Chapter 18. Detection and Attribution of Observed Impacts

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Executive Summary

[To be done post-ZOD]

18.1. Introduction

This chapter assesses the scientific evidence for observed changes (or the lack of change) in physical, biological and human systems that are consistent with climate change. It assesses the degree to which detected changes 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.

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 (Pielke, 2001; Brander et al., 2011; Stocker et al., 2011; Hoegh-Guldberg et al., 2011). Formal detection studies provide robust evidence of where climate 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 thresholds 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. It may be extremely difficult for some systems with diverse responses and many confounding drivers such as land use change, overfishing and inherent adaptive capacity (Parmesan et al., 2011). This chapter assesses the studies that exist for both full and partial attribution, and the methodologies that can be bought 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 other impact 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 confounding factors of environmental 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 conditionality and even low likelihood of conditionality has not been used as a reason to omit any findings.

[INSERT FOOTNOTE 1 HERE: The criteria for "key vulnerabilities" identified in the AR4 (identified in Chapter 19 of the WGII contribution and carried all the way through the Summary for Policymakers of the Synthesis Report) include: "magnitude, timing, persistence/reversibility, the potential for adaptation, distributional aspects, likelihood, and 'importance'" (see footnote 19 of the AR4 Synthesis Report SPM).]

18.1.1. Detection and Attribution of Impacts in the Context of Adaptation and Mitigation of Climate Change

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 (i.e., observe the change and respond), for example, 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 developing countries.

Regional 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 expansion of 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 Behind Detection and Attribution

Attribution of change in environmental systems to external drivers can be performed using a number of methodological frameworks. This chapter considers four broad categories of approaches characterized by the logical inference and the end points of the analysis (following a summary document for an IPCC Expert Meeting on Detection and Attribution, IPCC, 2010).

Detection of change is the process of demonstrating that a system has changed in some defined statistical sense, without providing a reason for that change. A certain change may be considered detected in observations if its likelihood of occurrence by chance in isolation of any potential external drivers is determined to be small.

Attribution of change is defined as the process of evaluating the relative contributions of multiple external drivers to that change with an assignment of statistical confidence. An external driver is any external factor outside the system of interest that causes it to change. Such factors may be climatic in nature (e.g. temperature changes), may affect the system of interest via the climate system (e.g. anthropogenic emissions of greenhouse gases), or may be independent of climate sometimes termed "confounding factors" (e.g., changes in demography or expansion of urban development).

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Box 18-1. The Use of Numerical Models in Detection and Attribution Studies

Almost all impact detection and attribution analyses must employ some modeling tool, because it is generally impossible to experiment with the climate system or most potentially impacted systems under control conditions. The nature of such models may vary depending on the details of the system being studied. One option is to use process-based models, which explicitly simulate the underlying processes involved in the climate and/or impact system. This is the most frequent approach in detection and attribution analyses of the physical climate system because it is governed primarily by a few well understood dynamical and radiative laws (Stott et al., 2012).

For many impact systems, however, variations are not governed by a similarly small set of well-understood rules. For instance, even the simplest ecosystems are highly complex, with variability depending on biochemistry complicated by interactions between species (Parmesan et al., 2011). In these circumstances, statistical models constructed empirically using data from observational studies from related cases or systems offer an alternative approach. These statistical models can be constructed using results of controlled laboratory experiments. Alternatively, if a sufficiently long temporal record exists, they can be derived from a pre-industrial era when climate change was minimal. If direct data for the direct formulation of such models is lacking, a collection of trend investigations of independent items can be merged into an associative analysis in which tendencies in a large fraction of the items is used to infer a statement of collection.

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[It is planned to develop additional text about the need to identify drivers and mechanisms (to link with for example Pall example below) i.e. (1) the driver is required in order to explain the response, (2) a mechanism has been identified that can explain the connections between driver and response]

18.2.1. Approaches to Attribution

18.2.1.1. Attribution to Changes in Observed Local Climate Conditions

These attribution studies assess whether an observed change in a measure of interest (in physical, biological or human systems) is attributable to observed variations and changes in local climatic conditions. These assessments are typically based on modeling studies that project how absolute and relative changes in the measure are expected to be influenced by various observed drivers (meteorological and other). Projected changes are then compared to observed changes.

No analysis is necessarily performed of the cause of observed changes in the relevant climatic conditions. Therefore it is generally not possible to make any inference about the role of anthropogenic emissions in the observed change in the measure of interest. These studies are valuable in revealing vulnerability to climatic variations. Studies following this approach have traditionally comprised the large majority of detection and attribution studies of the impacts of climate change.

[Specific examples from the literature will be added here]

18.2.1.2. Associative Pattern Attribution to Climate Drivers

An associative pattern approach is used to provide a synthesis assessment of the attribution of collective changes over a range of measures of interest (and possibly systems). It combines observations of changes over a large number of measures, and assesses the consistency of change in each to observed climate variability and, by inference, expected trends in climatic conditions. These measures can range across multiple systems, for instance covering changes in phenology and distribution exhibited by a variety of species. Associative approaches have generally been used as one usually early step in multi-step attribution analyses. (18.2.1.4).

[Specific examples from the literature will be added here]

18.2.1.3. Single-Step Attribution to Changes in External (Human) Drivers of Climate Change

In order to attribute observed changes to human causes, it is necessary to extend attribution beyond local climatic conditions to include the human drivers of those conditions. Single-step methods are the first of several possible methodological approaches that can be employed in this regard. They use explicit modeling of the response of the measure of interest to external drivers, including the external drivers of anthropogenic climate change, within a single comprehensive analysis. The modeling tool can comprise a single model, or a sequence of models, provided the output of each model can be directly employed as an input for the next model in a logical sequence. The detection and attribution analysis is performed through a comparison of the change in the modeled measure of interest with its observed counterpart (see Figure 18-1, end-to-end analysis).

[INSERT FIGURE 18-1 HERE
Figure 18-1: [This caption needs adapting to our text, and simplifying] A schematic diagram comparing approaches to attribution for an ecological system. The sequential 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. The meta-analysis approach takes results from studies of many ecological systems and takes consistency among all of these results as support for the individual results. The meta-analysis is shown here operating on results from sequential analyses but could also operate on results from end-to-end analyses. The synthesis approach compares the pattern of changes in many ecological systems to what would be expected given historical weather, and then brings the result into a sequential approach. (Stone et al., 2009).]

An example of an attribution analysis employing a single-step approach is the study of recent changes in cold- and heat-related mortality in England and Wales by Christidis et al. (2010).

[Specific examples from the literature will be added here]

18.2.1.4. Multi-Step Attribution to Changes in External (Human) Drivers of Climate Change

In contrast to single step analyses of the sort just described, multi-step attribution approaches generally employ sequences of separate attribution studies across the various processes that logically link a measure of interest with external drivers of anthropogenic climate change (Figure 18-1 "sequential analysis"). A multi-step approach could include an analysis of the attribution of changes in a measure of interest to changing climatic conditions (18.2.1.1), and a separate analysis of how external climate drivers affected relevant climatic conditions. The separation of these analyses can create gaps or inconsistencies between the outputs from one step and the inputs to the next. These gaps mean that confidence in the overall attribution will generally be weaker than confidence of the weakest link in the overall sequence.

For example, Pall et al. (2011) used a multi-step approach to examine the degree to which anthropogenic greenhouse gas emissions had affected the probability of flooding in England and Wales in autumn 2000 by changing runoff of rainfall. To do this they required many realizations of possible runoff series. While a single-step approach might have been desirable in theory, in practice this requirement of many realizations would mean the use of a coarse resolution climate model that would not be properly resolving the synoptic storm systems that pass over Britain during the autumn. Instead they employed a two-step approach. The first step was based on previous studies (Stott et al., 2006; Nozawa et al., 2005) which found that anthropogenic greenhouse gas emissions were required in order to explain past sea surface warming. The second step found that estimated changes in the probability severe runoff (i.e. flooding) could be explained by a simple thermodynamic response to the large-scale warming from what is probably a more local region in the North Atlantic, while the effects of small-scale warming variations and of changes in atmospheric circulation could not account for the changes. This logical gap between the two analyses means that the study followed a multi-step approach limited by the degree to which global temperatures changes reflect regional ones.

18.2.2. Caveats, Limitations, and Challenges

All approaches face challenges that can be overcome only to some degree. Caveats and limitations must be recognized in assessing the results that they produce. Here we review some of the major sources of these challenges.

18.2.2.1. Quality of Observations

Detection and attribution studies infer confidence in the connecting signals across observational records that might have been expected from broad observed sets of potential drivers. It follows that high quality observational records for those drivers and response variables are critical to the analysis.

The quality of the observational records of drivers depends strongly on the nature of the driver considered. If the study is attributing impacts to changes in external drivers of climate change, then the quality of monitoring of anthropogenic aerosol burden may be restrictive because this is the driver with the combination of poorest understanding and monitoring [Ref to relevant WGI chapter]. For studies attributing impacts to changes in local climate, then the relevance of available meteorological observations may limit confidence in the overall result if, for example, the meteorological and impact variables are not co-located in space and time.

Most often with impact attribution studies, the main limiting observational factor is with the variable measuring the potential impact. Monitoring of ecosystems, for example, is generally not of the standard to resolve anticipated impacts, especially in areas with complex ecosystems (i.e. without significant human presence) (see Box 18-2). Most significantly, most monitoring systems have not been designed with the intention of measuring incremental long-term changes, the sort of changes that are usually anticipated under anthropogenic climate change. Consequently, the record length may be too short or discontinuous to be useful, or measuring standards may have been improved through time resulting in measuring 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 determination of long-term trends.

