Chapter 2
Climate Variability and Change Data and Information for Global Public Health

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Abstract Using climate data correctly is a critically important challenge that underpins robust science and decision making about the health effects of climate change. Researchers in this interdisciplinary field must be informed enough to ask the right questions, to find and understand the right data that ultimately provide scientifically sound information to help people make the right decision. This requires active recognition of the need to really understand the caveats and best uses of a particular dataset or product. Some more widely used data and products such as those developed for the Intergovernmental Panel on Climate Change may have well-defined tutorials and use parameters. In most cases, however, it is wiser to find the owner or originator of the data, and work with them to ensure appropriate use of the data and therefore robust scientific findings that inform decisions and move this interdisciplinary field forward in both science and policy contexts.

Keywords Climate variability and health • Climate and Health • Global public health • Health consequences of climate variability • Climate data • Global Ocean Observing System • National Oceanic and Atmospheric Administration

One of the great challenges in understanding the health consequences of climate variability and change is the paucity of temporally and spatially compatible data to underpin evidence-based scientifically sound knowledge and action. Robust results

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require data from many different disciplines, ranging from medical, epidemiology, social science, environment, oceanography, to climate. Within each of those disciplines, there is yet greater granularity, variability, and quality of data. The key is to have a well-defined problem, ask the right questions to identify the most appropriate data, and find out as much as you can about the data, preferably by reaching the person who owns, collected, or processed the data, and at the very least the metadata manager. This level of data familiarity is critical to continually improve the quality of research in this field, and support greater knowledge about health consequences and adaptation options. Too often those in a specific discipline think their data are the most complex or difficult and will think it straightforward to simply download or use data from another discipline, do their analysis, and publish the results without a clear understanding of the data and its limitations. The reality is that most datasets are complex and have significant strengths and weaknesses. Knowing how and when to use them appropriately is critical. Otherwise, the result is often erroneous conclusions about causality, or mechanism, which fundamentally detracts from the scientific rigor that underpins this interdisciplinary community.

Climate Data

This chapter is designed to provide a common understanding of climate terminology, climate data, and to highlight the major, long-standing data and modeling centers through which climate data and models are available. Even within the climate and weather community there is often not consensus about the definitions that follow. This chapter is intended to provide general guidelines and definitions that harmonize terminology across the physical and biological sciences to facilitate more fruitful interactions.

Data Cultures

Just as epidemiology is the study of patterns of disease in a specific population at a specific location over a specific period of time; person, place, and time, climatology is somewhat similar in concept, but differs greatly in approach. One of the biggest differences–and opportunities–between the climate and health communities is the approach to data—volume, scale, scope, frequency, continuity, and treatment. The climate community has a culture of voluminous data collection through targeted and sustained in situ, space-based and airborne platform observations, data management, archiving, reanalysis, and creating modeled datasets. Data management is a highly respectable career; Entire highly respectable careers are spent on data management. International cooperation is built around data sharing (see GEO). Supercomputer power is critical to manage and model it. In contrast, health data tend to be event and illness specific, often without continuous collection over long time periods that establish to baseline conditions, and usually without any geo-referenced environmental parameters. Actual health outcome data may even be more sparse, or due to privacy

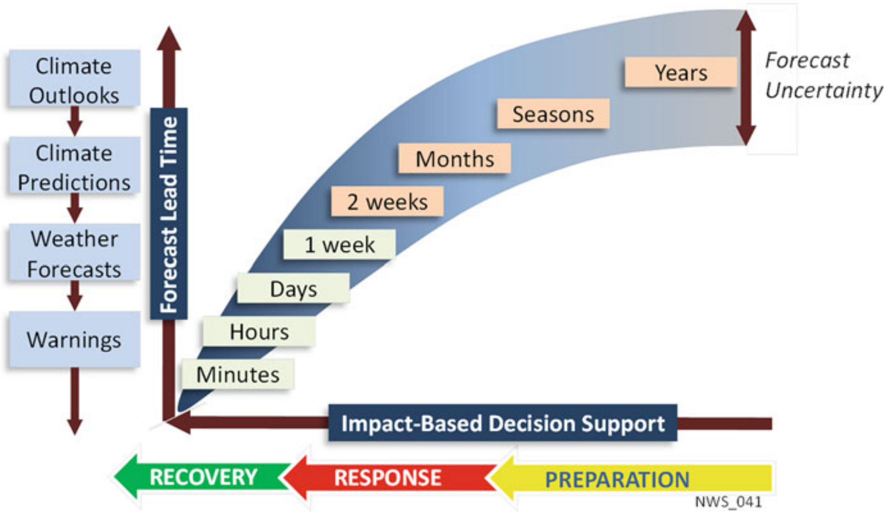

Fig. 2.1 NOAA seamless suite of forecasts (Courtesy of National Oceanic and Atmospheric Administration, www.noaa.gov/)

issues, unavailable at all. Multidisciplinary collaboration will require each of us to learn from the other to improve data collection, access and ultimately the public health usefulness, let's learn from each other and together tackle this data disconnect.

