings from descriptions of **what the weather will be** into assessments of **what the weather will do**, in order to inform **preventive action**

Example:

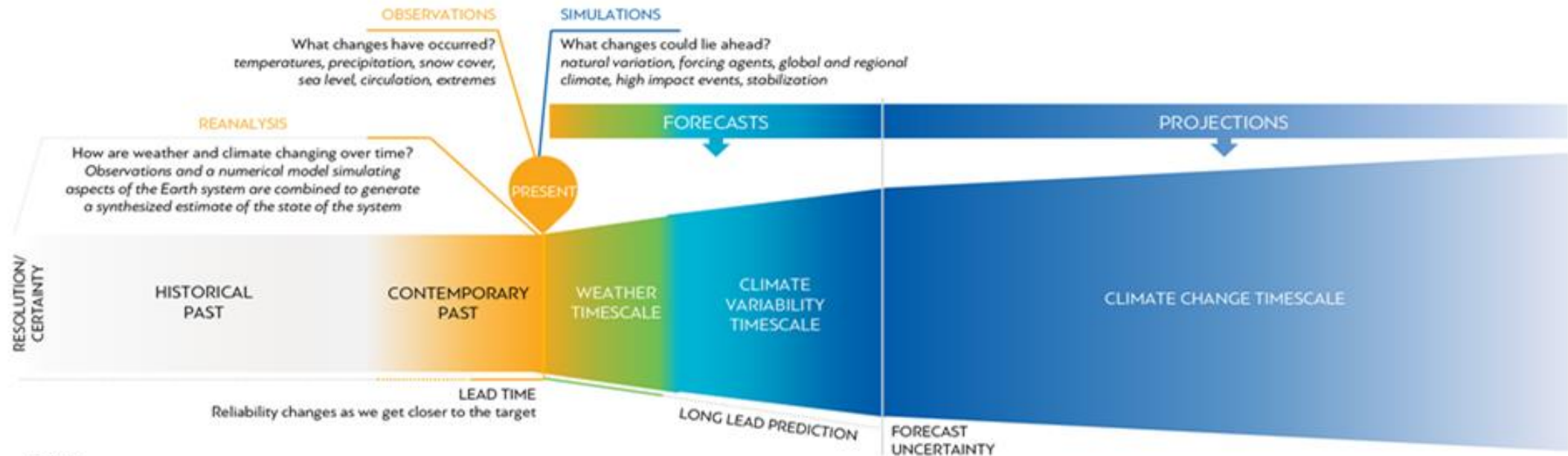
- **Threshold-based Warning:** “Strong winds are expected tonight with wind speeds of 20m/s likely”
- **Impact-based Warning:** — “Strong winds are expected tonight, which may result in delays or cancellations to ferry services and keep small fishing boats tied up”

Table 1. Comparisons between Traditional Forecasts, Impact-based Forecasts, and Co-produced Impact-based Forecasts

Hazard	Forecast	Impact-based forecast for Individuals/ members of public	Impact based forecast for Sector specific users
Flooding	Heavy rain is forecast. 100 to 150mm of rain is expected within a three-hour period.	Flash flooding of the County River is expected. Dwellings, farm buildings and grazing land within 30m of the river channel are expected to flood and be damaged.	The forecast water level in the recreational district is expected to cross the +0.85 alert threshold in 5 days and remain above for a further 3 days. An impact forecast of loss of household assets is over 25% and affected population over 40%.
Tropical Cyclone	A tropical cyclone category 3, windspeed of 125 km/h is expected in the next 48 hours.	A tropical cyclone category 3, windspeed of 125 km/h is expected to make landfall in 12 hours, in X and Y regions, likely to damage critical infrastructure such as bridges, blocking transport from region X to region Y.	A Tropical cyclone, lead time of 30 hours, with wind speed greater than 125 km/h, corresponding to an impact forecast of damage of 25% of housing.

<https://www.forecast-based-financing.org/wp-content/uploads/2020/09/Impact-based-forecasting-guide-2020.pdf>





DATA

Historical data consists of
Instrumental data - century-long measurements of surface temperature and precipitation, records of daily data
Paleoclimate data - derived from natural sources such as tree rings, ice cores, corals, and ocean and lake sediments

Monitoring
 Uses data from recent past and the present

Sub-seasonal to Seasonal
 Flash flood guidance
 Severe weather forecasting
 Tropical cyclone forecasting

Interannual
 Climate Change Indices

PRODUCTS

Past climate
 Climate trends, Extreme climate indices, Sector-specific climate indices, Reanalyses, Return periods of extremes, Climate Normals, World Weather Records

Weather
 Initial conditions

Climate variability
 Boundary conditions (sea surface, snow cover, land),
 Climate monitoring and watch

Multi-decadal

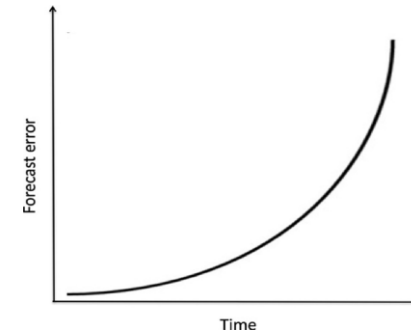
Projections
 Operational projections on climate change timescales



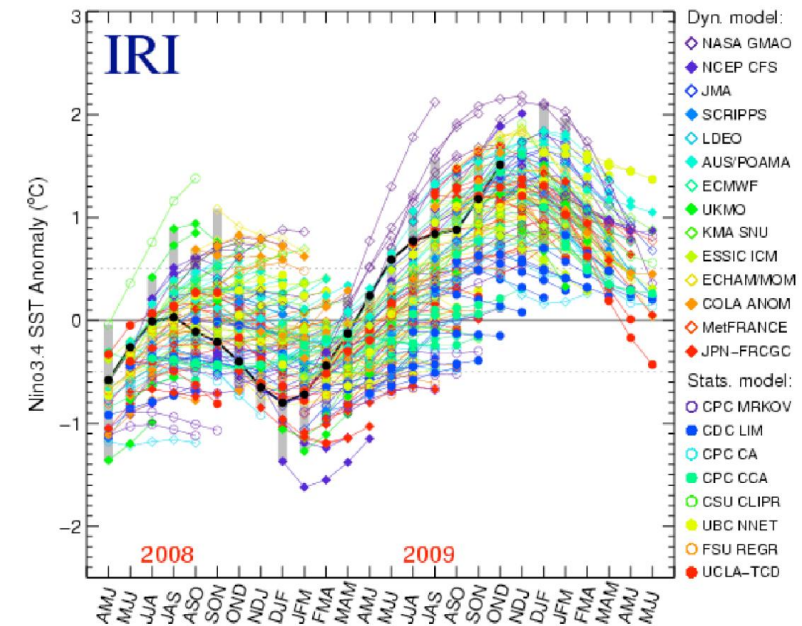
1.1 WEATHER AND CLIMATE FORECASTS – Uncertainty in forecasts/predictions

Numerical weather and climate predictability:

- Weather and climate forecasts are generated by collecting data on the **current atmospheric conditions** at a specific location and time, then predicting **how these conditions will evolve**.
- Current forecasting heavily relies on computer-based modeling, which can take many variables into account. However, **forecasting inaccuracies** persist due to the **chaotic nature** of the atmosphere, including **errors in measuring the initial conditions** upon which predictions are based, as well as a lack of understanding of **atmospheric processes**.
- Thus, **uncertainties** in prediction increase as the forecast range extends, as illustrated in the figures.

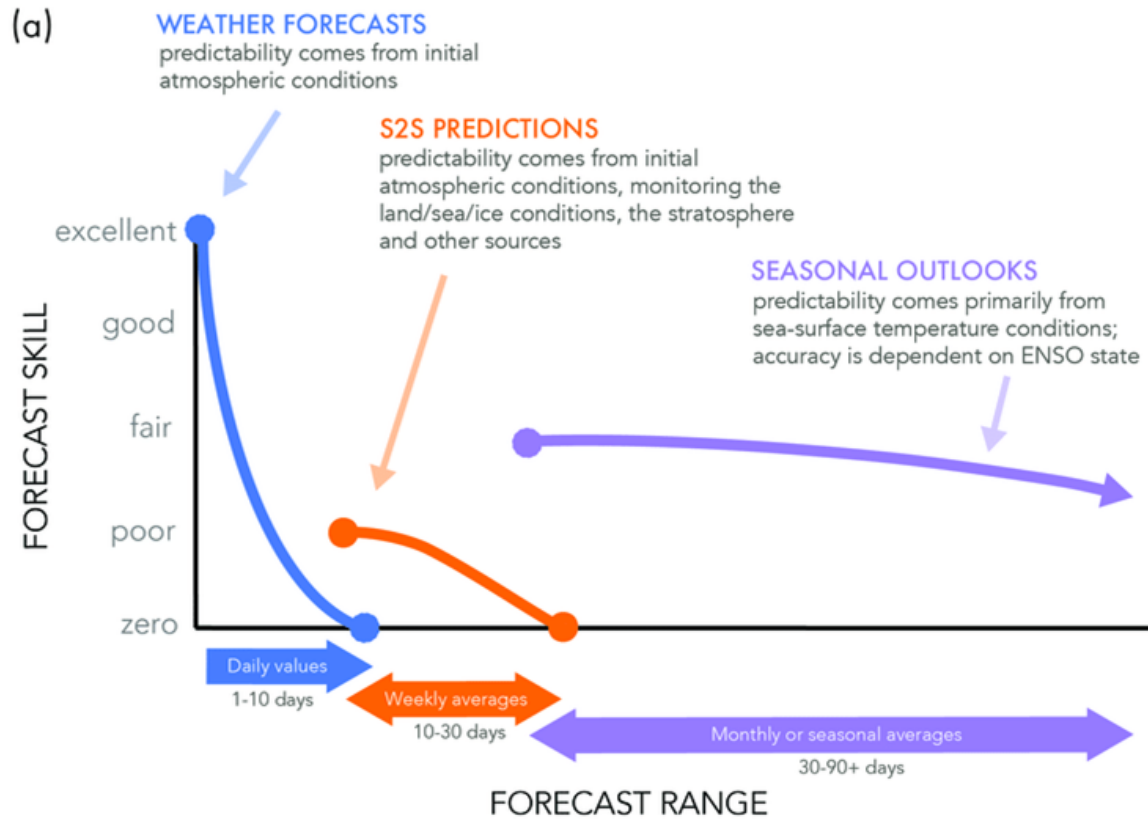


The exponential growth of linearly evolving perturbation or error variance associated with instabilities in chaotic systems (with arbitrary units). SOURCE: Sub-seasonal to Seasonal Prediction (2018)

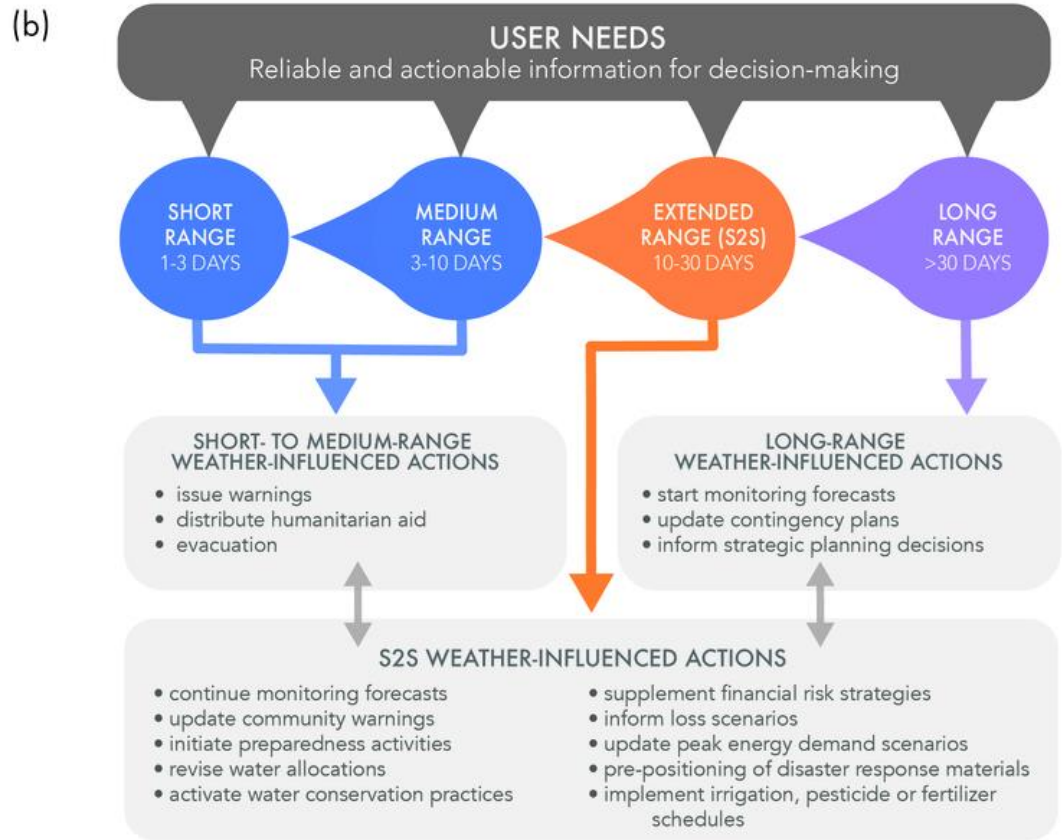


Predictions from various statistical (colored circles) and dynamical (colored diamonds) models along with observations (black circles) for sea surface temperature anomalies in the equatorial Pacific Ocean. Many of the model predictions track the evolution of the anomalies, but the spread among the models is still rather large. The models' starting points vary, and each prediction extends for approximately 5 months, as predictions tend to diverge significantly after this period. SOURCE: International Research Institute for Climate and Society (IRI)

1.1 WEATHER AND CLIMATE FORECASTS – Uncertainty in forecasts/predictions



(a) Qualitative estimate of forecast skill based on forecast range from short-range weather forecasts to long-range seasonal predictions, including potential sources of predictability. Relative skill* is based on differing forecast averaging periods. *Forecasts are skillful when they outscore an alternative set of forecasts.



(b) Schematic highlighting the relationship between the subseasonal to seasonal (S2S) 'extended-range' forecast range and other prediction timescales, with examples of actionable information that can enable decision-making across sectors. Actions are examples only and are not exclusive to a forecast range.

1.1 WEATHER AND CLIMATE FORECASTS – Uncertainty in forecasts/predictions

Steps taken to make predictions:

- 1. Observation:** Take measurements of the current state of the weather (temperature, rainfall, winds, humidity, air pressure, etc.). These observations are obtained through surface observations (weather stations), at different altitudes above the weather stations (using radiosondes and aircraft observations), and through remotely sensed observations (satellite and radar measurements).
- 2. Analysis:** Estimate the current state of the atmosphere over the whole globe and from the surface up to at least about 10 km. The analysis is complex and computationally intensive and is performed only by forecasting centres with the most powerful computers; These are made available to other centres, which then use them to initialize their own weather prediction models.
- 3. Initialization:** Input these measurements and estimates into a computer model. Initializing a model involves specifying the starting values for the model's equations. That is, the equations in the Numerical Weather Prediction (NWP) model need to be initialized with estimates of the current weather – the initial conditions.
- 4. Integration:** Use the model to predict how the current state of the atmosphere will evolve. NWP models involve a set of so-called primitive equations that describe how air behaves. They describe what is happening at a specific location and are calculated at many points over a region of interest or the globe. The equations predict various meteorological parameters from current values.
- 5. Post-processing:** Determine how that future state will affect the weather at the locations and times of interest. The outputs from the NWP model(s) may be inadequate for forecasting. Thus, they must be addressed by applying a statistical correction, which can range from simple linear regression to highly complex procedures that use **ensembles of forecasts** from multiple NWP models.

1.1 WEATHER AND CLIMATE FORECASTS – Uncertainty in forecasts/predictions

Sources of uncertainty

- **Initial condition uncertainty:** One primary reason weather forecasts sometimes fail is that forecasters do not always have an adequate estimate of the current weather, i.e., the initial conditions.
- **Chaotic nature of the weather:** A chaotic system is one in which future states are highly sensitive to small differences in current states, i.e., the smallest difference now can evolve into substantial differences in the future. A slightly inaccurate estimate of the current weather can lead to a large error in the forecast at some point in the future. Lorenz first articulated chaos theory when he observed that his meteorological model produced completely different results when he used three decimal places instead of six (“butterfly effect”).
- **Model uncertainty:** We do not know perfectly all the equations that govern our weather, and even those we do know cannot be modeled exactly due to computer limitations. Weather forecasts are time-sensitive and must be produced quickly, necessitating model simplification. Even if the current weather were measured precisely, forecasts would still be limited by these simplifications. Access to immensely powerful computers would not solve the problem entirely, as random effects - such as volcanic activity and various human actions- make perfect forecasting impossible.
- Despite these theoretical and practical challenges, a chaotic system may be **predicted with reasonable accuracy**, as long as we do not try to predict too far into the future.

1.1 WEATHER AND CLIMATE FORECASTS – Uncertainty in forecasts/predictions

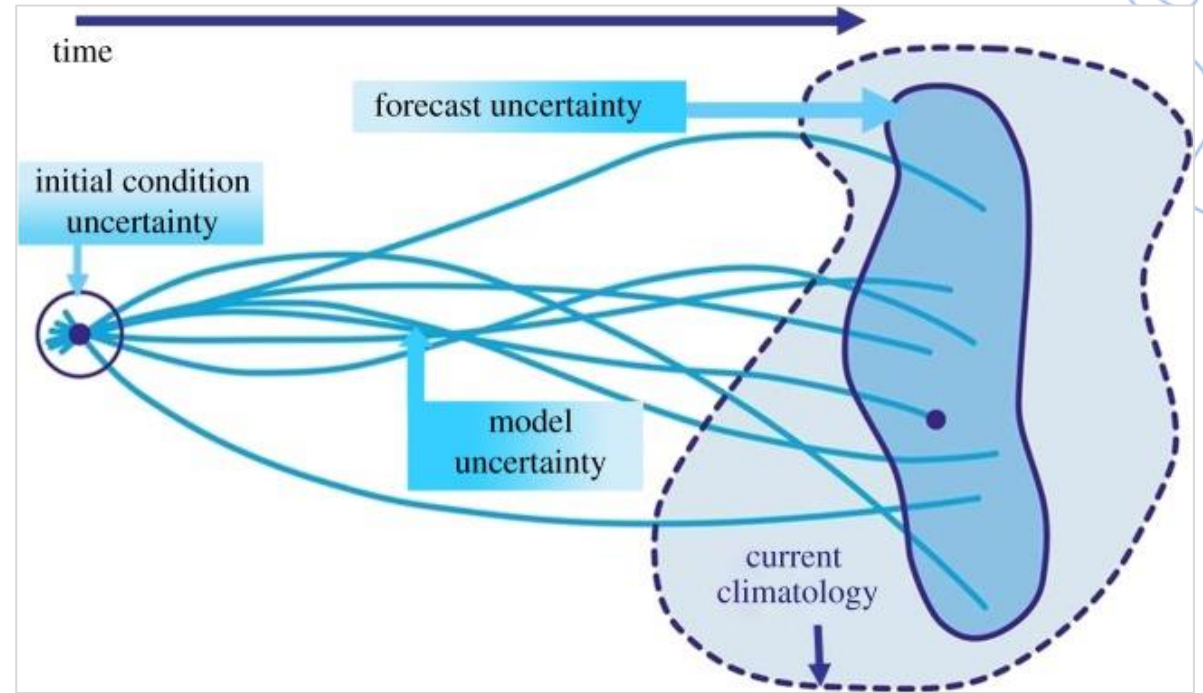
Sources of uncertainty

Initial condition uncertainty:

- Errors in the measurement of the starting conditions for the forecast (garbage in, garbage out!)
- This uncertainty is due to a) limited observations of the atmospheric conditions, such as temperature, humidity, wind speed, air pressure, etc., and b) using indirect measurements such as satellite images (because of indirect sensing, estimates may not always be reliable or usable in all circumstances; require calibration and validation against ground-based data).

Chaotic nature of the weather:

- Because the atmosphere is nonlinear, small, random perturbations to the atmospheric state variables (temperature, humidity, winds, pressure) in the analysed initial condition are amplified by chaotic processes, and each forecast diverges from the others.



Uncertainty in the initial condition, however small, will lead to uncertainty in the forecast after a variable period, depending on the initial state of the atmosphere.