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

Assessment of the recent Nature Climate Change detection/attribution debate; Camille Parmesan has agreed to supply one – post ZOD. This argues about the difficulties of detection and attribution in biological systems due to high variability and confounding factors, etc.

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18.2.2.2. Spatial and Temporal Resolution

Attribution to climate change requires the detection of a signal of change above the “noise” of climate variability. This implies that 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. [to be developed alongside text in WGI ZODs on trends vs variability in climate, time necessary to detect change in different aspects of climate that themselves operate on different scales e.g. temperature trends may need less time to detect than extreme but rare events changing frequency such as drought].

Change can be detected in environmental systems on multiple spatial scales from local to global. Attribution of such change to recent 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 since many local factors affect climate in ways that may mask the global trends, for example, topography. Flat landscapes will respond differently to changing climate conditions than mountainous landscapes, where temperature gradients are compressed and species do not need to cover great distances in order to respond to a broad-scale warming trend. On the other hand, local climatic conditions lead to more complex responses of mountainous landscapes to global trends, e.g., with respect to rainfall patterns which will affect both ecosystems and streamflow. Local climate conditions may even go in the opposite direction to global trends e.g. a change in cold water currents due to global climate change making some areas of the oceans cooler while globally sea surface temperatures are rising (see section 18.3.1.7).

Land use and land use change operate at a multitude of scales in space and time, in forestry, agriculture, fishery, urbanization, nature conservation (protected areas), etc., and patterns differ among regions and biomes. If one compares forestry and agriculture between e.g., north and central Europe with tropical areas, the latter are more complex and small-scaled; and so change might be expected to be driven by local factors in response to, among other things, local manifestations of climate. In many parts of the world, traditional land use dynamics occur at a finer scale than for example cattle ranging, biofuel plantations or other types of large scale activities – consequently climate-driven changes, if they occur, manifest themselves in observations at different scales [to be developed].

18.2.2.3. Confounding Variables and Omitted Variables

In broad terms, the statistical approach to attribution involves the establishment of a statistically significant relationship between a response – such as crop yield or the boundary of a species range – and one or more measures of climate change – such as increased rainfall or surface temperature. Although this general approach raises longstanding issues concerning the non-equivalence of correlation and causality (Holland 1986), as a practical matter, if they are done well, statistical studies of this kind can provide valuable information to decision-makers and others.

The basic question in statistical attribution studies is whether the empirical relationship between the response and the measures of climate change is too strong to be due to other factors affecting the response. To answer this question, it is clearly important to identify these other factors and account for them in the statistical analysis. Changes in crop yields may be due to changes in temperature or precipitation, but also to changes in soil nutrient levels unconnected to climate, while observed changes in species ranges may be due to climate change, but also to changes in population size and observational effort. Failure to include relevant factors in a statistical attribution study – what is sometimes called the problem of omitted variables (Spanos 2006) – can have serious consequences, leading either to misattributing a change in the response to climate change or masking the effect of climate change on the response. It follows that statistical attribution studies based on a clear understanding of and accounting for the underlying processes (including observational processes) are generally more convincing than 'black box' studies based purely on correlations among time series.

[possible box here on adaptive capacity in biological and human as a confounding factor to detecting climate change impacts]

Statistical attribution studies must 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 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, an 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, only that they cannot without great care – and sometimes not at all – simultaneously provide an assessment of the significance of the relationships that they identify.

18.2.2.4. Missing Studies and Publication Bias

Conclusions about the effect of climate change on natural and human systems are commonly based on a synthesis of available literature. A potential problem with this approach is publication bias. Publication bias refers to the preferential treatment by scientific journals and other outlets of papers reporting statistically significant findings. Publication bias may be a particular problem in climate change science because of the acute interest in it. The effect of publication is 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.

[placeholder for text: large scale observation networks set up for reasons other than detecting climate change can provide a less biased view of change. However there are large gaps that exist in places of the world with frequent observations – we will assess those gaps once the chapter is more complete]

18.3. Detection of Observed Changes and Attribution to Observed Local Climate Change Across Sectors

18.3.1. Physical Systems

This section assesses literature about detected climatic changes to selected key physical systems; some will suggest attribution to anthropogenic sources, but some will not. [Subsection will include summary coverage of related assessment conducted by the authors of the SREX and AR5-WGI on topics particularly germane to impacts, adaptation and vulnerability, to be written as that material becomes available with appropriate modification of subsequent text].

18.3.1.1. Rainfall and Freshwater Resources

A large proportion of land areas of the tropics and subtropics are subject to monsoon circulation with often well-defined wet and dry seasons. In various parts of the world, the beginning and length of the wet and dry seasons, as well the amount of heavy rainfall events, has undergone some change. River flow has changed in several large rivers around the world (Vörösmarty et al., 2000). This affects activities such as freshwater availability for drinking, irrigation for agriculture, river navigation and hydroelectric power generation. Attribution of observed changes can be to many drivers besides changing regional climate (essentially rainfall), such as changing land use and land cover, or increasing population and water demand. The relative strength in the various factors varies considerably around the world. For example, for the Nile, water use and human intervention on the river flow are quite intense, and the effect of climate variability and change is a minor component of the adaptation process (Conway, 2005). In Africa, a decreasing trend in river flow has been attributed to a climatic drying trend (Jury 2010; Jury and Whitehall 2010).

Central India has seen a 10% increase per decade in the level of heavy rainfall (more than 100 mm day^{-1}) with more than double the number of very heavy daily rainfall events (> 150 mm day^{-1}) in 1981-2000 compared to 1951-1970 (Goswani et al. 2006). Moderate daily events (between 5 and 10 mm day^{-1}) show a decreasing trend. The total monsoon rainfall (from June to September) has trends that are regionally diverse from no trend at all to increasing trends and decreasing trends (Rana et al. 2011).

In South America, wet season rainfall has increased in duration from an average of 170 days before 1972, to 195 days after (Carvalho et al. 2010). The seasonal rainfall total has steadily increased since the 1950s, with a significant change in trend from an increase of 2.7 mm yr^{-1} before 1976 to an increase of 7.5 mm yr^{-1} after 1976. The La Plata Basin has experienced an increase in rainfall over the last four decades of the 20th century, and a shift in location of high rainfall and associated human impacts. The line of 600 mm yearly total rainfall corresponds to a threshold for lands that can be used for agriculture. In Argentina, this isoline has moved about 200 km to the west over the last four decades of the 20th century. This has lead to an increase in the area of Argentina under agriculture, and also more frequent flooding (Berbery et al., 2006). The change from pasture to crops around the Uruguay River has been attributed to a change in runoff that is dominated by a change in rainfall over the change in land use using models (Saurral et al., 2008). Peak discharges due to heavy rainfall events occur two days earlier. Throughout La Plata Basin river flows have increased at least 40% in four decades for various small to medium river basins. In the northern part, there is a strong contribution from land cover change that reduces evaporation and augments runoff, while in the Southern half, most of the change can be attributed to rainfall increase (Doyle and Barros, 2010). The Amazon Basin shows an overall decrease in the number of wet days and of the maximum daily rainfall for the period between 1970 and 2001 (Buarque et al. 2010), with the northern half of the basin showing a tendency for slightly positive trends while the southern part shows negative trends (Marengo 2004). For the yearly maximum of 2 day accumulated rainfall the trend is clearly negative throughout the basin and of about 0.5 mm yr^{-1}.

In the Southwestern United States there has been an increase in the number of heavy rainfall events during the period 1931 to 1996 with an upward trend of 3% per decade (Kunkel et al., 1999). One study observed little change in total annual river discharge in western US, although there was widespread earlier spring snowmelt by about 1 to 2 weeks with changes in the annual cycle of the river flow (Stewart et al. 2005). In a multivariate detection and attribution analysis for the western US, 60% of the changes detected in river flow and timing of snow melt and snow pack were found to be due to human induced global warming (Barnett et al. 2008).

The Yellow river basin in China has also experienced some change in the last four decades. In 1972, the Yellow River ran dry for the first time for 15 days. In the following decades it ran dry for increasingly longer periods leading to water shortages. Most of the change has been attributed to soil erosion due to land use in highly erodible soils in steep slopes - sediments that eventually get deposited in the river bed impacting river flow and water management (Zhang et al., 2007).

18.3.1.2. The Cryosphere and Freshwater Resources

Components of the cryosphere include mountain glaciers and ice caps, ice sheets and floating ice shelves, sea, lake and river ice, subsurface ice (permafrost) and snow. Due to the high sensitivity to climatic changes the cryosphere is among the primary indicators of regional climate change. The response of the cryosphere to warming is diverse, however, and detection and attribution studies therefore have followed different avenues.

This chapter focuses on changes that have already been detected, however there is a range of lag or response times of different cryosphere components to a climatic change such that committed changes due to past climate change may not yet be detected. Seasonal snow has a direct interface with climate, and the response to any temperature change is immediate. For mountain glaciers, response times have been relatively well known for quite a while, depend on glacier geometry and climatic setting, and may range between years, several decades and up to a century (Jóhannesson et al., 1989). The ice sheets of Greenland and Antarctica have significantly longer response times on the order of centuries or millennia. However, observations of extended surface melting and strongly accelerated outlet glacier flow made in recent years in Greenland suggest that the response to climate change may be much faster in some respects (Tedesco et al., 2008; Van de Wal et al., 2008). Sea ice is strongly conditioned by seasonal weather patterns, but also multi-year effects, upper air and ocean circulation are important drivers.