Defining Terms

Understanding and using the correct terminology will greatly facilitate communication across disciplines, the development of a robust problem statement, and identification of appropriate data to use in answering that problem. Climate is a continuum encompassing short-term weather to seasonal, decadal, and long-term changes in the climate system. On top of this is layered the operative functional capacity, i.e., forecast, early warning, prediction, and scenario, with each having associated levels of uncertainty based on the lead time and model error. To really understand the complexity inherent in these coupled human and natural systems requires the consideration of other social and economic factors. Figure 2.1 provides an overview of the relationship between time scale and uncertainty.

Weather is the day-to-day state of the atmosphere, at a specific place and time, and its short-term (minutes to days) variation. Weather is described as the combination of temperature, humidity, precipitation, cloudiness, visibility, and wind speed and direction. We talk about the weather in terms of "What will it be like today?" "How hot is it right now?" and "When will that storm hit our section of the country?" [1].

Climate is the slowly varying aspect of the atmosphere-hydrosphere-land surface system, defined as statistical weather information that describes the variation of weather at a given place for a specified interval. It is typically characterized in terms of averages of specific states of the atmosphere, ocean, and land, including variables such as temperature (land, ocean, and atmosphere), salinity (oceans), soil moisture (land), wind speed and direction (atmosphere), and current strength and direction (oceans). In popular usage, it represents the synthesis of weather; more formally it is the weather of a locality averaged over some period (usually 30 years) plus statistics of weather extremes [2].

Local or regional climate is in terms of the averages of weather elements, such as temperature and precipitation, derived from observations taken over a span of many years. In this empirically based context, climate is defined as weather (the state of the atmosphere) at some locality averaged over a specified time interval. Climate must be specified for a particular place and period because, like weather, climate varies both spatially and temporally [3].

In the most general sense, the term *climate variability* denotes the inherent characteristic of climate which manifests itself in changes on seasonal, interannual, decadal and multidecadal time scales. These climate variability phenomena which affect weather includes regimes such as the El Nino-Southern Oscillation (ENSO), Madden-Jullien Oscillation (MJO), Atlantic Oscillation (AO), North Atlantic Oscillation (NAO), Pacific North American Oscillation (PNA). A suite of weather and climate forecast products can be found at http://www.cpc.ncep.noaa.gov/products/forecasts/. The degree of climate variability can be described by the differences between long-term statistics of meteorological elements calculated for different periods. The term *climate variability* is often used to denote deviations of climate statistics over a given period of time (such as a specific month, season, or year) from the long-term climate statistics relating to the corresponding calendar period. In this sense, climate variability is measured by those deviations, which are usually termed anomalies [4].

Climate change is a change in the statistical distribution of weather over periods of time that range from decades to millions of years [5]. Climate change is expressed in terms of years, decades, or even centuries—but its impacts can be felt in the present. Scientists study climate to look for trends or cycles of variability (such as the changes in wind patterns, ocean surface temperatures, and precipitation over the equatorial Pacific that result in El Niño and La Niña) and also to place cycles or other phenomena into the bigger picture of possible longer term climate changes [2]. Epidemiologists too look for trends or cycles of disease incidence or patterns of outbreak.

Global warming is the gradual increase in the average temperatures of Earth's near-surface air and oceans since the mid-twentieth century and its projected continuation [5].

Early Warning, Outlook, Prediction, Forecast, Projection, and Scenario

In addition to the basic definitions, the application of those terms to a suite of predictive tools across time scales warrants similar clarification.

Early warning can mean basic monitoring, forecasts, or predictions that provide advance notice to decision makers that allow preventive action to take place. This can cross time scales ranging from tornado warning a to a risk map of potential pathogenic vibrio affecting shellfish, or using an El Nino forecast to help manage malaria risk (see figure XXX Malaria Early Warning System).