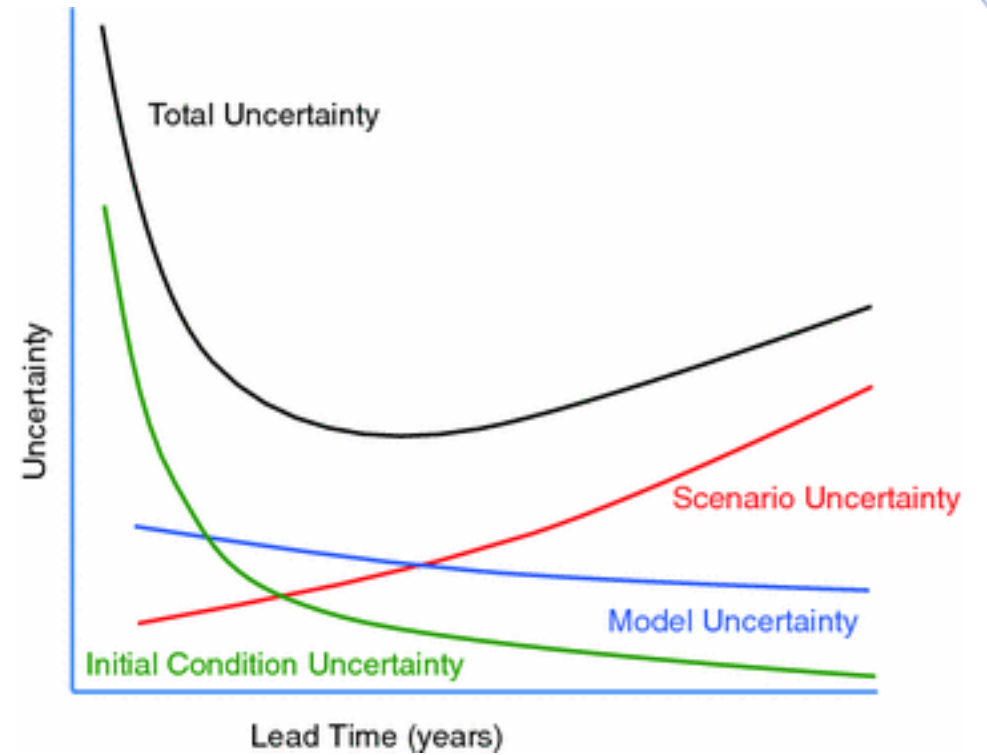
This graph illustrates a probabilistic weather forecast based on uncertainties in initial conditions. The blue lines depict trajectories of individual forecasts diverging due to uncertainties in both initial conditions and the representation of subgrid-scale processes in the model. The dashed-lined, lighter blue envelope represents the range of potential states of the real atmosphere, while the solid-lined, dark blue envelope represents the range of states sampled by model predictions.

1.1 WEATHER AND CLIMATE FORECASTS – Uncertainty in forecasts/predictions

Sources of uncertainty

Model uncertainty:

- Resulting from mathematical modelling limitations
- Mainly due to excessive simplifications of the complex atmosphere in modelling, such as errors in the development of parametrization schemes
- Model uncertainty can be significantly reduced by using an approach, “multi-model ensemble forecasting”. This approach can account for various biases that may arise from each forecasting model.

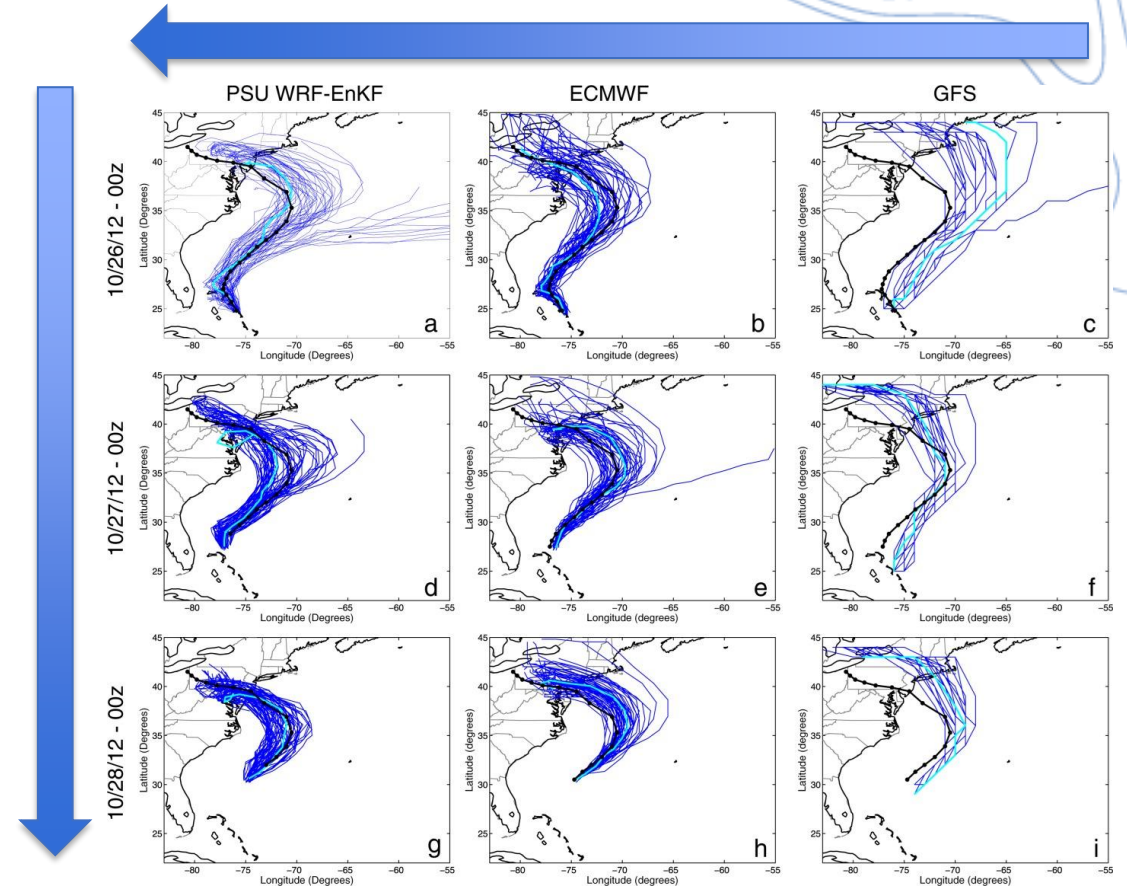


Types of uncertainty. Uncertainty is illustrated here as a function of lead time. Initial condition uncertainty is shown in *green*, model or structural uncertainty in *blue*, scenario uncertainty in *red*, and total uncertainty (the sum of the three uncertainties) in *black*. Initial condition uncertainty is large initially, then shrinks, and scenario uncertainty grows over time. *Source*: Based on Hawkins and Sutton (2009)

1.1 WEATHER AND CLIMATE FORECASTS – Uncertainty in forecasts/predictions

Ensemble forecasting:

- A method used in NWP with a set of multiple forecasts. The collection of predictions for the same target period is called ‘ensemble’.
- Ensemble forecasting is typical for all weather and climate forecasts beyond about three days.
- It aims to provide a range of potential future atmosphere states using Monte Carlo simulation in order to minimize uncertainty that is created by the chaotic nature of the atmosphere.
- The two major sources of uncertainty are a) the measurement errors in the initial condition, also called “sensitive dependence on initial condition”, and b) the errors in mathematical model formulation.
- As seen in the figure, an ensemble of multiple predictions provides improved accuracy with lowered uncertainty using a probabilistic approach.



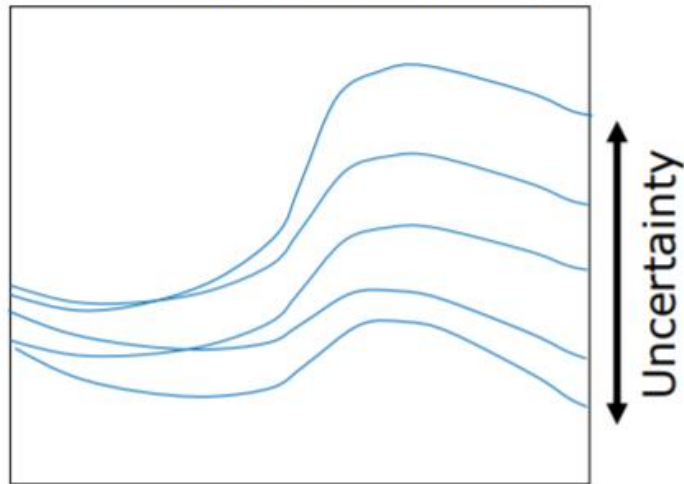
Prediction and uncertainty of Hurricane Sandy. The three forecasting systems utilize 60, 50, and 20 ensemble members, respectively (the darker the top arrow, the more ensemble members there are). Figures a-c: 96h lead time (forecast made 4 days in advance), Figures d-f: 72h lead time, Figures g-i: 48h lead time. Overall, the performance of the models (columns) becomes more consistent as the lead time decreases. The National Hurricane Center’s best track for Hurricane Sandy is overlaid in black.

Munsell EB, Zhang F (2014). Prediction and uncertainty of Hurricane Sandy (2012) were explored through a real-time cloud-permitting ensemble analysis and forecast system assimilating airborne Doppler radar observations, J Adv Model Earth Syst, 6(1), 38-58.

1.1 WEATHER AND CLIMATE FORECASTS – Uncertainty in forecasts/predictions

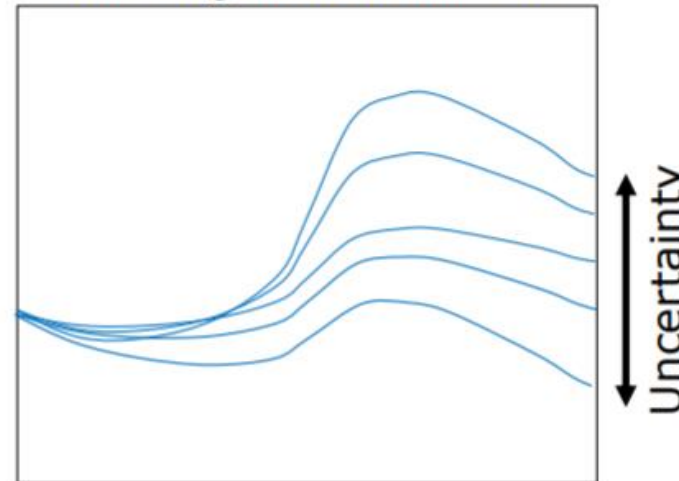
Initial condition uncertainty vs. model uncertainty:

Same model, but using different data (initial conditions)



Time

Same data (initial conditions), but using different models



Time

In **seasonal forecasting**, uncertainty primarily comes from the model we choose and the initial conditions. In **climate projections**, uncertainty also comes from the model we choose, but a significant contribution comes from the emissions scenario used (see next chapter).

1.2 – Climate projections



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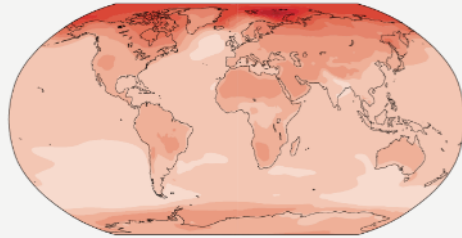


1.2 CLIMATE CHANGE PROJECTIONS – Global climate models

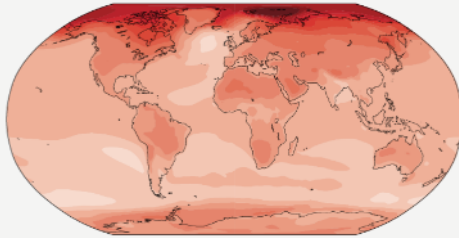
(b) Annual mean temperature change (°C) relative to 1850–1900

Across warming levels, land areas warm more than ocean areas, and the Arctic and Antarctica warm more than the tropics.

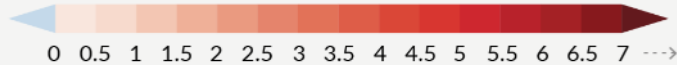
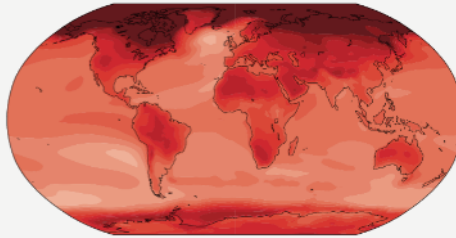
Simulated change at 1.5°C global warming



Simulated change at 2°C global warming



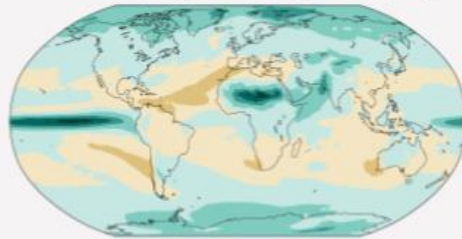
Simulated change at 4°C global warming



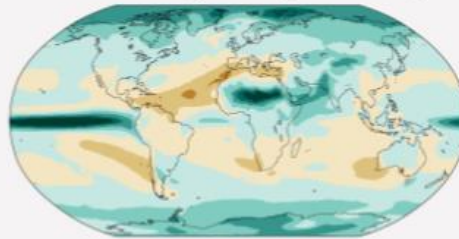
(c) Annual mean precipitation change (%) relative to 1850–1900

Precipitation is projected to increase over high latitudes, the equatorial Pacific and parts of the monsoon regions, but decrease over parts of the subtropics and in limited areas of the tropics.

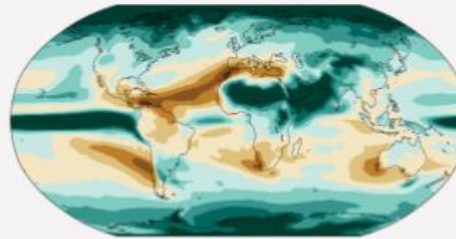
Simulated change at 1.5°C global warming



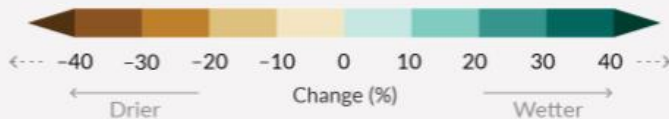
Simulated change at 2°C global warming



Simulated change at 4°C global warming



Relatively small absolute changes may appear as large % changes in regions with dry baseline conditions



Climate projections are model-derived estimates of the future climate.

'Decadal prediction' encompasses predictions on annual, multi-annual, and decadal timescales.

Global climate models (GCMs) are used to create climate projections.

These simulations of Earth's climate in future decades (typically until 2100) are based on assumed 'scenarios' for the concentrations of greenhouse gases, aerosols, and other atmospheric constituents that affect the planet's radiative balance.

1.2 CLIMATE CHANGE PROJECTIONS – Global climate models

Global Climate Models (1)

Climate models are important tools for improving our understanding and predictability of climate behavior on seasonal, annual, decadal, and centennial time scales. Models investigate the degree to which observed climate changes may be due to natural variability, human activity, or a combination of both.

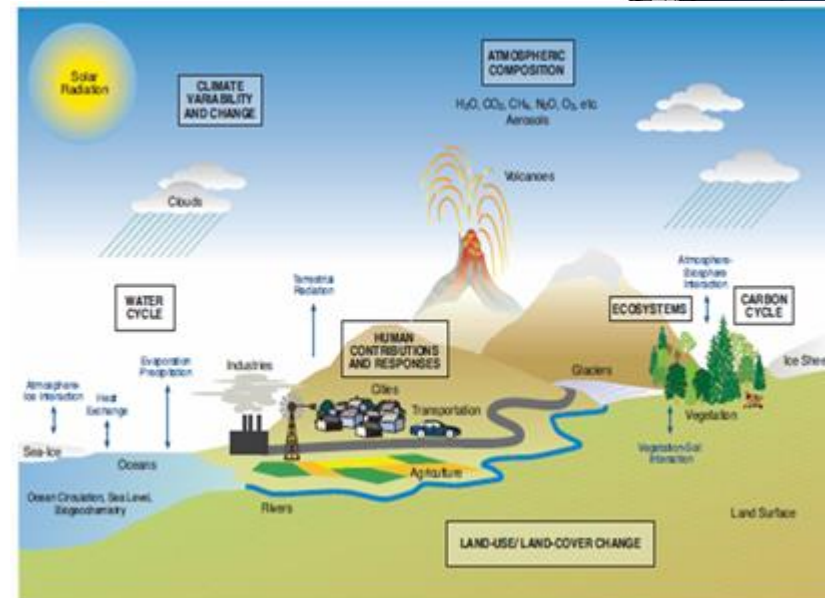
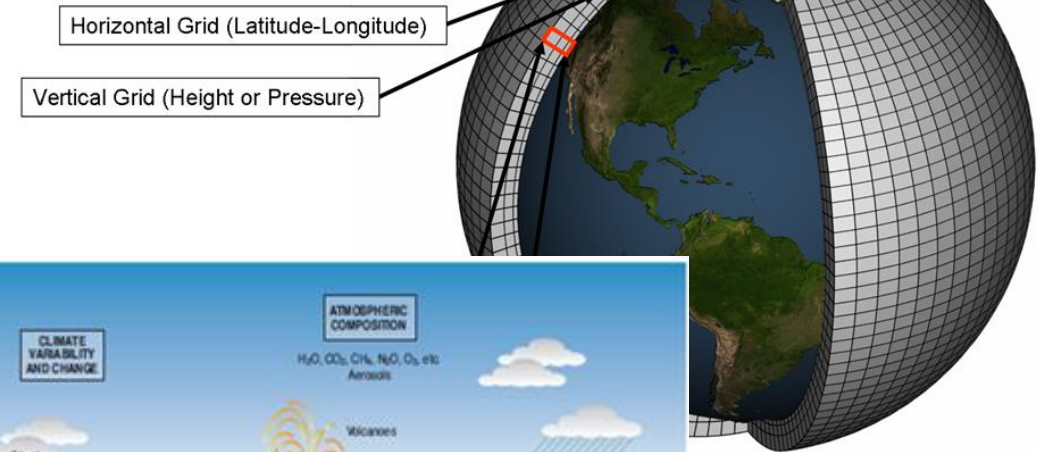
Their results and projections provide essential information to better inform decisions in areas such as water resource management, agriculture, transportation, and urban planning.

What they are: A complex mathematical representation of the major components of the climate system and their interactions.

The main climate system components treated in a climate model are:

- The **atmospheric** component, which simulates clouds and aerosols, plays a large role in the transport of heat and water around the globe.
- The **land surface** component, which simulates surface characteristics such as vegetation, snow cover, soil water, rivers, and carbon storage.
- The **ocean** component, which simulates current movement and mixing, and biogeochemistry, since the ocean is the dominant reservoir of heat and carbon in the climate system
- The **sea ice** component, which modulates solar radiation absorption and air-sea heat and water exchanges.

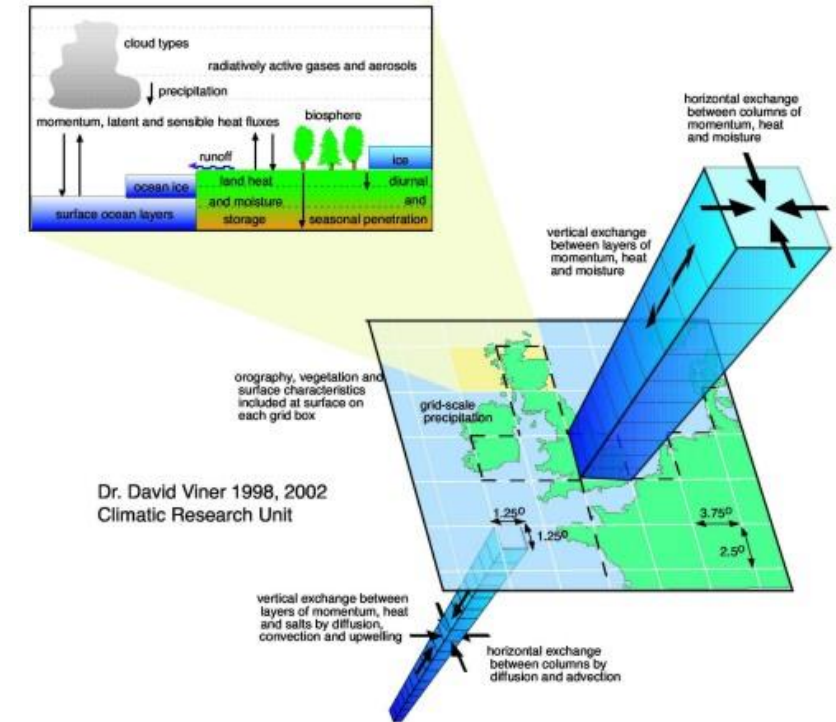
Schematic for Global Atmospheric Model



1.2 CLIMATE CHANGE PROJECTIONS – Global climate models

Global Climate Models (2)

- Climate models divide the globe into a **three-dimensional grid of cells** representing specific geographic locations and elevations.
- Each of the components (atmosphere, land surface, ocean, and sea ice) has equations calculated on the global grid for a set of climate variables such as temperature.
- In addition to model components computing how they are changing over time, the different parts exchange fluxes of heat, water, and momentum. **They interact with one another as a coupled system.**
- There are two types of processes within climate models that are used today:
 - (1) **Simulated processes** are larger than grid-scale and based on bedrock scientific principles (conservation of energy, mass, and momentum). An example of a simulated process is one that represents tropical cyclones and storm activity.
 - (2) **Parameterized processes** represent more complex processes that are smaller than grid scale (so, cannot be physically represented) using simpler processes. An example of a parameterized process is one that represents the composition of clouds and aerosols.