Glaciers

For mountain glaciers and small ice caps changes in glacier length, area, volume or mass balance have been used to extract a climate signal, or to attribute these changes to climate change. Accounting for individual climate sensitivity and response times of a worldwide set of glaciers (n = 308), Leclercq and Oerlemans (2011) have reconstructed temperature variations for the past 400 years on global and hemispherical scale. Glacier length changes represent a signal that integrates several meteorological and glaciological parameters, and derived temperature reconstructions are in good agreement with instrumental records (global cumulative warming of 0.94 ±0.31 °C for 1830-2000).

Glacier mass balance variations are a more direct climate signal driven by temperature, precipitation, humidity, solar radiation and other factors. However, glacier mass balance is primarily coupled with short-term meteorological conditions, and only to a lesser degree with longer term climatic conditions. 50-70% of the response of Swiss glaciers to climate change between 1850 and 1985 was masked by geometric adjustment of the glaciers, meaning that only 30-50% of the long-term climate signal is visible in mass balance changes (Paul, 2010). The effect of the different climate variables on mass balance may be variable for glaciers in different latitudes and climate regimes. For instance, while for a mid-latitude Alpine glacier mass balance was found to be more than 3 times more sensitive to a 1°C temperature increase than to a 10% precipitation change (Klok and Oerlemans, 2004), on a tropical glacier in Africa the sensitivity was 2 to 4 times greater for a 20% precipitation change than for a 1°C temperature change (Mölg et al., 2008).

As reported in AR4, the mass loss of glaciers has clearly been increased towards the end of the 20th and beginning of the 21st century (Lemke et al., 2007). Zemp et al. (2007) report a mass loss of 0.14 m (water equivalent) between 1976 and 1985, 0.25 m between 1986 and 1995, and increase to 0.58 m during the period 1996-2005. The vast majority of monitored glaciers worldwide has been shrinking over the past years, with consistent retreat and mass loss pattern over large regions including tropical Andes (Vuille et al., 2008), the Alps of Europe (Paul and Haeberli,

2008) or Alaska and western Canada (Larsen et al., 2007; Bolch et al., 2010; Berthier et al., 2010) and the Canadian Arctic (Gardner et al., 2011). There exist a few regions with stagnant or advancing glaciers, such as Karakorum (Scherler et al., 2011). However, those glaciers that are stagnant or advancing are partly decoupled from climate, by heavy debris cover, or glacier dynamics (e.g. glacier surge), and therefore are not suitable indicators of climate change, or lack thereof.

More recent studies provide a more coherent pictures over large mountain regions in terms of ice thickness and volume changes. Larsen et al. (2007) found that the surface elevation of 95% of glaciers in southeast Alaska and northwest British Columbia lowered during the second half of the 20th century, with maximum thinning exceeding 600 m. The rate of maximum downwasting at glacier terminal areas has been reported between 4 to 5 m/yr and 5 to 10 m/yr for the Swiss Alps, and Alaska, respectively, for about the last two decades of the 20th century (Larsen et al., 2007; Berthier et al., 2010; Paul and Haeberli, 2008).

[Placeholder for additional text on consistency with WGI]

Impacts of changes in glaciers

It is estimated that mass loss from glaciers and ice caps currently contribute about 60% to sea-level rise that is not attributed to ocean warming (Meier et al., 2007), although regionally detailed assessments indicate that this contribution might be less (Berthier et al., 2010), see section 18.3.1.6.

The strong and rapid downwasting observed on many glaciers in alpine regions in recent years has prompted a number of additional impacts. At the front of many retreating glaciers in the Alps of Europe, Himalayas, Andes and other mountain regions lakes have formed or expanded. In some areas such as in the Swiss Alps, the formation of lakes has led to multiple outburst floods since 2008, impacting mountain communities (Werder et al., 2010). As a direct response, both, risk reduction measures on the order of tens of millions USD were necessary, but also the construction of new tourist infrastructure to accommodate an increasing number of people attracted by glacier lakes (Huggel et al., 2011). Furthermore, an increasing number of slope instabilities associated with glacier downwasting processes has been observed in the Alps and elsewhere (Haeberli and Hohmann, 2008; Huggel et al., 2011).

Since AR4 more evidence has been collected on changes in river runoff patterns in relation to glacier melt runoff in different regions of the world. Based on modeling studies, Zhang et al., (2008) found an increase of glacier runoff over the period of 1961-2004 for a tributary of the Yangtze river in western China, especially pronounced in the 1990s. Instrumental records from south-central China document a runoff increase from glacier areas, both seasonally and annually (Zongxing et al., 2010). In the central Andes of Peru, it has been found that for a catchment with 9% glacier area up to 67% of the runoff during the dry season is contributed by glacier melt, and thus has a significant impact on the agricultural and energy (hydropower) sectors (Condom et al., 2011). For a catchment with 40% glacier cover in the same region a 13% runoff increase over 1953-1997 was detected (Pouyaud et al., 2005), as well as shifts in seasonality (Bury et al., 2011). Similarly, for glacier-fed streams in British Columbia and Yukon, Canada, increasing runoff trends have been found (Stahl et al., 2008; Moore et al., 2009).

In general, whether river runoff due to glacier melt increases or decreases primarily depends on percentage glacier cover in the catchment, and the season considered. Accordingly, runoff changes over the past decades vary both, within and between different mountain ranges with different cover of glaciers around the world, and can be attributed to climate change (Casassa et al., 2009). In the Swiss Alps positive trends in river runoff over the past decades have happened primarily in highly glacier covered catchments (Collins, 2006; Pellicciotti et al., 2010). In areas with over 60% glacier cover, summer runoff follows temperature trends, 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). A study on the major European rivers originating in the Alps underlines that glacier melt does not generally increase runoff (Huss, 2011). For instance, for Po and Rhone gauging stations with <1% basin glacier cover in the catchment, the contribution of glacier melt to total runoff in August was significantly lower for 2004-2008 than for the previous twenty years, but was still 15% and 21%, respectively.

Sea ice

Important changes have been detected for Arctic sea ice, especially in the first decade of the 21st century, in terms of sea ice thickness and September extent decline as well as old thick multi-year sea ice (Comiso and Nishio, 2008; Giles et al., 2008). A record low sea ice extent was reached in summer 2007 with 37% less compared to the 1979-2000 reference period (Schweiger et al., 2008); since 2007 sea ice extent has remained at 30% or more below the reference period [ref]. Recent studies show that atmospheric deposition of black carbon (BC) accounts for 25 % of the reduction of Arctic sea ice by lowering of the albedo (Yu et al. 2009). The soot comes mainly from wildfires and household burning at much lower latitudes, and in this case is not a direct effect of global climate change. Increasing frequency of wildfires in regions with a Mediterranean climate due to summer drought could however be an important climatic driver.

Arctic sea ice has declined in recent years at a much greater rate than foreseen by model projections, and this has had impacts in both economic and political sectors. There is tremendous interest of Arctic countries in the newly emerging possibilities of exploiting the vast reserves of oil and gas. Political tensions have arisen after a Russian submarine planted the nation's flag on the sea floor of the North Pole in 2007, provoking reactions by the United States, Canada, Denmark and Norway. While tensions have not yet resulted in conflict, the greatest potential is attributed to the re-delineation of the outer limits of the Arctic nations' continental shelves (Proelss, 2009). The recognition that climate impacts have made Arctic sovereignty a more pressing issue, led to the 2008 Ilulissat Declaration where the Arctic countries confirmed their will to respect international law (Crawford et al., 2008). However, it has also been underlined that there are currently no overarching political or legal structures for an orderly development of the region, as historically there is no precedence to the currently evolving conditions of significantly less sea ice (Borgerson, 2008). New opportunities have also been identified concerning navigability of the Arctic, in particular the Northwest and Northeast Passage, with an important impact on shipping routes and trade, fishery and tourism.

Permafrost

Changes in spatial extent, thickness and temperature of permafrost are recognized as indications of climate change. Signals of warming permafrost have been detected in many arctic lowlands around the world. Observed warming is greatest in cold permafrost such as found on the north slopes of Alaska, Canada and Russia (Romanovsky et al., 2010; Smith et al., 2010). Trends are less pronounced but still increasing for warm permafrost with high annual variations and different magnitudes of change in Scandinavia, Greenland and Svalbard (Christiansen et al., 2010), Tibetan Plateau (Cheng and Wu, 2007) or North America (Smith et al., 2010). In mountain regions permafrost temperature trends are less clear, for instance in the Swiss Alps with no clear trend found for the past 15 years (Gärtner-Roer et al., 2011). Strongly increasing thickness of active layer has been observed in high-latitude and mountain permafrost (Callaghan et al., 2010; Gärtner-Roer et al., 2011). Since AR4, there is new evidence for significant flow speed acceleration of rock glaciers in the Swiss Alps, attributed to ground temperature increase, and with surface flow-speed of up to 4 to 15 m/yr resulting in rock fall and debris flow (Kääb et al., 2007; Delaloye et al., 2008). 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 is particularly sensitive to permafrost degradation, with retreat rates of 2 to 3 m/yr observed at some Arctic coasts, and a doubling of the erosion rate at Alaska's northern coastline over the past 50 years (Karl et al., 2009).

Snow cover

Snow cover is primarily related to seasonal weather patterns, and accordingly, the spatial variability (horizontally and vertically) is high (Brown and Mote, 2009). In general, snow cover duration has the strongest relation to climate variations, and maritime climates with extensive winter snowfall are more sensitive to climate change than continental, cold and dry climates (Stott et al., 2010). In some cases snow cover extent could be attributed to large scale atmospheric circulation patterns, such as atypically small snow cover extents in western and central Europe with positive phase of the North Atlantic Oscillation (NAO) (Bednorz, 2010). Several decades of observations are required to potentially extract a signal of climate change from snow cover extent. Performance of such studies is limited due to a lack of long-term data although a few studies indicated decreasing trends of snow cover extent that could be attributed primarily to temperature changes (Henderson and Leathers, 2010).

