IPCC WGII Fourth Assessment Report – Draft for Expert Review

Chapter 1: Assessment of Observed Changes and Responses in Natural and Managed Systems

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Executive Summary

Non-Climate Driving Forces

A large number of non-climatic drivers influence observed responses of sectors and systems to climate variations, making analysis of the role of climate in observed changes complex (*high confidence*). Non-climatic drivers can influence systems and sectors directly and/or indirectly through their effects on climate variables such as albedo, soil moisture regimes, and heat island effects. Socio-economic processes, including land-use change (e.g., forestry to agriculture; agriculture to urban area) and land-cover modification (e.g. ecosystem degradation) are of major importance. Furthermore, many systems and sectors are affected by various aspects of pollution (e.g., in the atmosphere, soil and water).

Observed Changes in Systems and Sectors

Cryosphere: Changes in systems and sectors related to accelerated melting in the cryosphere have been documented in glacial floods, ice and rock avalanches in mountain regions, runoff in snow and glacial basins, Arctic mammals, Antarctic Peninsula fauna, permafrost-based infrastructure in the Arctic, relocation of ski centres to higher elevation areas and impacts in indigenous livelihoods in the Arctic (*high confidence*). Some of these changes show an accelerated trend in recent decades, consistent with the enhanced warming and observed changes in the cryosphere itself (*medium confidence*). The changes in systems and sectors parallel the abundant evidence that allows the assessment that the cryosphere is undergoing accelerated melting in response to global warming, including sea ice, freshwater ice, ice shelves, Greenland ice sheet, glaciers, snow cover, and permafrost (*very high confidence*).

Hydrology and Water Resources: Recent evidence also shows that areas most affected by increasing droughts are located in arid and semiarid regions due to the presence of already warm and dry climate (*high confidence*). In the last 20 years, there are documented increase in flash floods and landslides due to intensive and heavy rain in mountain areas during the warm season (*high confidence*). On a global scale, the observed increasing trend in runoff in higher northern latitudes and drought in some subtropical regions is coincident with recent global rainfall trends (*modest confidence*). There are observed rises in some lake levels and decreases in others, and loss or disappearance of some epishelf or permafrost-controlled lakes due to warming (*modest confidence*).

Coastal Processes and Zones: Widespread coastal erosion and wetland losses are occurring under current rates of sea level rise, but, at present, these are mostly the consequences of anthropogenic modification of the shoreline (*medium confidence*). Apparent global increases in extreme high water levels since 1975 are related to mean sea level rise and to large-scale inter-decadal climate variability. In many low-lying coastal areas, development in conjunction with sea-level rise over the last century has exacerbated the damage to fixed structures from modern storms that would have been relatively minor a century ago.

Marine and Freshwater Biological Systems: Many of observed responses in marine and freshwater systems have been associated with rising water temperatures (*high confidence)*. Climate change, in tandem with other human impacts, has already caused substantial damage to coral reefs (high confidence). The documented poleward movement of plankton by 10 degrees in the North Atlantic is larger than any documented terrestrial study. Observations indicate that lakes and rivers around the world are warming, with effects on thermal structure, lake chemistry, abundance and productivity, community composition, phenology, distribution and migration *(High confidence*).

Terrestrial Biological Systems: The overwhelming majority of studies examining global warming impacts on terrestrial species reveal a consistent pattern of change (*high confidence*). Responses of terrestrial ecosystems to warming across the northern hemisphere are well documented by phenological changes, especially the earlier onset of spring phases. Climate change over the past decades has resulted in population decrease and disappearance of certain species (*medium confidence*) and movement of wild plant and animals poleward and upward in elevation (*medium confidence*). Some evidence of adaptation is found in migratory species (*medium confidence*). In most cases, non-climate related factors limit migration and adaptation capabilities. In the majority of studies, the observed trends correspond to predicted changes in terms of magnitude and direction (*high confidence*), but not all processes, often due lack of data, have yet been studied.

Agriculture and Forestry: In North America and Europe, there is a lengthening of the frost-free growing season and an advance in spring-summer crop phenology, which may be attributed to recent warming (*High confidence*). Viniculture appears to be highly sensitive, with a documented improvement of quality related to warming. Reduction in precipitation on decadal scales in the Sahel are responsible for lower crop yields (*high confidence*). Effects of regional climate changes to-date are of limited economic consequence and appear to lie within the ability of the sectors to adapt, but both the agriculture and forestry show vulnerability to recent extremes in heat and drought events.

Human Health: Evidence of human health outcomes related to climate trends include cholera incidence related to the El Nino-Southern Oscillation, increased incidence and range of some vector-borne diseases, some water-borne diseases, and some dust and pollen-borne diseases (medium confidence). Evidence linking climate changes with famine-related nutrition is inconclusive. The evidence regarding observed changes in the health sector related to climate trends supports the conclusion that global climate change remains an issue for human health. An increased vulnerability is apparent in poorer countries.

Disasters and Hazards. **While global catastrophe losses reveal rapidly rising costs of catastrophes since the 1970s, the dominant signal remains that of the significant increases in the values of exposure at risk; these datasets are problematic for demonstrating global trends in long-term catastrophe occurrence**. However for specific regions and perils, including extreme floods on some of the largest rivers, there is evidence for an increase in catastrophe occurrence. For tropical cyclones in both the Atlantic and Northwest Pacific Oceans over the past 30 years a strong correlation has been found between a doubling in ‘destructiveness’ (a combination of intensity and duration) and increases in sea surface temperatures.

Aggregated Results, Absence of Evidence, and Attribution

Documented evidence of observed changes in systems and sectors in response to observed regional climate changes has increased since the TAR *(high confidence)*. The TAR cited 16 studies documenting cryosphere and hydrology changes and 44 studies documenting changes in biological systems (60 studies in total). The AR4 cites ~50 studies of cryosphere changes, ~60 studies of hydrology and water resources, ~30 studies of coastal processes and zones, ~80 studies of marine and freshwater biological systems, ~150 studies of terrestrial biological systems, ~30 studies in agricultural and forestry systems, and ~10 studies of disasters and hazards (~400 studies in total). (Numbers of studies to be updated in the SOD).

For regions where there are both significant warming and observed changes, there is a much greater probability of finding coincident significant temperature change and observed responses in the expected direction than finding significant temperature change and no response or response in an unexpected direction (*High confidence*). In regions with no change in temperature, there is a greater probability of finding no observed response than of finding an observed response in either direction. Inductive analysis of presence/absence of regional temperature changes and presence/absence of observed responses shows that there are many locations that are experiencing significant warming for which there are no observations of changes in systems or sectors.

Observed responses in systems and sectors have been jointly attributed to anthropogenic climate change through a two-step process involving attribution of the responses to regional temperature changes and attribution of the regional temperature changes to increases in greenhouse gases and aerosols in the atmosphere (*High confidence*). Because of the wide variety of observed responses to regional climate trends in expected directions, and because the regional climate trends have been attributed to anthropogenic causes, anthropogenic climate change is having an impact on multiple systems and sectors.

Vulnerability and Adaptation

Observed changes within certain systems and sectors – cryosphere, marine biological systems, and terrestrial biological systems – are exhibiting greater sensitivity to observed temperature changes than others. For many systems, there is a larger response for a larger observed temperature change. However, lag responses and adaptation need to be considered in evaluating observations related to temperature increases. Developing countries appear to be more vulnerable to observed changes in regard to water resources and health, because of their geographical and climatic conditions, high dependence on natural resources, lack of water infrastructure, and often constrained financial and technological capacity to adapt to changing climate. Assessment of observed changes reveals that adaptation occurs in both biological and human systems.

1.1 Introduction

The IPCC Working Group II Third Assessment Report found evidence that recent regional climate changes, particularly temperature increases, have already affected many physical and biological systems (TAR Summary for Policymakers) (IPCC 2001). This chapter focuses on studies since the TAR that analyze responses in physical, biological, and human systems related to observed climate change. The studies are evaluated in regard to current functional understanding of process-level responses to climate change, to factors that may confound such relationships, such as land-use change, urbanization, and pollution, and to simulated projections of impacts. They are also examined to evaluate what they may reveal about adaptation and vulnerability to climate change. The chapter also considers the issue of 'joint attribution,' i.e., the determination of whether the observed changes may be related to anthropogenic climate change forcing. Absence of evidence, i.e., cases where there is evidence of climate change without evidence of accompanying system or sector change, is also evaluated, since this is important for assessing whether responses to recent warming are systematic across regions, systems, and sectors.

1.1.1. Summary of observed changes in TAR

The WGI TAR described an increasing body of observations that gave a collective picture of a warming world and other changes in the climate system (IPCC 2001). Besides evidence in physical and biological systems related to warming, the IPCC WGII TAR also found preliminary indications that some human systems have been affected by recent increases in floods and droughts in some regions, such as damages related to increased precipitation extremes in North America and to persistent low rainfall in the Sahelian region of Africa. Associations between regional climate trends and impacts related to energy, industry, and human settlements in the TAR were sparse (IPCC 2001).
Changes in physical and biological systems related to regional climate changes documented in the TAR include:

Changes in physical systems:

- *Sea ice:* Arctic sea-ice extent had declined by about 10-15% since the 1950s. No significant trends in Antarctic sea-ice extent were apparent.
- *Glaciers and Permafrost:* Glaciers were receding on all continents, and Northern Hemisphere permafrost was thawing.
- *Snow cover*: Extent of snow cover in the Northern Hemisphere had decreased ~10% since the late 1960s and 1970s.
- *Snowmelt and runoff*: Snowmelt and runoff had occurred increasingly earlier in California since the late 1940s.
- *Lake and river ice*: Annual duration of lake- and river-ice cover in Northern Hemisphere mid- and high latitudes had been reduced by about 2 weeks and become more variable.
- *Extreme precipitation*: Increased frequency of extreme rainfall in the middle and high latitudes of the Northern Hemisphere.

Changes in biological systems:

- *Range:* Plant and animal ranges had shifted poleward and higher in elevation.
- *Abundance:* Within the ranges of some plants and animals, population sizes had changed, increasing in some areas and declining in others.
- *Phenology:* Timing of many lifecycle events, such as blooming, migration, and insect emergence, had shifted earlier in the spring and often later in the fall.
- *Differential change:* Species changed at different speeds and in different directions, causing a decoupling of predator-prey relationships.

1.1.2 Scope and goals of chapter

The aim of this chapter is to assess studies of observed changes in systems and sectors related to recent climate change, particularly temperature rise, in order to advance understanding of the effects of climate change. The chapter evaluates the accumulating body of evidence with regard to the following questions:

1. Can changes in systems and sectors related to changing regional climates be detected?
2. Are observed changes consistent with functional understanding and modelled predictions of climate impacts?
3. Do observed changes provide information about the potential vulnerability and adaptation of systems to climate change?
4. Are observed changes prevalent across diverse systems, multiple sectors, and geographic regions?
5. Is there a coherent signal in patterns of observed changes?
6. Can the observed changes be attributed to anthropogenic climate change forcing?

We review methods of detection of observed changes, investigating the roles of climate and non-climate drivers of change, issues of scale, and techniques of meta-analysis. We then examine evidence of recent observed changes in sectors and systems relevant to Working Group II: cryosphere, hydrology and water resources, coastal processes and zones, freshwater and marine biological systems, terrestrial biological systems, agriculture and forestry, human health, and disasters and hazards. Evidence regarding other socio-economic effects, including energy use and tourism, is also assessed.

Indigenous knowledge of observed changes is considered where available and applicable. Sources of indigenous knowledge include the Arctic Climate Impact Assessment, the Database of Climate Change Information Sources for Northern Canada, the Alaska Traditional Knowledge and Native Foods Database, and the Snowchange project, a multi-year research and education project of the Circumpolar North (www.snowchange.org).

After assessing the state of knowledge in the individual systems and sectors, we consider the regional aspects and dimensions of the issue and studies that have analysed the changes through larger-scale aggregation and meta-analyses. Such studies relate observed changes in systems and sectors to regional climate trends, and analyze possible relationships of observed regional climate trends and observed changes to anthropogenic climate change at the global scale in the process of joint attribution.

1.2 Methods of detection and attribution of observed changes

Identification of significant changes in observed climate and attributing these changes to specific causes has been discussed in each of the earlier assessments by the IPCC (IPCC 2001). The detection and attribution of climate change is essentially a signal-to-noise problem, for which methods have been developed to enhance possible forced climate change signals and to reduce the noise associated with the natural variability of the climate system. Following usage in the TAR (Mitchell, Karoly *et al*. 2001), *detection* is the process of demonstrating that an observed change is significantly different (in a statistical sense) than can be explained by natural internal variability. However, the detection of a change does not necessarily imply that its causes are understood.

The identification of observed changes in natural and managed systems and assessment of these as possible responses to changes in climate are even more complex. There are several main methods of change detection, including the use of satellite data, and on-site measurements. Each of these, though, has inherent advantages and limitations. Satellite measurements, for instance, have a short period of record. On-site measurements, on the other hand, are subject to methodological inconsistencies. For accurate detection, a combination of detection methods and explicit consideration of other causal factors is needed.

1.2.1 Climate and non-climate drivers of change

Both climate and non-climate factors affect sectors and systems. While climate is an important factor in some systems, a large number of non-climatic drivers influence observed responses of sectors and systems to climate variations, making analysis of the role of climate in observed changes complex. Non-climatic drivers can influence systems and sectors directly and/or indirectly through their effects on climate variables such as albedo and soil moisture regimes. Socio-economic processes, including land-use change (e.g., forestry to agriculture; agriculture to urban area) and land-cover modification (e.g. ecosystem degradation or restoration) are of major importance. Furthermore, many systems and sectors are affected by various aspects of pollution (e.g., in the atmosphere, soil, and water).

1.2.1.1 Climate drivers of change

Climate is a very important factor in determining the distributions of natural and managed systems. The dramatic changes in the distribution of ecosystems during the ice ages illustrate the way that climate determines the distribution of natural ecosystems. Similarly, the geographical distribution of ecosystems in the current climate can vary greatly over short distances where there are large spatial variations of climate, such as reductions of temperature with elevation in mountainous regions or reductions of rainfall away from coastal regions in the subtropics. Hence, changes in climate are expected to be one of the important drivers of changes in natural and managed systems.

Many aspects of climate are important in determining these distribution of natural systems, including temperature and rainfall, and their variability on all time scales from days to the seasonal cycle to interannual variations. While changes in all of these aspects of climate may be important in driving changes in natural systems, we focus on the climate parameters for which it is easiest to identify changes as a possible response to anthropogenic forcing (with the largest signal-to-noise). Mean temperature (including daily maximum and minimum temperature) and the seasonal cycle in temperature over relatively large spatial areas show the clearest signals of change in the observed climate. Precipitation has much larger variability than temperature on most space and time scales, and it is therefore much more difficult to identify as a clear driver of changes in systems. Box 1.1 describes the recent heat wave in Europe in 2003, a recent example of extreme temperature variability.

There are a number of other possible climatic drivers of changes in natural and managed systems. Some of these include increases in carbon dioxide concentration in the atmosphere, which aid vegetation growth but also lead to increased acidity it the oceans, and changes in solar radiation due to changes in cloudiness or aerosol amounts, which affect photosynthesis.

Box 1.1: Heat wave in Europe, summer 2003

The heat wave that affected much of Europe during summer 2003 produced record-breaking temperatures particularly during June and August (Beniston and Diaz 2004; Schar, Vidale *et al*. 2004). It was probably the hottest summer in Europe since at least 1500 (Luterbacher, Dietrich *et al*. 2004). An exacerbating factor for the temperature extremes was the lack of precipitation in many parts of western and central Europe, leading to much-reduced soil moisture and surface evaporation and evapotranspiration (Beniston and Diaz 2004). It is likely that anthropogenic climate change more than doubled the risk of the occurrence of a similar magnitude heat wave (Stott, Stone *et al*. 2004). Some impacts of this heat wave are described in boxes in later chapters. Further details of the climate anomalies are given in Box 3.5.5, Chapter 3 Observations: Surface and atmospheric climate change, WGI FOD AR4.

1.2.1.2 Non-climate drivers of change

Non-climate drivers, such as land use, land degradation, urbanization, and pollution, affect systems and sectors directly and indirectly through their effects on climate (Table 1.1). These drivers can operate independently or also in association with one another (LUCC 2005, IGBP (2000) and HDP (2005). Complex feedbacks and interactions occur on all scales from local to global (Walker *et al*; Janssen *et al* 2004).

Table 1.1: *Direct and indirect effects of non-climate drivers.*

Non-climate driver	Examples	Direct effects on systems/sectors	Effects on climate
Geological processes	Volcanic activity, earthquakes	Lava flow and ash, shocks, coastal zone damage, enhanced basal melting of glaciers, rockfall and ice avalanches	Cooling from stratospheric aerosols, change in albedo
Land-use change	Conversion of forest to agriculture	Declines in wildlife habitat, biodiversity loss, increased erosion, nitrification	Change in albedo, lower evaporation, altered water and heat balances
	Urbanization	Ecosystem fragmentation, deterioration of air quality, increased runoff and water pollution	Change in albedo urban heat island, increase in downwind precipitation,
	Afforestation	Restoration of ecosystems	Change in albedo, altered water and energy balances, carbon sequestration
Land-cover modification	Ecosystem degradation (desertification)	Reduction in ecosystem services, reduction in biomass	Changes in micro-climate
	Change from monoculture to agroforestry, soil protection and conservation	Change in insects, weeds, and diseases; change in water use and erosion.	Changes in micro-climate, increased evaporative cooling, lower temperature

	measures		
Invasive species	Eucalyptus, tamarisk	Reduction of biodiversity, salination	Change in water balance
Pollution	Toxic waste, oil spills, exhaust, pesticides and herbicides	Reduction in breeding success, species mortality, reduction in biodiversity	Sulphate aerosol cooling, change in albedo
CO_2	Increasing atmospheric concentration	Direct physiological effects on photosynthesis and water-use in C3 and C4 plant species, affecting competition; acidification of sea water	Enhanced global greenhouse effect

Socio-economic processes that drive land-use change include population growth, economic development, trade, and migration; these processes operate at both global and regional scales. Earth observations from satellite and published statistical data demonstrate that land-use change, including that associated with the current rapid economic development in Asia and South America, is proceeding at an unprecedented rate (Rindfuss, Walsh *et al*.). Land-use changes influence albedo, energy budget and evaporation, which can be quantified in terms of radiative forcing. Some studies have linked land-use change with changes in the planetary energy and water balances as well as to changes in air quality and pollution that affect the greenhouse process itself (Kalnay and Cai 2004; Vose *et al* 2004; Pielke, 2002 dynamics). Pielke *et al* (2002a and 2002 b) report that the impact on climate is greatest in Southeast Asia and in parts of Central and South America. Land-use and land-cover change can also strongly magnify the effects of extreme climatic events, both on direct health outcomes (e.g., heat mortality, injuries/fatalities from storms, and ecologically mediated infectious diseases (Patz, Campbell-Lendrum *et al*. 2005). Intensification of land use, as well as the extent of land-use change, is also affecting the functioning of soil ecosystems and hence on emissions of greenhouse gases such as carbon dioxide and methane (NASA 2004).

A frequently raised question is the role of urbanization in modifying climate. Cheng and Castro (2003) describe how urban areas exert enhanced drag on atmospheric boundary layer flows and significantly alter the energy balance of the atmospheric boundary layer. Kalnay and Cai (2004) estimated that urbanisation accounts for about one-half of the observed increase in diurnal temperature range. However, Parker (2004) provides an analysis demonstrating similar temperature trends in urban and non-urban areas between 1950 and 2000. This would suggest that there may be other factors, possibly feedback processes, that result in urban and non-urban areas having similar temperatures trends.

1.2.2 Data

Long temporal records and broad spatial scales are required for rigorous analysis of observed changes related to climate trends. However, variable quantities of data are available for different systems and sectors. Depending on the system examined, needed data may be scarce (e.g., density of African birds) or prevalent (e.g., plant phenology data across Europe). Additionally, many data sources have not been fully tapped, such as fishery by-catch records, botanical gardens, agricultural research stations, photographic archives (including aerial photography), and indigenous knowledge. Recently, however, the search for evidence of climate-change impacts has intensified. Data sources and types for observed changes vary in temporal and spatial scales according to sector (Fig. 1.1). Small-scale data at individual sites may be continuous or intermittently monitored, and tend to have longer time-series.

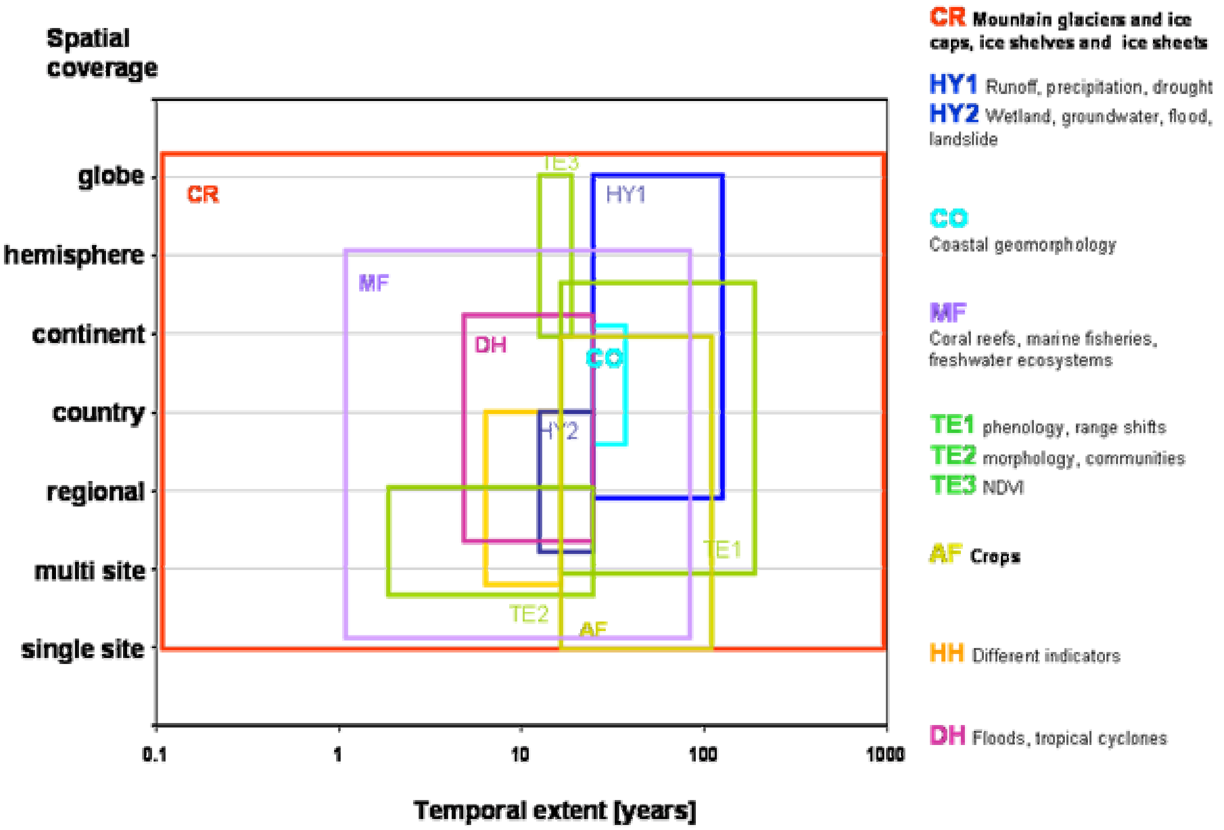

Fig. 1.1: *Temporal and spatial scales of observed changes in systems and sectors: CR, Cryosphere; HY, Hydrology and Water Resources; CO, Coastal Processes and Zones; FM, Marine and Freshwater Biological Systems; TE, Terrestrial Biological Systems; AF, Agriculture and Forestry; HH, Human Health; DH, Disasters and Hazards. NDVI, Normalized Difference Vegetation Index.*

1.2.2.1 Remote sensing

Remote sensing, mainly by satellite (but also by conventional air photography) is a significant tool for observing changes in various systems and sectors at regional and global scales. Beginning with Landsat in 1973, time series of remote sensing data are now long enough to detect significant changes in terrestrial vegetation. Remote sending is also used to characterize changes in glacier, snow, sea ice and freshwater ice extent, including passive microwave data, radar observations from Radarsat or ERS and more recently airborne and satellite-based laser altimetry (IceSat). Land-use changes are also observable from low-resolution sensors such as VEGETATION on board SPOT 4 and 5, MODIS on board AQUA, and MERIS on board ENVISAT. However, time-series from these systems are only several years at present. Over time, they will allow quantification of geographical shifts in vegetation and temporal changes in phenology, productivity, forest fires, etc.

A common application is the estimation of net primary productivity (through vegetation indices derived from reflectances in different wavelengths) (Fig. 1.2) and the derivation of absorbed Photosynthetic Active Radiation (PAR) (Nemani, Keeling *et al*. 2003). These often rely on data from the NOAA-AVHRR satellites in operation from about 1980. A limitation in remotely sensed data lies in the lack of continuity and consistency in spatial and spectral resolution from successive sensors. This makes quantitative inter-comparison and calibration among sensors difficult. However, significant progress in calibration has enabled a reliable assessment of changes in Northern Hemisphere forest productivity (Zhou, Tucker *et al*. 2001) (see Section 1.3.6).

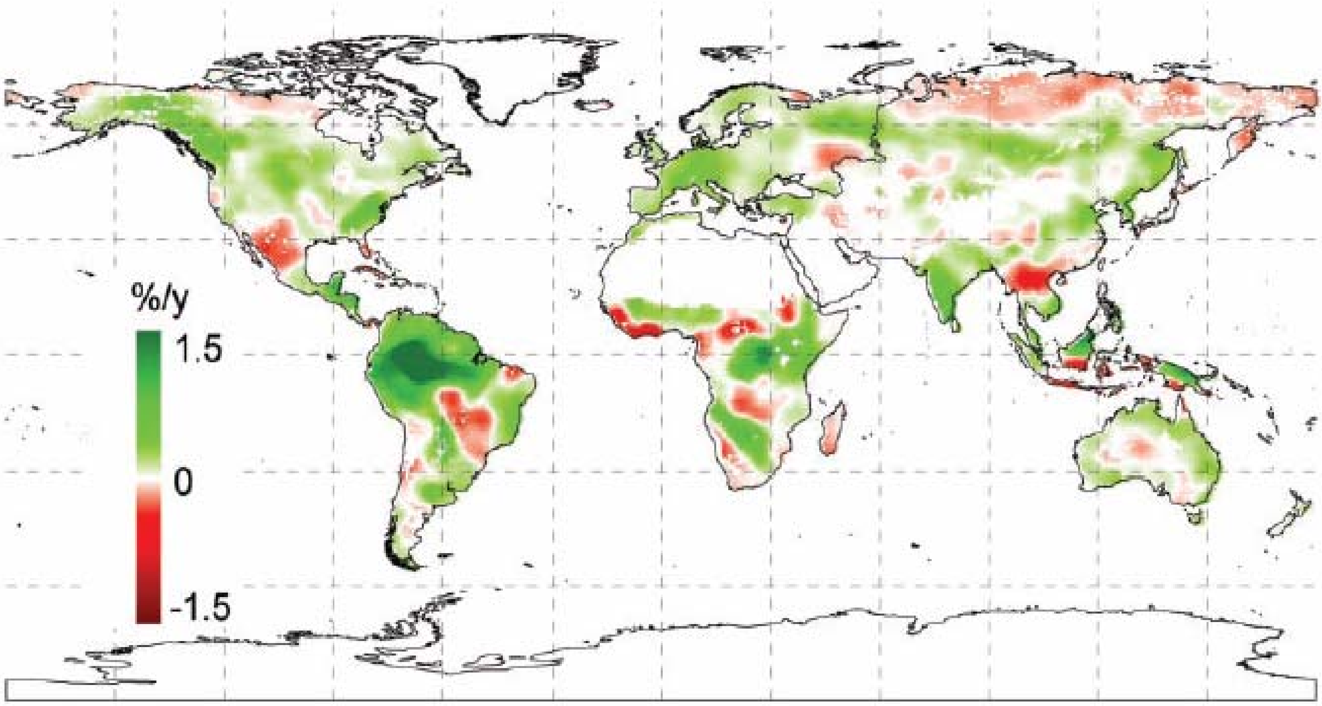

Fig. 1.2: *Spatial distribution of linear trends in estimated net primary productivity (NPP) from 1982 to 1999. NPP was calculated with mean fraction of photosynthetically active radiation (FPAR) and Leaf Area Index (LAI) derived from Global Inventory Monitoring and Modelling Studies (GIMMS) and Pathfinder Advanced Very high Resolution Radiometer Land (PAL) satellite data sets (Nemani, Keeling et al. 2003).*

1.2.2.2 Analysis of evidence of no change

There are two different approaches currently used in studying changes in abiotic processes (e.g., melting glaciers) or species due to climatic change that are able to examine evidence of no change: 1) Using systematic network data covering larger areas/regions without any restrictions (e.g., sites explicitly experiencing climate change) e.g., (Menzel and Dose 2005); 2) Investigating a suite of processes or species at numerous locations experiencing climatic change e.g., (Parmesan and Yohe 2003). Information gathered by these methods fit into four different categories related to climate change and system response: processes or species changing and temperature changing or not, and processes or species not changing and temperatures changing or not (Fig. 1.3).

The two methods are able to address different questions: 1) "Of all network species observed in different regions, which of those species and which sites are changing and which are not, and to what degree do those records match with temperature time-series concerning occurrence of changes and strength of trend?" and 2) "Of all species located in a region, which of those are changing and which are not? Are the species changes associated with temperature changes?"

