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Discussions on the structure of the final report of the Group of Experts

An Overview of Recent Climate Change Trends and projections affecting transportation in the ECE Region (Part I)

Note by the secretariat

I. Introduction

1. This document has been prepared in line with the output/activities of cluster 2: "Transport trends and economics (including Euro-Asian transport links)" of the programme of work of the transport subprogramme for 2016–2017 (ECE/TRANS/2016/28/Add.1, para. 2.2) and the Terms of Reference of the United Nations Economic Commission for Europe (UNECE) Group of Experts on Climate Change impacts and adaptation for transport networks and nodes (ECE/TRANS/2015/6) as adopted by the Inland Transport Committee on 24–26 February 2015 (ECE/TRANS/248, para. 34).

II. Climate Change: Recent Trends and Projections

A. Climate Change Trends

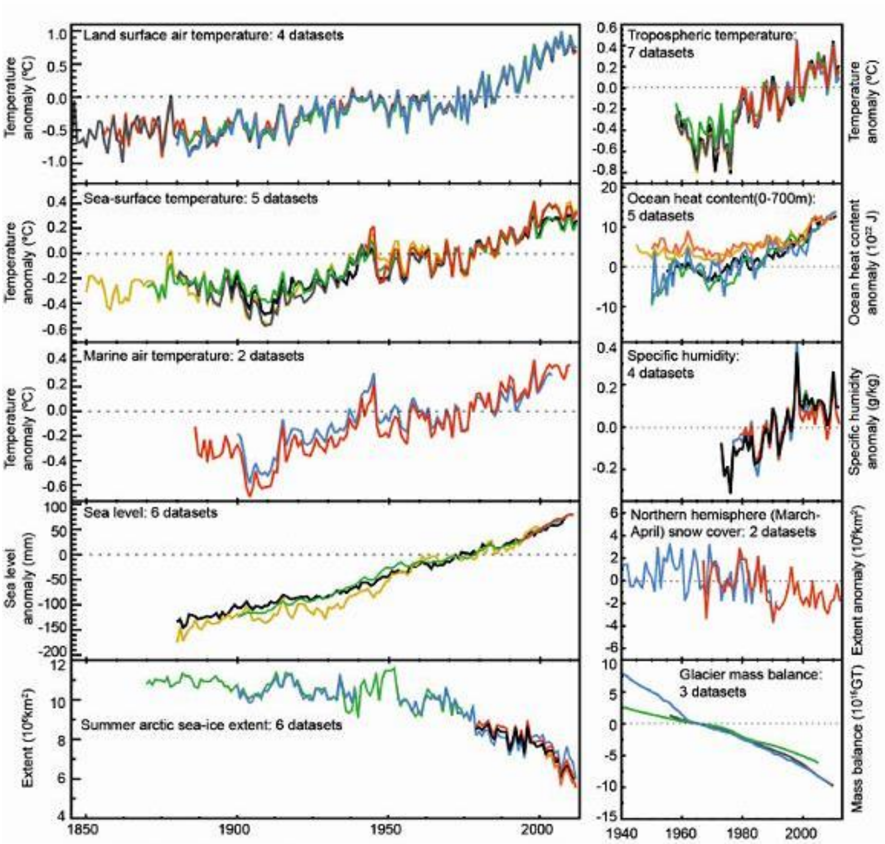
2. The climatic information presented here refers to the most recent period (the last decade). Some of the information (climatic factor trends/projections until 2013) was presented in the previous ECE report (ECE, 2013); in this (draft) report, focus is placed on the most recent period (2011–2015) as well as on the emerging recent multi-annual trends

and projections on Climate Variability and Change (CV & C). There is overwhelming evidence for a warming world since the 19th century, verified by independent scientific evidence from different environments (from the upper atmosphere to the ocean deeps). In most cases, discussions on Climate Change focus on land surface temperature increases, which is only just one of the indicators of changing climate with others being changes in e.g. the atmospheric/oceanic temperature, sea level, precipitation, and glacier, snow and sea ice covers (Fig. 1).

Figure 1

Change of climatic factors

(Each line represents an independently derived estimate of change in a climate element. In each panel all data sets have been normalized to a common period of record (IPCC[1], 2013))



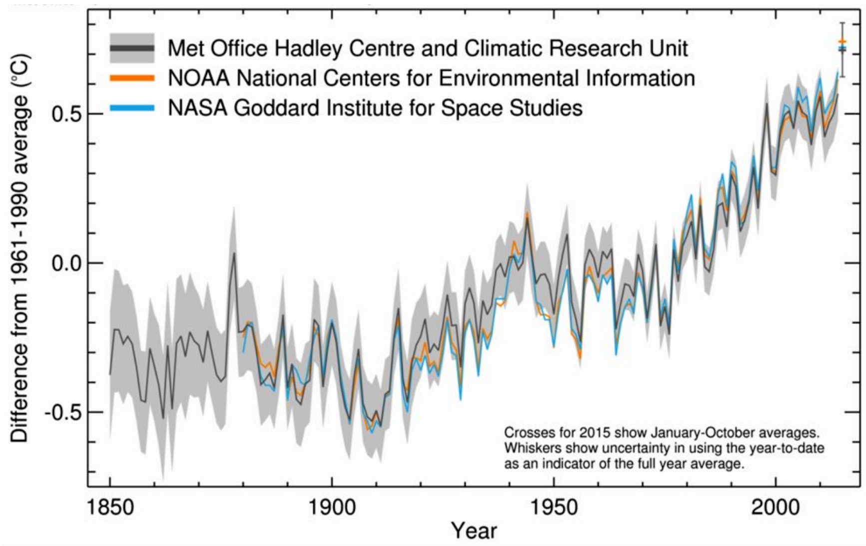
3. Temperature increases have been observed in the troposphere during the last decades. The oceans, which may have absorbed more than 80 per cent of the excess energy associated with the increased emissions since the 1970s, show significant increases in heat content (IPCC, 2013; Melillo et al., 2014); these have resulted in a steric increase of the sea level that is considered as a main driver of sea level rise (Hanna et al., 2013). At the same time, glacier, ice and snow covers have been declining over the last few decades. Arctic sea ice has decreased by > 40 per cent since satellite records began (1978), particularly at the end (in September) of the annual melt season (Melillo et al., 2014). Spring snow cover has shrunk across the Northern Hemisphere (NH) since the 1950s and glacier ice has been consistently decreasing during the last 20 years (IPCC, 2013).

[1] Intergovernmental Panel on Climate Change

1.1.1 Temperature and precipitation

4. Globally-averaged, near-surface temperature is the most cited Climate Change indicator. Although each year (or decade) is not always warmer than the previous, there is a long-term warming trend (Fig. 2). Most of the 16 warmest years since 1880 (when the records began) occurred since 2001, with the 2015 being the warmest year in the instrumental record (94 per cent certainty) (NASA[2], 2016). Globally averaged land and ocean surface temperature in 2015 has risen by 0.76 ± 0.09°C above the 1961–1990 average. The prior world breaking record year was 2014 when the global average temperature was 0.56 ± 0.1°C above the 1961–1990 average (MetOffice, 2014). Record temperatures were widespread in the western part of North America, the northern, southern and Eastern Europe, western Asia, the Indian Ocean, parts of the Arctic Ocean and the western North Atlantic.

