Chapter 18. Detection and Attribution of Observed Impacts

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Executive Summary

The discernible influence of recent climate change on physical and biological systems on all continents and in most oceans is strengthened by observations made after the AR4 as well as through more extensive analyses of longer-term trends. The main drivers of observed impacts are regional temperature increases in the air and the ocean (very high confidence of influence), shifts in rainfall patterns (high confidence of influence) and ocean acidification (low confidence of influence) [18.3-18.6]. Attribution of impacts in most studies is related to all recent changes in climate beyond historical means and variability. The smaller number of robust attribution studies that link responses in physical and biological systems to *anthropogenic* climate change, using climate, process-based and statistical models has increased. Evidence for such attribution typically comes from aggregated assessments of many observations or studies, from the assessment of observations in combination with improved process understanding, or from a combination of both [18.2.1, Box 18-2].

Impacts of recent climate change on human systems remain difficult to discern due to adaptation and environmental degradation or other non-climatic drivers, but evidence is emerging in a number of sectors (low to medium confidence) [18.4]. Impacts on human systems pose additional challenges due to longer causal chains, complexity of drivers and moving baselines; thus quantitative statements remain difficult. However, there is increasing evidence in some areas that climate change is emerging as a strong driver of impacts.

For several "reasons for concern" (as expressed by IPCC TAR and AR4), additional evidence demonstrates that attributable observations have already been recorded (medium to high confidence) [18.6.1-3, 18.6.5].

For natural systems, new or stronger evidence for discernible impacts of climate change demonstrates that:

- Climate change continues to affect many aspects of systems related to snow, ice and frozen ground (high confidence) [18.3.1]
- Hydrological systems change in many regions, due to changing rainfall or melting glaciers, affecting water resources and water quality [18.3.1] and coastal zones [18.3.3] (medium confidence)
- Ocean warming, acidification and expanding hypoxia are impacting ocean systems, including marine biota, in particular tropical coral systems (very high confidence) [18.3.4, 18.5.9, Box 18-5]
- An increasing range of species and communities in terrestrial ecosystems are impacted by recent climate change (very high confidence). Some species and communities are responding by changes in productivity and/or geographic range. For some recent species extinctions climate change has had a major influence (medium confidence) [18.3.2].

For managed ecosystems and human systems, responses to recent climate changes are difficult to identify due to multiple non-climate driving forces and the presence of adaptation, but effects have been detected with some confidence:

- Productivity and carbon storage in forests has increased in some areas due to warming and higher atmospheric CO_2 concentration (low confidence), although this is counteracted in some areas by increased disturbance [18.3.2]
- On top of technological advances, agricultural crop yields have increased in some (mid to high latitude) regions, due to warming and higher CO_2 (low confidence), and decreased in other (mainly low latitude) regions due to water shortages and higher temperatures (medium confidence) [18.3.5]
- Sensitivity of crop yields to temperature extremes is known to be high, but observed trends in the agricultural markets cannot presently be attributed to climate change [18.3.5]
- A statistical relation exists between economic growth and warming, particularly in low income countries with respect to agricultural and light manufacturing exports [18.4.2]
- There has been an increase in economic losses due to weather extremes, but the contribution of trends in extreme weather events due to anthropogenic emissions has yet to be clearly identified [18.4.2.2, Box 18-3]
- For the tourism sector, visitor numbers in low-lying winter sport areas have been affected by recent changes in weather patterns and investments in artificial snow machines have increased [18.4.2.4]

- For health, evidence that observed changes in vector-borne diseases are attributable to warming remains local and sparse. Evidence that heat-related deaths are increasing and cold-related deaths are decreasing in numbers in mid-latitude populations in response to the observed increase in very hot days is stronger [18.4.3]
- Responses of indigenous groups, particularly in (but not limited to) regions of snow, ice and frozen ground, e.g., changes in the migration patterns, health, and range of animals and plants on which they depend for their livelihood and cultural identity [18.4.5, 18.5.7, Box 18-4].

Impacts are still particularly well documented in Europe and North America, due to higher research and monitoring capacities but new information about impacts of climate change is available from most regions of the world, including:
- Recent warming of the surface waters of the Great Lakes, Africa (high confidence), although there is low confidence in attribution of shifts in lake ecology to this warming [18.5.1]
- Attribution of violent conflicts and/or migration in Africa to recent climate trends is a new area of research, yet to converge on a coherent conclusion [18.4.4, 18.5.1]
- Evidence for phenological changes and range shifts of many plants and animals in Central and Northern Europe is growing [18.5.2]
- Reductions in agricultural yield in parts of Europe are attributed to warming (low confidence) [18.5.2]
- Shifting rainfall patterns in Central and Eastern Asia have significantly increased water availability in some regions (Himalaya and Central Asia) and decreased water availability in others (China) [18.5.3]
- Permafrost in Siberia, Central Asia and Tibet is receding due to recent warming, causing changes in tundra ecosystems [18.5.3]
- Numerous additional changes in phenology and plant productivity have been observed and attributed to warming in Japan, Russia, Malaysia and elsewhere in Asia [18.5.3]
- Glaciers in New Zealand are retreating as a consequence of warming, while treelines in the same regions have not changed [18.5.4]
- Major poleward shifts in marine communities in Australasian waters have occurred, consistent with warming trends [18.5.4]
- Water resource availability in mountain regions of South America has been reduced by warming-induced glacier melt in the Andes (with consequences for hydropower potential), while streamflow has increased in other river basins due to changed rainfall patterns [18.5.6]
- Warming has had negative impacts on agricultural productivity in some regions of South America (central Argentina), while rainfall changes may have increased productivity in others (Eastern Argentina, Paraguay, Southern Brazil and Uruguay) [18.5.6]
- In polar regions, the continuing loss of permafrost has triggered large-scale hydrological and ecosystem changes [18.5.7]
- In small islands, environmental degradation (coastal erosion) still masks possible impacts of climate change, despite the known high sensitivity, first indications of saltwater intrusion and negative ecological consequences are however available from the Florida Keys [18.5.8]
- The tropical and subtropical open oceans continue to be characterized by the loss of coral reefs due warming (high confidence), while the influence of acidification is not discernible yet [18.5.9, Box 18-5].

18.1. Introduction

This chapter assesses observed changes in physical, biological and human systems in relation to climate change. It assesses the degree to which detected changes in such systems can be attributed to changing climate conditions during recent decades. It further assesses, where possible, the relative importance of anthropogenic drivers of climate change for the detected impacts. Climate is only one of many possible drivers that can cause systems to change, and so the confounding influence of other drivers is also considered.

18.1.1. Scope and Goals of the Chapter

Previous assessments, notably Rosenzweig et al., (2007) in the IPCC Fourth Assessment Report (AR4), and the increasing body of literature published since, indicate that numerous physical and biological systems are affected by recent climate change. Rigorous formal assessment of the literature going beyond just detection of change across a variety of regions and sectors, to scientifically robust attribution to climate change and its anthropogenic drivers is critical for several purposes (e.g. Brander et al., 2011; Hoegh-Guldberg et al., 2011). Formal detection studies provide robust evidence of where climate change impacts are being felt and where they are not, supporting near-term planned adaptation if and where necessary. It provides evidence for policy makers and the public to make judgments on the importance of mitigation both locally and globally. Detection and attribution are vital parts of the evidence base requested of the IPCC by signatories to the United Nations Framework Convention on Climate change to judge policies aiming to stabilize “greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous atmospheric interference with the climate system”.

Complete attribution along the chain of human drivers of climate change through to impacts felt in human and biological systems is still rarely achieved in the scientific literature. This may be extremely hard to accomplish for some systems with diverse responses and many confounding drivers such as land use change, overfishing and inherent adaptive capacity (Parmesan et al., 2011). In contrast, the number of studies attributing changing systems to local climate change only, without direct linkage to anthropogenic drivers, is steadily increasing, requiring identification of the regional and systemic nature of the observed impacts. This chapter assesses the studies that exist for both full and partial attribution, and the methodologies that can be brought to bear on attribution and the uncertainties inherent in doing so.

The assessments of IPCC WGI continue to add evidence of human influence on the climate system. The present chapter (alongside other WGII chapters) assesses the extent to which those atmospheric changes influence ecosystems, infrastructure, human health and activities in economic sectors. It is necessary to associate these influences to the degree to which they may constitute actual risks for human livelihoods or other values through either the likelihood of those influences or their consequences. This assessment includes the analysis of the relative importance of climatic change as compared to other environmental and social determinants of change. In cases where the associated risks are small, conclusions are likely to be without direct policy relevance, but still potentially suggestive and provocative for future research. In cases where risks are large and support growing concern about “key vulnerabilities”, even contingent conclusions should attract considerable attention.[1] Care has been taken to make sure that every point raised in this assessment can be supported in the literature, but very low confidence in the attribution has not been used as a reason to omit any findings.

[FOOTNOTE 1: The criteria for “key vulnerabilities” identified in the AR4 include: “magnitude, timing, persistence/reversibility, the potential for adaptation, distributional aspects, likelihood, and ‘importance’” (see footnote 19 of the AR4 Synthesis Report SPM).]

Adaptation and mitigation are tools for responding to climate risks as identified in IPCC (2007). Both can be viewed as investments that either spread risk, like conventional social insurance, or reduce consequences of climate change. Short-term iterative adaptation to the manifestations of climate change can be expected to proceed without attribution to cause – it is sufficient to detect a change in the risk level and invest in whatever adjustment most efficiently reduces that risk. In this regard, higher perceived risks can be attributed to higher likelihoods of damaging events (from, e.g., observed changes in climate trends or climate variability) or higher sensitivity to those events (from, e.g., better understanding of current or future socio-economic context). For example, we now know that New Orleans is more vulnerable to hurricanes than anticipated before Hurricane Katrina made landfall – not necessarily because we believe hurricanes of that magnitude are more likely, but because physical protections and response measures were found to be of limited effectiveness.

Long-term adaptation to climate change, on the other hand, requires attribution to drivers related to climate change because evaluation of relative efficacy of alternative adaptive options depends on projections of how the local climate might change. Mitigation adds attribution to human activities to the list of requirements, but that is not the only challenge. The value of mitigation, in terms of diminishing risk by reducing the likelihood of unattractive futures, is derived from impacts that are projected around the world and into the future.

18.1.2. Summary of Findings from the AR4

Rosenzweig et al., (2007) reported that "Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases." In particular, they highlighted several areas where this general conclusion could be supported by specific conclusions that were reported with high confidence:

- Changes in snow, ice and frozen ground had be seen to increase ground instability in mountain and other permafrost regions; these changes had led to changes in some Arctic and Antarctic ecosystems and produced increases in the number and size of glacial lakes.
- Some hydrological systems had been affected by increased runoff and earlier spring peak discharges; in particular many glacier- and snow-fed rivers and lakes had warmed, producing changes in their thermal structures and water quality.
- Spring events had appeared earlier in the year so that some terrestrial ecosystems had moved poleward and upward; these shifts in plant and animal ranges were attributed to recent warming.
- Shifts in ranges and changes in algal, plankton and fish abundance as well as changes in ice cover, salinity, oxygen levels and circulation had been associated with rising water temperatures in some marine and freshwater systems.

These conclusions were derived from analyses of more than 29,000 observational data series from 75 studies that detected significant change in many physical and biological systems in response to observed changes in some manifestation of local climate. As indicated in IPCC (2007) and updated slightly in Rosenzweig et al., (2009), more than 89% of these system-changes were consistent, at least in terms of direction, with responses that would be expected given the observed climate change. Attribution of system-changes all the way back to anthropogenic climate change was less secure, but nonetheless supported in many cases. The assessment revealed a notable lack of geographic balance in data and literature on observed changes, with marked scarcity in low and middle income countries.

Observed impacts to human systems were less obviously attributed to anthropogenic climate change. Rosenzweig et al. (2007) concluded with medium confidence only that, "other effects of regional climate change on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers. They especially noted effects of temperature increases on

- Some agricultural and forestry management practices in the higher latitudes of the Northern Hemisphere; these included earlier spring planting as well as changes in the disturbance regimes of fires and pests.
- Some aspects of human health, including heat-related mortality in Europe, changes in some vectors of infectious diseases across the world, and phenological changes in allergenic pollen in the mid to high latitudes of the Northern Hemisphere.
- Some human activities in the Arctic (like hunting and travel) and in lower-elevation alpine areas (like mountain sports).

18.2. Methodological Concepts for Detection and Attribution of Impacts of Climate Change

IPCC Working Group I has assessed the science of detecting climate change and its attribution to anthropogenic forcings (Chapter 10, Bindoff et al. in prep.). This chapter assesses the degree to which perceived changes in natural and human systems can be attributed to recent climate change and, wherever possible, its anthropogenic component. There are three substantial challenges to the detection of climate impacts and their attribution to global climate change. First, as all systems are also affected by environmental factors other than climate; to detect a climate impact, it is necessary to control for the effects of such confounding factors. Second, the ability of many systems to adapt to change complicates the detection and attribution of any impacts; that is, adaptation can mask an impact. Third, because systems are typically affected by local or regional climate, attribution of a detected climate impact to global climate can be difficult, especially given scale issues. To overcome these difficulties and to best account for all available knowledge on observed impacts, a range of methods are employed here. They are summarized in this section.

At the highest level, the domain of interest can be separated into three connected subsystems; we name them here as the climate system, the natural system, and the human system (Figure 18-1). Many external drivers may influence any system, including the changing climate and other confounding factors (Hegerl et al., 2010). Each climate, natural or human subsystem affects the other two directly or indirectly. For example, the human system may directly affect the natural system through deforestation, which in turn affects the climate system through changes in albedo; the result can be higher surface temperatures which feed back on natural and human systems.

[INSERT FIGURE 18-1 HERE
Figure 18-1: Schematic of the subject covered in this chapter. External drivers outside of the three systems considered are marked with black arrows. Direct drivers of the human system on the climate system are denoted with a red arrow; some of these drivers may also directly affect natural systems, for example through CO_2 fertilization, as denoted by the second arrow. Further influences of each of the systems on each other that do not involve direct anthropogenic climate drivers are represented by blue arrows.]

If the driver of an observed change stems from the human system and impacts from the climate system, we call this an anthropogenic climate driver. In order to highlight potential reasons for concern (including the uncertainties in detection and attribution), impacts of climate variability and change are also covered, irrespective of whether the particular aspect of climate variability and changes has been identified as anthropogenic.

18.2.1. Concepts and Approaches

Concepts and approaches to detection and attribution have been evolving throughout the work of the IPCC. In 2010, an IPCC Expert Meeting on Detection and Attribution was held to reconcile methods and terminology across working groups. The report from this meeting (Hegerl et al., 2010) is an important conceptual basis for this chapter.

18.2.1.1. Concepts of Detection and Attribution of Climate Change Impacts

Detection addresses the question of whether some aspect of a system is changing beyond what might be considered normal behavior, in a defined statistical sense, without considering the cause for that change. Since most systems are in some way inherently evolving, or changing for reasons unrelated to climate but including changes in their vulnerability and exposure (e.g., Bouwer, 2011a), we here consider detection only where there is an expectation that the observed change could be due to change in climate.

A key component of detection is the estimation of how the system might have behaved in the absence of climate change. This estimation may be derived from process understanding as encapsulated in a model, from other surveys, or, where available, from analysis of records stretching back hundreds of years.

Attribution follows from detection by addressing the question of whether climate change has contributed significantly to the detected change. In practice, attribution studies ask whether the observed change is consistent with the estimated response of the system to the identified potential primary drivers, and whether the observed change is inconsistent with the estimated response when a particular driver is removed. For a quantitative analysis, attribution consists of the evaluation of all relative contributions of conceivable external drivers to that change, with an assignment of statistical confidence.

Failure to include relevant factors in a statistical attribution study can lead to erroneous attribution conclusions. This may imply the interpretation of correlation as a measure of causality, and because these are in fact not equivalent (Holland, 1986) to confidence in statements from attribution studies. This concern not only reflects the specific results of the analysis, but also can be reflected in statements about the overall confidence in our understanding of the cause-effect relationships and of the dynamics of the system considered (see Box 18-1).

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Box 18-1. Methodological Issues for Health Outcome Studies with Respect to Detection and Attribution

The evaluation of causal effects of environmental determinants (including changing temperatures) on human health outcomes requires epidemiological analyses (the study of disease patterns in populations). Detection of a change over time in a health outcome provides little or no information relevant to climate change. Disease patterns change considerably over time due to changes in exposures (e.g. smoking patterns), control measures (vaccination, drug resistance), and population structures (population ageing). Even when these determinants are well understood, changes in data quality over time also have to be considered, for example, improvements in reporting and changes to diagnostic definitions. Reporting bias is something that needs to be addressed and carefully avoided; bias cannot be corrected for in the analysis. The term “attribution” is widely used in environmental epidemiology to describe a causal association between the health outcome and the exposure (in this case, the appropriately parameterised meteorological variable). Causation cannot be assumed, and in some cases may be population specific (that is, cannot be extrapolated to other populations) due to the complexity of disease systems. It is a necessary but not sufficient condition for causation that there is an established biological mechanism. A second order level of attribution to the change in the meteorological parameter over time also has to be carefully considered. Any analyses much consider measured and unmeasured confounders which are factors that are associated with both the exposure (changing temperatures) and the outcome. Population growth can be addressed to some extent, for example, Alonso et al. (2011) used a population indicator to account of changes in the denominator in a region where increases in malaria had been observed. In the most part, studies that claim attribution to climate change can only demonstrate evidence of attribution to local warming patterns (see Hegerl et al., 2010 for types of attribution to climate change, and discussion in Section 18.2.1.3 and Box 18-2). There is a distinct difference between the attribution of deaths to a heat wave and the attribution of a single heat wave event to anthropogenic forcing. The latter can only be evaluated by climatologists (WGI). The observed trend in hot days may be associated with increased burden of disease due to heat, but this would rely on the assumption that temperature-mortality relationship has not changed over time, although there is evidence of changes in both heat and cold related sensitivity at the decadal scale (e.g., Carson et al., 2006). Any overall synthesis of the evidence also needs to take into account publication bias (Kovats et al., 2001). Given the limited amount of data available, systematic reviews are unlikely to be possible, and would need to be narrowly focused on a single disease system.

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Statistical attribution studies also adhere to other basic principles of statistical inference. One is that effects of formal or informal variable selection – in which a range of statistical models is screened to identify the best-fitting – must be taken into account to avoid spurious attribution (Chatfield, 1995). This concern includes the choice of time lags in the relationship between the response and climate variables. A second important principle is that, to avoid spurious attribution, a hypothesized relationship between a response and one or more measures of climate change cannot be tested using the same data that were used to formulate the hypothesized relationship (Solow, 2006). Neither of these principles implies that analyses that identify such relationships are without value. But it does mean that they must be considered with great care – and sometimes be discarded – even though they provide an assessment of the significance of anticipated relationships.

Qualitative attribution studies typically involve the identification of multiple, intersecting “impact chains” that recognize confounding variables acting alongside climate change. These studies usually do not specifically attribute or isolate certain social or environmental changes to climate change alone. Instead, they aim to identify dynamic interactions among an assemblage of intersecting forces in human-environment systems. Moreover, they illustrate how the boundaries between human and natural systems are blurry, making it difficult to isolate the impact of climate change as opposed to the influence of climate alongside other social, political, cultural, economic, and environmental forces. Take, for example, a particular case in which mostly qualitative attribution in human-environment systems are derived from studies that use traditional ecological knowledge (TEK). They are often collected from indigenous people, as indicators of environmental change and its impact on human livelihoods (see Box 18-4), but care must be taken in interpreting memories of the way things were and how they have changed.

Evidence for testing the hypothesis that some observed change can be attributed to climate change may come from different sources. While in some cases, such as observed warming and the melting of glaciers, the process causing the impact may be clear from basic understanding; some type of model may be necessary to obtain more specific information on the underlying processes occurring in the impacted system, but the process is well understood. The nature of these models may vary depending on the details of the system being studied. These models can be mechanistic, for example, representing a system through a chain of explicit functions based on understanding of the individual processes that together comprise the mechanics of the system. These mechanistic models are often formulated numerically, but they can also consist of non-numerical logical arguments. An advantage of such models is that they can provide useful information for uncertainty analysis.

For many impact systems, however, variations are not governed by a small and well-understood set of rules. For instance, even the simplest ecosystems are highly complex, with variability depending on life histories and biochemistry, complicated by interactions between species (Parmesan et al., 2011). In these cases, empirical models may be useful, relating the response of a system to external drivers according to mathematical relationships estimated through observation, experimentation, or survey. In practice, though, many modeling setups will contain both mechanistic and empirical components.

18.2.1.2. Detecting Adaptation to Climate Change

Human and (unmanaged) natural systems are thought to have evolved towards optimal adaptation to a relatively stable local climate within a given (historical) period of time. Throughout history, many natural and human systems have adapted autonomously to fluctuations of climate, by spatial displacement or by changing some aspect of their functioning. Separating the effects of climate change from responses to other drivers implies taking adaptation into account explicitly wherever possible. For example, if a farmer were to notice a persistent (or even anticipated) shift in local climate to a drier hotter climate, then (s)he might adjust by installing irrigation equipment, switching crop varieties to more drought resistant varieties, or simply shifting planting dates. After these active adaptation measures have been taken, yields of crops may have changed little or not all; and so a survey of impacts calibrated on yield would detect nothing even though a lot had happened. It follows that using yields as basis for whether there are detectable impacts of climate change could lead to a conclusion that nothing had happened even though a lot had transpired. Indeed, we observe climate change impacts in natural systems by observing their reaction – so what is the difference?

Several approaches discussed in this chapter recognize detection and attribution of active adaptation to climate change as a signal of an impact. To be sure, attributing these active adaption measures to anthropogenic climate drivers requires a careful implementation of quantitative or qualitative methods, as in many settings agents (e.g., farmers) react not only to climate drivers but also to changing socioeconomic conditions.

18.2.1.3. Approaches to Attribution

There are many levels at which drivers and responses can be defined for observed impacts of climate change (Table 18-1). In practice, three different levels of external drivers tend to be used:

- Attribution to climate variability, where impacts are related to variations in weather and climate irrespective of their nature. While studies examining this relationship do not formally consider the implication of climate change, they are useful for identification of reasons for concern.
- Attribution to climate change, where impacts are related to identified trends in climate. Studies examining this relationship do not formally identify the role of anthropogenic emissions in the observed climate change or, by extension, in the observed impact, but they do indicate the degree to which the system is sensitive to long term climate change.

- Attribution to anthropogenic climate change, where impacts are related, via the climate, to anthropogenic emissions of greenhouse gases and other human activities that are affecting the climate. Because of the complexity of the causal chain, investigation of this relationship is extremely challenging (Parmesan et al., 2011) and only a limited number of these studies have been performed to date.

[INSERT TABLE 18-1 HERE
Table 18-1: A sample of global and local climate drivers and some local non-climate drivers that might influence a natural or human system.]

Model-based attribution studies use two main approaches (Hegerl et al., 2010) (Figure 18-2). Single-step methods consider all relevant systems in a single setup. The assessment tool can comprise a single model or a sequence of models, provided the output of each model is directly employed as an input for the next model in a logical sequence. The attribution analysis is performed through a comparison of the change in the final output of interest against the observed change in climate.

[INSERT FIGURE 18-2 HERE
Figure 18-2: A schematic diagram comparing approaches to attribution for an ecological system. The multi-step approach differs from the end-to-end approach in having a discontinuity between the attributed climate change and the observed weather driving the ecological model.]

Multi-step attribution approaches comprise multiple attribution analyses, with an overall conclusion deduced from the collection of analyses. A multi-step approach could include an analysis of the attribution of changes in a measure of interest to changing climatic conditions and a separate analysis of how external climate drivers affected relevant climatic conditions. Typically, the separation of these analyses creates gaps or inconsistencies between the outputs from one step and the inputs to the next. These gaps must be assessed themselves with respect to their impact on the confidence in the overall attribution.

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Box 18-2. Detection and Attribution of Changes in Biological Systems

Detecting significant trends in biological systems, and assigning confidence levels to them, is particularly difficult because observations are often patchy in quantity and quality, and natural yearly fluctuations are often large. The AR4 (Rosenzweig et al., 2007) and other studies (e.g., Parmesan and Galbraith, 2004; Parmesan, 2005) identify traits of species or systems which lead to a higher confidence in both detecting real change and in attributing that change to climate change or anthropogenic climate change. These traits include: good prior understanding of the mechanistic (cause and effect) links between climate and a biological process, good historical and current records of population and species' status, little lag time between changes in climate and species' response, and relatively weak influence of other non-climatic confounding (anthropogenic and natural) factors.

High to very high confidence in attribution of an observed biological change to anthropogenic climate change has been gained through multiple approaches.

1. Biological “fingerprints” of climate change can be detected in very long biological time series. Parmesan and Yohe (2003) defined one type of fingerprint as “sign-switching.” The argument for use of sign-switching patterns in biological attribution studies is that expected impacts of climate change differ across geographic space (e.g., across a species' range, poleward boundaries are expected to expand while equatorial boundaries are expected to contract) and across long time-spans (e.g., a species is expected to advance their timing of spring events during decadal warming periods and delay timing during decadal cooling periods). Alternate causal agents would therefore have to “switch sign“ of their impacts within a study if they were to form credible competing explanations. Parmesan and Yohe (2003) found patterns of sign-switching uniquely predicted by climate change in 84% of 334 species distributed across marine and terrestrial systems in the northern hemisphere.

2. Multiple “Lines of Evidence” of climate links to observed changes (Ahmad et al., 2001, Rosenzweig et al., 2007, Parmesan et al., 2011, Parmesan et al., 2013)**.** Confidence in attribution to either climate change or anthropogenic climate change is increased when multiple, independent sources evidence draw the same conclusions. Evidence in biological systems may come from a combination of correlational patterns with patterns that would be predicted from processes identified in experimental manipulations of environmental parameters such as temperature, rainfall or CO_2 concentration. Examples of multiple lines of evidence (observational, correlational and experimental) being used to link observed biological changes to recent climate changes are: (1) the Sachem Skipper butterfly, *Atalopedes campestris*, range expansion in Pacific Northwest of USA (Crozier, 2004) and (2) Pine processionary moth, *Thaumetopoea pityocampa*, range shifts and abundance changes in France and Italy (Battisti et al., 2005).

3. Replication across diverse species, systems and geographic regions. Most studies do not fit one or more of the above traits, being relatively local and short term. Biologists have therefore focused on gaining higher confidence in attribution of detected biological observed changes to anthropogenic climate change by increasing power through replication, reducing positive publication bias by focus on multi-species studies, and minimizing the role of non-climatic confounding factors by inclusion of diverse species, systems and geographic regions into single databases and analyzing trends simultaneously via meta-analyses. This has resulted in high to very high confidence in attribution of biological changes to climate change from meta-analyses of multi-species studies at a global scale (Figure 18-3). Examples include coral bleaching, and global meta-analyses of diverse terrestrial and marine taxa (Parmesan and Yohe, 2003; Root et al., 2003; Root et al., 2005; Rosenzweig et al., 2008; Poloczanska et al., in prep.; see also Chapters 6 and 30 of this report).