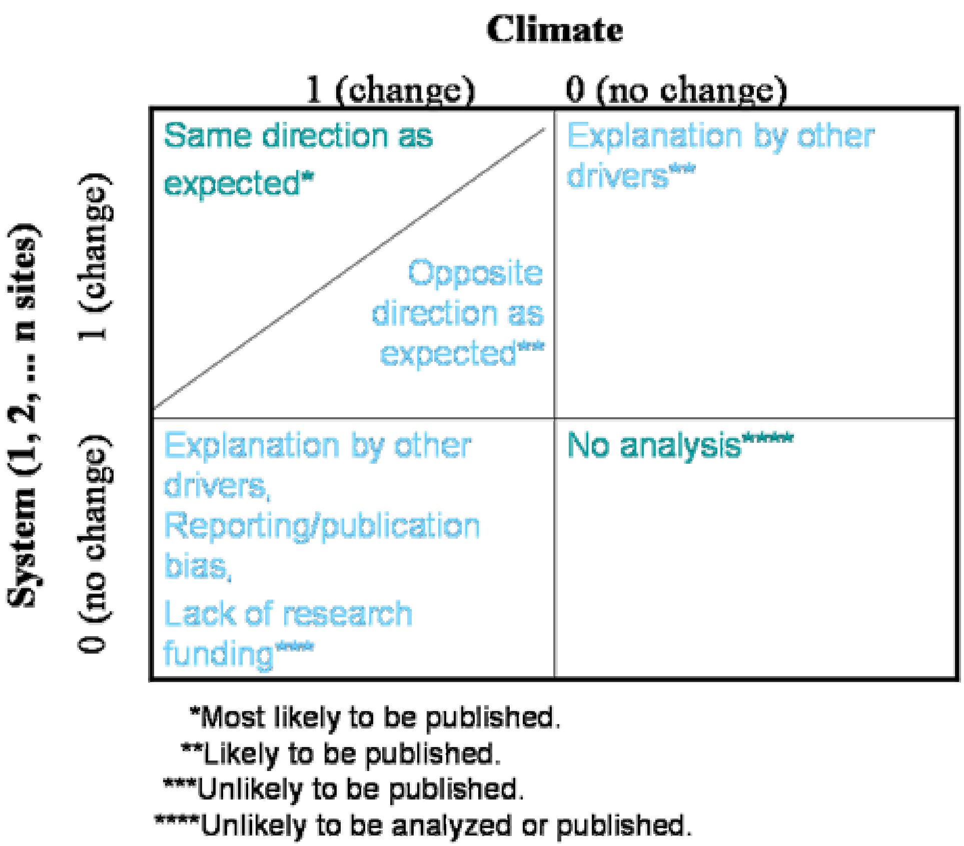

Fig. 1.3: *Categories of system responses to observed changes and non-changes in climate and relation to publication biases.*

Both approaches have strengths and weaknesses. Network studies (Method 1) are the only method that systematically analyses regions, sites, and species without changes. When using network data, publication bias is of little concern, because all species are recorded regularly, regardless of change or not. Network study areas, at the moment, are mostly restricted to North America and Europe, often on a national basis. Method 2 can examine many species in any location, but publication bias may be large because species showing no change have a higher likelihood of being overlooked. The resulting ratio of how many species are changing over the total number of species rests on the assumption that all species in the area have been examined, which at times may not be the case. Both Methods 1 and 2 are amenable to analysis of resilience and thresholds since no species data are eliminated.

1.2.3 Methods

Where long series of data exist, detection of trends in a system or sector attribute through time has most commonly been made with regression, correlation, and time-series methods. The detection of an abrupt change in a data series or of a relationship with climatic variables is also a common goal of analysis; regression and correlational methods are frequently used in the latter. When data exist from two (or more) discontinuous time periods, two-sample tests have frequently been employed.

1.2.3.1 Statistical techniques

Continuous and discontinuous data series, collected or summarised on an annual basis, are typically examined for evidence of trend using statistical analysis, with calculation of a significance level, i.e., the confidence of a real trend being present rather than a pattern occurring by chance from random data. Studies that report data over long periods (Abu-Asab, Peterson *et al*.) that cover wide geographic areas (Menzel and Fabian 1999) or that span a number of different variables such of multi-taxa (Bradley, Leopold *et al*. 1999) are likely to produce the most reliable results. Autocorrelation in data series can be overcome by using time-series analyses that specifically take into account the dependencies between successive data values. Abrupt change in a data series can be identified by change-point analysis, including Bayesian techniques (Dose and Menzel 2004).

Even when some data exist as series, researchers have sometimes chosen to compare results from an early group of years with a more recent group of years, when a step change in the recorded variables may have been apparent in line with a step change in temperature (Fitter and Fitter 2002; Butler 2003). When data do not form a series of observations but derive from two time points, typically recent and older in time, two sample comparisons as noted above may still be possible. An alternative approach is to count the number of changes in a certain direction. If no change has occurred then equal numbers of positive and negative changes would be expected.

For evidence of climatic response, three commonly used methods involve (i) correlation with an ever-increasing number of climatic variables, (ii) examining trends through time and (iii) a comparison between two points in time. Some authors suggest that an approach that combines empirical and process-based evidence for detecting a climate influence on living organisms (Sparks and Tryjanowski 2005). While many phenological models are based on regressing an observed phenological event against temperature measured over a fixed period, such models are unable to represent within-population variation in phenology. Gienapp (Gienapp, Hemerik *et al*.) have proposed a ‘proportional hazards model’ to describe phenology and illustrate it with an example from breeding time in birds.

1.2.3.2 Meta-analyses

Meta-analysis is a statistical method of combining quantitative findings from multiple studies investigating similar factors. The methods used in the various studies, however, need not be similar. Meta-analyses have examined phenological changes and changes in ranges of both plant and animal species (Root, Price *et al*. 2003), (Parmesan and Yohe). The criteria for inclusion of studies in a meta-analysis are determined *a priori* to avoid ‘cherry picking.’ Criteria might include, e.g., all studies that span a time period long enough to allow a trend to be noted (e.g., >/= 20 years). All studies or data that meet the criteria must be included in the meta-analysis to prevent investigator bias. A criterion regarding the number of species included in the individual studies depends on the questions being addressed by the meta-analyses. Network data (Menzel 2005)or studies from any location with groups of species (Parmesan and Yohe 2003)may be used to investigate evidence of no change, resilience and thresholds. Another method includes studies of one or many species (Root, Price *et al*.; Root, MacMynowski *et al*. 2005), but only species that show a change are included. Meta-analysis including re-analysis of data for all species allows the assessment of reporting bias as well as the assessment of all changes, including the frequency of no change (Menzel, Sparks *et al*. 2005). However, such studies are rare.

1.2.3.3 Attribution

As noted in the TAR (Mitchell, Karoly *et al*. 2001), *attribution* of climate change to anthropogenic causes (i.e., the isolation of cause and effect) involves statistical analysis and the assessment of multiple lines of evidence to demonstrate, within a pre-specified margin of error, that the observed changes are

- unlikely to be due entirely to internal variability;
- consistent with the estimated responses to the given combination of anthropogenic and natural forcing; and
- not consistent with alternative, physically-plausible explanations of recent climate change that exclude important elements of the given combination of forcings.

Attribution of observed changes and responses in systems to anthropogenic forcing is more difficult, as it is a two-stage process. First, the observed change in a system must be demonstrated to be associated with an observed local or regional climate change with a specified degree of confidence, and not to some other local driving factor, such as those described in section 1.2.1.2. The confounding influences of multiple drivers make attribution of observed responses to local climate change more difficult. Second, the observed local climate change must be attributed to anthropogenic causes with a similar degree of confidence.

Hence, following the definition of climate change attribution above, the attribution of changes in natural or managed systems to regional climate change involves statistical analysis and the assessment of multiple lines of evidence to demonstrate that the observed changes are:

- unlikely to be due entirely to internal climate variability or natural variability of the system;
- consistent with the estimated biophysical response to a given regional climate change; and
- not consistent with alternative, plausible explanations of the observed change that exclude regional climate change.

Then *joint attribution* of the observed change to anthropogenic climate change involves both the attribution of the observed change to regional climate change and the attribution of the regional climate change to anthropogenic causes.

1.2.4 Exploring confidence in methods and results

Confidence in the methods and results in observed changes studies relies on the quality, size, and time length of data sampling, and the robustness of the techniques, both for individual studies and for meta-analyses. Even with excellent time-series data, linking biological and other system/sector trends to climate trends is inherently correlational. Major issues in establishing confidence in studies of observed changes related to climate change include the role of process-level understanding of change, non-climate driving forces, and adaptation.

1.2.4.1 Plausibility, statistical probability, strength from multiple analyses

Apart from problems inherent in summarizing information from diverse studies of numerous subjects and methods, plausibility issues have been addressed through the use of theoretical understanding of expected biological and physical responses to climate variables, such as temperature; this allows, for example, the analysis of that fraction of species that exhibit change in the direction expected with local temperature trends (Parmesan and Yohe 2003; Root, Price *et al*. 2003). Parmesan and Yohe (Nöthiger) further define a diagnostic fingerprint of temporal and spatial 'sign-switching' responses using twentieth century climate trends, which further contributes to plausibility. However, since their evidence was drawn primarily from Europe, its representativeness for the entire Northern Hemisphere is not clear.

Attribution is also difficult given the many confounding factors that may simultaneously drive the species or ecosystem in the same direction as climate warming. Identifying a unique climate change fingerprint, such as earlier blooming dates, and poleward migration across undisturbed ecosystems, can provide clearer attribution for systems and sectors (Parmesan and Yohe 2003). Attribution is bolstered by empirical or modelling studies that illustrate a response to climate in the observed direction. Concerns over the positive publishing bias can be alleviated by synthesizing results from multi-species studies where non-response is documented with climate change response (Parmesan and Yohe 2003). Such meta-analyses allow the accumulation of results across many studies to establish general findings. New Bayesian methods can incorporate particular sources of error and quantify the uncertainty in estimates of many biological characters, such as changes in abundance, distribution, or phenology (Dose and Menzel 2004)

1.2.4.2 Adaptation issues

Characterizing an observed change is difficult, since observed responses may be adaptations, in and of themselves, in biological systems either more or less managed. In biological systems, non-stationarity of the correlates over the period of study is a concern, if, for example, a species response to warming changes over time. However, phenological records covering the last century do not reveal a change in response with time (Menzel and Dose 2005). Determining the influences of climate trends on more managed sectors such as agriculture and human health is complicated by the multiple ways that they are influenced by many other factors besides climate, especially management. For example, adaptive responses in agriculture may be manifested as changes in area sown, crop varieties, and management inputs such as irrigation, fertilizers, pesticides, and labour. Timeframes and time lags of adaptation may vary from sector to sector, and among socio-economic groups.

Adaptation likely plays a role in disasters and hazards, where changes in insurance premiums may also be an adaptive response to changes in climate (Mills 2003). However, since inflation, population growth, changing demographic distribution, changes in per capita real wealth, as well as other factors play a role in damages, characterizing the role of climate alone, if any, in human responses to disasters and hazards is especially complex. One approach to test if adaptation to climate change is occurring is to analyze damages related to climate-related and non-climate-related events separately to see if they experiencing similar or different trends. However, since the principal non-climatic hazards are geological (e.g., volcanoes, earthquakes, and tsunamis), where the return period between events tends to be much longer than that for hydro-meteorological hazard events (which also tend to be more locally manifested), such approaches need to ensure that large and less-frequent events do not distort the findings.

1.3 Observed Changes in Systems and Sectors

The following sections assess studies that have been published since the TAR of observed changes in the cryosphere, hydrology and water resources, coastal processes and zones, freshwater and marine biological systems, terrestrial biological systems, agriculture and forestry, human health, and disasters and hazards. Each section describes climate and non-climate driving forces for the system or sector, assesses the evidence regarding observed changes in key processes, highlights issues regarding the absence of observed changes and conflicting evidence, and considers how the evidence of change in the system or sector relates to adaptation and vulnerability.

1.3.1 Cryosphere

The cryosphere is a sensitive indicator of present and past climate changes. The main components of the cryosphere are mountain glaciers and ice caps, floating ice shelves and continental ice sheets, seasonal snow cover on land, frozen ground (including seasonally frozen ground and permafrost), sea ice and lake and river ice. There is abundant evidence that all these cryospheric components are undergoing generalized recession in response to global warming, which in turn has effects on the environment and human activities. Moreover, the recession shows an accelerated trend in recent decades, consistent with the enhanced observed warming.

In Chapter 4 of WGI, the changes in the cryosphere since the TAR are described in detail. Here we concentrate on the effects of cryospheric changes on the environment and on human activities. A main effect of the reduction of both polar and non-polar cryospheric components is the contribution to eustatic sea level rise. Its characteristics, trends and effects are found in Section 1.3.3 (Coastal processes and zones), in Chapter 6, Chapter 15 and in WGI.

Nearly all mid-latitude, tropical and equatorial mountain regions in the world have experienced significant warming during the last century, with a large spatial variability of precipitation patterns. The strong warming observed in these mountain regions has resulted in a strong reduction of most cryospheric components, with a general accelerating trend since the 1990s. There is ample evidence suggesting that the 20th century recession of mountain glaciers is outside the range of normal climate variability of the last several millennia. South Cascade Glacier in Washington State, USA, for instance, fluctuated in length between 3.6 and 4.6 km from 4000 years BP to 1958; but by 1995 it had receded to only 2.92 km, and recession continues (Krimmel 2002) . This result is consistent with results from several Alpine glaciers as well as a number of other palaeoclimatic indicators (Haeberli and Holzhauser 2003).

The Arctic has experienced nearly twice the global warming while in the Antarctic some areas have cooled while others have warmed, with a particularly strong warming in the Antarctic Peninsula at a rate nearly five times the global warming during the last five decades. In both the Arctic and in the Antarctic Peninsula, the effects of the warming have had greater impact than the enhanced precipitation observed due to increased moisture availability. A geographical distribution of changes observed in the cryosphere is presented in Fig. 1.4.

The surface energy balance of the cryosphere is driven by several climatic parameters including solar radiation, albedo, long wave radiation, relative humidity, wind, temperature and precipitation. Of these the most critical parameters are temperature and precipitation, which are in turn driven by changes in the heat budget of the earth, and reorganization through atmospheric and oceanic circulation patterns. In addition to climatic forcing, the cryosphere can respond to other external and internal forcing factors and is subject to various feedback mechanisms.

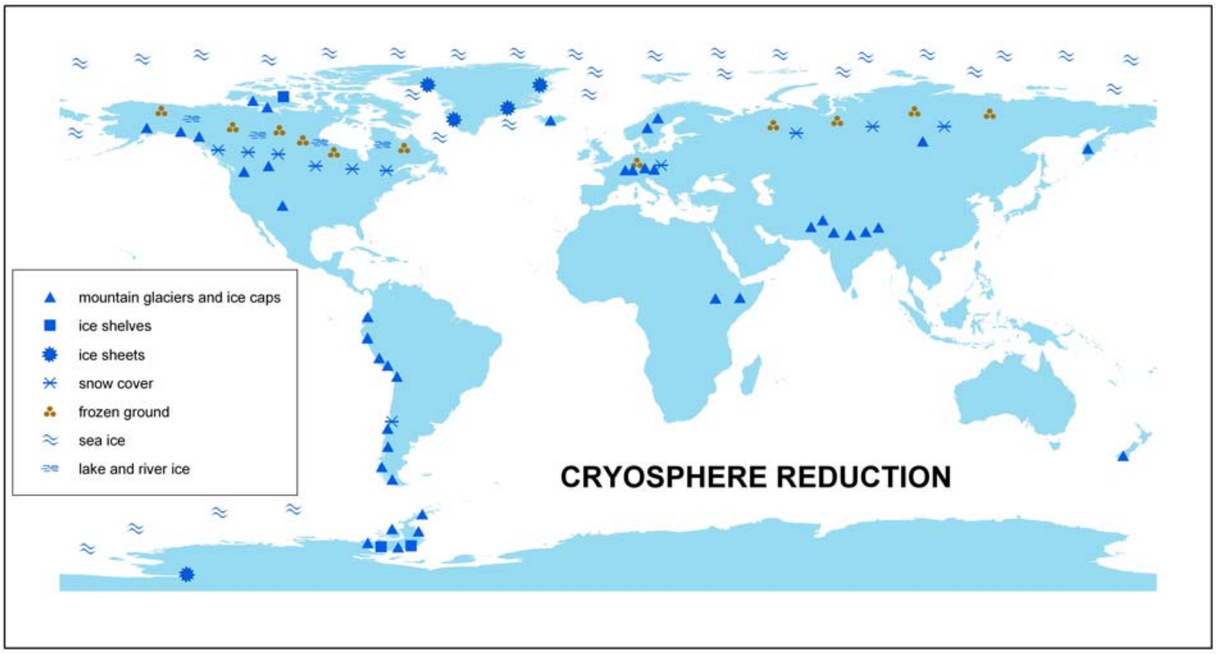

Fig. 1.4: *Geographical distribution of present cryospheric reduction. The figure has been compiled based on changes reported in the literature since the TAR. For references see Chapter 4, WGI.*

The components of the cryosphere show variations at different timescales and different spatial scales. In the case of snow cover, seasonally frozen ground, sea ice and lake and river ice, response times are daily to seasonal, and their changes can be directly related to recent warming. This is also the case for mountain glaciers which have a response time of several years~decades. In the case of ice caps, ice shelves, and ice sheets, and permafrost, a common question is whether area and volume reduction in the 20th century is due to recovery from previous worldwide cold periods such as the last glaciation (which peaked at ca. 18.000 yBP – Last Glacial Maximum or LGM,) and the Little Ice Age (LIA, which culminated in 1850-1900), or are a result of anthropogenic greenhouse warming (Meier, Dyurgerov *et al*.). Although there is a secular reduction of permafrost and large ice masses since the LGM (COHMAP Members, 1988) and more recently since the LIA (Grove 1988), there is now wide evidence of reduction of large ice masses in the last few decades due to warming during the last century. A clear example of this is the collapse of millennial ice shelves in the Arctic (Mueller *et al*., 2003) and in the Antarctic Peninsula (Scambos 2004) due to recent regional warming.

In addition to climate, the cryosphere responds to external forcings such as geothermal heating and earthquakes. Landslides and rockfalls triggered by earthquakes can produce large changes in glaciers, snow cover and frozen ground, particularly in steep mountain regions. The cryosphere is regulated by various natural feedback mechanisms, of which the positive snow-ice albedo feedback is one of the most relevant (Box 4.1 of Chapter 4, WGI). Other physical mechanisms that can affect the cryosphere are local topography, geometry and hypsometry; internal dynamics of snow, ice and frozen ground; and changes in the ocean-cryosphere interface. At geologic time-scales, the continental mass distribution on earth and mountain building can be relevant for sustaining cryospheric components in polar regions and elevated areas.

In addition to anthropogenic greenhouse warming, other human-induced forcings can affect the cryosphere. The modelled effect of increased anthropogenic soot emissions shows an albedo influence on cryosphere reduction and warming, particularly in the Arctic but probably in other areas as well (Hansen and Nazarenko 2004). There are local examples of artificial increase of snow and ice albedo for producing enhanced melting. Some examples of mining activities have resulted in glacier reduction, for example in central Asia and Chile. Radiation shields have been installed over permafrost and glaciers at local scales in the Alps.

1.3.1.1 Effects of changes in mountain glaciers and ice caps

Mountain glaciers and ice caps show an accelerated recession worldwide in response to global warming, with a few glacier areas that are advancing due to increased local and regional precipitation and also cooling in some sectors. Effects of changes in mountain glaciers and ice caps have been documented in runoff, gravity flows, ocean freshening, sea level rise, and other processes.

Increased glacial runoff
Many small glaciers in mid and low latitudes are disappearing, with consequences for water resources (e.g., in the Alps, Andes, central Asia, Africa, and the Arctic). Increases in glacial melt lead at first to increased river runoff and discharge peaks and increased melt season (Boon 2003; Hock 2005; Hock in press; Juen In Press), which can be sustained in the medium term (years-to-decades) depending on glacier size. In the long range (decadal-century scale), glacier wasting is amplified by positive feedback mechanisms and glacier runoff starts decreasing (Janssens, Freibauer *et al*. 2003). The temporary increase in glacier melt can produce enhanced glacial lake outburst floods (GLOFs), with examples in central Asia (Kääb 2003), in Peru (INRENA-IRD 2004) and in Chile (Peña and Escobar 1985), although the link to global change is not fully established yet. Enhanced glacial melt can produce increased glacier lubrication at the bed and subsequent glacier acceleration, which can result in glacier creep thinning. This may be happening already in Patagonia (Rignot 2003; Rignot).

Gravity flows
Glacier retreat can result in more frequent gravity flows such as ice avalanches, rock avalanches and enhanced outburst floods from glacial lakes, as has been detected, for example, in central Asia (Kääb 2003)and in Peru (INRENA-IRD 2004).

Ocean freshening
Enhanced glacier melt can lead to freshening (reduced salinity and density) of the oceans. There is already initial evidence of freshening in the North Atlantic (ACIA 2004), which may slow down the meridional ocean circulation. Wasting of ice shelves and sea-ice reduction plays also a major role in sea-water freshening (see below).

Sea level rise
Global glacier volume losses show strong acceleration since the end of 1980s (Meier, Dyurgerov *et al*. 2003). This global glacier wastage has resulted from ice-wastage increases throughout the earth, for example in Alaska (Arendt 2002), Patagonia ice fields (Rignot 2003), North Western USA and Canada, High Mountain Asia and in the Arctic (Dyurgerov 2005). The average glacier loss in 2002-2003 is around 1 m/y of water equivalent, which is about three times the average loss in the warm decade of the 1990s and almost twice the second highest biennial average loss (WGMS. 2005). The contribution of mountain glaciers and ice caps to

sea-level rise is estimated to have doubled from 0.3 mm/y to 0.6 mm/y in the period 1990s-early 2000s (Chapter 4 of WGI) with respect to pre-1990s levels (IPCC 2001).

Impact on the earth's gravitational field and crustal uplift
The main component of the Earth's obliquity, known as J_2, is decreasing on a secular time frame, due to tidal friction, post-glacial rebound and other causes (e.g. Munk), which causes an acceleration of the Earth's rotation rate. In 1998 J_2 began to increase, which is believed to be partially due to accelerated melting of mountain glaciers and ice caps (Dickey 2002). Recent glacier melting is also resulting in local and regional crustal uplift in Alaska and other mountain regions (Larsen 2005).

Obliteration of paleoclimatic records
Melting is also affecting the chemical signals of ice core records in high mountain areas due to enhanced melting resulting in water percolation and mixing of chemical species that destroys potentially valuable records of past climate (Thompson; Bolius Submitted).

Plant and animal colonization
Enhanced colonisation of plants and animals in deglaciated terrain is a direct effect of glacier retreat (Jones 2003). The consequences of plant and animal colonization have not yet been quantified.

Tourism
Glacier retreat has resulted in a relevant loss of ice climbs in several mountain ranges (Bowen 2002). Scenic impact due to glacier retreat will affect tourism in many mountain regions around the world.

1.3.1.2 Effects of changes in ice shelves

The ice shelves of the Antarctic Peninsula and in the Canadian Arctic are not just retreating but are also undergoing collapse (Scambos 2004) and (Mueller 2003), respectively) in response to regional warming. Ice-shelf collapse and increased basal melting of ice shelves should result in partial freshening of ocean water, as has been measured, for example, in the Ross Sea (Jacobs 2002). Because they are already floating, melting of ice shelves does not contribute to sea level rise. However, the collapse of ice shelves has resulted in some cases in significant acceleration of inland glaciers (Scambos 2004) which can contribute to sea level rise.

1.3.1.3 Effects of changes in ice sheets

The negative mass balance reported for the Greenland ice sheet (Krabill and Martin 2004), for the Amundsen Sea sector of West Antarctica (Thomas, Cameron *et al*. 2004) and for the Antarctic Peninsula (Rignot 2004) is contributing to sea level rise and freshening of ocean water. The enhanced flow of these ice streams and glacier systems, most probably as a result of the collapse of their respective ice shelves (Rignot 2003; Thomas 2003; Rignot 2004) can result in increased production of iceberg calving. Increased calving can in turn affect sea navigation, although no clear evidence for this exists yet.

1.3.1.4 Effects of changes in snow cover

There is a general worldwide decrease of snow cover in recent decades, particularly regarding spring snow-cover extent, which is well reported for the Northern Hemisphere (Armstrong 2001; Ueda 2003), in spite of local increases in winter precipitation in some areas in North

America (Mote 2005). There are a few high- latitude areas, such as Finland and the former Soviet Union, where increases in winter precipitation have resulted in a larger snow-cover extent (Kitaev 2002; Hyvärinen 2003). In the Southern Hemisphere, changes in snow cover are not yet well quantified.

Increased snow melt

A direct consequence of the reduced snow cover is that spring peak river flows are occurring earlier, which is well reported for North America (Cayan 2001; Regonda 2005; Stewart 2005, decline). In Alaska, a snowmelt advance of 8 days has been detected since the mid-1960s (Stone 2002). In northern Russia, earlier snowmelt runoff has been detected (Ye and Ellison 2003). Elsewhere in Eurasia and in the Southern Hemisphere, there is lack of evidence of snowmelt changes.

Ski areas

There is a trend towards less snow at low altitudes in the Alps, which is affecting ski areas. In central Chile, an annual increase of 6 m/y in the zero-degree isotherm altitude has been measured from 1975-2001 using radiosonde data, which is thought to have resulted in a corresponding snowline rise, an evidence of which might be the rise of lowermost constructed ski lifts from an elevation of 2600 m a.s.l. in 1950 to ~ 2935 m a.s.l. in 1987 (Carrasco 2005), although enhanced pollution might also play a role in this area located close to Santiago.

1.3.1.5 Effects of changes in seasonally frozen ground and permafrost

Permafrost, defined as underground materials that remain at or below 0ºC continuously for two or more years, shows a general warming trend and degradation (i.e., decrease in thickness and areal extent) during the last century, mainly in response to climate warming, with at least partial evidence for acceleration. Strong evidence for this warming is provided by deep borehole records in the Northern Hemisphere. The active layer, that is, the ground above permafrost that seasonally thaws and freezes, has shown a significant thickening in many regions (Frauenfeld 2004). In areas with no permafrost, the thickness of seasonally frozen ground has decreased in many regions (Frauenfeld 2004). In the Southern Hemisphere no conclusive data are yet available, although permafrost and seasonally frozen ground should also be affected there by warmer atmospheric conditions.

Impacts on surface runoff

Degradation of seasonally frozen ground and permafrost and increase in active-layer thickness should result in increased importance of surface water (for example, in wetlands and thermokarst pond formation) and groundwater in the local water balance (McNamara 1999), although there is very limited evidence so far. Thickening of the active layer is thought to be partly responsible for increased river runoff in central Asia (Zhang, Douglas *et al*. 2004). Extensive thermokarst areas formed by thawing of ice-rich permafrost have been detected in Alaska, presumably in response to atmospheric warming (Yoshikawa 2003).

Vegetation and wetland changes

Permafrost and frozen ground degradation are resulting in an increased areal extent of wetlands in the Arctic. It is still unknown whether wetland increase will produce increased release of carbon dioxide and methane due to enhanced microbial activity or an increased carbon uptake due to vegetation increase.

Infrastructure damage

Permafrost warming and degradation together with an increasing depth of the active layer cause mechanical weakening of the ground, and ground subsidence and formation of thermokarst have a weakening effect on existing infrastructure such as buildings, roads, airfields and pipelines (Couture 2000; Nelson 2003). There are several hundred cases of structures in the Arctic that have already been affected by thawing, although at least part of the thawing may be attributed to urbanization and heat-island effects (Tutubalina; Hinkel).

Slope stability problems
Thawing and deepening of the active layer in high-mountain areas can produce slope instability and rock falls, which in turn can trigger outburst floods. The best reported case is the exceptional rock fall activity in the Alps during the 2003 summer heat wave, when the active layer in the Alps deepened significantly, from 30% to 100% (Noetzli J. 2003; Gruber S.; Schar, Vidale *et al*. 2004). In the Andes, rockfall activity has occasionally triggered outburst floods (Casassa 1993; Carey in press), but there is no evidence of increased activity in the last few decades.

1.3.1.6 Effects of changes in sea-ice

Changes in sea ice can have a relevant effect on the radiation balance of polar oceans due to the ice-albedo feedback, since sea-ice cover modifies the heat, gas and momentum exchange between the atmosphere and the ocean. Changes in sea ice extent affect the distribution of freshwater during freezing (by salt rejection) and melting (by input of freshwater). Variations in the radiation balance and salinity can affect the buoyancy forcing and produce changes in ocean circulation.

In the Arctic, sea ice can cover more than 15 million km^2 in spring, shrinking to 7 million km^2 in summer. Arctic sea ice has reduced significantly in the last few decades, which is consistent with the observed atmospheric warming. In the Antarctic as a whole, sea-ice trends are not significant, although there are regional variations.

Ecosystem impacts
There are several changes in the marine Arctic ecosystem which have been related to ocean freshening and reduction of sea ice. For example, a reduction of krill biomass and increase in salps has been reported in the Antarctic and linked with sea ice reduction (Loeb 1997; Atkinson, Siegel *et al*. 2004). In the Arctic, marine algae have died in the period 1970-late 1990s and have been replaced by less productive algae species usually associated with freshwater (ACIA). More detailed description of impacts in given in Section 1.3.4.5 (Changes in marine ecosystems).

Navigation
Reduced sea ice will probably result in increased shipping access and possibly a rise in offshore oil operations as well (ACIA 2004), although there are no quantitative data to support this at the moment.

Ocean freshening and circulation
There is some evidence for freshening of North Atlantic waters, which is probably a combination of reduced sea-ice formation and sea-ice melting, glacier melt, increased precipitation, and increased river runoff to the Arctic ocean (Dickson). There is some indication of reduction in deep flow from the Nordic seas, which might be related to reduced sea ice (Hansen); this in turn may imply a weakening of global thermohaline circulation and reduced inflow of Atlantic water to the Nordic seas.

1.3.1.7 Effects of changes in lake and river ice

Seasonal variations in lake and river ice are relevant in terms of freshwater hydrology, freshwater ecosystems and human activities such as ice skating, winter transportation, bridge and pipeline crossings. In addition to the forcing caused by atmospheric changes, lake and river ice is very sensitive to changes in snow cover. There is abundant evidence for a spatial reduction of lake and river ice (Prowse and Beltaos 2002; ACIA 2005 Arctic) with evidence of earlier timing of freshwater ice break-up (Bonsal).

Impacts of frozen lakes
Changes in lake thermal structure and quality/quantity of under-ice habitat have been reported (Wrona).

Impacts of river ice
Earlier and more intense melt conditions can result in significant break-up events due to ice jamming, which can, in turn, result in severe flooding (Prowse 2002). However, there is a lack of scientific evidence that this is already happening.

1.3.1.8 Evidence of adaptation & vulnerability

Although non-indigenous and indigenous communities living in the Arctic and in mountain regions exposed to cryospheric reduction are considered to be very vulnerable to climate change, they have a significant degree of adaptation (ACIA 2004), but the associated economic costs can be high. Adaptation measures include changes in road construction techniques (Couture); relocation of settlements affected by permafrost degradation (US Arctic Research Commission Permafrost Task Force, 2003); relocation of skiing resorts to higher-elevated areas (Carrasco); production of artificial snow in skiing resorts; radiation shielding of glaciers (e.g., in the Swiss Alps) and permafrost (e.g., in the Tibet-Qinghai railroad) by means of artificial covers.

Vulnerability of cryospheric components is highly dependent on snow and ice temperature. Active layer thickness, seasonal snow, seasonal lake and river ice, ice shelves close to the melting point and temperate glaciers are highly sensitive to changes in atmospheric warming since they are close to or at the melting point. The extremely rapid collapse of the Larsen B ice shelf in the Antarctic Peninsula in less than 5 weeks in early 2002 (Scambos 2004) is a demonstration of the high vulnerability of ice masses affected by melting. Cold ice masses such as in the interior of the Greenland and Antarctic ice sheets are more vulnerable to changes in precipitation, and there is already evidence of ice sheet growth in some upper areas affected by increased accumulation (Mosley-Thompson 1999, 20th).