Figure 2
Average global near-surface temperature for the period 1850–October 2015, including uncertainties (grey shading)



Source: HadCRUT4, NOAA[3]-GlobalTemp, NASA-GISS[4] (WMO[5], 2016)

5. Since the end of the 20th century, there has been a slowdown in the rate of global temperature rise (Fig. 3) compared to projections of the global climate models. This discrepancy (the global warming hiatus) has been attributed to uncertainties in the simulations related to e.g. external climate forcing (IPCC, 2013), such as volcanic eruptions, stratospheric water vapour changes, industrial aerosols, solar activity and inter-annual to decadal variability of ocean cycles (e.g. El Niño and La Niña events) (MetOffice, 2014).

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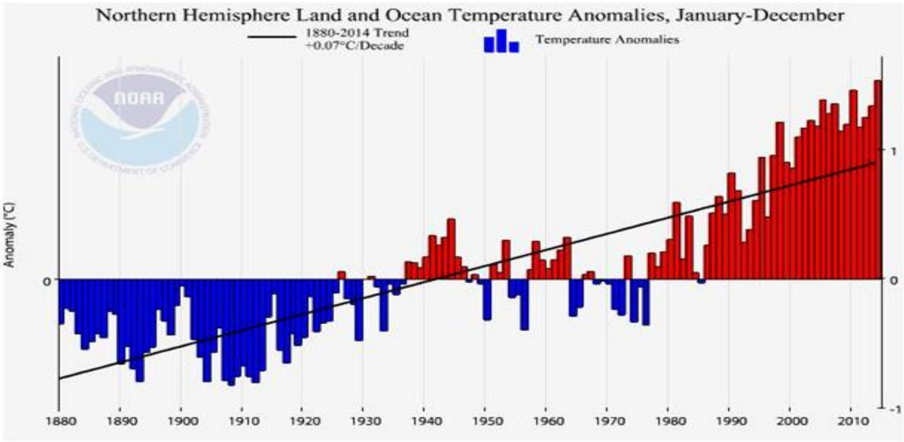
2 National Aeronautics and Space Administration
3 National Oceanic and Atmospheric Administration
4 NASA Goddard Institute for Space Studies
5 World Meteorological Organization

Figure 3

Trends: Land and ocean temperature anomalies 1880–2014

(NOAA, 2016a)

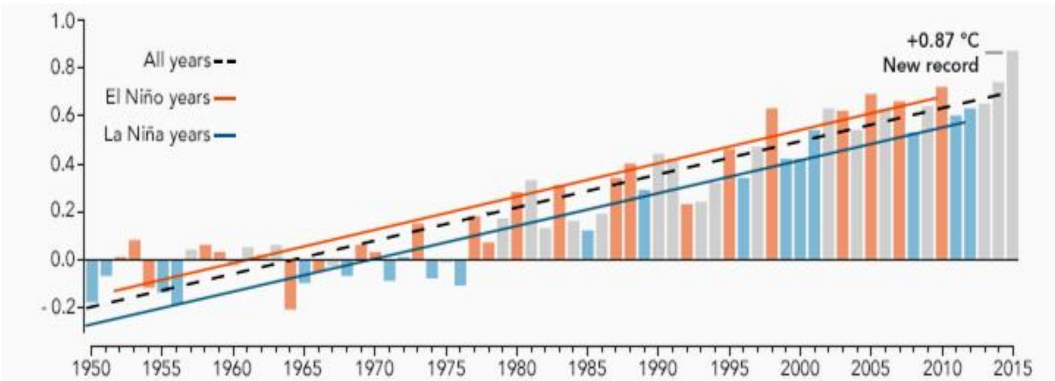


6. It has been observed that years starting during an El Niño event are warmer than non El Niño years (neutral or La Niña years) (Fig. 4). The 2015 temperature record was affected by the strong El Niño conditions in the Pacific, and temperatures are predicted to be also high in 2016 (NASA, 2016). In comparison, although 2014 was a neutral El Niño year, near surface land temperatures were 0 88 ± 0 20°C higher than the 1961–1990 average according to NOAA estimates (WMO, 2014). However, recent research (e.g. Cowtan and Way, 2014; Karl et al, 2015) has questioned the decreasing rising temperature trend, suggesting that there were biases in surface temperature datasets and that re-analysis of corrected/updated data indicate that global trends are higher than reported in previous studies (e.g. IPCC, 2013).

Figure 4

Annual temperatures compared to 1951–1980 average

(Blue and red bars represent the annual temperature anomalies in El Niño and La Niña years, respectively while blue and red lines represent the trend. Neutral years shown in grey; the dashed line represents the overall average trend since 1950. (NASA, 2016))



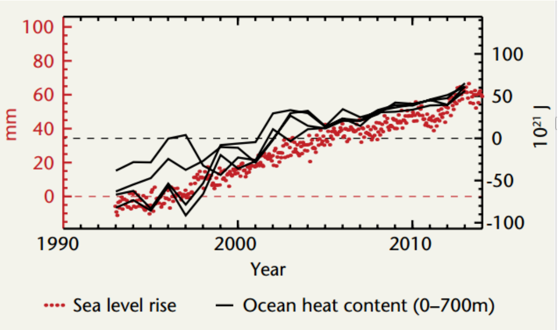
7. Climate is controlled by the heat inflows and outflows and its storage dynamics in the various constituents of the Earth System, i.e. the ocean, land and atmosphere (IPCC, 2013). Most of the heat storage occurs in the ocean as it absorbs about 80 per cent of the heat added to the climate system and, thus, changes in ocean temperature are important indicators of climatic changes. In recent years, there has been ample evidence of ocean warming, with the rate being estimated as 0.64 Wm-2 for the period 1993–2008 (Lyman et al., 2010). Water temperature rise has been observed down to depths of 3000 m from 1961 (IPCC, 2013). There is an apparent

consistency (Fig. 5) between the increase in ocean heat content and sea level rise, which is the presumed result of thermal expansion (NASA, 2016).