18.3.1.3. Floods

Floods are influenced both by natural processes such as high-intensity precipitation, storm surges, snow/ice melt, soil conditions, or natural damming as well as by anthropogenic factors such as land-use and management, dikes or reservoirs (Bates et al., 2008). IPCC AR4 concluded that no gauge-based evidence had been found for a climate-related trend in the magnitude/frequency of floods during the last decades (Rosenzweig et al., 2007). There are a number of studies on river flood changes in North America and Europe (e.g., Petrow and Merz, 2009; Villarini et al., 2009) but fewer in other parts of the world. These studies indicate that there is no clear evidence for changes in magnitude/frequency of floods (IPCC SREX). However, changes have been detected in heavy precipitation events and it is likely that this has also implied changes in pluvial floods (IPCC SREX). While in general attribution studies of floods are rare, one such study applying a probabilistic multi-step attribution found that anthropogenic greenhouse gas emissions are very likely to have substantially increased the risk of major floodings such as those in 2000 in the UK (Pall et al., 2011).

Glacial lake outburst floods (GLOFs) are characterized by their low frequency and high magnitude with most devastating impacts on downstream areas. No clear evidence exists so far for a change in frequency or magnitude of GLOFs in any high-mountain regions of the world (IPCC SREX). Nevertheless, significant changes have been observed in the number and area of glacial lakes, 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).

18.3.1.4. Droughts

Based on several lines of evidence, including a detection study that identified an anthropogenic fingerprint in a global drought index data set with high significance (Burke et al., 2006), 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 several factors leading to drought conditions, including impacts from 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 SREX). Depending on the type of impact and sector affected, one may distinguish between meteorological, hydrological or agricultural (also called soil moisture) droughts. Accordingly, indicators are different and, thus, one drought type may not necessarily coincide with another one. Similarly, the same drought event may cause impacts on different levels. For instance, the severity of drought in terms of area and number of affected crops may not correspond to the severity of drought in terms of its meteorological (or soil moisture) definition. On a subsequent impact level, e.g. people or farmers affected, the consistency with drought indicators is likely to be even lower. This is due to the increasing influence of non-climatic drivers of drought impact for lower-level impact levels. Studies on possible changes in lower-level drought impacts are very scarce or missing.

18.3.1.5. Landslides and Avalanches

Landslides include shallow or deep-seated mass movements with a range of flow velocity and trigger mechanisms. Heavy precipitation events are important triggers while non-climatic factors such as soil conditions, topography or land-use and management determine the susceptibility to landslide (Sidle and Ochiai, 2006). Detection of changes in the occurrence of landslides is considerably 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 landslides has changed over the past decades (Huggel et al., 2011), even not 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).

High-mountain regions are more likely to permit detection of a potential climate related change of landslide occurrence because (i) human (land-use) influence is minimal or non-existent, and (ii) landslide occurrence is not only driven by precipitation but indirectly also by temperature due to effects related to changes in glacier, permafrost and snow distribution. Recent studies have provided evidence that rock slope failures in mountain areas of the Alps of Europe and New Zealand with permafrost occurrence have increased since the 1990s, as compared to earlier decades, with a striking increase in the 21st century (Ravanel and Deline, 2010; Allen et al., 2010; Huggel et al., 2011; Fischer et al. manuscript). Possible inconsistencies in event documentation over the observation period were reduced by focusing on high-magnitude landslides (Fischer et al. manuscript) and small-scale areas (Ravanel and Deline, 2010), thus making the statement more robust.

No clear evidence exists for a change in frequency of shallow landslide and debris flows from deglaciated mountain areas in the European Alps (Jomelli et al., 2004; Stoffel et al., 2005). Processes not, or indirectly driven by climate change effects, such as sediment yield, can be important in influencing debris flow frequency and magnitude (Lugon and Stoffel, 2010), with a potential to massively increase landslide hazards at a local level (Huggel et al., 2011). Furthermore, observations in North America, New Zealand and the European Alps suggest that warm extreme events can have a substantial effect on triggering large slope failures in rock and ice (Huggel et al., 2010), and warm extremes in these regions have increased since the 1950s (IPCC SREX).

With respect to snow avalanches no change in the natural activity has so far been detected in Switzerland over the past 50 years (Laternser and Schneebeli, 2002) and in Europe (Voigt et al., 2011). 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.

18.3.1.6. Sea-Level Rise, Coastal Zone, and Low-Lying Areas

[Placeholder for a more systematic review that will draw heavily from WGI-AR5 and from various chapters in WGII-AR5 (beginning with the ZOD this summer). It draws heavily on the Report of the Science Panel of America's Climate Choices – NRC (2010)] Global sea level is driven by two fundamental processes: (1) the thermal expansion of the existing water in the world's ocean basins (a predictable component) and (2) water added from land-based sources like shrinking glaciers and melting ice sheets (a less predictable component, section 18.3.1.2). NRC (2010) reports that "80 to 90 percent of the heating associated with human GHG emissions over the past 50 years has gone into raising the temperature of the oceans" and that the "subsequent thermal expansion of the oceans is responsible for an estimated 50 to 60 percent of the observed sea level rise since the mid-19th century."

Tide gauges have measured sea levels for more than 100 years. During the past few decades, tide gauge records augmented by satellite measurements have produced more precise sea level maps across the entire globe. These modern records indicate that the rate of sea level rise has accelerated since the mid-19th century (Bindoff et al., 2007). Seas were rising about 0.6 mm yr^{-1} in the late 19th century and 1.8 mm yr^{-1} in the second half of the 20th century (Church and White, 2006; Miller and Douglas, 2004). Katsman et al. (2008) and Vermeer and Rahmstorf (2009) now put the pace in excess of 3 mm yr^{-1} in the past 15 years.

Different locations have experienced different rates of sea level rise because of differences in settling or uplifting of coastal zones and because of variance in the local manifestations of ocean circulation. Some coasts are still rising in response the disappearance of glaciers. In other regions, distant glacial rebounding or local withdrawal of water, oil or natural gas is causing coasts to subside. The Earth's rate of spin is also having differential localized effects as water is redistributed from high latitude ice melting. Bamber et al. (2009) suggest that both coasts of the United

States are experiencing 20 percent greater sea level rise than the global average for this reason. Satellite measurements have already uncovered broader differential spatial patterns; see Wunsch et al. (2007).

Many coastal areas are densely populated and growing quickly. This portends a high degree of development and use of coastal resources for economic purposes. Sea level rise affects all of these activities and their accompanying infrastructure, particularly when considered in the context of climate variability and coastal storms. Even if the frequency or intensity of coastal storms has not changed over the past few decades, increases in average sea level has magnified the impacts of extreme events on coastal landscapes.

Moving down the causal chain from observed increases in concentrations to observed increases in temperature to consider coastal erosion and flooding adds another layer of complication since they are both driven primarily by storm surges, land-use decisions, and other processes whose intensities and frequencies change from place to place. These changes alter the characters of associated risks from climate variability even if changes in the intensities and frequencies of the storms, themselves, cannot be projected. To be more specific, the social and economic ramifications of these physical manifestations of climate change depend critically on patterns of future development and population growth. It is, therefore, extremely difficult to offer credible broad-based estimates of vulnerabilities and potential adaptation costs; see, for example, Kirshen et al. (2008). At best, in fact, we can offer suggestive ranges of aggregate risk and more quantitative estimates only for specific locations.

Figure 6.6 in Nicholls et al. (2007) offered a portrait of the geographic spread of deltas and mega-deltas where mega-cities are at the greatest risk from rising seas – these are the “hot-spots” of “key vulnerabilities” in the coastal zone both now and in the future. Ericson et al. (2006) estimated that nearly 300 million people currently inhabit a sample of 40 such deltas with an average population density of 500 people per km^2. The human faces behind the global displacement results portrayed here can, of course, be seen in examples of erosion from coastal storms and rising seas. In the Arctic, Newtok, Alaska is already preparing for complete displacement, for example, and several neighboring towns face the same fate in the near future; the source of this vulnerability is lost sea ice that exposes the shoreline to ocean waves. Meanwhile, Nicholls et al. (2007) reported that many small island states like Tuvalu, the Maldives, and the Cook Islands are observing rising seas and foresee similar futures this century if sea level rise continues.

18.3.1.7. Ocean Systems

[Placeholder for possible text here on physical changes in the ocean as a summary from WGI, (temperature, circulation and acidification changes), but a lot of this is in ocean biology systems impacts below so may not need it in two separate places]

18.3.2. Biological Systems

Biological systems have been known to respond to changes in climate for a long time – indeed it would be difficult to explain if there was no such response. On paleo-climatic time-scales, the changing geographic distribution of species and biota has been one primary source of information of the varying climate, despite uncertainties about the possible delays in species response. Since the Second Assessment Report of the IPCC, evidence has been accumulating that responses occur in most regions, on land and in the ocean, and at the level of species as well as ecosystems and landscapes. Chapter 4 of this report summarizes the full range of literature on the subject since the AR4 – this section discusses specific cases where attribution has largely led to new insights about the impacts of (anthropogenic) climate change on biological systems.