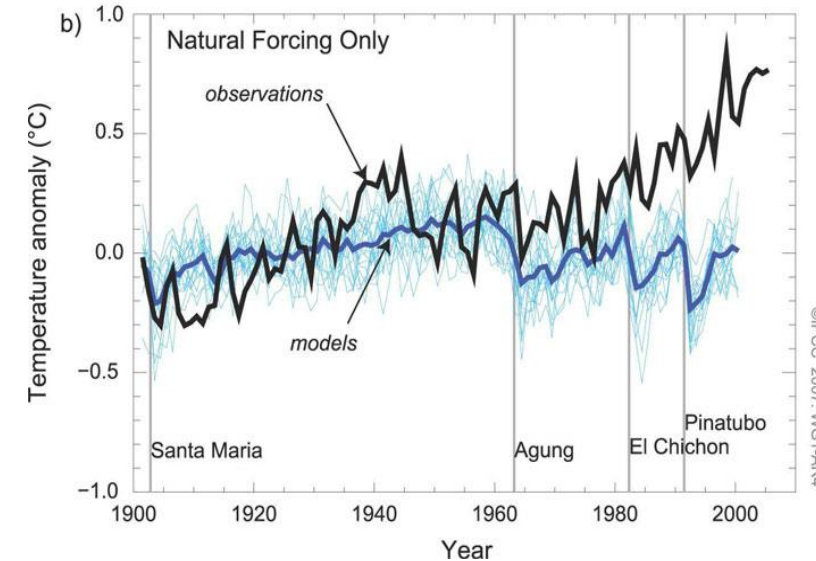
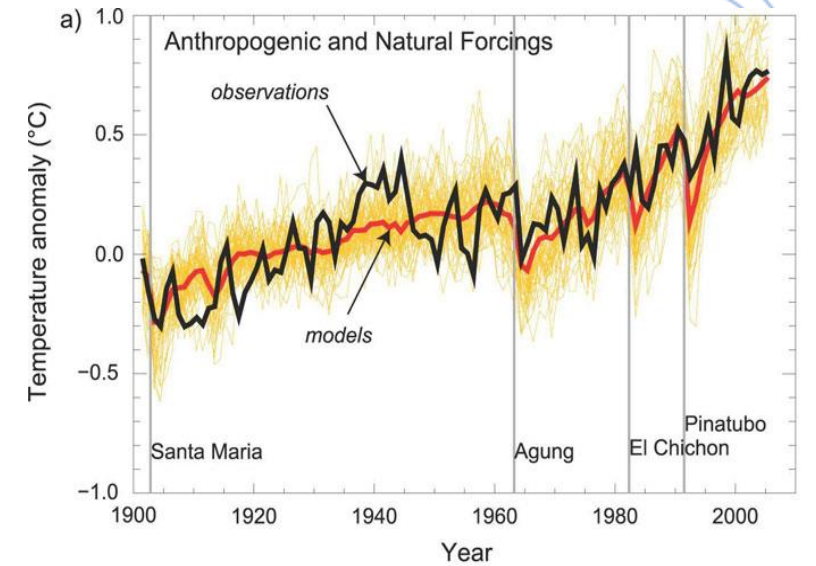
Conceptual model of a GCM

1.2 CLIMATE CHANGE PROJECTIONS – Global climate models

Global Climate Models (3)

- **Their uses:** models allow us to determine the distinct influence of different climate features by providing a way of exploring climate sensitivities with experiments that cannot be performed on the actual Earth, such as the projection of warming or cooling ocean surface temperatures.
- **How accurate:** these models are based on well-founded physical principles either directly for simulated processes or indirectly for parameterized processes. Generally, models produce simulations of current and past large-scale climates that agree with observations. Climate models have also produced an accurate hindcast of 20th-century climate change, including increased warming partly due to CO₂ emissions.
- **Agreed among models:** all models show rising global temperatures with amplified warming in the Arctic, enhancement of the hydrologic cycle (dry places becoming drier and wet places becoming wetter), and rising sea level.
- **Disagreed among models:** models can disagree on many results and projections due to natural variability, differences in forcing, and differences in feedbacks. Among them, forcings are the primary drivers of climate change, and the main differences among models lie in aerosols.

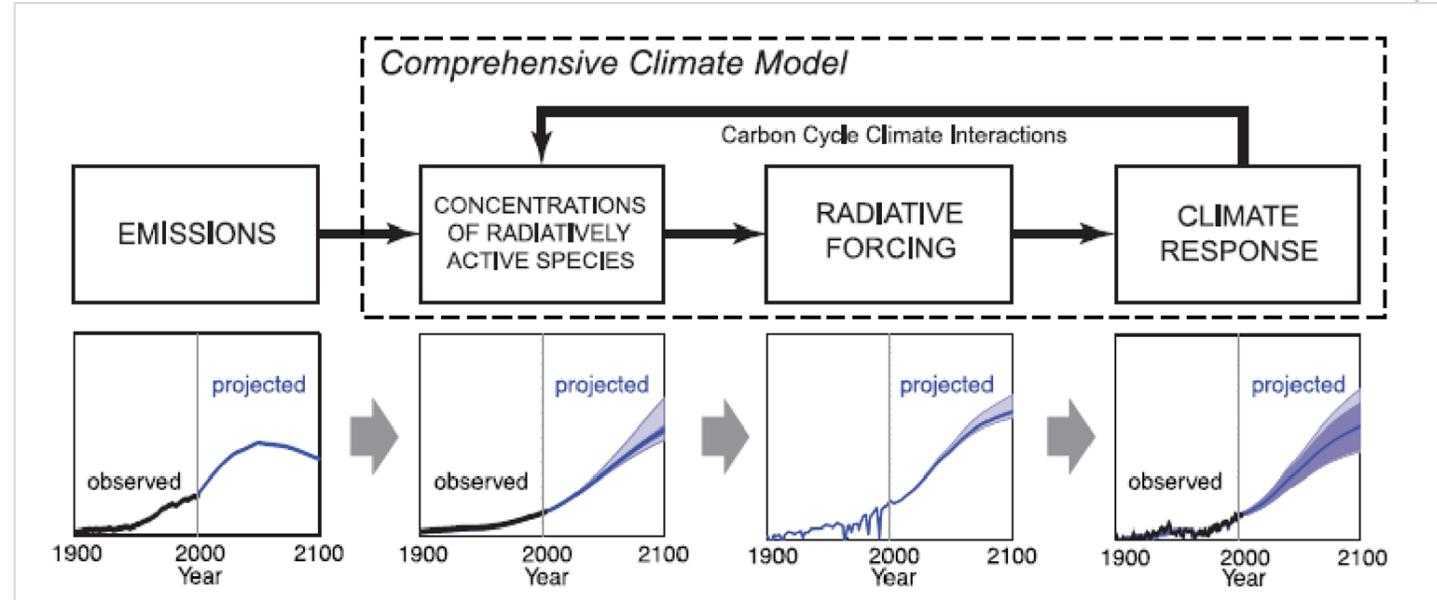
*The processes that cause it to change, whether natural or anthropogenic (human-caused), are known as **forcing**. Changes in solar radiation are considered natural; changes in greenhouse gases are considered **anthropogenic**.*



1.2 CLIMATE CHANGE PROJECTIONS – Global climate models

Uncertainty arises in various steps towards a climate projection

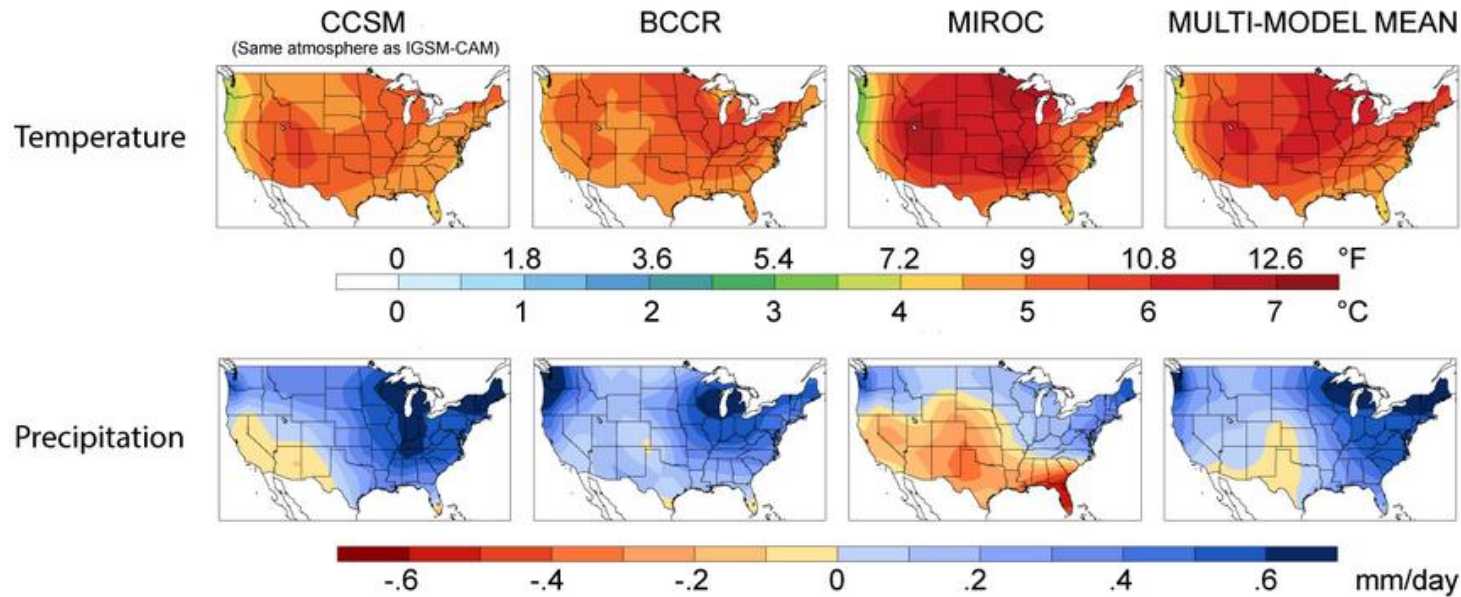
- For a given **emissions scenario**, various biogeochemical models are used to calculate **concentrations of constituents in the atmosphere**.
- Various radiation schemes and parametrizations are required to convert these concentrations to **radiative forcing**.
- Finally, the response of the different climate system components (atmosphere, ocean, sea ice, land surface, chemical status of atmosphere and ocean, etc.) is calculated in a comprehensive **climate model**.
- In addition, the formulation of, and **interaction with, the carbon cycle** in climate models introduces important feedbacks which produce additional uncertainties.
- In a **comprehensive climate model**, physical and chemical representations of processes permit a consistent quantification of uncertainty. Note that the uncertainties associated with the future emission path are of an entirely different nature and are not considered in this figure.



Several steps from emissions to climate response contribute to the overall uncertainty of a climate model projection. These uncertainties can be quantified through a combined effort of observation, process understanding, a hierarchy of climate models, and ensemble simulations. In a comprehensive climate model, physical and chemical representations of processes permit a consistent quantification of uncertainty. Adapted from IPCC AR4 Chapter 10-1.

1.2 CLIMATE CHANGE PROJECTIONS – Global climate models

Changes in temperature and precipitation in 2100 (2091-2110 mean) relative to present-day (1991-2010 mean) for different climate models. Values assume a climate sensitivity of 3°C under the Reference scenario.



Monier, E., X. Gao, J.R. Scott, A.P. Sokolov, and C.A. Schlosser. 2014. A framework for modeling uncertainty in regional climate change. *Climatic Change*. DOI:10.1007/s10584-014-1112-5.

For more information, visit EPA's "Climate Change in the United States: Benefits of Global Action" at www.epa.gov/cira.

The sources of uncertainty considered are the emissions projections (using different climate policies), climate system parameters (represented by different values of climate sensitivity and net aerosol forcing), natural variability (by perturbing initial conditions), and structural uncertainty (using different climate models).

Uncertainty in temperature changes is mainly driven by policy choices and the range of climate sensitivity considered.

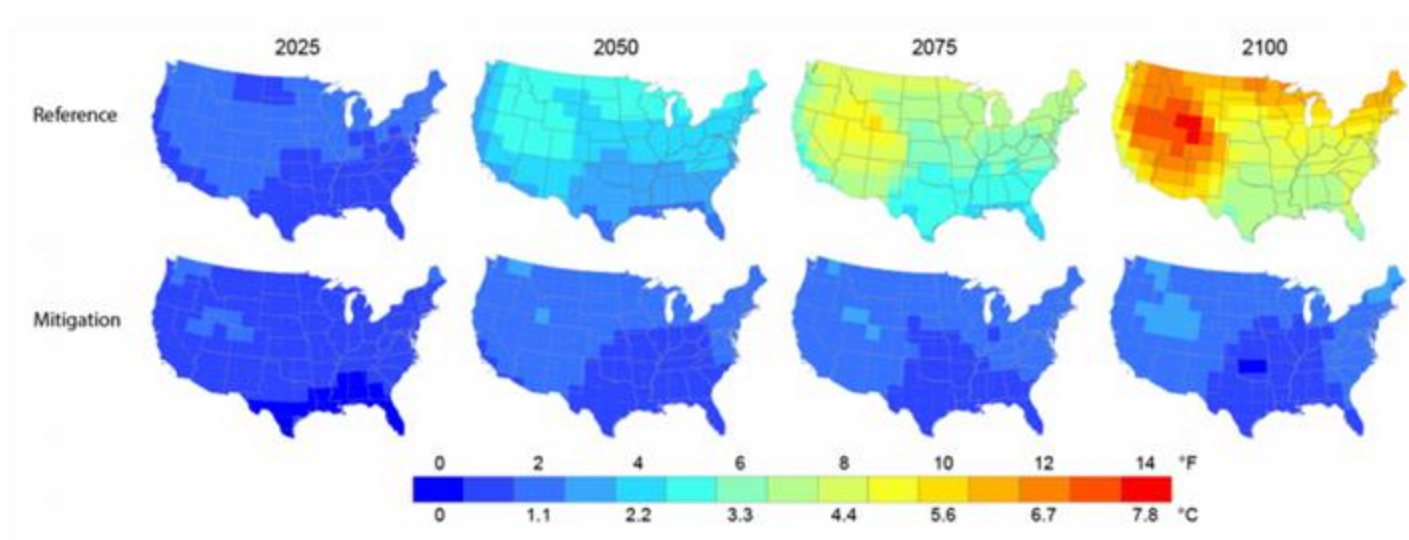
Meanwhile, the four sources of uncertainty contribute more equally to precipitation changes, with natural variability having a large impact in the first part of the 21st century.

Overall, the choice of policy is the largest driver of uncertainty in future projections of climate change over the US.

1.2 CLIMATE CHANGE PROJECTIONS – Global climate models

Scenario uncertainty:

- This type of uncertainty is more relevant in climate change predictions from the imperfect knowledge and information on the socioeconomic and technological developments in the future.
- This uncertainty can be measured using sensitivity analysis by comparing various scenarios, such as Representative Concentration Pathways (RCP) or Shared Socioeconomic Pathway (SSP), on the future climate.
- This uncertainty can be reduced by continuously monitoring societal and technological changes and mitigation actions, and by applying these changes to the prediction modelling.

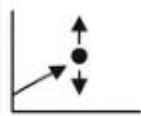

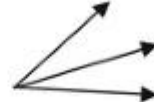
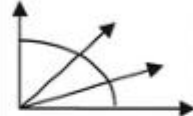
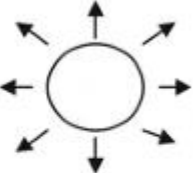


Change in temperature in the USA with or without global GHG mitigation: Under the Reference scenario, temperatures are projected to increase significantly, while under the mitigation scenario, temperature increases are far lower, with no regions experiencing increases of more than 4°F.

1.2 CLIMATE CHANGE PROJECTIONS – Global climate models

Levels of uncertainty:

- Levels indicate how difficult it is to describe uncertainty. Levels 1-5 are between complete certainty (left from level 1) and total ignorance (right from level 5). Levels 4 and 5 are often referred to as “deep uncertainty”, in which
 - we cannot quantify more probabilities;
 - we know there could be surprises;
 - we know neither the mechanisms, functional relationships nor statistical properties;
 - and we do not agree on or do not know the valuation of the outcomes.
- The five levels are defined with respect to the knowledge assumed about various aspects of a policy problem: (a) the future world, (b) the model of the relevant system for that future world, (c) the outcomes from the system, and (d) the weights that various stakeholders will put on the outcomes.
- Climate change prediction is likely to be at an under level 1-3, depending on the climate variable (as some variables may be more uncertain than others).

		LEVEL					Total Ignorance
		Level 1	Level 2	Level 3	Level 4	Level 5	
LOCATION	Context	A clear enough future 	Alternate futures (with probabilities) 	Alternate futures with ranking 	A multiplicity of plausible futures 	An unknown future 	
	System model	A single (deterministic) system model	A single (stochastic) system model	Several system models, one of which is most likely	Several system models, with different structures	Unknown system model; know we don't know	
	System outcomes	A point estimate for each outcome	A confidence interval for each outcome	Several sets of point estimates, ranked according to their perceived likelihood	A known range of outcomes	Unknown outcomes; know we don't know	
	Weights on outcomes	A single set of weights	Several sets of weights, with a probability attached to each set	Several sets of weights, ranked according to their perceived likelihood	A known range of weights	Unknown weights; know we don't know	

Walker W.E., Lempert R.J., Kwakkel J.H. (2013) Deep Uncertainty. In: Gass S.I., Fu M.C. (eds) Encyclopedia of Operations Research and Management Science. Springer, Boston, MA.

1.2 CLIMATE CHANGE PROJECTIONS – The Coupled Model Intercomparison Project

What is the CMIP?

- Climate models are constantly being updated, as different modelling groups around the world incorporate higher spatial resolution, new physical processes, and biogeochemical cycles. These modelling groups coordinate their updates around the schedule of the **Intergovernmental Panel on Climate Change (IPCC) assessment reports (AR)**.
- These coordinated efforts are part of the **Coupled Model Intercomparison Projects (CMIP)**. The 2013 IPCC fifth assessment report (AR5) featured CMIP5 climate models, while the latest 2021 IPCC sixth assessment report (AR6) features CMIP6 models.
- The objective of the **Coupled Model Intercomparison Project (CMIP)** is to better understand past, present and future climate changes arising from natural, unforced variability or in response to changes in radiative forcing in a multi-model context.
- The understanding includes **assessments of model performance** during the historical period and quantifications of the causes of the spread in future projections.
- An important goal of CMIP is to make the multi-model output publicly available in a standardized format.
- CMIP began in 1995 under the auspices of the **Working Group on Coupled Modelling (WGCM)**. The first set of common experiments involved comparing the model response to an idealized forcing - a constant rate of increase, which was accomplished using a CO2 increase of 1% per year compounded.

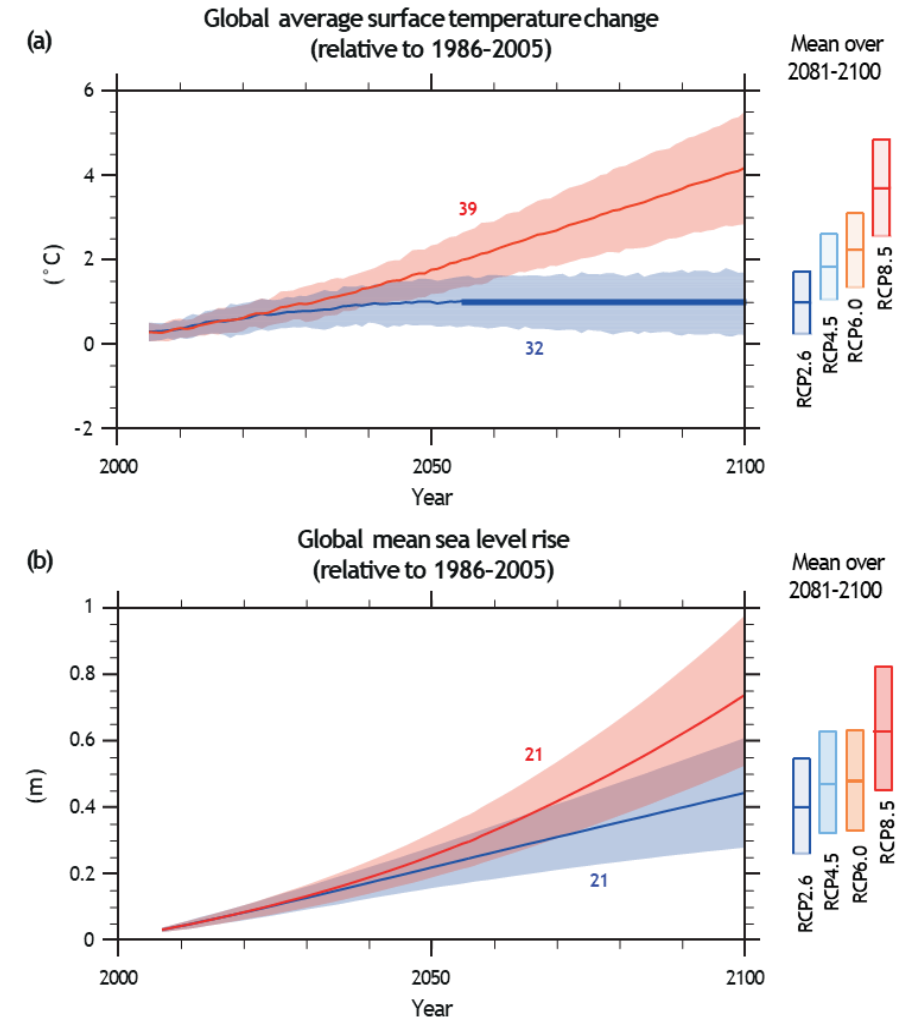


This short movie gives insight into the world of climate modelling, particularly WCRP's initiative CMIP. It stresses the importance of sharing, comparing and analyzing the outcomes of global climate models to deliver high quality climate information, serving as the basis for climate assessments and negotiations.: <https://www.wcrp-climate.org/wgcm-cmip>

1.2 CLIMATE CHANGE PROJECTIONS – The Coupled Model Intercomparison Project

The Coupled Model Intercomparison Project Phase 5 (CMIP5)

- The CMIP5 project (2010-2014) provided an unprecedented level of information for climate projections, including new Earth System Models with a more complete representation of forcings, the introduction of Representative Concentration Pathways (RCP) scenarios, and an expanded set of outputs available for analysis.
- The main objectives of CMIP5 are to
 - evaluate how realistic the models are in simulating the recent past,
 - provide projections of future climate change on two-time scales, near-term (out to about 2035) and long-term (out to 2100 and beyond), and
 - Understand some of the factors responsible for differences in model projections, including quantifying some key feedbacks such as those involving clouds and the carbon cycle.
- RCPs are scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs), aerosols, and chemically active gases, as well as land use/land cover.
- RCPs usually refer to the portion of the concentration pathway extending up to 2100, for which integrated assessment models produced corresponding emission scenarios.