Figure 5

Observed global average sea level rise and change in ocean heat content for a 20 year period (1993–2013)

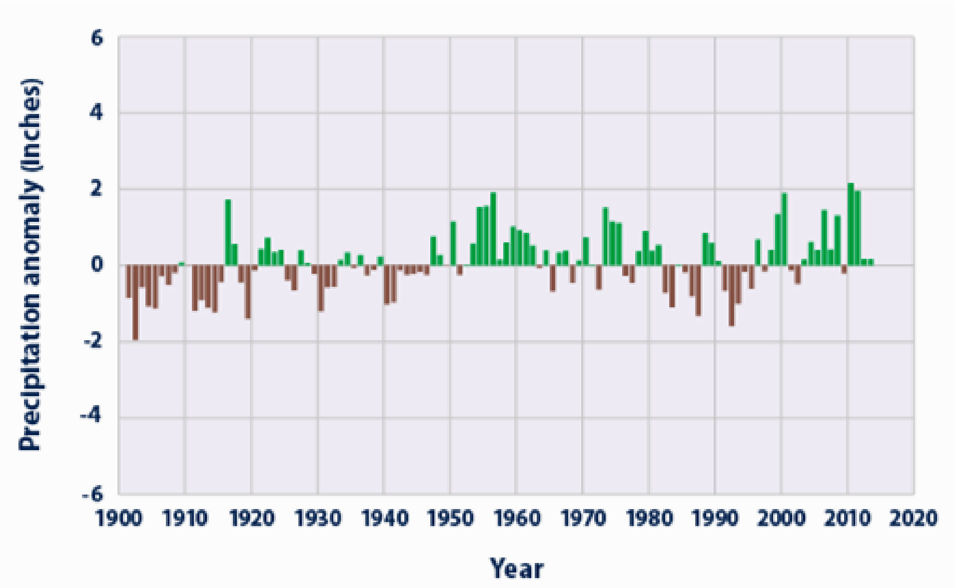
(Sea-level data from a combination of TOPEX (1993–2001), Jason-1 (2002–08) and Jason-2 (2008–13) (available from http://sealevel.colorado.edu/). Ocean heat content is for the top 700 m relative to the 1993–2012 average; data from CSIRO/ACE CRC; PMEL/JPL/JIMAR; NODC; and EN4.0.2 (MetOffice, 2014))



8. Analysis of global precipitation data from land areas reveal that there is an increasing trend in the 20th Century, especially in middle and high latitudes (low confidence before 1951, medium confidence afterwards). However, when the analysis includes only the mid-latitudes of the NH, confidence in the precipitation trends for the years after 1951 is high. Generally, global precipitation data show mixed (and no statistically significant) long term trends (IPCC, 2013), with strong regional variability been observed. Heavy precipitation events have increased in intensity and/or frequency in many parts of Europe and North America (Fig. 6), whereas there has been an increased frequency and intensity of drought events in the Mediterranean and parts of Africa (IPCC, 2013).

Figure 6

Total annual global precipitation over land for the period 1901–2013 in relation to the 1901–2000 (EPA, 2015)



1.1.2 Sea Level

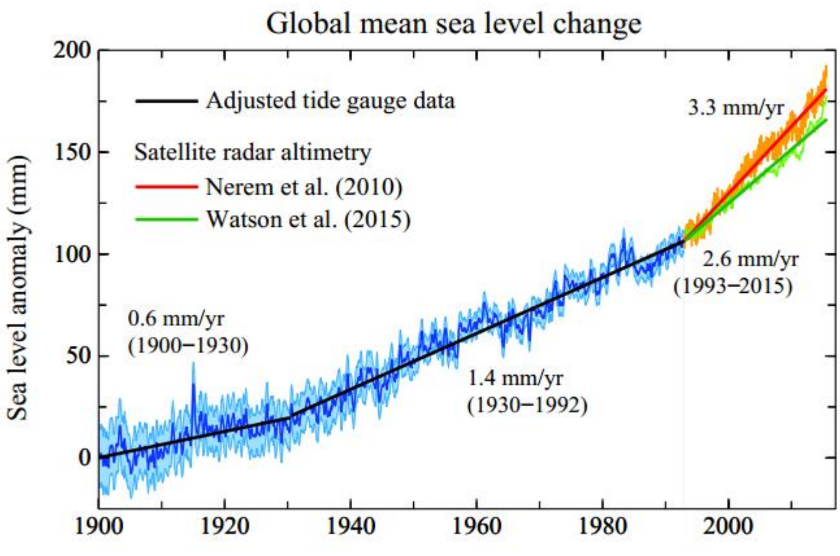
9. During the last decades a significant rise of the mean sea level has been observed due to: (a) ocean thermal expansion (OTE), i.e. ocean volume changes due to steric effects; (b) glacio-eustasy i.e. ocean mass increases from the melting of the Greenland and Antarctic ice sheets (GIS and AIS) and the glaciers and ice caps (GIC); (c) glacio-isostatic adjustment (GIA); and (d) changes in terrestrial water storage (e.g. Hanna et al., 2013). The rate of global sea-level rise increased sharply above the relatively stable background rates of the previous 2000 years (e.g. Church and White, 2006; Engelhart et al., 2009; Gehrels and Woodworth, 2012; IPCC, 2013; Horton et al., 2014). Since 1860, sea level has increased by about 0.20 m, with the rate of increase becoming progressively greater, particularly since the 1990s. The global rate of sea level rise has averaged 1.3 to 1.8 cm per decade (Church et al., 2013; Hay et al., 2015). As with temperature, the long-term upward trend in sea level has varied over the decades. For example, there were lower rates of increase during the early part of the 20th century and much of the 1960s and 1970s; sea level increased more rapidly during the 1930s through the 1950s. Since 1993, satellite observations and tide gauges have shown a global sea level rise of 3.3 ± 0.25 cm per decade (Church et al., 2013) and there is a discernible acceleration in global sea level since the 1900s (Fig. 7).

10. Mean sea level trends and variations in regional climate have led to changes in the trends of extreme high water levels in the late 20th century. There is considerable spatial variability in the sea level rise trends, particularly along the coast (Menendez and Woodworth, 2010). Other recent studies have shown that there is high regional variability. In Europe, for example, sea levels have increased along most of the coast in the last 40 odd years, with the exception of the N. Baltic coast (EEA[6], 2012).

Figure 7

Estimated sea level change (mm) since 1900

(Data through 1992 are the tide-gauge record of Church and White (2011) with the change rate multiplied by 0.78, so as to yield a mean 1901–1990 change rate of 1.2 mm year−1 (Hansen et al., 2016))



[6] European Environment Agency

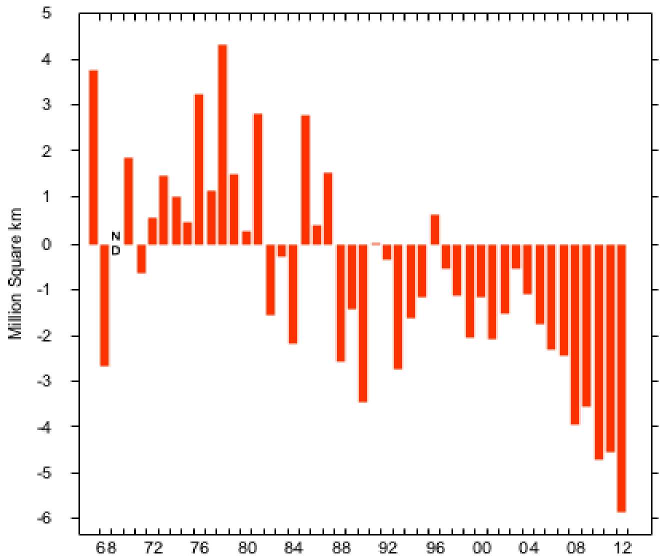
1.1.3 Arctic Ice, Snow and Permafrost

11. The warming trend also affects the cryosphere. Snow cover in the North Hemisphere (i.e. about the 98 per cent of the global snow cover) has declined by 11.7 per cent per decade in June (EEA, 2015a) over the period 1967-2012 (Fig. 8). However, this trend is not uniform. Some regions (e.g. the Alps and Scandinavia) show consistent decreases in the snow cover depth at low elevations but increases at high elevations, whereas in other regions (e.g. the Carpathians, Pyrenees, and Caucasus) there are no consistent trends (EEA, 2012).