18.3.2.1.Terrestrial Biological Systems

Phenology

The life cycles of plants as well as animals undergo cyclic events that often are directly triggered by changes in the environment (temperature, light, moisture), many of them seasonal and often easily observed. The AR4 presented a huge body of phenological observations, notably from widely differing sources such as satellite measurements and ground-based observations. Nearly all of them point towards systematic change occurring at the large scale, very commonly in agreement with the expected response to observed change in meteorological conditions. [This literature is continuing to accumulate and will be evaluated for the forthcoming drafts of this chapter and also chapter 4]

Productivity

Several indicators show changes in the productivity of terrestrial ecosystems during recent decades, notably satellite records of absorbed photosynthetically active radiation which is interpreted as a direct proxy for productivity. These changes can be positive and negative, depending on the region observed and the duration of the observation. Since changes in productivity occurs in response to the sum of changing environmental drivers (incoming net radiation, atmospheric CO_2 concentration, nitrogen deposition, temperature, frost damage, moisture availability etc.) it is often problematic to directly attribute changing productivity to anthropogenic climate change. [There will be more literature here to be summarized as the assessment unfolds]

Biomass

Long-term observations of tropical forest sites have recently been interpreted to indicate significant biomass increases in African and Latin American rain forests (Lewis refs.). Also here, attribution is somewhat ambiguous but the balance of evidence seems to suggest that a combination of warming and increased atmospheric CO_2 might have been the main driving force.

Disturbance regimes

Many biological systems are characterized by natural disturbance regimes such as fires, floods, droughts, windstorms or major frost events. Changes in these regimes occur, both with respect to increasing disturbance and also in some cases reduced disturbance, and some of these changes can be attributed to anthropogenic climate change. The extent to which changes in biological systems can be attributed to climate-driven changing disturbance regimes will be summarized on the basis of forthcoming literature.

Species distributions and biodiversity

The AR4 already summarized numerous cases of changing species distributions (plants and animals) which, together, constitute a major driver of biodiversity change (besides other drivers such as habitat destruction, invasive species introductions etc.). For a number of keystone cases, attribution to local or regional warming trends is unequivocal, notably in the case of species that occupy new habitats, such as at higher elevations in mountain regions, or in the Arctic. Attributing extinctions to warming is significantly more difficult, because many extinctions occur without direct observations, or are caused by habitat destruction as primary driver. While there are many cases where distribution changes represent risks or direct losses of habitat, species and whole ecosystems, this is not always the case.

Shrub encroachment

Shrub encroachment is common over much of the world's arid and semiarid biomes. In a meta-analysis of 244 data sets from several regions (western US, Australia, South Africa, and the Mediterranean Basin), 43 response variables were investigated by Eldridge et al. (2011). The observed changes were attributed to a set of multiple external factors, viz. overgrazing and subsequent land degradation, recovery from earlier (traditional) societies, increasing atmospheric N deposition, increasing CO_2, invasive alien species, and predator suppression. Climate change played some role, but most of the possible impact was masked by the other variables. [This perhaps finds a more appropriate place in the methods section]

In Northern tundra ecosystems, steadily increasing shrub abundance is also observed (northern Alaska, Sturm et al. 2005, as well as throughout the Pan-Arctic, Tape et al. 2006). In a recent study on *Betula nana* and *Salix pulchra*, two species of deciduous shrubs increasing in cover in northeastern Siberia, Blok et al. (2011) present data on growth ring chronologies, and successfully attributed the observed changes to climate change, notably early summer temperature during a given year of growth, and weaker positive correlations with summer precipitation, and temperature and precipitation during the preceding summer. No effect of winter snow precipitation was detected, somewhat contrary to the observation by Sturm et al. (2005) that increasing shrub cover accumulates snow and creates a positive feed-back thanks to leaf bud protection. No non-climate variables appeared plausible for attribution of the observed change in shrub cover increase in Siberia.

Tree line dynamics

In many mountain areas around the globe, the tree line is rising, mostly due to local warming but in many areas also due to abandonment of grazing by domestic animals. the Torne träsk area in northern Swedish Lapland, climate has warmed by 2.5°C between 1913 and 2006. In a study on alpine tree line dynamics in Swedish Lapland, with local warming of 2.5°C between 1913 and 2006, Van Bogaert et al. (2011) found that the tree line response was lagging behind expectations. However, above the current tree line other non-climate factors are holding the advancement back, particularly winter grazing by hares (Molau 2010). [There will certainly be more tree-line literature to summarize in this place later]

18.3.2.2. Freshwater Biological Systems

[closely based on material from chapter 4 ZOD – further drafts will be made ensuring that there are no redundancies] IPCC AR4 documented numerous observations indicating that lakes and rivers around the world were warming, with effects on thermal structure and lake chemistry that in turn affect abundance and productivity, community composition, phenology, distribution and migration. Evidence has continued to accumulate of detection of change.

Freshwater systems have the highest rates of extinction of any ecosystem, with estimates of at least 10,000-20,000 freshwater species extinct or at risk, placing freshwater systems among the ecosystems on the planet that are most threatened from human activities (Dudgeon et al., 2006; Vörösmarty et al., 2010). Drivers include water extraction, dams and flow regulation, intensive urban and agricultural land use, increases in nutrient loading and other pollutants. Climate change impacts on freshwater ecosystems through changes in temperature, precipitation, river flow and discharge and, in the case of coastal wetlands, sea level rise.

Freshwater ecosystems at high altitudes and/or latitudes are particularly vulnerable to climate, including arctic and subarctic bog communities on permafrost, and alpine and arctic streams and lakes (Smith et al., 2005; Smol & Douglas, 2007), see also 18.3.1.2. – most of them subjected to comparatively low level of direct impact from human activities (Vörösmarty et al., 2010). Evidence of rising stream and river temperatures over the past few decades across several continents has been linked to shifts in invertebrate community composition, including declines in cold species with limited temperature ranges (Brown et al. 2007; Chessman, 2009; Durance & Ormerod, 2007; Ormerod, 2009). Rising water temperatures are also implicated in changes in the composition of river fish communities

(Buisson et al., 2008; Daufresne & Boet, 2007), especially in headwater streams where species are likely to be sensitive to warming (e.g. Buisson & Grenouillet, 2009).

Long-term warming increased the duration of lake stratification by 25 days in Lake Washington over a 40 year period, leading to earlier phytoplankton blooms and mixed responses in zooplankton changing, indicating an interruption in energy flows among species levels and changing community composition. The phytoplankton changes were tightly linked to temperature and weather systems, whereas the zooplankton changes depended more on biotic factors (Winder & Schindler, 2004). Warming has shifted dominance to smaller phytoplankton (Parker et al., 2008) and cyanobacteria (Jöhnk et al., 2008; Wiedner et al., 2007), especially in those areas experiencing high anthropogenic loading of nutrients (Wagner & Adrian, 2009); with impacts to water quality, food webs and productivity (Gyllström et al., 2005; Parker et al., 2008; Shimoda et al., 2011; Verburg et al. 2003). Long-term shifts in macroinvertebrate communities have also been observed in European lakes where temperatures have increased (Burgmer et al., 2007).

18.3.2.3. Marine Biological Systems

[This text is based directly on chapter 6 – further development of both chapters will occur in a coordinated way, avoiding redundancies] It is virtually certain that, during recent decades, marine ecosystems have responded to a combination of natural climate variability and anthropogenic change. These factors include changes in mean temperature, seasonal temperature extremes, stratification, but also eutrophication, oxygenation, and ocean acidification (see chapter 6 and references therein). Climate change not only involves the concomitant change of various stressors, but also their synergistic or antagonistic effects and affects geography, diversity, development reproduction behavior and phenology (Edwards and Richardson, 2004; Beaugrand et al., 2009; Brierley and Kingsford, 2009).

In the following we list a number of examples of marine ecosystem changes over the last decades to century. Effects of changing temperature have been best documented for a number of systems, though other synergistic factors may act on the ecosystem and are often not discernable due to the high inter-correlation of environmental parameters in the marine system.

Over the last 50 years, changes in the seasonal abundance of phytoplankton, rapid northerly movements of temperate and subtropical species of zooplankton (copepods) and phytoplankton (dinoflagellates and diatoms), and changes in ecosystem functioning and productivity have been documented in the North Atlantic. These have been related to temperature changes (Beaugrand et al. 2002; Edwards and Richardson, 2004; Edwards et al., 2001). Warm water copepods have expanded their range by 10° (Beaugrand et al., 2009), affecting phenology and causing a mismatch of trophic levels (Edwards and Richardson, 2004). Colder water plankton have retreated their distribution area (Beaugrand et al., 2002; Bonnet et al., 2005; Lindley and Daykin, 2005; Richardson et al., 2006). The mean poleward movement reached up to 200–250 km per decade (Beaugrand et al., 2009). The lack of geographical barriers and contribution of advective processes enables more rapid shifts than for terrestrial species which have a meta-analytic average of 6 km per decade (Parmesan and Yohe, 2003).

These responses strongly depends on the physiology and ecology of the organisms and their specialization on climate and are therefore not uniform (Johns et al., 2001; Johns et al., 2003; Mackas and Beaugrand, 2010; McGinty et al., 2011). A strengthening of the colder Labrador Current has been linked to an increase in the abundance of a number of arctic boreal plankton species in the NW Atlantic, notably copepods and dinoflagelates, and a southerly shift of the copepod *C. hyperboreus* (Johns et al., 2001). These changes in hydro-climatic variability cause large-scale biogeographical changes, abundance and community structure of marine species (Richardson, 2008) for example increased warm water zooplankton taxa in the Californian upwelling system (Field et al., 2006). Changes in SST variability likely reduce the diversity and abundance of diatoms, major contributors to carbon export and hence important constituents to the biological pump (Sarmiento et al., 2004; Bopp et al., 2005; Hashioka and Yamanaka, 2007).

