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Needs Assessment for Climate Information on Decadal Timescales and Longer

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Abstract

Societal needs for climate information on decadal timescales is confirmed in terms of its potential value and relevance as a driver in sector decision-making, but such information is currently lacking. Predictions and observationally based analyses for decadal climate variability and change are needed. In addition, the following issues have been identified as those that must be addressed in order to facilitate effective use of climate information on decadal timescales in the decision-making processes of different socio-economic sectors: building effective partnership systems linking stakeholders, users and decision-making sectors and climate information providers; more research and investment is to translate information of large-scale decadal variations into the regional and local scales required for decisions; maintaining and sustaining the Global Climate Observing System (GCOS), in particular, enhancement of the global ocean observing system; and, ways to assemble, check quality, reprocess and reanalyse datasets relevant to decadal prediction. Ways of securing climate observing systems particularly in least developed regions are urgently needed.

Keywords: Agriculture and food production; water management; energy; marine fisheries and ecosystems; land degradation and fire management; health

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1. Introduction

Improvement in our ability to assess the impacts of variations and future changes in climate is crucial. It would enable governments, communities and businesses to determine strategies to reduce potential negative impacts and to take advantage of opportunities by adapting infrastructure, activities and plans. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report confirmed that global warming is unequivocally happening and that these changes are due to anthropogenic causes [1]. Nevertheless, there is considerable regional variation in the upward trend of temperature and the issue about how much of the regional climate changes is attributable to natural variations and how much is due to anthropogenic activities has not yet been resolved [2].

During recent decades there has been considerable effort in trying to understand the decadal variability of the climate system. In particular, the Pacific decadal variability (PDV) and its possible impacts on regional and global climate has been the subject of much research (for example, Mantua et al. [3]; Trenberth and Hurrell [4]; Deser et al. [5]). Century-long reconstructions of sea-surface temperature (SST) and sea-level pressure suggest that several ''regime shifts'' associated with PDV have occurred during the twentieth century particularly around 1925, 1947, 1976 and perhaps recently in the mid-1990s. Decadal to inter-decadal variability in the atmospheric circulation is especially prominent in the North Pacific (for example, Trenberth and Hurrell [4]) where fluctuations in the strength of the wintertime Aleutian low pressure system co-vary with North Pacific SST in what has been termed the Pacific Decadal Oscillation or PDO (for example, Mantua et al.[3]). Very similar timescale fluctuations in SST and atmospheric and ocean circulation are present across the whole Pacific Basin, known as the Inter-decadal Pacific Oscillation (for example, Power et al.[6]). Moreover, PDV may consist of more than one mode of variability, including a dominant one in the tropical Pacific, which is called the decadal ENSO-like variability (for example, Zhang et al.[7]) and is associated with decadal periods of 20–30 years in the tropical Pacific Basin. It is widely accepted that PDV influences climate anomalies over North and South America, Australia and Europe as well as the El Niño–Southern Oscillation (ENSO) period and strength (for example, Latif and Barnett [8]; Mantua et al. [3]; Power et al.[6]).

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The North Atlantic Oscillation (NAO) is characterized by a seesaw in surface pressure, with coherent changes over the high and m
latitudes, and has been clearly linked to surface temperature and precipitation variations over Europe and North America [9]. Variations
the NAO have been in particular associated with air–sea interaction on decadal and multidecadal timescales [10]. Large multideca
variations in sea-surface temperature of the Atlantic sector have been related to precipitation anomalies in North-east Brazil [11], Afric
Sahel (for example, Folland et al.[12]), North American and European summer climate (for example, Enfield et al.[13]), the formation
major Atlantic hurricanes (for example, Molinari and Mestas-Nuñez [14]) and sea ice concentration in the Greenland Sea [15]. These S
variations have a global component [16] and a distinctive Atlantic component called the "Atlantic Multidecadal Oscillation" (AMO) (
example, Knight et al.[17]). A warm AMO phase occurred in the 1930s through the 1950s and was associated with decreased rainfall
North-east Brazil and the United States, as well as enhanced Sahel rainfall and hurricane formation. Conversely, cool AMO phase
occurred in the 1900s through the 1920s and the 1960s through the 1980s, the last period particularly associated with high rainfall
North-east Brazil and the United States, while Sahel rainfall and Atlantic hurricane formation were reduced.