12. Over the past few decades, research shows a downward trend in the extent and duration of snow cover in the Arctic region. Minimum Arctic sea ice extent which is taking place in late summer has declined by about 40 per cent since 1979 and the 9 lowest September ice extents during the period 1979–2015 have all occurred in the last 9 years (NSIDC[7], 2012). The extent of summer Arctic sea ice in 2012 has been estimated at 3.39 million km2, which is the lowest value ever recorded; summer surface melting of Greenland ice sheet was also above average in the period 2011-2015 (WMO, 2016). However, Arctic sea ice has not been declining as rapidly in winter as it has been in summer; the lowest winter maximum was recorded as 14.39 million km2. Greenland's ice sheet mass was measured by Velicogna et al. (2014) who found that the magnitude of the loss is 280 ± 58 Gt year−1, accelerating by 25.4 ± 1.2 Gt year−2. On the same study, an ice mass loss of 74 ± 7 Gt year−1 was observed from nearby Canadian glaciers and ice caps with acceleration of 10 ± 2 Gt year−2.

Figure 8

Northern Hemisphere snow cover extent for June in the 1967–2012 period (NSIDC, 2012)



13. The above processes have had significant effects on global sea level rise. Observations indicate that Greenland's ice loss has very likely contributed in an increase from 0.09 (–0.02 to 0.20) mm yr–1 for 1992–2001 to 0.59 (0.43 to 0.76) mm yr–1 for 2002–2011, while the contribution of Antarctica's ice sheet loss likely increased from 0.08 (–0.10 to 0.27) mm yr–1 for 1992–2001 to 0.40 (0.20 to 0.61) mm yr-1 for 2002–2011;

7 National Snow and Ice Data Center

altogether, ice sheet contribution to sea level rise (SLR) is 0.60 (0.42 to 0.78) mm yr–1 for the period 1993-2010 (IPCC, 2013).

14. During the last 5 years (2011-2015), Arctic sea ice continued its decline exceeding the 1981-2010 mean value, particularly for the winter maximum. In contrast, ice extent in the Southern Ocean reached 20.16 million km2 in September 2014, 1.45 million km2 above the 1981-2010 average and the highest extent in the satellite record. An abnormally slow winter freeze in 2015 resulted in sea ice extent returning to near-average levels by spring 2015 (maximum – early October – of 18.83 million km2, only 0.7 per cent above the 1981–2010 average (WMO, 2016). Mountain glaciers also continued their decline during the last 5 years, while there was also warming down to 20 m depth in Arctic permafrost regions. Permafrost temperature has increased in most regions by up to 2 ºC since 1980, leading to significant infrastructure damage; thickness of the NH permafrost has decreased by 0.32 m since 1930 (IPCC, 2013). Snow cover extent was also well below average during the last 5-years (2011–2015). In the NH, anomalies in the snow cover extent showed strong seasonal variability, but the overall mean extent in the 5-year period was close to the 1981–2010 average. The highest seasonal anomaly occurred in the winter 2013, when snow cover extent was well above normal through the winter (WMO, 2014).

1.1.4 Extreme Climate Events

15. Changes in the mean climate can also lead to changes in the frequency, intensity, spatial coverage, duration, and timing of weather and climate extremes, potentially resulting in unprecedented extremes. These extremes can, in turn, modify the distributions of the future climatic conditions. Thus, future mean conditions for some climatic variables are projected to lie within the 'tails' of the present-day conditions (IPCC, 2013). Extreme events (e.g. storms, floods, droughts and heat waves) as well as changes in the patterns of particular climatic systems (e.g. the monsoons) (King et al., 2015) can be, at smaller spatio-temporal scales, the most impacting climatic phenomena (IPCC, 2013) since they may induce more severe effects/natural disasters than changes in the mean variables. Moreover, societies are rarely prepared to efficiently face extreme weather events, having become dependent on predictable, long-term climatic patterns (MetOffice, 2014).

16. Many indicators of climate extremes and variability showed changes consistent with warming, including a widespread reduction in the number of frost days in mid-latitude regions and discernible evidence that warm extremes had become warmer and cold extremes had become less cold in many regions (IPCC, 2013). Evidence indicates a general change in the frequency of high impact temperature and precipitation extremes over land, irrespective of the type of dataset and processing method used (MetOffice, 2014).

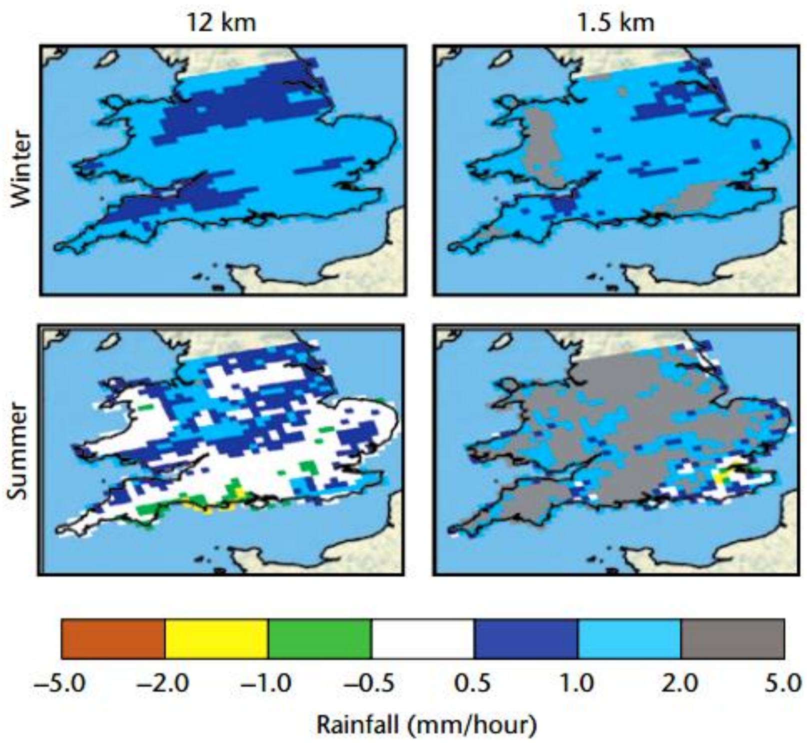
17. Extreme events have consequences that are difficult to predict. Their variability covers a large spectrum, such as sudden and transient temperature changes, rapid retreats of sea ice, bouts of abnormally high precipitation, intensive storms, storm surges, extended droughts, heat waves and wildfires and sudden water releases from melting glaciers and permafrost slumping that may have substantial impacts. In addition, there is evidence to suggest that extreme events, such as tropical and temperate storms, may respond to a warming climate by becoming even more extreme (Emanuel, 2005; Ruggiero et al., 2010; WMO, 2014; MetOffice, 2014). For example, even a modest increase (of 5 m/s) in the surface wind speed of the tropical cyclones driven by a 1°C rise in the ocean temperature might result in a substantial increase of the incidence of the most intense and destructive (Category 5) cyclones (e.g. Steffen, 2009). The implications of these extreme events for e.g. the coastal communities/infrastructure could be severe, as they may increase the likelihood of extreme sea levels-storm surges and wave run ups (e.g. Stockdon et al., 2012) and consequent coastal floods, especially if combined with the projected increases in the mean sea level (Hallegate et al., 2013).

