Topic 1 – Observed changes in climate and its effects
(15 May 2007)

1.1 Observations of climate change

Since the Third Assessment Report, improvements and extensions of numerous datasets and data analyses, broader geographical coverage, better understanding of uncertainties, and a wider variety of measurements have confirmed that the climate system is warming and provided evidence of other, more regional climate changes including precipitation trends over some large regions. {WGI SPM}

BOX 1.1: Climate change

Climate change in IPCC usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the Framework Convention on Climate Change, where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level (Figure 1.1). {WGI 3.2, 4.2, 5.5, SPM}

Eleven of the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). Global mean surface temperature has increased with a linear trend of 0.74 [0.56 to 0.92]°C[1] over the last 100 years (1906-2005) (Figure 1.1), larger than the corresponding trend for 1901-2000 given in the Third Assessment Report of 0.6 [0.4 to 0.8]°C. The linear rate of warming over the last 50 years (0.13 [0.10 to 0.16]°C per decade) is nearly twice that for the last 100 years. {WGI 3.2, SPM}

The warming is widespread over the globe, and is a maximum at higher northern latitudes. Warming has occurred in both land and sea domains, although land regions have warmed at a faster rate than the oceans. Land temperatures have warmed at about 0.25ºC per decade since 1979, with the greatest warming in winter and spring in the Northern Hemisphere. Global ocean heat content increased over 1961-2003, and the ocean is taking up over 80% of the heat being added to the climate system. New analyses of balloon-borne and satellite measurements of lower- and mid-tropospheric temperature show warming rates similar to the surface temperature, largely reconciling a discrepancy noted in previous assessments. {WGI 3.2, 3.4, 5.2, 5.5, SPM}

[1] Numbers in square brackets indicate a 90% uncertainty interval around a best estimate, i.e., there is an estimated 5% likelihood that the value could be above the range given in square brackets and 5% likelihood that the value could be below that range. Assessed uncertainty intervals are not always symmetric about the corresponding best estimate.

Observed decreases in snow and ice are consistent with warming (Figure 1.1). Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7 [2.1 to 3.3]% per decade, with larger decreases in summer of 7.4 [5.0 to 9.8]% per decade. Mountain glaciers and snow cover have declined on average in both hemispheres. The maximum area covered by seasonally frozen ground has decreased by about 7% in the Northern Hemisphere since 1900, with a decrease in spring of up to 15%. Average Arctic temperatures have increased at almost twice the global average rate in the past 100 years. Temperatures at the top of the permafrost layer have generally increased since the 1980s in the Arctic (by up to 3°C). {WGI 3.2, 4.6, 4.7, 4.8, 5.5, SPM}

Increases in sea level also are consistent with warming (Figure 1.1). Global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm per year over 1961 to 2003 and at an average rate of about 3.1 [2.4 to 3.8] mm per year from 1993 to 2003. Since 1993 thermal expansion of the oceans has contributed over half of the observed sea level rise, with decreases in glaciers and ice-caps contributing about a quarter. The Greenland and Antarctic ice sheets each have made a similar contribution of 0.21 mm per year, but there is a relatively larger uncertainty for the Antarctic ice sheet contribution. {WGI 4.6, 4.8, 5.5}