Changes in plankton cascade up the food web in combination with direct climate effects on higher taxa. For example, latitudinal movements of fish species have paralleled the large-scale biogeographical shifts observed in the plankton (Quero et al., 1998; Brander et al., 2003; Perry et al., 2005), with likely unifying mechanisms in operation. Northward range extensions or redistributions in fishes likely related to intensified NAO and AMO were largest along the European Continental shelf from Portugal to Norway and have been attributed to regional warming and intensified circulation, ranging from sardines and anchovies (Alheit et al. manuscript), red mullet and bass to Mediterranean and north-west African species (Beare et al., 2004; Brander et al., 2003; Genner et al., 2004). Since 1600, high catches of sardines have occurred in association with a southeasterly shift and intensification of the Aleutian Low off Japan (Yasuda et al., 1999). Northward range extensions of pelagic fish species related to warming have been reported for the Northern Bering Sea region (Grebmeier et al., 2006). Even in ecosystems that are strongly influenced by nutrient enrichment and overfishing, fractions of those changes are likely attributable to recent climate change (Philippart et al., 2011).

Limited information is available on the response of ocean benthos to climate change. The distribution of sublittoral benthos appears to respond more slowly to warming than that of plankton, fish and intertidal organisms (Hinz et al., 2011, Reise and van Beusekom, 2008). NAO-driven variability of circulation has been linked to variability in growth rate for bivalves (Schöne et al., 2005, Carroll et al., 2011) and coralline algae (Halfar et al., 2011) although a role for temperature control needs to be unequivocally demonstrated. Poleward shift of the kelp has been document along European coasts (Müller et al., 2011), in Japan (Kihara et al. 2006) and changes in distribution and abundance in the eastern north Pacific during major El Nino events (Tegner and Dayton, 1987, Tegner et al., 1996). Analysis of ecosystem effect on sedentary organisms and benthic macroalgae are complicated by the influence of local dynamics and topographic features (islands, channels, coastal lagoons) on biogeographic boundaries (Poloczanska et al., 2011).

Warming also affects the spreading of marine epidemics, which can occur at faster rates than in terrestrial systems, leading to range shifts of known pathogens (Harvell et al., 1999). This also includes the spreading of detrimental pathogens for oysters from the mid-Atlantic states into New England (Harvell et al., 1999).

In the tropics growth reductions in *Porites* and other corals have occurred over the last two decades, a change unprecedented in preceding centuries (Lough, 2008; De'ath et al., 2009). These changes have tentatively been linked to temperature and carbonate saturation state (Cooper et al., 2008), although causality cannot, as yet, be established for complex systems such as the Great Barrier Reef (chapter 5). These changes are regionally different as for example for the Red Sea changes in calcification have been attributed solely to temperature.

[INSERT FIGURE 18-2 HERE
Figure 18-2: Atmospheric CO_2 (bottom) and temperature (middle) changes with associated biotic changes (top) for the industrial era. CO_2 data are based on measurements at Mona Loa (Keeling et al., 2009), ice core records from Antarctica (Etheridge et al., 1998). The AMO is shown to highlight natural temperature fluctuations (Enfield et al., 2001). Biotic responses include coralline algae growth increment changes (Halfar et al., 2011) and coral calcification as a product of density and linear extension (De'ath et al. 2009). Abundance data of planktonic foraminifers indicates the temperature change and consequent range expansion or retraction in all three time intervals. This figure is presented in Chapter 6 along with changes on paleo timescales that support the mechanisms of a climate response of biological organisms.]

18.3.2.4. Coastal Biological Systems

[This text is a placeholder for a more systematic review that will draw heavily from WGII-AR5 chapters (beginning with the ZOD this summer). It draws heavily on the Report of the Science Panel of America's Climate Choices – NRC (2010)] Coastal ecosystems (wetlands, estuaries, dunes, mangroves, etc…) are the source of many ecosystem goods and services: nursery habitats for certain fish and shellfish, various birds, mammals, and reptilian species; protective or buffering services for coastal infrastructure from coastal storms; water filtering; flood retention; carbon storage; and economic value derived from beaches and other environments that support recreation and tourism. Physical changes in coastal systems and their attribution to sea level rise are described in section 18.3.1.6.

Nicholls et al. (2007) and the recent *Global Climate Change Impacts on the United States* report by the USGCRP (2009) noted the documentation of increasing physical damage from coastal storms and related flooding, erosion, and cliff failures. Coastal wetlands, particularly those that are constrained by human development or deprived of river-borne sediment, are being lost at an increasing rate. Water quality in these areas is declining as a result contaminated effluent, higher water temperatures, and saltwater intrusion. Daily high water marks are rising faster than average sea level in some places for reasons not yet fully understood. In general, coastal ecosystems are almost exclusively negatively impacted by the confounding combination of all these influences. Nonetheless, the Nicholls et al. (2007) conclusion that direct losses of coastal habitat and built environments from gradual sea level rise can be greatly amplified by the enlarged manifestations of extreme events calibrated in terms of flooding, erosion, and wind damage has persisted.

18.3.3. Human Systems

18.3.3.1. Food Production Systems and Food Security (Agriculture)

There is a growing body of evidence that agricultural production is affected by anthropogenic climate change, particularly by increases in the frequency and intensity of hot, wet and dry extremes. Repeated consistent observations across community-based studies indicate that increases in temperatures, particularly in winter, changing seasons, wet and erratic rain patterns, and increasing intensity in winds and storminess have led to decreased agricultural production (Jennings, 2009).

Diminishing trends in growing season precipitation experienced in regions of important grain crop growth were attributed to anthropogenic warming in AR4 (IPCC, 2007), and is now further supported by subsequent studies. For instance, along the western rim of the Indian Ocean, growing-season rainfall has diminished by 15% in food-insecure countries (Funk et al., 2008, Funk and Brown, 2009). Empirical and model-based explorations link the warming Indian Ocean to a drier eastern African seaboard and suggest that greenhouse gas and aerosol emissions have contributed substantially to the observed late 20th century warming (Funk et al., 2008). These, in general, agree with the AR4 projection that semiarid Africa may experience large-scale water stress.

Freshwater availability has also been shown to have undergone changes as a result of climate-induced circulation changes (See section 18.3.1.1). In particular, the greenhouse gas-induced warming in the Indian and Pacific Oceans has caused circulation changes leading to rainfall deficiencies across certain crop-growing areas such as the eastern edge of tropical Africa, from southern Somalia to the northern parts of the Republic of South Africa (Lobell et al., 2008; Brown and Funk, 2008; Funk and Brown, 2009).

Recent studies have strengthened the AR4 findings that changes in crop phenology provided important evidence of crop responses to recent regional climate change (see Table 18-1). Across Canada, there is a lengthening of the growing season due to significantly earlier start and a significantly later end of the growing season (Qian et al., 2010). There also are significant positive trends observed for effective growing degree days and crop heat units at most locations across the country. In China, global warming over the period 1961-2008 has not been observed to increase the high-temperature stress (HTS) in rice crops except in the heading-flowering stage in early rice in the mid-lower Yangtse River Valley, but had reduced low-temperature (LTS) in irrigated rice across the entire country (Sun et al., 2011).

[INSERT TABLE 18-1 HERE
Table 18-1: Observed changes in agricultural crops.]

A study disentangling the influence of climatic trend and management practices (in particular, choice of crop variety and management options) in three selected sites in the North China Plain (NCP) shows that while previous studies showed that a warming trend in the region led to negative impacts on crop yield, changes in observed phenology of wheat and maize crops in these sites were varied (Liu et al., 2010). Shortening trends in pre-flowering, post-flowering and total growth duration for both crops varied.

A global-scale analysis of the relationship between crop yields and the recent (1961-2002) warming attributable to human activities suggests a discernible negative impact on the global production of major crops which include wheat, rice, maize, soybean, barley and sorghum (Lobell and Field, 2007). The study used multiple linear regression to evaluate the relationship between yield and climate (growing season average monthly temperature and rainfall). Assuming that year-to-year changes in management were either uncorrelated with climate, or were themselves caused by climate, the variance in the yield (an estimated 30% or so of year-to-year variations in global average yields for the six crops) is explained by the climate variations during the period. For wheat, maize and barley, there was a clear negative response of global yields to increased temperatures. The results indicate that warming between 1981 and 2002 has resulted in annual losses of these three crops equivalent to 40 million t/yr. The study also indicates that the impact of rising temperatures was likely offset by fertilization effects of CO_2 levels, although the magnitude of these effects is uncertain. Moreover, adaptation measures taken by farmers such as changes in planting dates or use of different cultivars, may have also countered the negative impacts of temperature increases.

In a statistical modeling exercise, Lobell et al. (2011) used a global crop yield database combining national reports for the years 1980-2008. Temperature trends exceeded one standard deviation of historical year-to-year variability in cropping regions and growing seasons of most countries over the globe, with the exception of the United States. As a consequence, global maize and wheat production declined by 3.8% and 5.5%, respectively compared to when there were no climate trends (Lobell et al., 2011). The authors attribute the observed change mainly to temperature, with effects strongest at low latitudes. Effects of altered precipitation were more mixed. Additional drivers that were not accommodated in the model include increased carbon dioxide fertilization (unimportant for maize as this crop species exhibits the C4 photosynthetic pathway), expansion of cropping areas to cooler regions within countries (do not show up in national statistics), switching to new varieties, and shifting to earlier planting dates. However the study indicated that in some countries, climate trends were large enough to offset a significant portion of the increases in the average yields as a result of technology, carbon fertilization and other factors. For soybean and rice there were no trends at the global scale, although rice yields increased at the higher latitudes.