Consequences of cryosphere changes for society are highly regional-specific and vary according to characteristics of the society in question, affecting polar regions of both hemispheres, mountainous areas, and some lowland parts of river systems. The Arctic is particularly sensitive to small changes in temperature and precipitation. Native populations are highly dependent on the animals, plants, and natural resources for their livelihoods. Vulnerabilities in the Arctic derive in large part from the regions' reliance on extractive industry (Chapin). High diversity of activities in the past has tended to give way to a concentration on a smaller number of species and sectors (such as oil and gas).

The ACIA report (ACIA) presents evidence of adaptation and vulnerability in the Arctic regions. The deep empirical knowledge held by native cultures has fostered mechanisms to adapt to changes in past environments. Resiliency to future changes is dependent on assuring that native stakeholders remain involved in decision-making so that their understanding of the processes controlling long-term dynamics can be incorporated into policy (Chapin).

At the same time, native populations fear for their livelihoods, based on current observation of warming conditions. They have noted that ice is breaking up sooner in spring and leaving more ice-free waters during the summer. As a result, seals and polar bears are less accessible and more costly to hunt both because they are found farther from land and because boating conditions to reach them have become more hazardous (Nichols).

Increased river flooding and glacial lake outburst floods (GLOFs) endanger people worldwide and are the subject of studies of the relation between changing glacier processes and probability of more frequent and more intense flooding, although the increased occurrence of GLOFs in response to enhanced melting is not yet fully established. The level of vulnerability and the capacity for adaptation and response are nevertheless highly dependent on local social, political, institutional factors and these have so far received less research attention. Local populations' mistrust of the government and neglect of marginal populations by political elites are identified as factors leading to inadequate mitigation measures in Peru (Carey in press).

Identity issues for local populations whose cultures have been built on long-term relations with glaciated landscapes are an additional and often neglected consequence of their diminishment. Glaciers and their waters not only shape livelihoods and institutions, but also influence definitions of self. Rituals and cults but as well as political mobilization are common responses. Presence of particular landscapes also important to outsiders who value glaciated landscapes and thus the disappearance of glaciers will affect crucial economic activities such as tourism.

1.3.1.9 Summary

There is abundant evidence that most of the cryospheric components in polar regions and in mountain areas are undergoing generalized recession in response to global warming. The observed impacts of cryosphere reduction include initial increase in glacial runoff and subsequent decrease as glaciers disappear; snowmelt advance; increased surface runoff and formation of thermokarst terrain in thawing permafrost; infrastructure damage in regions under permafrost degradation; enhanced gravity flows and slope instability due to mechanical weakening driven by ice and permafrost melting; ocean freshening and changes in thermohaline circulation; sea level rise due to glacier reduction; disappearance of ice-core records of past climate due to melting of high mountain glaciers; biotic colonization in deglaciated terrain; reduced outdoor and tourism activities related to skiing, ice skating, ice climbing and scenic activities in glacier areas affected by cryosphere degradation; changes in lacustrine and marine ecosystems affected by lake-ice and sea-ice reduction. Indigenous and non-indigenous communities living in glaciated landscapes are very vulnerable to climate change, but they have a significant degree of adaptation both based on deep empirical knowledge held by native cultures and based on modern technological means available at present.

1.3.2 Hydrology and water resources

The hydrological cycle at regional scales is affected by and affects both climate and catchment characteristics. In addition, rapid growth in population, agricultural production, urbanization and industrialization is placing stress on water resources in many regions. This section focuses on the relationships of runoff, lake levels, wetlands, groundwater, floods and droughts and water quality with observed climate variability, climate trends, land-use and land-cover change, as well as on water-resource management adaptations to changing environmental conditions.

Climate variables important for change in surface water systems, groundwater levels and extreme events are precipitation (P), air temperature (T), humidity, wind speed and solar radiation. Among these climate variables, P and T are most used for detection and attribution analysis. There are three temporal and three spatial scales of interest: long-term changes in mean annual P, T, and runoff (R) at the global scale; inter-annual, inter-decadal variability at the continental scale; and short-term extreme events at the catchment scale. Trends in these variables are analysed over decadal-to-century periods.

Anthropogenic activities at the watershed scale affect the hydrological cycle both directly and indirectly. Socioeconomic development and population growth bring increasing water use, while land-use and land-cover changes, such as industrialization, urbanization, reclamation, deforestation-afforestation and water-resource development, in turn affect evaporation and transpiration, soil moisture storage, infiltration and percolation into soil and groundwater, and thus affect runoff quantity and timing and water quality. Under dry and warm climatic conditions, these effects may be exacerbated, creating additional adverse impacts such as reductions in the amount of water availability (Liu and Liu 2004), degradation of water quality, as well as intensification of stream flow peaks leading to floods. There is still uncertainty in the magnitude of management effects on the different components of the hydrological cycle depending on the climatic (including year-to-year variability), social and ecological characteristics of the watershed analyzed (Tollan 2002).

1.3.2.1 Effects of changes in surface water systems

Surface water systems provide a large percentage of the world’s water resources for human activities and ecological services. Recent studies reveal trends in many of these systems, including runoff and streamflow, lakes, and wetlands (Table 1.3). Streamflow records for the world’s major rivers show large decadal to multi-decadal variation with small secular trends for most rivers (Cluis and Laberge 2001; Lammers, Shiklomanov *et al*. 2001; Pekarova 2003). Labat *et al* (Labat, Godderis *et al*. 2004) reconstructed global and continental runoff time series that show trends of increasing runoff in North America, Asia, and South America, stability in Europe, and decreasing trends in Africa.

The evolution of lake levels and areas is affected by natural variations and human activities. Documented observations involve three categories of variation in lake levels and areas. The first is related to climate warming; the second is related to the combination of drought and human activities; and the third is related to excessive diversion for agriculture and artificial impoundment . Wetland losses have occurred on many river systems around the world since the early 20th century. Up to half of the world’s wetlands are estimated to have been lost; losses are attributed to natural changes as well as to land drainage for conversion to agriculture and settlements, or disease control (UNDP).

Table 1.3: *Observed variations and trends in (a) runoff and streamflow; (b) lake levels.*

(a) Runoff and streamflow

Continents	Years of record	Description	Reference
Arctic	1936-2002 During the last 12 years	Increased total annual runoff of the six largest rivers of Eurasia discharging to Arctic Ocean Arctic Ocean received an additional 2500 km^3 of water, including 1500 km^3 from the territory of Russia	(Peterson 2002); (Shiklomanov 2003)
North America	During the latter half of the 20th century Since 1970s During the last 30-50yr. From 1910-2002	Increased streamflow in many parts of US due to increased precipitation Earlier snowmelt leading to earlier spring peak streamflow in west US and New England US Decreased streamflow in Canada due to decreased precipitation Decline in mean annual discharge for 31 rivers flowing to Pacific, Arctic and Atlantic Oceans due to decline in precipitation and warmer temperatures	(Groisman, Knight *et al*. 2004) (Cayan, Kammerdiener *et al*. 2001; Hodgkins, James *et al*. 2002; Hodgkins, Dudley *et al*.; Mote 2005) (Zhang 2001) (Stewart 2005)
South America	During the last 20 yr.	Large interannual variability of river discharge in La Plata River basin in southeastern South America. Many major discharge anomalies of Parana River and major flow events in Paraguay occur during El Nino events	(Bischoff 2000; Krepper, Garcia *et al*. 2003) (Camilloni and Barros 2003) (Barros 2004)
Europe	During the last 15-20yr	Increased annual runoff in large river of Russia Decreased annual runoff in Don and Dnieper rivers	(Frenkel 2004; Shiklomanov 2005) (Vishnevsky and Kosovets 2004).
Asia	From 1935-1999 During the last 25 yr	Increase in streamflow in Lena River basin in Siberia Decreased annual runoff in the rivers of Uzbekistan-Tashkent, Azerbaijan and Kura of Central Asia Decreased streamflow in Hai River and Yellow River caused by decreasing P and increasing T	(Yang, Kane *et al*. 2002) (Chub 2000; Fatullaev 2004; Makhmudov 2004) (Liu and Liu 2004), (Yang, 2003, Yenisei)

(b) Lake levels

Authors	Period	Location	Observed changes
(JaeChan 2002)	last decades	Northern Europe	Observed earlier occurrence of ice break-up
(Kumagai and Maruo	last decades	Lake Hovsgol in Mongolia	Increased glacier or permafrost

2003)			melting
(Li Yuan 2003)	last decades	Inland lakes in China	Snow or ice melting
(Meuller 2003)	last decades	Disraeli Fiord epishelf lake	Loss of lake caused by break-up of Ward Hunt Ice Shelf due to cumulative long-term warming
(R.N.Jones 2001)			
(Smith 2005)		Three closed lakes in Australia	Decrease of three lakes levels due to dry and hot climate
(Coe 2001); (Shen Fang 2003); (Robarts 2004)	Since 1970s	Siberia	Disappearance of permafrost-controlled Arctic Lakes
	last decades	Lake Chad in Africa	Lakes shrunk due to the combination effect of drought and human activities
(Zhang Zhenke 2001)	last decades	Qinghai Lake in China	
(Revenga 1998; Glantz1999, Creeping)	last decades	Devils Lake in North Dakota; Lake Kariba in Zimbabwe and Zambia, and Lake Chilwa in Malawi	
	300 years	Daihai Lake in China,	Decrease in lake levels caused by excessive diversion for agriculture and artificial impoundment
	Since 1960s	Central Asia's Aral Sea	Lost three-quarters of its volume and over 36,000 km^2 in surface area
	Last 40 years	Dead Sea	Observed drop over 20m

1.3.2.2 Effects of changes in groundwater

Over the last 20 years, water levels have been dropping in aquifers due to droughts, warming and human activities in semi-arid zones around the world. In southern Manitoba, Canada and in Northern Chile, long-term declines in ground water level are mainly caused by climate fluctuations on decadal-to-century timescales as opposed to overexploitation (Chen, Grasby *et al*. 2002; Houston 2002). But in others regions – such as South Asia, the North China plains, Africa, Mexico, and the Great Plains of the USA – the combination of intensive pumping for agriculture and several years of below-normal precipitation accelerated the downward trend in water levels. Pumping from subsoil aquifers at rates much greater than they are recharged leads to decline of water tables, causes groundwater depression, land subsidence, disappearance of wetlands, and intrusion of seawater in coastal zones (Zhang 2001).

1.3.2.3 Effect of changes in extreme events

Multidecadal variability of rainfall and high streamflow events has been documented during the twentieth century. Floods and associated landslides, and winter storms can have severe effects on human populations, infrastructure, and ecosystems (Table1.4a). For example, very heavy rains experienced by Haiti and the Dominican Republic in May 2004 generated numerous landslides leading to the death of more than 1000 people (Qubbels 2004, Flood Disaster). Increasing damages due to landslides may be caused by growing population and regional development. In the U.S. frequencies of precipitation extremes in the late 1800s/early 1900s were about as high as in the 1980s/1990s; this indicates that natural climate variability cannot be discounted as the cause or one of the causes of the recent increases in floods (Kenneth 2003). Observations of recent trends in droughts and the changing character of precipitation (Trenberth 2003) are shown in Table 1.4b.

Box 1.2 describes the long-term drought in the Sahel.

Table 1.4: *Observed changes in (a) winter storm, floods and landslides, and (b) droughts.*

(a) winter storm , floods and landslides

Authors	Period	Location	Observed change
Lawson (Lawson 2003),	1953-1997	Canadian Prairies	Increased intense winter storms.
Graham (Graham 2001)	and	and West Coast of	
(Groisman, Knight *et al*.	Since 1948	the US.	
2004),(Douglas 2000)	20th century	Eastern US.	High streamflow events associated
Kundzewicz (Kundzewicz			with heavy and very heavy
2004)			precipitation.
Frolov (Frolov 2005)	Last decades	Europe	
	Last decades	Russia	Increasing floods
Buzin (Buzin 2004)			Increasing floods from heavy rain with
	2001	Lena river in Russia	snowmelt.
Chowdhuryl (Chowdhury			Catastrophic floods of 0.5-1%
and Ward 2003)	1980s-1998	Bangladesh.	frequency due to ice jam/break up
Qian (Qian and Zhu 2001)	1990s	Yangtze river	Severe floods from strong monsoon.
Danielle (Danielle 2004).	Last decades	Australia	Severe floods.
			Significantly enhanced rainfall and
Dartmouth Flood			streamflow during the La Nina phase
Observatory homepage	1985-2004	Global	of ENSO.
			Increasing flood with recurrence less
Guzzetti (Guzzetti and			than 20 yr. and decreasing floods with
Salvati 2003)	1900-2002	Italy	recurrence interval greater than 100
Hervas (Hervas. 2003)			9.5 floods and 18.4 landslides with
	Since 1960s	Northern England	fatalities occurred every year.
		and Scotland	The magnitude of extreme rainfall has
			increased two-fold

b) Droughts

Dai (Dai 2004)	Since 1970s	Global	Increased very dry areas (PDSI <-3.0)
			from ~12% to 30%.
Shabbar (Shabbar 2004)	From 1940s	Canada	Drier condition after 1995 of summer
	to recent.		PDSI averaged for entire country.
Barlow (Barlow 2002)			Severe drought
Dai (Dai 2004)	After 1980	Central and SW Asia	Drying due to warm and dry climate
Dai (Dai, Lamb *et al*. 2004)	Since 1950	Middle East.	Though rain in the 1990s recovered
	Since 1960s	Sahel	somewhat through 2003, late 1960s
			drought has not ended.
Peter (Peter 2003)			Annual precipitation decreased 15-20%
Wang (Wang 2003),	20^{th} century	Western Russia	Drying due to decreasing rainfall and
Ma (Ma and Fu 2003)	Since 1980s	Central north China	increasing temperature
Pagano (Pagano 2005)			Consecutive wet years along with
Andreadis (2005, droughts)	Since 1980s	Western US	multiyear extreme droughts
Fauchereau (Fauchereau			1998-present is among the most severe
2003)	1915-2003	Western US	drought
			Intensifying droughts associated with
	20^{th} century	Southern Africa	ENSO

> ***Box 1.2: Sahel drought***
>
> The Sahel region in western Africa shows the largest decrease of annual rainfall over the period 1901-2003 for any region of the globe (see Fig. 3.3.2 of Chapter 3, WGI AR4). Drought conditions have affected the Sahel since the early 1970s. There has been a partial recovery since 1990 but the mean rainfall for the last decade is still below the pre-1970 level (Dai, Lamb *et al*. 2004) Fig. 3.7.5 of Chapter 3 WGI AR4). Sea surface temperature changes are likely to have been the dominant influence on the rainfall changes in the Sahel, and not land-use changes (Taylor, Lambin *et al*. 2002). Some impacts of this heat wave are described in boxes in later chapters. Further details of these rainfall anomalies are given in Chapter 3, WGI and their causes are discussed in Section 9.5.3.2.1, Chapter 9, WGI FOD AR4.

1.3.2.4 Effects of changes in water quality

Trends of changes in water quality have been documented in three aspects, i.e. thermal properties, chemical and biological for lakes (Table 1.4)

Table 1.4: *Observed changes in water quality*

Authors	Period	Location	Observed change
Gerten (Gerten and Adrian.R. 2002)	last few decades	Northern hemisphere	Higher lake temperatures, shorter periods with ice cover, and shorter stagnation periods
Robarts (Robarts 2004)	From middle to the late 20th century.	Lake Kariba	The alkalinity of the water from the Zambezi River entering the lake had increased two-fold.
Robarts (Robarts 2004)	2001-2004	Endorheic lakes of the North American prairies.	Declining water levels and increasing chemical concentration due to decreasing precipitation.
Rogora (Rogora, Mosella *et al*. 2003)	Last few years	Lakes in the central Alps.	Increase in solute content due to climate warming.
Meuller (Meuller 2003)	Recently	Disraeli Fiord epishelf lake	Unique biological community of both freshwater and marine species of plankton effected by loss of fresh and brackish water due to warming.
Gerten (Gerten and Adrian 2002)	Last few decades.	European lakes, north American lakes.	Algal spring blooms developed early after mild winters
Flanagan (Flanagan 2003).	During the ice-free season	Arctic and temperate lakes 41^{o} and 79^{o}N.	The average algal biomass increased significantly with phosphorus levels

1.3.2.5 Absence of observed effects & conflicting evidence

At present, while some warming has occurred, climate change appears not to have impacted large lakes, such as the St Lawrence Great Lakes, the Africa Great Lakes, Lake Baikal and Aral Sea (Alfred 2002). There were somewhat conflicting conclusions regarding trend in floods studied and argued by some authors in the US depending in part on length of time series and whether these data are affected by human activities (Kunkel 2003). In the Western Himalayas during the period 1961-2000, there was an increase in diurnal temperature range and downward trend in summer temperature and runoff, which is consistent with the observed thickening and expansion of Karakoram glaciers, in contrast to widespread decay and retreat in the Eastern Himalaya (Fowler 2005).

1.3.2.6 Evidence of adaptation & vulnerability

Documented adaptation to current climate variability includes the use of traditional knowledge by local farmers and communities. Relocation, raised houses and buildings on stilts have proven to be cost-effective ways of coping with high water and floods in Bangladesh. Rainwater harvesting in Nepal and China was shown to be a cost-effective strategy to cope in arid climates, increasing water security in water scarce areas (Cosgrove and Kuylenstlerna 2004). The move toward integrated water resources management based on the perception of water as an integral part of the ecosystem, a natural resource, and a social economic good is a response in part to the trends documented in this section. In the UK and US, an integrated water resources plan is emerging as a tool to develop water supplies and demand management strategies (M.Beuhler. 2003; Subak. 2000). The interactions of climate variability and change with human activities is increasing the vulnerability of water resources. Evidence of climate variability over the past several decades has shown that hot and dry regions are more vulnerable to changes that have occurred already.

1.3.2.7 Summary

Human activity at the catchment scale has played an increasingly influential role in hydrology and water resources, making determination of the impact of climate variability and change difficult. Many uncertainties still remain with respect to trend detection and attribution in hydrology and water resource for short-term hydro-meteorological data with high variability in time and space and effects of human activities. On a global scale, the observed increasing trend in runoff in higher northern latitudes and drought in some subtropical regions is coincident with recent global rainfall trends. There are observed rises in some lake levels and decreases in others, and loss or disappearance of some epishelf or permafrost-controlled lakes due to warming. In the last 20 years, there are documented increases in flash floods and landslides due to intensive and heavy rain in mountain areas during the warm season. Recent evidence also shows that areas most affected by increasing droughts are located in arid and semiarid regions due to the presence of already warm and dry climate.

1.3.3 Coastal processes and zones

Many coastal regions are already experiencing the effects of relative sea level rise, from a combination of climate-induced sea level rise, land subsidence, anthropogenic, and other local factors. Most vulnerable to sea level rise are low-lying coasts, such as river deltas, estuaries and lagoons, coral reefs, barrier islands, and coastal plains, especially in areas where relative (local) rates of sea level rise exceed the global average. A major challenge is to separate the different factors affecting the shoreline and identify the contribution of global warming.

Global sea level has been rising at a rate of ~1.5 mm/yr over the last century (IPCC 2001; ADB). More recent estimates suggest a rate of around 1.7-1.8 mm/yr over the last 50 years, with a possible acceleration during the last decade (Church, White *et al*. 2004; Holgate and Woodworth 2004 glacial isostatic adjustments, neotectonics, and/or subsurface fluid withdrawal), long-shore currents, and cyclonicity. While extreme high water levels have been increasing worldwide since 1975, this increase is closely linked to mean sea level rise and to indices of regional and inter-decadal climate variability such as the El Nino Southern Oscillation (ENSO), North Atlantic Oscillation (NAO) or Pacific Decadal Oscillation (PDO) (Woodworth 2004).

A number of geological and anthropogenic processes contribute to coastal evolution. Geological processes include ongoing glacial isostatic adjustments, in particular the collapse of the peripheral forebulge at the edge of former ice sheets (along the East Coast of North America, low countries of Europe, and parts of the British Isles), sediment loading and compaction at major river deltas (e.g., Mississippi River Delta, Nile Delta , Ganges-Bramaputra Rivers), or local effects of neotectonism at convergent plate boundaries (e.g., circum-Pacific Ocean Alaskan coast following the 1962 earthquake. Although geological processes operate over long time scales, they exert a strong control over short-term dynamics, thus affecting the evolution of coastal geomorphology.

Human activity has already greatly modified downstream flow, in particular by construction of reservoirs that trap sediments (Syvitski, Vorosmarty *et al*. 2005) and other land-use transformations (Gornitz, Couch *et al*. 2001). Curtailment of sediments reaching the shore has exacerbated coastal erosion, as for example in Louisiana (Penland, 2005; Georgiou, 2005). Urbanization has increased pressures on the littoral zone through the construction of high-rise buildings, expansion of ports and harbour facilities, highways and other transportation corridors, leading to removal of the natural vegetation cover and creation of a highly modified coastline. In addition, other anthropogenic activities, such as construction of "hard" engineering structures (e.g., groins, jetties, breakwaters), which interfere with littoral drift, and beach sand mining aggravate coastal erosion.

Pumping of groundwater and other fluids (e.g., hydrocarbons) enhances land subsidence (Syvitski, Vorosmarty *et al*. 2005), also contributing to coastal erosion. In Venice, Italy, pumping of groundwater between 1930-1970 led to significant land subsidence. Although pumping ceased after 1970, the long-term sea level rise of 1.9 mm/yr (Camuffo and Sturaro 2004) is resulting in more frequent episodes of "acqua alta" (high water). Clearing of coastal wetlands and mangroves, and damaging coral reefs by pollution, mining, and development of tropical coasts for tourism reduce the buffering capacity of these habitats against damaging storm surges (Wong 2003).

1.3.3.1 Changes in coastal geomorphology

Beach erosion already affects an estimated 70% of the world’s sandy beaches (Bird 1985; Bird 1993). While historic sea level rise is a likely contributing factor, anthropogenic modification of the shoreline is exacerbating this trend. Although beaches hit by major storms along the east coast of the United States tend to recover to their long-term positions (Zhang, Douglas *et al*. 2002), 75% of the shoreline removed from the influence of spits, tidal inlets, and engineering structures are nonetheless eroding (Zhang, Douglas *et al*. 2004). The average annual erosion rate in the beach communities of Delaware's Atlantic coast varies between 2 and 4 ft/yr and is threatening the sustainability of the area as a major summer recreation attraction (Daniel 2001). The average rate of shoreline erosion in Louisiana was 0.61m/yr between 1855 and 2002. Since 1988, rate of shoreline erosion have accelerated to 0.94 m/yr (Penland, Connor *et al*. 2005). On shorelines far from inlets and structures, long-term beach erosion has been linked to historic rates of sea level rise (Zhang, Douglas *et al*. 2004). However, Stive (Stive 2004) cautions that in addition to sea level change, coastal erosion is driven by other factors, such as wave energy, sediment supply, or local land subsidence.

In Estonia, on the other hand, the most active periods of shoreline displacement are associated with severe storms and high surge levels, which have been increasing in recent decades (Orviku, Jaagus *et al*.). A decrease in sea ice cover, due to milder winters, has also exacerbated coastal damage there. Arctic coastlines in many permafrost regions, such as the Beaufort Sea and Laptev Sea shores, are undergoing rapid retreat, caused by several factors including global sea level rise, thawing, subsidence, and erosion of ice-rich sediments (thermokarst), and increased wave energy due to lengthened ice-free periods. Warmer summers also lead to greater slumping and flow on slopes and cliffs, thereby accelerating coastal erosion. Even coastlines that are rising because of ongoing glacial rebound and that would otherwise be accreting, have significant sections that are eroding, as for example along Hudson Bay, Canada (Beaulieu and Allard 2003).

Beach erosion has increased in parts of Fiji within the last 40 years, in part due to sea level rise, but more importantly to extensive clearing of mangroves for building materials, firewood, pest control, and mining of beach sand and coral for construction (Mimura and Nunn 1998). Wong (Wong 2003) further documents beach erosion in the tropics, much of which is linked to human development of the shoreline. Recent coastal subsidence in the San Juan delta on the Pacific coast of South America is evidenced by increased occurrence of non-storm washover events, increased erosion of barrier islands, and a relative sea level rise (Restrepo, Kjerfve *et al*. 2002). At several beaches on the island of Trinidad in the Southern Caribbean, average erosion rates are about 1 to 2 meters per year. However, for a single year, extreme erosion rates approaching 10 to 12 meters have been noted, although these abnormal rates have been followed by accretion (Singh and Fouladi 2003).

Another important contributor to coastal erosion is sediment starvation brought on by the construction of dams on major rivers (Syvitski, Vorosmarty *et al*. 2005). For example, the sediment discharge from the Yangtze River to the sea has decreased by 19% between 1977-2000, as compared to the period from 1953-1976, largely due to upstream reservoirs (Chen, Zhang *et al*. 2005). Most of Alexandria, Egypt beaches appear to be experiencing mild erosion with evidence of sand losses, and some beaches have disappeared, while a few are generally stable. The erosion is generally caused by sediment deficiency due to construction of dams and barrages across the Nile, combined with the natural reduction of Nile floods due to climatic changes over east Africa (Frihy, Dewidar *et al*. 1996).

1.3.3.2 Changes in coastal wetlands

In the United States, losses in coastal wetlands have been observed in Louisiana (Boesch, Josselyn *et al*. 1994), the mid-Atlantic region (Kearney, Rogers *et al*. 2002), and in parts of Connecticut and New York (Hartig, Gornitz *et al*. 2002; Hartig and Gornitz 2004), in spite of recent protective environmental regulations (Kennish 2001). Many of these marshes have had a

history of anthropogenic modification, including dredging and filling, bulkheading, and channelization, which in turn could have contributed to sediment starvation, eutrophication, and ultimately marsh submergence. In New England, low marsh cordgrass (Spartina alterniflora) has been migrating landward, partly in response to sea level rise (Donnelly and Bertness 2001; Bertness, Ewanchuk *et al*. 2002). On the other hand, salt marsh losses in south-east England are not related to local sea level rise nor to "coastal squeeze" (Hughes and Paramor 2004). Elsewhere, there is evidence that not all coastal wetlands are retreating. High sediment supply to a number of macrotidal estuaries along the Normandy coast, France have resulted in progradation and areal expansion (Haslett, Cundy *et al*. 2003).
Tropical mangroves play an important role in trapping sediments, also in reducing the erosive potential of waves and currents (Furukawa, Wolanski *et al*. 1997; Mazda, Magi *et al*. 1997; Wolanski, Spagnol *et al*. 2002). Although natural accretion rates of mangroves generally compensate for current rates of sea level rise, of greater concern at present are the impacts of clearance for agriculture, aquaculture (particularly shrimp culture), forestry, and urbanization. According to Valiela (Valiela, Bowen *et al*. 2001), at least 35 per cent of the world's mangrove forests were removed in the last two decades, but possible sea-level rise effects were not considered.

1.3.3.3 Changes in storm surges, flood heights and areas

Along the U.S. East Coast, although there has been no significant long-term change in storm climatology, storm surge impacts on the shore have increased due to the regional sea level rise (Zhang, Douglas *et al*. 2000). Since the mid-1960s, the frequency of flooding surges in Venice has averaged close to 2 per year, as compared to only 0.19 surges per year between 1830-1930 (Camuffo and Sturaro 2004). Although global sea level rise plays a role, land subsidence and expanded sea-lagoon interactions (due to channel dredging) account for most observed late 20th century rise. Surges show a slight decrease in Brittany, France in recent decades, largely due to changes in wind patterns (Pirazzoli, Regnauld *et al*. 2004). Apparent global increases in extreme high water levels since 1975 are also related to mean sea level rise and to large-scale inter-decadal climate variability (Woodworth and Blackman 2004).

The increasing volatility of the Pacific Region's weather and climate is already apparent. Figure 1.5 shows how the significant open water wave heights associated with powerful tropical cyclones in the vicinity of Rarotonga, Cook Islands, have increased in recent years, as has the frequency of such events.

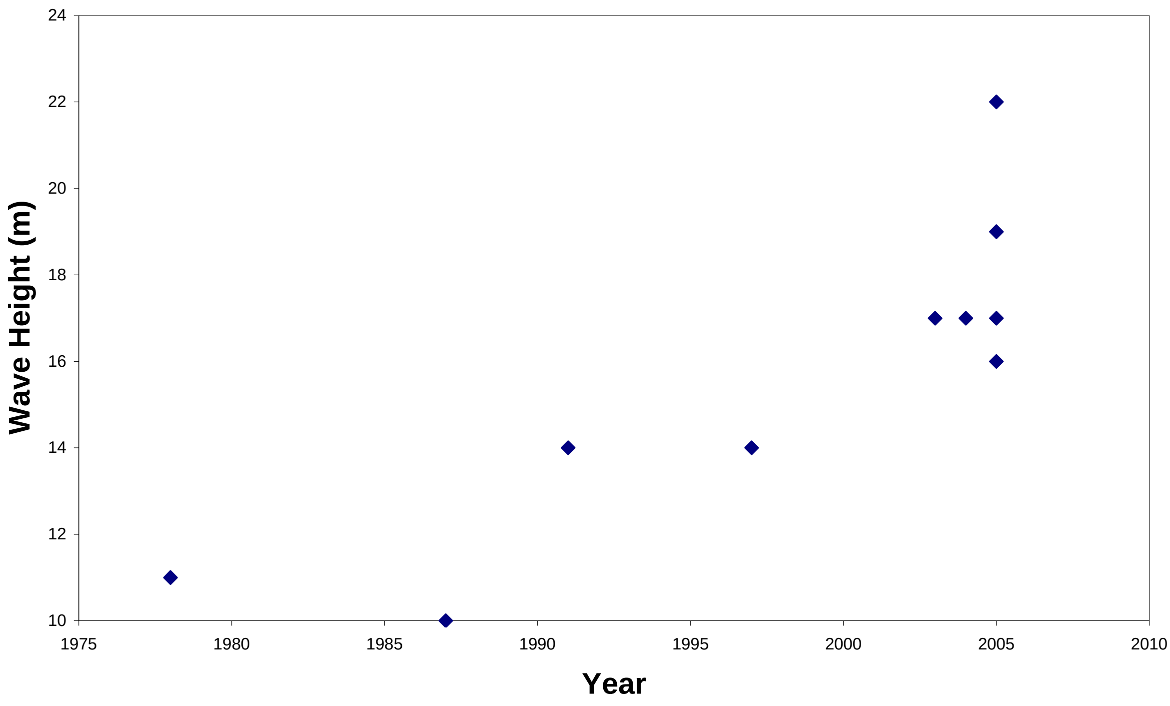

Figure1.5: *Significant open water wave height (m) associated with tropical cyclones in the vicinity of Rarotonga, Cook Islands.* (ADB)

1.3.3.4 Absence of evidence

There is currently an absence of evidence of saltwater intrusion and changes in intertidal zones as a result of sea level rise.