The interest in climate predictions out to a few decades has become a compelling issue that emerged from the IPCC Fourth Assessm
Report in 2007. This is a time frame of interest for many decision support activities and impacts, but is not explicitly delivered by curr
climate change projections and experiments. However, evidence of observed decadal variability briefly described above makes clear t
the anthropogenic climate change signal at the regional level can be strongly modulated by natural climate variations, particularly tho
driven by the decadal or multidecadal oceanic variability [2]. An example of how year-to-year variability combines with slower chang
on inter-decadal timescales, which then rides on top of the man-made climate change signal is given in Figure 1 for a regi
encompassing the state of Colorado in the United States. Evident in the decadal record of precipitation, the Dustbowl (in the 1930s) a
the Great Plains drought (in the 1950s) were historical droughts with huge impacts that were associated with particular phasing of t
AMO and PDO. Therefore, finding ways to account for the decadal and multidecadal variations through initialized climate predictio
may provide society with much better information on what kind of climate change to expect [18].
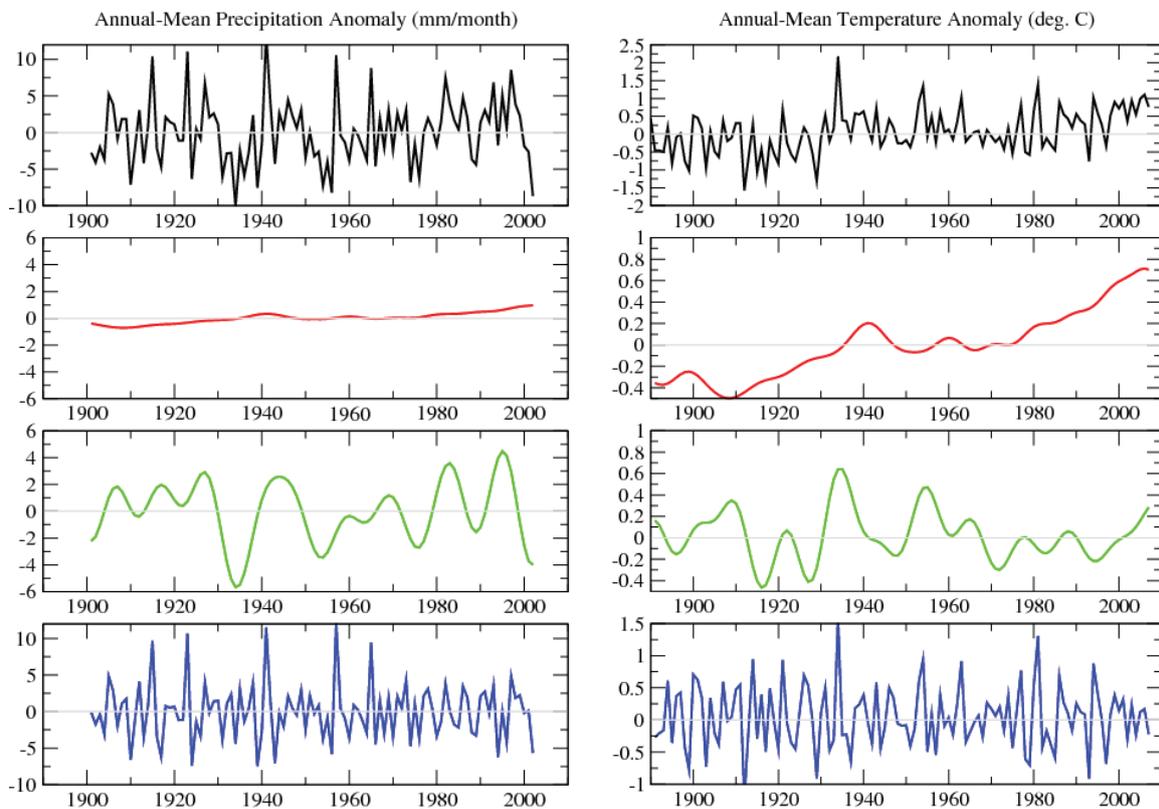
Figure 1. Signals of climate variability and change for temperature (left) and precipitation (right) anomalies computed in a box over
the state of Colorado in the United States (Courtesy of Goddard and Greene, IRI, United States)
From top to bottom: annual mean anomalies, climate change signal, filtered anomalies on decadal timescales, and filtered anomalies
interannual timescales.

The observational studies of climate variability on decadal and longer timescales are significantly limited by the lack of adequate d
for many regions. Thus, there has been a heavy reliance on models, but observations are also necessary to validate models. Furthermo
models do not always agree with each other or with observations and thus, while models have been helpful in identifying possi
mechanisms, the true mechanisms behind decadal variability patterns are still not fully known [19].

Coupled ocean–atmosphere predictions of ENSO and other seasonal variations depend critically on observations to initialize t
models with the observed state. But projections of climate change, such as those used in the IPCC Fourth Assessment Report, have
been initialized with observations and have been regarded as a "forced" problem that is dominated by changes associated with those

radiative forcing. Decadal prediction falls between these initial value and boundary value problems, and capitalizes on both for presum
skill. Part of the expected skill comes simply from the inertia in the climate system owing especially to the future commitment to char
as the climate adjusts to radiative forcing already in place. It is evident, therefore, that decadal variability falls between and overlaps r
only with the long-term climate change signal but also with interannual variability. Many of the applications of decadal prediction rely
and confront this overlap [20].

Over the last 20 years there have been important developments in the prediction of climate variability on seasonal scales, and curren
many centres around the world routinely make seasonal forecasts. In contrast, decadal to multidecadal climate predictions are at an ea
stage of development (discussed in the companion paper by Murphy et al.[21]). As with seasonal forecasting, the value of decadal
multidecadal climate predictions lies in their credibility, availability and relevance to planning the future in all fields that depend
climate to some degree. But unlike seasonal forecasting, the relevant periods are longer than a single political reign, and anthropoger
forcing becomes a key component [19].