18. In addition, increases in the intensity and frequency, and/or changes in the patterns, of extreme waves (e.g. Ruggiero, 2013; Bertin et al., 2013) will also induce, at least temporarily, coastal erosion or inundation, particularly when combined with increasing mean sea levels (e.g. Losada et al., 2013). Storm surges pose a particular threat to highly developed coastal areas, particularly the low lying coasts such as the Rhine, Danube and the Mississippi river deltas which are considered hotspots of coastal erosion/vulnerability due to their commonly high relative mean sea level rises (ECE, 2013). Studies of the trends in extreme coastal sea level/storm surges from tide gauges have shown that changes in extreme water levels tend to be dominated by the mean sea level rise (e.g. Marcos et al., 2011). Coastal areas currently experiencing erosion and/or inundation are projected with high confidence that will continue to do so in the future, due to increasing sea levels, all other contributing factors being equal (Hallegatte et al. 2013).

19. One of the clearest trends appears to be the increasing frequency and intensity of heavy downpours; this increase has been responsible for most of the observed increases in overall precipitation during the last 50 years. Projections from climate models suggest that these trends will continue during this century (Karl et al., 2009). A fine resolution model (MetOffice, 2014) projected that whereas United Kingdom of Great Britain and Northern Ireland (UK) summers are to become drier by 2100, summer downpours will be heavier (Fig. 9). It is likely that the frequency of such events will increase over many regions in the 21st century, especially in the high and tropical latitudes and the northern mid-latitudes in winter. Heavy precipitation events are also predicted with medium confidence to increase even in regions with projected decreases in the total precipitation (ECE, 2013).

Figure 9

Future changes in heavy rainfall in the 12 km (left) and 1.5 km (right) resolution models, for winter (top) and summer (bottom). Both models show increased hourly rainfall intensity during winter, but the 1.5 km model also reveals significant increases in short-duration rain intensity during summer. Changes are for 2100 under the high emission scenario Representative Concentration Pathways (RCP)8.5 (Met Office, 2014)

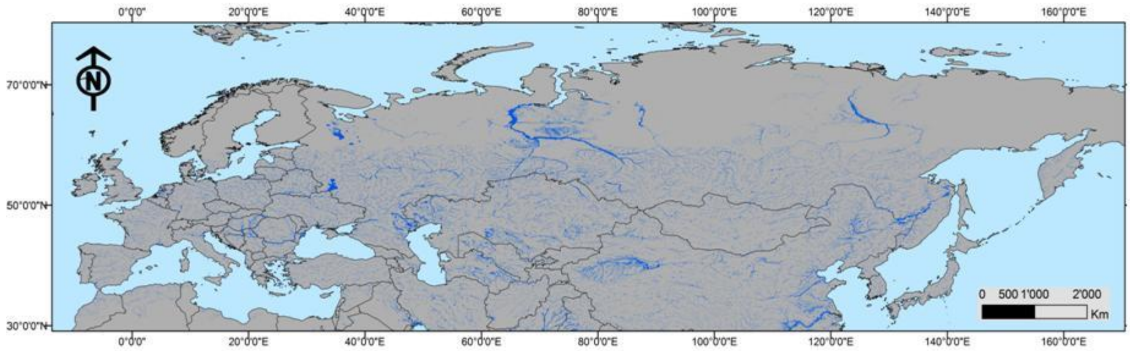


20. River flooding is the most serious and widespread weather hazard (King et al., 2015). Between 1980 and 2014 river floods accounted for 41 per cent of all loss events, 27 per cent of fatalities and 32 per cent of losses (Munich Re, 2015). Riverine floods involve both physical and socio- economic factors. The former are strongly connected to the hydrological cycle (influenced by changes in temperature, precipitation and glacier and snow melts) whereas the latter by land use changes, river management schemes, and flood plain construction (EEA, 2010). In the ECE region, floods are an ever present threat. The current trends in the Eurasian countries show a significant flood hazard (for the 1 in a 100-year events), particularly for central and eastern Europe, the central Asia and along the large S-N drainage basins of Siberia (Fig. 10). However, changes in extreme hydrological events and their impacts are better studied at a regional/local scale, with most existing studies focusing on the generation and impacts of floods due to e.g. increases in torrential precipitation. In Europe, annual water discharges have generally been observed to increase in the north and decrease in the south (EEA, 2012), a trend that is projected to hold in the future, as is associated with projected changes in precipitation (EEA, 2015c). By the 2050, there is at least a 50 per cent chance that climate change alone would lead to a 50 per cent increase in flooded people across sub-Saharan Africa, and a 30 to 70 per cent chance for such an increase in Asia; by 2100 the risks have been projected to be greater (King et al., 2015).

Figure 10

Current flood hazard (95 per cent probability) in the Eurasian region of the ECE for the 100-year flood from a global GIS model based on river discharge time-series

(DEM resolution 90 m. Areas over 60 0N are not fully covered (From UNEP-GRID[8] and UNISDR[9], 2008). (ECE, 2013))



21. Slope failures/landslides are also expected to increase at mountainous areas, as are also linked to heavy downpours (e.g. Karl et al., 2009). Consequently, flood damages in e.g. Europe are expected to rise considerably by the end of the century, being generally higher in the north than in the south (Alfieri et al. 2015). There is also evidence to suggest increases in the frequency and intensity of heat waves (e.g. Beniston and Diaz, 2004; IPCC, 2013); generally, there has been a 3-fold increase since 1920s in the ratio of the observed monthly heat extremes to that expected in a non-changing climate (Coumou and Rahmstorf, 2012). At a global scale, with mean temperatures continuing to rise, models project that increases in the frequency/magnitude of hot days and nights and decreases in the cold days and nights are virtually certain (IPCC, 2013). Since 1950s, it is very likely that there has also been an overall decrease in the number of unusually cold days and nights and an overall increase in the number of unusually warm days and nights at the global scale (for