[INSERT FIGURE 18-3 HERE
Figure 18-3: Confidence landscape in biological attribution studies. Green lines depict levels of confidence in attributing a given detected change in a wild species or biological system to detected trends in climate or changes in climatic patterns. Pale green = studies with <20 years of continuous data, dark green = studies with >50 years of continuous data. The blue line represents studies with ‘double attribution’, that is, attribution of a given detected change (or changes) to greenhouse gas driven climate change. (Modified from Parmesan et al., 2011); Numbered references in figure: [1]Perrins et al., 1997; [2]Southward et al., 1995; Southward et al., 2005; [3]Kearney et al., 2010; [4]Parmesan, 1996; Parmesan, 2003; Karl et al., 1996; Dunn and Winkler, 1999; Johnson et al., 1999; Karoly et al., 2003; Zwiers and Zhang, 2003; [5]Foden et al., 2007; [6]Parmesan and Yohe, 2003; Root et al., 2003; Root et al., 2005; Parmesan, 2007; Rosenzweig et al., 2008; [7]Hoegh-Guldberg, 1999; Fedorov and Philander, 2000; Hansen et al., 2006; Latif and Keenlyside, 2009; WGII Chapters 6 and 30; [8]Oechel et al., 2000; Sturm et al., 2001; Sturm and Racine, 2006.]

Given the above constraints and caveats, there are a few systems and/or metrics that may, through their particular attributes, provide higher confidence for attribution than others. For example, there are a few species for which we have a very good mechanistic (process-based) understanding of how climate variability affects key traits, and for which good, predictive biological models already exist. For example, phenological processes of many species are better understood than are the causes of species' range shifts, also crop plants are much better studied than are wild plants. Therefore, multi-step attribution studies (sensu Stone et al., 2009, Hegerl et al., 2010) on, for example, the timing of blooming or harvesting for fruit trees provides conclusions with higher confidence than would a study on the range shift of a native oak tree. Metrics that quantify aggregate properties of whole ecosystems may allow higher confidence in attribution, such as net primary productivity.

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18.2.2. Limitations to Detection and Attribution

18.2.2.1. Types and Quality of Observations

Many changing phenomena can be measured directly, e.g., the temperature of a lake or the air above that lake. More commonly, however, changes of interest are detected by more subtle indicators, for instance the number of deaths due to heat waves, or the percentage of species with northward or upward migration; in the first instance, adaptation matters but humans are essentially irrelevant in the second Some aspects of human systems may be more adequately described in qualitative than in quantitative terms, other aspects and other context are not. The pertinence of the indicator for the objectives of the assessment must be established.

Once an indicator is identified, a further limiting factor is the observable quantity supporting the indicator. Monitoring of ecosystems, for example, is often not of the standard to resolve anticipated impacts, especially in areas with complex ecosystems (see Box 18-2). Most monitoring systems have not been designed with the intention of measuring incremental long-term changes, and have not been optimized for the detection of climate-related changes (Midgley et al., 2007). Consequently, the record length may be too short, too heterogeneous or discontinuous to be useful, or measuring standards may have been improved through time resulting in measurement artifacts. This latter factor is most visible in the extensive and long-running networks designed to monitor human health, where the priority is an accurate timely assessment of current health status and risk rather than the determination of long-term trends (see Box 18-1).

18.2.2.2. Spatial and Temporal Characteristics of Change

Detection studies must be based on observations covering sufficient time periods, typically longer than the periods required for detection of trends in the underlying driving variables such as climate. Observational records are typically too short to assess the internal variability with sufficient confidence. A key issue here is identifying any lag times that are critical in characterizing the response of an impact system to a change in a driver. These may vary among different impact systems and within them, from seconds or minutes to centuries or millennia. In the cryosphere, for instance, mountain glaciers typically show response times to a climatic change on the order of years to decades, while the ice sheets of Greenland and Antarctica have significantly longer response times that may be on the order of century or even longer. Forests have decades to centuries to respond and adapt to new climatic conditions while for soils the corresponding range is more between centuries and millennia.

Non-linear system response to change is a fundamental issue for detection studies. Some systems may respond by step-wise changes, other systems may have tipping points, showing little or no change until a certain threshold where they suddenly start to respond vigorously and often in a chaotic way.

Change in environmental systems occurs on multiple spatial scales from local to global. Attribution of change to climate change (e.g., over the last several decades) faces different challenges at different scale levels. At the local scale, detection may be straightforward due to some series of observations, but attribution will be difficult because many local factors affect climate in ways that may mask the global trends.

18.2.2.3. Publication Bias

Conclusions about the effect of climate change on natural and human systems in this report are based on a synthesis of findings in the scientific literature. A potential problem with this approach is publication bias as noted in Parmesan and Yohe (2004). Publication bias refers to the preferential publication of papers reporting statistically significant findings. The effect of publication bias could be a false impression of the strength of the evidence in favor of an hypothesized effect. For example, Kovats et al. (2001) discussed the effect of publication bias in assessing the effect of climate change on vector-borne diseases. Although methods exist for detecting and correcting for publication bias in formal meta-analysis (Rothstein et al., 2005), this is not the case in less formal literature reviews. To reduce the effect of publication bias, the analysis for this report has included special efforts to critically assess findings of no-effect of climate change on potentially impacted systems.

18.3. Detection and Attribution of Observed Climate Change Impacts in Natural and Managed Systems

The IPCC AR4 provided extensive reporting on observed impacts of climate change (Rosenzweig et al., 2007, and other chapters of WG2) and the scientific literature on this topic is growing quickly. The following section provides an overview of the state of knowledge across major sectors of natural and managed systems, broadly following the structure of the overall WG2 report. Findings about observed impacts are firstly assessed in the sectoral chapters 3, 4, 5, 6 and 7, following a common framework based on section 18.2. The following text delivers a synthesis of material presented in the mentioned chapters. *[Additional material has been included, in particular in section 18.3.1]*

18.3.1. Freshwater Resources

Freshwater resources are affected by climate change worldwide, with different characteristics of change in different regions. Observed changes in each of the components of the water system are assessed by the IPCC working group (WG) 1 in their AR5 chapter 10, and WG2 (AR5 chapters 2, 3 and regional chapters). Where possible, the observed changes are attributed to recent climate change (or other drivers).

Figure 18-4 presents a synthesis of confidence in detection of changes in freshwater resources and related systems, and their attribution to climate change. Frozen components of freshwater systems tend to show higher confidence in detection and attribution, while components with a high level of non-climatic drivers, such as groundwater or river flow, have lower confidence.

[INSERT FIGURE 18-4 HERE
Figure 18-4: Levels of confidence in detection and attribution of observed climate change impacts for Freshwater Systems, including the Cryosphere]

18.3.1.1. The Regional Water Balance

The regional water balance results from sources (precipitation, ice and snow melt, river and groundwater outflow) and sinks (evapotranspiration, water use and river and groundwater inflow). Impacts include limited access to freshwater for use (droughts) or excess water (floods). Evapotranspiration, being a function of surface temperature, soil moisture and wind, is affected by the changing climate, but also by changing vegetation processes and land cover.

The IPCC Special Report Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (IPCC, 2012) concludes that more locations have experienced an increase than a decrease in heavy rainfall, yet with significant regional and seasonal variations. Of the 26 continental sub-regions considered. 73% of the sub-regions have seen a varying sign of the trend since 1950, with medium or low confidence. Increase in heavy rainfall is seen in 15% of the sub-regions, half with high confidence and half with medium confidence. IPCC (2012) concludes that there is medium confidence that anthropogenic influence has contributed to changes in extreme precipitation (see also Min et al., 2011).

Heavy rainfall is an important driver of floods. There is limited to medium evidence available to assess climate-driven observed changes in the magnitude and frequency of floods at a regional scale because the available instrumental records of floods at gauge stations are limited in space and time, and because of other drivers of changes, such as land-use and anthropogenically altered river channels (IPCC, 2012). Despite an increase in heavy precipitation events which likely has had consequences for pluvial floods, several studies on river flood changes in North America and Europe (e.g., Petrow and Merz, 2009; Villarini et al., 2009) find evidence for increases as well as decreases in floods. A first attribution study of floods suggests that an anthropogenic signal is detectable for an increased flood risk for the autumn 2000 floods in England and Wales (Pall et al., 2011), see also Box 18-3.

In mountain areas, glacial lake outburst floods (GLOFs) are characterized by their low frequency and high magnitude with most devastating impacts on downstream areas. While there is no evidence for a change in frequency or magnitude of GLOFs anywhere (IPCC, 2012), significant changes in the number and area of glacial lakes have been observed, with a slight to substantial increase in several regions over the Hindu Kush Himalayan mountain arc in the past two decades (Gardelle et al., 2011), and a similarly strong increase in lake numbers in the

Andes of Peru in the second half of the 20th century (Carey, 2005). The growing number of these lakes is of concern since it makes GLOFs more likely to occur in the near future.

The IPCC AR4 assessed that it is more likely than not that anthropogenic influence has contributed to the increase in the droughts observed in the second half of the 20th century (Hegerl et al., 2007). Subsequent studies have improved the understanding of the main factors leading to drought, including land-use changes (Deo et al., 2009), but significant uncertainties remain. Detection and attribution studies are complicated by different drought definitions, and difficulties and inconsistencies in measuring drought (IPCC, 2012).

For dryness, as an indicator of drought, the IPCC (2012) indicates that in 77% of the global sub-regions a regionally varying trend was observed, 53.8% of which was assigned low confidence. Regarding regions with a clear signal of change, IPCC (2012) assesses that 11.5% of the sub-regions having seen an increase in dryness (medium confidence) and 11.5% showing a decrease in dryness (medium confidence). IPCC (2012) furthermore concluded that there is medium confidence that since the 1950s some regions of the world have experienced trends toward more intense and longer droughts, in particular in southern Europe and West Africa, but in some regions droughts have become less frequent, less intense, or shorter, for example, in central North America and northwestern Australia.

Change in river flow is a direct indicator of a changing regional water balance. For example, the Uruguay River in South America experienced a positive trend in average stream-flow from 1960 to 2000, due to increased rainfall, with shorter-term peaks in runoff caused by changes in land cover (Saurral et al., 2008). In the Yellow River in China, long-term change in stream-flow was mostly attributed to anthropogenically enhanced soil erosion rather than due to climatic changes (Zhang, G. et al., 2007). Changes in rainfall seasonality in monsoon systems also affect river flows. In South America, for example, wet season rainfall has increased in duration from an average of 170 days before 1972, to 195 days after (Carvalho et al., 2010), potentially affecting the Amazon Basin in the tropics and the La Plata Basin in the subtropics. The observed increase in river flow in La Plata Basin over the second half of the 20th century had been described by Robertson and Mechoso (1998). For the Amazon Basin, there are rivers with 24% increase in discharge after the 1970s where half of the increase has been appointed to the change in rainfall amount and the other half to land-use and land-cover change (Costa et al., 2003). This feature of the South American monsoon is not seen in the other monsoon systems, especially those in the Northern Hemisphere where a decreasing trend in rainfall has been observed over the last 50 years (Li et al., 2010). In a global review of changes in river flow, it was found that only one-third of the top 200 rivers show statistically significant trends during 1948–2004, with the rivers having downward trends (45) outnumbering those with upward trends (19) (Dai et al., 2009).

Overall, there is high confidence in the detection of changes in rainfall and river flows but a lower degree of confidence in the attribution of the impacts to climate change, land use and water use. This holds true also for the subsequent changes in groundwater recharge and level.

Observed changes in groundwater level and storage have been primarily attributed to human activities, such as in northeastern India where groundwater depletion as detected by satellite data for the 21st century was attributed to groundwater withdrawal for irrigation and other anthropogenic use (Rodell et al., 2009). Attribution of groundwater change to climatic drivers is more rare. For Kashmir (India) Jeelani (2008) suggests that the observed decline in groundwater recharge between 1981 and 2005 can be attributed to decreasing precipitation and glacier decay, while a modeling study for southeast Spain indicates an effect of temperature related changes in evapotranspiration on groundwater (Aguilera and Murillo, 2009).

Water quality in watersheds and lakes is expected to change with increasing temperature through an increase in eutrophication as discussed in Chapter 3 of this report. Eutrophication is mostly driven by other causes, such as untreated sewage inflows in urban and industrial areas and surface runoff carrying remains of fertilizers used in agriculture, and vegetation decay and manure inputs in flooding events – the component which might be due to climate is therefore difficult to identify (e.g., Kundzewicz and Krysanova, 2010). There is emerging, yet limited evidence for downstream impacts on water quality due to upstream climate impacts, such as high sulfide content in rivers of Peru’s Cordillera Blance due to sulfide-rich rocks that became exposed as glaciers retreated (Fortner et al. 2011).

18.3.1.2. The Cryosphere

There is extensive evidence of significant changes in various elements of the cryosphere, including mountain glaciers and ice caps, ice sheets and floating ice shelves, sea, lake and river ice, subsurface ice (permafrost) and snow. It is likely that there is an anthropogenic component in the changes observed in Arctic sea ice, Greenland surface melt, mountain glaciers, permafrost and snow cover (WGI Chapter 10, Bindoff et al. in prep.).

Depending on regional climate, changes in glacier extent are not uniform over the globe, but they nevertheless provide a largely homogeneous signal of retreat. In general, the trend of glacier shrinkage and mass loss reported in AR4 (Lemke et al., 2007) continues, with a trend of recent increasing loss for Central Europe, Alaska, the Canadian Arctic and southern Andes (WGI chapter 4, Comiso et al., in prep.). There are only few regions with stagnant or advancing glaciers, for instance the Karakorum, where regional climate pattern and non-climatic glacier dynamics (surging) are considered important drivers (Bolch et al., 2012). There is high confidence that glacier changes over the past several decades exceed internal variability, but only few studies are available that attribute these glacier changes to anthropogenic forcing (WGI chapter 10, Bindoff et al., in prep.). The absolute contribution of glaciers and ice caps to sea level rise has increased since the early 20th century and has been close to 1 mm yr^{-1} for the past decades (WGI, chapter 4, Comiso et al., in prep.), around a third of total observed sea level rise. Changes in Greenland and Antarctica are difficult to attribute to (anthropogenic) climate change, especially for Antarctica, due to multiple factors of change, including regional climate, ocean currents and warming, ice flow dynamics and others (WGI, chapter 10, Bindoff et al., in prep.).

The loss of ice sheets and glaciers causes accelerated uplift of underlying land in the North Atlantic Region (Jiang et al., 2010), as well as glacio-isostatic deformation around the Vatnajökull ice cap in Iceland (Pagli et al., 2007). There is medium confidence regarding the effects of ice loss on seismicity due to unloading of the lithosphere beneath ice sheets (Hampel et al., 2010) and Alaskan glaciers (Sauber and Ruppert 2008), and volcanic activity such as enhanced magma generation (Sigmundsson et al., 2010). The strong and rapid downwasting observed on alpine glaciers has prompted a number of impacts. At the front of many retreating glaciers in the Alps of Europe, Himalayas, Andes and other mountain regions lakes have formed or expanded, increasing the risk of outburst floods with potentially severe impacts on mountain communities. In the Swiss Alps and the Peruvian Andes, the formation of lakes has led to multiple outburst floods since 2008, impacting mountain communities (Carey et al., 2012b; Werder et al., 2010). As a direct response, risk reduction measures on the order of tens of millions USD were necessary, and new tourist infrastructure has been built to accommodate an increasing number of people attracted by glacier lakes (Huggel et al., 2011). The new lakes can represent a potential for hydropower generation (Terrier et al., 2011). Slope instabilities are another consequence associated with glacier downwasting processes (Haeberli and Hohmann, 2008; Huggel et al., 2011).

Observed changes from glacier retreat on downstream systems furthermore include changes in runoff. An increase in runoff from glacier areas has been documented for catchments in western and south-central China over the past several decades (Zhang, Y. et al., 2008; Zongxing et al., 2010). Similarly increasing runoff trends have been found for glacier-fed streams in British Columbia and Yukon, Canada (Stahl et al., 2008; Moore et al., 2009). In a catchment in the central Andes of Peru, 67% of the runoff during the dry season is contributed by glacier melt, and therefore the loss of glaciers has a significant impact on the agricultural and energy (hydropower) sectors (Condom et al., 2011). For another catchment in the same region shifts in runoff seasonality over the period 1953-1997 were attributed to changing glaciers (Bury et al., 2010). More recently, in seven out of nine glacier-fed catchments in the Cordillera Blanca water runoff during the dry season has begun to decrease (Baraer et al., 2012). This decrease in water availability is consistent with qualitative observations made by local people (Bury et al., 2010; Carey et al., 2012a).

Due to local conditions, runoff changes from glaciers over the past decades vary both within and between different mountain ranges around the world, often attributed to climate change (Casassa et al., 2009). In the Swiss Alps, positive trends in river runoff have occurred primarily in highly glaciated catchments (Collins, 2006; Pellicciotti et al., 2010), while for a 35 to 60% glacier cover a runoff decrease was detected for the warm and dry 1990s, and for areas with less than 2% glacier cover runoff basically follows precipitation trends (Collins, 2006). For very large catchments (Po and Rhône catchments with <1% basin glacier cover), the contribution of glacier melt to total runoff in August was significantly lower for 2004-2008 than for the previous twenty years (Huss, 2011).

Earlier reported trends of Arctic sea ice decline have continued, with a decrease in annual average extent of 4%, and in end of summer extent of 12% per decade since 1979, and a significant increase of the rate of sea ice decline in the first decade of the 21st century (WGI, chapter 4, Comiso et al., in prep.). High confidence also exists that the thickness of Arctic sea ice decreased since the 1980s. Antarctic sea ice has slightly increased over the past 30 years, yet with strong regional differences. It is likely that decline in Arctic sea ice can be attributed to anthropogenic climate forcing (WGI chapter 10, Bindoff et al., in prep.). Observations by Inuit people in the Canadian Arctic confirm with high confidence the instrumental observations on the various changes of sea ice (see Box 18-4).

For lake and river ice, there is generally high confidence of later freeze-up earlier break-up over the past 100+ years, yet with regional differences (WGI chapter 4, Comiso et al., in prep.). Changes in lake and river ice can have effects on freshwater ecosystems, transport and traffic over frozen lakes and rivers, and ice induced floods during freeze-up and break-up events (Voigt et al., 2011a). Some evidence exists in Europe that ice-jam floods were reduced during the last century due to reduced freshwater freezing (Svensson et al., 2006).

Combined in-situ and satellite observations indicate a decline in snow cover extent in most months of the period 1922-2010, with the largest decline in spring (8%) (WGI chapter 4, Comiso et al., in prep.). Snow cover is primarily related to seasonal weather patterns, and accordingly, the spatial variability is high (Brown and Mote, 2009). Only few formal detection and attribution studies exist but they consistently indicate an anthropogenic influence on snow cover (WGI chapter 10, Bindoff et al., in prep.). For the western United States one study detected changes in snow pack and runoff timing between 1950 and 1999 and suggested that up to 60% of the changes could be attributed to anthropogenic climate forcing (Barnett et al., 2008). Impacts on winter tourism have been observed (see 18.4.2.4).

Widespread changes and degradation of both high-latitude/low-land and high-elevation mountain permafrost have been observed over the past years and decades (WGI chapter 4, Comiso et al., in prep.). Generally, the permafrost boundary has been moving northwards and to higher elevations, and the active layer thickness has increased at many sites. Regional differences of changes, though, are strong and are not only related to temperature changes but also to other factors such as seasonal snow cover. Formal attribution studies are hardly available for any of the above mentioned permafrost parameters. However, several impacts have been attributed to permafrost changes. Significant and partly dramatic increases of flow speed of Alpine rock glaciers has been observed, resulting in rock fall and debris flows, and has been attributed to ground temperature increase (Kääb et al., 2007; Delaloye et al., 2010). In many Arctic permafrost regions expansion and deepening of thermokarst lakes has been observed over the past years; ice-bearing permafrost exposed to the Arctic ocean retreated with rates of 2 to 3 m yr^{-1} at some sites, generally resulting in a doubling of the erosion rate at Alaska's northern coastline over the past 50 years (Karl et al., 2009). Furthermore, expansion of channel networks (Toniolo et al., 2009), increased river bank erosion (Costard et al., 2007) and higher dynamics in lake and pond changes (shrinking and expanding) (Rowland et al., 2010) have been observed in the Arctic, as well as an increase in hillslope erosion and landsliding in Northern Alaska since the 1980's (Gooseff et al., 2009). Complex feedbacks and interactions across surface systems, and spatial and temporal scales complicate detection of drivers and effects. For example, drying of land surface due to permafrost degradation may cause an increase in wildfires, in turn resulting in a loss of ground surface insulation and change in surface albedo that accelerates permafrost thawing (Rowland et al., 2010).

18.3.1.3. Erosion, Landslides and Avalanches

There is high confidence that erosion and landsliding increases during phases of deglaciation in mountain areas, with significant evidence for post-Ice Age periods (Ballantyne, 2002; Korup et al., 2011) but yet limited evidence for contemporary deglaciation. There is medium confidence that sediment flux has increased in western Himalaya in relation with hydrologic extreme events (Wulf et al., unpubl.) that have been shown to have increased over the past 60 years (Malik et al., 2011), with important impacts on hydropower schemes. For southern China, there is robust evidence of decline in sediment load in some rivers since the 1980s and 1990s (Zhang, S. et al., 2008). There is high confidence in qualitative attribution of recent decline in sediment load to dam construction and low confidence in attributing the change to climate impacts for the Yangtze catchment in China (Xu et al., 2008).

Changes in sediment yield, related or unrelated to climate impacts, can significantly influence frequency and magnitude of alpine shallow landslides and debris flows (Lugon and Stoffel, 2010), but no clear evidence exists so far for a change in frequency of shallow landslide and debris flows from recently deglaciated mountain areas in the European Alps (Jomelli et al., 2004; Stoffel and Huggel 2012).

Recent studies provide high confidence that rock slope failures in mountain areas of the Swiss and French Alps of Europe with permafrost occurrence have increased since the 1990s (and medium confidence for New Zealand Alps), as compared to earlier decades, with a striking increase in the 21st century (Ravanel and Deline, 2010; Allen et al., 2010; Fischer et al., 2012; Huggel et al., 2012), with similarly high confidence that glacier retreat and downwasting, permafrost degradation and high-temperature events have contributed to many high-mountain rock slope failures over the past 20 years (see Figure 18-5)

[INSERT FIGURE 18-5 HERE
Figure 18-5: Changes in frequency of alpine rock slope failures since 1900 detected at two spatial scales: a regional scale over the Swiss and adjacent Alps (upper panel) and a detailed local scale at Mont Blanc area, French Alps (middle panel). Documentation bias exists at the regional level, especially for small failures in the early 20th century. To improve confidence in detection the local level (virtually bias free) can be compared with the regional level, and only large-volume slides can be considered which should show minimum bias.]

In North America, New Zealand and the European Alps warm extreme events may have had a substantial effect on triggering large slope failures in rock and ice (Huggel et al., 2010). Such extremes have increased since the 1950s (IPCC, 2012). In some specific cases in the Swiss Alps costs (on the order of tens of millions of USD) related to damage and mitigation of historically unprecedented debris flows can be qualitatively attributed to climate change (including a likely anthropogenic influence) through downstream impact chains, starting from rock fall activity related to permafrost degradation (Huggel et al., 2012).

Detection of changes in the occurrence of landslides is complicated by incomplete inventories, both in time and space, and inconsistency in terminology. So far, there is no clear evidence that frequency or magnitude of shallow landslides has changed over the past decades (Huggel et al., 2012a,b), not even in regions with a relatively complete event record (e.g., Switzerland, Hilker et al., 2009). The increase of landslide impacts (in terms of casualties, or loss) in South, East and South-east Asia over the past years, where landslides are predominantly triggered by monsoon and tropical cyclone activity, is largely attributed to changes in exposure, i.e. population growth (Petley, 2010).

With respect to snow avalanches no change in the natural activity has so far been detected neither in Switzerland over the past 50 years (Laternser and Schneebeli, 2002) nor in Europe (Voigt et al., 2011b). While in Switzerland the missing trend in avalanche activity contrasts with a significant increase in winter precipitation over that time, methodological difficulties in these analyses are acknowledged (Laternser and Schneebeli, 2002). The detection of changes in snow avalanche impacts, such as fatalities and property loss, is difficult over the past decades due to changes in snow sport activities and avalanche defense measures.

18.3.2. Terrestrial Systems (and Inland Water Systems)

As documented by previous IPCC reports (notably, Rosenzweig et al., 2007), numerous changes in terrestrial and inland water systems have been attributed to recent climate change. Confidence in such detection of change is frequently very high (when there is high agreement between many independent sources of evidence of change, and when there is robust evidence that changes in ecosystems or species are outside of their natural variation). Confidence in attribution to climate change is also often high, due to process understanding of responses to climate change, or strong correlations with climate trends and where confounding factors are understood to have limited importance. Here, statements of confidence for detection and attribution are given without references, as detailed traceability is provided in chapter 4.

18.3.2.1. Phenology

Since the AR4 there has been a further significant increase in the spatial, temporal and taxonomic coverage of observations of phenology (the timing of key life history events, such as flowering in plants or nesting for birds) of plants and animals, showing that many, but not all species has shifted to some degree over the last decades to centuries. New satellite-based analyses confirm earlier trends, showing that the onset of the growing season in the northern hemisphere has advanced by 5.4 days from X to 2008 and its end has been delayed by 6.6 days (Jeong et al., 2011). New findings are reported, for example, for amphibians, birds, mammals, plants. Attribution to climate change is supported by new experimental evidence, parameters include temperature, growing season length, precipitation, snow cover duration and others. More refined analyses account for regional differences in warming trends, urban heat island effects, confounding effects of other global change drivers, non-linear responses of phenology to warming. Breeding is an important phenological trait in many species, having advanced significantly across many groups and regions, similar to migration. In some cases, changing phenology affects competitive or other relationships between species. (see Chapter 4.3.2.1).

18.3.2.2. Biomass and Carbon Stocks

Many terrestrial ecosystems are now net sinks for carbon over much of the Northern hemisphere and also in parts of the Southern hemisphere. This is shown, for example, by inference from atmospheric chemistry, but also by increased tree growth in many regions including Europe, the United States, tropical Africa and the Amazon. Total land net primary productivity is estimated to be approx. 5% above preindustrial level, contributing to a net carbon sink on land of 2.6 ± 0.7 Pg C yr-1 (see AR5 WG1 chapter 6; (Raupach et al., 2008; Le Quéré et al., 2009), despite ongoing deforestation. Trends are in part due to N deposition, afforestation and altered land management which makes attribution to climate change difficult. The degree to which rising atmospheric CO2 concentrations contribute to this trend remains poorly known (see Chapter 4.3.2.2, 4.3.2.3).

18.3.2.3. Biodiversity

Across the world, species extinctions are at or above the highest rates of species extinction in the fossil record. However, only a small fraction of observed species extinctions have been attributed to climate change — most have been ascribed to invasive species, overexploitation or habitat loss or modification. For those species where climate change has been invoked as a causal factor in extinction, there is little agreement among investigators concerning the importance of climate variation in driving extinction and even less agreement that extinctions were caused by global warming. Therefore, confidence in the attribution of extinctions to climate change is very low. Changes in climate have nevertheless been identified as one of the key drivers of extinctions of amphibians, many of them in Central America (Pounds et al., 2006) (see Chapter 4.3.2.5).