Outlooks are typically on of for one to thirteen months in the future. Extended range outlooks for 6-10 and 8-14 days also exist for degree days, drought, and soil moisture. (cite http://www.cpc.ncep.noaa.gov/products/forecasts/) weeks to monthly to seasonal time scales.

Climate prediction is generally intraseasonal to seasonal to interannual. A *prediction* is a probabilistic statement that something will happen in the future based on what is known today and is most influenced by the initial, or current, conditions. A prediction generally assumes that future changes in related conditions will not have a significant influence. For example, a weather prediction indicating whether tomorrow will be clear or stormy is based on the state of the atmosphere today (and in the recent past) and not on unpredictable changes in "boundary conditions" such as how ocean temperatures or even society may change between today and tomorrow. For decision makers, a prediction is a statement about an event that is likely to occur no matter what they do [6].

Climate predictions are usually expressed in probabilistic terms (e.g., probability of warmer or wetter than average conditions) for periods such as weeks, months, or seasons. A prediction is a probabilistic statement of something that could happen in the future based only on what is known today. Climate *projections* are long-range predictions of the future climate based on changing atmospheric conditions, such as increased or decreased pollutants due to emissions from the burning of fossil fuels (coal, oil, gas) [7].

Forecasts are typically on weather time scales (daily and out 7–10 days). In cases of extreme weather events such as hurricanes or tornados, the forecasts can be less than hourly with frequent updates. Related to a prediction is a *forecast*, which I would suggest is a best prediction made by a particular person or with a particular technique or representation of current conditions. An example of a forecast is a statement by a weather forecaster that it will rain at 3:30 PM tomorrow—that is, that individual's best judgment, perhaps drawn from a prediction that there is a 70 % chance of rain tomorrow afternoon. For a decision maker, the credibility of the forecast depends critically on the credibility of the forecaster (or forecasting technique) as well as on the inevitability of the event. The recent development of "ensemble forecasts" (i.e., assembly of a set of forecasts that are each based on a separate technique or set of initial conditions) can be considered a step toward transforming forecasts into predictions.

Climate projections are generally decadal to centennial. In contrast to a prediction, a *projection* specifically allows for significant changes in the set of "boundary conditions" that might influence the prediction, creating "if this, then that" types of statements. Thus, a *projection is a probabilistic statement that it is possible that something will happen in the future if certain conditions develop*. The set of boundary conditions that is used in conjunction with making a projection is often called a scenario, and each scenario is based on assumptions about how the future will develop. For example, the IPCC recently *projected* a range of possible temperature changes that would likely occur for a range of plausible emissions scenarios and a range of model-derived estimates of climate sensitivity (the temperature change that would result from a CO_2 doubling). This is clearly a projection of what *could* happen *if* certain assumed conditions prevailed in the future—it is neither a prediction nor a forecast of what will happen independent of future conditions. For a decision maker, a projection is an indication of a possibility and normally of one that could be influenced by the actions of the decision maker [6].

A *scenario* is a coherent, internally consistent, and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold. A projection may serve as the raw material for a scenario, but scenarios often require additional information (e.g., about baseline conditions). A set of scenarios is often adopted to reflect, to the extent possible, the range of uncertainty in projections. For instance, the Intergovernmental Panel on Climate Change will run several scenarios with different boundary conditions such as emissions and economic growth rates. Other terms that have been used as synonyms for scenario are "characterization," "storyline," and "construction."

Scenarios are best thought of as "plausible alternative futures—each an example of what might happen under particular assumptions"; scenarios are not predictions or forecasts because they depend on assumed changes in key boundary conditions (like emissions) and scenarios are not fully projections of what is likely to happen because they have considered only a limited set of possible future boundary conditions (e.g., emissions scenarios). For the decision maker, scenarios provide an indication of possibilities, but not definitive probabilities. For instance, the Intergovernmental Panel on Climate Change will run several scenarios with different boundary conditions such as emissions and economic growth rates [8]. In a public health context, a scenario may be an attempt to simulate a certain event or decision-making exercise, which is very different from how scenario is used in the climate context.

How to Think About Climate Data: or When to Use What

Climate data are comprised of many different types, scales, and resolution of data, derived from multiple sources (satellite or in situ) and made available through a number of products and service modes.