1.3.3.5 Evidence of adaptation & vulnerability

Mimura and Nunn (Mimura and Nunn 1998) have documented trends in adaptation to coastal erosion and sea encroachment over the last 40 years in rural Fiji. Barnett (Barnett 2001) has considered vulnerability and adaptation to sea-level rise in Pacific Island States. Yoshikura (Yoshikura 2000) compiled the number of damage occurrences and the restoration project expenditures for port-related disasters in Japan between 1950 and 1999. Causes of the port-related disasters include high waves and storm surges by typhoons, as well as earthquakes and tsunamis. The number of cases has been decreasing as the protective measures are developed. However, the average annual number of damage cases accounts for more than 440, and the restoration expenditure exceeds US $240million.

1.3.3.6 Summary

Mean global sea level has been rising over the last century at rates of 1.5 to 2.0 mm/yr, although much higher rates exist in subsiding regions. Coastal erosion and wetlands losses are widespread problems today, under current rates of sea level rise. At present, these are largely caused by anthropogenic modification of the shoreline due to construction of hard structures such as jetties, groins, breakwaters, sand mining, building of dams, deforestation and land clearance, groundwater overdraft, and channelization. In the future, the coastal zone will be caught between increased developmental pressures and accelerating sea level rise due to the projected global warming. As a consequence, these trends are likely to be exacerbated.

1.3.4 Marine and freshwater biological systems

The marine pelagic realm is the largest ecological system on the planet occupying 70% of the planetary surface. The pelagic ecosystem plays a fundamental role in modulating the global environment via its regulatory effects on the Earth's climate and its role in biogeochemical cycling. Perhaps equally important to global climate change, in terms of modifying the biology of the oceans, is the impact of anthropogenic CO_2 on the pH of the oceans that will affect the process of calcification for some marine organisms (Feely, Sabine *et al*. 2004). Other driving forces of change that are operative in marine and freshwater biological systems are overfishing and pollution from terrestrial runoff (from deforestation, agriculture and urban development).

Any observational change in marine and freshwater environments associated with climate change should be considered against the background of natural variation on a variety of spatial and temporal scales. Recently long-term decadal observational studies have focused on known natural modes of climatic oscillations at similar temporal scales such as the El Nino-Southern Oscillation (ENSO) in the Pacific and the North Atlantic Oscillation (NAO) in relation to ecosystem changes (Stenseth, Mysterud *et al*. 2002). Many of the biological responses observed have been associated with rising temperatures. However, discerning the effects of climate change embedded in natural modes of variability such as the NAO is difficult and direct evidence of biological impacts of anthropogenic climate change must be treated with caution.

Within the marine biological systems, coral reefs are iconic, highly diverse ecosystems of enormous economic, cultural and aesthetic value. Located within a broad latitudinal band from 30^oN to 30^oS, the geographic spread of reefs encompasses a wide range of physical and chemical conditions (e.g. in temperature, alkalinity, turbidity and productivity). Habitats associated with coral reefs include mangrove forests and seagrass beds. Besides pollution, scuba diving by tourists also places stress on coral reefs.

Many changes in marine commercial fish stocks have been observed over the last few decades in the Atlantic and Pacific Oceans but it is difficult to separate, in terms of changes in population densities and recruitment, regional climate effects from direct anthropogenic influences like fishing. Geographical range extensions or changes in the geographical distribution of fish populations, however, can be more confidently linked to hydro-climatic variation and regional climate warming.

Freshwater biological systems of lakes and rivers are highly susceptible to changes in temperature. This has been clearly demonstrated by paleolimnologic approaches examining changes on millennial time scales. The same paleolimnological techniques, along with the increasing amount and length of empirical data records, indicate that these freshwater systems are responding to recent climate warming (Schindler, Baldwin *et al*. submitted). The type and magnitude of the response to climate change depends upon many factors, including size, water depth/flow, latitude, and altitude.

1.3.4.1 Changes in coral reefs

Twenty percent of the world's coral reefs are already seriously degraded, and a further 24% are under imminent risk of collapse from human impacts (Wilkinson). Although there are some ongoing local successes at sustaining healthy coral reefs, improved management of reefs is urgently required to halt and reverse world-wide declines.

On many reefs, depleted stocks of herbivorous fishes and eutrophication have promoted ecological shifts. Removal of fishes change the structure and stability of foodwebs (from the top-down), while added nutrients promote species lower down (from the bottom-up). Top-down and bottom-up affects both promote blooms of macroalgae (fleshy seaweeds) that smother corals and prevent their recruitment. Consequently, overfishing and pollution have reduced coral reef resilience, i.e. the regenerative capacity of corals is impaired following disturbances such as hurricanes or bleaching events caused by climate change (Bellwood, Hughes *et al*. 2004). Importantly, the ability of reefs to cope with climate change is pre-conditioned by the extent to which they are already overfished and polluted (Hughes, Baird *et al*. 2003; Pandolfi, Bradbury *et al*. 2003).

The most visible manifestation of climate change occurs when stressed corals become pale and bleached due to the loss of their endosymbiotic micro-algae (zooxanthellae). Regional-scale bleaching events have become increasingly prevalent since the 1980s. Recurrent bleaching was first documented in the eastern Pacific, the Caribbean and Polynesia. In 1998, the largest bleaching event to date killed an estimated 16% of the world's corals, primarily in the western Pacific, Australia, and the Indian Ocean (Wilkinson 2004). Bleaching is highly selective, affecting species and strains (of both corals and zooxanthellae) to different extents (Loya, Sakai *et al*. 2001; Coles and Brown 2003; Little, van Oppen *et al*. 2004). The mechanisms underlying this variation are poorly understood. Bleached corals have markedly higher rates of mortality. However, some corals regain zooxanthellae and can recover from bleaching, although they may suffer temporary reductions in growth and reproductive capacity (Baker, Starger *et al*. 2004; Little, van Oppen *et al*. 2004).

The link between rising sea surface temperatures and coral bleaching is incontrovertible. Bleaching usually occurs when temperatures exceed a 'threshold' of ~2^{o}C above mean summer maximum levels for several weeks. Maximum temperatures range by more than 10^{o}C within the geographic boundaries of most species (e.g. along latitudinal gradients). Cooler locations have lower bleaching thresholds, implying that there is strong local adaptation to thermal conditions, and ongoing evolution of temperature tolerance (Hughes, Baird *et al*. 2003). How quickly further evolutionary responses can occur is unknown.

The incidence of disease in corals, gorgonians, sea urchins and other reef organisms has increased dramatically, especially on reefs that are already degraded (Harvell, Mitchell *et al*. 2002). The extent to which these emergent pathogens can be controlled by restoring foodweb structure and improving water-quality is unknown. The trend in species composition in favour of weedy species that can colonize and grow quickly suggests that reefs are being exposed to more frequent and intense tropical storms (Nystrom, Folke *et al*. 2000; Bellwood, Hughes *et al*. 2004).

The analogy of coral reefs being the 'canary' ecosystem that is likely to disappear within a few decades has been overstated. There is nonetheless great uncertainty whether the present level of ecosystem goods and services that reefs provide to maritime tropical and subtropical nations can be maintained (Moberg and Folke 1999; Knowlton 2001; McClanahan, Polunin *et al*. 2002; Bellwood, Hughes *et al*.).

1.3.4.2 Changes in marine ecosystems

There is an accumulating body of evidence to suggest that many marine ecosystems, including managed fisheries, both physically and biologically, are responding to changes in regional climate caused predominately by warming of air and sea surface temperatures (SSTs) and to a lesser extent by modification of precipitation regimes and wind patterns (Table 1.5). The biological manifestations of rising SSTs have included biogeographical, phenological, physiological and species abundance changes. Perhaps equally important to global climate change, in terms of modifying the biology of the oceans, is the impact of anthropogenic CO_2 on the pH of the oceans. Evidence collected and modelled to date indicates that rising CO_2 has led to chemical changes in the ocean which has led to the oceans becoming more acidic (Society 2005). Satellite-in situ blended ocean chlorophyll records indicate that global ocean annual primary production has declined more than 6% since the early 1980s (Gregg, Conkright *et al.*) (Fig. 1.6).

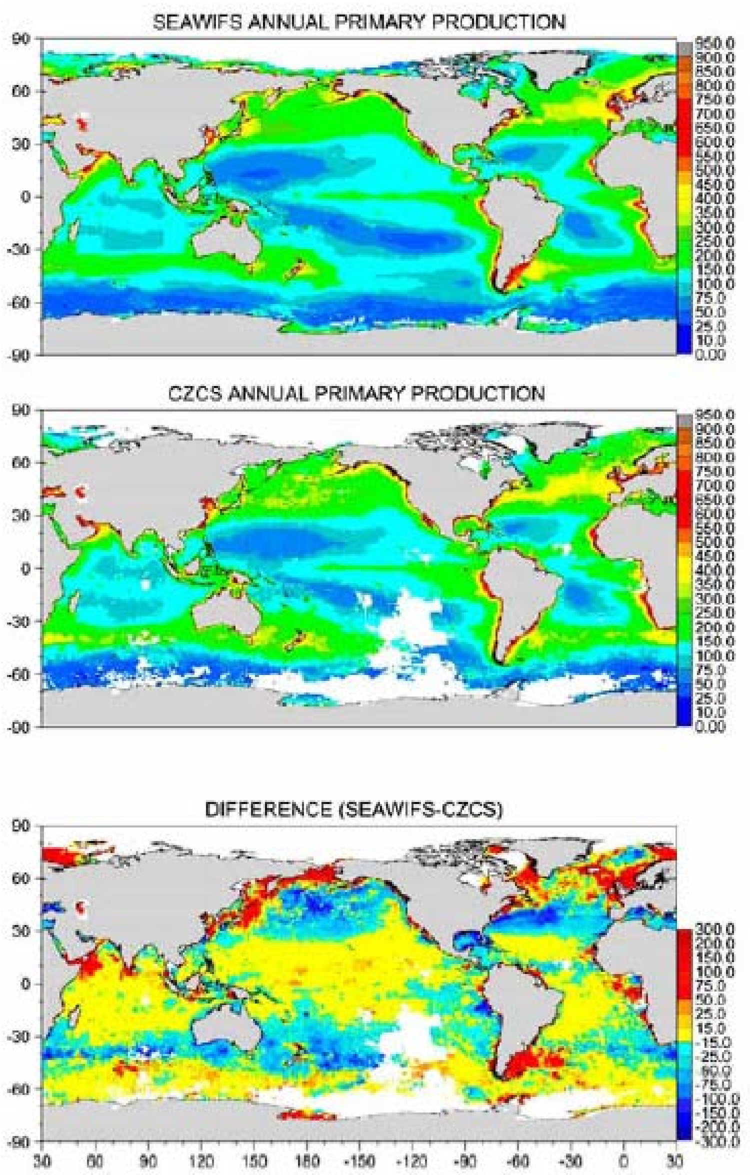

Fig. 1.6: *Primary production distribution for the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) era (1997-mid 2002), the Coastal Zone Colour Scanner (CZCS) era (1979-mid 1986), and the difference. Units are g C m^{-2} y^{-1}. White indicates missing data.*

In the North Atlantic both phytoplankton and zooplankton species and communities have been associated with Northern Hemisphere Temperate (NHT) trends and variations in the NAO index. These have included changes in species distributions and abundance, the occurrence of sub-tropical species in temperate waters, changes in overall phytoplankton biomass and seasonal length, changes in the North Sea ecosystem, community shifts, phenological changes and changes in species interactions (Fromentin and Planque 1996; Reid, Edwards *et al*. 1998; Edwards, Reid *et al*. 2001; Reid and Edwards; Beaugrand, Ibanez *et al*. 2002; Edwards, Beaugrand *et al*. 2002; Beaugrand, Brander *et al*. 2003; Beaugrand and Reid 2003; Edwards and Richardson 2004; Richardson and Schoeman 2004). Over the last decade, numerous other investigations have established links between the NAO and the biology of the North Atlantic including the benthos, fish, seabirds and whales (Drinkwater, Belgrano *et al*.). In the Benguela upwelling system in the South Atlantic, long-term trends in the abundance and community structure of coastal zooplankton have been related to large-scale climatic influences (Verheye, Richardson *et al*. 1998).

In the Pacific researchers have found similar changes to the intertidal communities where the composition has shifted markedly in response to warmer temperature change (Sagarin, Barry *et al*.). Similar shifts were also noted in the kelp forest fish communities off the southern Californian coast and in the offshore zooplankton communities (Roemmich and McGowan 1995; Holbrook, Schmitt *et al*.; Lavaniegos and Ohman 2003). These changes are associated with oceanic warming and the resultant geographical movements of species with warmer water affinities. Like the North Atlantic, many long-term biological investigations in the Pacific have established links between changes in the biology and regional climate oscillations such as the ENSO and the Pacific Decadal Oscillation (PDA) (Stenseth, Mysterud *et al*. 2002). In the case of the Pacific these biological changes are most strongly associated with El Nino events which can cause rapid and sometimes dramatic responses to the short-term SST changes accompanying El Nino events (Hughes)

The progressive warming in the Southern Ocean has been associated with krill decline (Atkinson, Siegel *et al*. 2004), decline in the population sizes of many seabirds and seals monitored on several breeding sites (Barbraud and Weimerskirch 2001; Weimerskirch, Inchausti *et al*. 2003), and marine diseases (Harvell, Kim *et al*. 1999).

Recent macroscale research has shown that the increase in regional sea temperatures has triggered a major re-organisation in calanoid copepod species composition and biodiversity over the whole North Atlantic basin (Beaugrand, Ibanez *et al*. 2002). During the last 40 years there has been a northerly movement of warmer water plankton by 10° latitude in the north-east Atlantic and a similar retreat of colder water plankton to the north. This geographical movement is much more pronounced than any documented terrestrial study, presumably due to advective processes. In terms of the marine phenological response to climate warming, many plankton taxa have been found to be moving forward in there seasonal cycles (Edwards and Richardson 2004). In some cases a shift in seasonal cycles of over six weeks was detected, but more importantly the response to climate warming varied between different functional groups and trophic levels, leading to mismatch (Fig. 1.7)

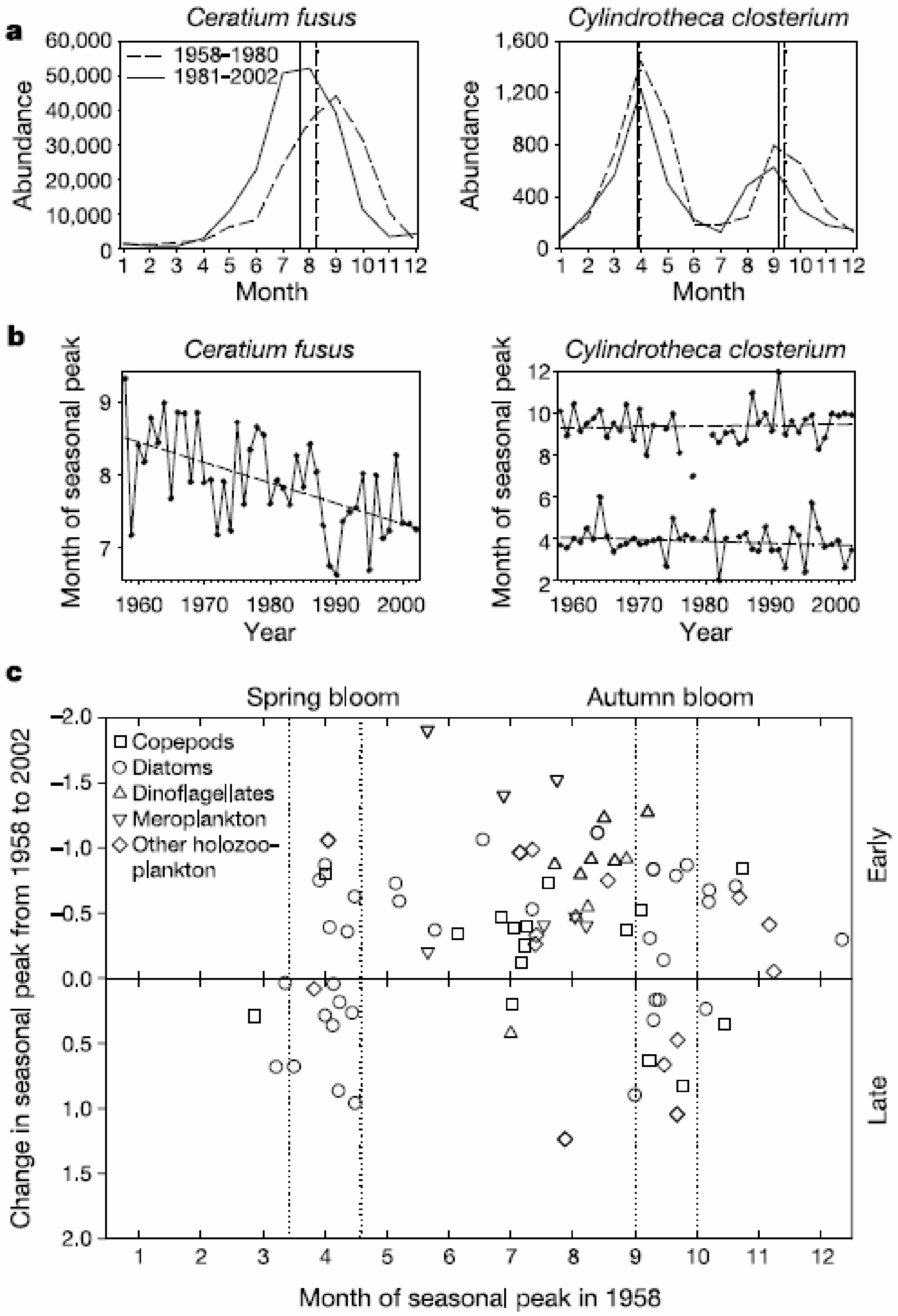

Fig. 1.7: *Changes in phenology throughout the pelagic season. a) Examples of seasonal cycles for two of 66 taxa—the dinoflagellate Ceratium fusus and the diatom Cylindrotheca closterium—used in the analysis for the periods 1958–1980 and 1981–2002. Timing of seasonal peaks, using indicator of central tendency, is also shown. b) Interannual variability of seasonal peak for the above two species from 1958 to 2002. c) Change in timing of seasonal peaks (in months) for the 66 taxa over the 45-yr period from 1958 to 2002 plotted against the timing of their seasonal peak in 1958. (Edwards and Richardson)*

1.3.3.3 Changes in managed fisheries

Similar to the observed changes in marine ecological systems (section 1.3.4.5) many long-term changes in fish populations have been associated with known natural modes of climatic oscillations such as the El Nino-Southern Oscillation (ENSO) in the Pacific and the North Atlantic Oscillation (NAO) in the North Atlantic (Stenseth, Mysterud *et al*. 2002; Drinkwater, Belgrano *et al*.).

Northerly geographical range extensions or changes in the geographical distribution of fish populations have been recently documented for European Continental shelf seas and along the European Continental shelf edge (Brander, Blom *et al*. 2003; Beare, Burns *et al*. 2004; Genner, Sims *et al*. 2004; Perry, Low *et al*. 2005). These geographical movements have been related with regional climate warming and are predominantly associated with the northerly geographical movement of fish species with more southern biogeographical affinities. These include the movement of sardines and anchovies northward in the North Sea and red mullet and bass extending their ranges northward to western Norway (Brander, Blom *et al*.; Beare, Burns *et al*. 2004). New records were also observed over the last decade for a number of Mediterranean and north-west African species on the south coast of Portugal (Brander, Blom *et al*.). The cooling and the freshening of the north-west Atlantic over the last decade has had an opposite effect, with some groundfish species moving further south in their geographical distribution (Rose and O'Driscoll 2002).

Regional climate warming in the North Sea has affected cod recruitment via changes at the base of the food web (Beaugrand, Brander *et al*. 2003). Cod, like many other fish species, are highly dependent on the availability of planktonic food during their pelagic larval stages. Key changes in the planktonic assemblage caused by the warming of the North Sea over the last few decades has resulted in a poor food environment for cod larvae and hence eventual recruitment success. This research is an example of how both the duel pressures of over-fishing and regional climate warming have conspired together to negatively impact a commercially important fishery. Recent work on pelagic phenology has shown that plankton communities, including fish larvae, are very sensitive to regional climate warming with the response to warming varying between trophic levels and functional groups (Edwards and Richardson). These changes, again seen in the North Sea, have the potential to be of detriment to commercial fish stocks via trophic mismatch. The ability and speed in which fish and planktonic communities adapt to regional climate warming is not yet known.

Table 1.5: *Changes in marine ecosystems and managed fisheries.*

Key changes	Climate link	Location	References
Pelagic productivity/ Zooplankton abundance/ plankton assemblages	Biological responses to regional changes in temperature, stratification, upwelling and other hydro-climatic changes.	North Atlantic North Pacific South Atlantic Southern Ocean	(Fromentin 1996; Reid 1998; Edwards 2001; Edwards 2002; Johns 2003; Beaugrand 2003; Beaugrand 2003; Richardson 2004; Roemmich 1995; McGowen 1998; Walther 2002; Lavaniegos 2003; Verheye 1998; Walther 2002; Atkinson 2004)
Pelagic phenology	Earlier seasonal appearance due to increased temperatures	North Sea	(Edwards and Richardson; Greve 2004)

	and trophic mis-match		
Pelagic biogeography	Northerly movement of plankton communities due to general warming	North Atlantic	(Beaugrand, Reid *et al*. 2002)
Rocky shore/intertidal communities	Community changes due to regional temperature changes	British Isles North Pacific	(Sagarin, Barry *et al*.; Hawkins, Southward *et al*.)
Kelp forests/ macroalgae	Affect on communities and spread of warmer-water species due to increased temperatures	North Pacific Mediterranean	(Holbrook 1997; McGowen 1998; Walther 2002)
Marine pathogens and invasive species	Geographical range shifts due to increased temperatures	North Atlantic	(Harvell, Kim *et al*.; Walther, Post *et al*.; McCallum, Harvell *et al*.)
Fish populations and recruitment success	Changes in populations, recruitment success, trophic interactions and migratory patterns related to regional environmental change	British Isles North Pacific North Atlantic Barents Sea Mediterranean	(Attrill 2002; Genner 2004; McGowen 1998; Chavez 2003; Walther 2002; Drinkwater 2003; Beaugrand, 2003; Beaugrand 2003, copepod; Brander 2003; Stenseth 2002; Walther 2002)
Fish biogeography	Geographical range shifts related to temperature	NE Atlantic NW Atlantic	(Beare 2004; Brander 2003; Genner 2004; Perry 2005; Rose 2002)
Seabirds and marine mammals	Population changes, migratory patterns, trophic interactions and phenology related to regional environmental change	North Atlantic North Pacific Southern Ocean	Drinkwater 2003; Walther 2002; McGowen 1998; Hughes 2000, signal; Walther 2002; Barbraud 2001; Weimerskirch 2003)
Marine biodiversity	Regional response to general warming	North Atlantic	(Beaugrand, Reid *et al*.)

Note: Most significant changes have occurred over the last few decades. Generally, review papers were used.

1.3.4.4 Changes in freshwater ecosystems

Observations indicate that lakes and rivers around the world are warming, with effects on thermal structure, lake chemistry, abundance and productivity, community composition, phenology, distribution and migration (Table 1.6). Empirical temperature measurements and ice freeze/breakup observations indicate that lakes and rivers around the world are warming. Spring breakup dates for large lakes and rivers are around 10 days/150 years earlier and freeze dates are around 9 days/150 years later, with reduced areal ice cover in large lakes (Assel 2003, Magnuson 2000, Todd 2003, Yoo 2002, Schindler 2005, Hodgkins 2002). Water temperatures are also warming due to climatic changes. Since the 1960s, surface water temperatures have warmed by 0.2 to 1.5 °C in large lakes in Europe and North America (Adrian and Deneke 1996; King, Shuter *et al*. 1998; Livingstone and Dokulil 2001; Carvalho and Kirika 2003; Livingstone 2003; Straile, Johnk *et al*. 2003; Arhonditsis, Brett *et al*. 2004; Dabrowski, Marszelewski *et al*. 2004). Along with warming surface waters, deep water temperatures (which reflect long-term trends) of the large East African lakes (Edward, Albert, Kivu, Victoria, Tanganyika, Malawi) have warmed by 0.2 to 0.7 °C since the early 1900s (Hecky, Bugenyi *et al*. 1994; O'Reilly, Alin *et al*. 2003; Verburg, Hecky *et al*. 2003; Lorke, Tietze *et al*. 2004; Vollmer, Bootsma *et al*. 2005; O'Reilly). Several large rivers have warmed by 1 to 2 C, attributed to atmospheric warming (Peterson and Kitchell 2001; Daufresne, Roger *et al*. 2004; Bartholow).

1.3.4.5 Changes in Lakes

Thermal Structure

Increased water temperature and longer ice-free seasons influence thermal stratification and internal hydrodynamics of lakes. In warmer years, epilimnetic water temperatures are higher, evaporative water loss increases, summer stratification occurs earlier in the season, and thermoclines become shallower (Hondzo and Stefan 1991; Hambright, Gophen *et al*. 1994; Adrian, Deneke *et al*. 1995; King, Shuter *et al*.; Winder and Schindler 2004). In several lakes in Europe and North America, the stratified period has advanced by up to 20 days and lengthened by 2-3 weeks, with increased thermal stability (Livingstone 2003; Winder and Schindler 2004). In Lake Tanganyika, East Africa, the thermocline has become shallower by up to 100 m and thermal stability has tripled (O'Reilly, Alin *et al*. 2003). Globally, the factors responsible for lake warming and increased stratification appear to be warmer night time temperatures and warmer winters (Livingstone 2003, Vollmer 2005, O'Reilly submitted, Todd 2003, Hambright 1994, Adrian 1996).

Lake chemistry

Increased stratification reduces water movement across the thermocline, inhibiting upwelling and mixing that provide essential nutrients to the food web. There have been decreases in nutrients in the surface water and corresponding increases in deep water concentrations of European and East African lakes because of reduced upwelling due to greater thermal stability (O'Reilly submitted, Africa; Adrian 1995, study; Hambright 1994, changes; Straile 2003, winter).

Increased temperature also alters catchment processes and inputs to lakes. Weathering rates may increase by an order of magnitude when temperatures increase from 0 to 25 °C, if precipitation is kept constant (White and Blum 1995). These magnitudes of temperature change occur in sunny areas that were previously snow-covered throughout the year. Many lakes have increased concentrations of sulphate, base cations, silica, alkalinity, and conductivity related to increased weathering of silicates, calcium and magnesium sulphates, or carbonates in their catchment (Sommaruga-Wograth, Koinig *et al*.; Rogora, Mosella *et al*.; Karst-Riddoch, Pisaric *et al*.). In contrast, when warmer temperatures enhanced vegetative growth and soil development in high alpine ecosystems, alkalinity decreased because of increased organic acid inputs (Karst-Riddoch, Pisaric *et al*.). Glacial melting increased the input of organochlorines (that had been atmospherically transported to and stored in the glacier) to a sub-alpine lake in Canada (Blais, Schindler *et al*. 2001).

Increased temperature also affects in-lake chemical processes. There have been decreases in dissolved inorganic nitrogen from greater phytoplankton productivity (Sommaruga-Wograth, Koinig *et al*.; Rogora, Mosella *et al*.) and greater in-lake alkalinity generation and increases in pH in soft water lakes (Psenner and Schmidt 1992). In addition, changes in temperature can influence metal chemistry. Decreased solubility from higher temperatures significantly contributed to 11-13% of the decrease in aluminium concentration (Vesely, Majer *et al*. 2003), whereas lakes that had warmer water temperatures had increased mercury methylation and higher mercury levels in fish (Bodaly, Rudd *et al*. 1993).

Abundance/productivity

There have been changes in lake productivity and plankton abundance. In high latitude or high altitude lakes where reduced ice cover has led to a longer growing season and warmer temperatures, many lakes are showing increased algal abundance and productivity over the past century (Schindler, Beaty *et al*. 1990; Hambright, Gophen *et al*. 1994; Adrian, Deneke *et al*. 1995; Gajewski, Hamilton *et al*. 1997; Wolfe and Perren 2001; Battarbee, Grytnes *et al*. 2002; Korhola, Sorvari *et al*.; Karst-Riddoch, Pisaric *et al*.). There have been similar increases in the abundance of zooplankton, correlated to warmer water temperatures and longer growing seasons (Adrian and Deneke 1996; Weyhenmeyer, Blenckner *et al*. 1999; Straile and Adrian 2000; Battarbee, Grytnes *et al*. 2002; Gerten and Adrian 2002; Carvalho and Kirika; Winder and Schindler 2004; Hampton; Schindler, Rogers *et al*. 2005). For upper trophic levels, rapid increases in water temperature after ice breakup have enhanced fish recruitment in oligotrophic lakes (Nyberg, Bergstand *et al*. 2001). In contrast to temperate lakes, tropical lakes that are permanently stratified are experiencing reduced algal abundance and declines in productivity because stronger stratification reduces upwelling of nutrient-rich deep water (O'Reilly submitted). Primary productivity in Lake Tanganyika may have decreased by up to 20% over the past 200 years (O'Reilly, Alin *et al*.), and for the East African Rift Valley lakes, recent declines in fish abundance have been linked with these climatic impacts on lake ecosystems (O'Reilly, submitted).

Community composition

Increases in the length of the ice-free growing season, greater stratification, and changes in relative nutrient availability have generated shifts in community composition. Paleolimnological records showed widespread changes in phytoplankton species composition since the mid to late-1800s, with increases in chrysophytes and planktonic diatom species and decreases in benthic species (Gajewski, Hamilton *et al*. 1997; Wolfe and Perren; Battarbee, Grytnes *et al*. 2002; Sorvari, Korhola *et al*. 2002; Laing and Smol 2003; Michelutti, Douglas *et al*. 2003; Perren, Bradley *et al*. 2003; Ruhland, Presnitz *et al*. 2003; Karst-Riddoch, Pisaric *et al*.; Smol, Wolfe *et al*.). These sedimentary records also indicated changes in zooplankton communities (Douglas, Smol *et al*. 1994; Battarbee, Grytnes *et al*. 2002; Korhola, Sorvari *et al*. 2002; Brooks and Birks). In relatively productive lakes, there was a shift towards more diverse periphytic diatom communities due to increased macrophyte growth (Karst-Riddoch, Pisaric *et al*.). In lakes where nutrients are becoming limited due to increased stratification, phytoplankton composition shifted to relatively fewer diatoms, potentially reducing food quality for upper trophic levels (Verburg 2003; O'Reilly submitted; Adrian 1996).