For different species and species groups, detected range shifts vary, and so does the confidence of detection and the degree of attribution to climate change. The number of species studied has considerably increased since the AR4. Overall, terrestrial species have recently moved poleward about 17 km per decade (sites in Europe, North America and Chile) and 11 m per decade in altitude up mountains (sites in Europe, North America, Malaysia, and Marion Island), which corresponds to predicted range shifts due to warming (Chen et al., 2011c). Over the last decades, arthropods have moved large and statistically significant distances towards the poles (many 10's of km). Species with short life cycles and high dispersal capacity – such as butterflies or herbaceous plants – are generally tracking climate more closely than longer-lived species or those with more limited dispersal such as birds and trees (Lenoir et al., 2008; Devictor et al., 2012) (see Chapter 4.3.2.5).

18.3.2.4. Impacts on Major Systems

Many of the world's forests are currently changing, due to a combination of changes in physiology and management (incl. deforestation and afforestation). Climate change, and increasing atmospheric CO2, likely play a role, but the extent of this influence can presently not be determined. In part, the current net carbon sink in the world's forests may be due to climate. There are indications that the stimulatory effects of global warming and rising CO2 concentrations on tree growth may have peaked in many regions (Refs) and that warming and changes in precipitation are increasing tree mortality in a wide range of forest systems, acting via heat stress, drought stress, pest outbreaks and a wide range of other indirect impact mechanisms (Allen et al., 2010) (see 4.3.3.1).

In many freshwater ecosystems, rising temperatures have been linked to shifts in invertebrate and fish community composition, especially in headwater streams where species are more sensitive to warming (see Chapter 4.3.3.3).

In tundra ecosystems, the particularly strong warming has impacted composition and structure of manu ecosystems, notably by expansion of shrubs, changing mammal populations (foxes, polar bears, caribous etc.), and decomposition of previously frozen soil carbon stocks. Alpine ecosystems throughout the world are noted to change in plant community composition by displacement to higher elevations, including extinction of species previously growing at summit levels (see Chapter 4.3.3.4).

18.3.3. Coastal Systems and Low Lying Areas

Coastal habitats and ecosystems have changed due to impacts from climatic and non-climatic stressors. Coastal ecosystems, being subject to both land- and ocean-based anthropogenic stressors, experience the greatest cumulative impact of human activities (Halpern et al., 2008). Most coral reefs, seagrass beds, mangroves, rocky reefs and shelves have undergone substantial impact. Coral bleaching, detected with high confidence, is attributed to warming with very high confidence (see Box 18-5). Overexploitation and habitat destruction, however, have been responsible for most of the historical changes that occurred in coastal systems (Lotze et al., 2006).

18.3.3.1. Rocky Shores

Changes in abundance and distribution of rocky shore species have been observed since the late 1940s in the North East Atlantic (Hawkins et al., 2008) and experiments has shown the role of temperature (e.g., Peck et al., 2009). The challenge is to distinguish the response to changes from climatic stressors, hydrology or from natural temporal and spatial fluctuations. The AR4 (Nicholls et al., 2007) reported shifts of range limits of many intertidal species of up to 50 km per decade, much faster than most recorded shifts of terrestrial species. However, the geographical distribution of some species did not change in the past decades. This lack of range shifts could be due to weak local warming (Rivadeneira and Fernández, 2005) or overriding effects of variables such as timing of low tide, hydrographic features, lack of suitable bottom types, larval dispersal, food supply, predation and competition (Poloczanska et al., 2011). Changes in current patterns and increased storminess can dislodge benthic invertebrates and affect the distribution of propagules and recruitment. For example, changes in hurricane activity may have subjected mussels to more frequent and more severe disturbances compared to those that occurred during 1971-1994 (Carrington, 2002).

Rocky shores are among the few ecosystems for which field evidence of effects of ocean acidification is available. The community structure of a rocky shore on Tatoosh Island (Washington State, USA) has during the period 2000-2008 experienced decreasing pH, while shifting from a mussel to an algal-barnacle-dominated community, but attribution to a specific stressor or set of stressors is difficult (Wootton et al. 2008). The mechanisms behind the tolerance to low pH of these communities are well understood from several naturally CO_2 enriched locations (Rodolfo-Metalpa et al., 2011; Thomsen et al., 2010), but evidence for attributable impacts is still lacking.

18.3.3.2. *Beaches and Sand Dunes*

Throughout the world, beaches and dunes, as well as bluffs and cliffs, are eroding due to a variety of processes. Some of these processes may be climate related, e.g., rising mean sea levels (Ranasignhe and Stive, 2009), storms (Mitrovica et al., 2010), changes in wave propagation due to sea level changes (Tamura et al., 2010), changes in the direction of mean wave energy (Reguero et al., 2012), the loss of natural protective structures such as coral reefs (Grevelle and Mimura, 2008) or mangrove forests due to increased ocean temperatures or ocean acidification (Bongaerts et al., 2010), permafrost degradation and sea ice retreat (Manson and Solomon, 2007). Due to the scarcity and fragmentary nature of the information available and to the multiple natural and anthropic stressors contributing to coastal erosion, attributing shoreline changes to climate change is still difficult.

18.3.3.3. *Submerged Vegetation*

Evidence for negative effects of high temperature on seagrass biomass has been reported for seagrass meadows in the Atlantic Ocean (Reusch et al., 2005), Mediterranean Sea (Marbà & Duarte, 2010) and Australia (Rasheed and Unsworth, 2011). Cardoso et al. (2008) concluded that extreme weather events contributed to the overall degradation of seagrass meadows in a Portuguese estuary.

Range shifts of macroalgae may be slow (Hinz et al., 2011) and poleward shifts have been documented for warm-water species only (Lima et al., 2007). Hence, the expectation of poleward range shifts of macroalgae due to increasing temperature should be considered with caution as it does not seem to be a universal process (Lima et al., 2007).

18.3.4. Ocean Systems

In the marine realm, climate change may involve the combination of temperature effects with those of other climate related drivers (progressive ocean acidification, expanding hypoxia zones, organism shifts resulting in changing food availability, changes in habitat structure, e.g., loss of sea ice, further human interference, e.g., eutrophication). Synergistic amplification of warming effects can be expected based on process understanding and experimental studies in macroorganisms (high confidence). Observed changes in general processes are shown in Table 18-2.

[INSERT TABLE 18-2 HERE
Table 18-2: Confidence levels for Detection (CLD) and Attribution to climate change (CLA) of changes in general processes in Ocean Systems, by category: Geological record (GR), Phenology (PH), Distribution (DI), Calcification (CA), Abundance (AB), Demography (DE), Shift in Community Composition (SCC); Ocean Biogeochemistry (BGC); Regime Shift (RS), Migration (MI).]

18.3.4.1. *Ocean Warming, Acidification and Expanding Hypoxia*

Since AR4 the reported trends of ocean acidification have been confirmed. Furthermore, the geological record has provided robust evidence that a number of past events share characteristics of ongoing and projected climate change. However, the present and predicted rate of anthropogenic CO_2 input and hence resulting ocean acidification is unprecedented in the last 300 Ma. Effects of extant ocean acidification on marine organisms have, with medium levels of evidence and confidence, been observed in very few species, e.g., mirrored in decreases of shell weight in foraminifera in the field. Attribution is supported by robust experimental evidence showing that species from many phylogenetic groups develop species specific responses and diverse sensitivities. Midwater hypoxic zones (‘oxygen minimum zone’, OMZs) with very low oxygen levels expand due to enhanced stratification and microbial respiration, as detected and attributed with high confidence to climate induced warming trends. Similarly, marine sedimentary habitats have OMZs below shoaling sediment horizons due to limited penetration and movement of dissolved oxygen. With high confidence expanding hypoxia exerts strong local and regional effects, favoring hypoxia tolerant species, excluding the calcifiers and benefiting the microbes. Such shifts are associated with a reduction in biodiversity and the loss of high activity life forms in those areas. Vertical expansion of OMZs has led to compression of oxygenated water layers as a habitat for pelagic fishes with a high oxygen demand.

There is high confidence that many examples of change detected in ocean ecosystems are largely attributed to ongoing anthropogenic warming. Temperature effects reflect the specialization of, especially higher life forms on limited ambient temperature ranges. There is robust evidence and high confidence in both detection of temperature related effects on marine animal species and their attribution to temperature through applicability of the OCLTT concept (oxygen and capacity limited thermal tolerance) by integrating findings across levels of biological organisation, molecule to ecosystem as well as the effects of multiple stressors like ocean acidification or hypoxia.

18.3.4.2. Microbial Processes and Biogeochemical Fluxes

Oceans provide about 50% of the oxygen consumed by human activities. Net primary production (NPP) may shift between regions with medium confidence based on limited evidence, but confidence is low that this increase may be linked to climate change. There is also low confidence in our present knowledge of alterations in microbial effects (ME). A unifying microbial concept comprehensively explaining the effect of climate change on various species and organism level processes of marine microbes (e.g., bacteria, archaea and protists) is lacking, leading to low confidence in detecting related effects in the field. This limits the confidence to low in attributing detected effects to larger scale influences of climate change. As a result, evidence is limited and confidence low in that shifts in biogeochemical pathways such as oxygen production, carbon sequestration and export production, nitrogen fixation, climate-feedback by dimethylsulfide (DMS) production, nutrient recycling, or calcification are presently happening at detectable scales, paired with low confidence in attribution to climate change.

18.3.4.3. Ecosystem Shifts and Consequences for Fisheries

Present variability in oceanographic conditions link to large fluctuations detected with high confidence in the structure of marine ecosystems, with a key role for temperature effects and circulation regimes as drivers (see Table 18-3 for some key examples). Macroorganism (fish, invertebrates and macrophytes) effects (medium confidence in detection, medium confidence in attribution) include (i) changes in abundance and overall biomass, for example of corals or intertidal species detected with high confidence when organsims are exposed to increasing extreme temperatures; (ii) loss of habitat, (iii) changes in community composition and species richness, associated with reduced body body size, (iv) changes in species biogeographical ranges, e.g., to higher latitudes or larger depths as detected in fishes and attributed with high confidence to climate change, or in macroalgal species and rocky shore community distribution which are shifted polewards in response to warming. Long term observations also show shifts in phenology (timing of seasonal activities) and migration patterns, and in competetive as well as trophic relationships (alterations to the predator-prey system dynamics). As a consequence, local changes in catch potential result, e.g., for cod in the Southern North Sea (high confidence) and is, with high confidence attributable to climate change and exacerbated by maintained fishing pressure. The biota in certain regions may be more vulnerable to change than in other regions. In particular, those organisms in changing polar waters are unable to migrate or may be unable to acclimate or adapt to rising temperatures on relevant time scales.

[INSERT TABLE 18-3 HERE
Table 18-3: Confidence levels for Detection (CLD) and Attribution (CLA) for species or site specific processes in Ocean Systems, by category Geological record (GR), Phenology (PH), Distribution (DI), Calcification (CA), Abundance (AB), Demography (DE), Shift in Community Composition (SCC); Ocean Biogeochemistry (BGC); Regime Shift (RS), Migration (MI).]

In marine mammals and birds, confidence is high that effects are mostly mediated through climate dependent changes in habitat structure, availability and phenology of prey organisms, or foraging efficiency, especially in mammals (polar bear, walrusses) and birds (pinguins, albatrosses), such that differential sensitivities result between species. Due to variability between species, confidence in detection is medium but high in attribution to climate change.

Over the last three decades, several species of shallow water reef-building warm water corals have with very high confidence displayed increased bleaching and decreasing calcification, and thereby, with very high confidence responded negatively to the ongoing warming trend and the associated rise in extreme temperature events and amplitudes. The patterns seen may involve an increasing influence of ocean acidification, confirmed by medium evidence for similar phenomena during mass extinctions in earth history (see also Box 18-5).

18.3.5. Food Production Systems and Food Security

Food production systems have experienced a drastic transformation over the past half century. Innovations unrelated to climate or ambient CO_2 concentrations have led to steep increases in output of many food systems, most strongly witnessed during the “Green Revolution”. Due to their relatively small historical impact, effects of changes in climate or ambient CO_2 are often regarded as noise when trying to quantify the impact of agronomic or genetic changes (Bell and Fischer, 1994).

The complexity of food systems makes formal detection and attribution of impacts extremely challenging. Studies that infer an impact of changing conditions on food production or food security, for instance by using a crop model, can be considered a part of formal attribution of impacts, assuming that the change in conditions can be attributed to anthropogenic activity. Identifying a unique fingerprint associated with greenhouse gas emissions is currently not possible. No studies simulate historical trends in food-related outcomes with and without changes in anthropogenic emissions of greenhouse gases, with the possible exception of Auffhammer et al., (2009) for the case of rainfed kharif rice yields in India. Evidence for climate change impacts on food productions systems other than crops and fisheries is very limited.

18.3.5.1. Crops

Attribution of crop changes to climate change implies assumptions about adaptation by famers. It is often assumed that farming practices or technologies did not change in response to weather over the study period. While this assumption may hold true in some cases (Schlenker and Roberts 2009) there is evidence of substantial technology adaptation to climate for a number of crops and locations (Zhang, T. et al., 2008; Liu et al., 2009).

As stated in chapter 7 of this report, many studies of cropping systems have estimated impacts of observed changes in climate over the past few decades. Based on these studies, there is high confidence (high agreement, robust evidence) that climate trends have negatively affected wheat and maize production for many regions, as well as medium confidence (high agreement, medium evidence) for negative impacts on global aggregate production of these crops (see Figure 7-3). There is also high confidence (high agreement, robust evidence) that warming has benefitted crop production in some cold regions, such as Northeast China or England (Jaggard et al., 2007; Chen et al., 2011a). A number of crop modeling studies were concerned with production for individual sites or provinces, scales below which the changes in climate conditions are likely attributable to anthropogenic activity (WG1, Chap x). Similarly, most crop studies have focused on the past few decades, a time scale shorter than most attribution studies for climate. However, some focused on continental or global scales (Lobell and Field, 2007; You et al., 2009; Lobell et al., 2011), at which trends in several climatic variables, including average summer temperatures, have been attributed to anthropogenic activity (e.g. Jones et al., 2008). In particular, global temperature trends over the past few decades are attributable to human activity (see WG1 Chapter 10)., and crop models indicate that this warming has had significant negative impacts on crop yield trends.

18.3.5.2. Fisheries

For fisheries one of the best studied areas is the North East Atlantic, where the temperature has increased rapidly in recent decades, associated with a poleward shift in distribution of fish (Brander, 2007). In the North Sea, average species richness has increased by approximately 33% between 1985 and 2006, broadly attributed to warming (Hiddink and ter Hofstede 2008).

For inland fisheries O'Reilly et al. (2003, 2009) estimate that warming has reduced primary productivity of Lake Tanganyika in East Africa. This warming would have led to a decrease of approximately 30% in fish yields, an important source of animal protein for local communities.

18.3.5.3. Impacts of Extreme Weather Events on Food Production

Frost damage is an important constraint on crop growth in many crops, including for various high-value crops. Significant reductions in frost occurrence have been observed and attributed to greenhouse gas emissions in nearly every region of the world (Alexander et al., 2006; Zwiers et al., 2011; add Ref to IPCC, 2012). Positive trends in the occurrence of unusually hot nights are also attributable to human activity in most regions. These events are likely damaging to most crops, an effect that has been observed most commonly for rice (Peng et al., 2004; Wassmann et al., 2009; Welch et al., 2010). Extremely high daytime temperatures are also damaging and occasionally lethal to crops (Porter and Gawith, 1999; Schlenker and Roberts, 2009), and trends at the global scale in annual maximum daytime temperatures have been attributed to greenhouse gas emissions (Zwiers et al., 2011). At regional and local scales, however, trends in daytime maximum are harder to attribute to greenhouse gas emissions because of the prominent role of soil moisture and clouds in driving these trends (Christidis et al., 2005; Lobell et al., 2007; Zwiers et al., 2011).

18.3.5.4. Effects of Changes in Atmospheric Composition

In addition to effects of climate change, there are clear effects of changes in atmospheric composition on crops. There is very high confidence (high agreement, robust evidence) that the increase of atmospheric CO_2 by over 100 ppm since pre-industrial times has enhanced yield growth, especially for C_3 crops, although these benefits played a minor role in driving overall yield trends (Amthor, 2001; Long et al., 2006; McGrath and Lobell, 2011). As described earlier, increases in carbon dioxide are expected to have negative impacts on carbon accretion in coral reefs with potentially serious negative consequences for associated ecosystems and dependent social and economic activities (Hoegh-Guldberg et al., 2007).

Emissions of CO_2 have also been associated with ozone (O_3) precursors that have driven a rise in tropospheric O_3 that harms crop yields (Morgan et al., 2006; Mills et al., 2007). There is high confidence (high agreement, robust evidence) that elevated O_3 has suppressed global production of major crops, with estimated losses of roughly 10% for wheat and soybean and 3-5% for maize and rice (Van Dingenen et al., 2009). Impacts are most severe over India and China, but are also evident for soybean in the United States in recent decades (Fishman et al., 2010).

18.3.5.5. Food Security

The evidence that climate change has affected food production has potential implications for food security. Quantifying this effect is very challenging, as one needs to make a significant number of assumptions about the larger food system and how it interacts with the remainder of the regional and global economy. There is thus limited direct evidence that unambiguously links climate change to impacts on food security.

One important aspect of food security is global food prices, particularly for poor urban consumers as well as the millions of net consumers in rural areas. Prices for major cereals, oilseeds, and other crops have exhibited an increasing trend over the past decade in a reversal of declining real prices over the previous century. The past decade has also witnessed relatively large volatility in prices, although previous periods such as the 1970's had similar levels of variability when adjusted for inflation (Naylor and Falcon, 2010; Wright, 2011).

In a study of global production responses to climate trends, (Lobell et al., 2011) estimated a price increase of 19% due to the impacts of temperature and precipitation trends on supply, or an increase of 6% once the beneficial yield effects of increased CO_2 over the study period were considered.

18.4. Detection and Attribution of Observed Climate Change Impacts in Human Systems

Observed impacts on human systems have received considerably less attention in previous IPCC reports and the scientific literature than have impacts on natural systems. The following sections provide a synthesis of findings with regard to human settlements, infrastructure and industry, as well a human health, well-being and security that are documented in greater detail in chapters 8, 9, 10, 11, 12 and 13. Additional material has been included from regional chapters and the available literature, in particular for the discussion of impacts of extreme events, human security, and observed changes in indigenous communities.

18.4.1. Cities and Urbanization

There is robust evidence across a set of case studies that climate in many urban areas has shown increasing variability and change consistent with climate change projections. The most robust evidence emerges from observational data for mean annual temperature and precipitation rates, days of extreme temperature, number of extreme rainfall events, and rate of sea level rise. This shifts are associated with an increased probability of flooding, droughts, inland flooding, coastal flooding and storm surge and heat waves, and declines in the number of extreme cold days (see Hunt and Watkiss, 2011; Romero-Lankao and Dodman, 2011; Rosenzweig and Solecki, 2011 for recent reviews). The consequences of these climate-related risks and vulnerabilities in urban areas are linked to the character and extent of urbanization, which varies markedly between cities or regions throughout the world.

Attribution of observed climate change impacts in cities is more difficult to assert. Opportunities to discern climate change signals in cities are complicated by the pattern and pace of urbanization which have consequences for local environmental conditions such as intensification of urban heat islands, land subsidence associated with groundwater withdrawal, and heightened flooding probability resulting from increase of impervious surfaces. These conditions interact with ongoing climate change and as a result make it difficult to provide evidence and attribution agreement of climate change signals in cities. Agreement and evidence of detection and attribution of climate change impacts can be most strongly defined in cities such as London or New York where the current rate of local environmental transformation is relatively low and where data on local climate conditions is particularly rich (i.e., lengthy record period, wide range of data collected). From a century of detailed climate records in New York City, one can observe a trend of increasing mean annual temperatures and more frequent, intense rainfall events in recent decades (NPCC Climate Risk Information 2009).

18.4.2. Economic Impacts, Key Economic Sectors and Services

18.4.2.1. Economic Growth

A negative cross sectional correlation has been observed between per capita income and temperature both across countries (Nordhaus, 2006) and across regions within countries (Dell et al., 2009). Though such correlations are not taken to imply causation, they are nevertheless sometimes considered overly simplistic ("climate determinism"), because the underlying mechanisms are usually complex and often not quantifiable (e.g., Liverman, 2009). In low income countries, careful tracking of incomes and temperatures over an extended period, taking into account important confounders shows that higher temperatures result in substantially lower economic growth (Dell et al., forthcoming). This effect is not limited to the level of per capita income, but also to its rate of growth. Broadly, a 1 degree Celsius increase in annual average temperature has been found to lower economic growth in the same year by 1.3%, which is both statistically and economically significant (Dell et al., forthcoming). The impacts on medium and long run growth are smaller and are detected only with low confidence. The same relationships do not hold for high income countries. Generally, higher temperatures affect economic growth through impacts on the agricultural and industrial sectors (Dell et al., forthcoming). In addition, temperature shocks negatively affect the growth of developing countries' exports, for which 1 degree Celsius of warming in a given year reduces the growth rate of its exports by 2.0-5.7%. The export sectors most affected are agricultural and light manufacturing exports. There is no detectable effect for higher income countries (Jones and Olken, 2010).

18.4.2.2. Economic Losses due to Extreme Weather

Extreme weather impacts encompass both direct as well as indirect damages. Direct damages include monetary losses inflicted as a direct consequence of the weather event, on all types of tangible assets, infrastructure, public facilities or natural resources.Indirect damages are losses outside the area or not directly related to the event, for instance disruption of the documented formal or undocumented informal economy, or longer-term health consequences. Both types of losses can include assets, facilities or resources that are traded in markets, but some are not and these therefore lack a monetary value, for instance, health, the loss of cultural heritage or ecosystem services (Handmer et al. 2012, their Chapter 4.5.1, 4.5.3).

The IPCC Special Report Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (IPCC, 2012) reports on the current understanding of changes in impacts from weather extremes and their causes, including climate change. It established with high confidence that losses from extreme weather at the global level have increased (Handmer et al. 2012; their Chapter 4.5.3.3.; 4.5.4.1.) about 8-fold between 1960s and 1990s, with insured losses rising even faster. One study determined the slope of the linear trend in global insured weather-related losses, deflated to 2008 values, in the period 1980–2008 to be US$ 1.4bn per year (Barthel and Neumayer, 2011).

The chapter in IPCC (2012) dealing with human and ecosystem impacts from weather extremes (Handmer et al., 2012) assessed studies on long-term changes in records of economic losses from weather extremes in detail. These studies have statistically analysed records of economic losses in order to detect changes for a range of weather extremes, including tropical and extra-tropical storms, river floods, tornadoes, wild fires, hailstorms, and flash floods. The main approach applied in such studies is the 'normalisation' of the loss record, which takes account of changes in exposure due to the number of people and number and value of assets at risk (see below). This method has now been applied to many studies on various extreme weather types and using different normalisation approaches (Bouwer, 2011a), that provide the basis for the conclusions drawn in this section. There are no studies available that have attempted a formal attribution in order to link past detected changes in economic losses to anthropogenic climate change (Bouwer, 2011a; Handmer et al., 2012). Some variations that are detected over shorter time spans however have been associated to climate variability, including ENSO (e.g. Pielke and Landsea, 1999).

Much of the analyses on extreme weather losses use data from insurance companies, also many other time series used for analyses are directly or indirectly based on their data. The insurance sector data covers well defined direct monetary losses inflicted on tangible assets, together with a smaller proportion of monetarily defined secondary consequences such as business interruption periods or liability consequences. In most markets, insurance claims and payouts are monitored thoroughly by the insurance and reinsurance sectors. Opposite to insured losses provided by global loss databases of the largest reinsurers, direct overall losses are in those databases preferentially estimated on the basis of insurance claims and other loss indicators, while only one third is directly taken from official governmental sources (Kron et al., 2012). Thus the data on losses incurred by the insurance sector is on average more accurate than direct overall loss estimations, even though accounting for only a proportion of overall direct loss (Changnon, 2009a). While in high-income countries about 40% of direct economic losses are covered by insurance, only about 13% in middle-income countries and approx. 4% in low-income countries are covered (Cummins and Mahul, 2009).

The most prominent driver of the long-term increase in losses is the change in exposure to weather extremes, such as higher concentrations of people and destructible wealth in progressively urbanized environments. Increasing insurance penetration adds to this trend for insured losses. There is high confidence in this finding according to the IPCC, 2012 (Handmer et al. 2012, their Chapter 4.2.2, Box 4-2, and 4.5.3.3; Barthel and Neumayer, 2011; Bouwer et al., 2007; Bouwer, 2011a).

There is some uncertainty regarding the appropriate methods and data for the above mentioned process of normalisation. As data on exposed assets is often lacking, many studies have resorted to proxies that mimic changes in asset values over time, including estimates of population at (sub-)national level, household property value or income, and GDP. Importantly, the possible effects of forecasting, early warning and vulnerability reduction and improved building construction are often ignored in these studies (Nicholls, 2011; Handmer al., 2012, their Ch. 4.5.3.3) with a few exceptions (Crompton and McAneney, 2008), although the overall size of their effects remains to be shown and quantified (Bouwer, 2011b). The majority of studies are focused on high income countries, leading to high confidence with respect to these populations. Still, the wide diversity in data sets and methods used for the normalisation leads to the same results (Handmer et al., 2012), which increases our confidence in the findings from the many studies presently available.

The few studies on trends in normalized insured weather-related losses also focus on populations and regions in high income countries, in particular Australia, USA and Germany (Barthel and Neumayer, 2011; Crompton and McAneney, 2008; Chapterangnon, 2007; Changnon, 2008; Changnon, 2009a; Changnon, 2009b; see also Chapter 10.7). Due to the short time period covered and other confounding factors, it is challenging to conclusively estimate the degree to which detected trends in normalized insured weather losses indicate that an external driver, such as climate, is responsible for the increase in losses.

IPCC (2012) concluded that the main cause of increasing losses from weather extremes and disasters is due to increasing exposure of people and economic assets. No part of the trend towards increasing losses could be attributed to anthropogenic climate change (see IPCC 2012: SPM). This finding is most robustly established for windstorms: i.e. hurricanes in the USA (Pielke et al., 2008; Miller et al., 2008; Schmidt et al., 2009; Bouwer and Botzen, 2011) and Caribbean (Pielke et al., 2003), tornado losses in the USA (Brooks and Dowswell, 2001; Boruff et al., 2003; Simmons et al., 2012), and windstorms in Europe (Barredo, 2010). It is also in line with the absence of changes in tropical cyclone and storm activity that can be attributed to anthropogenic climate change (see also AR5 WG1, Chapter 2).

However, for smaller scale events such as hailstorms there are indications that insured losses may have increased over the past 20 years in some parts of Germany (Kunz et al., 2009). Other studies also indicate possible increases in building damages due to extreme drought in France (Corti et al., 2009). The recent upswing in hurricane hazard and associated losses since the mid-1990s appears at least partly to be connected to multidecadal climate variability (Handmer et al., 2012, their Chapter. 4.5.3.3.; Seneviratne et al., 2012, their Chapter. 3.4.4).