Scale

Climate data can be global, regional, or local in scale and is comprised of oceanic, atmospheric, and terrestrial data. Within that are mostly physical parameters such as precipitation, temperature (atmospheric and oceanic), sea level, waves, and winds. While collected separately, the data streams can be part of the same satellite or field collection effort. The different data streams are then combined to make climate data products and models. Scale is largely dependent on the means by which the data are collected (satellite or in situ observations), the area of coverage, and density of collection sites for in situ observations or grid size for satellites.

Source

Data are collected or provided from multiple sources: satellite or space-based sensors, airborned platforms, in situ, modeled, reanalyzed, and projections. Satellites provide periodic but global coverage from polar orbital satellites or consistent coverage over specific parts of the globe through geostationary satellites. Polar orbital satellites provide total earth coverage but will measure the same place twice each day at the same local time, every 12 hours, as part of their low earth orbit (approximately 500 miles altitude) moving from North Pole to South Pole. Because of their lower altitude, polar orbital satellites can use microwave radiometers which allows them to measure through clouds to sense precipitation, temperature in different layers of the atmosphere, and surface characteristics like ocean surface winds. Geostationary satellites are fixed high above the equator (approximately 22,000 miles altitude) providing continuous coverage of the same area, but the resolution is generally 1 km at best, and coverage is not global. In general, for climate and weather purposes, the National Aeronautics and Space Administration (NASA) launches research satellites mostly in polar orbital and in lower earth orbit. The National Oceanic and Atmospheric Administration (NOAA) operates the satellites needed for weather and climate predictions which include geostationary satellites.

In situ data are collected from ground, water-based, or airborne instruments and sensors. Availability varies by country, both in temporal and spatial coverage, and access. The quality varies according to the instrumentation and human skill in collection and recording. Metadata may or may not be available, and upkeep, updates, and archiving are problematic for many countries. In situ data are useful alone, can be combined with other data into more comprehensive products, and can be used to validate and enhance satellite data. The networks and instruments for in situ data collection vary widely and include everything from permanent weather stations, to tide gauges, to drifting buoys in the ocean and ships of convenience, to the atmospheric radiation, temperature and carbon dioxide measurements at Mauna Loa Observatory in Hawaii which has tracked CO2 since the 1950s.

Products

Data can also be processed into products such as sea surface temperature (SST), SST anomalies (commonly depicted during El Niño and La Niña events), vegetation indices, and sea ice (see http://www.realclimate.org/index.php/data-sources/ for additional products). A suite of climate and weather forecast products can be found at http://www.cpc.ncep.noaa.gov/products/forecasts/. One of the most well-known

Table 2.1 Global Ocean Observing System (GOOS) in situ measurements

3,000 Argo floats collect high-quality temperature and salinity profiles from the upper 2,000 m of the ice-free global ocean and currents from intermediate depths
1,250 drifting buoys record the currents of surface, the temperature, and the atmospheric pressure
350 embarked systems on commercial or cruising yachts which collect the temperature, salinity, the oxygen and the carbon dioxide (CO_2) in the ocean and the atmosphere, and the atmospheric pressure
100 research vessels measure all the physical, chemical, and biological parameters, between the surface of the sea and the ocean floors every 30 nautical miles out of 25 transoceanic lines
200 marigraphs and holographs which transmit information in quasi real time, thus providing the possibility of detecting tsunamis
50 commercial ships which launch probes measuring the temperature and salinity between the surface and the ocean floor on their transoceanic ways
200 moorings in open sea which are used as long-term observatories, recording weather, chemical, and biological parameters on a fixed site between the surface and the bottom

datasets is the Global Historical Climatology Network (GHCN) dataset, which is a global, daily in situ dataset derived from multiple sources, approximately 25,000 temperature stations, 44,000 precipitation stations, and 25,000 snowfall or snow depth stations, and currently ingests more than 1.6 billion daily observations with the earliest value from January 2, 1833 and the latest value from yesterday.

The scientific community has established three global networks for terrestrial, oceanographic, and climate data. The Global Ocean Observing System (GOOS) is a permanent global system for observations, modeling, and analysis of marine and ocean variables to support operational ocean services worldwide (Table 2.1). GOOS is comprised of a network of ocean-based observations and satellite observations and together with the Global Climate Observing System (GCOS), and the Global Terrestrial Observing System (GTOS) comprise a global network of monitoring to understand and predict climate, among other things.