Global average surface temperature change (a) and global mean sea level rise¹⁰ (b) from 2006 to 2100 as determined by multi-model simulations. All changes are relative to 1986–2005. Time series of projections and a measure of uncertainty (shading) are shown for the RCP2.6 (blue) and RCP8.5 (red) scenarios. The mean and associated uncertainties, averaged over 2081–2100, are shown for all RCP scenarios as coloured vertical bars on the right-hand side of each panel.

1.2 CLIMATE CHANGE PROJECTIONS – The Coupled Model Intercomparison Project

The Coupled Model Intercomparison Project Phase 6 (CMIP6)

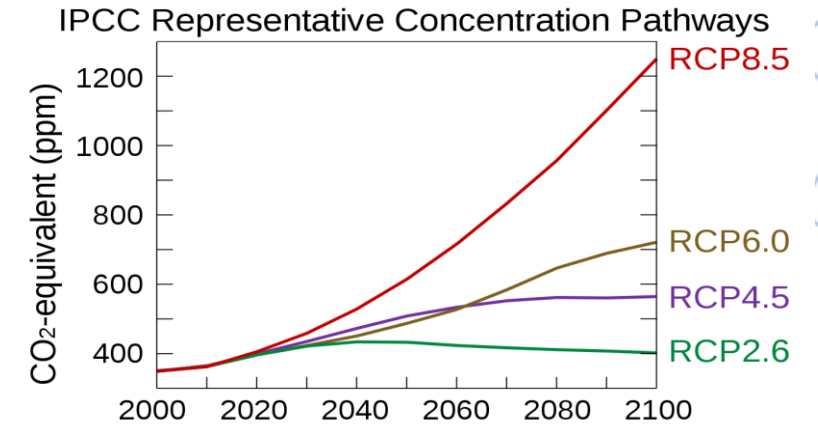
- These models include new and **better representations of physical, chemical and biological processes**, as well as **higher resolution**, compared to climate models considered in previous IPCC Assessment Reports.
- This has **improved the simulation** of the recent mean state of most large-scale indicators of climate change and many other aspects across the climate system. Some differences from observations remain, for example, in regional precipitation patterns.
- Projections of the increase in global surface temperature, the pattern of warming, and global mean sea level rise from previous IPCC Assessment Reports and other studies are **broadly consistent with subsequent observations**, especially when accounting for the difference in radiative forcing scenarios used for making projections and the radiative forcings that actually occurred.
- The CMIP6 historical simulations assessed in this report have an ensemble mean global surface temperature change within 0.2°C of the observations over most of the historical period, and observed warming is within the very likely range of the CMIP6 ensemble.
- However, some CMIP6 models simulate a warming that is either above or below the assessed very likely range of observed warming. Information on how well models simulate past warming, along with insights from observations and theory, is used to assess projections of global warming.



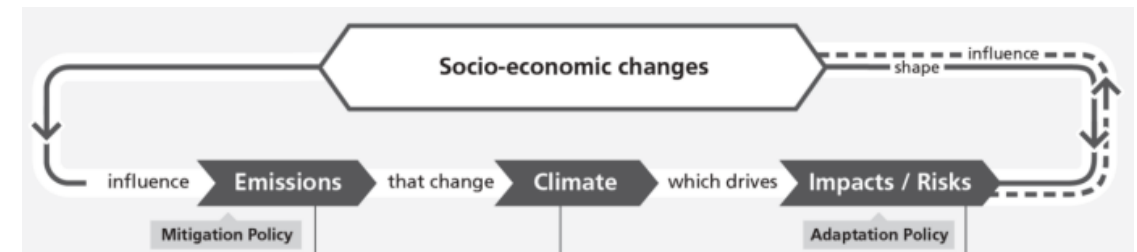
1.2 CLIMATE CHANGE PROJECTIONS – The Coupled Model Intercomparison Project

RCPs and SSPs

- **RCPs** focus on predicting various levels of **greenhouse gases and radiative forcings** expected by 2100. Four pathways were developed, ranging from low to high forcing levels, without integrating socioeconomic narratives.
 - **RCP2.6** (“Very stringent”): radiative forcing peaks at $\sim 3 \text{ Wm}^{-2}$ before 2100 and then declines
 - **RCP4.5** and **RCP6.0**: two intermediate stabilisation pathways in which radiative forcing is stabilized at $\sim 4.5 \text{ Wm}^{-2}$ and 6.0 Wm^{-2} after 2100
 - **RCP8.5** (“Business as usual”): radiative forcing reaches greater than 8.5 Wm^{-2} by 2100 and continues to rise for some amount of time
- **SSPs** examine how socioeconomic factors might evolve over the coming century. These factors included **population growth, economic development, education, urbanisation, and technological advancement**.
- The SSPs explored **five scenarios** portraying potential global evolution in the absence of climate policies and assessed how different levels of climate change mitigation could be realised by combining RCPs with SSPs.
- RCPs and SSPs were designed to complement each other.



All forcing agents' atmospheric CO₂-equivalent concentrations (in parts-per-million-by-volume (ppmv)) according to the four RCPs used by the fifth IPCC Assessment Report to make predictions.

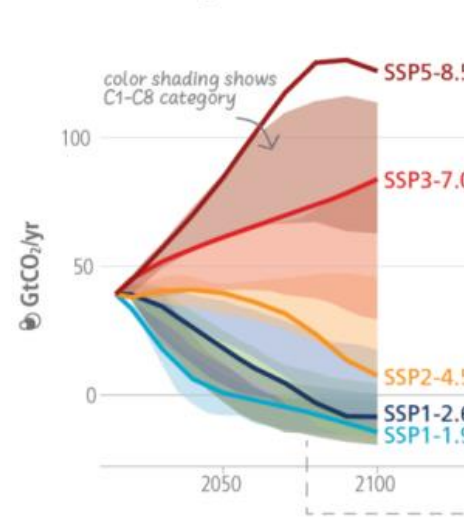


The dashed arrow indicates that the influence from impacts/risks to socio-economic changes is not yet considered in the scenarios assessed in the AR6.

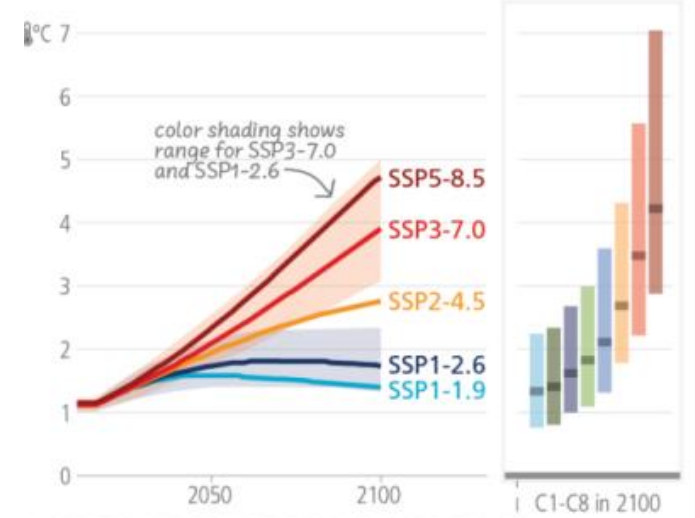
1.2 CLIMATE CHANGE PROJECTIONS – Shared Socioeconomic Pathways

Category in WGIII	Category description	GHG emissions scenarios (SSPx-y*) in WGI & WGII	RCPy** in WGI & WGII
C1	limit warming to 1.5°C (>50%) with no or limited overshoot	Very low (SSP1-1.9)	
C2	return warming to 1.5°C (>50%) after a high overshoot		
C3	limit warming to 2°C (>67%)	Low (SSP1-2.6)	RCP2.6
C4	limit warming to 2°C (>50%)		
C5	limit warming to 2.5°C (>50%)		
C6	limit warming to 3°C (>50%)	Intermediate (SSP2-4.5)	RCP 4.5
C7	limit warming to 4°C (>50%)	High (SSP3-7.0)	
C8	exceed warming of 4°C (>50%)	Very high (SSP5-8.5)	RCP 8.5

CO₂ emissions for SSP-based scenarios and C1-C8 categories



Temperature for SSP-based scenarios over the 21st century and C1-C8 at 2100



SSP1	Sustainability – Taking the Green Road	<ul style="list-style-type: none"> Inclusive development that respects environmental boundaries Emphasis on growth shifts towards human well-being
SSP2	Middle of the Road	<ul style="list-style-type: none"> Social, economic, technological trends do not shift markedly from historical patterns Development and growth proceeds unevenly; some improvements in resource and energy use
SSP3	Regional Rivalry – A Rocky Road	<ul style="list-style-type: none"> Nationalism; energy and food security goals are prioritized at the expense of broader-based development Low international priority for environmental issues; environmental degradation
SSP4	Inequality – A Road Divided	<ul style="list-style-type: none"> Inequality widens; social cohesion degrades, and conflict become more common Energy sector diversifies with investments in carbon-intensive fuels but also low-carbon energy sources
SSP5	Fossil-fueled Development – Taking the Highway	<ul style="list-style-type: none"> Increasing integration of global markets, strong investments in health, education, institutions Push for development is coupled with exploitation of fossil fuel and the adoption of resource intensive lifestyles



IPCC AR6 Report

Riahi et al. (2017) The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview, *Global Environmental Change*, 42, 153-68.

1.2 CLIMATE CHANGE PROJECTIONS – IPCC AR6 Observations

Recent and future change of four key indicators of the climate system

Atmospheric temperature, ocean heat content, Arctic summer sea ice, and land precipitation

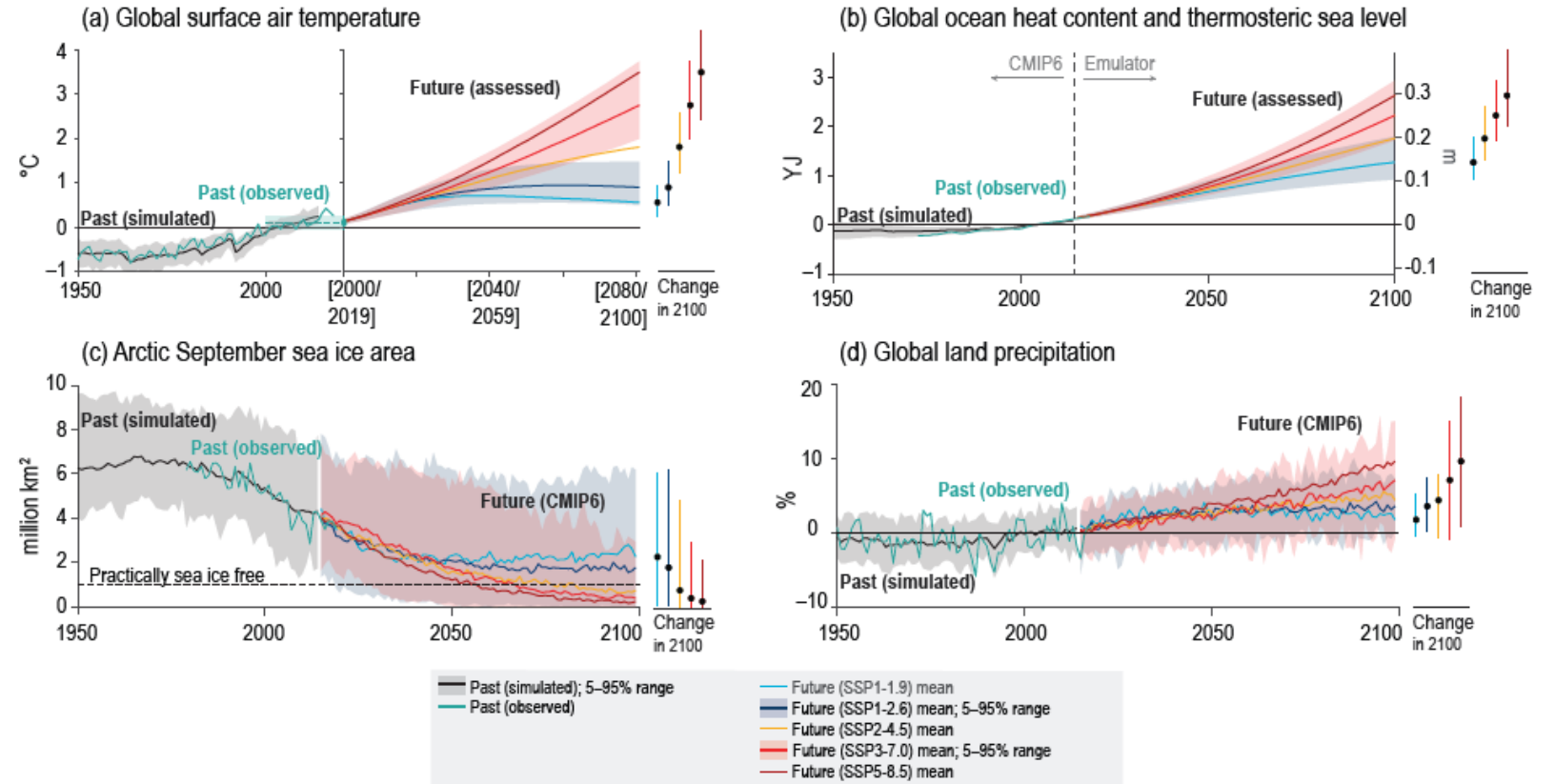
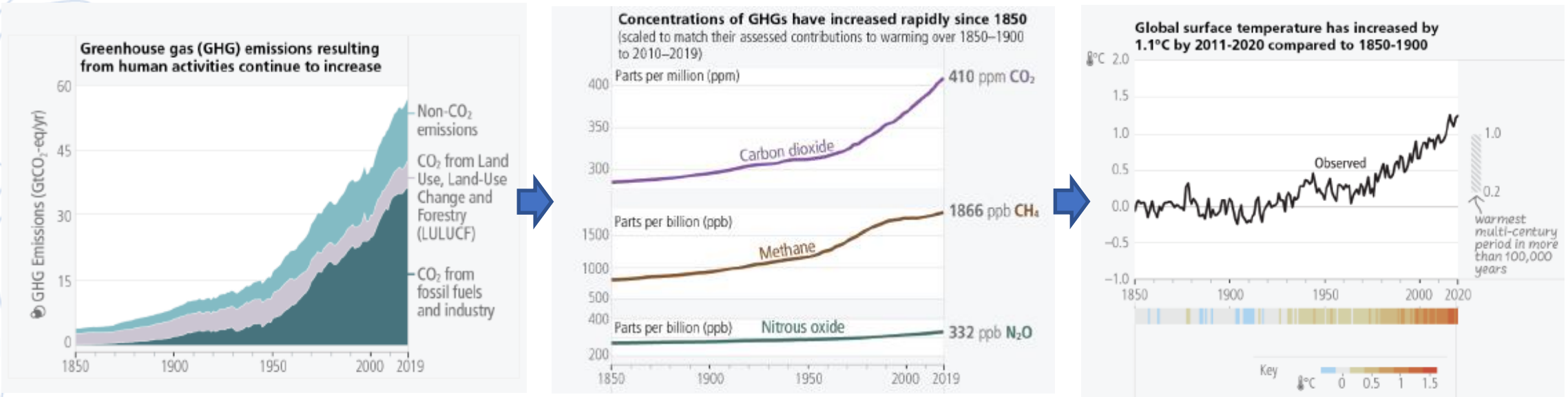


Figure TS.8 | Observed, simulated and projected changes compared to the 1995–2014 average in four key indicators of the climate system through to 2100 differentiated by Shared Socio-economic Pathway (SSP) scenario. The intent of this figure is to show how future emissions choices impact key, iconic large-scale indicators and to highlight that our collective choices matter. Past simulations are based on the Coupled Model Intercomparison Project Phase 6 (CMIP6) multi-model ensemble. Future projections are based on the assessed ranges based upon multiple lines of evidence for (a) global surface temperature (Cross-Section Box TS.1) and (b) global ocean heat content and the associated thermosteric sea level contribution to global mean sea level change (right-hand axis) using a climate model emulator (Cross-Chapter Box 7.1), and CMIP6 simulations for (c) Arctic September sea ice and (d) global land precipitation. Projections for SSP1-1.9 and SSP1-2.6 show that reduced greenhouse gas emissions lead to a stabilization of global surface temperature, Arctic sea ice area and global land precipitation over the 21st century. Projections for SSP1-2.6 show that emissions reductions have the potential to substantially reduce the increase in ocean heat content and thermosteric sea level rise over the 21st century but that some increase is unavoidable. The brackets in the x axis in panel (a) indicate assessed 20-year-mean periods. [4.3, Figure 4.2, 9.3, 9.6, Figure 9.6]

1.2 CLIMATE CHANGE PROJECTIONS – IPCC AR6 Observations

The causal chain from emissions to resulting warming of the climate system



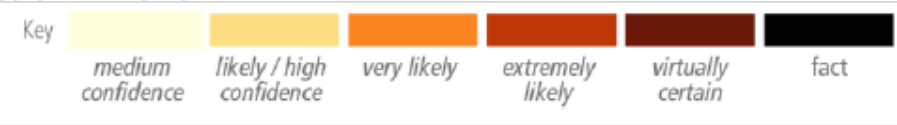
(a) Global net anthropogenic GHG emissions include CO₂ from fossil fuel combustion and industrial processes (CO₂-FFI) (dark green); net CO₂ from land use, land-use change and forestry (CO₂-LULUCF) (green); CH₄; N₂O; and fluorinated gases (HFCs, PFCs, SF₆, NF₃) (light blue).

(b) These emissions have led to increases in the atmospheric concentrations of several GHGs. Each subpanel's vertical extent for CO₂, CH₄ and N₂O is scaled to match the assessed individual direct effect of historical emissions on temperature change from 1850–1900 to 2010–2019. This estimate arises from an assessment of effective radiative forcing and climate sensitivity.

(c) The global surface temperature (shown as annual anomalies from an 1850–1900 baseline) has increased by around 1.1°C since 1850–1900.

1.2 CLIMATE CHANGE PROJECTIONS – IPCC AR6 Observations

Observed changes in indicators of mean climate across climate system components, and their attribution to human influence



The colour coding indicates the assessed confidence in / likelihood of the observed change and the human contribution as a driver or main driver (specified in that case), where available (see colour key). Otherwise, explanatory text is provided.