_____ START BOX 18-3 HERE _____

Box 18-3. Impacts of Recent Extreme Events and Their Link to Climate Change

With the climate changing, the frequency and intensity of extreme weather events is likely to change, potentially leading to altered impacts. The IPCC Special Report Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (IPCC, 2012) has concluded, with medium confidence, that the length or number of heat waves has increased and that some regions of the world, in particular southern Europe and West Africa, have experienced more intense and longer droughts. Further, there have been statistically significant increases in the number of heavy precipitation events in several regions. For many regions or systems, confidence in observed long-term changes remains low, e.g., in tropical and extra-tropical storms. Understanding of how this balance is changing requires systematic monitoring such that individual events can be placed in the context of extremes occurring worldwide (Chase et al., 2006, Stott et al., 2012), but a change in climate may also lead to new types of extreme weather events outside the bounds of historically documented weather. Such record-breaking extremes could therefore be an important way through which climate change is perceived. Since societies never experienced these kinds of meteorological extremes before, vulnerability tends to be high, and impacts may be severe.

Table 18-4 lists a number of unprecedented and well documented extreme weather events since 2000, for which attribution to recent climate change has been claimed in the scientific literature, along with a selection of impacts for which attribution to the event has similarly been claimed. Conclusions formed by joining these assessments are derived following a multi-step attribution process [18.2.1.3]. The interpretation and relevance of the attribution assessments of these events (and their impacts) remains dependent on the applied method and is therefore still controversial (Otto et al. 2012, Stott et al. 2012, see also AR5 WG1Ch10).

[INSERT TABLE 18-4 HERE
Table 18-4: Selection of record-breaking meteorological events since 2000, assessment of the confidence in the degree to which anthropogenic emissions made a substantial contribution, selected impacts attributed to the meteorological event, and assessment of the confidence in the degree to which the meteorological event made a substantial contribution to the impact event. Based on (Coumou and Rahmstorf, 2012).]

_____ END BOX 18-3 HERE _____

18.4.2.3. Energy Systems

Higher temperatures have been shown to raise the demand for cooling and lower the demand for heating. Cooling demand is largest in the summer and it has been shown that peak loads during the summer months have increased and that this peak is highly correlated with summer maximum temperatures (Franco and Sanstad, 2008). The literature showing the opposing effects of warmer winters and summers on electricity and gas demand using statistical methods have confirmed this U-shaped relationship of energy and electricity demand in temperature for the United States and elsewhere (Greenstone and Deschenes, 2011, Isaac and Van Vuuren, 2009; Akpinar Ferrand and A Singh, 2010).

Production losses from thermal power plants increase when temperatures exceed standard design criteria (e.g., Erdem and Sevilgen, 2006), as would be expected to occur more frequently under climate change. Power generation facilities may also experience performance losses and other impacts related to changes in access to and temperature of cooling water, as well as sea level rise and extreme weather events (AR5WG2Chapter10; Durmayaz and Sogut, 2006; CCSP, 2007; Kopytko and Perkins, 2011). Further, solar photovoltaic cells become less efficient during hot days (Skoplaki and Palyvos, 2009).

The impacts of higher temperatures and extreme weather events on energy delivery, transmission, and distribution vary across different empirical studies, facility characteristics, geographic regions, and other factors. Barges and ocean vessels that transport energy resources have been shown to be particularly vulnerable to hurricanes, storms, and flooding; pipeline performance can be affected by increasing ambient and soil temperatures, as well as extreme events (IPCC WG2 Ch10, Forthcoming; CCSP, 2007). Some studies have quantified the general relationship between temperature and electricity transmission and distribution infrastructure, finding that increased temperatures can accelerate the aging of transformer insulation, lead to efficiency losses, and create power system reliability issues (e.g., Swift et al., 2001; X Li et al., 2005; Askari et al., 2009).

18.4.2.4. Tourism

Tourism is a climate sensitive economic sector and ample research has been performed to understand its sensitivity to climate change and impacts of (future) climate change on tourism (cf. Scott et al., 2008, see also Chapter 10.6).

There is, however, little literature examining observed climate change impacts in the tourism sector. A comparatively well studied area is wintersports in lower lying areas. For example, the increase in investment in artificial snow machines in the European Alps can be attributed with high confidence to a general decrease of snow depth, snow cover duration and snow fall days since the end of the 1980's for low-elevation mountain stations (Durand et al., 2009; Valt and Cianfarra, 2010; Voigt et al., 2011a, which in turn has been attributed to anomalous warm winter temperatures over the past 20 years (Marty, 2008). Increased variability in precipitation, shrinking glaciers and milder winters have been shown to negatively affect visitor numbers in winter sports areas in Europe and North America (Becken and Hay, 2007).

18.4.3. Human Health

IPCC AR4 (Confalonieri et al., 2008) concluded that there was weak to moderate evidence (with low to medium confidence) of climate change effects on three main categories of health exposures: vectors of human infectious diseases (changes in distribution), allergenic pollen (changes in phenology), and extreme heat exposures (trend in increased frequency of very hot days and heat wave events). There was a lack of evidence for observed effects in human health outcomes, and this remains the case. The complexity of human disease systems, and the importance of social and non-climate environmental factors means that robust studies would require long time series of data on disease rates as well as other potential or actual causative factors. Only two disease systems have been well studied where health data are high quality (to minimize reporting biases), and changes in incidence occurred during and/or after observed warming periods. In all cases, the changes are relatively local and formal “attribution” for infectious diseases is limited to local warming, rather than anthropogenic forcing.

The detection of a change over time for any health outcome (infectious disease, non-communicable disease, injury) is complex and requires that changes in reporting over time need to be taken into account. Malaria incidence has been monitored in the Kericho region of Kenya for over 20 years. A local warming trend occurred during the end of the observation period (Omumbo et al., 2010). Other studies have confirmed that malaria incidence is sensitive to temperature and rainfall effects, but it is a complex ecological system (changes in vector, human and parasite behavior need to be accounted for). A straightforward regression analysis would be insufficient to establish the role of warming in the observed change in distribution. A mosquito-human model, however, has shown that predicted malaria cases exhibit a strongly non-linear response to observed warming (Alonso et al., 2011). A detailed review by Chaves and Koenraadt (2010) finds robust evidence that decadal temperature changes have played a role in changing malaria incidence. Temperature trends should nonetheless not be considered the main or sole cause of such changes in malaria in the east African highland region.

There is limited evidence regarding the role of observed warming in changes in tick-borne disease in mid to high latitudes. The upsurge of tick borne encephalitis (TBE) in the 1980-90s in central and eastern Europe has been attributed to socio-economic factors (human behavior) rather than temperature (Sumilo et al., 2008, 2009). Changes in the observed incidence of TBE in central Sweden remain unexplained however (Randolph et al., 2010). Changes in the latitudinal and altitudinal distribution of ticks in Europe are consistent with observed warming trends (e.g., Gray et al., 2009), but there is no evidence so far of any associated changes in the distribution of human cases of tick-borne diseases. In North America, there is good evidence of northward expansion of the distribution of the tick vector (*Ixodes scapularis*) in the period 1996 to 2004 (Ogden et al., 2010).

There is limited evidence of a change in distribution of rodent-borne infections in the US (plague and tularaemia) consistent with observed warming (Nakazawa et al., 2007). Specifically, a northward shift of the southern edge of the distributions of the disease (based on human case data for period 1965-2003) was observed. There was no change in the northern edge of the distribution. Temperature and rainfall have had effects on the incidence of rodent-borne hantavirus infections in Europe. The reported increase in NE (*Nephropathia epidemica*) in Belgium since 1993 is associated with temperature in the previous year causing an increase in rodents food sources (mast) (Clement et al., 2009). However, there is insufficient evidence to attribute the trend in cases to the observed warming trend.

For pollen production, changes in phenology have been consistently observed in mid to high latitudes with, for example, earlier onset in Finland (e.g. Yli-Panula et al., 2009) and Spain (D'Amato et al., 2007, Garcia-Mozo et al., 2010) (see also Chapter 4). In North America, the pollen season of ragweed (*Ambrosia* spp.) has been extended by 13-27 days since 1995 at latitudes above 44°N (Ziska et al., 2011). Allergic sensitization of humans has changed over a 25 year period in Italy, but the attribution to observed warming remains unclear (Ariano et al., 2010).

AR4 concluded that an increase in heat wave-related deaths could be attributed to climate change. However, this assessment is dependent on the attribution of single weather events (or a short term trend in weather events) to anthropogenic forcing (see WGI for further discussion on this point). The association between very hot days and increases in mortality in temperate populations is very robust. It is therefore very likely that the observed increase in very hot days will have been associated with an increase in number of heat-related deaths in mid-latitude populations, and similarly a decline in cold-related deaths.

18.4.4. Human Security

18.4.4.1. Violent Conflicts and Social Disruptions

There is some evidence that climate events, such as major droughts, have been associated with violent conflict, abrupt disruptions of normal political activities, or security disruptions. In a recent review of work that examines how climatic affect populations with fixed composition, 25 out of 26 quantitative analyses found substantial associations between climate and weather events and violent conflict, social instability or political disruption (Hsiang and Burke, 2012). The relationship of these climate events and their impacts with anthropogenic climate change remains undetermined however.

Associations between some modern violent conflicts and anomalies in rainfall, temperature, drought or water availability have been characterized in Africa at national (Miguel et al., 2004; Burke et al., 2009; Bruckner and Ciccone, 2011; Couttenier and Soubeyran, 2011; Pasquale and Travaglianti, 2010; Hendrix and Salehyan, 2012) and subnational (Harari and Ferrara, 2011; Theisen, 2012) scales, but some of these studies appear contradictory. Ultimately, though, the exact local relation may depend on a variety of other determinants including the local institutions' ability to mediate and cooperate (Adano et al., 2012; Thiesen, 2012).

In subnational datasets outside of Africa, associations between recent civil conflict and water availability have been described globally (Levy et al., 2005), between redistributive conflict and rainfall anomalies in Brazil (Hidalgo et al., 2010), between rainfall declines and inter-ethnic violence in India (Bohlken and Sergenti, 2010) and between high temperatures and personal violence in the United States (Jacob et al., 2007; Larrick et al., 2011). Irregular political transitions, indicating rapid destabilization of existing power structures, appear to be associated with anomalous climatic conditions in some individual countries (Burke and Leigh, 2010; Bruckner and Ciccone, 2011; Burke, 2011).

Measureable associations between anomalous weather and security disruptions have been noted at both municipal (Jacob et al., 2007) and global scales associated with El Niño events in the tropical Pacific (Hsiang et al., 2011). Similarly, changes in the risk of security disruptions have occurred in tandem with anomalous climatic conditions persisting over a variety of temporal scales, from anomalies lasting a week (Jacob et al., 2007) to those lasting roughly a year (Miguel et al., 2004; Burke et al., 2009; Bruckner and Ciccone, 2011; Couttenier and Soubeyran, 2011; Pasquale and Travaglianti, 2010; Hendrix and Salehyan, 2012; Hsiang et al., 2011) through to those lasting decades, centuries and millennia (Cullen et al., 2000; Kuper and Kröpelin, 2006; Chaney, 2011; Buckley et al., 2010; Stahle et al., 1998; DeMenocal, 2001; Haug et al., 2003; Tol and Wagner, 2010; Zhang, D. et al., 2007; Yancheva et al., 2007; Zhang et al., 2006; Bai and Kung, 2010).

The climatic conditions that are associated with security disruptions are almost always linked to lower agricultural yields in staple crops (Schlenker and Roberts, 2009; Lobell and Burke, 2010; Schlenker and Lobell, 2010). It is hypothesized that lost agricultural production may lead to security crises through food prices or other pathways (Lagi et al., 2011; Zhang, D. et al., 2011), but the importance of this pathway remains contested in the absence of clear evidence (Bezzi and Blattman, 2011**;** Carter and Bates, 2012). Large-scale political violence is less responsive to climatic changes in populations that are high-income (Hsiang et al., 2011), suggesting that certain resources or institutions may promote stability. In the absence of clearly defined causal pathways linking security risk with climate variations, it is not possible to assess the degree to which the risk of security crises are attributable to the climate variations.

18.4.4.2. Migration

Large population movements, in response to climatic events, are sometimes considered a human security issue. Possible empirical detection of such relationships has been slow because data sets on population movements are not yet well developed. Moreover, the attribution of migration to climate change is difficult because economic, political, social, demographic, and other environmental drivers interact with climatic drivers to influence migration (Black et al., 2011). Few studies measure or empirically demonstrate how rainfall or temperature changes cause a strengthening or weakening of the various forces driving migration, especially income levels and income variability (Lilleør and Van den Broeck, 2011).

Some large sample studies have been able to detect population movements in response to natural disasters (Smith et al., 2006; Boustan et al., 2012) and climate-induced agricultural losses (Feng et al., 2012) in the United States, where data quality is high. In both the United States and African contexts, crop losses have also been associated with rural to urban population movements within a country (Barrios et al., 2006; Feng et al., 2012). By statistical attribution, Marchiori et al. (2012) estimate that anomalous temperature and rainfall displaced roughly 128,000 people per year in Sub-Saharan Africa during 1960–2000.

Climate change-induced drought has prompted both short-distance (Tacoli, 2009) and long distance international migration, with the Mexican drought of the 1990s providing an example of the latter (Saldaña-Zorrilla and Sandberg, 2009; Feng et al., 2010). In Burkina Faso, temporary moves to other rural areas have increased as a result of a reduction in rainfall (Henry et al., 2004). Even though there is a statistically significant relationship between migration outcomes and rainfall variability, Kniveton et al. (2011) report from own fieldwork that only 27 of 3,517 households identified rainfall as a driver of migration.

18.4.5. Rural Areas, Livelihoods and Poverty

Poor people are expected to experience disproportionate harm from climate change impacts (see Chapter 13). Impacts of climate change on livelihoods and poverty in rural areas may be mediated through water resources, agriculture, ecosystems, infrastructure and other systems. Identifying climate change as a driver of impacts on poverty and livelihoods in rural areas is inevitably problematic though (e.g., Nielsen and Reenberg, 2010). Confidence in attributing observed impacts to climate change therefore tends to be low, even though the deterioration of human livelihoods related to climatic factors may well exist in many regions.

Recent assessments of poverty and climate impacts have focused on food availability and food prices (Ahmed et al., 2009). Repeated drought events erode the assets of the poor and marginal (Tschakert et al., 2011), With a lack of concurrent development, climate change is challenging the coping capacity of Mongolian pastoralists (Janes, 2010). Poverty is a multidimensional and dynamic process which is exacerbated by climate change in many ways, both directly and indirectly (see Chapter 13-9).There is mounting evidence that men and women are impacted differently by climate change, due to their different roles within the household, their communities, and wider socio-political and institutional networks (e.g. Carr, 2008).

For indigenous peoples, specific rights, including the right to life, adequate food, water, health, adequate housing, and the right to self-determination, are directly implicated by the impacts of climate change (Ford, 2009, see also Box 18-4). Violations of these rights are linked to geographic vulnerabilities, such as those of small island states, as well as poverty and existing vulnerabilities and inequalities (Limon, 2009).

_____ START BOX 18-4 HERE _____

Box 18-4. Detection, Attribution, and Traditional Ecological Knowledge (TEK)

Indigenous and local peoples often possess detailed knowledge of climate change that is derived from observations of environmental conditions over many generations. Consequently, there is increasing interest in merging this traditional ecological knowledge (TEK)—also referred to as indigenous ecological knowledge (IEK) or simply indigenous knowledge (IK)—with western science in order to better understand and detect climate change impacts (Ford et al., 2011; Green and Raygorodetsky, 2010; Huntington et al., 2004; Parry et al., 2007; Salick and Ross, 2009). TEK, however, does not simply augment western science, but rather stands on its own as a valued knowledge system that can be "co-produced" with science (Agrawal, 1995; Berkes, 2009; Byg and Salick, 2009; Cruikshank, 2001; Ford et al., 2011; Herman-Mercer et al., 2011; Hulme, 2008; Maclean and Cullen, 2009; Wohling, 2009).

Cases in which TEK and scientific studies both detect the same phenomenon offer a higher level of confidence about climate change impacts and environmental change (Alexander et al., 2011; Cullen-Unsworth et al., 2011; Green and Raygorodetsky, 2010; Huntington et al., 2004; Krupnik and Ray, 2007; Laidler, 2006; Salick and Ross, 2009) and the value of indigenous knowledge. For example, in Peru's Cordillera Blanca mountains, local residents and instrument-based scientific analysis both report increasingly rapid glacial recession, less snow in the upper watershed, decreased water supplies in glacier-fed basins, and an increase of falling glacier "blocks" since the latter half of the 20th century (Baraer et al., 2012; Bury et al., 2010; Carey, 2010; Carey et al., 2012). For another, in Tibet, many, but certainly not all, local residents observed warming temperatures, less snow, and shrinking glaciers, which are consistent with scientific interpretations (Byg and Salick, 2009). And at Clyde River, Nunavut, Canada, Inuit and scientific observations detect that wind speed has increased in recent years and that wind direction changes more often over short periods (within a day) than it did during past decades (Gearheard et al., 2010). Finally, in the Canadian Arctic, Inuit sea ice experts and scientists have both observed the thinning of multiyear sea ice, the shortening of the sea ice season, and the declining extent of sea ice cover, with Inuit observers reporting less predictability in the sea ice and more hazardous travel and hunting at ice edges (Aporta et al., 2011; Ford et al., 2009; Krupnik and Ray, 2007; Laidler, 2006; Nichols et al., 2004).

TEK can also inspire scientists to study new issues in the detection of climate change impacts. In one case, experienced Inuit weather forecasters in Baker Lake, Nunavut, Canada, reported that it had become increasingly difficult for them to predict weather, suggesting an increase of weather variability and anomalies in recent years. To test Inuit observations, scientists analyzing hourly temperature data over a 50 year period confirmed that afternoon temperatures fluctuated much more during springtime during the last 20 years—precisely when Inuit forecasters noted unpredictability—than they had during the previous 30 years (Weatherhead et al., 2010).

Despite frequent confluence between TEK and scientific observations, there are sometimes discrepancies between them. These discrepancies indicate uncertainty in the identification of climate change impacts. Attribution of impacts to anthropogenic climate change, for example, tends to have much less convergence between TEK and western science. While community members in Canada's Northwest Territories report that less ice cracking during the last decade was a result of winter warming caused by climate change, scientists have, concluded that the relationship between ice cracking and air temperature is much more complex and requires more research on water temperature, ice thickness, snow cover, and ice properties in order to attribute reduced ice cracking to global climate change (Woo et al., 2007).

Scale is another problem in the detection of climate change: TEK and scientific studies frequently focus on different and distinct scales that make comparison difficult. Local knowledge may fail to detect regional environmental changes while scientific regional or global scale analyses may miss local variation (Wohling, 2009). In some cases TEK and scientific studies measure or note distinct phenomenon that cannot be compared or have inaccuracies (Gearheard et al., 2010). Furthermore, TEK based observations and related interpretations necessarily need to be viewed within the context of the respective cultural, social, and political backgrounds (Agrawal, 1995). Therefore, a direct translation of TEK into a western science perspective is often not feasible.

_____ END BOX 18-4 HERE _____

Shifts from transient to chronic poverty due to climate change are suggested for livelihoods and households that, unlike more affluent ones, lack appropriate response options to climatic changes and, consequently, are squeezed out of alternatives, ending up as chronically poor with few if no opportunities to reverse this trend (Hardoy and Pandiella, 2009). A number of observed shifts consistent with this suggestion have been noted (see Table 18-5), drawing attention to the elderly poor women and socially and economically oppressed class strata worldwide who, due to highly variable access to critical assets and insufficient rights, are unable to cope with altered seasonalities, unpredictable seasons, and extreme events such as floods and droughts and, hence, are increasingly at risk of shifting into chronic poverty.

[INSERT TABLE 18-5 HERE
Table 18-5: Cases of regional livelihood impacts attributed to climate change or climate variability.]

18.5. Detection and Attribution of Observed Climate Change Impacts across Regions

The following section synthesizes new knowledge since the AR4 for the major regions of the globe, building directly on the corresponding chapters 22, 23, 24, 25, 26, 27, 28, 29 and 30 included in Part B of the AR5.

18.5.1. Africa

African systems present many strong challenges for the potential detection and attribution of responses to climate change. Given the weak spatial and temporal variations in temperature, there is smaller scope for migrational and phenological responses to anthropogenic climate change than in other parts of the world; for instance, natural vegetation coverage is largely controlled by precipitation (Greve et al., 2011). Furthermore, high quality monitoring is relatively sparse in time and space, and often can be badly designed for detecting changes across margins and borders where responses to climate change are often most expected (Midgley et al., 2007). The dearth of studies examining attribution questions means it is currently difficult to estimate the degree to which studies are selectively published based on results, and thus to determine whether each attribution study is only indicative of local reasons for concern or if it is more generally representative of a broader domain.

Since the AR4 there has been a particular research focus on three geographic domains: the effects of dryness in the Sahel since 1970 on tree density and river discharges (le Polaine de Waroux and Lambin, 2011; Gonzalez et al., 2012); the effects of surface warming and resulting increased stratification on the Great Lakes, particularly Lake Tanganyika, on the lake ecology (Verburg and Hecky, 2009); and the effect of warming on species ranges in southern Africa, where spatial temperature gradients are larger and there is more scope for range shifts as a measureable response (Foden et al., 2007; Raxworthy et al., 2008; Hockey and Midgley, 2009; Hockey et al., 2011). The Sahel drying appears to be driven largely by warming of the global ocean and thus a characteristic of larger scale climate change (Giannini et al., 2008); on the other hand, while the warming of the Great Lakes is unprecedented in at least a number of centuries (Tierney et al., 2010; Powers et al., 2011), the large number of recent stressors have made it difficult to determine a climatic contribution to the major trophic shifts of recent decades (Desky and Sarmento, 2008; Stager et al., 2009; Hecky et al., 2010).

There has been continued interest in the link between disease incidence and long-term climate change. Most of this research has tended to be located at the margins of endemicity (Alonso et al., 2011), thus while being indicative of local reasons for concern these studies may not be representative of changes over the continent as a whole (Lafferty, 2009). Gething et al., (2010) note that the overwhelming tendency over the continent over the last century has been toward lower malaria endemicity, mostly due to economic development and disease control (Prudhomme et al., 2010).

A new area of research since the AR4 has been on whether climate variability, and in particular extremes in rainfall, are a driver of conflict (Gleditsch, 2012, see also 18.4.4.1). There is evidence that extremes in rainfall, especially wet years associated with El Niño climatic events, are associated with various forms of political conflict in Africa generally (Hsiang et al., 2011; Hendrix and Salehyan, 2012), but results of studies in Kenya both support and refute this locally (Adano et al., 2012; Raleigh and Kniveton, 2012; Thiesen, 2012). Ultimately, the nature of the local relation may strongly depend on the local social institutions' ability to mediate and cooperate (Adano et al., 2012; Thiesen 2012).

Notably, trends in climate and trends in risks of impacts associated with those climate trends may not be obviously related. For instance, Di Baldassarre et al., (2010) note that flood-related fatalities have been increasing across the continent, but they find no noticeable changes in annual maximum discharges in catchments spanning Africa; instead, they conclude that the trend in flood risk arises from increased vulnerability accompanying unplanned settlement in flood-prone areas. On the other hand, while the tree species most affected by the recent Sahelian drought are fruit-bearing and were probably introduced by humans during the previous wet period (Maranz 2009), detection of an effect on the local communities is complicated as human populations in the region adopt livelihoods less dependent on climate (Nielsen and Reenberg, 2010).

18.5.2. Europe

Further and better quality evidence since 2007 supports the conclusion of AR4 (Alcamo et al., 2007) that climate change is affecting land, freshwater and marine ecosystems in Europe. Warming has caused advancement in the life cycles of many animal groups, including frogs spawning, birds nesting and the arrival of migrant birds and butterflies (see WGII chapter 4 and review by (Feehan et al., 2009). For common European birds, species with the lowest thermal maxima showed the sharpest declines between 1980 and 2005 (Jiguet et al., 2010). Between 1971 and 2000, the average advance of spring and summer was 2.5 days per decade. The pollen season starts on average 10 days earlier and is longer than 50 years ago (Feehan et al., 2009). Warming has shifted sea fish species ranges to higher latitudes [high confidence] and reduced body size in species [low confidence] (Daufresne and Boet, 2007; Daufresne et al., 2009). High temperatures have increased the frequency of harmful cyanobacterial blooms (Johnk et al., 2008).

In European mountain regions, warming has shifted species’ ranges to higher altitudes. Evidence for such shifts is provided by observed changes in vascular plant species richness in a standardized monitoring network across Europe’s major mountain ranges (Pauli et al., 2012). Alpine vegetation in multiple sites across Europe shows evidence of thermophilization – a decline in more cold adapted species and increase in the more warm-adapted species (Gottfried et al., 2012). These shifts had opposite effects on the summit floras’ species richness in boreal-temperate mountain regions (+3.9 species on average) and Mediterranean mountain regions (–1.4 species), probably because recent climatic trends have decreased the availability of water in the European south (Pauli et al., 2012).

A decline in the growth trend of cereal yields in Europe has been observed in the last 20 years (Olesen et al., 2011) although national statistical yields do not reach the potential yields (Supit et al., 2010). In France, genetic progress in wheat yields was partly counteracted from 1990 on by heat stress during grain filling and drought during stem elongation, as well as by agronomical factors (Brisson et al., 2010). This is consistent: i) with statistical modelling showing that cereal yields have been negatively affected by warming in some European countries since 1980, e.g. in France by -5% for wheat and -4% for maize (Lobell et al., 2011) and ii) with agro-climatic modelling showing over 1976-2005 a widespread decline of European potential crop yields, especially in Italy, central and eastern Europe, albeit increasing potential yields in the British Isles (Supit et al., 2010). Overall, the picture is complex and there is only low confidence that cereal yields have been negatively affected by observed warming in some European countries since 1980s [limited evidence].

There is limited evidence regarding the impact of observed climate warming on forest productivity, indicating both increases (Rodolfi et al., 2007) and decreases (Bertini et al., 2011) in Southern Europe (Italy). Since the AR4 there has been more evidence that climate change has affected plant pests and diseases. Higher temperatures have resulted in increased frequency and length of late summer warming events, producing a second generation of bark beetle in southern Scandinavia and a third generation in lowland parts of central Europe (Jönsson et al., 2011). Warming has caused the spread of blue tongue disease in ruminants in Europe (Guis et al., 2012) (medium confidence). Ticks, which are the primary arthropod vectors of zoonotic diseases in Europe, have likely extended their northern distributions with warming (van Dijk et al., 2010).