2. Sector-based assessments

The need for climate information on decadal timescales is assessed here for a set of different socio-economic sectors for which
climate sensitivity and vulnerability has been identified as high. The section obviously does not encompass all of the issues for all of
the socio-economic sectors that might be influenced by decadal climate variability. Nevertheless, the set of selected sectors provides
excellent examples that allow the identification of gaps in the data and information of decadal variability currently available, and the
limitations in the dissemination and use of current information. As a result they provide us with strategies to address these issues.

2.1 Agriculture and food production

Climate variability and change has already impacted and will further impact the agriculture sector and food production. It is clear
that sensitivity to climate as well as several to other driving forces, especially from the economic and societal domains, will
determine the future evolution of the sector. But climate influence must be taken into account as a first-order factor in the context of
the enormous challenge of providing food for about 8 billion people by 2100 compared to about 6 billion today.

Assessments of climate influence on crop functionality should consider stimulation of photosynthesis by the elevation of CO_2
atmospheric concentration as it can induce crop increments particularly for temperate species such as wheat, rice and soybeans [22].
In addition, the direct influence of climate variations on crop function evidently involves temperature, the effects of which may be
quite variable. Higher temperatures are generally favourable for growth in cold and temperate climates (except in extreme events)
and generally unfavourable for warm areas. Further warming has increasingly negative impacts in all regions. On the other hand,
rainfall variability seriously modulates the potential changes in plant growth resulting from the effects of increasing temperatures.
Tendencies towards drier conditions in some areas such as the Mediterranean basin or the south of Africa may cancel, at least
partially, the positive potential impact due to higher CO_2 or milder temperatures. Such combined climate influence leads to a variety
of contrasted effects on crop production, depending upon the type, the geographical zone and the level of adaptation. Regarding
livestock, Easterling et al [22] indicate thermal stress is known to reduce productivity and conception rate, and can be potentially life
threatening for livestock. Additionally, the increased climate variability, especially the increased occurrence of droughts, may lead to
serious losses. Severe droughts adversely affect pasture production, with large-scale losses of 50 per cent and more, far larger than
those of cereals.

Recently available assessment studies have targeted the end of the twenty-first century, which is important for assessing the
resulting impacts from different warming scenarios. However, the necessary adaptation, at least from the technical point of view,
occurs on a shorter timescale (typically about 10 years for annual crops or pastures, and 20–30 years for perennial crops like fruit
trees or vines). Such technical decisions considered at annual-to-decadal time horizons include choice of varieties, cultural practices,
pests and diseases. Also important are the impacts due to the occurrences of extreme climate events. These include hail (generally not
considered in climate change predictions, but responsible for large losses at local scales), droughts (both over short and long terms)
and, in the context of global warming, the risk of heatwaves [23]. Moreover, storms, violent winds or floods may severely impact
agriculture.

Improving the expected quality of the climate information needed by the sector relies on (a) better accuracy on the predictions
concerning variables other than temperature, especially rainfall, but also air humidity and solar radiation; (b) spatial downscaling to
furnish climatic variables at a resolution between 20 to 50 km; and (c) climate prediction in terms of probability allowing
quantification of a range of impacts, variable by variable.

2.2 Water management

Climate variability and change affects the function and operation of existing water infrastructure, including hydropower,
structural defences, drainage and irrigation systems as well as water management practices. In most parts of the world, current water
management practices may not be robust enough to cope with the impacts of climate variability and change. Observational records
and climate simulations provide strong evidence that freshwater resources are vulnerable and will be strongly impacted by climate
change, land use and land change and deforestation. Observed global warming over several decades has been linked to changes in the
large-scale hydrological cycle, including increasing atmospheric water vapour content; changing precipitation patterns, intensity and
extremes; reduced snow cover and widespread melting of ice; and changes in soil moisture and runoff [24]. As a result, during the
twenty-first century water availability is currently – and will be increasingly – dependent on a combination of both natural hydro-
climatic variability and anthropogenic-influenced climate change. Thus, a detailed understanding, monitoring, modelling and
prediction of the hydro-climatic variability, in particular at inter-decadal and decadal timescales, are essential for water resource
management.

Climate predictions several seasons in advance are currently making progress in narrowing the uncertainty in hydrologic

predictions for water resource management, natural hazard mitigation, and related decision-making and policy guidance. This has been possible particularly for river basins with high sensitivity to climate variations associated with large-scale ocean–atmospheric phenomena such as ENSO. The fact that the hydrologic variability associated with many of those basins (like those along the Americas and Australia) also seems to be related to decadal large-scale patterns like NAO and PDO confirms the need for decadal predictions in management planning. However, there is evidence that the use of climate information from seasonal prediction systems and climate change projections is often made by different water related sectors in different regions, with varying degrees of effectiveness. The quantities that climate models correctly predict are not necessarily the quantities needed by decision-makers for managing water resources or mitigating natural hazards. There is a need for forecasts to be issued probabilistically so that uncertainty estimates accompany the climate–hydrologic model outputs in order to provide better information for decision-making and management of risk. Methods for translating uncertain climate information to products useful for sector decision-making are in their infancy and much research is needed to advance them. A current barrier to effectively integrating the output from large-scale climate models in hydrology and water resource management is the lack of active collaboration among scientists in these various disciplines and between scientists and stakeholders. National and international opportunities for cross-disciplinary collaboration on important water resources and environmental management issues that are sensitive to climate variability need to be assured.