Change in indicator	Observed change assessment	Human contribution assessment
Atmosphere and water cycle	Warming of global mean surface air temperature since 1850-1900	<i>likely</i> range of human contribution ((0.8-1.3°C)) encompasses the <i>very likely</i> range of observed warming ((0.9-1.2°C))
	Warming of the troposphere since 1979	Main driver
	Cooling of the lower stratosphere since the mid-20th century	Main driver 1979 - mid-1990s
	Large-scale precipitation and upper troposphere humidity changes since 1979	
	Expansion of the zonal mean Hadley Circulation since the 1980s	Southern Hemisphere
Ocean	Ocean heat content increase since the 1970s	Main driver
	Salinity changes since the mid-20th century	
	Global mean sea level rise since 1970	Main driver
Cryosphere	Arctic sea ice loss since 1979	Main driver
	Reduction in Northern Hemisphere springtime snow cover since 1950	
	Greenland ice sheet mass loss since 1990s	
	Antarctic ice sheet mass loss since 1990s	<i>Limited evidence & medium agreement</i>
	Retreat of glaciers	Main driver
Carbon cycle	Increased amplitude of the seasonal cycle of atmospheric CO ₂ since the early 1960s	Main driver
	Acidification of the global surface ocean	Main driver
Land climate	Mean surface air temperature over land (about 40% larger than global mean warming)	Main driver
Synthesis	Warming of the global climate system since preindustrial times	

1.2 CLIMATE CHANGE PROJECTIONS – IPCC AR6 Observations

Climate change has impacted human and natural systems across the world:

- substantial damages, and increasingly irreversible losses, in **terrestrial, freshwater, cryospheric and coastal and open ocean ecosystems** (*high confidence*)
- reduced **food security** and affected **water security** due to warming, changing precipitation patterns, reduction and loss of cryospheric elements, and greater frequency and intensity of **climatic extremes** (*high confidence*)
- adverse impacts on human health, livelihoods and key infrastructure in **urban settings** (*high confidence*)
- increased likelihood of **compound extreme events** since the 1950s. Concurrent and repeated climate hazards have occurred in all regions, increasing impacts and risks to health, ecosystems, infrastructure, livelihoods and food (*high confidence*)
- **Economic impacts** attributable to climate change are increasingly affecting people's livelihoods and are causing economic and societal impacts across national boundaries (*high confidence*)
- Widespread **adverse impacts and related losses and damages to nature and people** (*high confidence*)
- Across sectors and regions, the **most vulnerable people and systems** have been disproportionately affected (*high confidence*)

1.2 CLIMATE CHANGE PROJECTIONS – IPCC AR6 Observations

Climate change has adversely impacted human health (*very high confidence*), including

- contributing to **humanitarian crises** where climate hazards interact with high vulnerability (*high confidence*)
- Increased mortality and morbidity due to **extreme heat events** (*very high confidence*)
- Increase in climate-related **food-borne and water-borne diseases** (*very high confidence*)
- Increase in **vector-borne diseases** due to range expansion and/or increased reproduction of disease vectors (*high confidence*)
- **Emergence of animal and human diseases**, including zoonoses, in new areas (*high confidence*)
- **mental health challenges** associated with increasing temperatures (*high confidence*)

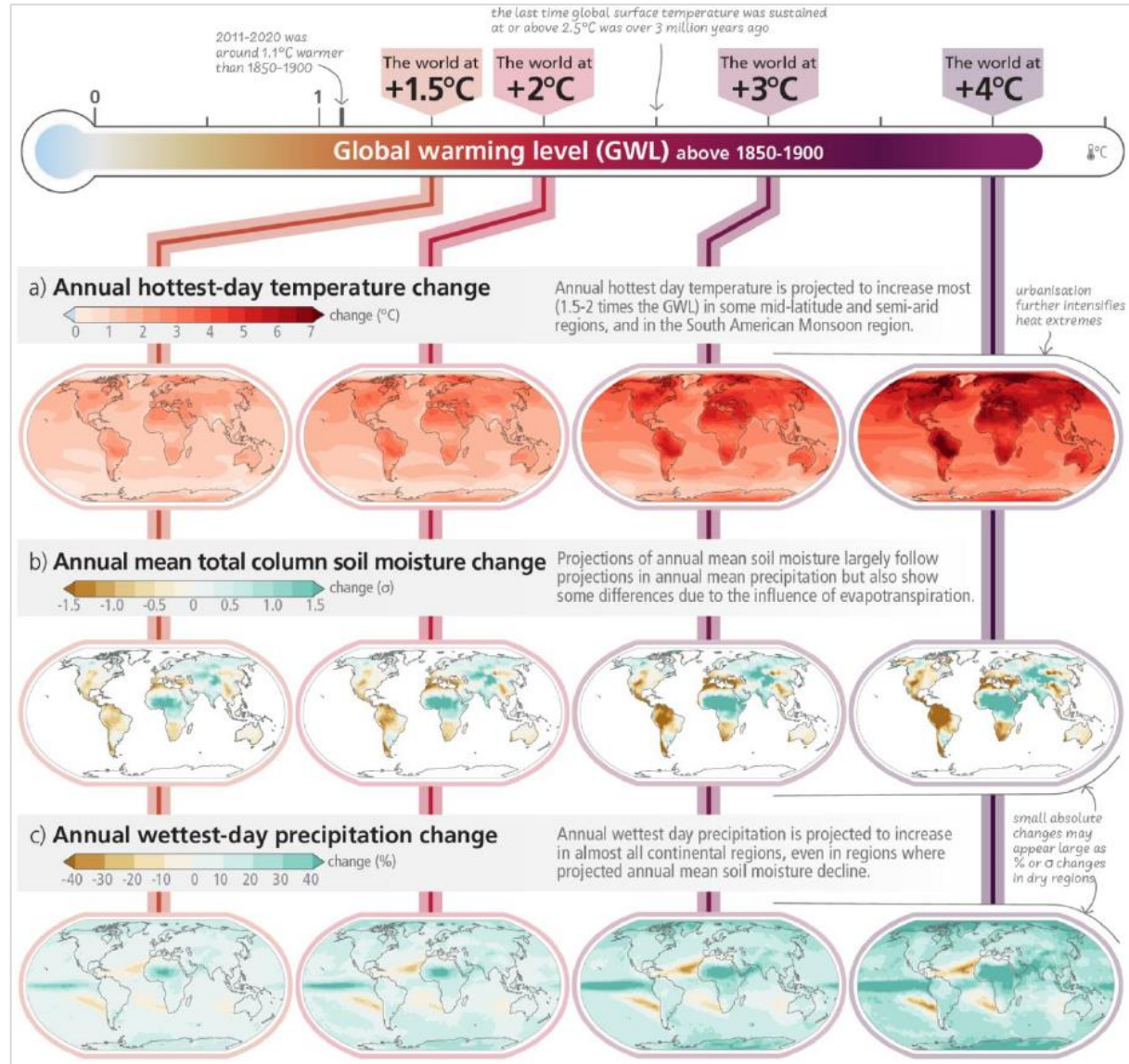
Climate change impacts on health are **mediated through natural and human systems**, including economic and social conditions and disruptions (*high confidence*)

- Climate and weather extremes are increasingly **driving displacement** in Africa, Asia, North America (*high*), and Central and South America (*medium*), with small island states in the Caribbean and South Pacific disproportionately affected relative to their small population size (*high confidence*)
- Through displacement and involuntary migration from extreme weather and climate events, climate change has **generated and perpetuated vulnerability** (*medium confidence*)

1.2 CLIMATE CHANGE PROJECTIONS – IPCC AR6 Projections

With every increment of global warming, regional changes in mean climate and extremes become more widespread and pronounced:

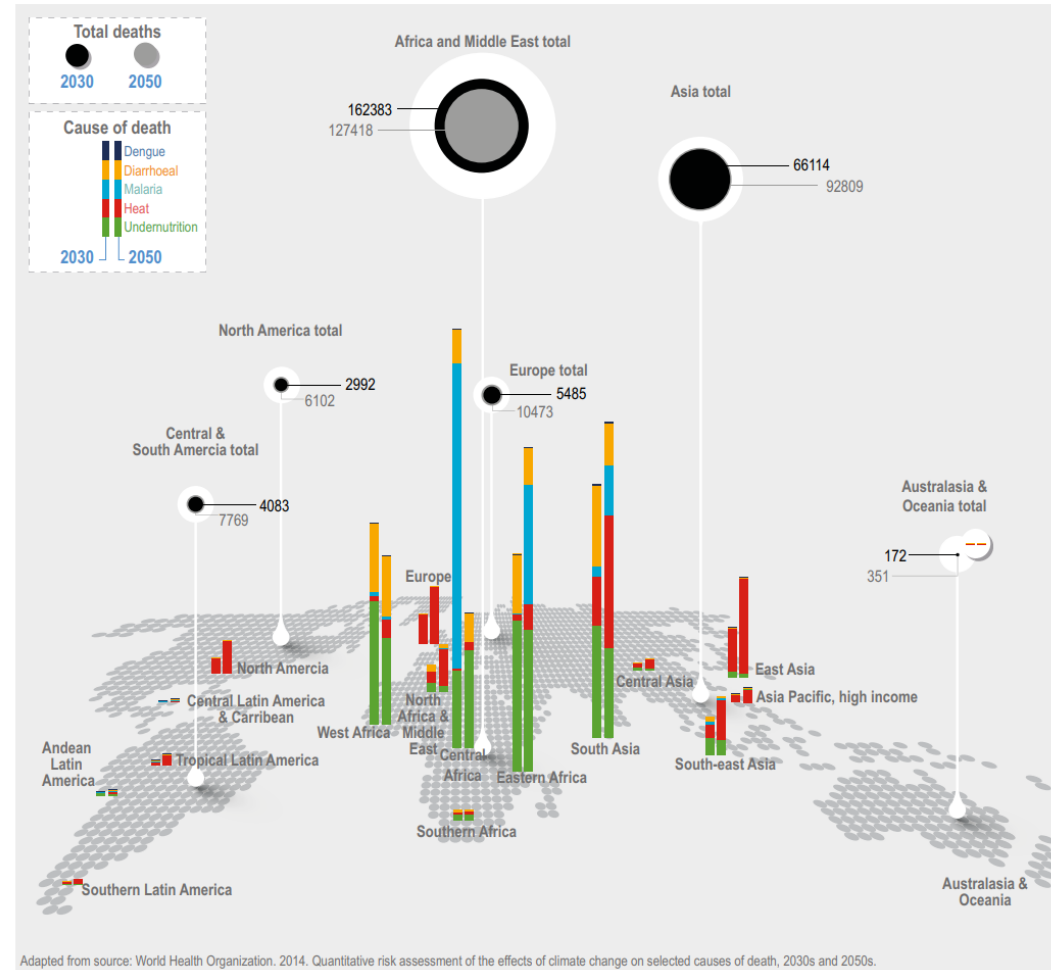
Projected changes of annual maximum daily temperature, annual mean total column soil moisture CMIP and annual maximum daily precipitation at global warming levels of 1.5°C, 2°C, 3°C, and 4°C relative to 1850–1900.



1.2 CLIMATE CHANGE PROJECTIONS – IPCC AR6 Projections: Impact on Health

Projected annual additional deaths attributable to climate change, in 2030 and 2050 compared to 1961–1990

■ Heat in elderly people ■ Diarrhoeal disease in children under 15 years ■ Malaria ■ Dengue ■ Undernutrition (stunting)

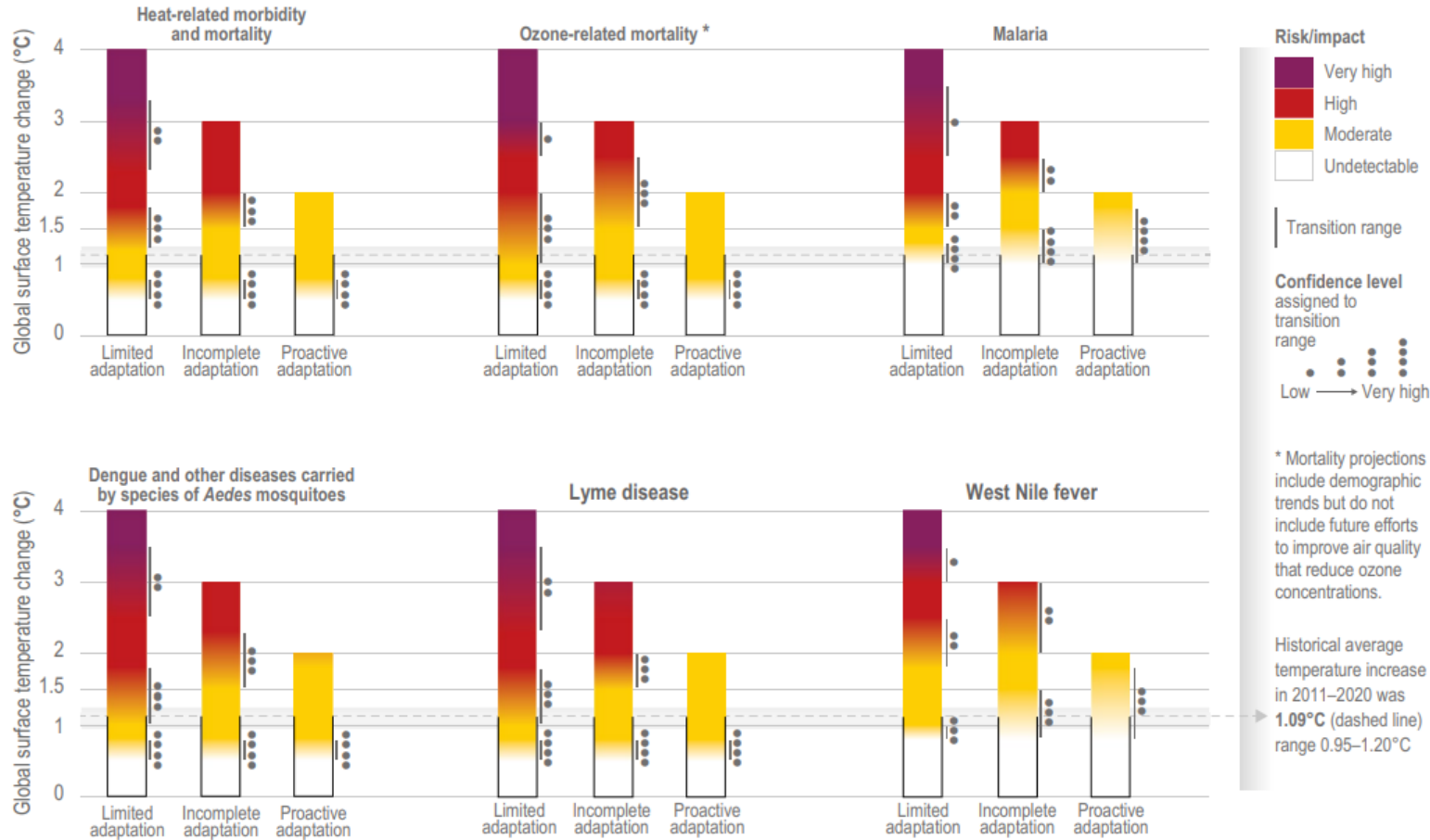


Adapted from WHO 2014, [Quantitative risk assessment of the effects of climate change on selected causes of death](#)

1.2 CLIMATE CHANGE PROJECTIONS – IPCC AR6 Projections: Impact on Health

Climate sensitive health outcomes under three adaptation scenarios

Scenario narratives
Limited adaptation: Failure to proactively adapt; low investment in health systems.
Incomplete adaptation: Incomplete adaptation planning; moderate investment in health systems.
Proactive adaptation: Proactive adaptive management; higher investment in health systems

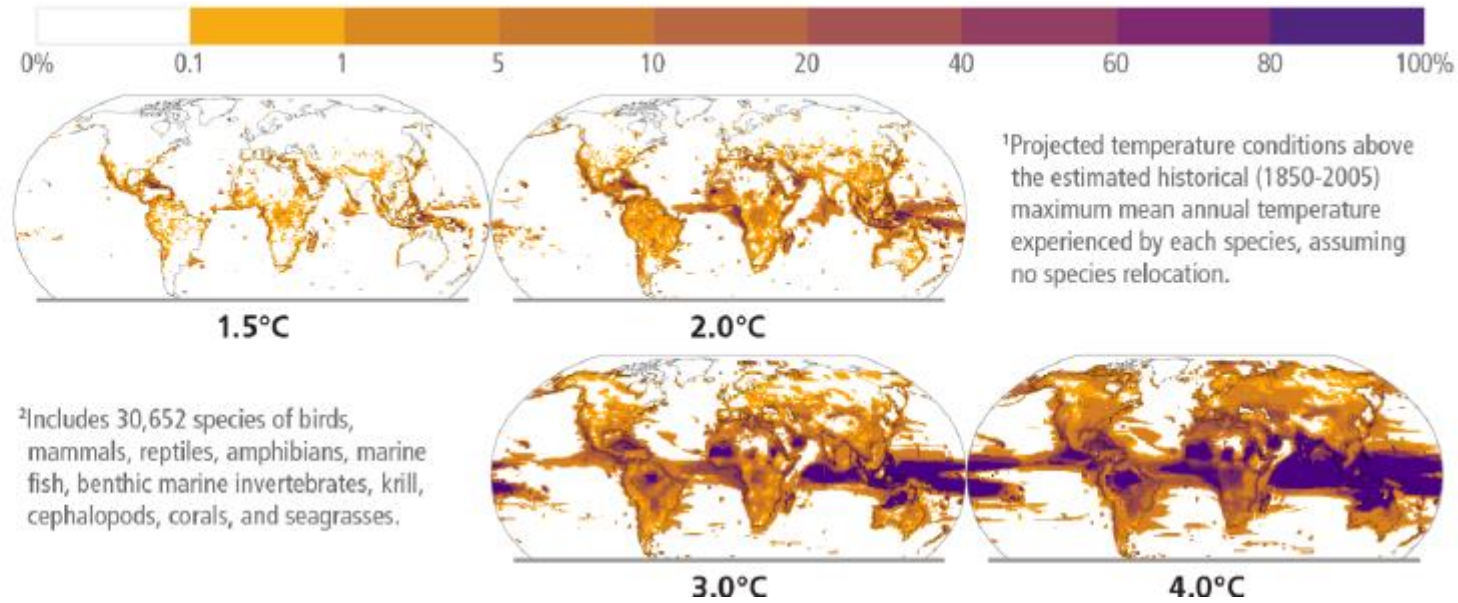


1.2 CLIMATE CHANGE PROJECTIONS – IPCC AR6 Projections

Future climate change is projected to increase the severity of impacts across natural and human systems and will increase regional differences

Examples of impact if no additional adaptation occurs:

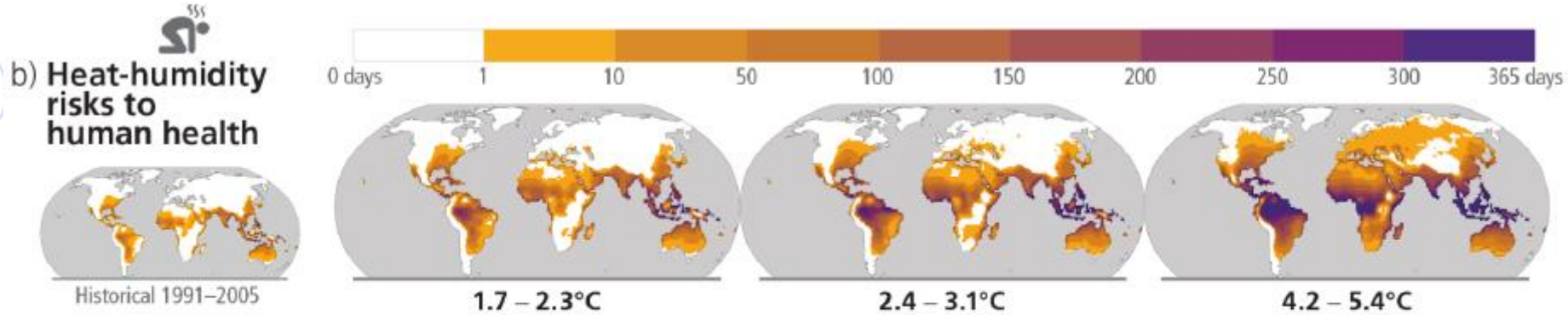
a) **Risk of species losses**
Percentage of animal species and seagrasses exposed to potentially dangerous temperature conditions^{1,2}



1.2 CLIMATE CHANGE PROJECTIONS – IPCC AR6 Projections

Future climate change is projected to increase the severity of impacts across natural and human systems and will increase regional differences

Examples of impact if no additional adaptation occurs:



Days per year where combined temperature and humidity conditions pose a risk of mortality to individuals³

³Projected regional impacts utilize a global threshold beyond which daily mean surface air temperature and relative humidity may induce hyperthermia that poses a risk of mortality. The duration and intensity of heatwaves are not presented here. Heat-related health outcomes vary by location and are highly moderated by socio-economic, occupational and other non-climatic determinants of individual health and socio-economic vulnerability. The threshold used in these maps is based on a single study that synthesized data from 783 cases to determine the relationship between heat-humidity conditions and mortality drawn largely from observations in temperate climates.