[8] United Nations Environment Programme Global Resource Information Database

[9] United Nations International Strategy for Disaster Reduction

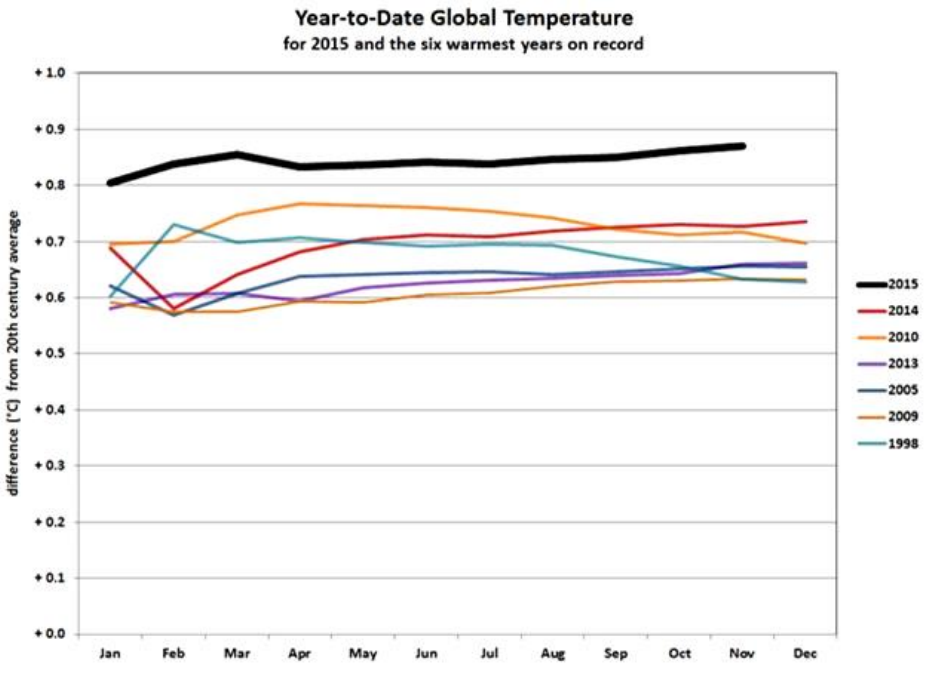
land areas with sufficient data). For example, most of North America appears to have experienced more unusually hot days and nights, fewer unusually cold days and nights and fewer frost days (ECE, 2013). Heat waves are often associated with severe droughts (as e.g. the European summer 2003 heat wave). Generally, droughts are becoming more severe in some regions, a trend that is projected to hold (and possibly increase) in the 21st century (IPCC, 2013).

1.1.5 The 2011–2015 period

Temperature and Precipitation

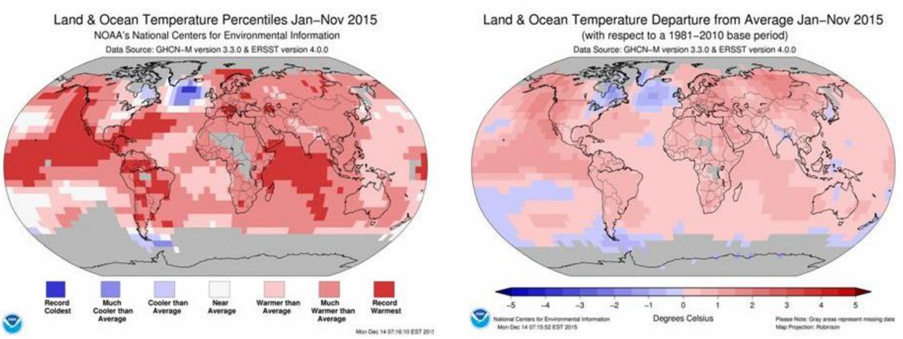
22. The last 5-year period (2011–2015) has been the warmest on record. Temperatures were > 1°C above the 1961-90 average (over most of Europe, northern Asia and the southwest US) and reaching > 3°C above average in parts of the Russian Arctic. 2015 was the warmest year on record (0.87°C higher than the 1901-2000 average of 14.0°C), surpassing the previous record (2014), with the average land surface temperature at record high (1.27°C above average) (Fig. 11). Nearly all of Eurasia were much warmer than average. Noteworthy are also the seasonal anomalies: the warmest springs on record were observed in North America (2012) and Europe (2014), whereas the hottest summer on record for North America was in 2012. The year 2015 was the first time the global average temperatures were 1°C or more above the 1880–1899 average (NASA, 2016). Phenomena such as El Niño (or La Niña) that can warm or cool the tropical Pacific Ocean may be responsible for such short-term variability in the global temperature and an El Niño event occurred for most of 2015. Globally, the 10 warmest years have all occurred since 1998, with 8 of these since 2005 (Fig. 11).

Figure 11
The 2011–15 period was the warmest 5-year period on record, with temperatures 0.57°C above the 1961-1990 average and 0.51°C above the 2006–2010 average. Land temperatures were > 1°C above the 1961-90 average over most of Europe, the southwestern United States (US) and the Asian sector of the Russian Federation and most areas north of 60 °N (NOAA, 2016b)



23. Sea surface temperatures for the same 5-year period were above average in most of the oceans, with the exception of areas in the Southern Ocean and the eastern South Pacific. Warm temperatures also occurred in the subsurface, with the integrated ocean heat content within the 0 – 700 m layer being higher in 2013 and 2014 than any previously recorded according to 5 different data sets (NOAA, 2016). Two notable ocean temperature anomalies have been observed in the late 2013: (i) a large area of very warm water (> 2°C above average) in eastern North Pacific locations; and (ii) a persistent pool of below-normal sea surface temperatures in the eastern North Atlantic.

Figure 12
Temperature anomalies in 2015 (NOAA, 2016c)



24. Land precipitation was strongly influenced early and late in the 2011-2015 period by the El Niño-Southern Oscillation (ENSO), with La Niña conditions for much of 2011 and early 2012, and El Niño conditions in the later part of 2015. 2011 was assessed by NOAA as being the world's second-wettest year on record, with 2012, 2013 and 2014 all close to the long-term average. A major feature of the 5-year period is the presence of persistent multi-year rainfall anomalies over several regions, most of which began after the end of the 2012 La Niña.

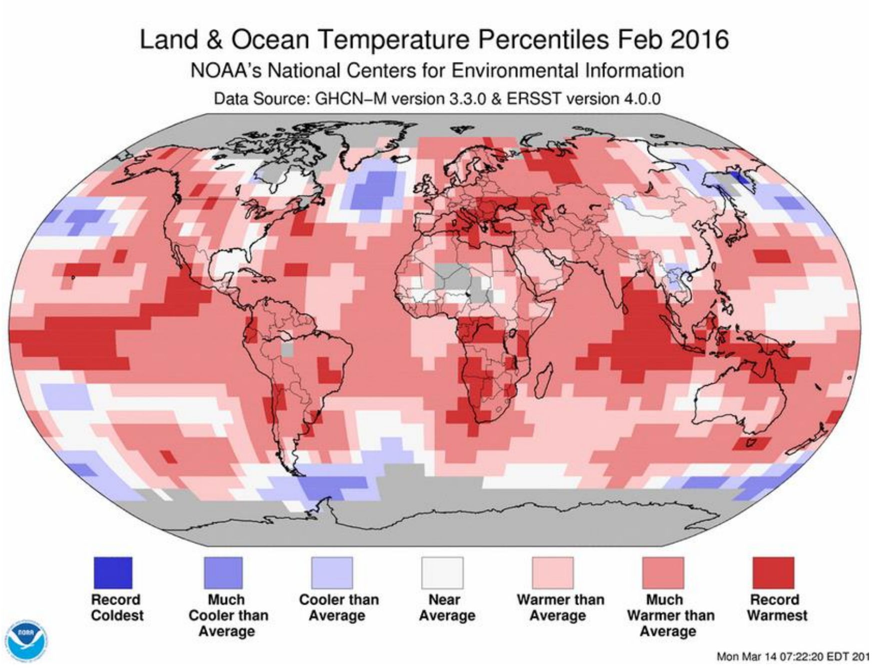
25. Three regions (eastern half of Brazil, western US, and parts of eastern Australia) had large areas in which rainfall for October 2012–September 2015 was below the 10th percentile, whereas there were regions where precipitation exceeded the 90th percentile (e.g. the eastern Russia). Regarding Europe, there was a marked north/south split with very wet conditions in Scandinavia and very dry conditions in much of central and southeast Europe. Major annual precipitation anomalies were less common in the years 2012–2014, with significant anomalies observed in northeast Europe, parts of China and Argentina (2012) and southeast Europe (2014); in the ECE region, very dry conditions occurred over much of the central US and central Russia (2012) and western Russia (2014).