Reanalysis

In order to create consistent and comparable global datasets, major efforts are made by the climate community to create reanalysis datasets. These are weather models which have the real-world observations assimilated into the solution to provide a "best guess" of the evolution of weather over time (although pre-satellite era estimates before 1979 are less accurate). The newest as of this writing is the NCEP/NCAR reanalysis with 6-h, daily, and monthly data available [9].

Projections

Data are also generated through climate projections and scenarios. A climate projection is a model-derived estimate of the future and the pathway leading to it. When the certainty around a projection is determined, with levels of certainty assigned such as 'most likely', the projection can become a forecast or prediction.

A forecast is often obtained using deterministic models, possibly a set of these, outputs of which can enable some level of confidence to be attached to projections. General Circulation Models (GCMs) are numerical models that represent the physical processes in the atmosphere, ocean, cryosphere, and land surface are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. While simpler models have also been used to provide globally or regionally averaged estimates of the climate response, only GCMs, possibly in conjunction with nested regional models, have the potential to provide geographically and physically consistent estimates of regional climate change which are required in impact analysis; GCMs depict the climate using a three-dimensional grid over the globe typically having a horizontal resolution of between 250 and 600 km, 10–20 vertical layers in the atmosphere, and sometimes as many as 30 layers in the oceans. Many physical processes and feedback mechanisms such water vapor and warming, or clouds and radiation, occur at smaller scales and cannot be properly modeled. Instead, their known properties must be averaged over the larger scale in a technique known as parameterization, which are sources of uncertainty in GCM-based simulations of future climate.

Assessing Climate Data Partners

NOAA not only houses much of the climate, weather, and ocean data for the United States but also serves as the main repository for the World Meteorological Organization and other international bodies. In the United States there is a three-tiered climate services support program. The partners of this program include NOAA's National Climatic Data Center (NCDC—http://www.ncdc.noaa.gov/), six Regional Climate Centers (RCCs—http://www.ncdc.noaa.gov/oa/climate/regionalclimatecenters.html), and individual State Climate Offices (SCO—http://www.stateclimate.org/). NCDC is the world's largest active archive of weather data with over 150 years of in situ, radar, and satellite data available for use in a wide variety of applications. The RCCs are a federal-state cooperative effort that is managed by NCDC. The RCCs are engaged in the timely production and delivery of useful climate data, information, and knowledge for decision makers and other users at the local, state, and national level. The RCCs support NOAA's efforts to provide operational climate services while leveraging improvements in technology and collaborations with partners to expand quality data dissemination capabilities. State Climatologists have the best understanding of the climate of their state and the ability and knowledge to provide climate data and information to local users. Additional NOAA climate partners include the National Weather Service Climate Services Division (http://www.nws.noaa.gov/os/csd/index.php), the Climate Prediction Center (http://www.cpc.ncep.noaa.gov/), the Climate Diagnostics Center (http://cires.colorado.edu/science/centers/cdc/), the Climate Program Office (http://www.climate.noaa.gov/), and six Regional Climate Service Directors that are located at the NWS Regional Headquarters.

Some applications require data and information for areas outside of the United States. While the agencies mentioned above focus primarily at the national, regional, and local level, some do participate in international activities as well. For example, NCDC operates a World Data Center for Meteorology (http://www.ncdc.noaa.gov/oa/wdc/index.php) and a World Data Center for Paleoclimatology. The World Data Centers are part of a global network of discipline subcenters that facilitate international exchange of scientific data. The World Meteorological Organization also maintains a list of member National Meteorological or Hydrometeorological Services (http://www.wmo.int/pages/members/members_en.html) in which users can go directly to the country of interest in order to obtain weather and climate data and information for their application.

Global Observing Systems Information Center is a one-stop shop for the GOOS, GCOS, and GTOS (http://gosic.org/goos).

Conclusion

In summary, climate data comes from multiple sources, can be observed data or modeled, covers time scales from weeks, to decades to centuries, and can provide a powerful tool for enhanced decision making. Researchers in this interdisciplinary field must be well-versed enough to ask the right questions that lead them to find and understand the right data, and which ultimately to provide scientifically sound information to help people make the right decision. This requires active recognition of the need to really understand the caveats and best uses of a particular dataset or product. In general, while some more widely used data and products such as those developed for the Intergovernmental Panel on Climate Change may have well-defined tutorials and use parameters, in general it is wiser to find the owner or originator of the data and work with them to ensure appropriate use of the data and therefore robust scientific findings that both inform decisions and move this interdisciplinary field forward in both science and policy contexts.

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