1.2 CLIMATE CHANGE PROJECTIONS – IPCC AR6 Projections

Future climate change is projected to increase the severity of impacts across natural and human systems, and will increase regional differences

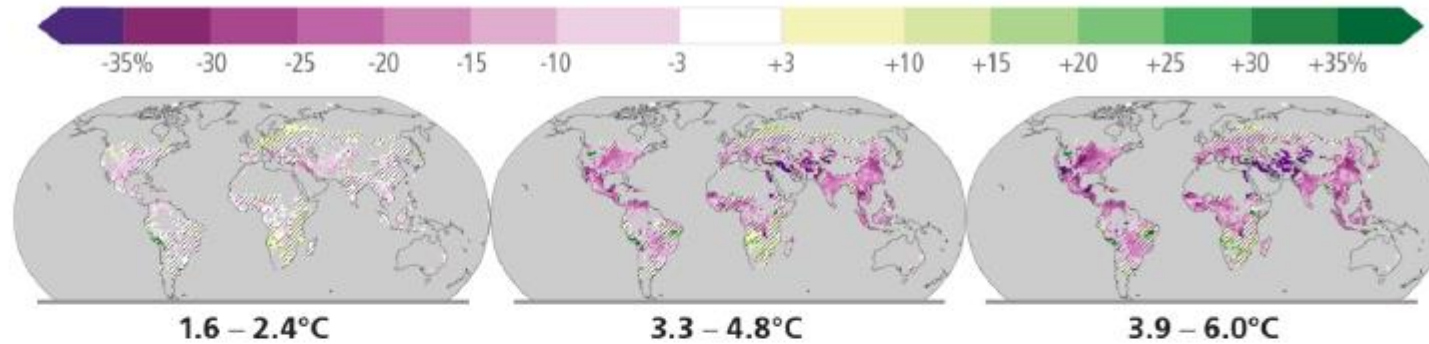
Examples of impact if no additional adaptation occurs:

c) Food production impacts



c1) Maize yield⁴

Changes (%) in yield

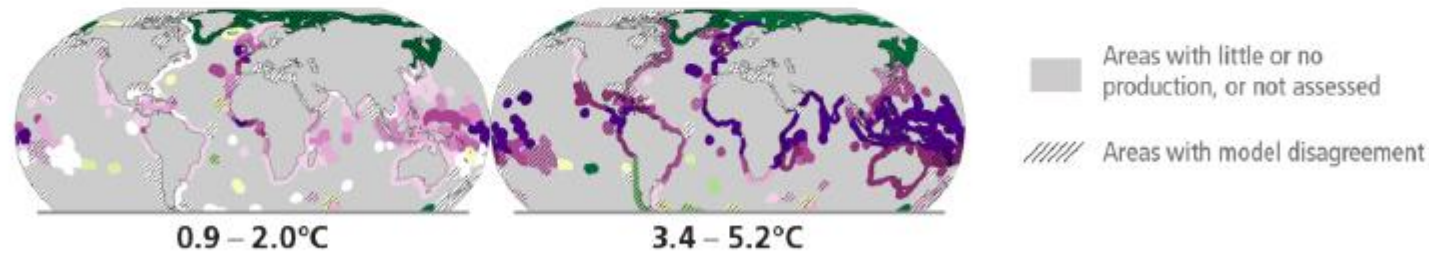


⁴Projected regional impacts reflect biophysical responses to changing temperature, precipitation, solar radiation, humidity, wind, and CO₂ enhancement of growth and water retention in currently cultivated areas. Models assume that irrigated areas are not water-limited. Models do not represent pests, diseases, future agro-technological changes and some extreme climate responses.



c2) Fisheries yield⁵

Changes (%) in maximum catch potential

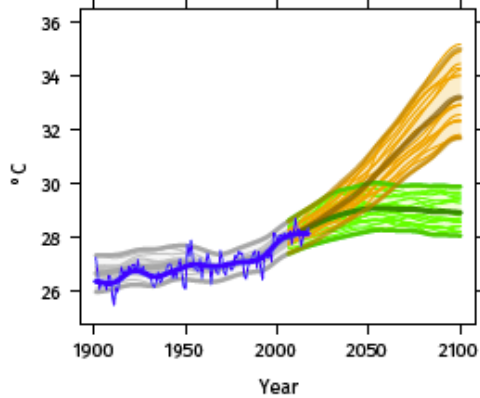


⁵Projected regional impacts reflect fisheries and marine ecosystem responses to ocean physical and biogeochemical conditions such as temperature, oxygen level and net primary production. Models do not represent changes in fishing activities and some extreme climatic conditions. Projected changes in the Arctic regions have low confidence due to uncertainties associated with modelling multiple interacting drivers and ecosystem responses.

1.2 CLIMATE CHANGE PROJECTIONS – Downscaling

Rising temperature

FIGURE 1: Mean annual temperature, 1900–2100



Under a high emissions scenario, mean annual temperature is projected to rise by about 5°C on average by the end-of-century (i.e. 2071–2100 compared with 1981–2010). If emissions decrease rapidly, the temperature rise is limited to about 1.4°C.

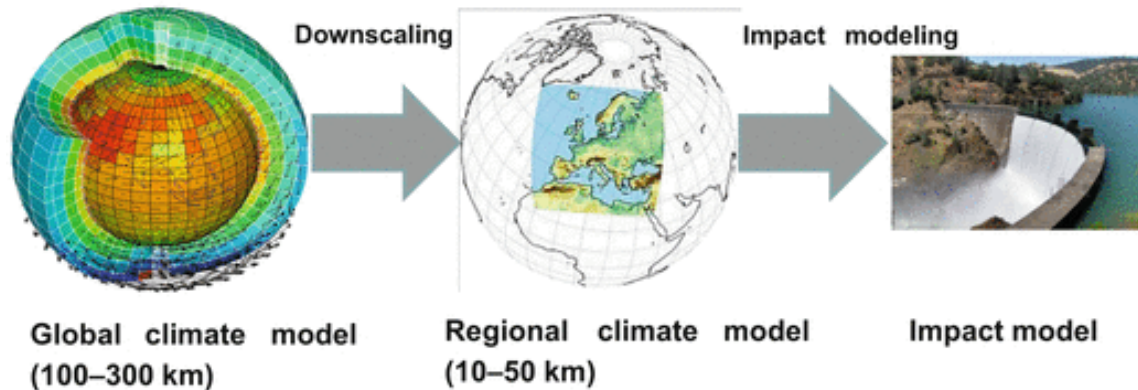
Downscaling: A general name for a procedure to take information at large scales to make predictions at smaller scales

Downscaling is conducted because information is often **required at smaller spatial and temporal scales** than GCMs can provide. Global climate models (GCMs) are run at spatial resolutions of the order of 150-200 km and are limited in resolving subgrid-scale features.

Example: Mean annual temperatures in the United Arab Emirates, see the figure. The long-term CMIP5 projects have been a key input to the **WHO’s Climate and Health Country Profile Reports**.

Output from GCMs can be downscaled **dynamically** – using a limited area regional climate model (RCM) - or **statistically**.

Regional climate projections



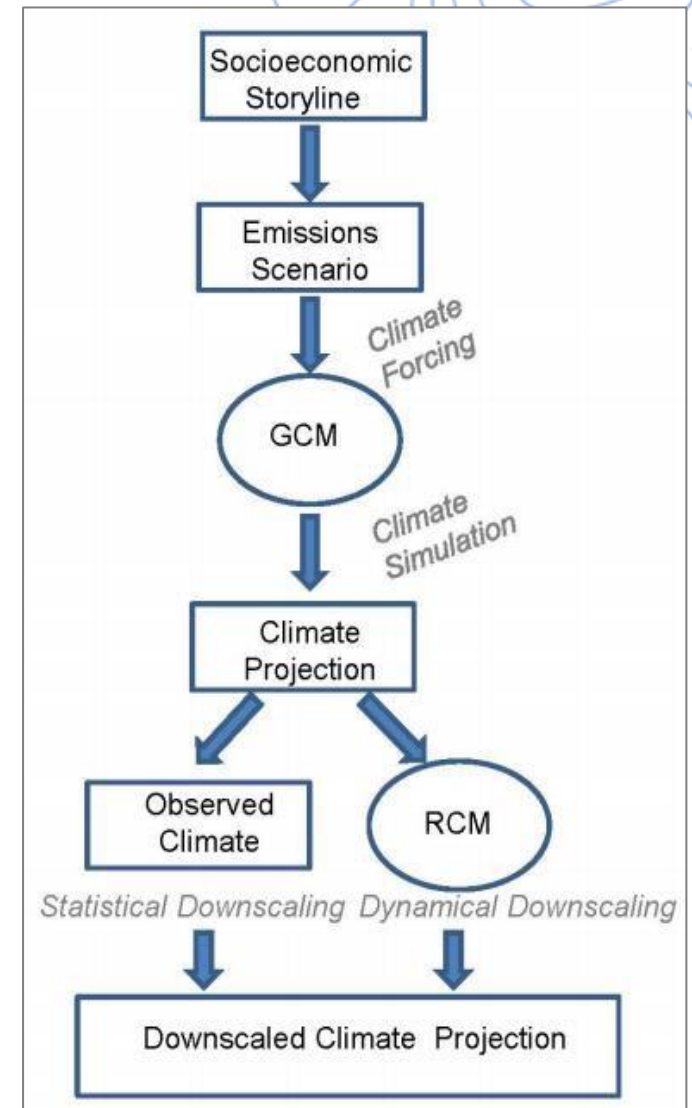
Regional climate projections are the key chain elements that provide information at a scale allowing impact calculations and the assessment of adaptation measures. The figure shows the modelling chain used to calculate the impacts of climate change on the river discharge or hydropower potential.

1.2 CLIMATE CHANGE PROJECTIONS – Downscaling

The two main approaches to downscaling spatial climate information are:

- **Dynamical downscaling:** by explicitly including additional data and physical processes in models similar to GCMs but at a much higher resolution and covering only select portions of the globe. This method has numerous advantages but is computationally intensive and requires large volumes of data as well as a high level of expertise to implement and interpret results, often beyond the capacities of institutions in developing countries.
- **Statistical downscaling:** by establishing statistical relationships between large-scale climate features that GCMs and local climate characteristics provide. In contrast to the dynamical method, the statistical methods are easy to implement and interpret. They require minimal computing resources but rely heavily on historical climate observations and the assumption that currently observed relationships will carry into the future. However, high-quality historical records are often not available in developing countries.

Deriving climate projections at local scales (downscaling) is a multistep process. At each step, assumptions and approximations are made. Uncertainties are inherent in projections of climate change and its impacts. They arise from different sources and need to be kept in mind, whether explicitly quantified or not.



Source: Daniels et al., 2012

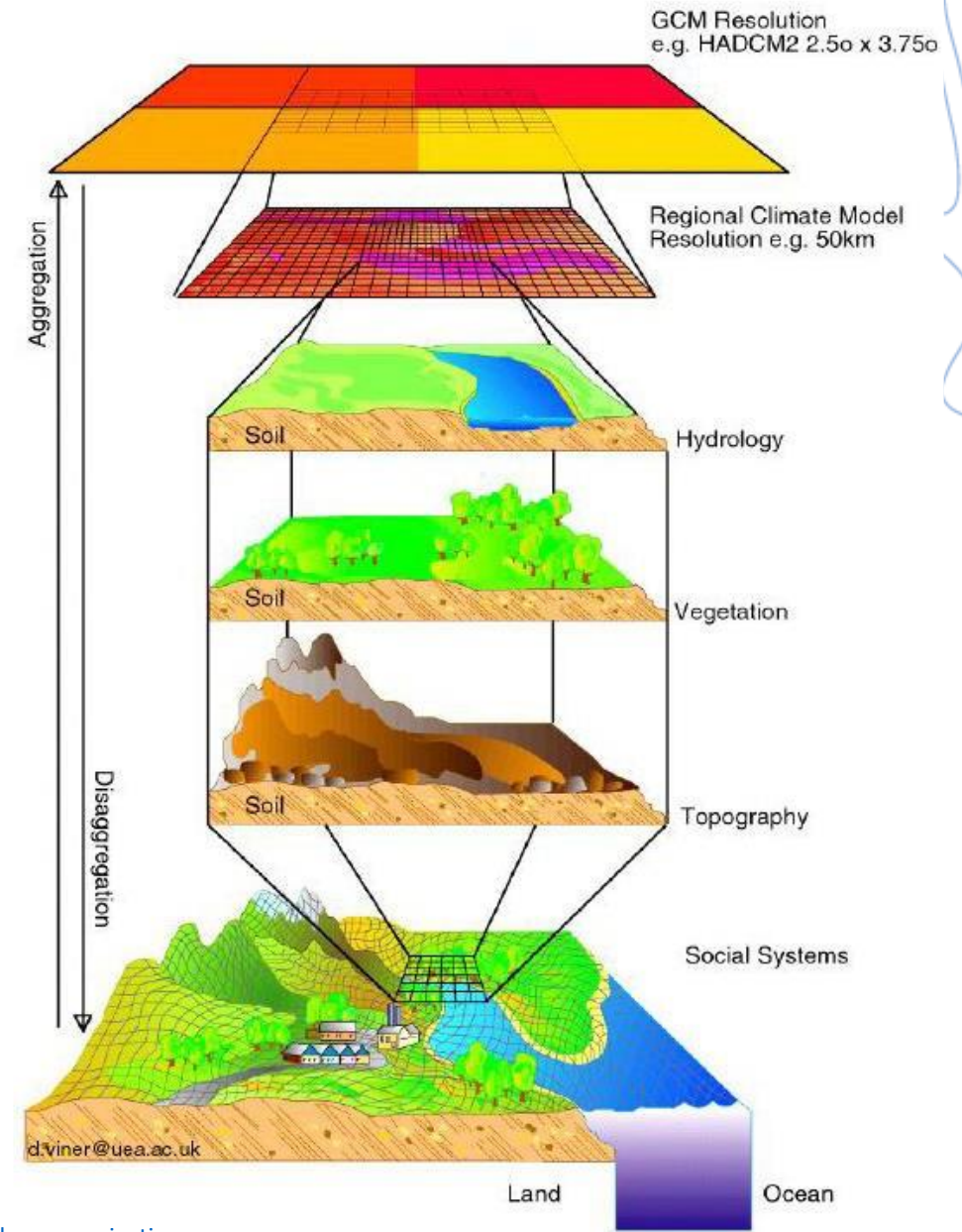
1.2 CLIMATE CHANGE PROJECTIONS – Downscaling

Dynamical downscaling relies on a regional climate model (RCM), similar in principle to a GCM but with higher resolution.

RCMs take the large-scale atmospheric information supplied by GCM output at the lateral boundaries and incorporate more complex topography, land-sea contrast, surface heterogeneities, and detailed descriptions of physical processes to generate realistic climate information at a spatial resolution of approximately 20–50 kilometres.

This is done because many of the processes that control local climate, e.g., topography, vegetation, and hydrology, are not included in coarse-resolution GCMs.

Since the RCM is nested in a GCM, the overall quality of dynamically downscaled RCM output is tied to the accuracy of the large-scale forcing of the GCM and its biases.



1.2 CLIMATE CHANGE PROJECTIONS – Downscaling

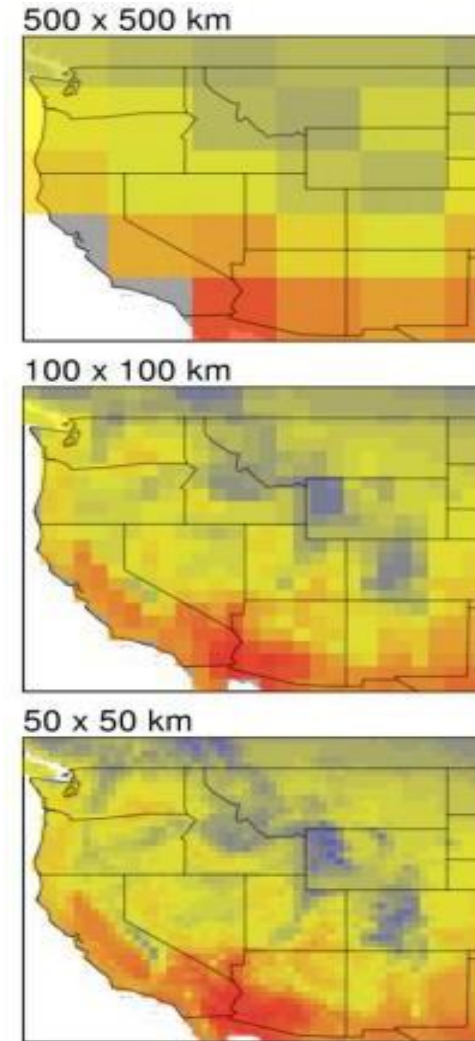
Statistical downscaling involves establishing empirical relationships between historical and/or current large-scale atmospheric variables and local climate variables.

Once a relationship has been determined and validated, GCM-projected atmospheric variables are used to predict future local climate variables.

Statistical downscaling can produce site-specific climate projections, which RCMs cannot provide, as they are computationally limited to a 20–50-kilometre spatial resolution.

However, this approach relies on the critical assumption that the relationship between present large-scale circulation and local climate remains valid under different forcing conditions of possible future climates.

It is unknown whether present-day statistical relationships between large- and regional-scale variables will be upheld in the future climate system.

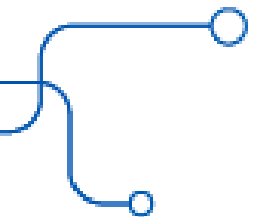


Mean annual temperature °C
Legend

18.8	19.9	20.9	21.9	23	24
12.6	13.7	14.7	15.7	16.8	17.8
6.4	7.5	8.5	9.5	10.6	11.6
0.2	1.3	2.3	3.3	4.4	5.4
-6	-4.9	-3.9	-2.9	-1.8	-0.8

Presented at a 500-kilometre typical GCM grid cell; 50-kilometre-typical RCM grid cell and 1 meter, which requires statistical downscaling.

Source: Daniels et al., 2012



Section 1.3: Health-tailored climate services

Learning objective:

Understand the **concept of climate services**, recognise the Global Framework for Climate Services, identify applications to the health sector, and develop a process for tailoring health applications to climate.

Case study:

Climate services for health in the Caribbean

Trotman T, Mahon R, Shumake-Guillemot J, Lowe R, Stewart-Ibarra AM. 2018. Strengthening climate services for the health sector in the Caribbean. World Meteorological Bulletin 67(2).

Resources:

- [Caribbean Health-Climatic Bulletin](#)
- [GFCS Health Exemplar](#)
- [US CDC Building Resilience Against Climate Effects \(BRACE\) Framework](#)
- [US Climate Resilience Toolkit - Assessing Health Vulnerability to Climate Change: A Guide for Health Departments](#)

Further learning opportunities:

- [Climate Services for Health Fundamentals and Case Studies for improving public health decision-making in a new climate \(2019\)](#)

How Can Climate Information and Services Help the Health Community?

Health decisions that can benefit from being informed by weather and climate information include:

- Risk and vulnerability identification;
- Disease control strategies;
- Health policy and regulations;
- Disease monitoring and surveillance;
- Financial and human resource allocation;
- Pharmaceutical, health, pesticide and vaccine supply flow;
- Health infrastructure siting and maintenance;
- Emergency preparedness;
- Community education and public health information dissemination, such as through public service announcements and alerts to raise awareness of risks;
- Targeted public advisories, medicines or supplies for vulnerable populations;
- Training of the health workforce for potential outbreaks or signs of illness;
- Impact assessment of climate-sensitive interventions



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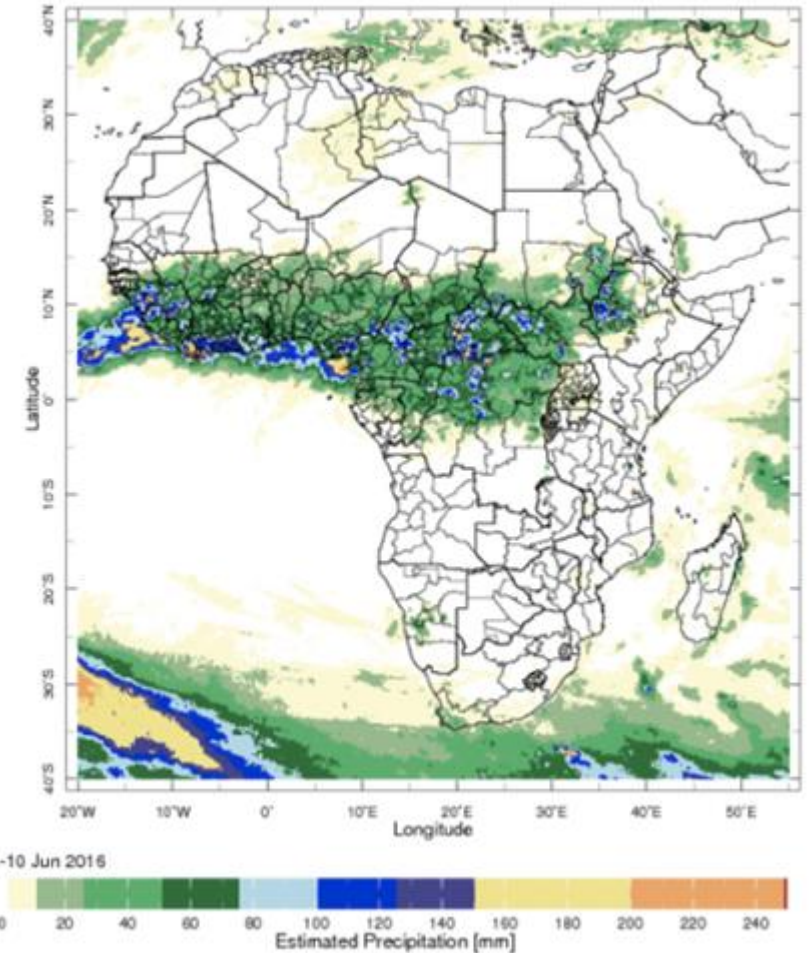
What kind of climate and weather information is useful to health partners?