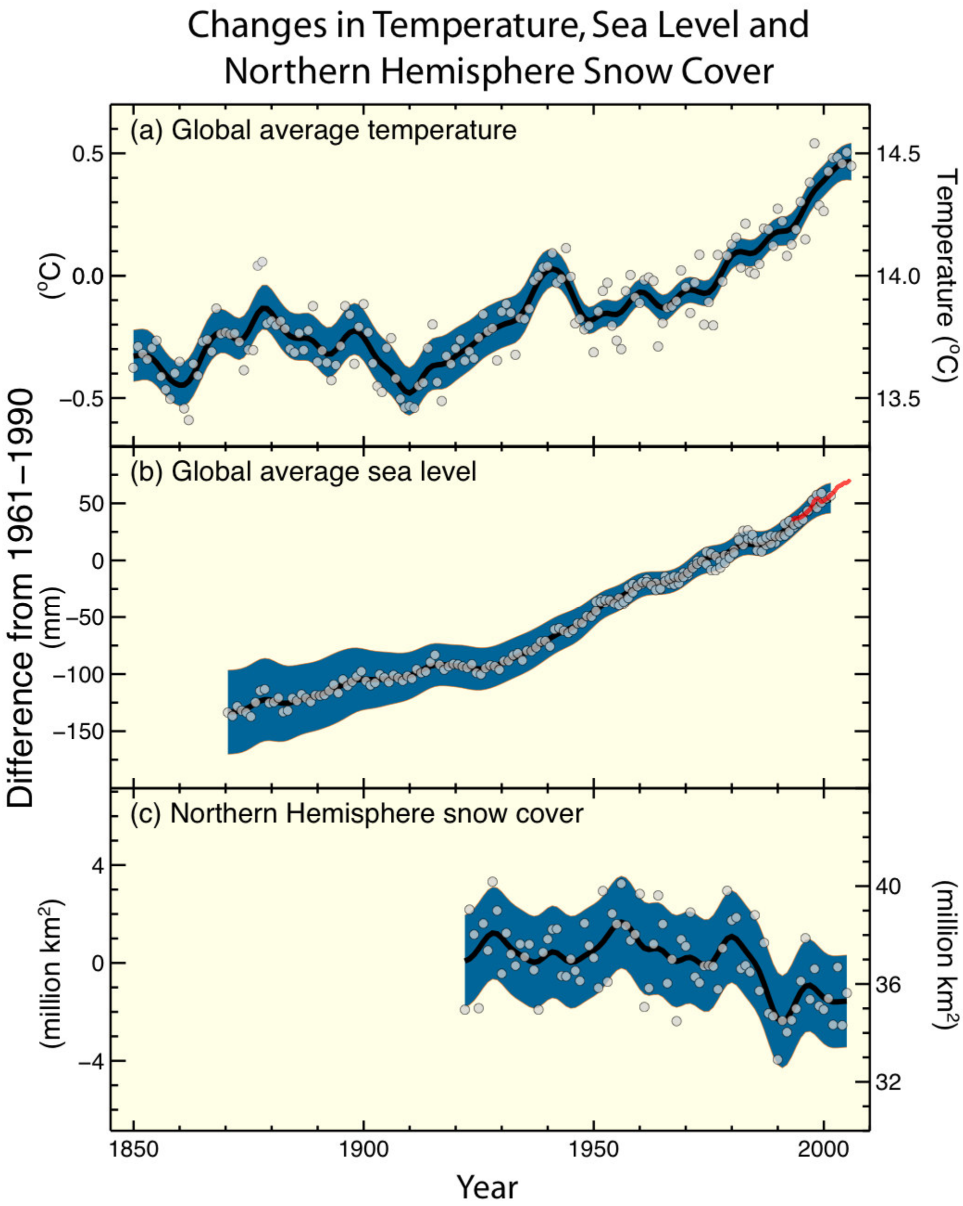

Figure 1.1. Observed changes in (a) global average surface temperature; (b) global average sea level rise from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All changes are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c). {WGI FAQ 3.1 Figure 1, Figure 4.2 and Figure 5.13, Figure SPM-3}

Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* higher than during any other 50-year period in the last 500 years and *likely* the highest in at least the past 1300 years. In earlier times, paleoclimate evidence indicates that global average sea level in the last interglacial period (about 125,000 years ago) was *likely* 4 to 6 m higher than during the 20th century, mainly due to the retreat of polar ice. Ice core data indicate that average polar temperatures at that time were 3 to 5°C higher than present, because of differences in the Earth's orbit. The Greenland ice sheet and other Arctic ice fields *likely* contributed no more than 4 m of the inferred sea level rise. There may also have been a contribution from Antarctica. {WGI 6.4, 6.6, SPM}