In addition, although observational data and data access are prerequisites for sector management, many observational networks are shrinking. The climate observing system particularly in least developed regions is poor and in some cases, such as in Africa, is deteriorating. Ways of securing climate observing systems and integrating climate information into water resource management are urgently needed.

2.3 Energy

The energy sector, as with other economic sectors, has been managing climate change and its consequences in its business plans with regard to medium-term energy demand planning and adaptation of the current operational facilities.

A key component in energy demand planning (1–5 years) is the prediction of a climate baseline. Until recently, this baseline, which is the representation of climatologically normal conditions for a certain area, was constructed from historical information of the last decades. But reliable estimates of near-future baseline conditions are urgent, and decadal predictions seem to be an appropriate tool to combine recent observations and possible future conditions. In addition to the average, information on the variability of parameters such as near-future changes on high or low percentile values are needed. Reliable information on key parameters such as temperature, precipitation, wind and radiation contribute to the planning of the cooling capacity for thermal power plants, and to the planning of renewable energy sources such as hydroelectric production, and wind or solar energy, all of which are becoming more and more important in the energy mix of all countries.

Regarding the needs for adaptation of current operational facilities, recent extreme events such as the 2003 heatwave in Europe have raised awareness that unprecedented temperature extremes can now be expected. The question is then: how frequently and how much more extreme? Currently, research efforts are being made in defining methodologies to estimate the characteristics of possible temperature extremes over the next decades, but these are based on trends in past observations or IPCC models and not on specific predictions of coming decades.

The sector also needs climate information for the coming decades at local spatial scales. Combinations of observations and projections through different downscaling methods have been used to service needs. However, methodologies will have to be designed to extract useful information from the decadal climate predictions and deliver it at the needed timescales. Another concern is how to improve the use of the probabilistic information given by such predictions. Many decision-makers are used to dealing with uncertainty (for example, in the case of having no forecasts), but they may not easily interpret probabilistic information in forecasts. Thus, closer collaboration between users and providers of climate information should address these issues and determine strategies that can lead to improvements in the energy sector applications and decision tools.

2.4 Marine fisheries and ecosystems

Climate variability on decadal and longer timescales has been identified as impacting marine ecosystems from the equator to the poles through changes in productivity, species distribution, recruitment, community structure and timing of biological events [25][26]. A particularly close link has been observed between biological processes and climate events, such as ENSO, and large-scale climate patterns, such as the PDO and NAO [26]. Some of the impacts of climate change will include loss of sea ice (impacting polar ecosystems), changes in freshwater systems (with impacts to fisheries such as salmon), increases in ocean acidification (resulting in reduced growth and survival of shellfish, corals and fish), changes in coastal upwelling (affecting the structure of plankton-based food webs), rising tropical and subtropical ocean temperatures (triggering coral bleaching) and sea-level rise (resulting in losses of coastal wetlands and loss of critical nesting and pupping habitats at oceanic islands) [25][27]. Given that marine ecosystems are capable of amplifying climate signals and respond non-linearly [28], the combination of natural patterns of climate variability and climate change will stress marine ecosystems in the future in ways not encountered before.

Predictions of future climate derived from General Circulation Models (GCMs) are already being used to estimate ecosystem impacts arising from climate change. Examples include: (a) modelled sea-level rise is used to forecast loss of terrestrial habitats for sea turtles, seabirds and monk seals at islands and atolls in the North-western Hawaiian Islands [29]; (b) GCM-derived outputs are used to drive ecosystem models to project changes in Pacific skipjack tuna habitat and the eastern tropical Pacific ecosystem [30][31] or changes in recruitment success in Atlantic cod [32]; and (c) a set of global biomes were derived from IPCC models and future projections of these variables were used to forecast how the area and productivity of these major biogeographic provinces would change due to global warming [33].

Reports on climate information needed for marine fisheries and ecosystems often produce a long list of physical variables (temperature, currents, winds, sea-level height, precipitation, mesoscale features including fronts and eddies, vertical stratification

and upwelling), chemical parameters (salinity, oxygen, nutrients and pH) and biological parameters (chlorophyll and primary production) on a range of spatial and temporal scales (including weekly and 10s of km in some instances). These requirements reflect an increased knowledge of the range of mechanisms through which climate impacts biological processes, both directly and indirectly [34].