CASE: February 2016, the warmest February since records began

Average land/ocean surface temperature for February 2016 was the highest for February since records began, at 1.21°C above the 20th century average of 12.1°C (surpassing the previous record set in 2015 by 0.33°C) (NOAA, 2016d). Overall, the 6 highest monthly temperature departures in the record have all occurred in the period September 2015-February 2016.

A vast NH region stretching from central Russia into Eastern Europe (as well as Alaska) showed February temperatures more than 5°C above the 1981–2010 average. A few pockets in Asia were cooler than average, including part of Far East Russia (Fig. B.1).

Figure B.1
Land/Ocean Temperature anomalies for February 2016 compared to the global Average (NOAA, 2016d)



Sea Level Rise

26. In 2011–2015, mean sea level continued to rise. The period began with global sea level about 10 mm below the long-term trend (probably due to the strong La Niña); however, by mid-2012, mean sea level trend had rebounded. A marked rise occurred in early 2015 (as El Niño developed), with sea levels being of about 10 mm above trend. The trend over the full satellite record (1993–2015, 3 mm/year) is higher than the average of the 1900–2010 trend (1.7 mm/year). Studies have suggested that the contribution of continental ice sheets, particularly those of Greenland (GIS) and west Antarctica (WAIS), to sea level rise is accelerating. The contribution of GIS melting to global sea level rise in the 2011–13 period (that includes the extreme melt year of 2012) was approximately 1.0 mm/year, well in excess of the 0.6 mm/year for the 2002–2011 period (IPCC, 2013). Regarding the Pacific Ocean, strong regional differences are apparent in the period 1993–2014 that have been attributed to El Niño and La Niña events. The western Pacific has shown the world's fastest rates of sea level rise over this period (> 10 mm/ year in places), in contrast to the eastern

Pacific. Sea level rise has been more consistent in the Atlantic and Indian Oceans with most parts of both oceans showing rates similar to the global average.

Major extreme events in the 2011-15 period

27. In 2011–2015 there have been many extreme weather and climate events such as heat and cold waves, tropical cyclones, floods, droughts and intense storms. Several of these events caused significant damage/losses, as e.g. the 2011 SE Asian floods, the Hurricane Sandy in the Carribean and the US (2012), droughts in the southern and central US (2012 and 2013), and floods in central Europe in May–June 2013 (WMO, 2016). In terms of casualties, flash floods in southern Brazil and SE Asia caused 1,700 deaths (2011), whereas Typhoon Haiyan (Yolanda) in the Philippines and floods in North India resulted in 13600 deaths (2013). More than 3,700 people have lost their lives from heat waves in India and Pakistan (May–June 2015). The most lethal extreme event has been the 2010-2011 drought in the horn of Africa that may have been the cause of the late 2010–early 2012 Somalia famine responsible for 258,000 excess deaths (WMO, 2016).

Heat waves and droughts

28. Significant heat waves have been recorded in Europe during the summers of 2012, 2013 and 2014. In Austria, it was the first time that temperatures reached 40°C or above. A prolonged heat wave affected many parts of eastern Asia in July–August 2013. The most intense heat waves of the period were recorded in May and June 2015 in India and Pakistan, during the pre-monsoon periods; temperatures were at, or above 45°C. In western and central Europe, the most significant heat wave since 2003 was recorded in the first fortnight of July 2015, with Spain, France and Switzerland breaking all time temperature records; a few weeks later, temperatures of 40.3°C were also recorded in Germany.

29. Severe droughts have occurred in 2011–2015. North America (US and northern Mexico) has experienced severe droughts in 2011, 2012 and 2013. In July 2012, 64.5 per cent of the US territory was classified as experiencing droughts, the largest areal extent since the 1930s. Total rainfall in 2011–2015 was also 30 per cent below normal, resulting in total economic losses of approximately US $60 billion. Significant long-term droughts also occurred in Australia and southern Africa, whereas the Indian monsoon season (June-September) rainfall was about 10 per cent below normal in both 2014 and 2015.

Cold and snow

30. Despite the overall high temperatures of the 5-year period, there were still episodes of abnormal cold and snow in the NH. A prolonged period of extreme cold affected Europe in February 2012. It was the worst cold spell since 1985 or 1987 in many parts of the central and Western Europe, with temperatures remaining below 0°C continuously for 2 weeks or more in most of central Europe, although no low temperature records were set. This event also brought extremely heavy snow in some places, especially in parts of eastern Italy. March 2013 was also notably cold in much of Europe with significant blizzards in places. The winters of 2013–14 and 2014–15 were both significantly colder than normal in many central and eastern areas of the US and southern Canada, with persistent low temperatures over the region for extended periods (although no records were set). The cold was especially persistent in February 2015, when locations such as Montreal, Toronto and Syracuse did not rise above 0°C at any time during the month. In coastal regions there were frequent snowfalls, resulting in Boston experiencing its greatest seasonal snowfall on record (WMO, 2016).

High winds and tornadoes

31. High winds and tornadoes caused major destruction. The number of cyclones characterized by high intensity winds increased during the 5-year period. The Northwest Pacific was particularly active in 2013 and 2015, and the North Atlantic in 2011. US had one of its most active tornado seasons on record in 2011, where the total number of tornadoes ranked as the 3rd highest on record. In 2012–2015, however, tornado activity was below the 1991–2010 average. Regarding hurricanes, Hurricane Sandy affected the Caribbean and the east coast of the United States in October 2012 causing major damage, i.e. severe coastal flooding and high record water levels and inundation (IPCC, 2013). There were 233 deaths in the US and the Caribbean whereas total economic losses were estimated as US $67 billion. Tropical cyclones had also major impacts in Asia (e.g. Typhoon Haiyan (Yolanda) and Washi (Sendong)), whereas cyclone Patricia was the most intense ever recorded with wind speeds reaching 322 km/h at Mexico.