At continental, regional, and ocean basin scales, numerous long-term changes in other aspects of climate have also been observed. Long-term trends from 1900 to 2005 have been observed in precipitation amount in many large regions, with increased precipitation in eastern parts of North and South America, northern Europe and northern and central Asia whereas precipitation declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics. Increased drying due to higher temperatures as well as decreased precipitation has contributed to this change. {WGI 3.3, 3.9, SPM}

Some extreme weather events have changed in frequency or intensity:

- It is *very likely* that cold days, cold nights and frost have become less frequent, while hot days, hot nights, and heat waves have become more frequent {WGI 3.8, SPM}
- Mid-latitude westerly winds have strengthened in both hemispheres since the 1960s {WGI 3.5, SPM}
- The frequency of heavy precipitation events *likely* has increased {WGI 3.8, 3.9}
- The incidence of extreme high sea level *likely* has increased at a broad range of sites worldwide since 1975 {WGI 5.5, SPM}
- A 1976-1977 climate shift toward more El Niño events affected many areas, including most tropical monsoons. {WGI 3.6}

There is evidence for an increase of intense tropical cyclone activity in the North Atlantic since about 1970, and suggestions of increased intense tropical cyclone activity in some other regions where concerns over data quality are greater. Multi-decadal variability and the quality of the tropical cyclone records prior to routine satellite observations in about 1970 complicate the detection of long-term trends in tropical cyclone activity. {WGI 3.8, SPM}

1.2 Observed effects of climate changes

The statements presented here are based largely on data sets that cover the period since 1970. The number of studies of observed trends in the physical and biological environment and their relationship to regional climate changes has increased greatly since the Third Assessment in 2001. The quality of the data sets has also improved. {WGII SPM}

These studies have allowed a broader and more confident assessment of the relationship between observed warming and impacts than was made in the Third Assessment. That Assessment concluded that “there was *high confidence* that recent regional changes in temperature have had discernible impacts on physical and biological systems”. {WGII SPM}

Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases. {WGII SPM}

There is *high confidence* that natural systems related to snow, ice and frozen ground (including permafrost) are affected. Examples are:

- enlargement and increased numbers of glacial lakes {WGII 1.3}

- increasing ground instability in permafrost regions, and rock avalanches in mountain regions {WGII 1.3}
- changes in some Arctic and Antarctic flora and fauna, including those in sea-ice biomes, and predators high in the food chain. {WGII 1.2, 4.4, 15.4}

There is *high confidence* that the following types of hydrological systems are being affected around the world: increased run-off and earlier spring peak discharge in many glacier- and snow-fed rivers; and warming of lakes and rivers in many regions, with effects on thermal structure and water quality. {WGII 1.3, 15.2}

There is *very high confidence*, based on more evidence from a wider range of species, that recent warming is strongly affecting terrestrial biological systems**,** including such changes as: earlier timing of spring events, such as leaf-unfolding, bird migration and egg-laying; and poleward and upward shifts in ranges in plant and animal species. Based on satellite observations since the early 1980s, there is *high confidence* that there has been a trend in many regions towards earlier 'greening' of vegetation in the spring linked to longer thermal growing seasons due to recent warming. {WGII 1.3, 8.2, 14.2}

There is *high confidence*, based on substantial new evidence, that observed changes in marine and freshwater biological systems are associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels, and circulation. These include: shifts in ranges and changes in algal, plankton and fish abundance in high-latitude oceans; increases in algal and zooplankton abundance in high-latitude and high-altitude lakes; and range changes and earlier fish migrations in rivers. {WGII 1.3}

Other effects of regional climate changes on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers. {WGII SPM}

Effects of temperature increases have been documented in the following systems (*medium confidence)*:
- Effects on agricultural and forestry management at Northern Hemisphere higher latitudes, such as earlier spring planting of crops, and alterations in disturbance regimes of forests due to fires and pests {WGII 1.3}
- Some aspects of human health, such as heat-related mortality in Europe, infectious disease vectors in some areas, and allergenic pollen season in Northern Hemisphere high and mid-latitudes {WGII 1.3, 8.2; 8.ES}
- Some human activities in the Arctic (e.g., hunting and travel over snow and ice) and in lower-elevation alpine areas (such as mountain sports). {WGII 1.3}