The observation that marine ecosystems under intense exploitation evolve towards stronger bottom-up control and greater sensitivity to climate forcing [35], has highlighted the difficulty of disentangling external multiple forcing and internal ecosystem dynamics. As a result, ecosystem management objectives have become increasingly connected to climate impacts research through the ecosystem approach – a strategy for the integrated management of marine ecosystems' use, taking into account the biological responses to climate variability, climate change and climatic events, and the synergistic interactions with other stressors (eutrophication, fishing and pollution, for example). Achieving these management objectives will require coupled atmosphere–ocean–chemical models that provide future projections at higher spatial and temporal resolution than current models. The outputs of these climate models may be further downscaled by using their outputs to drive high-resolution ocean models and/or ecosystem models that match the geographical and temporal scale of biological response.

In addition, there is a need for a better conceptual understanding of how ocean dynamics will change in the future. For example, how will the frequency and intensity of ENSO, PDO, NAO and extreme events such as storms change, and at what point will the monotonic global warming impacts exceed decadal signals? Furthermore, with recent heightened awareness of the potential ecosystem impacts from ocean acidification, future projections of changes in ocean chemistry represent a critical need. In planning for the increased uncertainty associated with climate change, the use of past responses to climate variability and a more complete understanding of climate effects appear to be essential to develop robust and more responsive management systems of the marine ecosystem.

2.5 Land degradation and fire management

Besides the significant role of human activity, there are complex non-linear interactions between land degradation and fire that are driven by climate [36][37]. Currently the major concern for drylands is that they mostly encompass less developed countries that are home to a third of the global population, and thus they have the highest dependence on ecosystem services worldwide due to widespread poverty [38]. Complex socio-economic factors in addition to exposure to hazards make these regions highly vulnerable to climate-driven land degradation and fire processes.

Both long- and short-term climate variability influence land surface conditions in terms of topography, soil type and conditions and type and amount of vegetation cover, all of which are important factors in assessing the susceptibility of an area to land degradation. Extreme events such as floods and drought usually accelerate the land degradation processes. Climate also has an indirect role by influencing the type and intensity of land use practiced, and may eventually contribute to land degradation and fire. Frequent and more intense fires reduce the biomass supported in an area, affecting the productive soil layer and leading to soil erosion, change in species composition, general decline in biodiversity and eventually land degradation. In coastal areas excessive evapotranspiration due to drought, combined with fire and land use activity, may result in increased sea water infiltration and soil salinization. Sea-level rise due to climate change will also have a significant role in the degradation of coastal areas with far-reaching socio-economic consequences. A widespread increase in the areas under drought has been observed in the past decades affecting especially the Sahel, eastern Asia and Southern Africa, with these changes being linked to reported high numbers of fire incidents [39][40]. The IPCC Fourth Assessment Report further noted that the land area under drought at a global scale may increase by the 2090s from 10 per cent in the present day to 30 per cent for extreme drought and 50 per cent for moderate drought, with major implications for both fire and land degradation. In addition, changes in fire regimes due to climate change likely will extend susceptibility to land degradation in both humid-temperate and boreal zones [41][42].

The availability of information about near-future climate is thus an important requirement for an effective response by policymakers, practitioners and communities to the risks of land degradation and fire. Integrated approaches are required in land use and fire risk management, combining climate information with land-use information and topography. The climate information should include seasonal-to-interannual climate variability as well as decadal and longer-term signals. Regional fire monitoring systems that incorporate climate data should be established as part of fire early warning systems and monitoring of areas burned, and should be linked to land degradation studies. Factors that are essential to address land degradation and fire include dedicated observations of the climate system combined with improved applications of agrometeorological methods; more accurate climate prediction; promotion of capacity-building in the application of meteorological and hydrological data; and generation of information on drought and flood preparedness and management [43].

2.6 Health

Climate change is the major global health threat of the twenty-first century [44], heavily impacting on the poorest in the world, and therefore deepening inequities. According to Frumkin et al. [45], the potential health effects of climate change are associated with the following:

(a)   Heat (heat stress, cardiovascular failure);

(b)   Severe weather (injuries and fatalities);

(c)   Air pollution (asthma, cardiovascular disease);

(d)   Allergies;

(e)   Vector-borne diseases (malaria, dengue, leishmaniasis, yellow fever, hantavirus);

(f)   Waterborne diseases (cholera, leptospirosis);

(g)   Water and food supply health issues (malnutrition, diarrhoea, harmful algal blooms);

(h)   Mental health (anxiety, post-traumatic stress);

(i)   Environmental refugees (forced migration, civil conflict).