The frequency of river flood events, and annual flood and windstorm damages in Europe have increased over recent decades. This increase is mainly due to increased exposure (high confidence), and contribution of climate change is not confirmed (Seneviratne et al., 2012, see also 18.4.2.2). The observed increase in the frequency of hot days and hot nights (medium confidence, WGI Chapter 10) is likely to have increased heat-related health effects in Europe (medium confidence), and well as a decrease in cold related health effects (medium confidence) (Christidis et al., 2010). Many impacts on health and welfare, and across multiple economic sectors have been observed due to the major heatwave events of 2003 and 2010 in Europe. The attribution of such events to anthropogenic climate change is discussed in WGI (e.g. Bindoff et al., in prep., 10.6)

18.5.3. Asia

Key findings from AR4 for Asia include a surface mean temperature increase of >1°C to 3°C during the las t century, which has been more pronounced in North Asia, and highly variable precipitation trends with increasing intensity and frequency of extreme weather events. These factors have led to changes in the hydrological cycle and thus, changes in water resources. The combination of warming, sea level rise and precipitation changes has impacted oceanic, coastal and other natural ecosystems, as well as human and managed systems.Since the AR4, a number of new studies have addressed impacts of climate change on natural and managed systems in Asia.

For freshwater resources, observed climate change-related impacts include increased surface water availability in areas of Central Asia, in particular, in the Himalayas and the central Asian Mountains (Cassasa et al., 2009; Shresta and Aryal, 2011; Zhang, J. et al., 2011). For Himalayan glaciers, there is evidence of rapid deglaciation (high confidence) leading to increased water availability in the short term, but attribution to climate change is still difficult due to the relatively short temperature and rainfall records in Nepal (Shresta and Aryal, 2011; Zhang, J. et al., 2011). Marked decline of water availability (low confidence) has been found in the arid and semi-arid areas of the region, such as in eastern Mongolia (Brutsaert and Sugita, 2008). Falling groundwater tables in the Yangtze and Yellow Rivers are observed (medium confidence in attribution to response to warming) as evidenced by falling lake water levels, drying swamps (Cheng and Wu, 2007) and reduced soil moisture in China (Wang et al., 2011). Increasingly, degrading water quality is detected, part of which must be attributed to confounding factors such as direct pollution (Prathumratana et al., 2008; Delpla et al., 2009; Huang et al., 2009; Zhang, G. et al., 2007).

In much of the permafrost zones of Siberia, Central Asia and the Tibetan Plateau, warming has caused a detectable reduction in permafrost areas and increased thickness of the active layer (ALT), with high confidence both in detection and attribution (Romanovsky et al., 2008; Romanovsky et al., 2010; Cheng and Wu, 2007; Zhang, N. et al., 2011; Zhao et al., 2010). This includes the Kazakh part of the Tien Shan Mountains in which there has been an increase of 23% in ALT compared to the early 1970s (Zhao et al., 2010). In northern Asia, the boundary between the continuous and discontinuous permafrost zone is advancing towards the north, while in the Qinghai-Tibet Plateau (QTP) and Central Asian region, decreasing permafrost areas are accompanied by increasing thickness of the active layer, rising lower limit of permafrost and thinning seasonal frost depth are due to the warming and other non-climate stressors such as human activities (Cheng et al., 2007).

Phenological changes consistent with the regional warming are being seen in Asia, such as changes in life cycles or behavior of plants and animals, and in vegetation distribution (Soja et al., 2007; Doi and Katano, 2008; Sokolov and Gordienko, 2008; Primack et al., 2009; Fujisawa and Kobayashi, 2010; Yu et al., 2010). In temperate East Asia, satellite-based monitoring (NDVI) has been used to detect changes in plant growth, indicating (with high confidence both in detection and attribution) a lengthening of the growing season by 9.5 days / decade during the period 1982-2000. This trend has not been confirmed, however, for the period 2000-2008 (Jeong et al., 2011; Piao et al., 2011). There is higher confidence in observed phenology changes in northern China and Japan than elsewhere in the region (e.g., for the flowering of apple and cherry trees in Japan (Fujisawa and Kobayashi, 2010; Primack et al., 2009). Part of this change is attributed to local effects (urban heat island). A change in distribution ranges in invertebrates is also being seen in central Japan (Tougou et al., 2008) with shifts of Lepidoptera in response to four decades of climate warming (high confidence) at Mt. Kinabalu, Malaysia (Chen et al., 2011b). In contrast to other parts of the globe, such as in Europe and Africa, where climate change has influenced the winter migration of birds, inter-annual fluctuations alone explain the dates of arrival for migratory birds in the Southern Urals, despite regional warming (Sokolov and Gordienko, 2008).

Recent changes in the distribution of species and biomes attributed to climate change are consistent with AR4 projections. There is strong evidence that climate trends have been driving the increase in species richness and diversity with decreasing latitudes in the permafrost wetlands in the Great Hing’an Mountains (Sun et al., 2011), the increasing forest productivity at the northern sites in the Siberian taiga and declining along the south (Lloyd et al., 2011) and even in central and semi-arid northeastern Asia where declines of productivity and regeneration is dominant within the Mongolian taiga forests due to increasing aridity (Dulamsaren et al., 2010a). There also are shifts to higher elevations and / or higher latitudes-the observed shift northwards and upslopes in the southern mountains across Russia (Soja et al., 2007), the invasion of trees into the tundra, steppe or alpine meadows at high altitudes of northern Asia (Soja et al., 2007; Kharuk et al., 2010), the expansion of forests in the North Ural Mountains (Moiseev et al., 2010) and the upward migration of the mountain treeline by as much as 70 m in southern Siberia (Kharuk et al., 2010; Kharuk et al., 2011). These studies attribute the changes to climate change-related factors, although some confounding factors such as competition between trees and grasses, infestation and wildfire disturbance are also considered important (Soja et al., 2007; Moiseev et al., 2010; Dulamsaren et al., 2010b; Eichler et al., 2011).

On the other hand, there have been decelerating growth rates in 58-95% of species in the tropical forests (low confidence) in Malaysia during the last 20 years (Feely at al., 2007), contradicting previous studies which have reported accelerated growth rates purported to be caused by rising concentrations of carbon dioxide emissions and carbon fertilization.

For coastal systems and low-lying areas in most of Asia’s non-Arctic coastal ecosystems, it is difficult to separate impacts of climate change from those of non-climate factors such as coastal subsidence, the impacts of groundwater withdrawal and other human activities (Syvitski et al., 2009). There is high confidence in the attribution of climate impacts on Asian coral reefs to climate change (Hoegh-Guldberg, 2011; see Box 18-5). In Japan, observed impacts such as the expansion towards the north of tropical and subtropical macroalgae and toxic phytoplankton (Nagai et al., 2011) are being attributed to the warming of the coastal waters. Similarly, the widespread decline in beds of large seaweeds in Japan is being seen as a result of increases in coastal surface waters, possibly confounded with longer herbivore activity (Nagai et al., 2011). Along the coastlines of Arctic Asia, erosion (an average rate of 0.27 m yr^{-1} in Chukchi Sea and 0.87 m yr^{-1} in the East Siberian Sea, and at larger rates in some parts since the second half of the 20th century) has been detected (Lantuit et al., 2011). Attribution of the coastal erosion to climate change includes both the contribution of permafrost and sea ice degradation (Are et al., 2008).

For managed systems such as food production systems, there are very few studies in Asia and they do not support the quantification of possible responses to climate change. For instance, in China, a study made to quantify the response of rice crops to recent climate change in the region using 1981-2005 data in experimental stations has indicated positive response to higher temperatures and increased radiation in some places but negative response to higher temperatures and increased rainfall in others (Zhang et al., 2010). Elsewhere in the region (Jordan) increasing climate variability, in particular that of rainfall has affected the production of wheat and barley (Bakri et al., 2010).

There is some evidence showing that warming has affected human health in Asia directly or indirectly (Kan et al., 2011; Huang et al., 2008). Most health studies use limited records both in terms of climate and disease surveillance, thus confidence in detected impacts is rather low.

18.5.4. Australasia

There is *very high confidence* that the regional Australasian climate is changing, with long-term warming trends in surface air and sea-surface temperatures, more hot and fewer cold extremes, and changing rainfall patterns, including marked declines in south-west since the 1970s and south-east Australia since the mid-1990s (Hope et al., 2010). Over the past 50 years, increases in regional average temperature can be attributed at least in part to increasing greenhouse gas concentrations *(high confidence)* and changes to rainfall in some parts of the region may also be partially so attributed (*medium confidence*).

The years 2001 to 2010 witnessed record dry conditions in many parts of inland eastern Australia (Potter et al., 2010) with the hydrological impacts exacerbated by record warm temperatures (Cai et al., 2009a) leading to record low river flows (Gallant and Gergis, 2011).

In Australia, late season snow depth, observed in four locations, has declined significantly (Hennessy et al., 2008b). In New Zealand, glacier ice volume has declined by almost 50% over the 20th century and by almost 25% since 1950 (ref.) Many glaciers have also responded to atmospheric circulation changes (e.g., typically higher equilibrium altitudes during La Ninas than during El Ninos) with significant volume losses up to the 1970s, gains after the mid-1980s and further losses since 2000 (Zemp et al., 2008).

The number of tropical cyclones in the Australia region has not changed over 1981-2007 nor has the proportion of intense storms (Kuleshov et al., 2010) (medium confidence). However, there is a trend to less frequent landfall of cyclones since the late 19th century (Callaghan and Power, 2011) and to more cyclones to the west of the Australia relative to the east (Hassim and Walsh, 2008) since 1980. Moreover, a positive trend exists in significant wave height over the southern ocean (Hemer et al., 2010; Young et al., 2011), although a regional study in Tasmania giving conflicting results (Hemer, 2010a).

In Australian terrestrial systems, there is medium to high confidence that some recently observed changes in species' distributions, genetics, phenology and vegetation can be attributed to recent climatic and atmospheric trends. The role of non-climatic drivers, such as fire, grazing and land-use remains uncertain. Phenological changes have been observed in butterflies (Kearney et al., 2010) and passerine birds show reduced body size correlated to local warming (Gardner et al., 2009). The recent expansion of monsoon forests (Banfai and Bowman, 2007) has been linked, in part, to wetter regional climate conditions, higher atmospheric CO_2 and changed fire regimes (Bowman, 2010). Alpine treelines in New Zealand, however, have remained roughly stable for several hundred years (high confidence) despite 0.9°C average warming (McGlone et al., 2010; McGlone and Walker, 2011). For Australian forests, recent changes have not been successfully linked to climate change (Simioni et al., 2009). In agriculture, advancing wine-grape maturation (high confidence) is being partly attributed to anthropogenic warming and the recent drying trends in southern Australia and also, the reduced soil moisture independent of increasing temperature (Webb et al., 2012)

The impacts of recent droughts in freshwater systems in the eastern states and the Murray Darling Basin have been severe, including salinity increases near the Murray mouth (Pittock and Finlayson, 2011). In New South Wales, Australia, a decline in families of macroinvertebrates that favor cooler and faster-flowing habitats (streams), and corresponding increase in families favoring warmer and more lentic conditions has been found (Chessman, 2009). Attribution to climate is difficult above the strong signal of over-allocation, pollution, sedimentation, and exotic invasions (Jenkins et al., 2011).

In the warming oceans around Australia and New Zealand, climate zones have shifted more than 200 km south along the NE Australian coast and about 100 km along the northwest coast (Lough, 2008). Impacts on marine species around Australia occur over a range of trophic levels and include changes in phytoplankton productivity (Johnson et al., 2011; Thompson et al., 2009), macroalgae (Johnson et al., 2011), rock lobsters (Johnson et al., 2011; Pecl et al., 2009), coastal fish (Neuheimer et al., 2011), coral (De'ath et al., 2009), seabirds (Chambers et al., 2011; Cullen et al., 2009), subtidal seaweeds (Johnson et al., 2011; Wernberg et al., 2011), sea urchins (Ling et al., 2009) and intertidal invertebrates (Pitt et al., 2010). The 2011 marine heat wave in Western Australia caused bleaching at Ningaloo reef for the first time, as well as southern range extensions of many marine species, and declines in local abundance (Pearce et al., 2011), see also Box 18-5.

No changes in distribution and abundance of marine species in New Zealand have been detected, likely because ENSO-related variability dominates in many time series (Lundquist et al., 2011; McGlone and Walker, 2011).

Recent heatwaves in Australia have been associated with increases in human mortality and hospital admissions (Khalaj et al., 2010; Loughnan et al., 2010; Tong et al., 2010a; Tong et al., 2010b) (high confidence). Total mental health admissions increased by 7.3% in metropolitan South Australia during heatwaves (1993-2006) (Hansen et al., 2008).

18.5.5. North America

[Subchapter and Synthesis of detection and attribution in North America will be developed post FOD in close cooperation with Chapter 26]

18.5.6. Central and South America

For Central and South America, the IPCC AR4 noted that shifts in water availability, due to changes in atmospheric circulation as and the associated rainfall patterns has been affecting water resources and agricultural activities for some time (Magrin et al., 2007). Where rivers come from glaciers, further changes have occurred due to melting. Besides these phenomena, no impacts have been attributed to climate change, due to the substantial and overriding impacts of land use and land cover change (Lopez-Rodriguez and Blanco-Libreros, 2008; Sampaio et al., 2007).

18.5.6.1. Freshwater Resources

The retreat of tropical glaciers in Venezuela, Colombia, Ecuador, Peru and Bolivia has been confirmed by a number of new studies (e.g. Vuille et al., 2008a; Jomelli et al., 2009; Bradley et al., 2009: Poveda and Pineda, 2009). Likewise, glaciers and icefields in the extra tropical Andes (Central-South Chile and Argentina) face significant reductions (Chapter 27 ref, see also 18.3.1). In this region the effect of glacier retreat is compounded with changes in snowpack extent, thus magnifying changes in hydrograph seasonality by reducing flows in dry seasons and increasing ones in wet seasons.

Rivers in the western Andes show changing discharge patterns attributed to the retreating glaciers and their effects on snowpack accumulation and melt, e.g., some of the most important river basins of Colombia where discharge has decreased during the last 30-40 years (Poveda and Pineda, 2009). Robust trends have also been found in sub-basins of the La Plata River basin (Pasquini and Depetris, 2007), which has shown a positive trend in streamflow in different sites (Conway and Mahé, 2009; Dai et al., 2009; Dai, 2011; Doyle and Barros, 2011; Krepper et al., 2008; Krepper and Zucarelli, 2010; Pasquini and Depetris, 2007; Saurral et al., 2008). Increasing runoff has been attributed to increasing precipitation, but also to trends in land use change that have reduced evapotranspiration (Doyle and Barros, 2011; Saurral et al., 2008). Precipitation increase has been more important in the southern sub-basins, whereas land use change has been more important in the northern ones (Doyle and Barros, 2011).

No trend has been detected in the runoff of the major rivers in the Brazilian North East, nor elsewhere in South America. Dai et al. (2009) performed trend analysis in several rivers, such as the Orinoco, Magdalena and Tocantins, without finding significant trends. The only study done for rivers in Central America is that of Dai (2011) who showed a drying trend in this region.

The reduction in glacier and snowmelt related runoff in the Andes poses important adaptation challenges for many cities, e.g. the metropolitan areas of Lima, La Paz/El Alto and Santiago de Chile (Bradley et al., 2006; Melo et al., 2010). On the other hand excess of water is a challenge in cities in the region. In São Paulo days with rainfall above 50 mm were nearly absent during the 1950s and now occur between 2 to 5 times per year (Marengo 2009b; Marengo et al., 2012b). Increases in floods have been observed also in the Buenos Aires province and Metropolitan region (Andrade and Scarpati, 2007; Barros et al., 2008).

Hydropower is by far the most important source of renewable energy in the region, and changing water resources have been shown to impact hydropower facilities in the Andes (Vergara et al., 2007).

18.5.6.2. Terrestrial and Inland Water Systems

Central and South America house the largest biological diversity and several of the world’s megadiverse countries (Guevara and Laborde, 2008; Mittermeier et al., 1997). Biodiversity loss is an important throughout much of the region (Bradshaw et al., 2009). Conversion of natural ecosystems is the main proximate cause of biodiversity and ecosystem loss in the region (Ayoo, 2008), and attribution of impacts to climate change is possible only under some exceptional circumstances. A well-studied case of extinctions attributed to climate change are amphibians, many of them in Central America (Pounds et al., 2006).

18.5.6.3. Coastal Systems and Low-Lying Areas

Sea-level rise (SLR) of 2mm yr^{-1} is being observed in Central and South America. The Western equatorial border, influenced by ENSO, shows a lower rise, rather variable and hence not distinguishable from past changes. The greatest flooding levels (hurricanes not considered) in the region are found in Rio de La Plata area, which combine a 5 mm yr^{-1} change in storm surge with SLR changes in extreme flooding levels (ECLAC, 2011).

High sea surface temperatures have occurred more frequently in the western Caribbean and have resulted in frequent bleaching events (1993, 1998, 2005, 2010) of the Mesoamerican coral reef, located along the coasts of Belize, Honduras and Guatemala (Eakin et al., 2010). Along the southwestern Atlantic coast, occasional observations since the 1980s and regular monitoring since 2001 indicate that coral diseases have intensified between 2005 and 2007.

18.5.6.4. Agricultural Production

In recent years, the global demand for food, forage, fiber and biofuels promoted a sharp increase in agricultural production in the countries of South and Central America, primarily associated with the expansion of planted areas, and to a lesser extent with increases in productivity. South East South America (Central Eastern Argentina, Paraguay, Southern Brazil and Uruguay) has experienced some of the most significant increases in precipitation during the 20th century (Giorgi, 2002). The rainfall increase has benefited crops (mainly the summer ones) and pasture productivity, partly contributing to a significant expansion of the agricultural area, particularly in climatically marginal regions of the Argentinean’s Pampas (Barros, 2010). Comparing the periods 1930-60 and 1970-2000, maize and soybean yields increased, respectively, by 34% and 58 % in Argentina, 49% and 57% in Uruguay, and 12% and 9% in Southern Brazil (Magrin et al., 2007b) attributed mainly due to precipitation increases.

Warming has also altered conditions for crop production (Lobell and Field, 2007). In central Argentina, warming has likely reduced potential wheat yields, which have been decreasing at accelerating rates since 1930 (Magrin et al., 2009). Changes in growing season temperature and precipitation appear to have slowed the positive yield trends due to bioengineering in Brazilian wheat, maize and soy, as well as Paraguayan soy (Lobell et al., 2011). In contrast, rice in Brazil and soybean in Argentina have benefited from observed precipitation and temperature trends.

18.5.6.5. Health

Climate variability and change are affecting human health in Central and South America (Rodríguez-Morales et al-. 2010, Rodríguez-Morales, 2011; Winchester and Szalachman, 2009). Heat waves and cold spells are affecting short term mortality in most cities (Bell et al., 2008; Hajat et al., 2010; Hardoy and Pandiella, 2009; McMichael et al., 2006; Muggeo and Hajat, 2009).

Re-emergence of diseases in non-previous endemic or previously eradicated/controlled areas has been observed in particular in the aftermath of extremes events such as storm surges and floods, e.g. Dengue fever outbreaks following floods in Brazil in the last decade (Teixeira et al., 2009).

Higher temperatures in conjunction with air pollution exacerbate chronic respiratory and cardiovascular problems. Dehydration from heatwaves increases hospitalizations for chronic kidney diseases (Kjellstrom et al., 2010), mainly affecting construction workers, and CA sugarcane and cotton workers (Crowe et al., 2009; 2010; Kjellstrom and Crowe, 2011; Peraza et al., 2012).

18.5.7. Polar Regions

[Text below is preliminary and will be revised and updated in close cooperation with Chapter 28. Revision will contain more in depth discussion of observed changes in Antarctica]

The Arctic is undergoing the most rapid climate warming on Earth, accompanied by rapid permafrost degradation. The consequences are large changes in the hydrological regime, and impacts on ecosystems and society are dramatic and often non-linear. For several ecosystems, “tipping points” may have been reached already. In terrestrial systems, the final disappearance of permafrost at the margins of its distributional area and in areas with discontinuous permafrost has caused hydrological system changes, leading to drainage in ecosystems underlain by mineral soil and by swamp and secondary lake formation in areas with organic soils (peat) (Molau, 2010).

In the Arctic tundra, several studies highlight the ongoing increase of shrub cover, triggering local feedbacks of warming the atmosphere. In large areas of the coastal tundra, degradation of permafrost has lead to swamp formation. The system of ice wedges and shallow pools is vanishing, with immediate causes on the populations of wading birds and plant communities. Also, run-off patterns of northern rivers have been altered (28.2.1.1). Other observed changes in the Arctic include tree-line advancement in altitude and latitude (Hedenås et al., 2011), a phenological mismatch between the arrival time of birds at their breeding sites, and coastal sea ice break-up (see 28.3.2.1), collapse or dampening of rodent and lemming cyclicity (28.2.3), and reduction of snowbed extent (Björk and Molau 2007).

A number of case studies with detected changes and there suggested attributions are provided on continental levels in Table 18-6, and on subcontinental scale in table 18-7. Attribution may be single step (temperature increase alone) or more complex, either brought about by multiple drivers (climate change, pollutants, and/or socio-economic changes) or by sequences of drivers, e.g., increased temperature inducing permafrost degradation, in turn affecting the ecosystems, ecosystem services, and the local and/or indigenous human communities in terms of human health, food security, and water quality. There are also examples of counteracting drivers, such as the case of altitudinal tree-line advance in northern Fennoscandia proceeding far slower than expected from climate warming alone (Hedenås et al., 2011).

[INSERT TABLE 18-6 HERE
Table 18-6: Detection and attribution of broad-scale impacts of climate change in Antarctica and the Arctic.]

[INSERT TABLE 18-7 HERE
Table 18-7: Detection and attribution of regional impacts of climate change in Antarctica and the Arctic on subcontinental scale.]

18.5.8. Small Islands

Many small islands are undergoing substantial changes in socio-economic conditions that are likely to mask evidence of climate change impacts. For example, coastal erosion is widespread and has adversely affected important tourist facilities, settlements, utilities and infrastructure. The attribution of such shoreline instability to factors like sea-level rise associated with climate change is rarely possible, despite the expectation that coastal erosion is consistent with models of sea-level rise resulting from climate change.

Many small islands are affected by coral bleaching and the consequences of ocean acidification, this issue is further discussed in Box 18-5.

18.5.8.1. Shoreline Change

Changing patterns of human settlement and direct impacts on shoreline processes present immediate erosion challenges in most populated islands and coastal zones (Yamano et al., 2007; Storey and Hunter, 2010; Novelo-Casanova and Suarez, 2010; Ford, 2012), making impacts of climate change and sea-level rise impossible to attribute. A study of widespread erosion on Majuro Atoll (Marshall Islands) found that erosion was common however attribution of this shoreline instability to factors like sea level rise were masked by pervasive anthropogenic impacts to the natural coastal systems (Ford, 2012). Likewise, Cambers (2009) measured average beach erosion rates of 0.5 m yr^{-1} in eight Caribbean islands from 1985-2000, but was unable to quantify the extent of attribution to anthropogenic factors, natural climate variability and / or climate change and sea-level rise.

18.5.8.2. Hydrology and Water Resources

Freshwater supply in small island environments has always presented challenges and has been an issue raised in all previous IPCC reports. Saline intrusion into fresh groundwater reserves on atoll islands is frequently attributed to incremental sea-level rise yet there is a paucity of empirical evidence to support this premises (e.g., Rozell and Wong, 2009). Wave overtopping and wash-over have been shown to impact freshwater lenses dramatically. On Pukapuka Atoll, Cook Islands storm surge over-wash occurred in 2005 and caused the fresh water lens to become immediately brackish, requiring approx. 11 months to recover to conductivity levels appropriate for human use (Terry and Falkland, 2009). While recent sea-level rise will likely have influenced freshwater resources on small islands, there is currently no new evidence demonstrating this.

18.5.8.3. Biodiversity and Forests

Climate change impacts such as sea level rise and increasing temperatures have been linked with disturbance of terrestrial species, communities and ecosystems within islands, but in all cases unequivocal attribution remains difficult (Blackburn et al., 2004; Didham et al., 2005). Sea level rise in conjunction with more frequent and intense hurricanes, have been observed to threaten the long-term persistence of freshwater-dependent ecosystems within low-lying islands in the Florida Keys (Goodman et al., 2012; Ross et al., 2008). On Sugarloaf Key, Ross et al. (2009) found that pine forest area declined from 88ha to 30ha from 1935 to 1991 due to increasing salinization and rising ground water, with vegetation transitioning to more saline tolerant species such as mangroves.
Among tropical bird species reduced reproductive success of the Mauritius kestrel appears to be linked to changing rainfall conditions in Mauritius over the last 50 years, due to a mismatch between the timing of breeding and peak food abundance (Senapathi et al., 2011). Otherwise, warming has influenced the distribution for disease vectors such as mosquitoes potentially threatening biota unaccustomed to such vectors (Freed et al., 2005). Changing climatic conditions have also enhanced conditions necessary for the spread of exotic and pest species in mid-latitude islands (Kudo et al., 2004) as well as in species poor sub-Arctic/Antarctic islands (Chapuis et al., 2004; Frenot et al., 2005), leading to changes in species assemblages and ecosystem function (Chown and Convey, 2007).

18.5.8.4. Human Health

Many small island state populations currently suffer from climate-related health issues, including morbidity and mortality from extreme weather events, certain vector-, food- and water-borne diseases (Ebi et al., 2006). Leptospirosis is an infectious disease that has been identified in the Caribbean as a “highly endemic zone for leptospirosis” with Guadeloupe, Barbados, and Jamaica representing the highest annual incidence (13 to 7.8 per 100,000 population) in the world with only the Seychelles being higher (43.2 per 100,000 population) (Pappas et al., 2008). Studies conducted in Guadeloupe demonstrated a link between El Niño occurrence and leptospirosis incidence with rates increasing to 13 per 100,00 population in El Nino years as opposed to 4.5 cases per 100,00 inhabitants in La Niña and neutral years (Storck et al., 2008). In Trinidad the incidence of leptospirosis during the period 1996-2007 showed seasonal patterns in the occurrence of confirmed cases, with 75% of all cases occurring in the wet season (May to November) (Mohan et al., 2009). Recently changes in the epidemiology of Leptospirosis have been detected especially in tropical islands with the main factors being climatic and anthropogenic (Pappas et al., 2008). While these studies demonstrate sensitivity of small islands to climate-caused health risks, no unequivocal attribution study has so far been made.

_____ START BOX 18-5 HERE _____

Box 18-5. Detection and Attribution of Mass Coral Bleaching and Mortality to Climate Change

Coral reef ecosystems are invaluable ecosystems that support hundreds of millions of people throughout tropics and subtropical regions (Chapter 5, Box 5-3). Coral reefs are also being impacted by a range of local human stressors including declining water quality, physical destruction and the overexploitation of ecologically important reef organisms (see Chapters 5, 29). Climate change through its impact on water temperature has increased the frequency and intensity of heat stress related mass coral bleaching and mortality. Some studies have reported the range shift of some coral species to higher latitudes (Precht and Aronson, 2004; Yamano et al., 2011) although these observations do not translate as the movement of coral reefs given the speed of climate change and the reduction of other critical requirements for coral reef growth at higher latitudes (e.g. light, carbonate ions). The accuracy of reported range changes also depend on the quality of historic studies of species ranges to which these observations are referenced. The loss of reef-building corals is occurring at the rate of 1-2% per year across many regions (Bruno and Selig, 2007; Carpenter et al., 2008; Gardner et al., 2003). Both local and climate change related pressures put at risk food, resources, coastal protection and revenue from industries such as tourism and fisheries (Box 5-5).