1.3 Consistency of changes in physical and biological systems with a warming world

Changes in the ocean and on land, with observed decreases in snow cover and sea ice, thinner sea ice, shorter freezing seasons of lake and river ice, glacier melt, decreases in permafrost extent, increases in soil temperatures and borehole temperature profiles, and sea level rise, all strongly support the view that the world is warming. {WGI 3.9}

Of the more than 29,000 observational data series[2], from 75 studies, that show significant change in many physical and biological systems, more than 89% are consistent with the direction of change expected as a response to warming (Figure 1.2). {WGII 1.4}

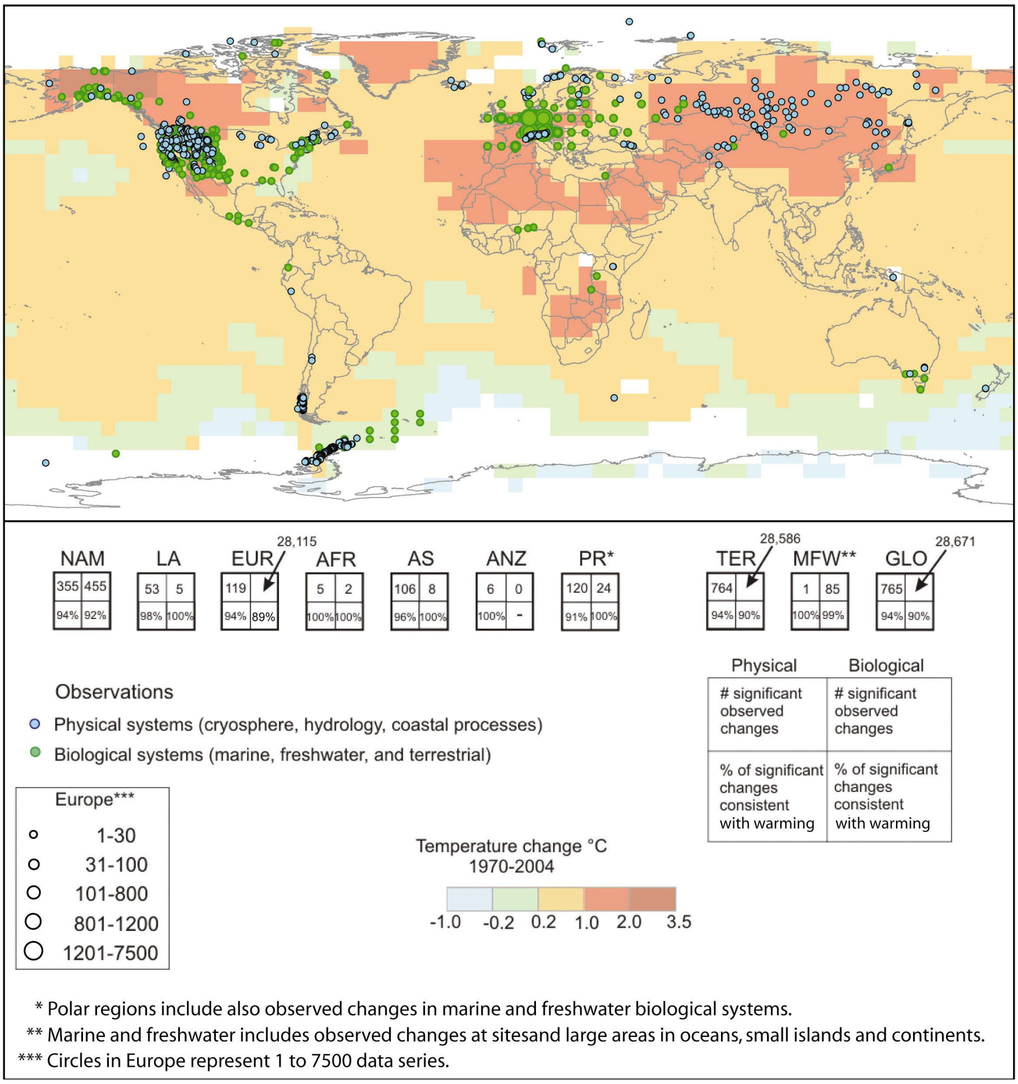

Figure 1.2. Locations of significant changes in observations of physical systems (snow, ice and frozen ground; hydrology; and coastal processes) and biological systems (terrestrial, marine, and freshwater biological systems) are shown together with surface temperature changes over the period 1970-2004. A subset of about 29,000 data series was selected from about 80,000 data series from 577 studies. These met the following criteria: (1) Ending in 1990 or later; (2) spanning a period of at least 20 years; and (3) showing a significant change in either direction, as assessed in individual studies. These data series are from about 75 studies (of which ~70 are new since the Third Assessment) and contain about 29,000 data series, of which about 28,000 are from European studies. White regions do not contain sufficient observational climate data to estimate a temperature trend. The 2x2 boxes show the total number of data series with significant changes (top row) and the percentage of those consistent with warming (bottom row) for (i) continental regions: North America (NAM), Latin America (LA), Europe (EUR), Africa (AFR), Asia (AS), Australia and New Zealand (ANZ), and Polar Regions (PR) and (ii) global-scale: Terrestrial (TER), Marine and Freshwater ((MFW), Global (GLO). The numbers of studies from the seven regional boxes (NAM - PR) do not add up to the global (GLO) totals because numbers from regions except Polar do not include the numbers related to Marine and Freshwater (MFR) systems. {WGI Figure 3.9b; WGII Figure 1.8, Figure 1.9, Figure SPM-1 }

[2] A subset of about 29,000 data series was selected from about 80,000 data series from 577 studies. These met the following criteria: (1) Ending in 1990 or later; (2) spanning a period of at least 20 years; and (3) showing a significant change in either direction, as assessed in individual studies.

1.4 Aspects of climate and effects not observed to have changed