In particular, decadal variability is closely related to changes in temperature and rainfall, which in turn affect propagation of disease vectors [20]. There is ample evidence relating outbreaks of several waterborne diseases and vector-borne diseases, with the interannual variability, and particularly with that associated with ENSO. For instance, malaria outbreaks have been associated with ENSO in Pakistan [46], Venezuela [47] and Colombia (for example, Poveda et al.[48]), among other regions. In particular, the evolution of malaria incidence indices in Colombia (Figure 2) shows clear interannual variability (with malaria outbreaks during El Niño years), superposed with inter-decadal variability (characterized by a predominance of one particular malaria pathogen over the others since the mid-1970s) and a long-term increasing trend of malaria cases (Poveda et al.[48]). Furthermore, interannual variability significantly influences anomalous seasonal outbreaks of cholera (for example, Emch et al.[49]). In particular, ENSO is linked with cholera outbreaks in Peru [50], and Bangladesh [51]. Moreover, diverse combinations of both phases of ENSO and NAO have been linked with increased transmission of diverse diseases such as pneumococcal meningitis in Cuba [52]. The North Atlantic Oscillation has also been related with the annual incidence rate of 14 viral, bacterial and protozoan human diseases in the Czech Republic [53].
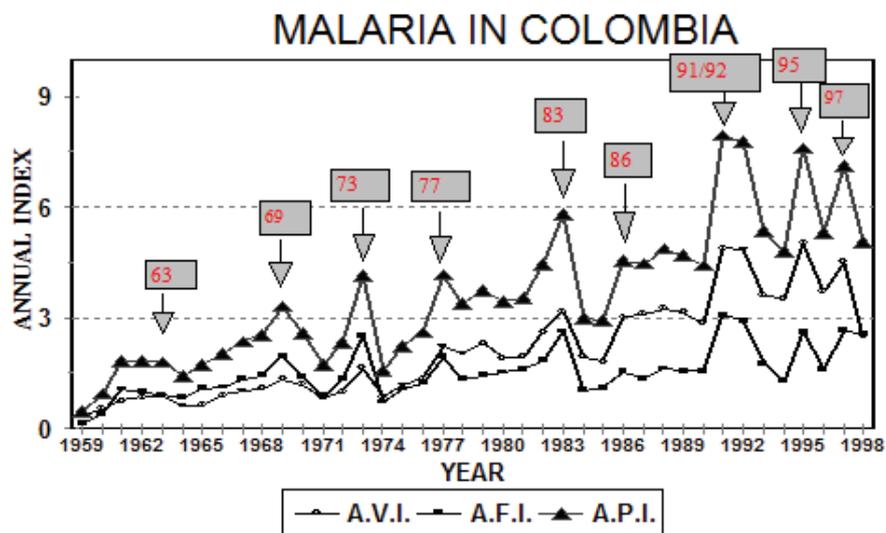
Figure 2. Evolution of malaria incidence indices in Colombia 1959–1998 (From Poveda et al. [48])

API is defined as the ratio between the number of cases reported and the population at risk per 10 000 inhabitants, computed as the total of cases of both *P. vivax* (A.V.I.) and *P. falciparum* (A.F.I.). Data reported by the Colombia Ministry of Health.

A public health approach to climate change, based on essential public health services, extending to both clinical and population health services and coordinating government agencies, academia, the private sector and nongovernmental organizations has been suggested [45]. In such an approach, scientific input is enhanced by the provision of climate predictions at long-term (annual to decadal to centennial) timescales. For example, the World Health Organization has proposed that malaria early warning systems that incorporate vulnerability assessment, seasonal climate forecasts, weather monitoring and case surveillance be developed for unstable areas in Africa [54]. The availability of climate information on decadal timescales would therefore enable the sector to set up early warning systems for diverse diseases, and to enhance disease treatments and develop prevention and mitigation plans.

Recent results show that skilful seasonal climate forecasts may provide early warning of changes of risk in epidemic-prone regions [55]. However, a key challenge has been the inability to predict when and where outbreaks will occur far enough in advance so that timely interventions can be implemented [56]. Advances in several areas could increase the sensitivity and specificity of early warning systems, including improving long-range forecasting, monitoring of environmental variables and case surveillance. Better understanding is needed of how to incorporate uncertainties when setting thresholds for early warning systems. In addition, in most areas where epidemic outbreaks occur, additional capacity is needed to effectively respond to a warning that an epidemic is predicted to occur.

2.7 Other sectors

Other sectors that can be identified as sensitive to climate variability and change, in particular at decadal timescales, include transportation, infrastructure and security.

As global surface temperature has increased over the past decades, so have the damages caused by extreme weather events. Therefore, if infrastructure vulnerability to climate-related events is currently a cause for concern, it will become even more so in the future. The current knowledge about climate variability and change and associated impacts on infrastructure is based on broad spatial analyses. Country and local level assessments are needed to aid policymakers in deciding the appropriate infrastructure mix in hazard-prone areas. Climate information for the near future should contribute to improved knowledge of specific infrastructure exposure to different types of climate events. Also, more accurate and quantified climate information for the next decades is needed to improve the reliability of the catastrophe models that are usually used to assess future damages from changes in the severity of future natural hazard events [57].

Climate variability and change affect decisions in every phase of the transportation management process: long-range planning and investment; project design and construction; management and operations of the infrastructure; and system evaluation. The current practice for public agencies is examining 20–30 years in the future to plan for transportation infrastructure. However, the analysis of how a changing climate might affect transportation is in its infancy and it requires an enhancement in the type of information that planners, engineers, operators and maintenance personnel consider to maintain a more robust and resilient transportation system, ultimately at lower cost. Better climate information is needed by transportation planners regarding changes in the likelihood and extent of extreme events, including temperature extremes, storms with associated surges and winds and precipitation events for the next decades at relatively high resolution [58].