Phenology

With earlier ice breakup and warmer water temperatures, some species have responded to the earlier commencement of the growing season, often advancing development of spring algal blooms as well as clear water phases (Scheffer, Straile *et al*.). The spring algal bloom now occurs about 4 weeks earlier in several large lakes (Weyhenmeyer, Blenckner *et al*.; Gerten and Adrian 2000; Straile and Adrian 2000; Winder and Schindler 2004). However, in many cases where the spring phytoplankton bloom has advanced, zooplankton have not responded similarly, and their populations are declining because their emergence no longer corresponds with high algal abundance (Gerten and Adrian 2000; Winder and Schindler 2004). Phenological shifts have also been demonstrated for some wild and farmed fish species (Ahas

1999; Elliott, Hurley *et al*. 2000). Because not all organisms respond similarly, differences in the magnitude of phenological responses among species has affected food web interactions (Winder 2004, uncouples).

1.3.4.6 Changes in rivers

Water flow is an important constraint in rivers which can influence water chemistry, habitat, and population dynamics, in addition to also affecting water temperature (Ozaki, Fukushima *et al*. 2003). Riverine dissolved organic carbon concentrations have doubled in some cases because of increased carbon release in the catchment as temperature has risen (Worrall, Burt *et al*. 2003).

Abundance, distribution and migration
Environmental changes in rivers have affected species abundance, distribution, and migration patterns. While warmer water temperatures in many rivers have positively influenced the breeding success of fish (Fruget, Centofanti *et al*.; Grenouillet, Hugueny *et al*.; Daufresne, Roger *et al*.), the stressful period associated with higher water temperatures for salmonids has lengthened as water temperatures have increased commensurate with air temperatures in some locations (Bartholow). In the Rhone River, there have been significant changes in species composition, as southern, thermophilic fish and invertebrate species have progressively replaced cold-water species (Doledec, Dessaix *et al*.; Daufresne, Roger *et al*.). Correlated with long-term increases in water temperature related to climate change, the timing of fish migrations in large rivers in North America has advanced by up to 6 weeks in some years (Quinn and Adams 1996; Cooke, Hinch *et al*. 2004; Juanes, Gephard *et al*. 2004). Increasing air temperatures have been negatively correlated with smolt production (Lawson, Logerwell *et al*. 2004) and earlier migrations are associated with greater en route and pre-spawning mortality (up to 90%) (Cooke *et al*. 2004).

Table 1.6: *Changes in freshwater ecosystems due to climate warming.*

Environmental factor	Change	Time period of change	Location of lakes/rivers	Number of lakes/rivers studied
Ice cover	9 to 18.4 days fewer	150 years	North America, Europe, Asia	68
Water temperature	0.2 to 1.5 °C increase	40 years	Europe, North America	17
	0.2 – 0.7 °C increase (deep water)	100 years	East Africa	6
Water chemistry	Decreased nutrient availability from increased stratification	100 years	North America, Europe, East Africa	8
	Increased catchment weathering or internal processing	10 – 20 years	North America, Europe	84

Productivity or biomass	Increases due to longer growing season Decreases due to decreased nutrient availability	100 years 100 years	North America, Europe East Africa	16 6
Algal community composition	Shift from benthic to planktonic species Decreased diatom abundance	150 - 100 years 100 years	North America, Europe East Africa, Europe	66 3
Phenology – spring algal bloom	4 weeks earlier	45 years	North America, Europe	4
Migration of anadromous fish	6 days to 6 weeks earlier	50 to 20 years	North America	17

1.3.5 Terrestrial biological systems

Species can successfully reproduce, grow or survive only within specific ranges of climatic and environmental conditions. If these conditions notably change, plants and animals are affected and respond either by adaptation or migration. If neither type of responses is feasible, local populations of species will become extinct. Since the TAR, the number of studies reporting evidence (associated with varying levels of confidence) that terrestrial ecosystems respond to changing climate has risen substantially. The observed characteristics are primarily comprised of altered morphology, phenology, reproduction and productivity, species distribution, and ecosystem composition for both plants and animals as well as altered animal migration. Recent global reviews are by Hughes (Hughes), Menzel and Estrella (Menzel, Estrella *et al.*), Walther (Munk), Parmesan (Nöthiger) and Root (Nöthiger); reviews on regional scales are by Parmesan and Galbraith for the US (Parmesan and Galbraith) and the EEA for Europe (EEA).

Growth of the vegetation is mainly determined by temperature, precipitation, photosynthetically active radiation (PAR), and atmospheric CO_2 concentration. Given adequate soil moisture and nutrients, growth of vegetation may be enhanced by higher temperatures, longer growing seasons and enhanced CO_2 levels. Increasing mean air temperature coupled with stable or reduced precipitation may cause drought stress, which can be intensified by higher precipitation variability and extreme temperature events. Other extreme events such as storms, hurricanes and floods act as disturbances for ecosystems. Although many studies have looked at the influence of large-scale weather variability systems such as the El Niño-Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), we focus on trends in temperature and precipitation and their observed relationships to ecosystems.

The influence of other driving forces besides climate increases with complexity of the processes studied, from phenology to morphology to ecosystems. Spring and summer phenological changes can be attributed to primary climate drivers, while autumn phenology may be triggered by atmospheric pollutants and other stressors (Menzel 2002). Plants and animals may be also affected by higher UV-B radiation (Cummins); plants are also affected by soluble-nitrogen deposition (Korner 2000). Species composition is not only influenced by climate (change), but also by species-specific responses to various drivers – competition, pests and diseases, and natural disturbances (e.g., wildfires) – as well as being dependent on soil properties (e.g., nutrient availability). Other factors such as land-use changes, habitat fragmentation (Hill, Thomas *et al*. 1999) or simply the absence of suitable areas, e.g., at higher elevations, also play an important role, especially in species extinction (Pounds, Fogden *et al*.; Williams, Bolitho *et al*. 2003). Animal distribution is dependent on the availability of suitable habitats for reproduction, raising of offspring, feeding, and wintering. Many animal populations have been under pressure from agricultural intensification and land-use change in the post-WWII period and many species are in decline.

1.3.5.1 Morphological and physiological changes

In-situ observations provide evidence of morphological changes in vertebrates that appears linked to climatic change. Changes in morphological traits of birds apparently associated with temperature, probably via food availability, have been reported for the river warbler (Kanuscak, Hromada *et al*. 2004). Reading and Clarke (Reading and Clarke) report some changes in toad (*Bufo* spp.) reproduction related to temperature, precipitation, and population density. There have been reported instances of egg-size changes in birds related to temperature, but examples of both larger (Jarvinen 1994; Jarvinen 1996) and smaller eggs have been reported (Tryjanowski, Sparks *et al*.). Following Bergmann's rule, animals are expected to become smaller with rising average temperatures (Yom-Tov). However, several studies on birds and mammals also revealed a trend towards larger body size in spite of globally and regionally increasing ambient temperatures (Nowaowski, Ulijaszek *et al*.; Yom-Tov, Yom-Tov *et al*.; Kanuscak, Hromada *et al*. 2004; Yom-Tov and Yom-Tov), which may be explained by increased food supply and altered habitat structure.

In the insectivorous barn swallow, temperature affects not only egg mass, but also concentration of maternally derived substances that can affect egg hatchability and offspring antiparasite defence and viability (Saino, Romano *et al*. 2004). Northwards range extension by some Orthoptera and butterflies has been assisted by the evolution of increased colonization capacity (flight duration) and morphology (increased wing length and wing musculature, but decreased reproductive output (Hill, Thomas *et al*. 1999; Thomas, Bodsworth *et al*. 2001; Hughes, Hill *et al*. 2003; Simmons, Barnard *et al*. 2004).

1.3.5.2 Changes in phenology

Phenology – the timing of seasonal activities of animals and plants – is perhaps the simplest process in which to track changes in the ecology of species in response to climate change. Changes of phenological events in plants and animals comprise shooting, leaf unfolding and flowering of plants, arrival of migrant birds, egg laying and first birdsongs, choruses and spawning of amphibians, appearance/emergence of butterflies in spring and summer as well as fruit ripening, leaf colouring, leaf fall of plants and migration of birds in autumn. The length of the growing season is often defined as the time span between spring and autumn events, or directly as the period of green leaves of distinct plant species.

Numerous studies concurrently document a progressively earlier start of vegetation activity in spring and, less homogenously, a later end, thus a lengthening of the growing season in most parts of the temperate and boreal zone of the northern hemisphere during the last 2-5 decades (see Table 1.7). Global meta-analyses have documented a mean advance of spring events by 2.3 days/decade (Parmesan and Yohe; Root, Price *et al*.). Three different methods provide similar results (Lucht, Prentice *et al*.): (1) analyses of remotely sensed vegetation indices (Myneni, Keeling *et al*.; Zhou, Tucker *et al*.), (2) analysis of the atmospheric CO_2 signal

(Menzel, Estrella *et al*. 2001; Sparks and Menzel 2002; Walther, Post *et al*. 2002; Menzel 2003 warmer; Root, Price *et al*. 2003). A parallel lengthening is also observed for the frost-free growing season in North America and Europe (see Section 1.3.6.2).

NDVI (normalised difference vegetation index) and the atmospheric CO_2 signal provide spatially and species-averaged information. Although phenological network studies differ in regions, species, phenophases, and applied methods, their data show a clear extension of the growing season by up to 2 weeks in the 2nd half of the 20th century in mid and high latitudes of the northern hemisphere. Analyses of single station data report a much greater lengthening of the growing season of 32 days in Spain (1952-2000) (Stefanescu, Penuelas *et al*. 2003), or a pronounced earlier birch leaf fall in Russia (1930-1998) (Kozlov and Berlina 2002).

Table 1.7: *Changes in length of growing season, based on observations within networks.*

Location	Period	Species/Indicator	Lengthening	Authors
Germany	1951-1996	Fagus sylvatica, Quercus robur, Betula pendula, Aesculus hippocastanum (Leaf unfolding-colouring)	0.11 to 0.18 d / a → 5.1 to 8.3 days (all stations, records)	(Menzel, Estrella *et al*. 2001)
Germany	1951-2000	4 deciduous tree species (s.o.)	0.13 - 0.23 d/a → 6.5 - 11.5 days (all stations)	(Menzel, Jakobi *et al*. 2003)
Switzerland	1951-2000	9 spring phases, 6 autumn phases	13.3 days (only stations displaying significant changes)	(Defila and Clot 2001)
Europe (Int. Phenological Gardens)	1959-1996	Different spring and autumn phases	13.7 days (all stations)	(Menzel and Fabian 1999; Menzel, Jakobi *et al*. 2003)
Japan	1953-2000	Gingko biloba (Leaf unfolding – leaf fall)	12 days	(Matsumoto, Ohta *et al*. 2003)

Altered timing of spring events are reported for a broad multitude of species and locations, e.g., earlier leaf unfolding of gingko in Japan (Matsumoto, Ohta *et al*. 2003), aspen flowering in Canada (Beaubien and Freeland; Menzel, Jakobi *et al*.; Walther). Network studies where results from all sites are reported, irrespective of their significance (Table 1.8), show that leaf unfolding and flowering have, on average, advanced by 1-3 days per decade in Europe, North America, and Japan. There are also indications that the onset of fruit ripening has advanced in many cases (Jones and Davis 2000; Penuelas, Filella *et al*. 2002) (Fig. 1.8).

Table 1.8: *Changes in the timing of spring events, based on observations within networks.*

Location	Period	Species / Indicator	Observed changes (- advance, + delay)	Author
Western USA	1957/68-1994	Flowering of lilac and honeysuckle	-0.15 / -0.35 d / a	(Cayan, Kammerdiener *et al*. 2001)

Northeast USA	1965-2001	leafing and flowering of lilac	-0.34 d/a and –0.26 d/a	(Wolfe, Schwartz *et al*. 2005)
Germany	1951-2000	Different spring phases	-0.16 d / a	(Menzel, Jakobi *et al*. 2003)
Switzerland	1951-1998	9 spring phases	-0.19 d / a	(Defila and Clot 2001)
Europe (Int. Phenological Gardens)	1959-1996	Different spring phases	-0.21 d / a	(Menzel and Fabian 1999) (Menzel 2000)
Europe (Int. Phenological Gardens)	1969-1998	Different spring phases index	-0.27 d / a	(Chmielewski and R”tzer)
Japan	1953-2000	Gingko biloba (leaf unfolding	-0.09 d / a	(Matsumoto, Ohta *et al*. 2003)
UK	Past 23 years	18 butterfly species appearance	- 2.8 to -3.2 days/decade	(Roy and Sparks 2000)
Europe, North America	Past 30-60 years	Numerous bird species	Earlier spring migration by 1.3-4.4 days/decade	(Crick, Dudley *et al*.; Crick and Sparks; Dunn and Winkler; Inouye, Barr *et al*.; Bairlein, Winkel *et al*.; Lehikoinen, Sparks *et al*.)
Europe, North America	Past 30-60 years	Numerous bird species	Earlier breeding by 1.9-4.8 days/decade	(Dunn)
UK, Poland	Past 25 years	Amphibians	Earlier breeding	(Beebee; Tryjanowski, Sparks *et al*.)

Records of the return dates of migrant birds have shown change in recent decades associated with changes in temperature in wintering or breeding grounds or on the migration route (Tryjanowski; Butler; Cotton; Huppop and Huppop). While inferences based on the very first observed bird may be affected by factors such as recorder effort, population size and observability (Sparks, Roberts *et al*.; Tryjanowski, Sparks *et al*.), studies based on strict protocol measuring the whole passage migration (Sokolov, Markovets *et al*.; Huppop and Huppop) tend not to be as affected. A recent meta-analysis of arrival dates (Lehikoinen, Sparks *et al*.) showed strong evidence of earlier arrival (of 983 series 39% were significantly earlier and only 2% significantly later for first arrival dates).

Several studies have reported an advance in egg-laying dates in birds (Dunn and Winkler; Dunn); for instance Crick & Sparks (Crick and Sparks) in UK suggested an advance in and temperature response in the majority of their studied species. The confidence in such studies is enhanced where the data cover a period of both local cooling and warming or are multinational and include sites experiencing both localised warming and cooling. An example of the latter is reported for Flycatchers in Europe (Both, Artemyev *et al*. 2004) where trend in egg laying dates matches trends in local temperatures.

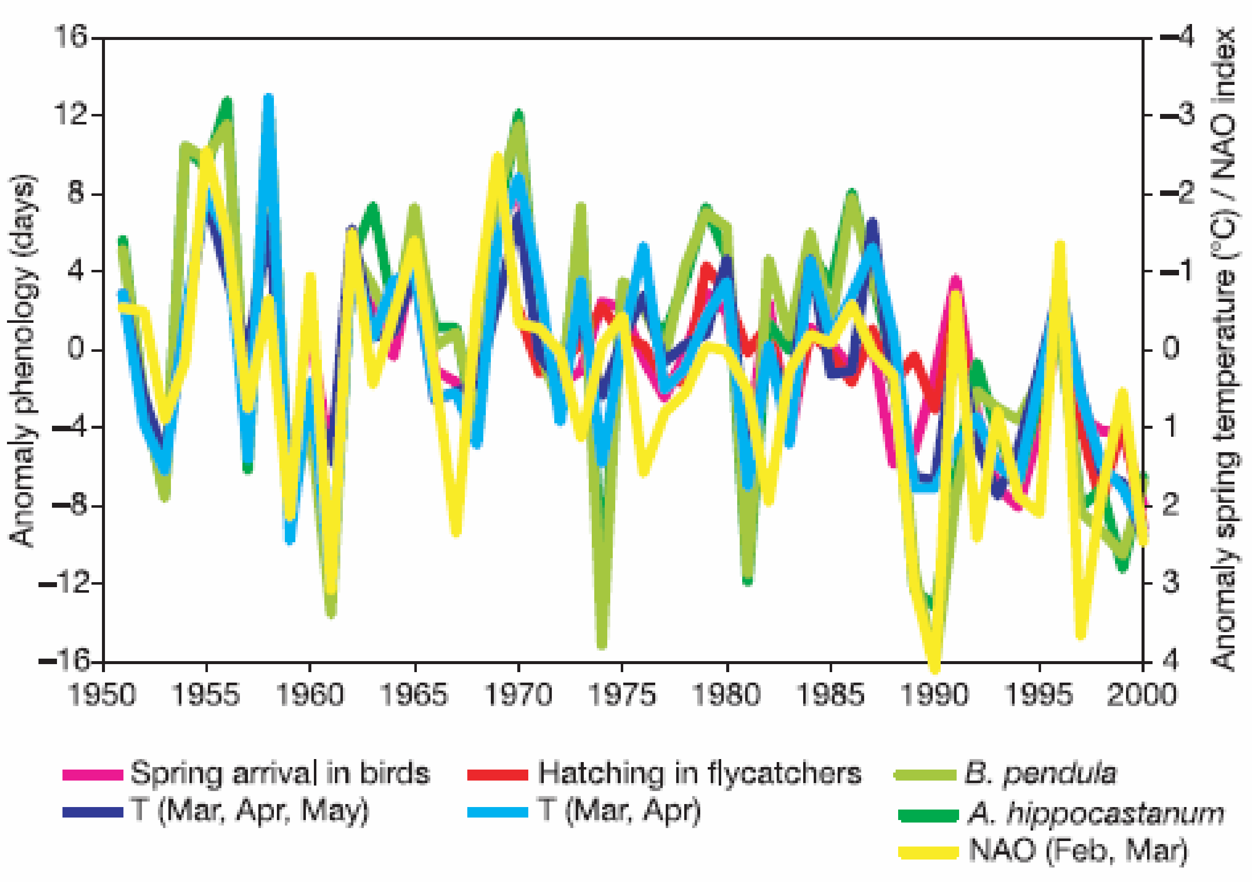

Fig. 1.8: *Anomalies of different phenological phases in Germany correlate well with anomalies on mean spring air temperature (T) and Nort6h Atlantic Oscillation (NAO) index (by PD. Jones, http://www.cru.uea.ac.uk/cru/data/nao.htm) (Menzel, Jakobi et al.). Temperature taken from 35 German climate stations. Phenological phases used: spring arrival in birds, island of Helgoland, North Sea; hatching in flycatchers (Ficedula hypoleuca), Northern Germany; and mean onset of leaf unfolding of Aesculus hippocastanum and Betula pendula (Walther, Post et al.).*

Fewer examples are reported of phenological change in mammals. There are examples of altered phenology at higher altitude and latitude, for example the appearance of marmots (Inouye, Barr *et al*.) and changes in the phenology of reindeer. In the Yukon, earlier breeding of Pikas has been reported (Franken and Hik 2004). In amphibians there have been numerous reports of advances in mating or calling allied with temperature (Gibbs and Breisch; Tryjanowski, Rybacki *et al*.). Changes in the length of the tadpole phase of common toad was reported by Reading (Nöthiger). Despite the bulk of the evidence in support of earlier activity as response to temperature, counter examples do exist (Blaustein, Belden *et al*.).

Advancement in the phenology of butterflies has been reported from a number of national (Roy and Sparks) and local studies (Forister and Shapiro; Stefanescu, Penuelas *et al*.). There is a growing literature indicating earlier activity in other invertebrates including crickets, aphids, and hoverflies (Hickling, Roy *et al*. 2005; Newman 2005)

Uncertainties/Variations

Changes in the length of the growing season and start of spring activities match in direction and extent quite well in northern temperate zones, however they differ by species (Abu-Asab, Peterson *et al*.; Penuelas, Filella *et al*.; Menzel 2003) or by time of season with early-season species exhibiting the stronger reactions (winter and spring temperatures have also changed more) (Abu-Asab, Peterson *et al*. 2001; Menzel, Estrella *et al*. 2001; Fitter and Fitter 2002; Sparks and Menzel 2002; Sparks and Smithers 2002). Concerning species-specific differences, annuals respond more strongly than congeneric perennials, insect-pollinated plants more than wind-pollinated plants (Fitter and Fitter), and woody plants less than herbaceous plants; but, there are no differences between Raunkiaer life-forms or different origins (Penuelas, Filella *et al*.). Variations in phenological responses of European *Parus* populations cannot fully be explained by variations in temperature change (Visser, Adriaensen *et al*.).

Spatial and temporal variability

Regional trends in phenology can vary (Schwartz and Reiter; Fitzjarrald, Acevedo *et al*.; Menzel, Estrella *et al*. 2001) and geographical differences are evident for both plants and birds, with later bird arrival in the Slovak Republic (Sparks, Heyen *et al*. 1999) and later start of the growing season in the Balkan region (Menzel and Fabian 1999). Variations in spring temperature trends are mirrored by varied advancement of egg laying in flycatchers across Europe (Both, Artemyev *et al*.). Spring has advanced more in maritime western and central Europe in contrast to little or no change in the continental east (Ahas, Aasa *et al*.; Schleip, Menzel *et al*.). In Switzerland, the proportion of stations with advancing onset of spring events increases with altitude up to 1100 m asl (Defila and Clot). Small-scale variability within networks may be due to differences in local mircroclimate, urban – rural areas, natural variability, genetic differentiation and other non-climate drivers (Menzel 2002).Similarly, short-distance migrating birds, which tend to migrate early in the season, often exhibit a trend towards earlier arrival while the response of later arriving by long-distance migrants is more complex, with many species showing no changes or even delayed arrival (Butler 2003; Strode). The previous species, because of their inherently shorter migration distances seem capable of greater responsiveness to temperatures at the breeding grounds than those who have to travel several thousand kilometres across many climatic zones.

Detection of changes depends on the underlying time frame of observations, which has to be taken into account when absolute changes are compared. Longer series covering the last century also include periods of later onset. Early spring events and a longer growing season in Europe is most apparent for time series ending in the mid 1980s or later (Schaber 2002; Scheifinger, Menzel *et al*. 2002; Dose and Menzel; Menzel and Dose 2005; Schleip, Menzel *et al*. 2005).

Signal

Spring and summer onset events and consequently the length of the growing season are very sensitive to climate and local weather (Sparks 2001; Lucht, Prentice *et al*.; Menzel). In contrast with the climatic factors controlling autumn phenology, the climate signal controlling spring phenology is fairly well understood: nearly all phenophases correlate with spring temperatures in the preceding months. Alpine species are also partly sensitive to photoperiod (Keller and Korner) or amount of snow pack (Inouye, Morales *et al*.). For birds, temperatures and weather conditions on the migration route are also important. Some spring events, such as spring arrival, egg-laying of several song birds and the start of the vegetation period in northern and central Europe, also correlate with the North Atlantic Oscillation (NAO) index corresponding to winter climatic conditions (Scheifinger, Menzel *et al*. 2002; Walther, Post *et al*. 2002; Menzel 2003). NAO also alters the speed and pattern of spring arrival in Europe (Menzel 2005). However, direction of NAO responses could differ across Europe (Hubalek 2003;

Kanuscak, Hromada *et al*. 2004). The temperature response of bird arrival may be modified by photoperiodic control, genetic regulatory systems and/or population size. Spring phenological changes in birds and plants are often similar, as described in some cross-system studies (Walther, Post *et al*. 2002).

Consequences
Synchronous phenological changes in different taxonomic groups may not have major ecological consequences. For example, there are no indications as yet of an increased risk of damage by late spring frost in Europe (Scheifinger, Menzel *et al*. 2002; Menzel). However, if links in food chains of two or more layers vary in their responsiveness, then some change is inevitable unless one or more of the food chain layers adapts to the new situation (see Section 1.3.5.10). Changes in growing season length can also affect species composition, in particular those with low adaptive capacity. Likewise, conservation will be affected if the growth and survival of protected species are further endangered by changes in the interactions between threatened and other species.

Adaptation
The relationships of phenology and growing season change to temperature are relatively well understood. However, gaps in data and knowledge exist about the impact of a changing growing season on plant growth, biodiversity, and synchronised timing in ecosystems. The extension of the growing season length, coupled with higher temperature, appears to enhance the productivity of the vegetation, but also lengthens the pollen season (Lucht, Prentice *et al*. 2002; Beggs 2004). Plants that cannot extend their growing season may be unable to compete and may be replaced by other species (see Section 1.3.5.7)

1.3.5.3 Changes in reproduction

Several studies report evidence for climate change effects not only on timing and duration of pollen season (see 1.3.5.5), but also on pollen amounts and pollen allergenicity (Beggs 2004). Among mammals, polar bear body condition and reproductive success have declined in areas that have become ice-free for prolonged periods, where the time available for hunting has been reduced (Derocher, Lunn *et al*. 2004).

1.3.5.4 Changes in species distribution

Many studies have focused on species abundances and distributions to corroborate predicted systematic shifts related to shifts in climatic regimes, often via species-specific physiological thresholds of temperature and precipitation tolerance. A certain inherent resilience of treeline forests is reported and the magnitude of elevational shifts of alpine plant species lags behind the isothermal shift, whereas some butterflies appear to track decadal warming quickly (Parmesan, Rhyrholm *et al*. 1999). There is some evidence that the habitat requirements of species change as one moves towards range boundaries (more specific at margins), e.g., species at their northern boundaries have recently expanded their habitat ranges as conditions have become less marginal (Thomas, Bodsworth *et al*. 2001).

Changes in the distribution of species have occurred across a wide range of taxonomic groups and geographical locations during the 20^{th} century (Table 1.9). Over the past decades a northward extension of various plant species has been observed which is likely to be attributable to increases in temperatures (CBD 2003; Parmesan 2003). Many Arctic and tundra communities are affected and have been replaced by trees and dwarf shrubs (Molau and Alatalo

1998; ACIA). In northwestern Europe, for example in the Netherlands (Tamis, Van 't Zelfde *et al*. 2001), and central Norway (EEA), thermophilic (warmth-demanding) plant species have become significantly more frequent compared with 30 years ago (in the Netherlands, by around 60%). In contrast, there has been a small decline in the presence of traditionally cold-tolerant species. The changes in composition are the result of the migration of thermophilic species into these new areas, but also due to an increased abundance of these species in current locations.

Table 1.9: *Evidence of recent latitudinal and altitudinal range shifts.*

Species / Indicator	Location	Observed changes	Author	Climate link
34 butterfly species	Europe	Northwards range shifts up to 240km, mainly in last 30 years	(Parmesan, Rhyrholm *et al.* 1999)	Increased temperatures
checkerspot, Euphydryas editha	N. America	124 m upward and 92 km northwards (extinction gradient)	(Parmesan 1996)	Increased temperatures
speckled wood, Pararge aegeria	Britain	Expanded N. margin, at 0.51 to 0.93 km/y, depending on habitat availability	(Hill, Collingham *et al*. 2001)	Increased temperatures
4 northern butterfly spp.	Britain	40 m mean increase in elevation, pre-1970 to 1995-99	(Hill, Thomas *et al*. 2002)	Increased temperatures
37 dragonfly and damselfly species	Britain	36 out of 37 species shifted northwards (mean 84 km), 1960-70 to 1985-95	(Hickling, Roy *et al*. 2005)	Increased temperatures
Lowland birds	Costa Rica	Extension of distribution from lower mountain slopes to higher areas	(Pounds, Fogden *et al*. 1999)	Dry season mist frequency
12 bird species	Britain	18.9 km average range movement northwards over a 20-year period	(Thomas and Lennon 1999)	Winter temperatures
Spittlebug	California coast	northward range shift	(Karban and Strauss 2004)	
15 of 120 species	Czech Republic	uphill / alitudinal shifts	(Konvicka, Maradova *et al.* 2003)	Most likely climate
Atalopedes campestris	Eastern Washington	range expansion	(Crozier 2004)	Increased Tmin
Treeline	Europe (Sweden, Spain), New Zealand	Advancement towards higher altitudes	(Meshinev, Apostolova *et al.* 2000; Kullman 2002; Penuelas and Boada 2003)	General warming
Arctic shrub vegetation	Alaska	Expansion of shrubs in previously shrub-free areas	(Sturm, Racine *et al*. 2001)	Environmental warming

Alpine plants	European Alps Montana, US	Elevational shift of 1-4 m/decade Decline in arctic-alpine indicator species	(Lesica and McCune 2004)	General warming
Ilex aquifolium	Germany, Southern Scandinavia	Coherent synchronous poleward shift of northern margin	(Walther, Berger *et al*. 2005)	Increasing winter temperature, bioclimatic model

Plant species in mountains

Altitudinal shifts of vegetation are well-documented (Dobbertin, Hilker *et al*. 2005). Higher temperatures and longer growing seasons, associated with climate change, have created suitable conditions for certain plant species. In the Alps, over the past 60 years spruce and pine species have migrated upward into the sub-alpine region (Pauli, Gottfried *et al*. 2001) and sub-alpine shrubs now grow on the summits (Motta and Masarin; Theurillat and Guisan 2001). Endemic mountain plant species are threatened by the upward migration of more competitive sub-alpine shrubs and tree species and are replaced by them, to some extent because of climate change (Grabherr, Gottfried *et al*.; Gottfried, Pauli *et al*. 1999). The net effect on species richness diverges from region to region and even within single regions. While richness has increased in some places, it has declined in others. The net effect is an increase in species richness in 21 out of 30 summits in the Alps compared with 50 to 100 years ago (Grabherr, Gottfried *et al*. 1994). Similar trends have occurred in the Pyrenees, central Norway mountains, Swedish Scandes, Central Balcan Mountains, the Ural, Tierra del Fuego (Chile), and Mt. Hotham (SE-Australia) (Meshinev, Apostolova *et al*. 2000; IPCC 2001; Wearne and Morgan; Cuevas; Klanderud and Birks 2003; Kullman 2003). However, there are also a lot of examples of a relatively stable treeline position in the last half century (Cullen, Stewart *et al*.; Masek; Klasner and Fagre 2002). Response of treeline position may be subject to "time-lag effects" due to poor seed production/dispersal. In addition, studies report structural changes of the vegetation: increase in population density, increased rate of growth, development of vertical tree stems from krummholz vegetation (see Section 1.3.5.8).

In mountainous regions, climate is the main driver of species composition, and human influence is relatively low. Species that are often endemic and of high importance for plant diversity (Vare, Lampinen *et al*.) are vulnerable to climate change because of (probably) enhanced response to higher CO_2-levels, characteristic small climatic ranges, severe climatic conditions and small isolated populations (Pauli, Gottfried *et al*. 2003) and the absence of suitable areas at higher elevations in which to migrate. Mountain regions are also often characterised by many micro-scale regions with different microclimates, in which endemic species might survive even if the wider climate changes beyond their tolerance limits (Korner).

Climate-linked extinctions

Consequences at longer time-frames could be extinction (Thomas, Cameron *et al*.). The extinction process in declining species is reflected by fragmented distributions (Wilson, Thomas *et al*.). Prominent examples for declines in populations and subsequent extinction/extirpation (Ron, Duellman *et al*. 2003) are found in amphibians around the world. In Puerto Rico, a synergistic interaction between drought and disease has been noted (Alexander and Eischeid 2001; Burrowes, Joglar *et al*. 2004), as well as reduced dry-season mist frequency (Pounds, Fogden *et al*.). In Central and South America, the synergy between UVB-ery radiation and other factors, such as acidification, have been hypothesized (Middleton, Herman *et al*. 2001). Climate variability (temperature, precipitation) is unlikely to be the direct cause of amphibian decline (Alexander and Eischeid 2001).