CLIMATE AND HEALTH DECISION DASHBOARD			
	Toolbox	Requirements	Examples
Past UNDERSTAND	<ul style="list-style-type: none"> • Descriptive baselines of health outcomes and risks • Descriptive analyses of local climate conditions (climatology/seasonality, ENSO influence) • Spatial and temporal epidemiological analyses of sensitivity: mechanistic and ecological impact studies • Analysis of population exposure and vulnerability 	<ul style="list-style-type: none"> ✓ Climate Services to provide historical Climate Data ✓ Sufficient historical Epidemiological Data ✓ Analytical Capacity 	<ul style="list-style-type: none"> › V&A Assessment › Climate Profiles › Scientific Literature
Present MONITOR	<ul style="list-style-type: none"> • Indicators, Indices, Thresholds • Risk Assessments • Seasonal Climate Bulletins • Risk monitoring • Integrated surveillance systems 	<ul style="list-style-type: none"> ✓ Consistent Climate Data Access ✓ Systems based data collection ✓ Decision process to feed into 	<ul style="list-style-type: none"> › Meningitis Bulletin › Air Quality and UV Indices › Outbreak Monitor
Future ANTICIPATE	<ul style="list-style-type: none"> • Disease Modeling and Mapping • Environmental Suitability Modeling and Mapping • Severe Weather Alerts • Early Warning Systems • Seasonal Forecasts and Impact Calendars • ENSO prediction and Monitoring • Climate Projections • Climate Scenarios 	<ul style="list-style-type: none"> ✓ Weather and Climate Services to provide SW Alerts, forecasts, projections, scenarios ✓ Partnerships 	<ul style="list-style-type: none"> › Weather and Emergency Advisories › Seasonal Disease Calendar › ENSO Profiles
Future PREPARE	<ul style="list-style-type: none"> ✓ Action Plans ✓ Adaptation Plans ✓ Risk Management ✓ Resilience Building ✓ Awareness, Communications, and Mobilization 	<ul style="list-style-type: none"> ✓ Sufficient evidence and understanding ✓ Political and social will ✓ Resources 	<ul style="list-style-type: none"> › Heat Action Plans › Safe Hospitals › H-National Adaptation Plans

What kind of climate and weather information is useful to health partners?

The type of weather and climate information that can be useful to health decisions varies greatly according to four factors:

- The **health problem** being addressed;
- The **timescale of climate-related risk decision needs**;
- The **geographic scope** of the problem;
- and **availability and quality of data**.



Adapted from WHO/WMO (2018), *Climate Services for Health: Fundamentals and case studies*.

What kind of climate and weather information is useful to health partners?

TIMESCALE

HISTORIC RECORD OF CLIMATE OBSERVATIONS	WEATHER MONITORING & NOWCASTING PRODUCTS	WEATHER FORECASTS	SUB SEASONAL CLIMATE FORECASTS	SEASONAL CLIMATE FORECASTS	INTER-ANNUAL CLIMATE FORECASTS	DECADAL CLIMATE FORECASTS	DECADE TO CENTURY CLIMATE INFORMATION
<i>OPERATIONAL</i>	<i>OPERATIONAL</i>	<i>OPERATIONAL</i>	<i>UNDER DEVELOPED</i>	<i>OPERATIONAL</i>	<i>UNDER DEVELOPED</i>	<i>UNDER DEVELOPED</i>	<i>OPERATIONAL</i>
Hourly, daily, monthly or annual records of past climate conditions	Current weather conditions provided in real-time or with some delay, and very short-term predictions	Hourly or daily weather conditions forecasted multiple times a day from hours to around 12 days ahead	Average climate conditions over a week (approx.) forecasted from 2 weeks to 60 days ahead	Seasonal climate conditions forecasted up to 6 months ahead	Seasonal climate conditions forecast around 1 year ahead	Multi-annual climate conditions forecasted annually	Conditions expected at different points in time the next 30 to 100 years and run every 5 years or upon specific needs

What are climate and weather services?

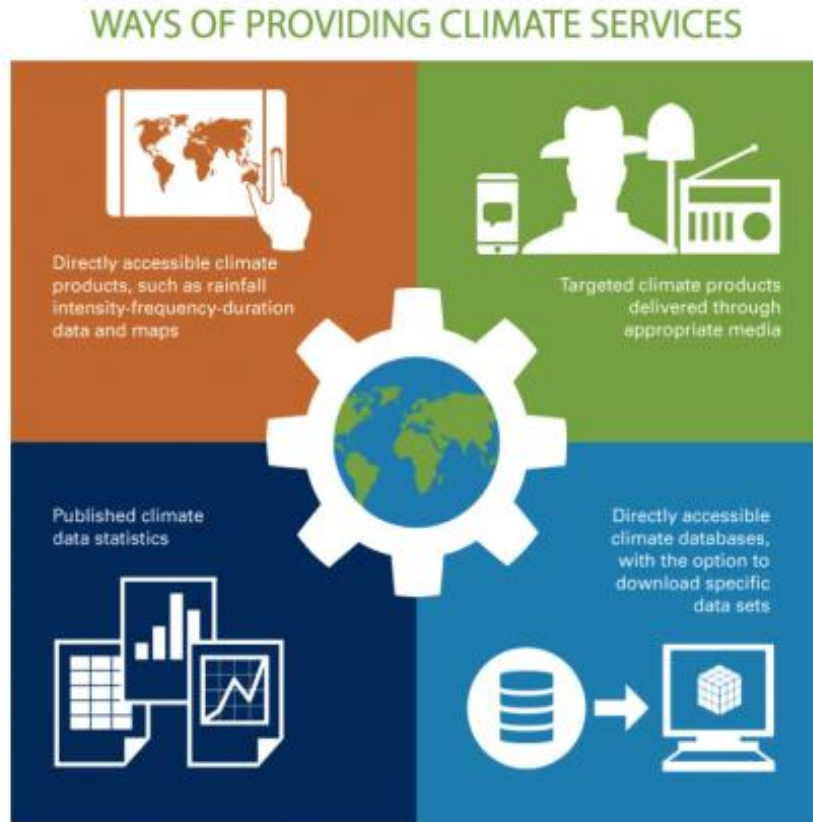
Climate services are “*mission-oriented processes driven by societal needs, which result in the production and delivery of fit-for-purpose, relevant, authoritative, timely and usable information about weather, climate, climate change, climate variability, trends, and impacts to improve decision-making in climate-sensitive sectors.*”

EXAMPLES OF CLIMATE SERVICES FOR HEALTH

- Heatwave Early Warning Systems
- Air quality risk mapping
- Pollen and Fire plume monitoring and forecasting
- Vector-borne disease risk modelling
- Integrated data management for risk monitoring
- Evaluation of health service performance
- Climate change projections and scenarios



What are climate and weather services?

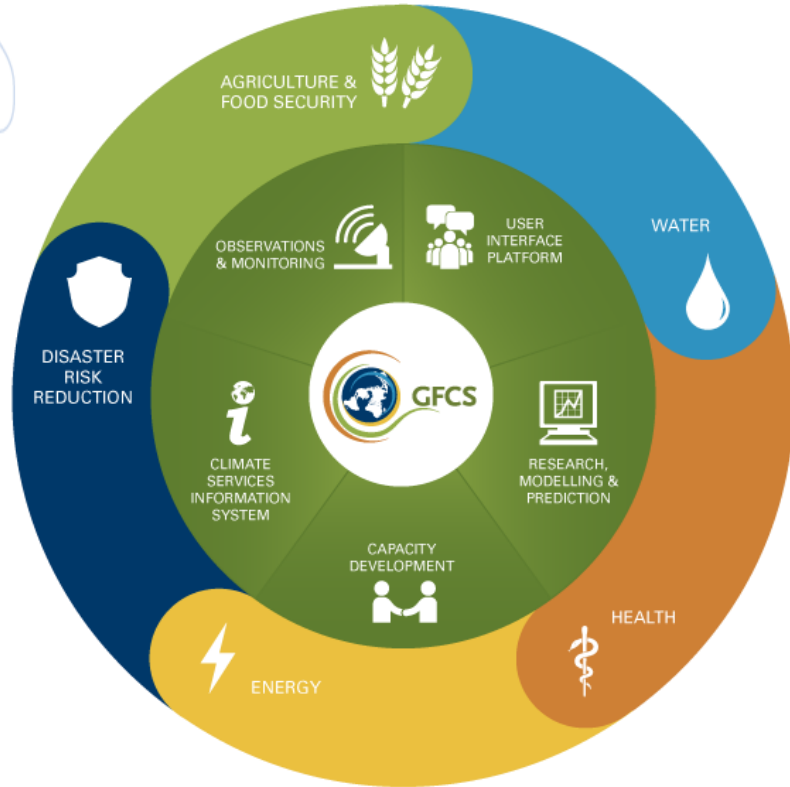


Adapted from WHO/WMO (2018), *Climate Services for Health: Fundamentals and case studies.*



Global Framework for Climate Services (GFCS)

The GFCS aims "To enable better management of the risks of climate variability and change and adaptation to climate change, through the development and incorporation of science-based climate information and prediction into planning, policy and practice on the global, regional and national scale."



The implementation of GFCS has five components:

- Observations and Monitoring
- Climate Services Information System
- Research, Modelling and Prediction
- User Interface Platform
- Capacity Development



GFCS focuses on developing and delivering services in five priority areas, which address issues basic to the human condition and present the most immediate opportunities for bringing benefits to human safety and wellbeing:

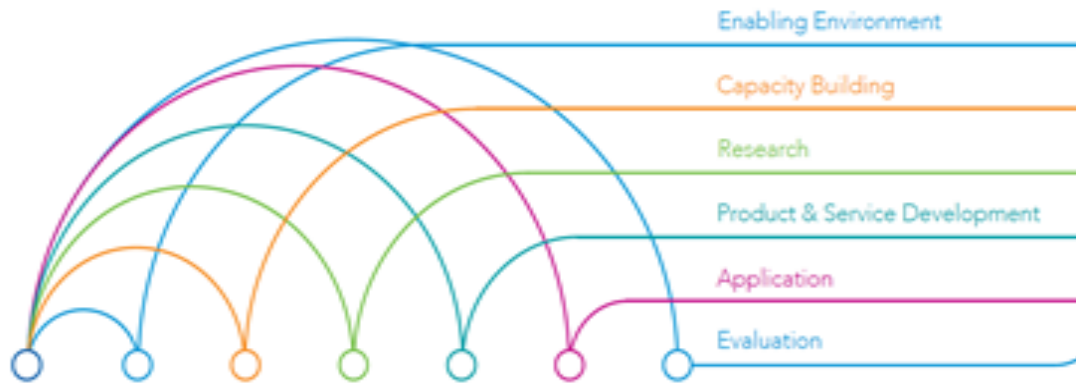
- Agriculture and Food Security
- Disaster Risk Reduction
- Energy
- Health
- Water

6-step process for co-designed climate services for health

Climate and weather science is a **probabilistic science** that is generated, processed and analysed in entirely different ways than health information and epidemiology.

Use of this knowledge by other fields calls not only for translation but also for understanding of specialised vocabulary and methods, as well as substantive dialogue to allow the synthesis and transfer of knowledge from one field to another.

Lessons from multidisciplinary teams around the world show that there is often a common journey in identifying, envisioning, developing, and applying climate services. Each phase is important to unlocking insights and unpacking the potential of applied climate knowledge.



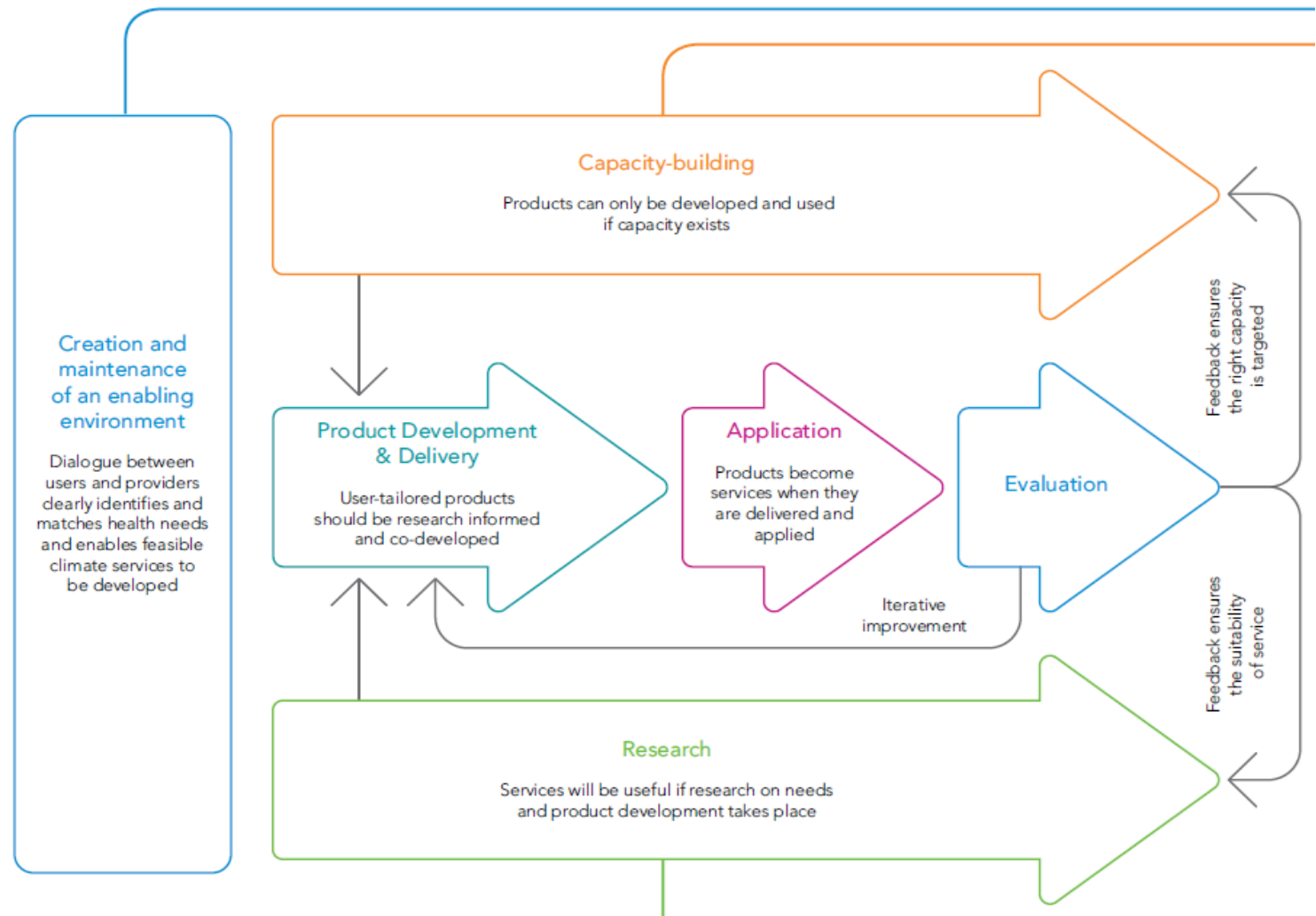
This common pathway is set out as a six-part framework:

1. Establish an **enabling environment** for partnership;
2. Build necessary **capacities**;
3. Identify needs and conduct **research**;
4. Co-develop and deliver **products and services**;
5. **Apply** the services to health policy and practice;
6. Iteratively **evaluate** the product and service delivery process.

6-step process for co-designed climate services for health

Each step interacts and sets the foundations and readiness for success in the other steps.

Steps are often simultaneous and not sequential



Adapted from WHO/WMO (2018), *Climate Services for Health: Fundamentals and case studies*.

STEP 1: CREATE AN ENABLING ENVIRONMENT

GOAL

Promote the close, coordinated, and sustained collaboration and exchange of information among the climate and health sectors and other relevant stakeholders, thereby building the technical, institutional, legal, and normative foundations that enable smooth, timely, and successful collaboration across activities within each process component.

ABOUT:

An **enabling environment** is the structured context that brings together the principal actors whose technical and practical expertise and decision-making are needed to inform, develop, and apply the climate service knowledge to solve problems within a health system on a sustainable basis.

An **enabling environment** is formed by the:

- *National policy and financial landscape*
- *Problem awareness and scientific and programmatic demand*
- *Institutional mandates, procedures, and capacities*
- *Multi-sectoral partnerships and communication mechanisms*

STEP 1: CREATE AN ENABLING ENVIRONMENT

STEPS TO TAKE TO CULTIVATE AN ENABLING ENVIRONMENT FOR CLIMATE SERVICES

- Clearly define the health problem being solved and its space and time dimensions.
- Envision together with relevant actors the scope of the type of climate products and services to be developed. Create mechanisms and norms for dialogue between partners to set appropriate expectations and to understand each other's needs, interests, and limitations, including data-sharing and resource-exchange policies.
- Evaluate the readiness for the specific products/service development, including capacity, research, political support, application requirements, and financial and technical resources.
- Explore the feasibility and sustainability of different implementation models. Define a service development progress monitoring system to identify and manage setbacks and breakthroughs.
- Establish rules and procedures for engagement (such as meeting schedules, memorandums of understanding, timetables, data sharing arrangements).
- Create a plan for evaluating, providing feedback, and making needed adjustments.
- Ensure the right policies and mandates are established to develop and apply the service. Generate a strategic plan for long-term financial sustainability.

STEP 1: CREATE AN ENABLING ENVIRONMENT

COMMON APPROACHES

Enabling environments are fostered in different ways, depending on the context, the national institutional environment, and partners' familiarity with the subject and with each other. Activities that help create and structure an enabling environment include:

- Assessing readiness and defining demand for climate services;
- Mapping national partners' interests and strengths;
- Collaborating with international stakeholders or partner countries to fill gaps in available knowledge or resources;
- Clearly defining the roles and responsibilities of partners;
- Formalising a memorandum of understanding or clear terms of reference outlining how the collaboration will work, and enabling key activities such as data exchange;
- Adopting common standards and schedules;
- Revising institutional mandates and policies, including formulating effective data-sharing policies;
- Creating a multidisciplinary team;
- Scheduling regular meetings, trainings, and workshops with all stakeholders;
- Involving high-level decision-makers to increase their understanding, appreciation and trust to use the information and services in order to make critical and often life-saving decisions;
- Partnering with academia and civil society organisations as neutral actors
- working between national health and climate authorities;
- Engaging and communicating actively with donors to ensure future sustainability.

STEP 1: CREATE AN ENABLING ENVIRONMENT

WHO SHOULD BE INVOLVED

Health professionals: Health authorities and programmatic decision-makers, planners, researchers, statisticians, epidemiologists, public health practitioners, clinical staff and community health workers, who may be working for the private sector, government or non-governmental health system.

Climate professionals: Meteorologists, climatologists, and researchers from the National Meteorological Services, academia, or applied institutes. Professionals from health-determining sectors: Water management, agriculture and food security, urban planning, and disaster risk management are also key actors in developing tailored information products related to or adapted from knowledge and decision tools used in these domains.

Knowledge brokers and professionals from complementary disciplines: Information and communication technologists, project managers, policy-makers, legal experts, statisticians and community representatives.

Community members: Individuals expected to use the climate information, and the media who may be transmitting information to the public, are also important stakeholders.



STEP 2: BUILDING CAPACITY FOR CLIMATE SERVICES

GOAL:

Ensure that **adequate human and other resources, institutional and community skills and know-how** are available to enable the appropriate development, optimal use, and sustainability of climate services.

ABOUT:

Capacity-building refers to the broad range of activities and resources needed to enhance human resource knowledge and technical skills, institutional abilities, and infrastructural capacities to generate and apply climate knowledge to decision-making.



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STEP 2: BUILDING CAPACITY FOR CLIMATE SERVICES

Three types of capacity to consider:

Human resource capacity – equipping individuals with the knowledge, skills and training to enable them to generate, communicate and use decision-relevant climate information.

Infrastructural capacity – enabling access to resources that help generate, archive, ensure quality control, communicate, exchange and use climate data and decision-relevant information and products, including both supply and demand side instruments for observing networks, data management systems, computer hardware and software, internet access, communication tools, manuals and scientific literature, with similar things on the health sector side but potentially much more diverse.

Institutional capacity – on the climate side includes elaborating management structures such as defining the position and terms of reference of the National Meteorological and Hydrological Services for climate services, processes, policies and procedures that enable effective climate services, not only within organisations but also in managing relationships between the different organisations and sectors (such as public, private and community, including international collaboration).

On the health side this includes mandates of government agencies to prioritize and address climate change as a health risk, as well as the organizational arrangements for disease control, nutrition, environmental management, and emergency preparedness and response; policies and procedures that facilitate intra- and inter-sectoral environmental, disaster, and climate risk management; data management and exchange policies; working relationships with other health sector partners (such as nongovernmental organizations, research institutions and universities) and the availability of personnel.

STEP 2: BUILDING CAPACITY FOR CLIMATE SERVICES

WHAT KIND OF CAPACITY IS NEEDED BY KEY ACTORS ACROSS THE PROCESS OF CLIMATE SERVICE DEVELOPMENT?