In addition, there is an increasing realization of the important role climate change at decadal timescales can play with respect to national and global security, even though the subject is still in its infancy as a topic of study. The potential for more areas of land under drought, among other issues, raises the potential for large numbers of climate refugees with the associated political and societal stresses. Water security could become an increasing source of tension between nations, and possible increases in food prices as a result of failures in major crops could have major implications for the poorest countries and the poorest people within countries. Increasingly, links are even being drawn between climate stresses and global terrorism as large numbers of people are forced to move from their traditional lands, often spending extended periods of time in refugee camps, and hence becoming disenfranchised and disillusioned.

3. Data and information needs

From the discussion included in Section 2, it is evident that quantitative climate information on decadal timescales is needed to address management and planning issues of a wide range of socio-economic sectors for the near future. The effort to explicitly produce decadal predictions from dynamical models is extremely new (described in the companion white paper by Murphy et al.[21]). In particular, a coordinated effort will soon make available decadal predictions, which may be included in the Fifth Assessment Report of the IPCC [59]. However, these results will be experimental, and do not in themselves constitute forecasts for the coming decade(s). Decadal forecasts will require evaluation of the hindcasts and appropriate interpretation of the model predictions. While decision-makers wait for information on the predictability of the low-frequency natural variability in dynamical models, it may still be possible to provide estimates of the magnitude and frequency of decadal scale variability of the past, given sufficient observational records. It is important also to keep in mind that for most climate risk management decisions, even those with time horizons extending 10–20 years into the future, year-to-year climate variability must be considered. The likelihood of climate shocks or the likely persistence of beneficial or adverse years within a decade alters decisions and perceptions.

In general, it is expected that climate information should be provided for variables relevant for each specific socio-economic sector, reflect the extremeness of climatic regime and have probabilistic form. In addition, resolution still remains a factor limiting the use of current climate information. Climate information still needs to be made quantitatively practical and meaningful at the scales on which decisions will be made. Recent advances in downscaling techniques show that it seems possible to improve the overall quantitative meaningfulness of the impact assessments of climate variability and change at smaller scales, even though uncertainty may increase. Additionally, whatever the downscaling approach, attention must be given in estimating the associated uncertainty with the resulting climate predictions. This means that any meaningful efforts to translate the decadal scale climate information to local scales will require adequate observations.

An ongoing challenge is to create climate data records from the observations to serve many purposes. Meeting this challenge requires the following:

(a)   Observations that satisfy the climate observing principles;

(b)   A performance tracking system;

(c)   The ingestion, archiving and stewardship of data;

(d)   Access to data, including data management and integration;

(e)   The analysis and reanalysis of the observations and derivation of products, especially Climate Data Records (CDRs) [60];

(f)   An assessment of what has happened and why (attribution) including likely impacts on human and ecosystems.

The IPCC (2007) report demonstrates shortcomings in many climate records, especially those from space. Coordination among the major space agencies is highly desirable to agree on algorithms and calibration procedures. In addition, considering that ocean observations will be indispensable for decadal climate prediction systems, continuous assessment of existing and planned ocean observing systems will be necessary.

A key part of the overall strategy in creating CDRs is the need to have a vibrant program for the reprocessing of past data [61] and reanalysis of all the data into global fields. Reanalysis is the reprocessing of all observations with a state-of-the-art system that is held constant in time. A further challenge is dealing with the changing observing system [62]. The result is a more coherent description of the changing atmosphere, ocean, land surface and other climate components that include derived fields not observed and which can be utilized by the many users of climate products. Reanalysis thus should be considered an essential component of a climate observing system.

4. Integration and dissemination of climate information

Science and scientific capacity-building on climate variability and change has been in general insufficiently translated into policy-relevant discourse and action. In order to make progress on that, it seems essential to enhance natural–social science coupling as well as to improve dialogue with decision-makers. Building effective partnerships between the providers and users of climate information is multi-faceted and often not straightforward, but it is crucial if the investments in climate science and their potential benefits to society are to be realized. Meinke et al. [63] describe three essential elements for building effective partnerships: saliency (the relevance of the information to sector concerns); credibility (the perceived technical quality of information); and legitimacy (the perceived objectivity of the process by which the information is shared). In simple terms, these elements boil down to trust and communication. For example, as part of providing meaningful climate predictions, climate scientists must make clear how the forecasts are produced on these longer timescales, their opportunities and limitations and the source and magnitude of forecast uncertainties. Conversely, stakeholders usually work in specific time-sensitive windows and climate information providers should be aware of that. Also, many decision-makers should still undertake to examine where their main vulnerabilities to climate variability and change lie, in order to make their systems more resilient and to identify what information they most need to consider.