Paleoecological evidence indicates variable range fluctuations in trees in response to environmental changes. Individual longevity, high intra-population genetic diversity and the potential for high rates of pollen flow might make tree species especially resistant to extinction (Hamrick 2004).

Climate-linked invasions

The clearest evidence for such a climate trigger occurs where a suite of species with different histories of introduction spread en-masse during periods of climatic amelioration (Walther). Prominent example are thermophilous plants that spread from gardens into surrounding countryside in southern Switzerland (Walther 2000; Walther, Post *et al*. 2002), and exotic thermophilous elements spreading into the native flora of Spain and Ireland (Pilcher and Hall; Sobrino, Gonzalez *et al*. 2001). Also, elevated CO_2 might contribute to the spread of non-indigenous plants (Hattenschwiler and Korner).

1.3.5.5 Ecosystem/species community changes

The assemblages of species in ecological communities reflect interactions among organisms as well as between organisms and the abiotic environment. Climatic change or extreme climatic events can alter community composition as species track their climatic tolerances by moving out of or into an area. This is often asymmetrical with species invading faster than resident species are receding. For example, plant species diversity has increased in certain regions (e.g. North Western Europe) due to a northward movement of southern thermophilic species, whereas the effect on cold-tolerant species is still limited (Tamis, Van 't Zelfde *et al*.; EEA).

In many parts of the world, including Europe, species composition has changed and species have become extinct at rates 100–1 000 times greater than is considered to be normal (IPCC; Hare). Although most changes are attributable to landscape fragmentation and habitat destruction, studies show a high correlation between changes in plant composition and recent climate change, also via frequency of weather based disturbances (Hughes 2000; Pauli, Gottfried *et al*.; Parmesan and Yohe).

Examples for altered or stable synchrony in ecosystems via multi-species interactions are still not abundant. Visser and Holleman (Visser and Holleman) found different responses in the Pedunculate Oak-Winter Moth-Tit food chain compared to Buse (Buse, Dury *et al*.) and van Noordwijk (vanNoordwijk, McCleery *et al*.).

1.3.5.6 Species evolutionary processes

Recent evolutionary responses to climate change have been reviewed by Thomas (Thomas). Changes have taken place in the plants preferred for egg-laying and feeding of butterflies, e.g., a broadened diet facilitated the colonisation of new habitats during range extension in Britain (Thomas, Blondel *et al*.). The pitcher-plant mosquito in the USA has prolonged development time in late summer by the evolution of changed responses to day length (Bradshaw and Holzapfel; Bradshaw, Quebodeaux *et al*.). The blackcap warbler has recently extended its overwintering range northwards in Europe by evolving a change in migration direction (Berthold, Gwinner *et al*.). Insects expanding their ranges have undertaken genetically-based changes in dispersal morphology, behaviour and other life history traits, as “good colonists” have been at a selective advantage (Hill, Thomas *et al*. 1999; Thomas, Bodsworth *et al*.;

Hughes, Hill *et al*. 2003; Simmons and Thomas) Evolutionary processes are also demonstrated by reproductive phenological change associated with climate change in North American Red squirrels (Berteaux, Reale *et al*.).

1.3.5.7 Productivity

The terrestrial carbon cycle is strongly linked to inter-annual climate variability. However, the rising atmospheric CO_2 concentration, nitrogen fertilisation, lengthening of the growing season and changed management have resulted in a steady increase in annual forest CO_2 storage capacity in the past few decades, which leads to a more significant net carbon uptake (Nabuurs, Pussinen *et al*. 2002). Northern vegetation activity inferred from satellite data of vegetation index has increased in magnitude by 12 % in Eurasia and by 8 % in North America from 1981-1999. Thus the overall trend towards longer growing seasons is consistent with an increase in the 'greenness' of vegetation, broad continuous in Eurasia and more fragmented in North America, reflecting changes in biological activity (Zhou, Tucker *et al*. 2001). Net primary production increased by 6% globally, with the largest increases in tropical ecosystems (Nemani, Keeling *et al*.) (See Fig. 1.2). During the 1990s the European terrestrial biosphere stored between 7 % and 12 % of the annual anthropogenic CO_2 emissions (Janssens, Freibauer *et al*.). Uncertainties in the calculations of the national and continental carbon flux density are still high. A regional-scale carbon sink in old-growth Amazonian forests during the previous two decades is suggested by Baker (Baker, Phillips *et al*.); satellite observation demonstrate a high interannual sensitivity of plant phenology and carbon fluxes in Amazon forests to El Nino events (Asner, Townsend *et al*.), thus forest biomass which experienced rapid declines associated with El Nino events, gradually accumulated again (Rolim, Jesus *et al*.).

1.3.5.8 Evidence of adaptation & vulnerability

The attribution of observed changes to climate change is, depending on the system, sometimes hampered by multiple forcing. The response to temperature might be well understood, however the reaction to climate extremes and the consequences for biodiversity are less easy to assess. Evidence of adaptation is found in the change of migration routes and overwintering areas by birds and perhaps also in differential response rates in different time periods. Autumn passage of migrants wintering south of the Sahara has advanced, presumably as a result of selection pressure to cross the Sahel before its seasonal dry period, whereas migrants wintering north have delayed autumn passage (Jenny 2003). Similarly, historical data anticipate an increased number of migrant Lepidoptera (Sparks, Roy *et al*. 2005). There is no evidence so far that temperature response rates of plants did change over the last century; however, earlier plant spring phenology is associated with higher spatial variability (Menzel 2005; Menzel and Dose 2005).

Non-climate related factors limit migration and adaptation capabilities, e.g., for some plant species particularly in high elevations and high latitudes, as migration is often difficult. Failure of adaptation or migration leads to high vulnerability of the species and systems.

1.3.5.9 Summary

The overwhelming majority of case studies on global warming impacts reveal a consistent pattern of change. Uncertainty over the response of plant species to climate change is modest, although there is still a lack of accurate data on the effect of climate change on plant species diversity. Climate change over the past three decades has resulted in population decreases and disappearance of certain plant species as well as in further high-latitude movement of many plant species. Non-climate related factors limit the migration and adaptation capabilities. Endemic mountain plant species are threatened to some extent, whereas the upward migration has led to an increase in plant species richness. Net primary production increased by 6% globally, with the largest increases in tropical ecosystems. The survival of different bird species wintering in Europe has increased. All indicators show a clear trend indicating that the impacts of climate change are already apparent worldwide. In the predominant majority of studies the observed trends correspond to predicted changes in terms of magnitude and direction, but not all processes, often due the lack of data, have yet been studied.

1.3.6 Agriculture and forestry

Although agriculture and forestry are known to be highly dependent on climate, little evidence of observed changes related to regional climate changes was noted in the TAR. Agriculture and, to a lesser extent, forestry are also strongly influenced by non-climate factors, especially management practices and technological changes (Easterling 2003) on local and regional scales, as well as market prices and policies related to subsidies. A recent example is given in the analysis of the winter wheat production in the EU from 1961 to 2000: the magnitude of anomalies due to climate variability is mainly limited to 0.2 t/ha, while the yield trend depicts progressive growth from 2.0 to 5.0 t/ha(Cantelaube, Terres *et al*. 2004).

The yield per hectare of all cash crops has increased worldwide in the last 40 years. This trend can mainly be explained by technological success in breeding, pest and disease control, fertilization and mechanization (Hafner 2003). Apart from changes in management practices and technical inputs that influence tactical choices of farmers or foresters at the field or production unit scale, economic driving forces, influenced by agricultural policies (such as the Common Agricultural Policy (CAP) of the European Union) or the global market, play an important role on strategic choices at the farm level.

There has been evidence of recent trends in agro-climatic indices, particularly those with a direct relationship to temperature, including some indices for forestry (Table 1.10). Large-scale recent warming is mainly confirmed in temperate regions (e.g., Europe, a major part of North America) where it lengthens the potential growing season. It is also apparent in Sahelian countries where its combination with rainfall reduction leads to more unfavourable conditions for crops. It is especially detectable in indices applicable to wine-grape cultivation (Box 1.3). Indicators of climate change in the UK for the agricultural sector (Cannell, Palutikof *et al*. 1999), such as use of irrigation water for agriculture, proportion of potato crop that is irrigated, potato yield, and area of vineyards and forage maize in production, have been selected for their potential to track responses to warmer and drier conditions, but the extent to which each indicator does this is difficult to distinguish precisely among the combined influence of other technical or economical driving forces. In the case of the Sahel region of Africa, changed climatic conditions have served as a catalyst for a number of other factors that have accelerated a decline in groundnut production (Van Duivenbooden, Abdoussalam *et al*. 2002).

Little is known about the timescales on which field-scale changes propagate to farm and regional levels. A further complicating issue is the precise nature and role of human adaptation in the agriculture and forestry sectors, since many of the responses to climate will be adjustments in management practices. In spite of these limitations, recent studies have begun to document changes and responses related to regional climate changes in these sectors.

1.3.6.1 Crops and livestock

Changes in crop phenology provide important evidence of responses to climate (Table 1.11a). Such changes are especially apparent in production of perennial crops, such as fruit trees and wine-grapes, which are less dependent on yearly farmer decisions than annual crops and are also often easier to observe. But some evidence also appears in annual crops. Phenological changes are often observed in tandem with changes in management practices by farmers (Table 1.11b). The reported studies all concern Europe, where recent warming has clearly advanced a significant part of the agricultural calendar.

No detectable change on crop yield directly attributable to climate has been reported for the EU, even though model simulations exhibit a tendency to lower potential biomass with observed levels of warming (Table 1.11c). Only local experiments (e.g., hay yield at an experiment station in the UK (Cannell, Palutikof *et al*. 1999)) are exhibiting clear trends. The same limit to a local scale appears for the reported study of IRRI in the Philippines (Peng, Huang *et al*. 2004), which reports a negative effect of warming for rice production in a tropical country. US yields demonstrate a significant influence of observed temperature trends during the 1982-98 period on maize (25%) and soybean (33%) yields at the county-level (Lobell and Asner 2003). Changes in crop area distribution have not yet been associated with regional climate trends, apart as indicators in UK (Cannell, Palutikof *et al*. 1999). For livestock (Table 1.11d), one study in Tibet reports a significant relationship of improved performance with warming in high mountainous conditions (Du, Kawashima *et al*. 2004).

1.3.6.2 Forestry

Generalized evidence of an extended growing season, together with warming and higher CO_2 concentrations, are factors that combine to favour an increase of forest productivity (Table 1.12a), as well as the possible influence of nitrogen deposition by rainfall. Climate warming has also been identified as a factor in the expansion of some damaging insects (Williams and Liebhold 2002; Battisti, Statsmy *et al*. 2004) and in the increase in forest fire occurrence in UK and North America (Table 1.12b and 1.12c) (Fig. 1.9) (Cannell, Palutikof *et al*. 1999; Gillett, Weaver *et al*. 2004). This is supported by McKenzie (McKenzie, Gedalof *et al*. 2004), who established that, in spite of management acting to reduce fuel load in forests, climate variability is the dominant factor affecting large wildfires.

1.3.6.3 Evidence of adaptation and vulnerability

There is little documented evidence of adaptation to regional climate trends in agriculture and forestry, with only a few studies related to the shift of sowing dates of annual crops. There is even less evidence related to food supply. In regard to vulnerability, evidence of observed effects (changes in planting or shifts in distribution) studies have focused on crops in developed countries, and not on effects in relation to subsistence agriculture in rural populations in low- and middle-income countries.

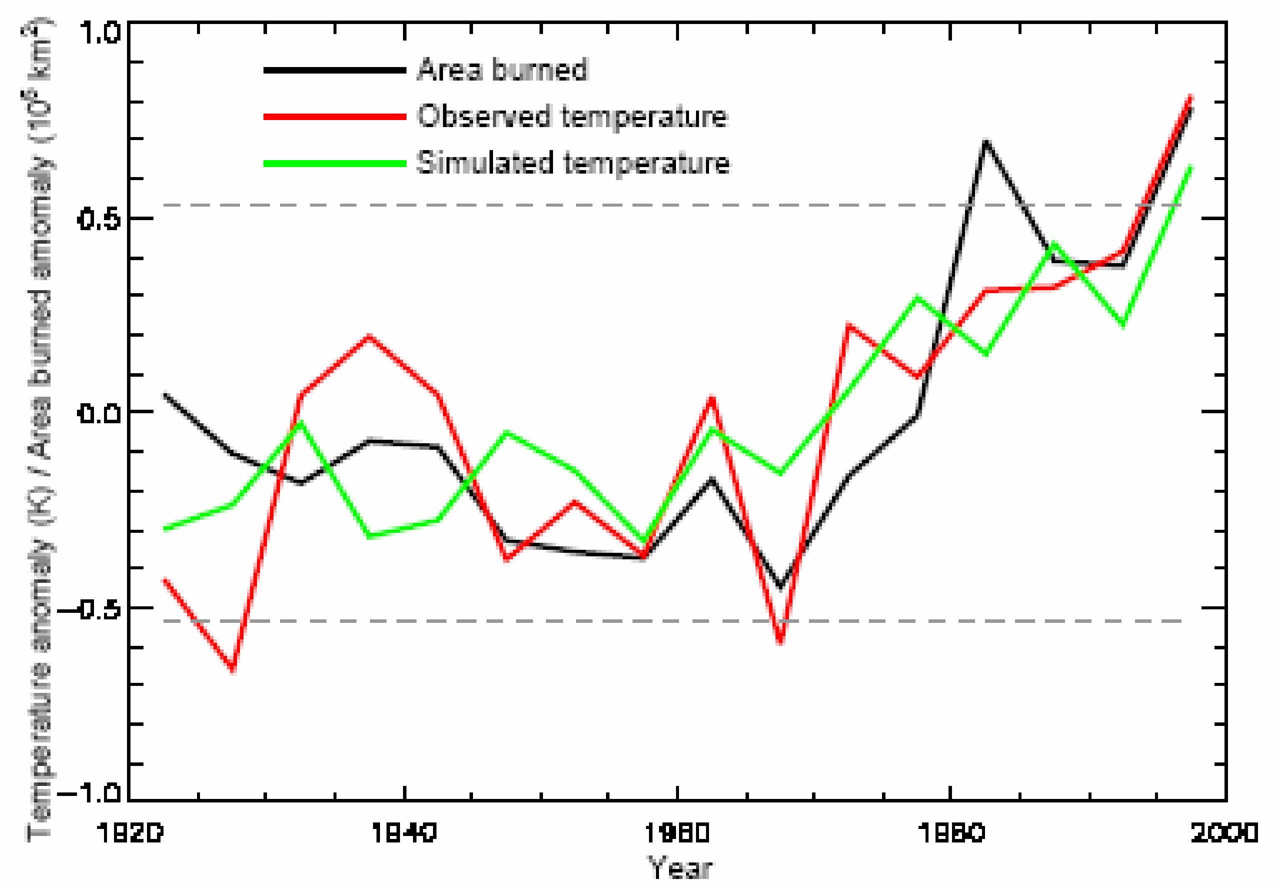

Fig. 1.9: *Area burned, observed temperature, and simulated temperature trends for Canadian forests. Black line shows total area burned anomalies over Canada for each five-year period from 1920 to 1999 (Van Wagner), in units of 105 km*^{2}*. The red line shows five-year mean observed May-August temperature anomalies (Jones 2003) weighted by area burned, in K. The green line shows ensemble-mean five-year-mean May-August area burned-weighted temperature anomalies from integrations of the CGCM2 model forced with anthropogenic greenhouse gases and sulphate aerosol. Gray dashed lines indicate the 5-95% range of internal variability in area burned, estimated from interannual variability. All anomalies are calculated relative to the 1920-1999 mean (Gillett, Weaver et al. 2004).*

Changes in vulnerability are difficult to assess in relation to recent changes in mean temperature at the decadal scale. Vulnerability in these sectors appears to be high in the case of extreme events or exceptional episodes, such as the summer of 2003 in Europe. The extreme warming (which was close to levels projected by end-of-century GCM climate change scenarios) resulted in the strongest negative deviation in crop production from the long-term trend in the last 43 years (FAO 2004). Greece, Portugal, Italy and especially France suffered yield decreases of up to 30%.

Global crop models have predicted that agriculture in developed countries will mostly benefit from climate change at least in the near-term, while developing nations, for the most part, will experience declines in production (Parry, Rosenzweig *et al*. 2004). The observed trends tend to confirm the model simulations. Regions in North America (Lobell and Asner 2003) and Northern Europe, apart from 2003 (Genovese, Lazar *et al*. 2005), in general, appear to be experiencing more favourable growing conditions, while regions, such as the Sahel (Van

Duivenbooden, Abdoussalam *et al*. 2002) and the Philippines (Peng, Huang *et al*. 2004), have experienced changes that have been unfavourable to crop production.

1.3.6.4 Summary

Individual climate variables or their combination into agro-climatic indicators are used to analyze recent trends in agricultural and forestry regions. These effects are hard to detect in aggregate agricultural statistics because of the complex and strong influence of non-climate factors. However, several agricultural and forestry studies have documented clear signals of changes in phenology, risk of frost, growing season duration, biomass, quality (for grapevines, a climate-sensitive crop), insect expansion, and forest-fire occurrence, that are in agreement with regional warming. The effects of recent regional climate change (mainly warming) to date are of limited economic consequence and appear to lie within the ability of the sectors to adapt, but both the agriculture and forestry sectors show vulnerability to recent extreme heat and drought events.

Box 1.3: Wine and Recent Warming

Wine-grapes are known to be highly sensitive to climatic conditions, especially temperature. They have been used as an indicator of observed changes in agriculture related to warming trends, particularly in Europe and in some areas of North America.

Using 30 years of data for grapevine production in Alsace, France, Duchêne (Duchene and Schneider 2005) found that the number of days with a mean daily temperature above 10°C (favourable for vine activity) in the last 70 years has increased from 170 to 210 at the end of the 20th century. The lengthening of the growing period is also clearly visible in the heliothermal index of Huglin Seguin (Seguin, Domergue *et al*. 2004) confirmed this for all the wine-producing areas of France, and also demonstrated a lower year-to-year variability in the last 15 years, which provides conditions favourable for wine, in terms of both quality and stability. .Jones (Jones 2005 in press) observed similar trends in the average growing-season temperatures (April-October for the Northern Hemisphere) at the main sites of viticultural production in Europe. Similar tendencies have also been found in the California, Oregon, and Washington vineyards of the U.S., Nemani (Nemani, White *et al*. 2001), (Jones 2005 in press).

Consequences of warming are already detectable in the wine quality. Duchêne (Duchene and Schneider 2005) have detected a gradual increase of the potential alcohol levels at harvest for Riesling in Alsace of nearly 2% volume in the last 30 years. On a worldwide level, Jones (Jones 2005 in press) has established, for 25 of the 30 analyzed regions, increasing trends of vintage ratings (average rise of 13.3 points on a 100-point scale for every 1°C warmer the growing season), with lower vintage-to-vintage variation.

Table 1.10: *Observed changes in agroclimatic indices.*

Authors	Period	Location	Observed changes
Feng (Feng and Hu 2004)	past 50 years	Western and Northern US (except from Idaho to northern California)	Decrease of annual number of frost days (3 for 10 years) Advance in last frost day in spring (4 days in 10 years) Delay in first frost day in autumn, increase of growing season length, increase of GDD for corn and soybean Rising soil moisture, with decrease of weeklong dry and wet spells
		Eastern and Southeastern US	No change for the same indicators First frost day in autumn earlier in some parts of Eastern
Robeson (Robeson 2002)	last 100 years	Illinois US	Earlier last spring freeze by one week No change for first fall freeze Resulting increase of growing season length (one week)
Menzel *et al*. (Menzel, Jakobi *et al*. 2003)	Past 50 years	Germany, (Austria, Switzerland, Estonia)	Earlier last spring frost by 0.24 (T_{min}<0°C), 0.23 (T_{min}<-3°C) and 0.32 (T_{min}<-5°C) days/year, lengthening of the frost free season by 0.49 days / year, lengthening of the growing season (T_{mean} constantly >7°C) by 0.36 days/ year
Moonen (Moonen, Ercoli *et al*. 2002)	122 last years	Pisa (Italy)	Earlier last spring frost and resulting sowing date No change in extreme events and soil moisture, in spite of decreasing rainfall (but fewer days of surplus in autumn)
Genovese (Genovese, Lazar *et al*. 2005)	1975-2001	Whole Europe	Generalized increase in active temperature (>0°C), with well-identified shifts for different geographic areas Most of the warming for May-August
Ben Mohamed (Ben Mohamed, Duivenboode n *et al*. 2002)	1951-1998	Zinder, Maradi, Dosso (Niger) Sahel (Africa)	Increase of number of days with Tmin>30°C Reduced length of vegetative period because of rainfall decrease, no longer allowing present varieties to complete their cycle
Schwartz (Schwartz and Reiter 2000)	1959-1993	North America	Earlier spring (6 days) from observed and modelled lilac blooming, strongest in northern regions Patterns of change not so strong in autumn, with areas in central US showing earlier first autumn freezes
Schwartz (Schwartz, Ahas *et al*. 2005)	1955-2002	Northern Hemisphere	Universal quicker onset (between –1.0 and 1.5 day/decade) of early spring warmth and last spring freeze lengthening of growing season (1.6 days/decade)
Delbart (Delbart, Le Toan *et al*. 2005)	1982-2004	Northern Eurasia	Advance of greening onset of boreal forests (determined by combining SPOT-VGT and NOAA-AVHRR) by 8 days in 1982-1991 and delay by 3.6 days in 1993-2004
Fillol (Fillol and Royer 2005)	1982-2000	Canada	Northern migration 12 km/year of the ecotone separating forest from tundra (by using combination of NDVI and T_s from the PAL database of NOAA-AVHRR satellite)

Table 1.11: *Observed changes in (a) Agricultural crop production and livestock; (b) Phenology; (c) Management practices, pests and diseases; (d) Yield; (e) Livestock.*

a. Agricultural crop production and livestock.

Authors	Period	Location	Observed changes

b). Phenology

Chmeliewski (Chmielewski, Muller *et al*. 2004)	1961-2000	Germany	Observed advance of stem elongation for winter rye (10 days) and emergence for maize (12 days)
Genovese(Genovese, Lazar *et al*. 2005)	1975-2001	European Union	Advance in wheat flowering (3 weeks) computed with CGMS model
Menzel (Nöthiger)	1951-2000	Germany	Observed advance in cherry tree flowering (0.9 days / decade), apple tree flowering (1.1 days / decade) in response (-5 days / °C) to March / April temperature increase
Chmeliewski (Chmielewski, Muller *et al*. 2004)	1961-1990	Germany	Observed advance in beginning of growing season for fruit trees (2.3 days/year), cherry tree blossom (2.0 days/10 years), apple tree blossom (2.2 days/ 10 years) in agreement with increase of annual air temperature of 1.4°C.
Seguin (Seguin, Domergue *et al*. 2004)	1970-2001	Lower Rhone valley (south of France)	Observed advance of fruit tree flowering of 1 to 3 weeks for apricot and peach trees, leading to increase in spring frost risks and more frequent occurrence of bud fall or necrosis for sensitive apricot varieties (Domergue 2004).

c). Management practices, pests and diseases

Chmeliewski (Chmielewski, Muller *et al*. 2004)	1961-2000	Germany	Observed advance of seeding dates for maize and sugarbeet (10 days)
Benoit(Benoit and Torre 2004)	last 30 years	France (4 INRA farms)	Observed advance of maize sowing dates by 20 to 3 weeks
Sauphanor (Sauphanor and Boivin 2004)	last 20 years	South of France	Observed partial shift of apple codling moth from two to three generations

d) Yields

Cannell (Cannell, Palutikof *et al*. 1999)	1965-1998	Rothamsted UK (Europe)	Observed lower hay yields, in relation with warmer summers (1°C increase in July-August leads to 0.33 t/ha loss)
Peng (Peng, Huang *et al*. 2004)	1992-2003	IRRI field Philippines	Decrease of rice yield associated with increase of annual temperature (0.35 °C and 1.13°C for maximum and minimum respectively during 1979-2003). Close linkage between yield and growing-season minimum temperature in dry season (loss of 15% degree^{-1})

e) Livestock

Du (Du, Kawashima *et al*. 2004)	1978-2002	Asia (Tibet)	Observed increase in sheep (106%), cattle (249%), beef (297%), mutton (133%) related to warming in mean annual temperature and summer. No significant relationship with winter temperature

Table 1.12: *Observed changes in forestry (a) Productivity; (b) Insect damages; (c) Forest fires.*

Authors	Period	Location	Observed changes
a. Productivity			
Duquesnay (Duquesnay, Breda *et al*. 1998)	last 50 years	Europe	Observed increase (30 to 40 %) of forest productivity. Attribution to CO_2 increase, recent warming and/or nitrogen deposition not established
Zhou (Zhou, Tucker *et al*. 2001)	last 20 years	Northern hemisphere	Observed large-scale increase of forest productivity based on vegetation indices from by low-resolution satellite data
b. Insect damages			
Williams (Williams and Liebhold 2002)	last 20 years	USA	Observed expansion in the range of bark beetles
Battisti (Battisti, Statsmy *et al*. 2004)	last 20 years	Europe (France and Italy)	Observed shift of processionary moth (27 km/decade in latitude towards north near Paris, 70m/decade upward shift in altitude for southern slopes and 30m/decade for northern slopes in Italian mountains)
c. Forest fires			
Cannell (Cannell, Palutikof *et al*. 1999)	1965-1998	Europe (UK)	Observed increases of outdoor fires in England and Wales, likely attributable to warmer and drier summer conditions
Gillett (Gillett, Weaver *et al*. 2004)	last 40 years	Canada	Observed increase in burned areas, in spite of improved fire-fighting techniques in agreement with simulated warming from GCM About half of the trend towards increasing area burned attributed to climate change from a statistical model

1.3.7 Human Health

The TAR (IPCC 2001) indicated that global climate change would have a wide range of health impacts. Here we evaluate evidence regarding observed changes in human health and regional climate change (Table 1.13). These observed changes are related to temperature and precipitation extremes and their resultant adverse impacts on food- and water-borne diseases, vector-borne diseases, and pollution and respiratory diseases brought on by allergens from the environment (See Chapter 8).

The superposition of natural climate variability on greenhouse-induced warming can produce fluctuations that may be key drivers of inter-annual variability in many parts of the world. Warming trends from such episodes are often associated with the transmission and occurrence of certain diseases (Kovats, Campbell-Lendrum *et al*.). Climate anomalies in temperature and precipitation have direct impacts, such as heat and cold extremes, which can result in human heat exhaustion and hypothermia, respectively. Additionally, these extremes can produce environmental and ecological disruptions that in turn may cause outbreaks of infectious disease such as vector-borne diseases (VBDs). Githeko and Ndegwa (Githeko and Ndegwa 2001) have shown, for example, how unusually high temperatures in the normally cool highlands of Kenya have been favourable to malaria outbreaks.

Table 1.13: *Disease studies related to seasonality and climate changes.*

Disease	Reference	Region	Climate-environment enhancing the disease	Interannual links	Seasonality changes	Climate change study
WBD - general	{Benson, 2000, Mid-Atlantic}	Mid Atlantic Region	Temperature, rainfall, storms QN			Increasing trend QN
Campylobacter spp.	{Kovats, 2005, campylobacter}	Europe, Canada, Australia, New Zealand	Climate, environment, contact with contaminated water, milk, meat, poultry or lightly cooked foods QN	-	Spring peak related with mild winters and geographic seasonality differences QN	-
Cryptosporidium spp.	{Chai, 2001, Korea}	Korea	Rainfall QN	-	Increase of incidence in spring QN	-
Salmonella spp.	{Hubalek, 2003, Czech Republic}	Czech Republic	Public health factors, NAO non-correlated QN	-	-	Increasing trend QN
	{D'Souza, 2004, ambient temperature}	South Australian cities	Air temperature QN	Lagged response to temperature QN	Explained by seasonal temperature changes QN	Increasing trend QN
Vibrio cholera	{Bouma, 2001, Bengal}	Bay of Bengal (Bangladesh)	ENSO QN	ENSO related to mortality QN	Spring mortality associated with SST and unknown winter peak QN	-
	{Codeco, 2001, aquatic reservoir}	Global	Environment and bad sanitary conditions QN	-	Seasonal changes in contact rates QN	-
	{Rodo, 2002, ENSO}	Bangladesh	ENSO QN	ENSO accounts for 70% of cholera variability in some time intervals QN	-	Comparison between 1893-1940 (no climate influence) and 1980-2000 (strong climate forcing) QN
	{Faruque, 2005, cholera phages}	Bangladesh	-	-	The presence of cholera phages affects seasonality QN	- -
Diarrhoeal diseases and gastrointestinal symptoms	{Singh, 2001, Pacific Islands}	Pacific Islands (Fiji)	Temperature QN	-	-	Increasing trend in diarrhoea incidence QN

Notes: QN → quantitative assessment QL → qualitative assessment.

There is a wide range of driving forces that can affect and modify the impact of climate change on human health indicators. According to Sutherst (Sutherst 2004), Githeko and Woodward (Githeko and Woodward 2003.), Molyneux (Molyneux 2003), and Tillman (Tillman, Fargione *et al*. 2001), these may include some of the following: Social factors such as human population density and behaviour; housing facilities; public health facilities such as water supply, waste management and vector-control programs; land use for food, fuel and fibre supply; results of adaptation (e.g., drug use and resistance of organisms as well as insecticide use and resistance of vector species). Patz (Patz, Campbell-Lendrum *et al*. 2005) emphasize the importance of considering changing land use and land cover and their associated effects on local climate and ecosystems when linking climate and health.

1.3.7.1 Analysis of evidence regarding ENSO and human health

The worldwide ubiquity of cholera (Fig. 1.10) and virulence changes in cholera-resistant stages and in non-infective forms, possibly triggered by sudden or sustained alterations of environmental conditions following climatic anomalies and extremes, seem the most plausible explanations for cholera outbreaks. Water temperature related to large-scale climate variability systems such as the El Nino-Southern Oscillation affects organism multiplication and occurrence of the infection in humans. Infected copepods in the water could be a vector of vector-borne disease (VBD). Cholera caused by *V. cholerae* appears to be affected by climate (Lipp *et al*, 2003, cholera).