Mass coral bleaching events began to occur began in the early 1980s and have affected most coral reefs since then (Chapter 5). Generally, mass coral bleaching occurs when sea temperatures increase 1°C above the long-term summer maxima. Depending on the size of the anomaly and exposure time, communities of reef-building corals may recover, or may experience impacts all the way to the large-scale mortalities seen in 2005 in the Caribbean (Eakin et al., 2010) and worldwide in 1998 (Hoegh-Guldberg, 1999; Wilkinson and Hodgson, 1999). Central to the impacts arising from anthropogenic climate change is the sensitivity of reef-building corals and their endosymbiosis with single cell, plant-like dinoflagellates (Chapter 6.2.2.4.4). Sudden changes in the environment trigger the disintegration of this all-important relationship, leading to the loss of the brown symbionts from the coral's tissues (Figure 5-5). This eliminates a vital energy source for corals leading to increased starvation, disease and death. In addition to heat stress, ocean acidification levels projected under anthropogenic emissions scenarios were shown to decrease calcification rates within experimental studies (Chapter 6.2.2.1.).

This has important implications for the carbonate balance of coral reefs. Given their central role, the loss of reef-building corals reduces the ability of reef systems to maintain their structure and role in providing habitat for thousands of plants and animals, many of which are important to human well-being (Chapter 5, Box 5-3).

Our understanding of the mechanisms underlying the sensitivity of reef-building corals to elevated sea temperatures is advanced and involves a sensitivity of light capture and related photosynthetic events within the dinoflagellate symbionts. In addition to this, the coral host is also sensitive to heat stress (Chapter 6.2.2.4.4). This understanding has led to satellite technology which has medium to high accuracy in the projection of when and where mass coral bleaching events are likely to occur (Donner, 2011; van Hooidonk and Huber, 2009). The satellite techniques use the accumulation of heat stress above 1°C above the long-term summer maxima to project when coral bleaching is likely to occur, and to some extent the speed of recovery (Eakin et al., 2010).

The experimental support, field evidence and robust process models that link mass coral bleaching and mortality to elevated sea temperature enable robust attribution of these impacts to climate change (very high confidence; Box 30.8.2). Using projected temperatures under various RCP scenarios reveals that sea temperatures will increase to levels which will exceed the ability of coral reefs to recover in all but RCP2.6 (Box 30.8.2, Figure 30-18). Under this situation, coral-dominated reef systems will continue to decline, reducing important ecosystem goods and services that support hundreds of millions of people living in the tropical and subtropical coastal areas.

_____ END BOX 18-5 HERE _____

18.5.9. Oceans

During recent decades, the world’s oceans have warmed (by 0.05°C/decade for deep oceans to >0.1 °C/decade in the upper 75 m), become more acid (decline in pH of 0.1 overall, with least decline in the tropics and most at high latitudes), and have had significant regional changes in salinity (increases and declines) (WGI Chapter 3). These changes have been attributed to rise in global GHG emissions (high to very high confidence, WGI Chapter 3). Changes in upwelling (both increases and declines), oxygen levels, and in ocean-atmospheric cycles (e.g., ENSO, NAO and PDO) have also been detected, but attribution of these trends to greenhouse gas forcing has been met with lower confidence.

There has been a rapid and substantial increase in the number of studies documenting significant changes in marine species and processes since the AR4. Significant changes in wild species and ecosystems have been attributed to these trends in water temperature, stratification of temperature, salinity and acidity with varying levels of confidence (from medium to very high) depending on the nature of the data (e.g. length and completeness of time series and sampling intensity) for the species or system and the scale of the study (see also Box 18-2; and Box 18-5 for detailed discussion on Coral Reefs).

A new global oceans database was established that compiled long-term observations of biological systems, with nearly half of the time series extending prior to 1960 and coverage of multiple ecosystems (coastal to open ocean), latitudes (Antarctic to Arctic) and trophic levels (phytoplankton to top predators) (Poloczanska et al. in prep). Among 1701 data series, 1286 time series showed a response to climate in either direction, 84% of these were consistent with local or regional temperature trends. This is similar to results for terrestrial species (Parmesan and Yohe, 2003; Rosenzweig et al., 2008) and to a regional study in the NE Atlantic (Tasker, 2008) and significantly different from null expectations (Poloczanska et al., in prep). 23% of the studies provided some level of process understanding of how climate affects a given species or system, providing improved traceable pathways from climate change to impact on species (Poloczanska et al. in prep).

The consistency of marine species’ responses across geographic regions, taxonomic groups, and among types of responses, overwhelmingly in the direction expected from local or regional temperature trends is at a global scale, matching the global scale for ocean warming attribution studies, and providing very high confidence that anthropogenic climate change has driven recent changes in ocean species and ecosystems. The level of attribution and confidence is lower for smaller geographic regions, specific taxonomic groups, or specific types of responses. For example, there are differences among groups of species in the relative roles of other anthropogenic drivers. Some taxonomic groups are driven by non-climate drivers that can be as strong as or stronger than climate change on a regional scale, such as commercial fish that suffer high fishing pressures. For example, the northward distribution shift in plaice *Pleuronectes platessa* in the North Sea between 1913 and 2007 is predominantly driven by warming temperatures (medium confidence), while both climate change and fishing play a role in the expansion of sole *Solea solea* into the cool southern North Sea (Engelhard et al., 2011) In the area west of Scotland, fish species diversity decreased with warming as the number of boreal species declined and no concurrent trend was found in the richness of southern species (ter Hofstede et al., 2010). It is likely that fishing pressure has contributed to this apparent lack of response by southern commercial fish.

In regions where sea surface temperature (SST) is the primary driver of biological change, and where trends in SST are particularly strong and/or consistent (e.g., the North Atlantic and the North Sea), it is nevertheless difficult to quantitatively separate climatic effects from other forcing factors, such as over-fishing, eutrophication, physical disturbance (e.g. trawling). Some studies found changes in abundance of fish species consistent with regional warming, but there were also differences in response between groups, likely due to their exploitation status (Tasker, 2008; Overland et al, 2010; Hakkonen et al., 2011; Schwing et al., 2010; Belkin, 2009). Several studies found that exploited fish, whose overall numbers are lowered through fishing pressure, are more sensitive to environmental variability in general, including temperature trends and extremes (Hsieh et al., 2005, 2008; Stiger et al., 2006).

In other regions, such as the California Current, high-quality databases support very high confidence in ability to detect significant change, but the nature of the climate change signal is more complex than elsewhere. El Niño and

PDO effects are very strong, and though recent studies indicate that this phenomenon is being altered by GHG forcing, there is still little agreement on the exact nature of that alteration (Bonfils and Santer, 2011). There is therefore low expectation to the possibility of linking biological change to observed increased upwelling and GHG forcing (see Chapters 6.y and 30.x of this report).

In summary, new research has uncovered a large number of significant changes in marine species and ecosystems that can be related to local changes in SST, upwelling timing and intensity, and freshwater input. However, extending those analyses on a local or regional scale to relate the specific observed changes in marine species to GHG forcing remains an important question for on-going major research (Stock et al., 2010; PROOCE PIO).

18.6. Synthesis

[Disclaimer: The synthesis of IPCC WG2 AR5 findings on detection and attribution of observed climate change impacts across sectors and regions is a process involving all regional and sectoral chapters of WG2. Material presented in this section is given as a description of the stage of this process in May 2012. It will evolve and strengthen as we prepare for the SOD.]

Results in the preceding sections build on the sectoral and regional assessments made by WG2 of IPCC AR5. For most assessments, care has been taken to develop confidence statements based on the quality of evidence and the level of agreement (Mastrandrea et al., 2010, see Figure 18-6). Since chapters have employed varying logics for their assessment, and since the underlying data and knowledge is highly heterogeneous, it is not yet possible to draw all of them together into one coherent framework. Instead, this framework will be developed during the remaining time of the assessment.

[INSERT FIGURE 18-6 HERE
Figure 18-6: Confidence as a function of evidence and agreement. Source: Mastrandrea, et al. (2010).]

The goal for our synthesis is to organize findings on detection and attribution in order to advance the assessment of “Reasons for Concern” (RfC’s), developed in IPCC-TAR (Smith et al., 2001) and adopted for a second time in IPCC-AR4 (e.g.IPCC, 2007, p.19). These were established in response to the United Nations Framework Convention on Climate Change’s (UNFCCC) commitment to “stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system”. The UNFCCC also highlighted 3 broad metrics with which decision-makers were to assess the pace of progress toward this goal: allowing “ecosystems to adapt naturally to climate change”, ensuring that “food production is not threatened”, and enabling “economic development to proceed in a sustainable manner”.

These RfC’s continue to provide useful insight into impacts that might be considered as evidence of “dangerous anthropogenic interference”, and they will again be employed in the contribution of Working Group II to the AR5 (see e.g. Chapter 19). They are noted here for the purpose of definition and provide a brief synopsis of historical context; in doing so, we take advantage of language that was approved as part of the Synthesis Report of the AR4:

1. **Risk to Unique and Threatened Systems**: In the AR4, there was new and stronger evidence of observed impacts of climate change on unique and vulnerable systems (such as polar and high mountain communities and ecosystems), with increasing levels of adverse impacts as temperatures increase further. Authors then noted an increasing risk of species extinction and coral reef damage that was projected with higher confidence than in the TAR.
2. **Risk of Extreme Weather Events**: The AR4 noted that responses to some recent extreme events reveal higher levels of vulnerability than the TAR. Even then, there was higher confidence in the projected increases in droughts, heat waves and floods, as well as their adverse impacts.
3. **Distribution of Impacts**: The AR4 noted sharp differences across regions. The AR4 highlighted that those in the weakest economic position were often the most vulnerable to climate change. AR4 authors emphasized increasing evidence of greater vulnerability of specific groups such as the poor and elderly not only in developing but also in developed countries.

4. **Aggregate Impacts**: These are market-based calculations of aggregate economic effects across the globe. Compared to the TAR, initial net market-based benefits from climate change were projected in the AR4 to peak at lower magnitudes of warming. In addition, damages were projected to be higher for larger magnitudes of warming so that the net costs of impacts of increased warming were projected to increase over time.
5. **Risks of Large Scale Discontinuities**: The AR4 reported that there is *high confidence* that global warming over many centuries would lead to a sea level rise contribution from thermal expansion alone that is projected to be much larger than observed over the 20th century, with loss of coastal area and associated impacts. There is better understanding than in the TAR that the risk of additional contributions to sea level rise from both the Greenland and possibly Antarctic ice sheets may be larger than projected by ice sheet models and could occur on century time scales. This is because ice dynamical processes seen in recent observations but not fully included in ice sheet models assessed in the AR4 could increase the rate of ice loss. The question here is whether or not we have observed any evidence of such discontinuities at an even smaller scale.

Each RfC categorizes impacts of a similar type, providing a set of admittedly aggregate metrics that reflect the severity of one type of risk or another. Relationships between various impacts reflected in each RfC and increases in global mean temperature have been portrayed visually. The first iteration of this visual was included in the Summary for Policy Makers for the Working Group II contribution to the TAR and was highlighted in the Synthesis Report for that assessment. The left-hand panel on Figure 18-7 displays that representation. The AR4 did not include a comparable figure, but it did organize its synthesis along the same metrics. A comparable representationwas subsequently published by Smith, et al. (2009); it is depicted on the right-hand panel of Figure 18-7.

[INSERT FIGURE 18-7 HERE
Figure 18-7: Reasons for Concernt (RfC) from IPCC (2001) and updated per IPCC (2007) in Smith, et al. (2009).]

Observed impacts of climate change relate to the bottom segment of the diagrams in Figure 18-7. The objective of the following synthesis is to interpret, to the degree possible, the available evidence on detected and attributed impacts with regard to the RfC terminology. Figure 18-8 displays a summary view of our current state of the AR5 assessment. There is a wide diversity in confidence on both detection and attribution. The upper-right hand corner suggests high confidence in a number of gradual impacts that have been detected and attributed; while the lower left corner offers insight into the opposite composite. In between, a range of systems' impacts indicate differences in confidence on both detection and attribution for a variety of observed impacts.

[INSERT FIGURE 18-8 HERE
Figure 18-8: Confidence in detection and attribution across various sectors and systems. Open symbols denote attribution with respect to anthropogenic emissions, while solid symbols denote attribution with respect to observed trends in relevant climate variables. Preliminary draft, will be revised and updated as this assessment proceeds. Chapter (Ch) numbers refer to Chapters within AR5 WG2 report, with Ch1 summarizing findings of WG1.]

18.6.1. Risk to Unique and Threatened Systems

Figure 18-9 displays current input about detected and attributed implications concerning "Risk to unique and threatened systems" as a result of trends in relevant climate variables.

[INSERT FIGURE 18-9 HERE
Figure 18-9: Confidence in detection and attribution of observed impacts on unique and threatened systems as a result of observed trends in relevant climate variables. Preliminary draft, will be revised and updated as this assessment proceeds.]

Coral reefs are standing out here, with very high confidence in both detection and attribution of impacts. Over the last three decades, communities of warm water reef-building corals have displayed increased bleaching and mortality, and decreasing calcification, responding negatively to the ongoing warming trend and the associated rise in extreme temperature events and amplitudes *(very high confidence)*. The growth of long-lived reef-building corals has declined since 1990 in at least three ocean regions, most probably due to increasing temperatures although ocean acidification is likely to play an increasing influence on the ability of corals to precipitate calcium carbonate (high confidence, 30.5.6.2). In some areas such as the semi-enclosed Arabian/Persian Gulf, the increasing frequency of extremes has driven a dramatic decrease in coral abundance and community structure (high confidence, 30.5.6.1 Paleontological evidence suggests that most marine mass extinction events, including the disappearance of reef-building corals and carbonate reef systems, were associated with ocean acidification (Box 18-5).

Arctic sea ice loss also ranks high in both confidence in detection and attribution, while confidence in associated implications on both ecosystems and human systems will be somewhat lower. Earlier reported trends in Arctic sea ice decline and thinning have been confirmed (high confidence), along with the shortening of the sea ice season. Inuit observers also reported less predictability in the sea ice, more hazardous travel and hunting at ice edges (Box 18-4, 18.3.1.2, 18.5.7, Table 18-5).

Coastal erosion and shoreline changes are being observed in many Small Island states. Even though this is consistent with expected impacts from Sea Level Rise, attribution to climate change is confounded by rapidly changing socio-economic conditions resulting in other adverse human impacts (18.5.8).

Decreasing populations of endemic high alpine plants are critical in the literature on terrestrial species extinction (or at least migration depending on the scale of the study). The links to climate change here are increasing temperatures that result in prolonged growing seasons, on the one hand, and increasing competition from subalpine species (e.g. in Pyrenees and the Alps, see 18.5.2), on the other.

In the Arctic tundra, terrestrial systems are influenced by the disappearance of permafrost at the margins of their distributional areas. Areas with discontinuous permafrost have experienced hydrological system changes, leading to drainage in ecosystems underlain by mineral soil and by swamp and secondary lake formation in areas with organic soils (i.e., peat). As a consequence, several ecosystem “tipping points” may have already been reached (18.5.7 and 18.3.2.5). Coastal communities in the Arctic are increasingly affected by coastal erosion attributed to a combination of degrading permafrost and increased wave activity due to earlier coastal see ice melt (high confidence; 18.5.7, 28.4.1.3.1).

There is *high confidence* in a largely homogeneous signal of glacier shrinkage all over the world, with equally high confidence that internal variability is exceeded. Robust evidence exists as regards observed impacts of glacier decay, e.g. in tourism, traffic, energy and security (risks) related aspects (18.3.1.2).

18.6.2. Risk of Extreme Weather Events

One of the most discussed manifestations of observed climate change relate directly to changes in the intensity and frequency of extreme weather events. . Every populated continent has seen extreme weather events and endured their consequences, but the magnitudes of those consequences are modulated by other policy and social decisions about where to develop and what to assume about associated risks. Figure 18-10 displays two sets of inferences with respect to confidence in detection and attribution. One reflects simply changes in the frequency and intensity of a variety of storms derived from a careful assessment for North America (see Kunkel et al., 2012). As shown in the figure, confidence in detecting a change over the past few decades and attributing those changes to climate drivers is higher in our understanding of alpine rock failures (see below), and extreme precipitation events in the US, but lower with respect to thunderstorms, ice storms in the US, and floods globally.

[INSERT FIGURE 18-10 HERE
Figure 18-10: Confidence in detection and attribution of extreme weather events and their impacts. [preliminary draft, will be revised and updated as this assessment proceeds]]

There are statistically significant trends in extreme precipitation events, with more increase than decrease but the observations are not uniform over the globe. Due to multiple drivers of change and limitations in the instrumental record there is low confidence in detection and attribution of changes in floods (18.3.1).

Both insured and non-insured losses due to extreme weather events have risen over the past decades but when those losses are 'normalized' for changes in exposure and welfare, most studies do not find any trend (18.3.1, 18.4.2.2, Box 18-3). They are noted in the graph, however, because associated risk is potentially high (given high consequences) even though confidence in attribution is particularly low.

An increase in alpine rock slope failures has been detected with high confidence in regions with a comparably good standard of documentation (European Alps). There is medium confidence that climatic changes and related impacts on glaciers and permafrost are influencing this signal. Both observations and process understanding suggest that it is difficult to detect changes in shallow landslides, mainly due to multiple drivers, including human drivers such as land-use changes (18.3.1.2, 18.4.1, 18.3.1.3).

18.6.3. Distribution of Impacts

Evidence of climate change impacts have been reported from all regions, systems and oceans. While strongest evidence is still from Europe and North America, considerable literature has developed elsewhere since the AR4, particularly in Asia, South- and Central America and Australasia. Figure 18-11 offers a limited current snapshot for several regions. Notice in particular, and in contrast to the AR4, that medium to high confidence in detection and medium confidence in attribution has been determined in Africa temperature change and some natural species impacts at a sub-continental level; attribution to climate change for impacts on human systems is still low for categories for which detection is recognizable.

[INSERT FIGURE 18-11 HERE
Figure 18-11: Confidence in detection and attribution across regions. Attribution of African temperatures is with respect to anthropogenic emissions, while other topics are with respect to trends in relevant climate variables. [preliminary and incomplete draft, will be revised and updated as this assessment proceeds]]

[Below we include text summaries for most regions. Graphic representation is still under development, and limited by lack of clear confidence statements at this point in time. We hope and even expect that comparable figures about confidence will be forthcoming for the SOD for all regions based on improved framework]

For example, evidence of cryosphere (including permafrost) and ecosystem responses in the Arctic to the most rapid warming on Earth has continued to grow since AR4. As noted above, *high to very high confidence* can be claimed in attribution of processes such as ongoing increase of shrub cover in arctic tundra, degradation of permafrost and swamp formation in the coastal tundra, altered run-off patterns of northern rivers, tree-line advancement in altitude and latitude, phenological mismatch between the arrival time of birds at their breeding sites, coastal sea ice break-up, collapse or dampening of rodent and lemming cyclicity, and reduction of snowbed extent (18.5.7).

[Input on Antarctica missing, but it will be developed in cooperation with Ch28 for SOD]

There remains a lack of studies for Africa, and so detection and attribution of impacts is challenged by comparably weak spatial and temporal variations in temperature, and sparse high quality monitoring. Range shifts have been detected for some southern subtropical and mountain-based species in directions expected due to regional warming (medium confidence), and the surface layers of the Great Lakes are now at their warmest in at least the past several hundred years (high confidence). Over the continent, other factors remain dominant over climate change in driving the recent trends in incidence of vector-borne diseases (medium confidence). The Sahel drying after 1970 appears to have been driven largely by warming of the global ocean (medium confidence), but attribution of impacts is sparse (18.5.4).

For South and Central America, increases in air temperature and possibly other climatic variables, have resulted in retreat of tropical glaciers, and significant reductions in glaciers and icefields in the extra tropical Andes (high confidence). Compounded with changes in snowpack extent, the latter are magnifying changes in seasonality by reducing flows in dry seasons and increasing them during wet seasons (low to medium confidence). Reduction in melt-related run-off in the Andes imposes challenges for several Megacities' water supply, for hydropower generation and irrigation.

Conversion of natural ecosystems is the main proximate cause of biodiversity and ecosystem loss in the region. Impacts on Coral Reefs have been documented throughout the region, with extreme high sea surface temperatures in the western Caribbean near the coast of CA resulting in frequent bleaching events of the Mesoamerican coral reef.

Increased precipitation has benefited crops and pasture productivity in South East South America, contributing to a significant expansion of the agricultural area in climatically marginal regions of the Argentinean Pampas. Increase in summer temperatures slowed positive yield trends for maize and wheat in Brazil, and soy in Brazil and Paraguay. In contrast, rice in Brazil and soybean in Argentina have benefited from observed precipitation and temperature trends.

Heat waves and cold spells are affecting short-term mortality in most South American cities, and re-emergence of diseases in non-previous endemic or previously eradicated/controlled areas has been observed in particular in the aftermath of extremes events such as storm surges and floods. Higher temperatures in conjunction with air pollution exacerbate chronic respiratory and cardiovascular problems, and dehydration from heat waves has increased hospitalizations for chronic kidney diseases (18.5.6).

For the world's oceans, there has been a rapid and substantial increase in the number of studies documenting significant changes in marine species and processes since the AR4. It is now possible to state that all major Ocean systems are impacted by climate change with medium to very high confidence (Ch 6 Figure 18, Ch 30 Figure 11D, 18.3.4), with few exceptions within the Eastern boundary currents, and Equatorial upwelling systems, where process understanding is insufficient and the number of studies designed to detect climate change is low.

Significant changes in maritime wild species and ecosystems have been attributed to (usually combined) trends in water temperature, stratification (due to temperature and salinity changes), salinity and acidity, with *medium to very high* varying levels of confidence. While on a global aggregate level, confidence is *very high* confidence that anthropogenic climate change has driven recent changes in ocean species and ecosystems, the level of attribution and confidence may differ for smaller geographic regions, specific taxonomic groups, or specific types of responses (18.3.4, 18.5.9).

In Europe, further and better quality evidence supports the conclusions of AR4 that climate change is affecting land, freshwater, marine and mountain ecosystems. There is *low confidence* that cereal yields have been negatively affected by observed warming in some European countries since 1980, and limited evidence regarding the impacts on forest productivity. There is increasing evidence that climate change has affected plant pests and diseases, and contributed to spread of zoonotic disease vectors and blue tongue disease.

There is *medium confidence* that observed climate change has affected both heat and cold related mortality. A contribution of climate change to the observed increase in flood and windstorm damages in Europe could not be confirmed (18.5.2)

There is *very high confidence* that the regional Australasian climate is changing, with long-term warming trends in surface air and sea-surface temperatures, more hot and fewer cold extremes, and changing rainfall patterns. In Australian terrestrial systems, there is *medium to high confidence* that observed changes in species' distributions, genetics, phenology and vegetation can be attributed to recent climatic and atmospheric trends, but with varying influence of non-climatic drivers, such as fire, grazing and land-use. Changes in species distribution, phenology and productivity have been observed in marine systems around Australia in a range of trophic levels, and many can be attributed to ocean warming with *medium to high confidence*. In New Zealand, no changes in distribution and abundance of marine species have been documented as driven by climate change, in part because ENSO-related variability dominates in many time series (18.5.4)

[Subchapter and Synthesis of detection and attribution in North America will be developed post FOD in close cooperation with Chapter 26]

In Asia, rapid deglaciation of the Himalaya mountains continues (*high confidence*). Shifting rainfall patterns in Central and Eastern Asia have significantly increased water availability in some regions (Himalaya and Central Asia) and decreased water availability in others (China). Permafrost in Siberia, Central Asia and Tibet is receding due to recent warming, causing changes in tundra ecosystems. Numerous additional changes in phenology and plant productivity have been observed and attributed to warming in Japan, Russia, Malaysia and elsewhere in Asia (18.5.3).

In Small Islands, environmental degradation (coastal erosion) still masks possible impacts of climate change, despite the known high sensitivity. However, first indications of saltwater intrusion and negative ecological consequences are available from the Florida Keys (18.5.8)

18.6.4. Aggregate Impacts

[There is very limited evidence in the literature reporting observed economic damages with clear attribution to climate change, and certainly not enough to sum to something aggregate. To inform the assessment, though, we take the spirit of the AR4 to suggest that aggregate impacts may be calibrated by many other metrics, as shown in the health example below]

There continues to be weak to moderate evidence (*with low to medium confidence*) of climate change effects on various human health exposures, and a lack of evidence for observed effects in human health outcomes. The complexity of human disease systems precludes formal attribution to local warming trends in most cases.

There is medium evidence that decadal temperature changes have played a role in changing malaria incidence in a single population in East Africa. Observed changes in the latitudinal and altitudinal distribution of ticks in mid to high latitudes are consistent with observed warming trends. However, there is no evidence of any associated changes in the distribution of human cases of tick-borne diseases.

There is limited evidence for changes in rodent borne infections in the USA and Europe consistent with observed trends in temperature and precipitation. However, evidence is insufficient to attribute those trends to local warming or anthropogenic climate change.

The association between very hot days and increases in mortality in temperate populations is robust. It is therefore very likely that the observed increase in very hot days will have been associated with an increase in number of heat-related deaths in mid-latitude populations, and similarly a decline in cold-related deaths. However, attribution of increases in heatwave-related deaths to climate change depends on the attribution of single weather events (or a short term trend in weather events) to anthropogenic forcing, which is still under debate.

18.6.5. Risks of Large-Scale Discontinuities

Large scale discontinuities are a source of future risk, as they refer to tipping points in the earth system that may alter the state of the system itself. Model based early warning signals (sensu Lenton, 2011) may be derived from monitoring changes in the climate system, which is discussed in WG1.

In some cases, such as the tundra ecosystem, or the Amazon forest dieback, observed impacts may already hint towards the onset of processes leading to such large scale shifts towards a different state of that system. Sufficient process understanding therefore allows medium confidence in attribution, even where evidence for detection may still be scarce (Figure 18-12).

[INSERT FIGURE 18-12 HERE
Figure 18-12: Confidence in detection and attribution of the onset of large scale discontinuities. [preliminary draft, will be revised and updated as this assessment proceeds]]

Confidence in detection and attribution is generally very low to medium, but paucity of observed and attributed evidence should not be taken as dismissing this reason for concern. It is to suggest, instead, that some modest evidence of potential discontinuous effects have begun to be detected and perhaps attributed.

18.7. Gaps, Challenges, and Opportunities

[Will be developed post FOD]

Frequently Asked Questions

[Expect additions post FOD as key messages evolve]

FAQ 18.1: What do detection and attribution mean with respect to observed impacts of climate change?
Two processes are involved in the revelation of observed impacts of anthropogenic climate change. *Detection* refers to the process of identifying a change in a system that was predicted to result from human-caused climate change. The main challenge in detection is to establish that an observed change is not just due to short term variation, but a true change. *Attribution* refers to determining whether a detected change is partly or fully the result of human-caused climate change. This requires ruling out the possibility that an observed change is fully due to other causes, including local or regional climate variations that are unrelated to human-caused climate change.