Therefore, partnerships are likely to be more complex than a simple linear producer-to-user relationship. Chains or networks of information and expertise may be more effective, given the scope and quantity of the work involved to advance predictions on this timescale and make them useable. An integrated and interdisciplinary framework has been recently suggested by Trenberth [64] and presented in Figure 3. Climate products and services are developed from basic research that feeds into applied and operational research, including technological transfer, and from the users who provide information on their needs and how to improve information. A system like this should be able to determine stakeholder interests and translate them into specific scientific questions to be investigated, answered and translated back into climate information that stakeholders can use effectively [65]. In addition, such a framework requires a strengthening of communication strategies which involves communication across disciplinary boundaries, with funding agencies, with practitioners and stakeholders and with the media.
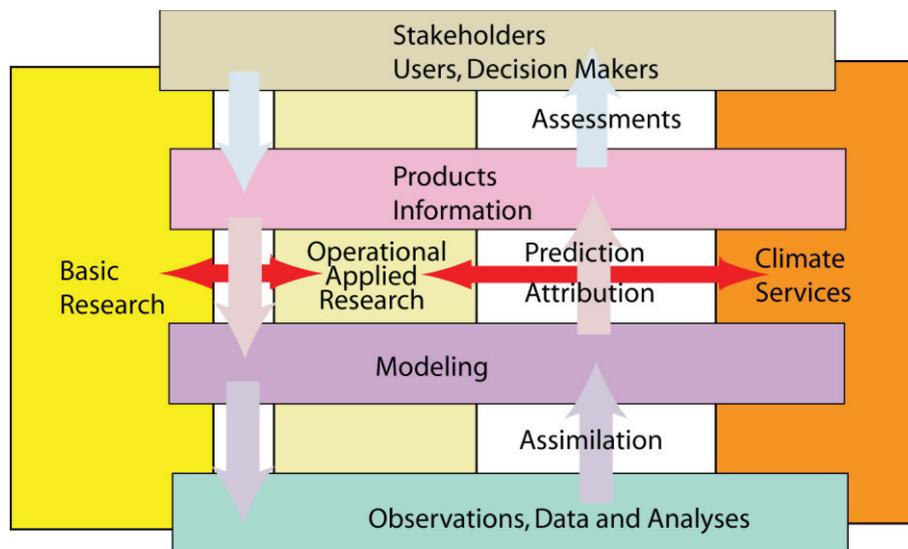
Figure 3. A schematic of the flow of the climate information system (Adapted from Trenberth [64])

5. Conclusions

The assessment of the societal needs for climate information on decadal timescales confirmed its relevance as a potential driver in sector decision-making. This driver would be present even in the absence of the human impact on climate. In developed countries public decision-making would be improved, and business opportunities would be raised and threats diminished if such information were available. In developing or least developed countries the availability of such information could potentially reduce vulnerability and enhance development opportunities. For the least developed countries, however, the basic requirement for coping with climate variability is better well-being, which will be achieved where basic development infrastructure such as communication networks, transport, housing and sanitation are available to support human development in the form of healthcare, education, employment and food security. These fundamental needs form the basic infrastructure for incorporating climate information into development plans. The absence of such information potentially becomes a major impediment in adaptation to climate variability and change in these countries.

The gaps between the current provision of the decadal scale climate information and societal needs are large, and this assessment identifies the following issues that need to be addressed in order to facilitate the effective use of climate information on decadal timescales in the decision-making processes for the different socio-economic sectors:

(a)   Building effecting partnership systems among stakeholders, users and decision-makers and climate information providers (including those in climate prediction, in climate observations and analysis and in operational climate sectors) is crucial. Partnership systems must be based on an interdisciplinary framework containing expertise in both climate science and the various sector sciences. Systems built on interdisciplinary and trans-sector knowledge are the only way to provide the climate information that can be effectively used by the different society sectors.

(b)   More research and investment is necessary to translate the decadal scale climate information into the spatial scales and relevant variables required for decisions. This effort must include:

(1)   Better determination and availability of agreed and reliable datasets and variables required to address specific socio-economic sector vulnerability, and identification of the specific regions where society is most vulnerable to changes in the near-future climate;

(2)   Improved knowledge of the multiscale nature of the full range of climate variability, in which decadal variation is embedded and including climate change trend impacting on specific socio-economic sectors;

(3)   Development of quantitative climate information on decadal timescales for a wide range of variables in addition to surface temperature and precipitation, and recognition that valuable climate information can still be extracted from observations;

(4)   Regional-to-local scale verification of the decadal scale climate information pursued together with a dynamical understanding of the processes behind the predictability, and a determination of the quality of experimental decadal predictions (including initialization issues) to provide guidance for climate model improvement;

(5)   Characterization of the uncertainties associated with decadal scale climate predictions including properly accounting for those aspects that are and are not predictable;

(6)   Tailoring of the larger-scale information on decadal scale climate variability and change to local scales, which will often be site and/or problem specific.

(c)   Maintaining and sustaining the Global Climate Observing System is essential. In particular, enhancement of the global ocean observing system is necessary for its fundamental role in decadal prediction systems. Also, ways to assemble, quality-check, reprocess and reanalyze datasets relevant to decadal prediction should be specifically addressed. Ways of securing climate observing systems particularly in least developed regions are urgently needed.

Although these recommendations resulted from the assessment of the need of climate information on decadal timescales, they are not restricted to this specific band of climate variability. They are likely to be similar to those related to the climate information needs in other bands of variability like the seasonal-to-interannual band. It is expected that the World Climate Conference-3 general outcomes will integrate the recommendations into a single framework.

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