Among water-borne diseases, cholera in South East Asia has a record that spans for more than a century. The coherence between strong changes in cholera dynamics and the ENSO index was studied in two periods, the first from 1893 to 1940 and the second covering the two last decades of the 20th century. Rodo *et al* 2002 presented quantitative evidence for an increased role of inter-annual climate variability on the temporal dynamics of cholera in Bangladesh, based on a time-series analysis of the relationship between ENSO and cholera in two different time intervals. The comparison of the cholera incidence in Bangladesh in both periods showed a more robust relationship in recent times, accounting sometimes for over 70% of variability at selected intervals between the more variable and intense recent El Niño events, and cholera prevalence (Rodo, Pascual *et al*. 2002). The climate phenomena accounted for over 70% of the disease variance. Climate-related increase in sea surface temperatures and sea level rise led to higher incidence of water-borne infections and toxin-related illnesses, such as cholera and shellfish poisoning (Patz, Epstein *et al*.).

A warming trend in surface air temperature in the period 1871-1997 was detected over the Tibetan Plateau and the Himalayas region, as reported by Kumar (Kumar, Rajagopalan *et al*. 1999), and partly attributed to both global warming and to the intensification of El Nino effects over that region (Kumar, Rajagopalan *et al*. 1999). Though ENSO effect on the Indian Ocean still remains an open question (Klein, Soden *et al*. 1999), ENSO-induced SST changes in bounded regions of the Indian Ocean and the Bay of Bengal may be associated with flooding over Bangladesh in the last decades of the 20^{th} century and with increases in transmissibility for cholera at interannual timescales (Koelle and Pascual 2004) However, at longer timescales, there is a coherent decrease in the same parameter in a statistical model for cholera, concomitant with a long-term increase in north-eastern Indian rainfall and the river discharge of the Brahmaputra river (Koelle and Pascual 2004).

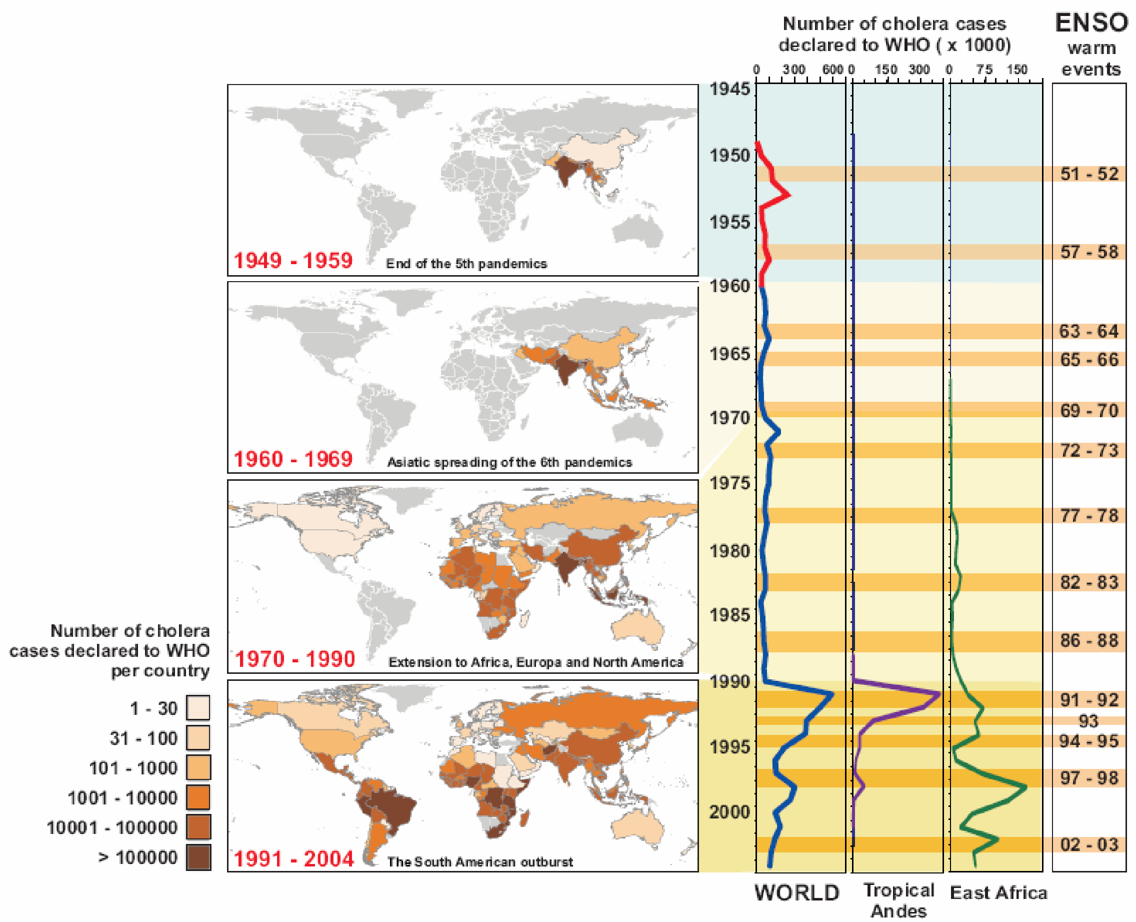

Figure 1.10: *Global cholera: Sum of cholera cases (autochthonous and imported) declared yearly to World Health Organization (WHO) by country in the second half of 20th century. (Left) cholera incidence per country for (a) end of the fifth cholera pandemics (1949-1959); (b) Asiatic spread of the 6th pandemics (1960-1969); (c) arrival to Europe, Africa and North America (1970-1990); and (d) outburst in South America (1991-2004). (Right) global and regional (Tropical Andes including Peru, Bolivia, Ecuador and Colombia; and East Africa comprising Kenya, Tanzania, Malawi, Zambia, Uganda and the Democratic republic of Congo) time-series of declared cholera incidence. El Nino events are defined following the International Research Institute for Climate Prediction. (Source: WHO Global Atlas of Infectious Diseases.)*

1.3.7.2 Trends in vector-borne diseases

There is evidence that observable changes have occurred in four major vector-borne diseases with climate change.

Lyme disease

Changes in the latitudinal spread and abundance of Lyme disease vectors in relationship to milder winters have been well-documented in Sweden (Lindgren and Gustafson 2001). In the United States, disease incidence has been correlated to wetter conditions in the period preceding the outbreaks (Suback 2002).

Dengue fever

Studies in Thailand have established that there is a significant complex, non-linear association between El Nino, climate variables and dengue fever and dengue haemorrhagic fever (DHF) (Cazelles, Chavez *et al*. 2005).

Tick-borne encephalitis (TBE)
Increase in TBE in Sweden since the mid-1980s may have been caused by milder climate in this period, permitting an increase in tick abundance (Lindgren and Gustafson 2001).

Malaria
Little evidence has been documented in altitudinal increases in malaria distribution. However increases in the frequency of epidemics in the highlands of Eastern Africa since the 1980's have been recorded (Githeko and Ndegwa 2001; Zhou, Minakawa *et al*. 2004) and these can be treated as cyclic transient changes. The temporal and spatial distribution of the epidemics is consistent with climate variability in the region. From fundamentals of biology, climate modulates malaria transmission while interventions control morbidity and mortality. Debate about the role of the different drivers in the incidence of malaria still continues (Hay, Shanks *et al*. 2005).

1.3.7.3 Effects of trends in heat and cold stress

Episodes of extremely hot or cold ambient temperatures have been associated with increased mortality independent of season in non-acclimatized populations (Huynen, Martens *et al*. 2001; Curriero, Heiner *et al*. 2002). Deaths related to extreme temperatures can occur on days outside of a "comfort zone" and not just during heat waves or cold spells, particularly in regions where extreme weather is infrequent.

There is evidence of recent increases in mean surface temperatures and in variability of high temperatures, with the extent of change varying by region (Karl and Trenberth 2003; Luterbacher, Dietrich *et al*. 2004; Schär 2004). This increase in variability has been associated with excess mortality during heat waves, as was dramatically illustrated in the 2003 heat wave in Central Europe, which was the hottest summer since 1500 (Luterbacher, Dietrich *et al*.). France was most affected, and more than 14000 excess deaths are estimated to have occurred during the heat wave (Institute de Veille Sanitaire, 2003, Vandentorren 2004). Excess mortality was also reported from Italy (Michelozzi, de' Donato *et al*. 2004); Spain (Martinez-Navarro, Simon-Soria *et al*.); Portugal (Falcao, Nogueira *et al*.); and the UK (Johnson, Kovats *et al*. 2004).

However, studies in Europe and in the United States of mortality over the past 30 to 40 years found evidence of declining death rates during summer months, which was attributed to increased use of air conditioning, improved health care, and increased public awareness of the risks of exposure to high ambient temperatures (Davis, Knappenberger *et al*. 2003; Davis, Knappenberger *et al*. 2003; Donaldson, Keatinge *et al*. 2003). The highest rates of excess winter mortality in Europe and the United States are in more southern regions (Curriero, Heiner *et al*. 2002; Wolanski, Spagnol *et al*.).

1.3.7.4 Emerging food- and water-borne diseases

Food- and water-borne diseases (WBD) are major adverse issues associated with global climate change phenomena. In five Australian cities from 1991-2001, a rising trend in salmonellosis incidence was reported in association with an increase in surface air temperature, also with temperature leading infection by one month (D'Souza, Beeker *et al*. 2004). A few other studies report what might be a similar climate change effect for other WBD. In US and Canada, there is a reported increase in outbreaks of Escherichia coli 0157:H7 and Cryptosporidium from 1950 through 2000 (Charron, Thomas *et al*. 2004), and though there is insufficient knowledge on its epidemiology (Rose, Huffman *et al*. 2002), half of the outbreaks followed extreme rainfall events. Increase in extreme precipitation has been claimed as a driver for WBD outbreaks (Curriero, Patz *et al*. 2001), though often in qualitative approaches (Casman, Fischhoff *et al*. 2001; Diergaardt, Venter *et al*. 2004). There also appears to be an increasing trend in harmful algal blooms (HAB) in coastal waters (see Box 1.4).

Box 1.4: Harmful Algal Blooms.

Mass proliferation of harmful algal blooms (HABs) pose a serious threat to human health in some regions of the world. Increases in 'red tides' and other (HABs) during the past 50 yr on both the Atlantic and Pacific coasts of Canada suggest that global-scale factors, such as climate change and increased international shipping trade, can be the main driving forces (Mudie *et al*., 2002; Van Dolah, 2000). However, most of the times the origin and climatic suitability conditions for red tide proliferations are not well-known (Yang, ZB; Hodgkiss, IJ (2004), such as for Fibrocapsa japonica (De Boer *et al*., 2005), Gymnodinium catenatum, Pyrodinium bahamense var. compressum, and recently Cochlodinium cf. catenatum. The variability and near-concurrence of species blooms in the modern (past 60 yr) record is unmatched in the past, according to the examination of the Holocene history of harmful phytoplankton species and suggests disequilibrium of the natural ecosystem structure (Mudie *et al*., 2002) and a climate change effect (via surface temperature and storminess) as the main driving force stimulating blooms.

1.3.7.5 Pollen- and dust-related diseases

There is evidence that observed climate change is affecting the timing of the onset of pollen production (Van Vliet, Overeem *et al*. 2002; WHO 2003; Beggs 2004). Studies, mostly from Europe, indicate the seasonal onset of some important allergens have become earlier in recent decades, and such shifts are consistent with observed changes in climate (Teranishi, Kenda *et al*. 2000; Rasmussen 2002; Emberlin, Detandt *et al*. 2003). However, there is no good evidence that temperature changes have increased pollen abundance or allergenicity, although laboratory and field studies suggest that increased CO_2 may facilitate increased pollen abundance (Ziska and Caufield 2000). Pollen abundance, however, is more strongly associated with land use change and farming practices than to weather. Changing agricultural practices, such as the replacement of haymaking in favour of silage production, have also impacted upon the grass pollen season in Europe. The impact on health of dust and dust storms has not been well described in the literature. Gyan (Gyan, Henry *et al*. 2003) reported a dramatic increases in respiratory disease in the Caribbean that they have attributed to increase in Sahara dust, which has in turn, been attributed to climate change.

1.3.7.7 Trends in adaptation and vulnerability indicators

For each adverse climate change-related health outcome, several adaptation outcomes may exist. These may include instituting adaptive health policies, strengthening of the public health infrastructure, or improving health-oriented management of the environment such as air, water, food and vector issues. There have been some negative results, however, such as the threat caused by the ongoing loss of drugs and pesticides (chloroquine and DDT respectively) due to selection of resistant pathogens and vectors (Sutherst 2004). This has resulted in increased vulnerability of communities to change in impacts, especially in developing countries.

1.3.7.8 *Summary*

Evidence of human health outcomes related to climate trends include cholera incidence related to the El Nino-Southern Oscillation, increased incidence and range of vector-borne disease, some water-borne diseases, and dust and pollen-borne diseases. Evidence linking climate changes with famine-related nutrition is inconclusive. The evidence regarding observed changes in the health sector related to climate trends supports the conclusion that global climate change remains an issue for human health. An increased vulnerability is apparent in poorer countries.

1.3.8 Disasters and hazards

'Rapid onset meteorological catastrophes' are taken to include floods, tropical & extratropical cyclone windstorms (along with their associated coastal storm surges), as well as the most severe supercell thunderstorms. By definition 'catastrophes' are rare events, with return periods in a location typically of 10-20 years or more – i.e. annual exceedence probabilities of 5-10% - as the built environment is generally designed to withstand the experience of more frequent extremes. Given that a strong rise in global temperatures only began in the 1970s, there is a fundamental problem in demonstrating a change in the occurrence of catastrophes at a given location simply from the recent historical record (Frei and Schar).

In the quest to identify a change in catastrophe return periods, there are a number of options:
1) Data may be pooled from independent and uncorrelated locations that share common peril characteristics so as to search for changes in occurrence across all of them collectively.
2) A statistically significant change in occurrence characteristics of relatively high frequency events (with return periods <5 years) can be used to infer changes at longer return periods.
3) Changes may be identified in the population of the meteorological events themselves, rather than their localized characteristics – as for example a change in the population of tropical cyclones that could affect the return period of extreme windspeeds measured at many individual locations.

1.3.8.1 Catastrophic river floods

In the most comprehensive available global study, Kundzewicz (Kundzewicz) examined worldwide information on annual extreme daily flows from 195 rivers, for which the best and longest data was available. Based on the analysis, certain classes of flood were found to be less frequent – including those triggered by ice-dams and thaw. While the record of rivers with suitably long flow records was considered too small in number to indicate any trends in Africa, Asia and South America, of the 70 time-series analyzed for rivers in North America, 14 showed a statistically significant increase in extreme flow frequencies, and 12 a statistically significant decrease (at the 90% level of confidence), with about half those showing a decrease being in Canada or Alaska and all those with an increase being in the coterminous US. 5 rivers in Australia showed a significant decrease and none were found to show increases. In Europe, of 70 flow time-series 11 showed a significant increase and 9 a significant decrease with a 3:1

ratio of those showing an increase to decrease in the UK. All but one of the flow datasets in Europe runs back to before 1960, and the extreme flows show a rising trend in terms of the decade of the maximum flow (see Fig. 1.11a) from 1960-1969, 7 in 1970-1979, 11 in 1980-1989 and 17 from 1990-2000 (although the higher number of extremes in the 1950s (7) than in the 1960s highlights that this trend is not monotonic). In a multi-century study of the frequency of great floods on two major central European rivers the 54,000km^2 Oder and the 95,000km^2 Elbe (Mudelsee, Borngen *et al.*), no trends were found through the 19th and 20th Centuries, apart from a reduction in the severity of winter floods. However summer floods with flow return periods greater than 100 years occurred on the Oder in July 1997 and the Elbe in August 2002.

Milly *et al* (Munk) undertook a pooled study of great floods with return periods > 100 yrs on very large rivers (with catchments greater than 200,0000km2) in Asia, North America, South America, Europe and Africa. For 29 basins with >30 years of historical record the ‘100-year flood’ was exceeded 21 times in the observational record of 2066 station years, with half the observations but 16 of the flood events occurring after 1953 (the probability under a constant occurrence rate is calculated to be 1.3%). For the smaller extratropical subset of basins 7 out of 8 flood events were in the second half of the record: a corresponding probability of 3.5% under random occurrence. Supplementary analyses for higher frequency flows up to 50-year return periods did not reveal significant trends, while the return periods of 200 year flows were found to have reduced even more than the 100 year flows. From the pooled record of all the rivers, the observed trend in the population of 100 year flood events, at a 95% confidence interval averaged across all basins, has been positive since the Mississippi Floods in 1993 and can be detected intermittently since 1972.

One specific region in which there is evidence for a change in flood occurrence over the last twenty years of the 20th Century is Scotland (Werrity 2002). Analysis of available longterm river flow records shows that since 1989 more than half of Scotland’s largest rivers (notably those draining from the west) have recorded their highest flows. Of 16 rivers surveyed – with a median record of 39 years, 8 had their maximum flow during 1989-1997: a period of exceptional North Atlantic Oscillation index values: consistent with a predominant storm track bringing precipitation to northern Britain.

1.3.8.2 Extratropical Cyclones

The Northeast Atlantic holds the record for deepest extratropical cyclone central pressure and highest measured accompanying windspeeds, as well as in countries of western Europe - the greatest windstorm impacts to buildings and forests. In terms of extratropical cyclone activity many researchers have identified an increase in the numbers of deep (and high wind speed) storms passing into Northwest Europe since 1980 (Günther, Rosenthal *et al*. 1998) returning to levels not previously seen since the late 19th century (Fig. 1.11b). Various measures, including the number of deep storms (with central pressures at nadir less than 970hPa) and the annual pressure minimum of storms crossing the Greenwich Meridian all show a significant increase in intensity, in particular between 1980 and 1993, when there were a series of major damaging and loss causing storms. In the Northeast Atlantic wave heights increased in the period from 1970-1995 (Woolf, Challenor *et al.*). This increase in storminess shows a strong correlation with the strength of the North Atlantic Oscillation index which reached its highest values ever in the years of 1989-1990. Intense storms returned at the end of the 1990s when there were three principal damaging storms across Western Europe in December 1999. However since that time, as winter NAO values have continued to fall (through to March 2005), there has been a significant decline in the number of deep and intense storms passing into Europe to some of the lowest levels seen for more than 30 years.

1.3.8.3 Tropical Cyclones

While overall numbers of tropical cyclones have shown little variation over the past forty years (Pielke, Landsea *et al.*), the basin with the highest volatility in tropical cyclone numbers is that of the Atlantic, for which the record is considered comprehensive back to 1945 (when hurricane hunter aircraft were first introduced). The number of years of high activity (8 or more) hurricanes in the Atlantic basin was four (out of 6 years) between 1950 and 1955, only four in total in the low activity phase between 1956 and 1994 but seven out of ten years between 1995 and 2004 (HURDAT, 2005). The most intense Cat3-5 storms have shown more variability than the overall population: with an average of 5 in the early 1950s, down to less than 2 in the 1960s to 1980s rising to an average of more than 4 since 2000. These shifts in hurricane activity are principally the consequence of a multi-decadal cycle of sea surface temperature variation in the tropical North Atlantic (Fig. 1.11c).

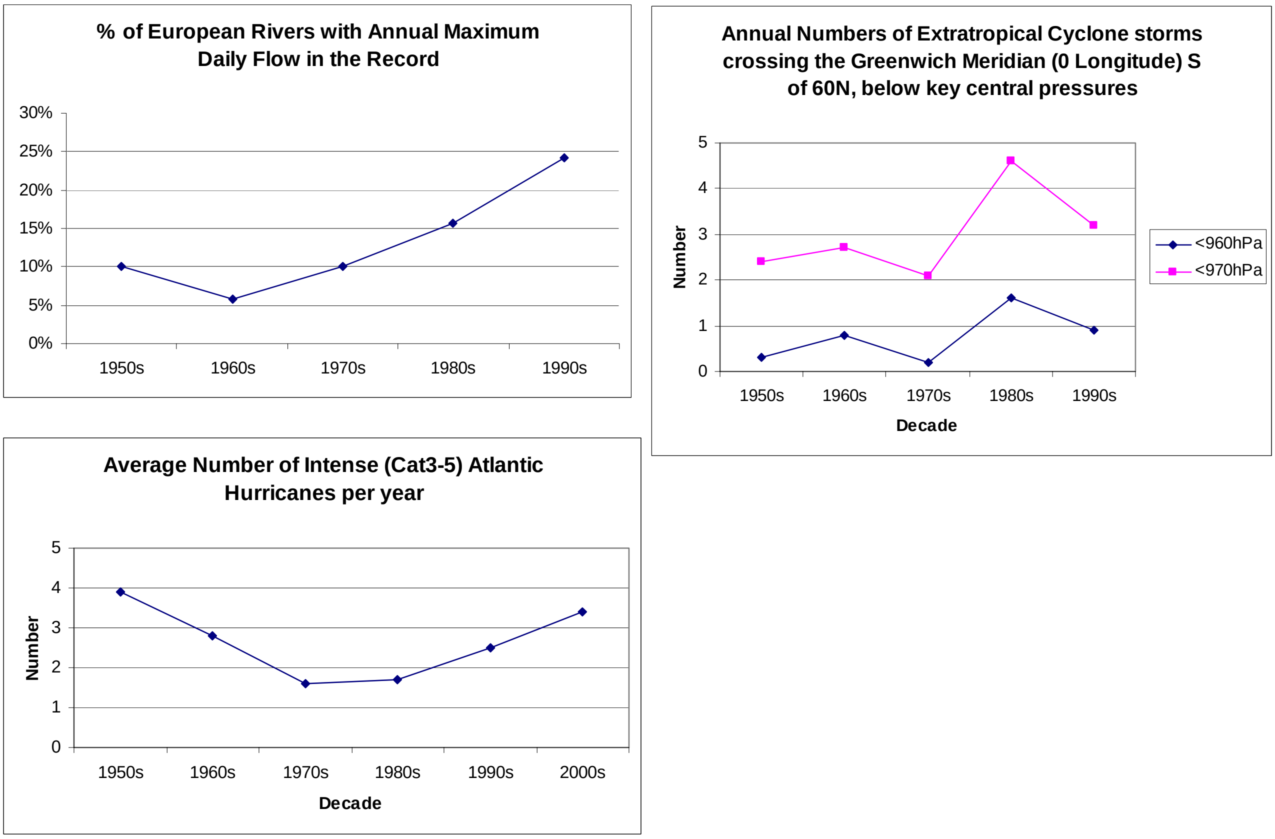

Fig. 1.11: *a) Percent of European rivers with annual maximum daily flow in the record; b) Annual numbers of extratropical cyclone storms crossing the Greenwich Meridian (0 longitude) S of 60N, below key central pressures; c) Average number of intense (Cat 3-5) Atlantic hurricanes per year. (Source: R. Muir-Wood).*

When considering the overall power dissipated by hurricanes (i.e., combining both intensity and duration) there is found to have been a strong correlation with the tropical sea surface temperatures in both the Atlantic and North West Pacific (the area of highest tropical cyclone activity) such that overall power released has effectively doubled over the past 30 years

(Emanuel 2005). This increase is significantly greater than had previously been anticipated on thermodynamic grounds based on the measured increases in sea-surface temperatures alone, and is ascribed by Emanuel as probably associated with climate change. However questions remain about how estimates of hurricane intensity prior to 1970 employed for calculating hurricane power (prior to 1970) might have been distorted by adjustments in contemporary wind speed estimates (Landsea 1993) or a failure to have captured the total track history of each storm.

The Emanuel study has however highlighted the role of duration as being as important as intensity in measuring hurricane impacts. Longer storm durations may have a greater impact where there are numerous islands, as in the Caribbean, where Hurricanes Georges in 1998 and Ivan in 2004 affected multiple territories at high intensity. However duration is less critical for hurricanes making continental landfall and for the US, in parallel with the increase in the number of intense hurricanes in the Atlantic, the proportion of these storms that make landfall at high (Cat3-5) intensity has decreased over the past 20 years from an average of around 25% (since 1950) to 15- 20%. The 2004 season remains a significant break with this pattern when there were 5 Cat3-5 hurricanes in the basin, 3 of which maintained this intensity at landfall in the US.

1.3.8.4 Economic and Insurance losses

Economic and insurance loss data condenses all the various damage agents and consequences of rapid onset meteorological catastrophes into the single numeraire of monetary loss. While global catastrophe losses appear to reveal exponentially increasing costs of catastrophes since the 1970s (IPCC TAR Chapter 8), issues around consistency and homogeneity make these datasets problematic for demonstrating global trends in long-term catastrophe occurrence.

Insurance losses filter catastrophe loss costs according to peril, so that even in most developed countries they do not include the majority of flood losses. The record of insurance loss is therefore weighted towards storm losses, principally in the US followed by Europe, Japan, the Caribbean and Australia. Furthermore, from one country and region to another, losses reflect widely different asset types, concentrations and values. Losses are strongly weighted towards the developed world, in particular for insurance costs: so that even if the population density is the same, the economic consequences from a tropical cyclone in the US may be x20, and the insurance losses x200 times those in India.

Going back in time, in particular prior to 1990, the record of economic losses becomes increasingly incomplete, both because countries in the Soviet bloc and China did not publicize the economic consequences of catastrophes, and also for many of the poorest countries, information about major floods or storms did not become disseminated. Finally, factors that affect loss inflation (and that therefore need to be corrected in order to normalize losses across different years) include: changes in values (the total of pre-existing properties, property improvements, and new builds), changes in exposure geography, including a shift to locations at higher risk (as to Florida where population increased by x6 since 1950), changes in the vulnerability of building materials and building contents, and changes in the attitude to making insurance claims and the prices charged for repairs (including new for old replacement costs).

For these reasons, it is difficult to employ information on cumulative global catastrophe losses from before the late 1980s. It is, however, possible to explore the evidence of trends for normalized (i.e., corrected for changes in exposure, vulnerability and all sources of inflation) losses from particular country peril-regions, in particular where, in the developed world, there is the best quality data. Overall, the temporal pattern of losses is fairly consistent with evidence from the hazards themselves.

There has been a notable increase in catastrophic flood losses in Europe since the 1980s associated with the summer floods of 1997 and 2002 as well as the Autumn floods of 2000. There is also evidence for an increase in European windstorm catastrophe losses in particular in 1990 and 1999, corresponding to the peaks of intense windstorm activity. (However windstorm catastrophe losses have been relatively subdued since 2000.) An increase in Atlantic hurricane activity since 1995, accompanied a rise in hurricane losses in the Caribbean and in 2004 higher activity in the basin, combined with a high rate of US landfalling, gave record US and Caribbean hurricane losses. The increasing disaster costs in the United States, as well as the rest of the world, are largely because of increasing societal vulnerability (Downton and Pielke 2005). However, in some areas, such as along the east coast of the United States, sea-level rise over the last century has exacerbated the damage to fixed structures from modern storms that would have been relatively minor a century ago (Zhang, Douglas *et al*.).

Once losses are normalized, no simple multi-decadal rising trend can be seen in tropical cyclone losses in other developed regions including Japan (where the highest normalized losses occurred at the end of the 1950s and beginning of the 1960s), and Australia where there has been no return to the high cyclone losses of the 1970s.

1.3.9 Socio-Economic Indicators

1.3.9.1 Energy

Buildings account for a significant part of total energy use, especially in developed countries (Lorch 1990), and the design and energy performance of buildings are related to climate (Steemers 2003). Work related to climate change and building energy use can be grouped into two major areas – weather data analysis and building energy consumption.

Weather data analysis
A study on the 1981-1995 weather data by Pretlove (1998) indicated that temperature and solar radiation in the London region (UK) had changed significantly over the period, and climatic data used for energy design calculations could lead to 17% inaccuracies in building energy-use estimates. Based on 1976-1995 temperature data from 3 key UK sites, Levermore (Levermore and Keeble 1998) found that the annual mean dry-bulb temperature had increased by about 1^{o}C over the 36-year period with milder winters and warmer summers. In subtropical Hong Kong, Lam (2004) analyzed the 40-year period (1961-2000) weather data and found an underlying trend of temperature rise, especially during the last 10 years (1991-2000). The increases occurred largely during the winter months and the impact on peak summer design conditions and cooling requirements, and hence energy use, was considered insignificant.

Building energy consumption
Energy use has been and will continue to be affected by climate change because space conditioning, a major energy end-user, is climate-dependent. However, the extent to which temperature rise has affected energy use for space heating/cooling in buildings is uncertain. It is likely that certain adaptation strategies (e.g. tighter building energy standard) have been (or would be) taken in response to climate change (e.g. Camilleri, Jaques *et al*. 2001; Larsson

2003; Sanders and Phillipson 2003; Shimoda 2003). Besides, in terms of thermal comfort, there is also the question of people adapting to warmer climates (e.g. de Dear 1998, Humphreys 1998, Nicol 2004).

1.3.9.2 Tourism

The climate of a destination is a major factor for tourists when choosing a destination (Aguiló, Alegre *et al*. 2005) and both tourists and tourism stakeholders are sensitive to fluctuations in the weather and climate (Wall 1998). Statistical analyses by Maddison (Maddison), Lise and Tol (Munk), and Hamilton (Nöthiger), and a simulation study by Hamilton (Nöthiger) have shown the relevance of climatic factors as determinants of tourist demand, next to economic and political conditions, fashion, media attention, and environmental quality. As a result of the complex nature of the interactions that exist between tourism, the climate system, the environment, and society, it is difficult to isolate the direct observed impacts of climate change upon tourism activity. There is also sparse literature upon this relationship at all scales.

1.4 Larger-scale aggregation and attribution

Larger-scale aggregation may offer insights into the attribution of the observed changes and responses. As described in Section 1.2.3.3, observed changes in systems and sectors are jointly attributed to anthropogenic climate change through a two-step process involving attribution of the responses to regional temperature changes and attribution of the regional temperature changes to increases in greenhouse gases and aerosols in the atmosphere. The first step – attribution of observed responses in systems and sectors to regional temperature changes – involves careful analysis of multiple lines of evidence to demonstrate that the observed changes are unlikely to be due entirely to internal climate variability; consistent with expected biophysical responses to a given climate change; and not consistent with alternative, plausible explanations of recent change (e.g., due to land use change, pollution, urbanization, progress in technology, and economy-driven changes). The second step – attribution of the regional temperature changes to increases in greenhouse gases and aerosols in the atmosphere – involves analysis of observed regional warming trends to determine if they are statistically significant and determining if the warming trends are consistent with the response to increasing greenhouse gases and sulphate aerosols and cannot be explained by internal climate variations.

1.4.1 Review of meta-analyses

Several studies have examined the 'fingerprint' of observed warming in recent decades on plants and animal species using meta-analyses (Root, Price *et al*.), (Parmesan and Yohe), (Menzel 2005). Root (Root, MacMynowski *et al*.) used 143 studies in their meta-analyses and found a consistent temperature-related shift in species ranging from molluscs to mammals and from grasses to trees. More than 80% of the species that showed changes were shifting in the direction expected on the basis of known physiological constraints of species. They concluded that a significant impact of global warming is already discernible in animal and plant populations.