FAQ 18.2: Why are the detection and attribution of climate-related impacts important?
In deciding how to respond to human-caused climate change, policymakers and others need to understand what impacts have already been observed and what their likely consequences are for natural systems and human society. The detection and attribution of such impacts supports this understanding.

FAQ 18.3: How is uncertainty in the detection and attribution of climate-related impacts assessed?
The IPCC has developed guidelines for characterizing uncertainty about all of its findings. In some situations, uncertainty can be characterized formally using the methods of statistics. In these situations, which typically require a relatively large amount of high quality data, the IPCC recommends using a likelihood scale that specifies the probability that a finding is correct. For example, a finding is said to be “very likely” if the probability that it is correct is greater than 90%, or “very unlikely” if this probability is less than 10%. In other situations, it is not possible to apply the methods of statistics and uncertainty has to be characterized in qualitative terms. In these situations, this characterization involves a subjective assessment of evidence including the strength of the theoretical basis of the finding and the degree of agreement among experts about it. In such cases, the IPCC recommends using a confidence scale ranging from “very low” to “very high”.

FAQ 18.4: Is it possible to attribute a single event, like a disease outbreak or the extinction of a species, to human-caused climate change?
Although it is possible in principle to attribute a single event to human-caused climate change, the high variability and complexity of most natural and human systems makes it very difficult to do so in practice. Instead, scientists tend to look for patterns - such as a change in the frequency of such events over time or space - that are unlikely to represent natural variations.

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Table 18-1: Sample of global and local climate drivers and some local non-climate drivers that might influence a natural or human system.

Drivers of global climate change which affect local climate Greeenhouse gas emissions Aerosol emissions Solar luminosity changes Explosive volcanic eruptions	**Local climate changes which are drivers of impacts** Air temperature changes Ocean temperature changes Precipitation changes Humidity changes	**Impacts on a natural or human system**
Drivers of local climate change Land use/cover change Aerosol emissions		
	Local non-climate drivers of impacts Land use/cover change, deforestation, urban encroachment Ecosystem management Air pollution Policies that enhance or reduce resilience	

Table 18-2: Confidence levels for Detection (CLD) and Attribution to climate change (CLA) of changes in general processes in Ocean Systems, by category: Geological record (GR), Phenology (PH), Distribution (DI), Calcification (CA), Abundance (AB), Demography (DE), Shift in Community Composition (SCC); Ocean Biogeochemistry (BGC); Regime Shift (RS), Migration (MI).

Process	**Cat**	**CLD**	**CLA**	**Additional remarks**	**Ref**
Information in Geological records consistent with present and expected CC	GR	high	Medium	Rate of current change much faster than in earth history	[1]
Reduction in foraminiferan shell weight due to ocean acidification effects	CA	medium	medium	Attribution supported by experimental evidence as well as physiological knowledge showing species specific responses and diverse sensitivities across taxa	[2]
Expansion of Ocean hypoxic zones	BGC	high	high	OMZs caused by enhanced stratification and bacterial respiration	[3]
Regional and local impacts of expanding Hypoxia	SCC	high	high	Reduction of biodiversity, compression of oxygenated habitat for intolerant species, Range expansion for tolerant taxa	[4]
Temperature effects on marine biota	PH, AB, DI, MI, RS	very high	very high	Attribution supported by experimental and statistical evidence as well as physiological knowledge of unifying principles (OCLTT) and species specific responses	[5]
Increasing Net Primary Production in high latitudes	BGC	medium	high	Due to sea ice decline	[6]
Small increase in Net Primary Production globally	BGC	medium	low	Discrepancy between satellite observations and open ocean time-series sites	[7]
Macroorganisms most clearly affected by climate change	AB, PH, DI, SCC	high	high	Involves changes in trophic and competitive interactions	[8]
Clear effects on marine air breathers in individual examples	AB	high	high	Effects mostly through changes in habitat structure and food availability	[9]
Reef-building warm water corals affected by warming and ocean acidification	AB	very high	very high	Effects mostly attributed to warming and rising extreme temperatures	[10]
Synergistic effects of climate drivers	all	low	high	Synergisms supported by experimental studies	[11]
Changes in microbial processes	BGC	low	low	Limited evidence and understanding of microbial processes, drivers and interactions	[12]
Biogeochemical Responses to CC	BGC	Low	high	Limited evidence for large scale shifts in biogeochemical pathways such as oxygen production, carbon sequestration and export production, nitrogen fixation, climate-feedback by DMS production, nutrient recycling, or calcification	[13]

[1] Hönisch et al., 2012; Ch. 6.1.2; [2] Moy et al., 2009, de Moel et al., 2009, Ch. 6.2.2, 6.3.4; [3] Stramma et al., 2008, Stolper et al., 2010, Ch. 6.2.2 [4] Levin et al., 2009; Ekau et al., 2010, Stramma et al., 2010, 2012, Ch. 6.3.3; [5] Perry et al., 2005; Beaugrand et al., 2010, Alheit et al., 2012, Merico et al., 2004; Pörtner and Farrell 2008; Ch. 6.2.2, 6.3.2; [6] Arrigo and van Dijken, 2011,, Ch. 6.3.1;[7] Behrenfeld et al., 2006, Saba et al., 2010, Ch. 6.3.1; [8] Müller et al., 2009, Sagarin et al., 2009, Veron et al., 2009, Stige et al., 2010, Ch. 6.3.2; [9] Grémillet D, Boulinier, 2009; McIntyre et al., 2011, Ch. 6.2.2.4¸[10] Veron et al., 2009; Ch. 6.2.2.4; [11] Crain et al., 2008, Walther et al., 2009; Boyd et al., 2010. Ch. 6.3.6.1; [12] Ch. 6.3; [13] Ch. 6.3.

Table 18-3: Confidence levels for Detection (CLD) and Attribution (CLA) for species or site specific processes in Ocean Systems, by category Geological record (GR), Phenology (PH), Distribution (DI), Calcification (CA), Abundance (AB), Demography (DE), Shift in Community Composition (SCC); Ocean Biogeochemistry (BGC); Regime Shift (RS), Migration (MI).

Process	Cat	CLD	CLA	Add. Remarks	Ref
Shift in distribution of atlantic cod, Regime shift and regional changes in Plankton Phenology in North Sea	DI; PH	high medium	medium medium	AC and PP both associated with temperature effects and influencing each other	[1]
Falling abundance of eelpout in Wadden Sea	AB	medium	high	Effect elicited and exacerbated by rising temperature amplitudes during extreme events	[2]
Collapse of spawning migration of Pacific Salmon in Fraser River, BC, USA	MI	high	high	Effect elicited and exacerbated by rising temperature amplitudes during extreme events	[3]
Growth and distribution patterns of banded morwong, NZ	DI, DE	high	medium	Example exemplifies specialization and performance scope of species depending on climate regime	[4]
Shift from sardines to anchovies in Japanese Sea	AB, RS	medium	medium	Effect correlated with temperature shift	[5]
Increments in fish species richness in temperate zones	SCC	high	medium	Effect associated with warming trends	[6]
Change in catch potential for Atlanic cod in Southern NorthSea	*	high	high	*FCP is a function of many categories	[7]

[1] Perry et al., 2005, Pörtner et al., 2008, Beaugrand et al., 2010, Ch. 6.3.2; [2] Pörtner and Knust, 2007, Ch. 6.3.2; [3] Eliason et al., 2011; Ch. 6.3.2; [4] Neuheimer et al., 2011; Ch. 6.3.2; [5] Takasuka et al., 2007, 2008; Ch. 6.3.2; [6] Hiddink and ter Hofstede, 2008; Beaugrand et al., 2010; Ch. 6.3.2; [7] Perry et al., 2005; Ch. 6.3.2.

Table 18-4: Selection of record-breaking meteorological events since 2000, assessment of the confidence in the degree to which anthropogenic emissions made a substantial contribution, selected impacts attributed to the meteorological event, and assessment of the confidence in the degree to which the meteorological event made a substantial contribution to the impact event. Based on (Coumou and Rahmstorf, 2012).

Year	**Region**	**Meteorological Record-breaking Event**		**Associated impact event**	
		Description	**Assessment of substantial contribution of anthropogenic emissions**	**Description**	**Assessment of substantial contribution of meteorological event**
2000	England and Wales	record-breaking daily precipitation in several regions led to wettest autumn on record since 1766 [Alexander and Jones 2001]	medium confidence [Pall et al. 2011, Kay et al. 2011, DEFRA 2001]	£1.3 billion of insured losses [Association of British Insurers 2001]	virtually certain [Environment Agency 2001, Pall et al. 2011, Kay et al. 2011, Association of British Insurers 2001]
2003	Europe	hottest summer in at least 500 years [Luterbacher et al. 2004, Schar et al. 2004]	very likely [Stott et al. 2004, Schär et al. 2004, Christidis et al. 2010]	death toll exceeding 70,000 [Robine et al. 2008]	very likely [Robine et al. 2008]
2005	North Atlantic	record number of tropical storms, hurricanes and category 5 hurricanes since 1970 [Trenberth and Shea 2006]	very low confidence [Emanuel 2005, Webster et al. 2005, Knutson et al. 2010, Pielke et al. 2008, Vecchi et al. 2008, Landsea et al. 2009]	1,700 deaths and over US$100B in damage [*Beven et al.*, 2008]	unequivocal [*Beven et al.*, 2008]
2006-2007	Europe	hottest record fall and winter in at least 500 years [Luterbacker et al. 2007, van Oldenborgh 2007]	high confidence [Cattiaux et al. 2009, Yiou et al. 2007]	partial second flowering or extended flowering in 2006, early flowering in 2007 [Luterbacher et al. 2007]	high confidence [Luterbacher et al. 2007]
2010	Western Russia	hottest summer since 1500 [Barriopedro et al. 2011]	medium confidence [Otto et al. 2012, Rahmstorf and Coumou 2011, Dole et al. 2011]	Burned area > 12,500km [*Müller*, 2011]	low confidence [Müller, 2011]

Table 18-5: Cases of regional livelihood impacts attributed to climate change or climate variability.

Population	**Observed climate change**	**Impact on livelihood**	**Reference**
Small-scale farmers, Ghana	Drought	Landscape transformation, poverty	Tschakert et al., 2001
Middle-class farmers, Australia	Drought	Landscape transformation, income loss from agriculture, social conflict, poverty	Alston, 2011
High Arctic Native people	Warming	Changing ice and snow conditions, dwindling access to hunting grounds	Ford et al., 2007; Ford 2009, see also box 18.2.1
Urban populations in Maputo, Accra, Nairobi, Lagos, Kampala	Flood frequency and severity increase	Direct impacts on people	Douglas et al., 2008
Industry workers in India	Warming	Ability to carry out physical work	Ayyappan et al., 2009; Balakrishnan et al.; 2010
Farmers in Subarnabad, Bangladesh	Sea-level rise	Salt water intrusion, shift from agriculture to shrimp farming, loss of agricultural livelihoods	Pouliotte et al. 2009
Ghana farmer’s wives	Change in seasonal climate	Pressure from husbands limiting involvement in agriculture, poverty	Carr, 2008
Cambodian rice farmers	Warming, rainfall irregularities	Shift in income generation patterns between men and women	Resurreccion, 2011
Poor children worldwide	Climate variability	Food price shocks, reduced caloric intake, physical stunting, reduced lifetime earnings	Alderman, 2010

Table 18-6: Detection and attribution of broad-scale impacts of climate change in Antarctica and the Arctic.

	System	**Detection in TAR/4AR**	**Detected change**	**attribution, confounding factors**
Antarctic	Lakes	yes	increased nutrient concentrations and phytoplankton production (28.2.1.1)	warming, longer ice-free period, albedo decrease, permafrost thawing
	Southern Ocean		changes in community structure (28.2.2)	Over-exploitation by top predators
	Shelf ice		Southern displacement of penguin colonies (28.2.2)	Reduced ice cover, warmer sea currents
	Southern Ocean		Albatross and petrel decrease (28.2.2)	Impacts from long-line fishery; plastic debris
	Southern Ocean		reduced krill abundance (28.2.2)	reduced sea ice extent
	Fur seals		increased numbers on subantarctic islands and Antarctic Peninsula (28.2.3.5.4)	release of hunting pressure; decreased competition with whales
Arctic	Coastal shores	AR4 15.4.6.1	erosion (28.4.1.3.1.)	wave erosion and permafrost melting
	Tundra shrub cover	AR4 15.2.1	continuing shrub increase (18.3.2, 28.2.3)	warming and prolongation of growing season
	Tundra vegetation activity		increased NDVI (28.2.3)	increased plant cover, particularly deciduous shrubs
	Arctic Europe		altitudinal treeline advancement (28.2.3)	warming and prolongation of growing season; counteracted by grazing pressure and moth outbreaks
	Tundra plant communities		community change (18.3.2; 28.2.3)	warming
	Arctic snowbeds	TAR	reduction (28.2.3), (Björk & Molau 2007)	warming and prolonged growing season; change from snowfall to rain
	Arctic basin		increased krill abundance (28.2.1.1)	intrusion of water from the North Atlantic and Pacific Oceans
	seabird communities		phenological mismatch in arrival relative to sea ice break-up, resulting in lower reproductive success (28.3.2.1)	warming and earlier sea ice break-up along coasts
	plant communities on formerly frozen mineral soils		increase of boreal species (18.3.2), (Molau, 2010)	warming, permafrost degradation
	plant communities on formerly frozen peat		swamp formation	
	river flow		earlier spring flood (28.2.1.1)	warming, earlier snowmelt
	river flow		increased winter flow (28.2.1.1)	permafrost thawing and/or increased precipitation
	lake ice		earlier break-up, later freeze-up (28.2.1.1) (Callaghan et al., 2010)	warming
	thermokarst lakes		increase/decrease (28.2.1.1)	
	ocean		increased primary production (28.2.2)	extended ice free period
	polar bears		reduced reproductive success, decreased survival rates (28.2.3.3)	reduced multiyear sea ice cover; pollutants

Table 18-7: Detection and attribution of regional impacts of climate change in Antarctica and the Arctic.

Region	System/Impact	Detection	Attribution, Confounding factors
Alaska	human health	increase in allergic reactions from insect stings and bites (28.2.4.2)	summer warming
Arctic Fennoscandia and Greenland	voles and lemmings	collapse or dampening of population cycles (28.2.3), (Björk and Molau, 2007; Molau, 2010)	warming, increased winter rain and ice layer formation in snow pack
Canadian Arctic	water quality	Deteriorating freshwater quality, increased water-borne diseases (28.2.4.2)	spring flood increases, permafrost degradation
Canadian High Arctic	shallow lakes	earlier summer drainage (28.2.1.1)	extended ice-free period accompanied by higher temperatures and evaporation
Canadian Low Arctic	limnic biogeochemistry: permafrost thaw	increased phytoplankton and macrophyte productivity in slump-affected lakes (28.2.1.1)	permafrost degradation inducing nutrient release and changes in water column light level
Eurasian Arctic	reindeer husbandry	decrease in some areas, increase in a few (28.1.2.1)	winter snowpack increase, ice crust formation, earlier spring flood, social and political factors, oil and gas exploration
Antarctic Peninsula	plant distribution	increase (28.2.3.5.1)	warming and increased water availability
European Arctic	birds	snow-bunting decrease (50%) ; (Molau, 2010)	snowbed reduction
North American Arctic	food security	decreasing utility of traditional ice cellar storage of fish and game (28.2.4.2)	warming, permafrost degradation

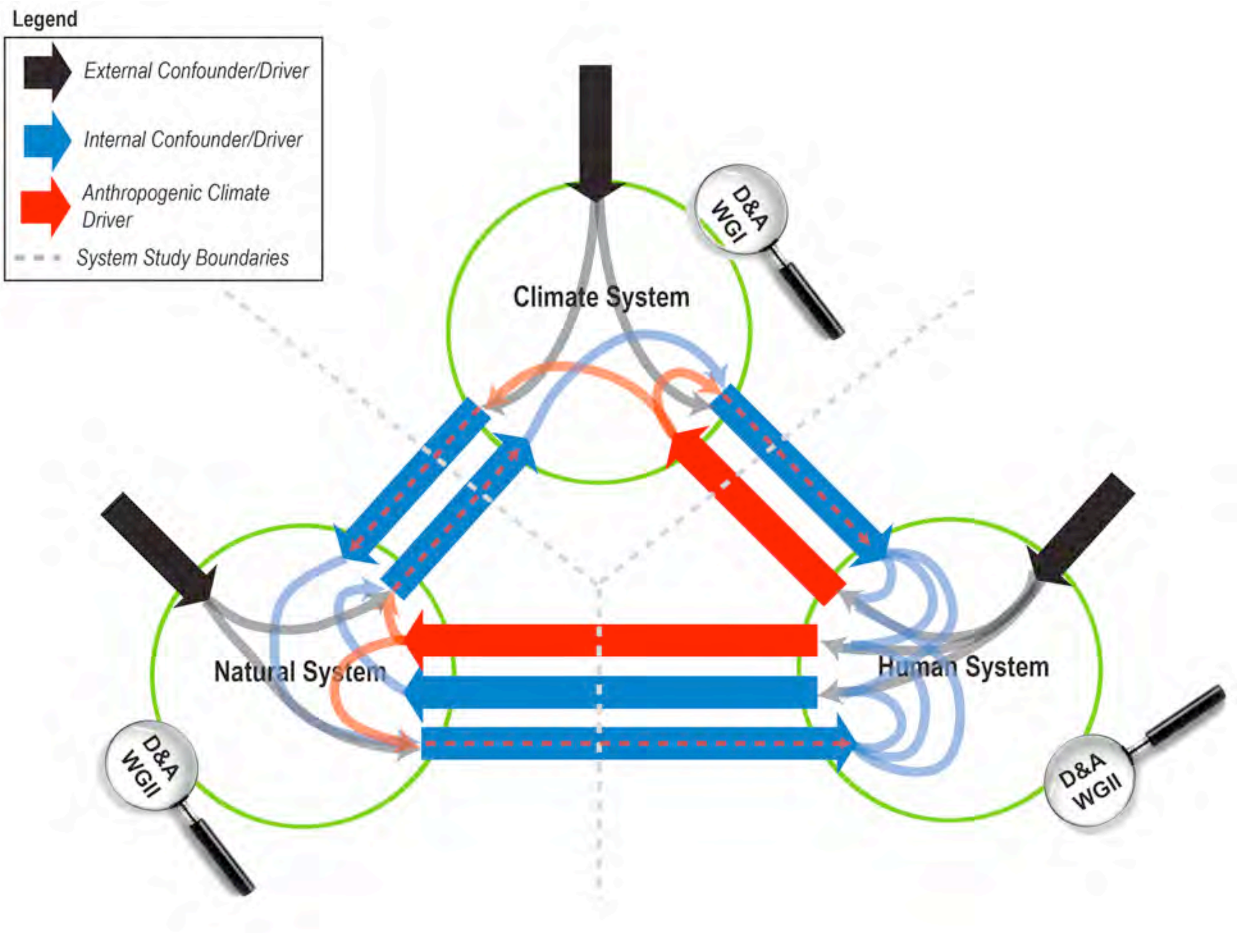


Figure 18-1: Schematic of the subject covered in this chapter. External drivers outside of the three systems considered are marked with black arrows. Direct drivers of the human system on the climate system are denoted with a red arrow; some of these drivers may also directly affect natural systems, for example through CO_2 fertilization, as denoted by the second arrow. Further influences of each of the systems on each other that do not involve direct anthropogenic climate drivers are represented by blue arrows.

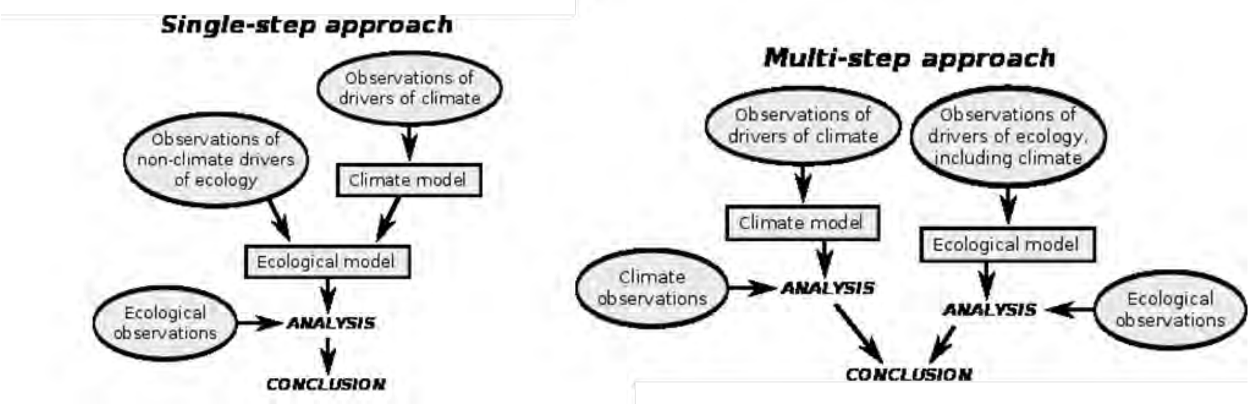


Figure 18-2: A schematic diagram comparing approaches to attribution for an ecological system. The multi-step approach differs from the end-to-end approach in having a discontinuity between the attributed climate change and the observed weather driving the ecological model (Stone et al., 2009).

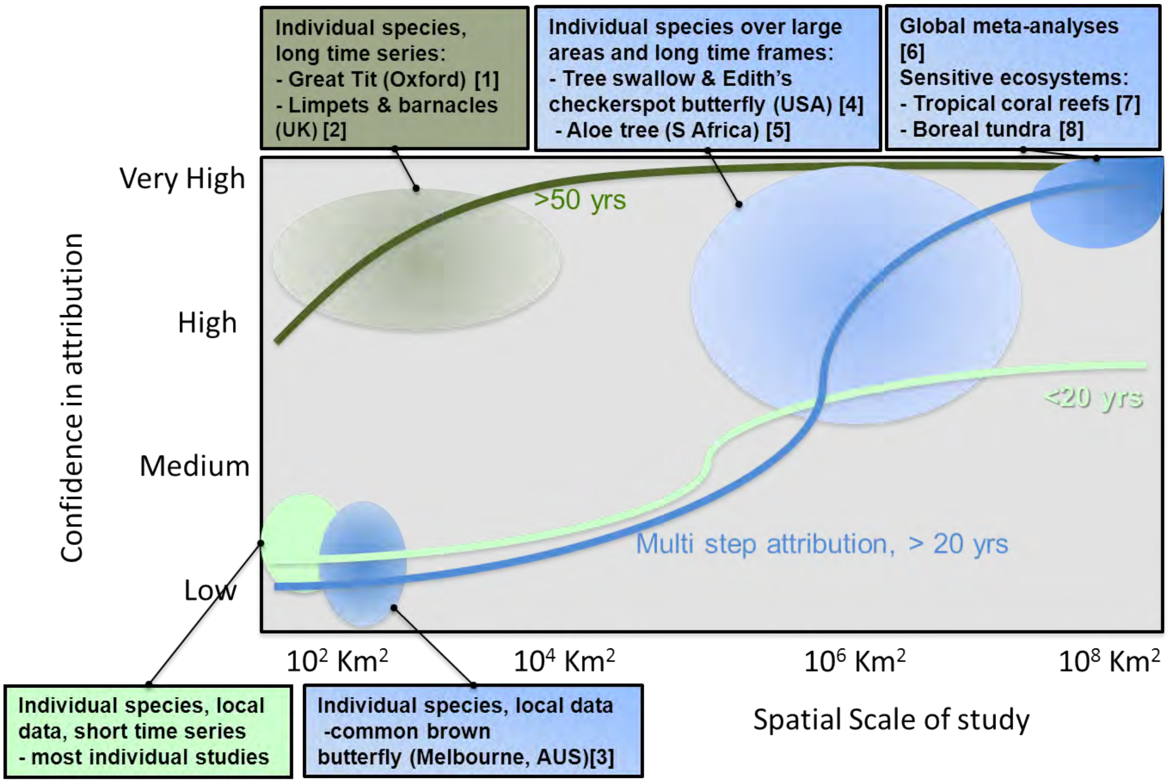


Figure 18-3: Confidence landscape in biological attribution studies. Green lines depict levels of confidence in attributing a given detected change in a wild species or biological system to detected trends in climate or changes in climatic patterns. Pale green = studies with <20 years of continuous data, dark green = studies with >50 years of continuous data. The blue line represents studies with 'double attribution', that is, attribution of a given detected change (or changes) to greenhouse gas driven climate change. (Modified from Parmesan et al., 2011); Numbered references in figure: [1]Perrins et al., 1997; [2]Southward et al., 1995; Southward et al., 2005; [3]Kearney et al., 2010; [4]Parmesan, 1996; Parmesan, 2003; Karl et al., 1996; Dunn and Winkler, 1999; Johnson et al., 1999; Karoly et al., 2003; Zwiers and Zhang, 2003; [5]Foden et al., 2007; [6]Parmesan and Yohe, 2003; Root et al., 2003; Root et al., 2005; Parmesan, 2007; Rosenzweig et al., 2008; [7]Hoegh-Guldberg, 1999; Fedorov and Philander, 2000; Hansen et al., 2006; Latif and Keenlyside, 2009; WGII Chapters 6 and 30; [8]Oechel et al., 2000; Sturm et al., 2001; Sturm and Racine, 2006.