	Meteorological professionals need capacity to:	Health professionals need capacity to:	Multi-disciplinary health relevant partners need capacity to:	Citizens need capacity to:
ENGAGEMENT	Listen and understand user and community needs Communicate climate science	Define, inform, and prioritize information and knowledge needs	Identify and translate risk or impact relevant information and stakeholders	Access information and value the benefits of climate services
RESEARCH	Conduct product research and development Access and understand global and regional products	Conduct research using climate information	Participate in climate and health research	Collect and provide community sourced information
PRODUCTION	Ensure quality observational data is available and related products and services are quality controlled and transparently produced. Develop and test products Deliver services	Identify and provide data and analytical inputs Develop and test products	Identify and support linkages Contribute relevant data and analytical inputs	Inform preferences for climate service outputs, i.e. language, format, frequency
APPLICATION	Communicate uncertainties and strengths/limitations of the services developed	Understand and internalize new information Institutionalize climate services as decision tools	Share information and build bridges to integrate knowledge into multi-sectoral risk management	Understand messaging Know how to respond appropriately to information and warnings
EVALUATION	Resources and methods to measure reliability and validity of products, as well as user-uptake and satisfaction	Resources and methods to measure and evaluate impacts	Resources and methods to measure and evaluate cross-sectoral impacts	Opportunities to provide feedback on user-experience and impact

Adapted from WHO/WMO (2018), *Climate Services for Health: Fundamentals and case studies*.



STEP 2: BUILDING CAPACITY FOR CLIMATE SERVICES

COMMON APPROACHES

Capacity-building needs will vary depending on the goals of the climate service being developed. However, some **useful common approaches** include:

- Mapping and assessing existing institutional, infrastructural, human resource, and community capacities through surveys or other instruments.
- Strengthening the enabling environment to reinforce institutional capacities.
- Investing in and upgrading information technology and communication equipment and systems.
- Training community leaders, volunteers and health workers on the health risks exacerbated by climate and weather conditions and appropriate responses that can be taken.
- Involving communities in health and climate data collection and interpretation.
- Training health professionals from local and regional health bureaus on health and climate linkages, disaster management, and analytical methods, such as environmental epidemiology and spatial biostatistics.
- Conducting workshops to build capacity at appropriate levels (local, regional and national) to use the climate products and services developed.
- Embedding climate and health courses in the course curricula of higher education institutions and engaging them in technology and knowledge transfers to the public health community.
- Developing tailored training and outreach materials especially targeted to high-risk groups.
- Organising multidisciplinary discussion groups to increase communication capacities across professionals from different fields.
- Organising regular knowledge refresher courses on climate-sensitive disease detection and diagnosis.
- Fostering expert and staff exchanges between national and regional partners, such as the WMO Regional Climate Centres.

STEP 3: RESEARCH TO INFORM CLIMATE SERVICES

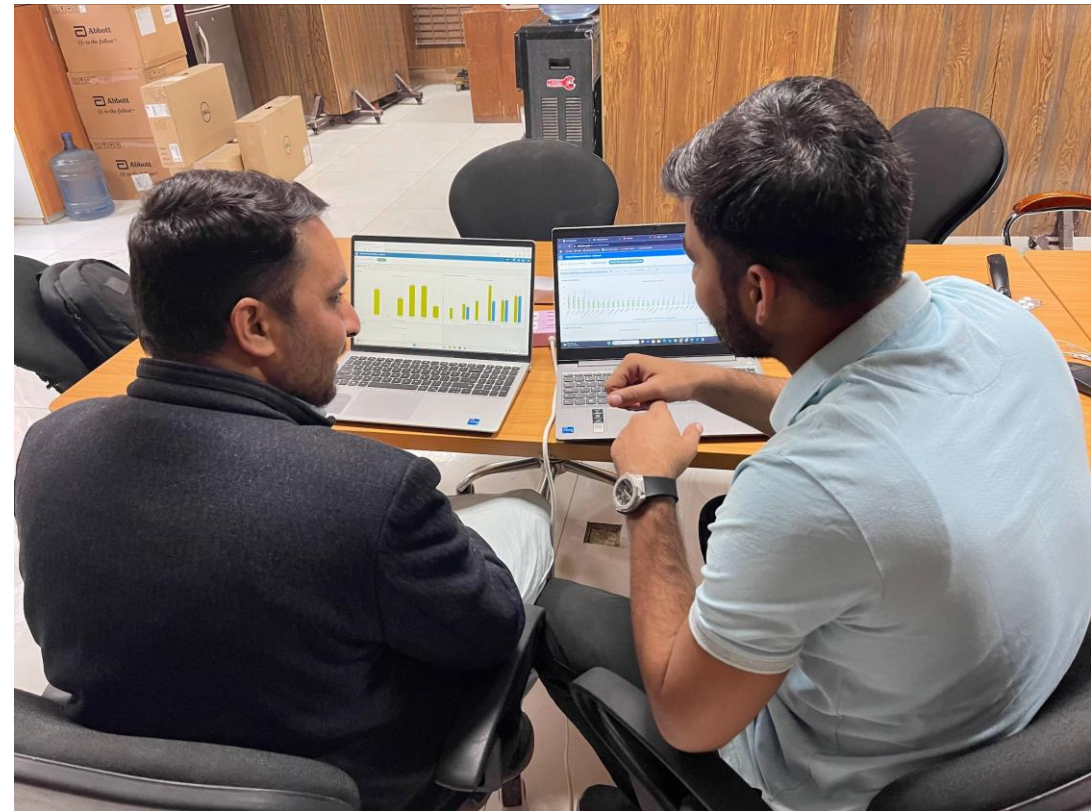
GOAL:

Generate evidence on the needs for climate services for health and produce the necessary know-how for the development and application of such services.

ABOUT:

Climate services for health begin with research that establishes associations between climate and weather conditions and health outcomes, risk factors, or health service delivery performance.

Understanding the “climate signals” which may play a role in disease outcomes is required for any application of climate information to decision-making.



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STEP 3: RESEARCH TO INFORM CLIMATE SERVICES

Research for climate services may take many forms, as a broad range of technical and context-specific information is needed to develop products and design effective services. Research activities often fall into three categories:

Applied research includes investigations undertaken to acquire knowledge about a specific practical aim or objective, such as understanding the linkages between climate conditions and health outcomes; the relative need for and value of climate information; data validation and development; and specific analytical methodologies to assess model validity and uncertainty.

Product research and development can include purpose-driven activities to generate sufficient know-how to develop tailored climate information products and services. Some examples include: exploration of context-appropriate data collection; data digitalisation and data transfer systems; analysis and refinement of the service's sensitivity to detect certain levels of climate-related risks; comparative evaluation of different risk indicators; or exploration of information visualisation and communication tools.

Operations research draws upon management and organisational sciences, using qualitative or quantitative techniques to explore and generate practical knowledge and know-how on climate services applications. Operations research is applicable to the entire climate services development process, and can include analyses on: the demand for and readiness of communities or organisations to use a climate service; the optimal internal administrative and human resources structures needed for the successful application and sustainability of the service; the legal institutionalisation of the service; the best stakeholder coordination and information-sharing mechanisms; as well as cost-efficiency assessments.

STEP 3: RESEARCH TO INFORM CLIMATE SERVICES

Common Research Topics and Tools

Iterative research and information collection for feedback are essential prior to the development of climate products or services. It informs product specifications, user needs and requirements, and identifies optimal communication and application. Research methodologies range from quantitative analyses to focus groups and surveys for exploring community perceptions and human resource capacities.

The **following types of research** are commonly used:

- Statistical analysis of health sensitivity to climatic conditions.
- Mathematical or statistical modelling of climate risk indicators and thresholds.
- Spatial or temporal risk modelling and mapping.
- Feasibility and readiness assessments of data or information systems.
- Qualitative study of population risk perceptions, behaviours, priorities, and practices.
- Operational or process research on health service delivery.
- Institutional and human resource capacity assessments.
- Assessment of adaptation options, including identification of climate information needs.
- Identification and development of appropriate communication strategies.

STEP 4: APPLIED CLIMATE PRODUCT AND SERVICE DEVELOPMENT

GOAL:

Collaboratively design and create tailored information products that are integrated and interoperable to user specifications, which provide decision-makers and communities with timely and relevant information to manage health risks specific to climate and weather.

Common Health-tailored Products and Services

A range of decision tools can be developed to inform and provide insight into a wide range of health problems.

Monitoring systems and integrated surveillance	Core analytics (indicators, thresholds, models, maps)	Risk forecasts	Early warning systems	Projections and scenarios
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STEP 4: APPLIED CLIMATE PRODUCT AND SERVICE DEVELOPMENT

Categories of tailored products	Example advantages	Example challenges
MONITORING SYSTEMS AND INTEGRATED SURVEILLANCE	<ul style="list-style-type: none"> • Provide comprehensive and real time detection of health risks. • Serve to trigger response plans. • Facilitate data sharing and access for relevant stakeholders. • Provide the basis for development of all other product categories. 	<ul style="list-style-type: none"> • Poor data quality, availability and interoperability across systems. • Establishment of data sharing agreements between stakeholders. • Effective links between monitoring activities and response plans.
CORE ANALYTICS	<ul style="list-style-type: none"> • Enable dynamic characterization of health risks across space and time. • Facilitate identification of vulnerable populations. 	<ul style="list-style-type: none"> • Lack of analytical capacity to calculate thresholds and develop risk models. • Lack of fundamental research to inform the development of key analytics. • Absence of standard indicator definitions. • Limited availability of geo-coded information.
RISK FORECASTS	<ul style="list-style-type: none"> • Anticipate the likelihood of when and where health impacts may occur. • Provide extended lead time for preparedness. 	<ul style="list-style-type: none"> • Varied level of skill in weather and climate predictions across regions and seasons. • Lack of sufficiently reliable and long data sets. • Poor mechanistic understanding of health risk dynamics.
EARLY WARNING SYSTEMS (EWS)	<ul style="list-style-type: none"> • Create awareness of prevention and preparedness needs and opportunities. • Provide authoritative and continuous source of information to guide risk management. 	<ul style="list-style-type: none"> • Dependencies on quality of all the above product categories. • Limited availability of robust thresholds to trigger warnings. • Reliance on weather and climate forecasts with limited predictive ability. • High levels of institutional commitment and capacity to sustain the EWS and respond to warnings.
PROJECTIONS AND SCENARIOS	<ul style="list-style-type: none"> • Enable foresight of future risks and alternative futures to inform mid- and long-term decision making. 	<ul style="list-style-type: none"> • High levels of uncertainty in climate projections.

STEP 5: APPLICATIONS

GOAL:

Apply climate knowledge to benefit individuals and communities.

The **ultimate goal** of developing tailored climate services is to apply the climate knowledge **to answer a specific health question** or **provide a solution** to a health risk management problem.

Applying climate products and services **bridges the gap** between largely theoretical research and development and the use of outputs to real-world problems. The successful application of knowledge entails activities that appropriately communicate information and integrate climate knowledge, decision tools, and information effectively into health decision-making and protection measures.

The **scope of application is extensive**. Relevant and tailored climate information is commonly used to enhance health decision tools, through the use of risk assessments, risk monitoring and disease surveillance; emergency response planning; health services planning and delivery; resource allocation; facilities siting and maintenance; evaluation of health interventions; health policy, standards and norms formulation; public safety advisories and community health education.

STEP 5: APPLICATIONS

COMMON APPROACHES

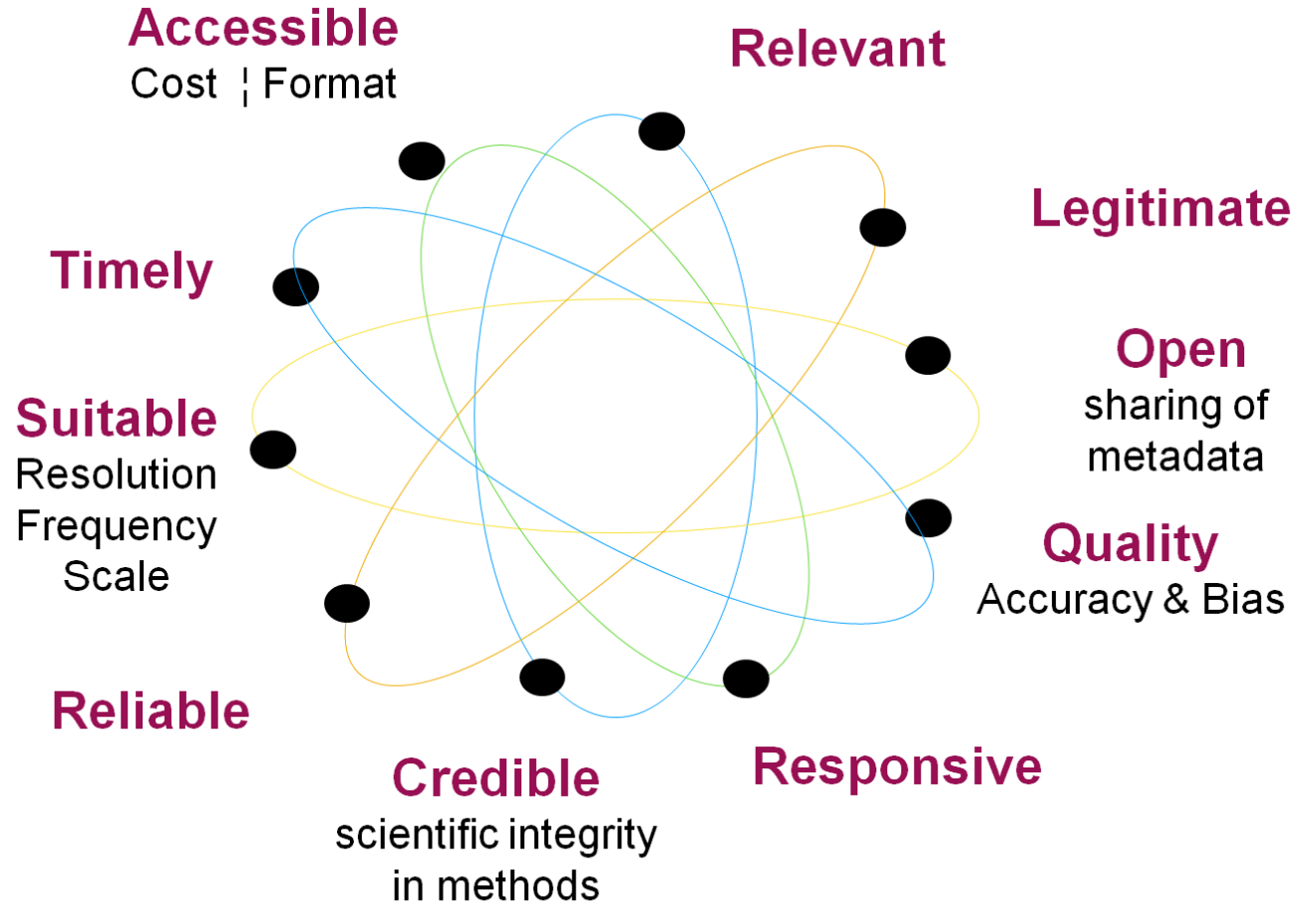
Several strategies can help operationalise and maintain climate services, as well as increase user appreciation and decision-makers' willingness to support and integrate such products and services. These strategies include:

- Mainstreaming partnerships and information products into health policies and programmes, by justifying the dependencies on climate information to improve health system performance and health outcomes.
- Jointly engaging ministries of health and national meteorological services to endorse, launch, and sponsor projects that establish the value of the climate service and increase its acceptance.
- Holding workshops to co-develop research and climate service features with national health authorities, to ensure that they are driven by national strategic health priorities.
- Providing open access to processed information and promoting available resources.
- Encouraging open discussion and feedback opportunities on climate products and services to increase understanding, ownership, and facilitate agreement on the essential climate service features, ensuring optimal fit-for-purpose and added value to health decision needs.
- Communicating local evidence of climate and weather impacts on community health and highlighting climate-informed risk management opportunities.
- Pilot testing the service prior to extensive implementation.
- Providing decision-makers with hands-on exposure to prototypes or preliminary versions of the services.
- Increasing capacity among medical professionals and health decision makers to value and use the information generated by the climate service.
- Supporting national agencies in technical implementation to address capacity gaps and maximise the quality and reliability of information.
- Encouraging regional knowledge exchange to ensure local lessons are shared.
- Ensuring appropriate and adequate investment in communications and capacity-building of end-users and ultimate beneficiaries.
- Partnering with the media and the use of social media and other communication technologies to conduct extensive communication campaigns.
- Holding evaluation meetings or using survey instruments to collectively evaluate and improve sub-optimal performing aspects of a service.
- Measuring and communicating the value and impact of using the climate information on health outcomes and health system performance.

STEP 5: APPLICATIONS

CHARACTERISTICS of successful and sustainable tailored climate services

Projects that do not meet these criteria often result in unused or unsustainable products and wasted resources.



Adapted from WHO/WMO (2018), *Climate Services for Health: Fundamentals and case studies.*



STEP 5: APPLICATIONS

Implementation of climate services: *Key steps*

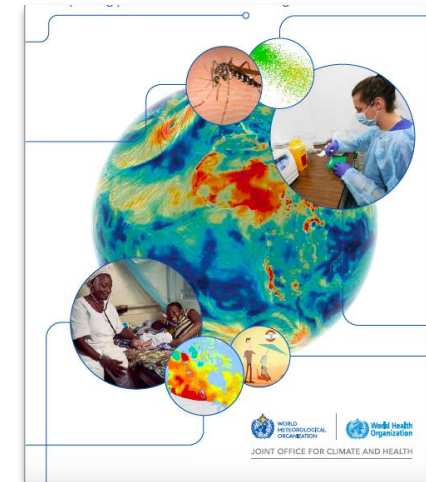
- Developing strong **partnerships and stakeholder engagement**
- Establishing effective **risk communication** strategies and plans
- Developing a logic model to identify key partners and stakeholders who would **evaluate** the program, develop metrics for ongoing **evaluation** and audit the public health impact and success

STEP 5: APPLICATIONS

CASE STUDIES

of end-to-end applications of climate knowledge to health problems

1. Innovative **heat wave early warning system** and action plan in Ahmedabad, India
2. Managing the health impacts of **drought** in Brazil: A comprehensive risk reduction framework
3. Early warning systems to guide **infectious disease control** in Europe
4. Improving **malaria evaluation and planning** with enhanced climate services in East Africa
5. Using climate information to predict and control **meningitis** epidemics in West Africa
6. Using climate knowledge to guide **dengue prevention and risk communication** ahead of Brazil's 2014 FIFA World Cup



WHO/WMO (2018), *Climate Services for Health: Fundamentals and case studies*.

STEP 6: EVALUATIONS

GOAL:

Provide evidence on the performance and effectiveness and the cost-effectiveness of climate services in saving lives and reducing climate-related health risks.

COMMON REASONS TO EVALUATE

An evaluation commonly assesses three aspects of a given climate service:

- **performance** of the products and services (such as their credibility, availability, reliability, usability, usefulness, suitability, responsiveness, sustainability and accessibility);
- **effectiveness** to have positive health impacts (such as its value to save lives and improve health outcomes);
- **cost-effectiveness** of the service in comparison to other alternative tools.

Other factors related to the process undertaken and the adequacy of the enabling environment or capacity are also frequently measured, including community perceptions, institutional capacity, partnership efficacy, and ethical dilemmas encountered.

STEP 6: EVALUATIONS

COMMON APPROACHES

Evaluation approaches for climate products and services are often adapted from those used in public health to measure health system performance or the efficacy of health interventions.

Important **outcomes and impacts** to evaluate include:

- increase in community protective behaviours;
- increase in human and institutional capacity;
- improvement in health service delivery;
- lives-saved;
- cost-effectiveness;
- improvements in timeliness, accuracy and credibility of decision-making;
- climate and health data availability at an adequate spatial and temporal scale;
- climate service usability (user-friendliness);
- climate service sustainability.



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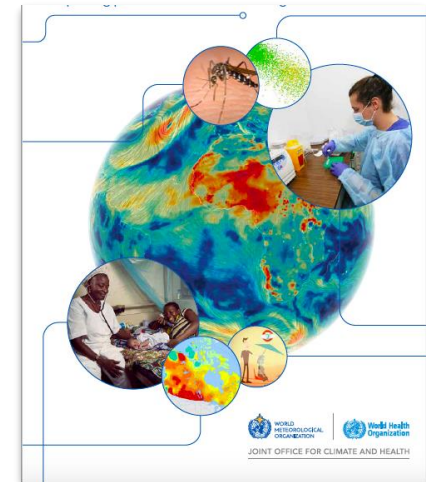
STEP 6: EVALUATIONS

CASE STUDIES

of climate services for health
evaluation approaches

EXAMPLE EVALUATIONS OF CLIMATE SERVICES

1. Building evidence that **effective heat alert systems** save lives in southeast Australia
2. Finding the right **thresholds to trigger action** in heat wave early warning systems in Spain
3. Looking back: Documenting **lessons learned** from a climate and health project in Ethiopia
4. How to reach **vulnerable populations**? Evaluation of UV index, heat warning system, air-borne pollen, and ozone forecasts in Germany



WHO/WMO (2018), *Climate Services for Health: Fundamentals and case studies*.