Some aspects of climate appear not to have changed, and for some others we cannot determine if they are changing because of data inadequacies. For instance, Antarctic sea ice extent shows inter-annual variability and localised changes but no statistically significant average trends, consistent with the lack of warming reflected in atmospheric temperatures averaged across the continent. There is insufficient evidence to determine whether trends exist in some other variables, for example the meridional overturning circulation of the global ocean or small-scale phenomena such as tornadoes, hail, lightning and dust-storms. There is no clear trend in the annual number of tropical cyclones. {WGI 3.2, 3.8, 4.4, 5.3, SPM}

Responses to climate changes in human systems are difficult to detect because of multiple non-climate driving forces and the presence of adaptations. For example, the major factors leading to increased vulnerability of tropical coasts are related to increased population, and development of vulnerable infrastructure. Changes in river systems related to water supply make it more difficult to determine how streamflow may be changing. Non-climatic factors important for changes in hydrological variables are human interventions in water catchments, such as land-use and land-cover changes, and changes in rates of water consumption for agricultural, industrial, commercial, and domestic uses. The attribution of changes in human diseases to climate change must first take into account the considerable changes in reporting, surveillance, disease control measures, population changes, and other factors such as land use change. {WGII 1.3, 8.2}

There is a notable lack of geographic balance in data and literature on observed changes, with marked scarcity in developing countries. {WGI 3.2.1; WGII 1.1}

1.5 Observations of direct (non-climate) effects of carbon dioxide

Ocean acidification is occurring although the impacts, for example on corals and the marine biosphere, are as yet uncertain. There is evidence that the average pH of surface seawater has fallen by 0.1 units in the last 200 years, i.e. a 30% increase in the concentration of hydrogen ions in the surface oceans. However, the effects of observed ocean acidification on the marine biosphere are as yet undocumented. {WGI 5.4; WGII 1.3}

The direct effects of increasing atmospheric CO_2 on terrestrial carbon uptake on a large scale cannot be quantified reliably at present. Plant growth can be stimulated by increased atmospheric CO_2 concentrations and by nutrient deposition (fertilisation effects). However, most experiments and studies show that such responses appear to be strongly coupled to other effects such as availability of water and nutrients. {WGI 7.3; WGII 5.4}