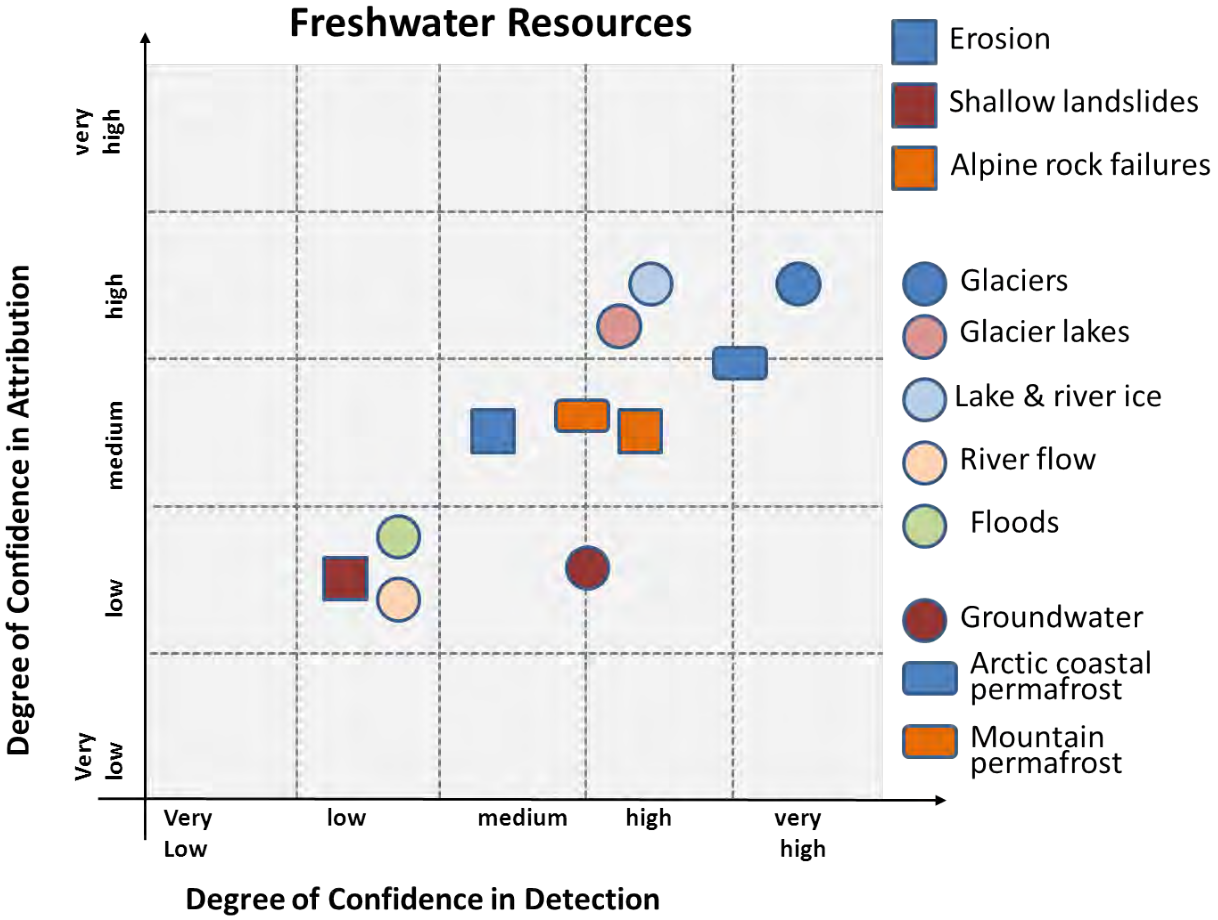


Figure 18-4: Levels of confidence in detection and attribution of observed climate change impacts for Freshwater Systems, including the Cryosphere.

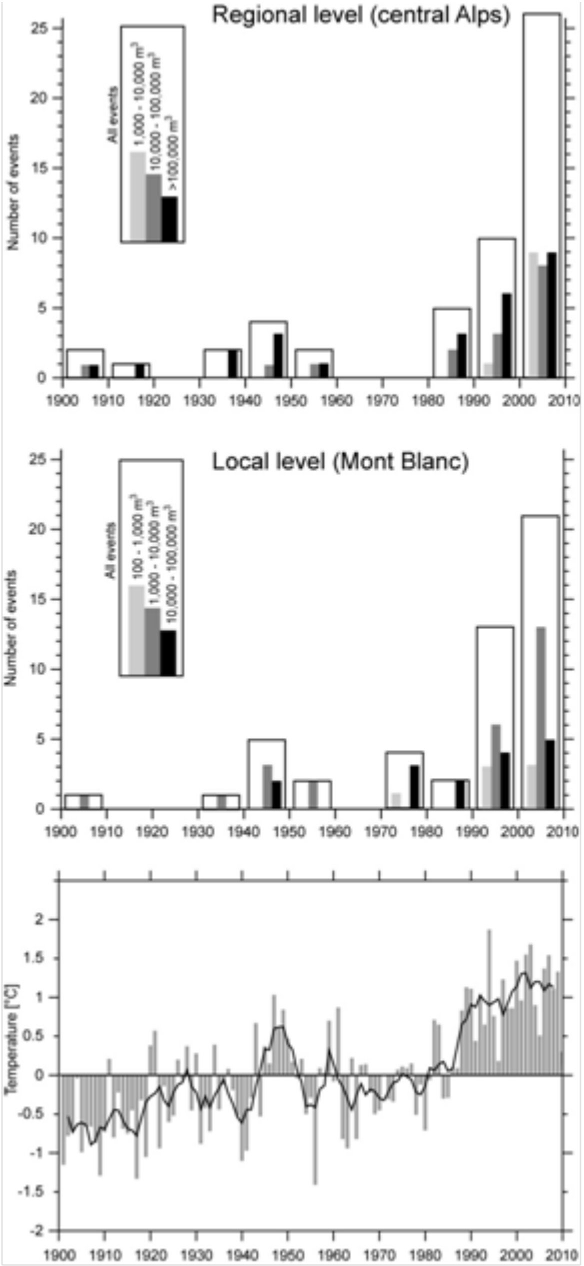
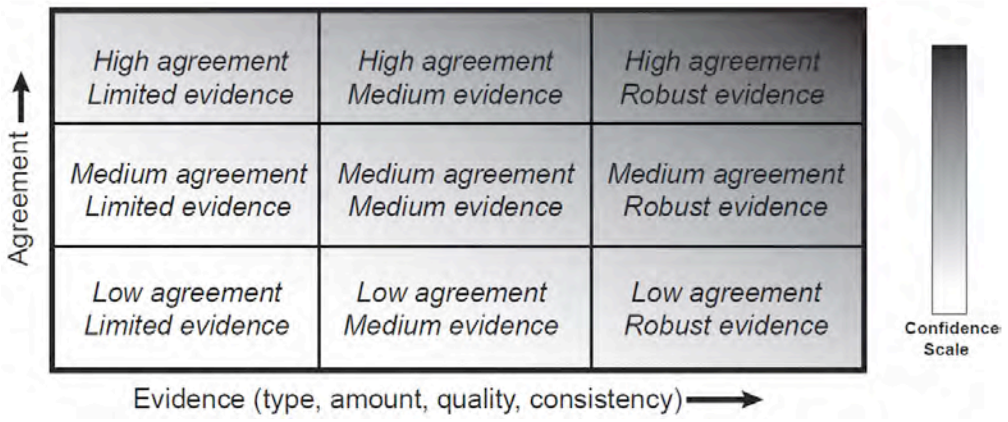


Figure 18-5: Changes in frequency of alpine rock slope failures since 1900 detected at two spatial scales: a regional scale over the Swiss and adjacent Alps (upper panel) and a detailed local scale at Mont Blanc area, French Alps (middle panel). Documentation bias exist at the regional level, especially for small failures in the early 20th century. To improve confidence in detection the local level (virtually bias free) can be compared with the regional level, and only large-volume slides can be considered which should show minimum bias.



High agreement Limited evidence	High agreement Medium evidence	High agreement Robust evidence
Medium agreement Limited evidence	Medium agreement Medium evidence	Medium agreement Robust evidence
Low agreement Limited evidence	Low agreement Medium evidence	Low agreement Robust evidence

Figure 18-6: Confidence as a function of evidence and agreement – Source: Mastrandrea, et al. (2010).

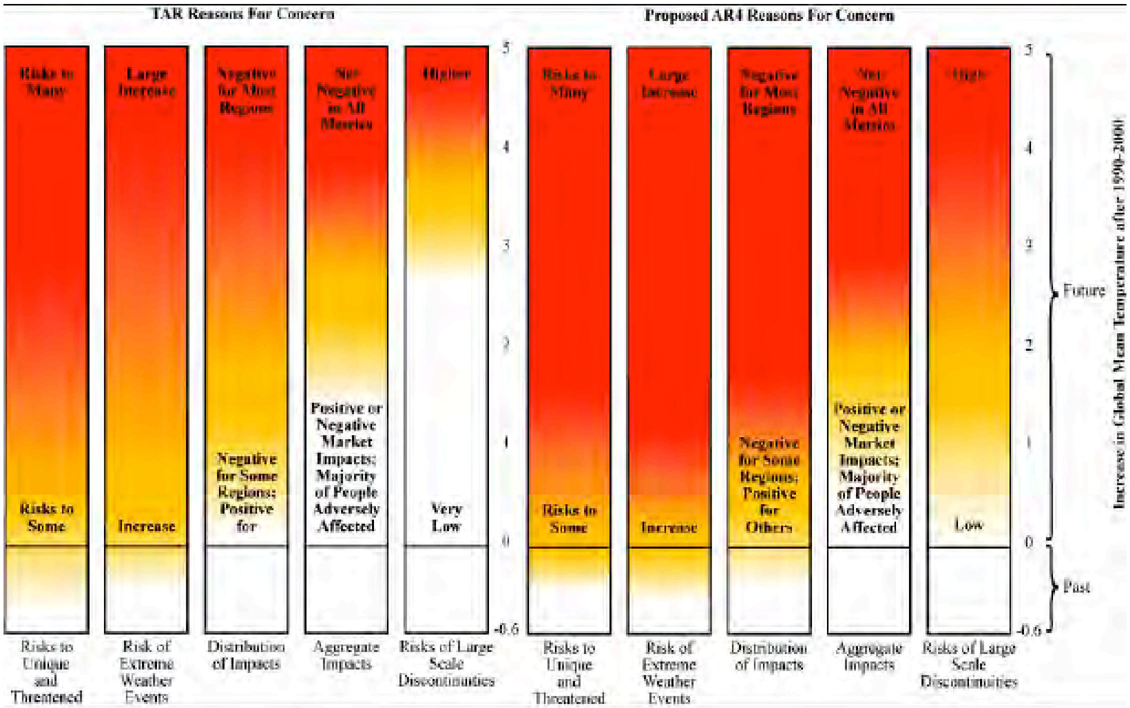


Figure 18-7: Reasons for Concernt (RfC) from IPCC (2001) and updated per IPCC (2007) in Smith, et al. (2009).

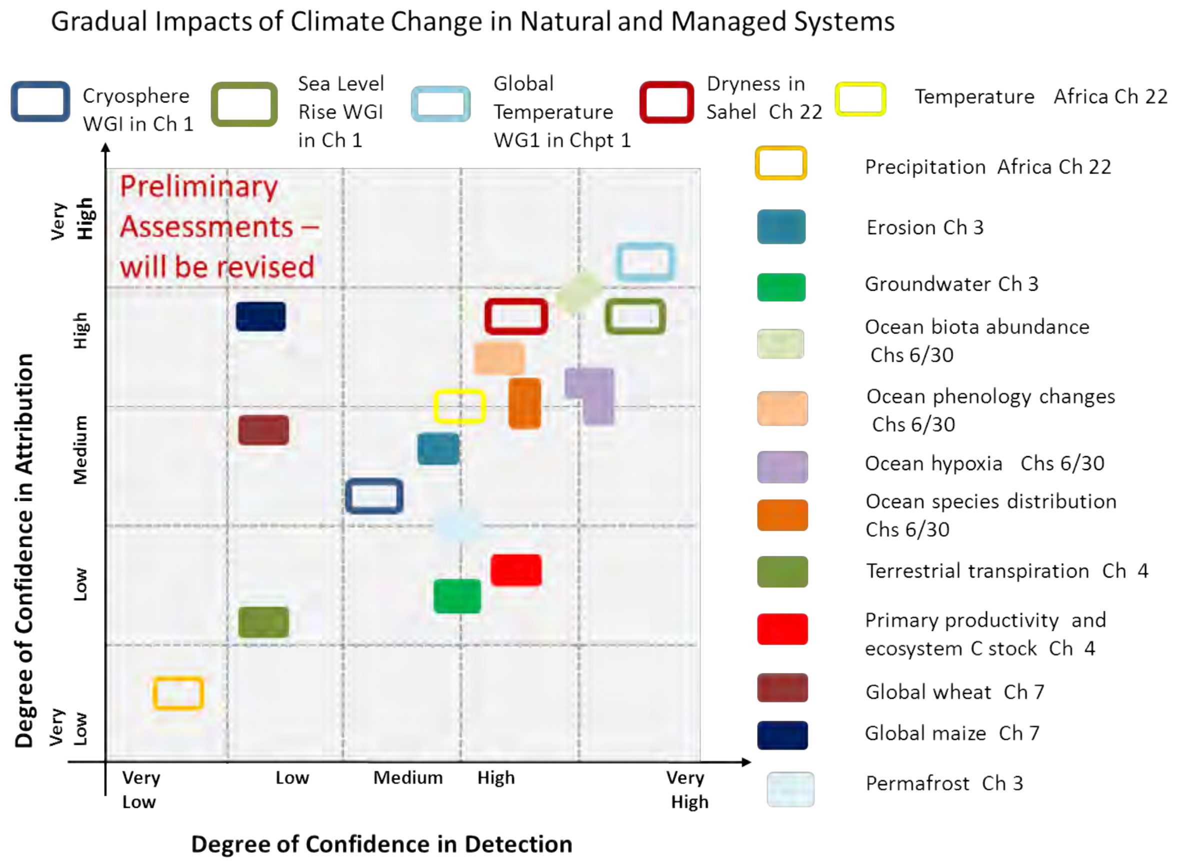


Figure 18-8: Confidence in detection and attribution across various sectors and systems. Open symbols denote attribution with respect to anthropogenic emissions, while solid symbols denote attribution with respect to observed trends in relevant climate variables. Preliminary draft, will be revised and updated as this assessment proceeds. Chapter (Ch) numbers refer to Chapters within AR5 WG2 report, with Ch1 summarizing findings of WG1.

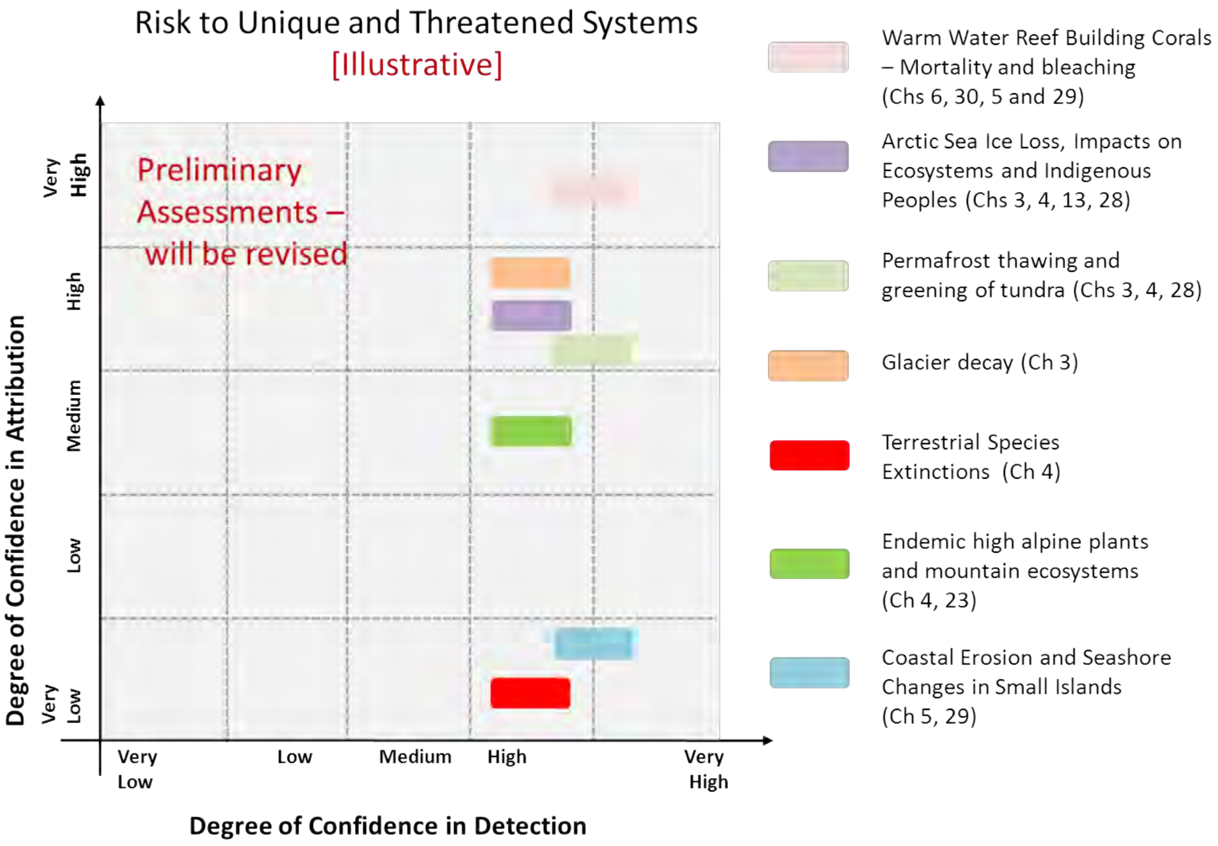


Figure 18-9: Confidence in detection and attribution of observed impacts on unique and threatened systems as a result of observed trends in relevant climate variables. Preliminary draft, will be revised and updated as this assessment proceeds.

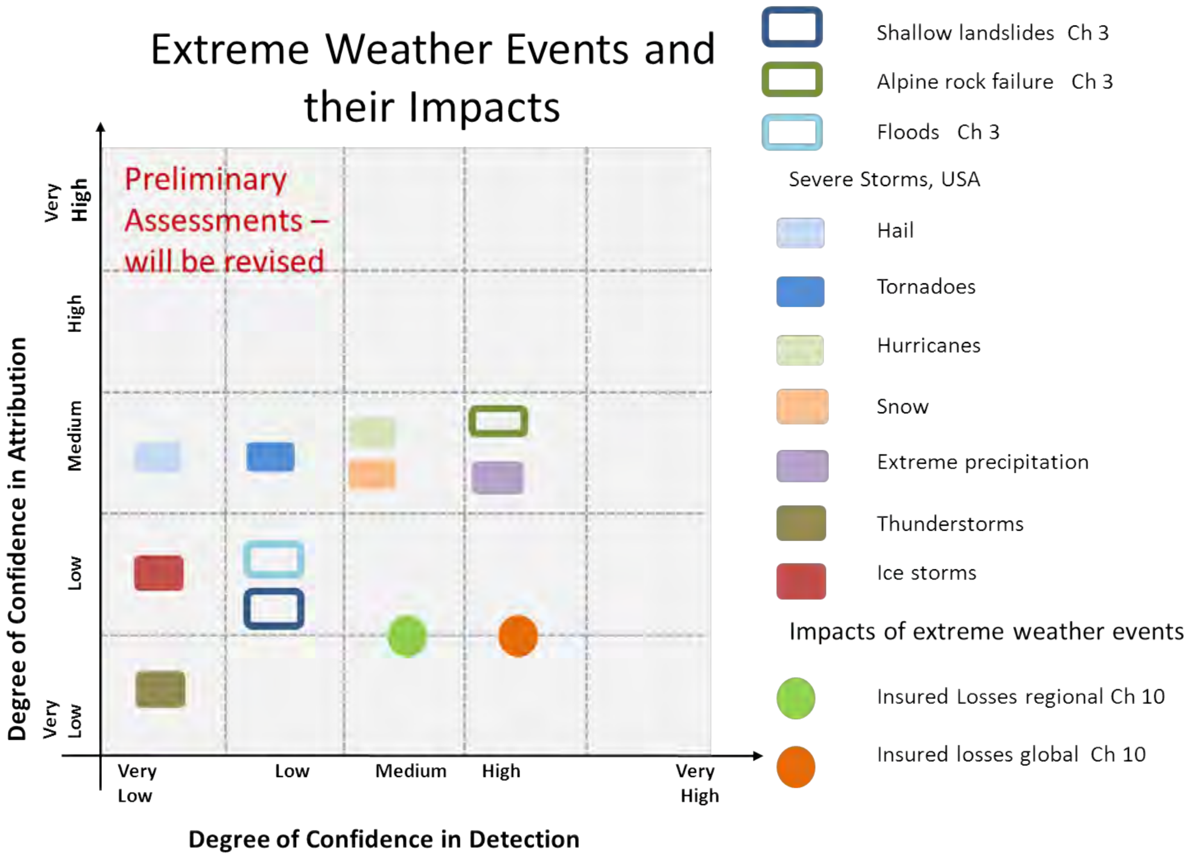


Figure 18-10: Confidence in detection and attribution of extreme weather events and their impacts. Preliminary draft, will be revised and updated as this assessment proceeds.

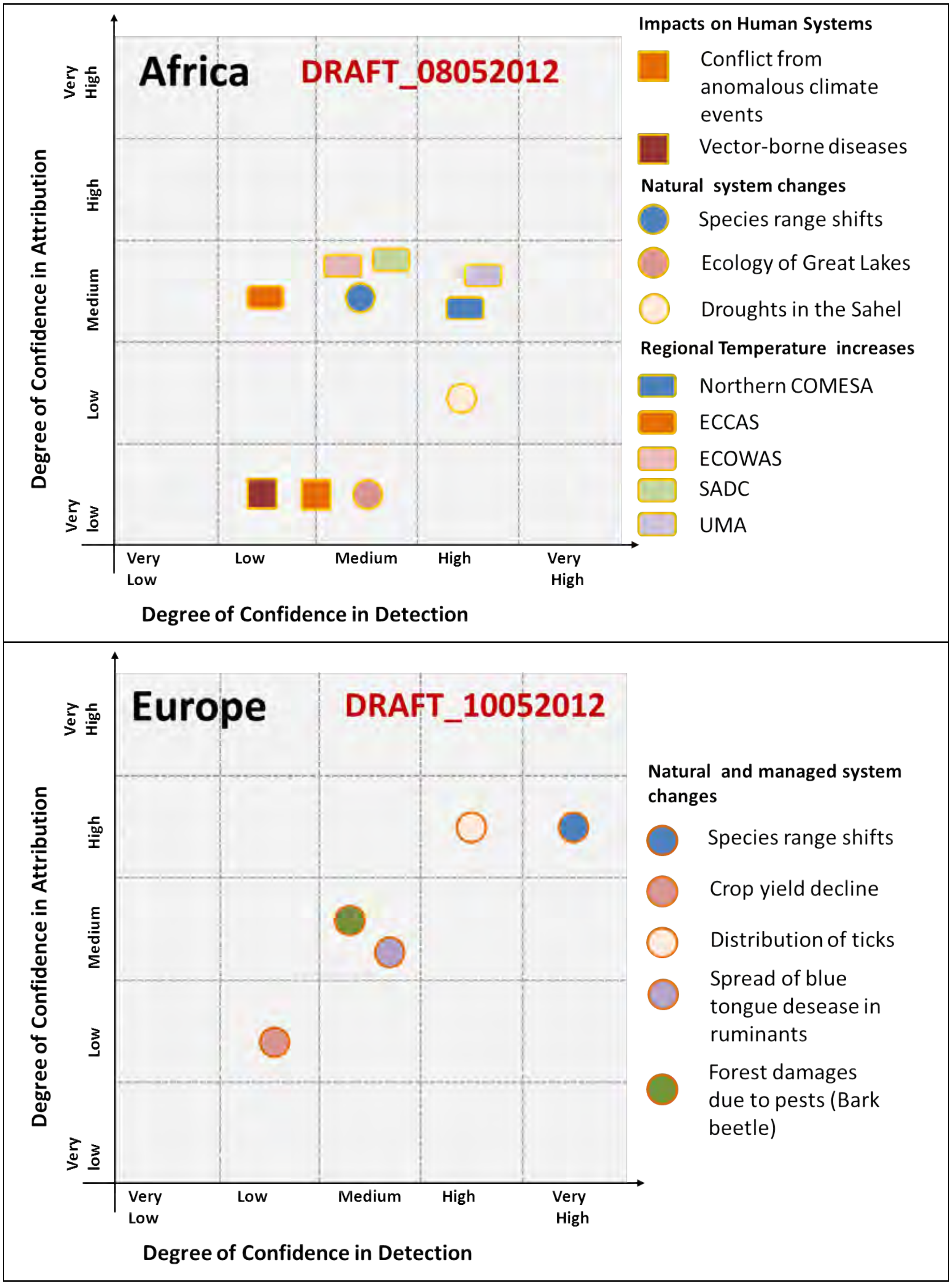


Figure 18-11: Confidence in detection and attribution across regions. Attribution of African temperatures is with respect to anthropogenic emissions, while other topics are with respect to trends in relevant climate variables. Preliminary and incomplete draft, will be revised and updated as this assessment proceeds.

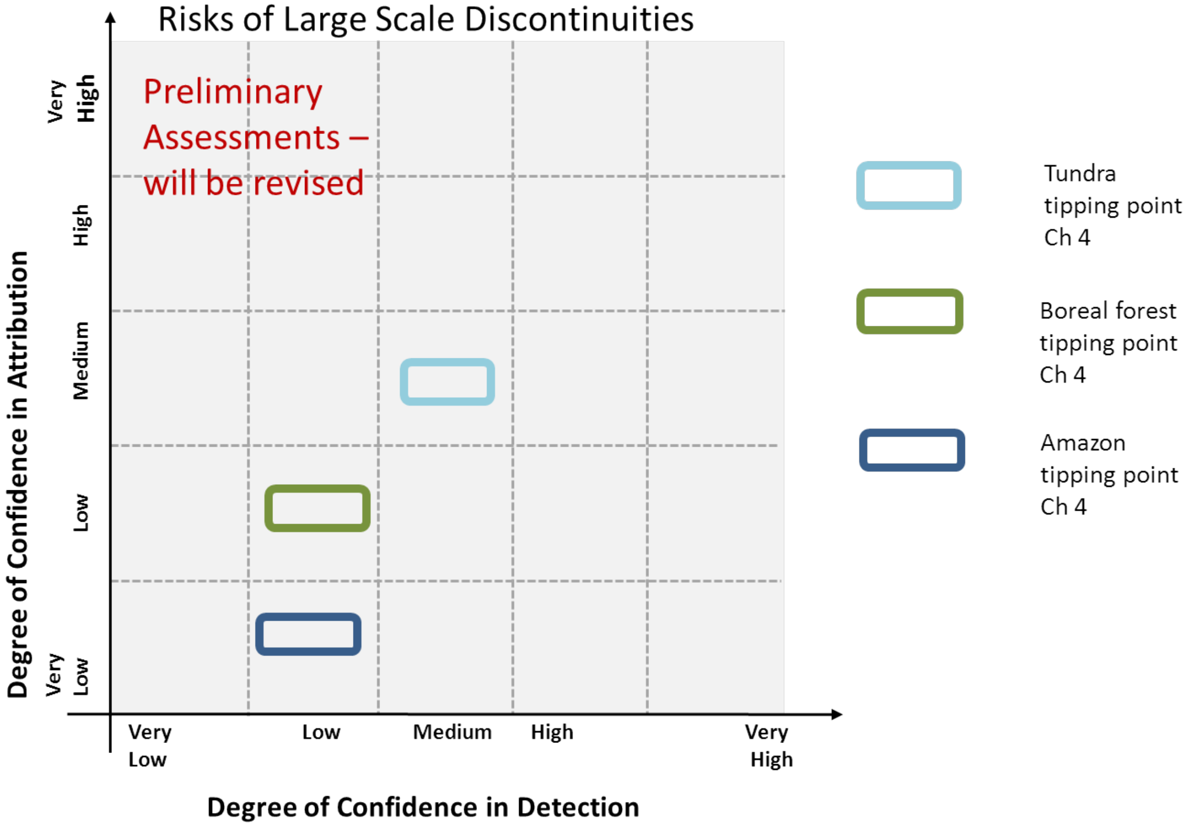


Figure 18-12: Confidence in detection and attribution of the onset of large scale discontinuities. Preliminary draft, will be revised and updated as this assessment proceeds.