Parmesan (Nöthiger)applied meta-analysis techniques to more than 1700 species, and showed that recent biological trends matched climate change predictions. Global meta-analyses documented advancement of spring events by 2.3 days per decade. They also defined a diagnostic fingerprint of temporal and spatial 'sign-switching' responses uniquely predicted by twentieth century climate trends. Among appropriate long-term/large-scale/multi-species data sets, this diagnostic fingerprint was found for 279 species. They concluded, with 'very high confidence' as defined by the IPCC that climate change is already affecting living systems.

The EU COST725 meta-analysis project systematically analysed plant phenological trends for European networks spanning 21 countries. More than 125 000 observational series of various growth stages in 542 plant species were systematically (re-)analysed for trends (1971-2000) in order to track and quantify the phenological response to changing climate. This exhaustive meta-analysis of nationally reported trends verifies numerous single-site or species studies, (with possible reporting bias), and intensively examines possible lack of evidence. Analysis of 254 mean annual national series demonstrated that species' phenology was responsive to temperature of the preceding month and differed by mean date and among phenophases. Spring and summer phases advanced on average by 2.5 days/°C, leaf colouring and fall was delayed by 1.0 day/°C. The systematic summary of more than 100 000 trends revealed that 78% of all leafing, flowering and fruiting records advanced (30 % significantly), and only 3% were significantly delayed. The signal of leaf colouring/fall was ambiguous. Averaged across European countries, leafing, flowering and fruiting phases advanced by ~ 2 days/decade, for all spring and summer trends, dominated by Central European records, for which the advance was 2.5 days/decade. The pattern of observed phenological change was consistent with measured temperature change across Europe. Nineteen country averages of observed leafing and flowering trends were very strongly related to temperature change of the previous month ($r=-0.69$, $p<0.001$), thus the phenology quantitatively mirrors climate warming.

A recent meta-analysis of bird arrival dates (Lehikoinen, Sparks *et al*.) showed strong evidence of earlier arrival. Of 983 data series, 39% were significantly earlier and only 2% significantly later for first arrival dates.

1.4.2 Synthesis of sectors and systems

Documented evidence of observed changes in systems and sectors in response to observed regional climate changes has increased since the TAR The TAR cited 16 studies documenting cryosphere and hydrology changes and 44 studies documenting changes in biological systems (60 studies in total). The AR4 cites 13 studies of cryosphere changes, 22 studies of hydrology and water resources, 30 studies of coastal processes and zones, 37 studies of marine and freshwater biological systems, 156 studies of terrestrial biological systems, and 32 studies in agricultural and forestry systems (258 studies in total). (Numbers of studies to be updated in the SOD).

Figure 1.12 shows the categories and geographic locations of observed changes documented since the TAR, as well as those documented by the TAR. These are overlayed with the temperature changes from 1973-2002 with regions with significant temperature trends delineated. The climate data used in the analysis is from (a) 5x5 degree dataset from Hadley Centre and NOAA. Monthly temperature and precipitation, and (b) GCOS (Global Climate Observing System) station data (from stations designated as high quality).

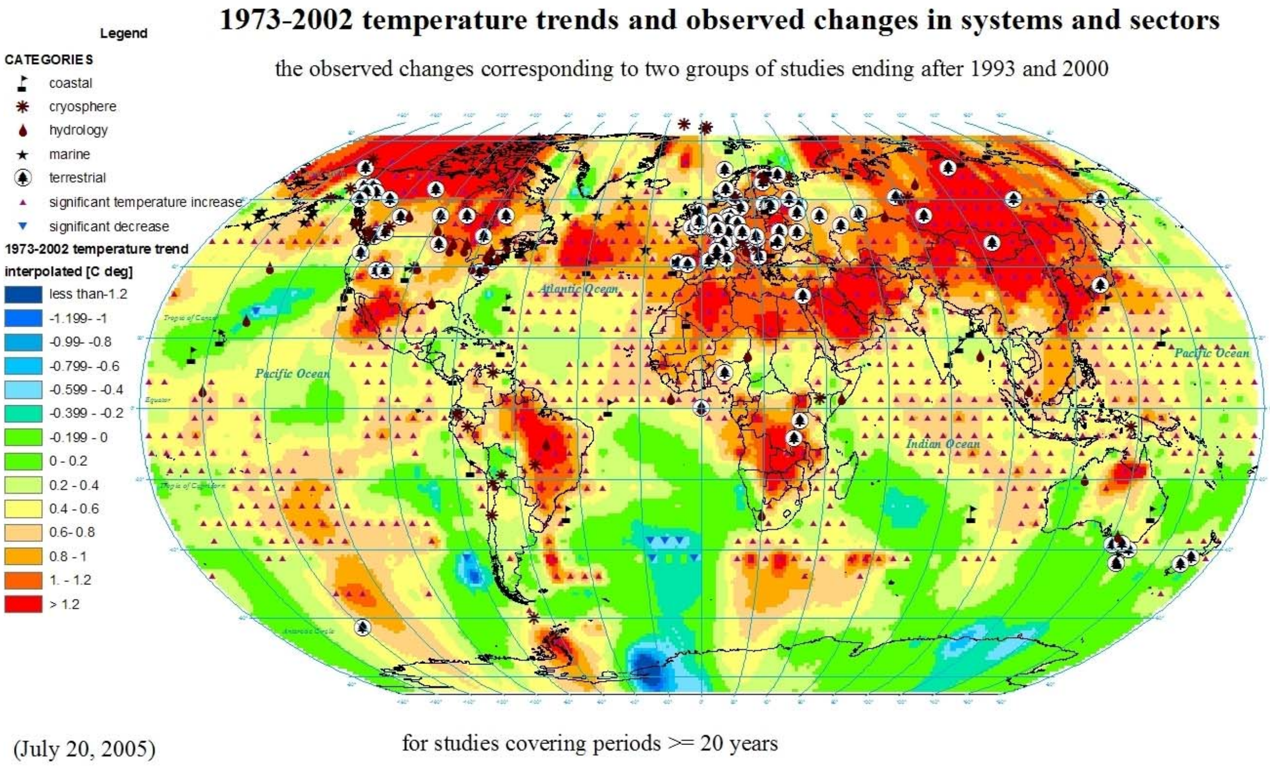

Figure 1.12: *Observed trends in surface air temperature over the period 1973-2002 (Karoly and Wu, 2005). Individual 5^o latitude-longitude regions are indicated where the observed trends are significantly larger than zero at the 95% level White regions do not have sufficient observational climate data to estimate a trend. Observed changes documented in IPCC TAR and since TAR in cryosphere, hydrology, coastal zones, marine and freshwater biological systems, and terrestrial biological systems for studies ending in 1993 or later with at least 20 years of data. (Observed changes data are preliminary and will be updated in the SOD.)*

Observed changes documented in the IPCC TAR and since the TAR are divided into the categories of cryosphere, hydrology, coastal zones, marine and freshwater biological systems, and terrestrial biological systems, as assessed in this chapter. Studies are selected ending in 1993 or later with at least 20 years of data. Studies previous to 2001 are re-analysed with the criteria of this new assessment to be able to compare with the new observations. For each observation in the studies, the change is characterized as ‘change in expected direction,’ ‘no change,’ and ‘’change in unexpected direction.’ Significance of change is also included. The assessment also enables examination of areas that have a significant change in temperature, but observation of change in systems or sectors.

Using information from the map, Table 1.14 shows the presence/absence of regional temperature changes and presence/absence of observed responses. There are nearly 500 5^o grid boxes that are experiencing significant warming for which there are no observations of changes in systems or sectors. For regions where there are both significant warming and observed changes, there is a greater probability of finding coincident significant temperature change and observed responses in the expected direction than finding significant temperature change and no response or response in an unexpected direction. In regions with no change in temperature, there is a greater probability of finding no observed response than of finding an observed response in either direction.

Table 1.14: *Presence/absence of regional temperature changes and presence/absence of observed responses. 'Change in expected direction' is defined as a process-based change related to temperature trend, either warming or cooling. Included studies are published in 1993 or later with 20 years or more of records. Studies in the TAR are included. (Observed changes data are preliminary and will be updated in the Second-Order Draft).*

	OBSERVED CHANGES IN SYSTEMS AND SECTORS				
	for studies lasting more than 20 years and ending after 1993				
	Change in expected direction (417)*	Observation with no change (26)*	Change in unexpected direction (8)*	Temperature cells containing no observations (**)	Total number of temperature cells (**)
Positive Significant Change in Temperature (total = 758)**	291.00	7.00	8.00	452.00	758.00
Insignificant Positive Change in Temperature (total = 779)**	82.00	16.00	0.00	681.00	779.00
0 C deg temperature change	10	0	0	237	247
Insignificant Negative Change in Temperature (total = 139)**	4.00	1.00	0.00	134.00	139.00
Negative Significant Change in Temperature (total = 9)**	0.00	0.00	0.00	9.00	9.00
	Total number of observations in cells with available temperature data (**)			Total	Total
	387.00	24.00	8.00	1513.00	1932.00

(*) indicates number of observations
(**) indicates number of temperature cells

Evidence of observed changes appear in every continent, including Antarctica. The majority of studies provide evidence of observed changes in Northern latitudes and high altitudes, and high latitude waters. Evidence in tropical regions is still sparse.

1.4.3 Assessing the relation of observed regional climate changes to anthropogenic causes

Since the TAR, it has been shown that an anthropogenic climate change signal is detectable in continental-scale regions using surface temperature changes over the 20th century (Karoly 2003, Stott 2003, Zwiers 2003; Karoly 2005) (See WGI, Chapter 9 for a more complete assessment of attribution of observed regional climate changes to anthropogenic forcing). Most of the observed warming over the last 50 years in the six major continents, including North America, Eurasia and Australia, is likely to be due to the increase in greenhouse gases in the atmosphere (Stott 2003). Many features of the observed temperature variability and change on decadal time scales in different regions are reproduced by the HadCM3 model including changes in anthropogenic forcing (see Fig. 9.4.7 in volume 1, reproduced from IDAG, 2005). Recently, it has been shown that observed regional warming trends over the last 50 and 30 years are statistically significant in most regions of the globe, even for regions of order 500 km (Karoly 2005, as shown in Fig. 1.12). These warming trends are consistent with the response to increasing greenhouse gases and sulphate aerosols and cannot be explained by internal climate variations.

The influence of anthropogenic forcing has also been detected in other recent climate changes, including increases in global oceanic heat content, increases in sea level, shrinking of alpine glaciers, reductions in Arctic sea ice extent, and reductions in spring snow cover, as described in WGI, Chapter 9, Section 9.5.

1.4.4 Joint attribution

Joint attribution involves a two-step linkage: discernible changes in regional traits are associated with temperature changes (i.e., detection), and that a significant amount of the change in temperature is due to human activities (i.e., attribution). To date, two studies have demonstrated joint attribution; one using forest fires as the regional trait (Gillet *et al*. 2004), and the other using wild plants and animals (Root *et al*. 2005).

Gillet and co-authors demonstrate a striking increase in the area of forests burned in Canada over the last four decades. Temperature, which has increased noticeably, is known to be a good predictor of forested area burned (Flannigan and Harrington 1988 A study of the relation of meteorological variables to monthly provincial area burned by wildfire in Canada (1953-1980) *J. Appl. Meteorol.* 27: 441-452). Using GCMs, Gillet and colleagues find that human have made a discernible contribution to the increased temperatures, which is outside the range of natural variability. They then show that the partly human-induced warming has had a detectable influence on the amount of forest area burns.

Root and colleagues (2005) demonstrate joint attribution when looking at changes in wild animal and plants. A significant portion of the changing in the timing of spring events in wild plant and animals (e.g., flowers blooming or animals migrating) seen empirically at the local and more regional scales can be directly attributed to temperature increases at the same scales. Using modelled temperature data from the HadCM3 global GCM they found a significant portion of the increased temperature to which the wild species are responding is attributable to the actions of humans. This is true for a wide variety of species (e.g., grasses to trees and insects to mammals) at local and regional scales for numerous locations around the northern hemisphere—where data are most readily available.

Using 145 species reported in 29 studies Root and colleagues calculated the mean annual phenological change for species in the Northern Hemisphere (Figure 1.13), which is approximately 3 days earlier per decade from 1969 to 1999 for all species, around 5 days for all birds and 2 days for herbaceous plants.

The mean annual phenological changes for the different species were compared to modelled temperature data obtained from the HadCM3 GCM using three temperature forcings: natural only, anthropogenic only, and combined natural and anthropogenic. The association is quite poor between the phenological changes in species and modelled temperatures derived using only natural climatic forcing (Figure 1.13 B). Quite strong agreement occurs, however, between the same phenological changes in species and temperatures modelled either using only anthropogenic forcing or using both natural and anthropogenic forcings together (Figure 1.13 C &D). Studies comparing anthropogenically forced models to empirical data in the oceans (Barnett 2004) and for planetary radiation balance (Hansen and Nazarenko) reach similar conclusions using very different data sets and models: that there is discernible skill in models driven by anthropogenic forcing (see Chapter 9 of Working Group 1).

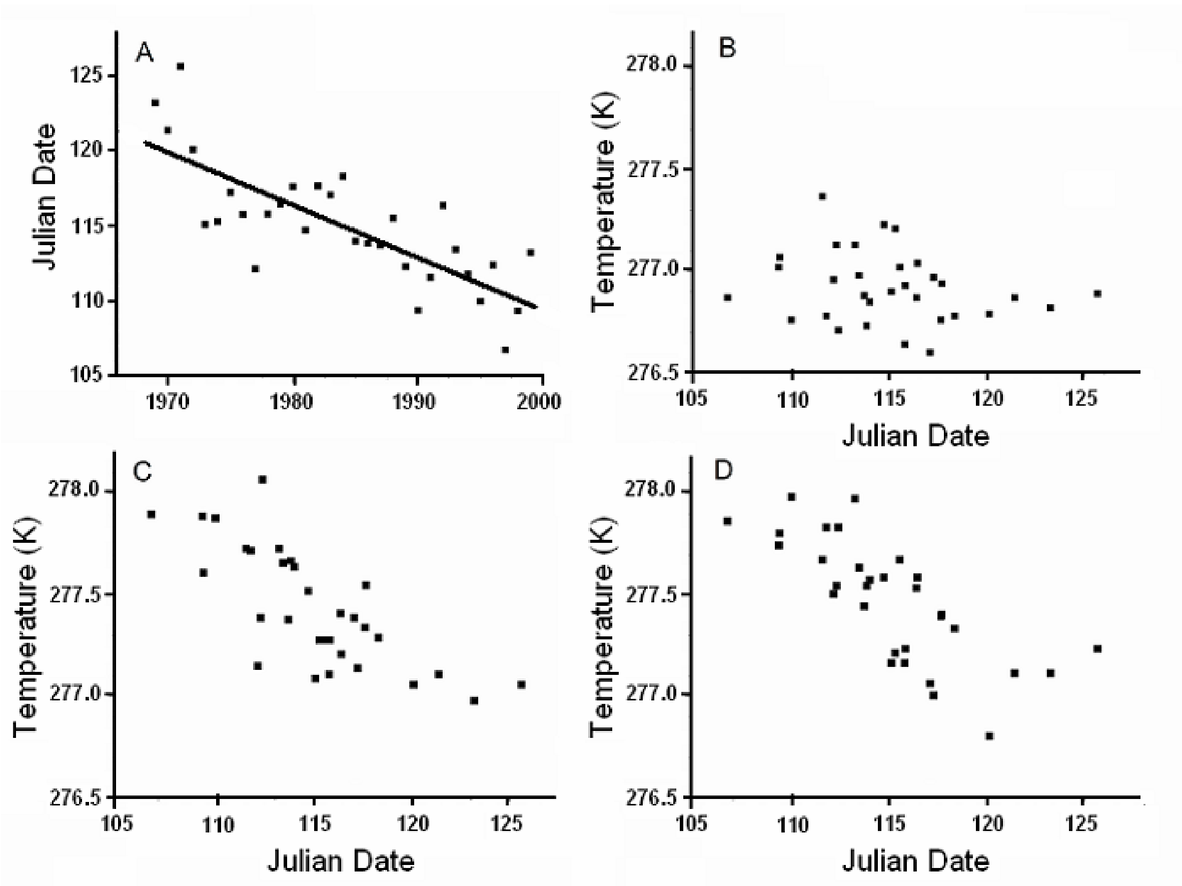

Figure 1.13: *For each year, the occurrence dates (Julian) of spring phenological traits are averaged over all Northern Hemisphere species exhibiting statistically significant changes in those traits (n=130). These averages are plotted against: A. year with a -3.2 day change per decade, B. the average modelled spring (March, April, May) temperatures including only natural forcings at each study location ($r = 0.22$, $p<0.23$), C. the same as B except including only anthropogenic forcings ($r = -0.71$, $p<0.001$), and D. the same as B except including both natural and anthropogenic forcings ($r = -0.72$, $p< 0.001$). Source Root et al, 2005.*

In summary, Root and colleagues consistently found: 1. Including anthropogenic forcings in the modelled temperatures result in the strong association with species phenological changes. This is true when combined with natural forcings or not. 2.The unambiguous detection and attribution of anthropogenically-forced climatic signals in the plant and animal record is a strong validation that HadCM3 GCM has discernible predictive ability across local and regional scales.

1.4.5 Relation to large-scale climate variability patterns

While Root and co-authors study addresses whether or not there is a strong consistent pattern evident around the Northern Hemisphere, individual studies provide additional insights into how organisms interact with the abiotic environment over multiple spatio-temporal scales. For instance, long-distance migratory birds can be affected by weather events on the migration route as well as conditions on the wintering and breeding grounds. Plants also respond to climatic conditions over multiple scales: Post (2003) has demonstrated the synchronization of flowering phenology of three species in Norway by the Arctic Oscillation while other researchers have shown the influence of snow depth upon species distribution (Shimizu, Ikegame *et al*. 2002). Thus, plants and animals can be vulnerable to shifts in weather and climate both locally and regionally.

The North Atlantic Oscillation (NAO) has widespread influence on manifold ecological processes. A comprehensive, long-term European plant phenological dataset (1879- 1998), including in total 23797 stations of (1) the historical first European Phenological Network (1882-1941), (2) the network of the International Phenological Gardens in Europe (1959-1998), and (3) network data of seven Central and Eastern European countries (1951-1998, EU FP5 project POSITIVE), was analysed to study the influence of NAO of the progression (direction, velocity) of nine phenological seasons across Europe (Menzel *et al*. 2005). Phenological phases in most of the area studied responded to higher NAO indices by earlier spring leaf unfolding and flowering, the correlation coefficients between mean onset and NAO ranged up to 0.8 (Fig 1.14, lower plate right). This did not necessarily implicate a high relevance of the NAO index in all regions in Europe. Differences in onset between the average NAO high and average NAO low years were more pronounced in the western (France, Ireland, UK) and north-western (south Scandinavia) parts of Europe and less distinct in the continental part of Europe (lower left panel). The two different patterns of progression are clearly evident SW-NE in years with high NAO index and S-N in years with low NAO index.

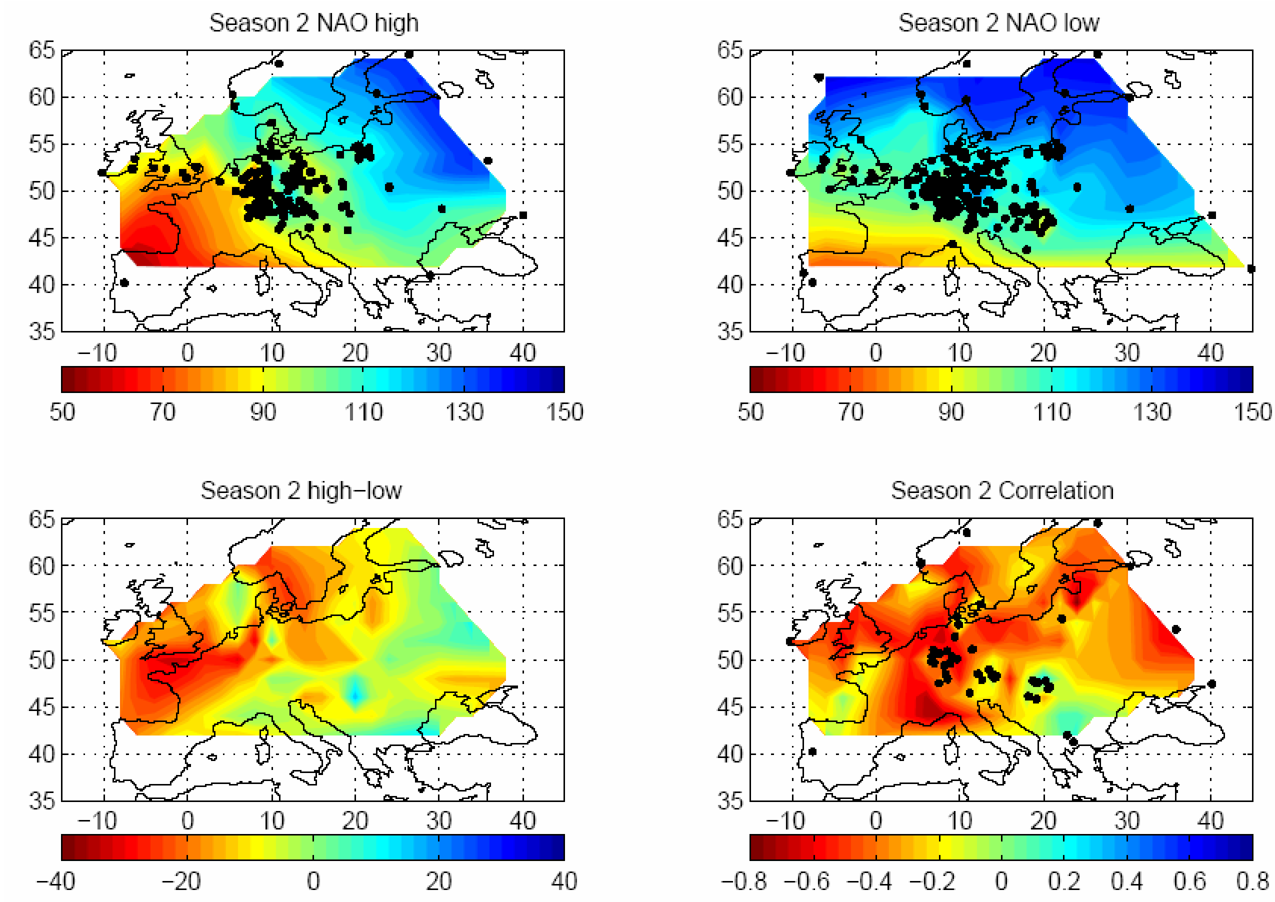

Figure 1.14: *Upper two plates: The mean onset of season 2 (mid spring, day of the year) in Europe for the 10 years with the highest (1990, 1882, 1928, 1903, 1993, 1910, 1880, 1997, 1989, 1992, North Atlantic Oscillation (NAO) high) and the ten years with the lowest (1969, 1936, 1900, 1996, 1960, 1932, 1886, 1924, 1941, 1895, NAO low) NAO winter and spring index (Nov – Mar) in 1879-1998; Lower plate left: differences between the mean onset of season 2 (days) in Europe in NAO high and low years (upper two plates); Lower plate right: correlation coefficient between the yearly onset of season 2 and NAO index (1897-1998). The vertical and horizontal axes represent degrees of latitude and longitude respectively (Menzel 2005).*

Various other studies have found connections between local ecological observations and weather/climate patterns at larger spatial scales, particularly with meso-scale climate phenomena indicated by indices of the North Atlantic Oscillation (NAO), El Nino-Southern Oscillation (ENSO), and Pacific Decadal Oscillation. Impacts have been demonstrated across diverse taxa (birds, mammals, fish). NAO has been associated with the synchronization of population dynamics of caribou and musk oxen (Post and Forchhammer 2002). Weladji and Holand (2003) identified risks to northern indigenous peoples due to the negative impacts of higher NAO indices upon reindeer calf survival. Three recent studies identified the impacts of NAO on fish, including abundance (Guisande, Vergara *et al*. 2004), phenology (Sims, Wearmouth *et al*. 2004), and range shifts (Dulcic, Grbec *et al*. 2004). A meta-analysis of ecological studies of NAO interactions found a clear NAO signature in freshwater, marine, and terrestrial ecosystems (Blenckner and Hillebrand 2002).

Bird populations and migratory timing have received particular attention. Huppop and Huppop (2003) find significantly earlier arrival of 17 species of migratory birds in Helgoland. For 23 of the 24 species studied, earlier arrival coincided with warmer local temperatures and correlation with higher NAO indices. Similarly, in the Czech Republic, Hubalek (2003) found that the earlier arrival of short-distance migrants correlated with positive winter/spring NAO index values. Pied flycatchers across Europe are breeding earlier and laying smaller clutches; these changes are correlated with increased spring temperatures and positive values of the winter NAO index (Sanz 2003). With the exception of Ballard and co-authors' (2003) study of population declines of songbirds in western North America, other recent avian studies have strongly linked NAO and/or ENSO to demographic dynamics, but do not attribute climate patterns to population trends (Sydeman, Hester *et al*. 2001; Jones, Hunter *et al*. 2002; Almaraz and Amat 2004).

1.4.6 Uncertainties and confidence levels

Uncertainties in observed change studies at the regional level relate to potential mismatches between climate and system/sector data in temporal and spatial scales and lack of time-series of sufficient length to determine if the changes are outside normal ranges of variability and if changes follow process-level understanding during periods of, e.g., climate warming and cooling. Non-stationarity of relationships between system/sector responses and climate is also a concern.

The issue of non-climate driving forces is also important. Tectonic activity, land use change, changes in human management practices, pollution, and demography shifts are all, along with climate, drivers of environmental change. More explicit consideration of these factors in observed change studies will strengthen the robustness of conclusions.

Since systems and sectors respond to an integrated climate signal, precise assignment of the proportions of natural and anthropogenic forcings in their responses is not possible. Through the use of combined observational and simulation studies, observed changes may be used to test the presence of the anthropogenic signal. Because of the wide variety of observed responses to regional climate trends in expected directions, and because the regional climate trends have been attributed to anthropogenic causes, anthropogenic climate change is seen to be having an impact on multiple systems and sectors.

1.4.7 Learning from current and recent observed responses and adaptation

Assessment of observed changes reveals information about adaptation in the areas of physical, biological, and human systems. (See Chapter 17.)

1.4.7.1 Physical

Adaptive strategies in water-resource management already underway in many countries include improving land-use and water-resources planning, floodplain use and building codes, and conducting public-awareness campaigns to highlight the value of the rivers and wetlands as buffers against increasing climate variability. Interbasin diversions in some regions of the world, particularly in California, Latin America and China have been created to mitigate increasing water stress caused by climate and non-climate factors (Cosgrove, Connor *et al*. 2004).

Adaptation measures for coastal erosion include sea defences, which are often limited by cost considerations, and retreat, which given limited land area, is often not feasible (Singh and Fouladi 2003). Adaptations to coastal erosion have been documented in Mimura and Nunn (Mimura and Nunn 1998), Barnett (Barnett 2001), Yoshikura (Yoshikura 2000). The number of port-related disasters has been decreasing as the protective measures are developed, although costs of adaptation are high.

1.4.7.2 Biological

High rates of gene flow or connectivity promote coral reef resilience following bleaching events. Gene flow in corals varies among species, and is generally lower than other reef organisms (e.g., most fish, molluscs, echinoderms). Consequently, the species composition of “recovering” assemblages changes in favour of species with high fecundity and high rates of migration.

Evidence of terrestrial ecosystem adaptation is found in the change of migration routes and overwintering areas by birds and perhaps also different response rates in different time periods. There is no evidence so far that temperature response rates of plants have changed over the last century, however, earlier plant spring phenology is associated with higher spatial variability (Menzel 2005; Menzel and Dose 2005).

In agriculture, little is known about the timescales on which field-scale climate-related changes propagate to farm and regional levels. A further complicating issue is the precise nature and role of human adaptation in the agriculture and forestry sectors, since many of the responses to climate will be adjustments in management practices. To date, there is little documented evidence of adaptation to regional climate trends in agriculture and forestry, with only a few studies related to the shift of sowing dates of annual crops. There is even less evidence related to food supply.

1.4.7.3 Human

The ACIA report (2004) presents evidence of adaptation and vulnerability in the Arctic regions. The deep empirical knowledge held by native cultures has fostered mechanisms to adapt to changes in past environments. Resiliency to future changes is dependent on assuring that native stakeholders remain involved in decision-making so that their understanding of the processes controlling long-term dynamics can be incorporated into policy (Chapin 2004).

Adaptation likely plays a role in disasters and hazards, where changes in insurance premiums may also be an adaptive response to changes in climate (Mills). However, since inflation, population growth, changing demographic distribution, changes in per capita real wealth, as well as other factors play a role in damages, characterizing the role of climate alone, if any, in human responses to disasters and hazards is especially complex. One approach to test if adaptation to climate change is occurring is to analyze damages related to climate-related and non-climate-related events separately to see if they experiencing similar or different trends. However, since the principal non-climatic hazards are geological (e.g., volcanoes, earthquakes, and tsunamis), where the return period between events tends to be much longer than that for hydro-meteorological hazard events (which also tend to be more locally manifested), such approaches need to ensure that large and less-frequent events do not distort the findings.

It is likely that certain building adaptation strategies (e.g., tighter building energy standards) have been (or would be) taken in response to climate change (e.g. Camilleri, Jaques *et al*. 2001; Larsson 2003; Sanders and Phillipson 2003; Shimoda 2003). Besides, in terms of thermal comfort, there is also the question of people physiologically or culturally adapting to warmer climates e.g. de Dear, 1998, adaptive model; Humphreys, 1998, Understanding the adaptive approach; Nicol, 2004, Adaptive thermal comfort.

1.4.8 Relative sensitivity, responses (resilience) and adaptive capacity of different systems

Observed changes within certain systems and sectors – cryosphere, marine biological systems, and terrestrial biological systems – are exhibiting greater sensitivity to observed temperature changes than others. For many systems, there is a larger response for a larger observed temperature change. These systems appear most vulnerable. However, lag responses and adaptation also need to be considered in evaluating observations related to temperature increases.

In regard to coral reefs, isolated locations are more vulnerable to impacts of bleaching because they are normally self-seeded. If local brood stocks die, recruitment from elsewhere may be too low to support a full recovery. Currently, low-diversity isolated regions are not a conservation priority (e.g. compared to biodiversity hotspots), yet they are likely to be more vulnerable to climate change.

For agriculture, evidence of observed effects (changes in planting or shifts in distribution) studies have focussed on crops in developed countries, and not on effects in relation to subsistence agriculture in rural populations in low and middle income countries.

Developing countries appear to be more vulnerable to observed changes in regard to water resources, coastal zones, and health, because of their geographical and climatic conditions, high dependence on natural resources, lack of water infrastructure, and often constrained financial and technological capacity to adapt to changing climate (Kashyap 2004), (Barnett 2001).

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