In Africa, an analysis combining a set of historical crop-trials for tropical maize yields (>20,000 historical data) with daily weather data, showed a non-linear relationship between warming and yields. Each degree-day above 30°C reduced the final yield by 1% under optimal conditions and by 1.7% under drought conditions (Lobell, 2011). Ahmed et al. (2010) examined the impact of climate change on African agriculture by determining empirically the crop productivity response to temperature and precipitation. They found that an increase in average growing season precipitation of 1 mm/month increased maize and rice yields by 0.005 t/ha and sorghum yields by 0.002 t/ha in Tanzania. A separate study indicated that anthropogenic climate change has probably produced societally dangerous increases in eastern and southern Africa food insecurity: At the same time as population growth had exceeded increases in agricultural infrastructure and cultivated area, there has been a tendency for main growing-season rainfall to decline due to the anthropogenic warming in the Indian Ocean (Funk et al., 2008).

In Argentina, a multivariate regression analysis of the impact of human-induced climate variability on soybean yields indicated that summer high temperature and rainfall excesses during the period of maturity and harvest had the greatest negative impact, while higher minimum temperatures during the growing season of the crop favored high yields (Penalba et al., 2007).

There has been increasing evidence since AR4 of newly established growing regions for viticulture (wine) production in Europe and the USA, and of warming effects on wine quality. Growing of grapes have long been observed to be dependent on climate requiring temperatures of 12 to 22°C for the growing season in both the northern and the southern hemispheres (Schultz and Jones, 2010). Grapevine phenology indicates the ripening period is significantly advanced in many growing regions experiencing much higher temperatures (Webb et al., 2007, 2008). Analysis of the link between temperatures and grape harvest dates (GHD) has confirmed the trend towards earlier harvests being more pronounced at higher temperatures (Schultz and Jones, 2010). Earlier maturity has also been observed in regions outside of Europe, for example in Australia (Petric and Sadras, 2008).

These above studies link changing agricultural yields to changing local climate conditions. While formal detection and attribution studies such as that of the Christides et al. (2011) indicate significant human influence on changes agriculturally important climate variables such as daily extreme events (increasing severity of increasing warm nights and decreasing severity of extremely cold days and nights), these are not directly attributed to food production, let alone food security. There are a lack of studies that explore the direct link between decreased food production and decreased food security.

[placeholder for text here on impacts on food protein availability from meat and fish including fish meal for animal feed, and links to nutrition impacts in health sector. Not so prevalent in detection literature and confounded by overfishing and dietary choice and economic decisions]

18.3.3.2. Human Health

[This text is based directly on chapter 11 – further development of both chapters will occur in a coordinated way, avoiding redundancies] 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, allergenic pollen, and extreme heat exposures (heat waves). 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. Such datasets are extremely rare. Only two disease systems have been well studied where health data are high quality (to minimize reporting biases), and changes in incidence occurred after observed warming periods.

The upsurge of 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).

For Malaria, a mosquito-human model has shown that predicted malaria cases exhibit a strongly non-linear response to observed warming (Alonso et al., 2011) and data from local weather stations in Kenya show a warming trend (Omumbo et al., 2010). 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 the east African highland region.

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 per se to the observed warming trend.

For pollen production, the known changes in seasonality, which are consistent with observed climate change effects on tree and plant physiology, have been confirmed 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). In North America, the pollen season of ragweed (*Ambrosia* spp.) has been extended by 13-27 days since 1995 at high 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 heatwave-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.

18.3.3.3. Energy Security

Climate directly affects the demand and supply of energy. There is a well established positive correlation between hourly electricity load and temperature at high temperatures in climate zones with demand for cooling at high temperatures (Franco and Sanstad, 2008) and a negative correlation between electricity/natural gas/fuel oil/coke and temperature at low temperatures in climates requiring heating for parts of the year. A warmer climate leads to lower heating demand and higher cooling demand in these areas. Further, areas which historically have seen little penetration of air conditioners may experience adoption of this technology under a warmer climate, especially when combined with growing incomes. The increased frequency of extreme heat events in areas with heavy cooling penetration has increased peak loads (Miller et al., 2011). During extreme heat events, the efficiency of coal and natural gas fired power plants suffers and transmission lines efficiency decreases. The demand for natural gas, wood and fuel oil is negatively correlated with temperature at low temperatures as heating demand decreases with decreasing heating degree days (Sailor and Munoz, 1998). Further increased need for agricultural irrigation water in environments with higher heat and drought stress leads to increased electricity demand through increased pumping duration (e.g. India study).

18.3.3.4. Disaster Losses and the Insurance Sector

[placeholder for links with chapter 10, offered support after ZOD]

Disaster impact may be expressed in monetary loss, human casualties or other impact and loss indicators. Reinsurance companies' payouts for natural disasters have grown significantly over the past 20 years. A significant share of the increase in payouts comes from disasters apparently related to climate change (Kunreuther and Michel-Kerjan, 2007). For the detection of observed changes of disasters and attribution to anthropogenic or natural climate change it is fundamental to distinguish between the occurrence of extreme events and their impacts. Previous sections discuss detection and attribution to climate of changes in floods (18.3.1.3), landslides and avalanches (18.3.1.5), and sea level rise and physical impacts on coastal zones and low-lying areas (18.3.1.6).

Without accounting for time-variant socio-economic factors a strong increase of disaster losses will be detected over the past decades (Pielke et al., 2005; Rosenzweig et al., 2007). Hence, to detect any signal of change in the disaster series one needs to adjust losses by the growth in value of the damaged assets. First, one needs to account for rising overall price levels by applying a standard inflation correction, which is a standard procedure for disaster databases of large re-insurance companies. The second step involves adjusting disaster losses for changes in population and wealth. Since information on changes in wealth in exposed areas is typically unavailable, proxy indicators are used. One of the earlier reference studies used changes in inflation, population and real per capita wealth as factors for normalizing hurricane damages in the U.S. (Pielke Jr and C. W Landsea, 1998). Others used changes over time in average nominal value and number of properties to normalize climate disaster losses (Crompton and McAneney, 2008), or changes in GDP per capita (Barredo, 2010). The insurance sector usually applies several loss adjustment procedures, including changes in values of exposed assets (MunichRe, 1999; MunichRe, 2008), or changes in property values and size of property market (Changnon, 2010). Assessments over regions with multiple countries such as Europe additionally need to account for inter-country and intertemporal price and exchange rate differences (Barredo, 2009).

On the other hand, factors offsetting disaster losses need to be considered for detection and attribution studies (Mills, 2005). These include improved building codes, early warning systems, hazard contro, defense measures, disaster preparedness and response, land-use planning and better institutions overall. Accounting for such factors in disaster loss trends is complex and in many cases unfeasible and there exist few studies that have approached the problem

(Neumayer and Barthel, 2011). There is, however, evidence that countries who are wealthier and/or have better institutions suffer from relatively smaller disaster losses measured in fatalities (Kahn, 2005).

A further major challenge of detecting trends in disaster frequency and impacts are limitations in disaster databases and catalogues. Disaster databases have been established and maintained by insurance companies, national governments, international organizations or non-governmental organizations. Limitations primarily relate to (i) time period of record, (ii) completeness of records, and (iii) consistency of indicators over the time period of record. Only few disaster databases extend further back than the 1970s and probably even less represent a consistent and reasonably complete record.

The great majority of studies applying afore-described normalization of disaster losses have not found any long-term trend that could be attributed to climate change. Most studies attribute the increase in loss due to disasters to increasing exposure of people and assets in areas at risk, and changes in social, political, or economic developments affecting vulnerability (Miller et al., 2008; L. M. Bouwer et al., 2007; Pielke et al., 2005).

However, there are a few studies that claim that a signal of anthropogenic climate change can be found in disaster loss records. For instance, (Mills, 2005) states that global weather-related losses in recent years have been increasing much faster than population, inflation, or insurance penetration, and faster than non-weather-related events. For hurricanes in Florida it is suggested that normalized losses have increased since the early 20th century, consistent with a small increase in hurricane intensity and size (Malmstadt et al., 2009). Similarly, it has been found for tropical cyclones in the U.S. that the increase in loss due to socio-economic changes has been about three times greater than that due to changes potentially attributable to climate change (Schmidt et al., 2010).

18.3.3.5. Other Key Economic Sectors and Services

Transport

Long range ocean transport has been positively affected by the opening of the Northwest passage due to a reduction in sea ice (Borgerson, 2008), see section 18.3.1.2. A number of exploratory vessels and two cruise ships have crossed the Northwest passage during summers when the passage opened, which was not previously possible. Large investments in guiding vessels and port infrastructure would be required to make this an alternative to the Panama Canal Crossings.

Industry

Economic growth has been shown to be negatively affected by climate shocks, although the effect is only statistically detectable in developing countries and not in developed countries (Dell, Jones and Olken, 2008). Further there is evidence that temperature shocks negatively affect developing countries' exports (Jones and Olken, 2010). The manufacturing sector in developed countries and developing countries alike is directly affected by climate change through higher cooling and lower heating requirements, which translates into higher input costs at the aggregate level. Further, there is evidence that indirectly that some parts of the manufacturing sector have benefited from climate change through governments' mitigation activities, which lead to sizable markets for previously uneconomical or unavailable technologies especially in the renewable energy sector (Greenhouse, 2008)

Tourism

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. Major environmental tourist attractions suffering from climate are changing eco tourism patterns across the world (Becken and Hay, 2007).