32. During this period, several windstorms associated with extra-tropical cyclones occurred in Europe. In 2013, Denmark experienced the highest recorded wind (53.5 m/s) that caused excessive damages (also in France, Germany, Netherlands, Sweden and UK). The highest storm surge levels since 1953 were recorded in Netherlands and the UK in this period. In the winter of 2013–2014, a sequence of storms led to the UK having its wettest winter on record, causing also significant wind damage and coastal erosion (WMO, 2016).

1.1.6 Forcing Mechanism

33. A major cause of the observed increase of the heat content of the planet is considered to be the increasing concentrations of atmospheric greenhouse gases (GHGs). These gases enhance the “greenhouse effect”, which is a well-documented and understood physical process of the Earth System, known since the 19th century (e.g. Canadell et al., 2007). Changes in the atmospheric GHG concentration affect the magnitude of the Greenhouse Effect. Water vapour is an abundant GHG and makes the greatest contribution to the ‘natural’ effect. Human activities have not yet shown to have had a significant direct effect on net global flows of water vapour to/from the atmosphere (e.g. Richardson et al., 2009), although locally they may have influenced such flows through e.g. deforestation and large irrigation schemes. Nevertheless, as the ability of the atmosphere to retain water vapour is strongly dependent on temperature, atmospheric water vapour is regulated by the Earth’s temperature, increasing with global warming. Thus, water vapour not only follows, but also exacerbates changes in global temperature that are induced by other causes, such as the increasing concentrations of the other GHGs (e.g. Richardson et al., 2009).

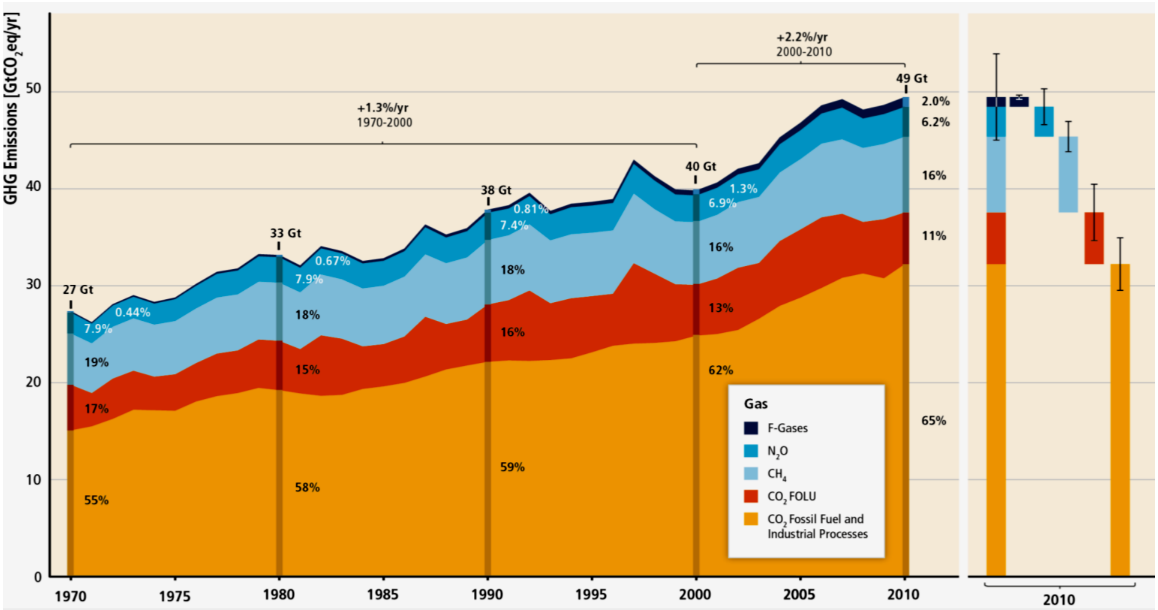
34. GHGs in the atmosphere absorb heat reflected back from the Earth’s surface and, thus, store more heat in the ocean, land and atmosphere. Without the greenhouse effect, average temperatures on Earth would be about -19 °C (i.e. about 34 °C colder than it is at present). All planets with heat absorbing gases in their atmosphere, experience a Greenhouse Effect. For example, the extreme surface temperature (about 440 °C) of Venus is explained by the high concentration of GHGs in its atmosphere. The observed increase in the Earth’s heat content is probably (at least partly) due to the increasing atmospheric concentrations of greenhouse gases (GHGs), that absorb heat reflected back from the Earth’s surface (IPCC, 2013)

35. It appears that the atmospheric concentrations of CO2, CH4 and the other GHGs have increased very substantially over recent decades, probably as a result of human activities (e.g. Caldeira, 2009). There is mounting evidence for a link between GHGs concentration and climate. For example, co-variation of CO2 concentration and temperature in Antarctic ice-core records suggests a close link between CO2 and climate during the Pleistocene ice ages, the exact nature of which is, nevertheless, unclear (e.g. Shakun et al., 2012). Measurements of CO2 in the atmosphere and in ice-trapped air show that GHGs

have increased by about 40 per cent since 1800, with most of the increase occurring since the 1970s when global energy consumption accelerated (EEA, 2015a). Furthermore, measurements from ice cores suggest that current CO2 concentrations are higher than at any time in the last 800,000 years, with the 400 ppm milestone reached in 09/05/2013 (NOAA, 2015). Despite a growing number of climate mitigation measures, total global anthropogenic GHG emissions have grown continuously over the period 1970–2010, reaching their highest level in human history in 2000–2010 (Fig. 13); this trend continued in 2011–2015 (WMO, 2016).

Figure 13

Total annual anthropogenic GHG for the period 1970-2010 (IPCC, 2014)



36. CO2 and N2O concentration had growth rates in 2011–14 slightly higher than those the 1995-2014 average. CH4 concentration also showed a renewed period of growth, following a period of little change in 1999–2006 (WMO, 2016). During the last 2 years (2014 and 2015), the annual mean concentrations of GHGs increased. In 2014, CO2, CH4 and N2O concentrations were 397 ppm, 1833 ppb, and 327.1 ppb, respectively (NOAA, 2015). Approximately 44 per cent of the total CO2 emitted by human activities from 2004 to 2013 remained in the atmosphere, with the remaining 56 per cent being removed into the oceans and the terrestrial biosphere (WMO, 2014, 2016).

37. Breakdown of the total anthropogenic GHG emissions in 2010 revealed that CO2 accounted for 76 per cent of them (65 per cent due to fossil fuel combustion/industry and 11 per cent due to land-use), CH4 for 16 per cent, N2O for 6 per cent and fluorinated gases for 2 per cent (IPCC, 2014). Analysis of the total CO2 emissions from fossil fuel combustion for the period 1971–2010 revealed that the primary drivers of the increasing trend are population growth and patterns of consumption/production (IPCC, 2014). Assessment of the CO2 emissions in relation to country income shows that these doubled for upper-mid-income countries (e.g. China and South Africa) for the period 1990–2010, almost reaching the level of high income countries like US and most EU countries (Fig. 14). A notable increase of CO2 emissions was also shown for lower-mid-income countries (IPCC, 2014).

Figure 14

Total anthropogenic GHGs in 1970, 1990 and 2010 by economic sector and country income groups (IPCC, 2014)