18.3.3.6. Livelihoods and Poverty

The links between climate change and poverty are not well quantified in the literature. The very limited discussion about poverty and climate impacts tend to focus on food availability and food prices (Fischer, 2009, Ahmed et al., 2009, Hertel et al., 2010). Existing research relates to direct climate impacts on agricultural outputs (See section 18.3.3.1), but little is known about how these agricultural impacts would affect human livelihoods around the world, particularly in poor countries (Easterling et al., 2007; Hertel et al., 2010). It has, been seen that repeated drought events erode the assets of the poor and marginal, and relief interventions struggle to protect such households effectively from food security and poverty (Thornton et al., 2011).

Direct crop impacts provide only partial understanding of the consequences for human livelihoods because production systems are interconnected through trade, coupled by the fact that households differ in the way they are affected by volatile price changes (Hertel et al., 2010). There has not been an adequate assessment of how the effects of human-induced sharp reductions in crop supply increase pressure on food prices, either within or between countries, limiting the ability to do more than infer significant poverty impacts. For instance, it is possible that a country which experiences significant negative yields, could still gain from higher commodity prices whenever there is a rise in prices in the international trade.

One study used a novel economic-climate analysis framework to assess the poverty impacts of climate volatility for seven economic groups in 16 developing countries. It concluded that, under present climate variability, extreme climate events increased poverty, especially among urban wage earners, in particular in Bangladesh, Mexico, Indonesia and Africa (Ahmed et al., 2009). Poverty changes were attributable to increased prices of staple foods due to climate-induced reductions in crop yields and supply. This study attributes poverty to climate variability and extreme climate events, but not to climate change directly. The impact of human-induced climate volatility on national-scale poverty has not yet been quantified, nor has the impact on the poor in different socio-economic strata (Ahmed et al., 2009)

In the case of Mongolia, failed development in terms of models of market development failing to support pastoralist strategy, collapse of regulatory regimes and conflicts over water and pasture was found to have exacerbated the vulnerability of climate-sensitive poverty in the country (Craig, 2010). Its consequences are seen to exert severe implications on food security and livelihoods.

18.3.3.7. Human Security

[The next draft will fully recognize the final version of IPCC SREX, especially 8.5.4.] There is little evidence of how climate change undermines human security, despite widespread concern that it may increase the risk of violent conflict (Barnett and Adger, 2007). Because human security is a function of multiple processes operating across space over time and space, climate attribution is a daunting task. Even if there is not a mono-causal relation between climate change, disasters, displacement and migration, it is now recognized that climate constitutes a factor of displacement (Volmannskog, 2010).

The impacts of greenhouse gas-induced climate change include both sudden climate shocks and events, and a progressive changing of climate systems globally with human consequences, making climate change a security issue (Huq, 2011). However intuitive it might appear, however, a systematic attribution of climate impacts on human security has not yet been accomplished.

18.4. Application of an Associative Detection-Attribution Method to Assess Confidence in Climate Signal Information

[In this section, we hope to use the data collected from the WGII-AR5 chapters as reported in Section 18.3 to assess confidence in detecting a climate signal from a disparate collection of studies. We hope to use the method described in Parmesan and Yohe (2003) to account for confounding factors, statistical significance, process contradictions and author/editor bias to investigate this confidence expressed in terms of the likelihood that any study selected at random from a growing collection of studies would correctly a detected change in a system to experienced climate change and then to anthropogenic climate change.]

18.5. Gaps, Challenges, and Opportunities

[To be done last in consultation with others in the WGII AR5, probably not before late 2012]

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[References have been checked neither for completeness nor correctness.]

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Table 18-1: Observed changes in agricultural crops.

Agricultural metric	Observed change	Location	Period	References
Phenology	Significant lengthening of the growing season due to significantly earlier start and a significantly later end of the growing season. Significant positive trends of effective growing degree-days and crop heat units at most locations.	Canada	1895-2007	Qian et. al., 2010
	Reduced low-temperature stress in irrigated rice across the country. No increase in high temperature stress	China	1961-2008	Sun, et al., 2011
Yields	Lower soybean yields attributed to summer high temperature and rainfall excesses during the period of maturity and harvest. High soybean yields attributed to higher minimum temperatures during the growing season.	Argentina	1973-2000	Penalba et al., 2007
	Decrease of maize yields by 1% with each degree day above 30°C under optimal rain-fed conditions and by 1.75 under drought conditions	Africa	1999-2007	Lobell et al., 2011
	Increase in maize and rice yields by 0.005 t/ha and in sorghum yields by 0.002 t/ha with an increase in average growing season precipitation of 1mm/month	Tanzania	1992-2005	Ahmed et al., 2010
	~30% or more year-to-year variations in average yields for wheat, maize and barley due to growing season temperatures and precipitation	Global	1961-2002	Lobell et al., 2007
	Decline of maize and wheat production by 3.8% and 5.5%, respectively compared to when there are no climate trends	Global	1980-2008	Lobell et al., 2011

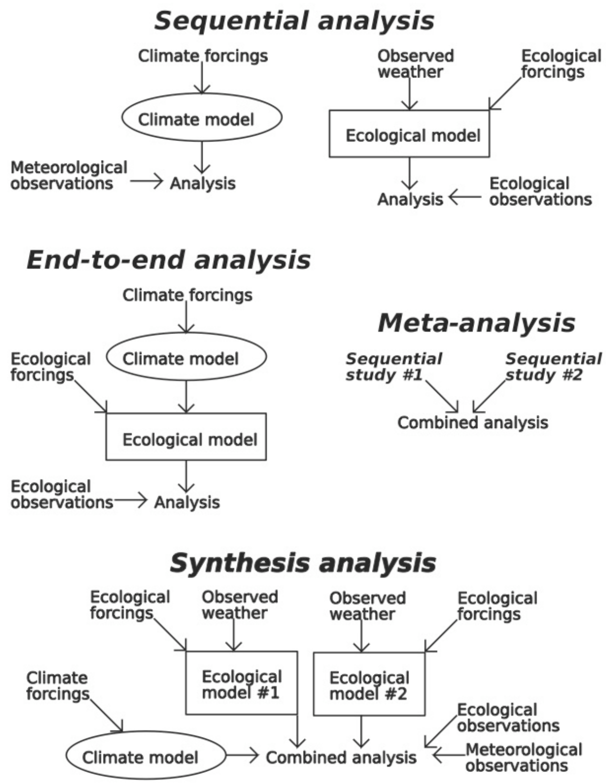

Figure 18-1: [This caption needs adapting to our text, and simplifying] A schematic diagram comparing approaches to attribution for an ecological system. The sequential approach differs from the end-to-end approach in having a discontinuity between the attributed climate change and the observed weather driving the ecological model. The meta-analysis approach takes results from studies of many ecological systems and takes consistency among all of these results as support for the individual results. The meta-analysis is shown here operating on results from sequential analyses but could also operate on results from end-to-end analyses. The synthesis approach compares the pattern of changes in many ecological systems to what would be expected given historical weather, and then brings the result into a sequential approach. (Stone et al., 2009)

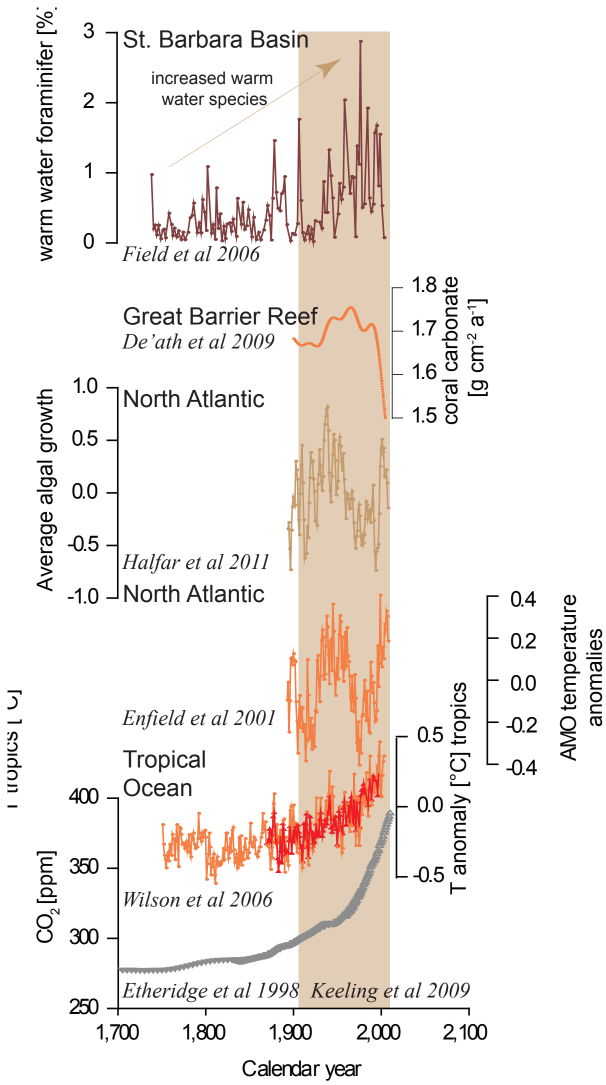

Figure 18-2: Atmospheric CO_2 (bottom) and temperature (middle) changes with associated biotic changes (top) for the industrial era. CO_2 data are based on measurements at Mona Loa (Keeling et al., 2009), ice core records from Antarctica (Etheridge et al., 1998). The AMO is shown to highlight natural temperature fluctuations (Enfield et al., 2001). Biotic responses include coralline algae growth increment changes (Halfar et al., 2011) and coral calcification as a product of density and linear extension (De'ath et al. 2009). Abundance data of planktonic foraminifers indicates the temperature change and consequent range expansion or retraction in all three time intervals. This Figure is presented in Chapter 6 along with changes on paleo timescales that support the mechanisms of a climate response of biological organisms.