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An Overview of Recent Climate Change Trends and Projections Affecting Transportation in the ECE Region

Presented by Prof. A. F. Velegrakis

UNECE Group of Experts on Climate Change Impacts and Adaptation for Transport Networks and Nodes, 11-12-April 2016, Geneva

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DRAFT REPORT

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1. Climate Change: Recent Trends and Projections

1.1 Climate Change Trends

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 Variabilty and Change ((CV & C)[1]. 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).

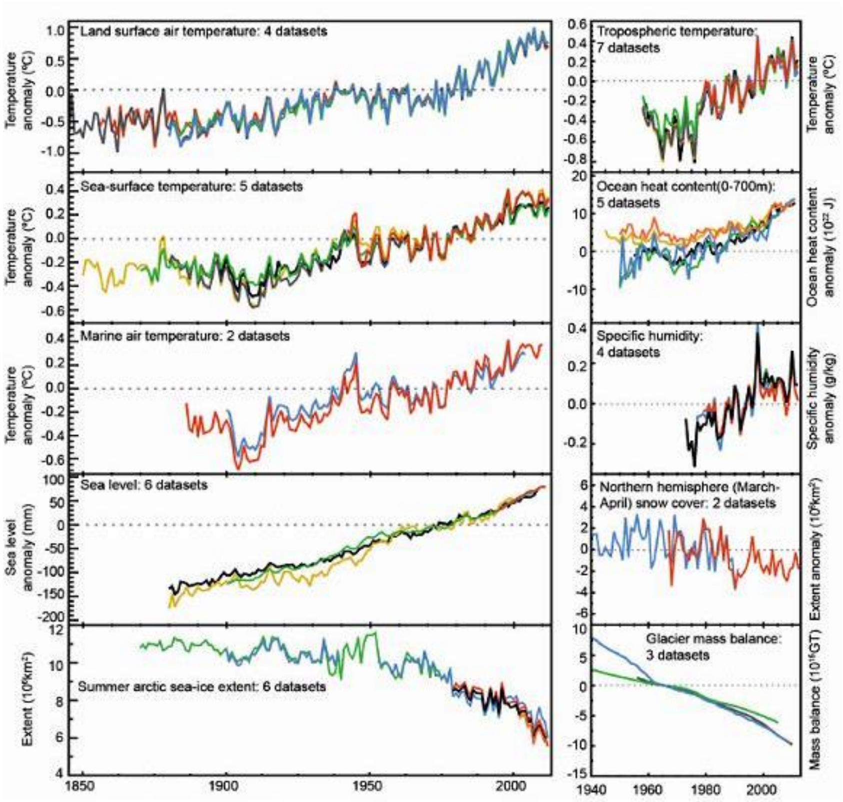

__Figure 1.__ Change of climatic factors. Multiple independent indicators of changing climate. Each line represents an independently derived estimate of change in the climate element. In each panel all data sets have been normalized to a common period of record. (IPCC, 2013 – Chapter 2, pp. 199)

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[1] Note that Climate Variability and Change (CV & C) refers to the variability and sustained change of climatic conditions relative to a reference period, e.g. the first period with accurate records (1850s-1860s) or the average climate of periods with accurate climatic information and construction of infrastructure used today (e.g. 1961-1990 1980-1999).

Temperature increases have been observed in the troposphere during the last decades. The oceans (which probably have absorbed more than 80% of the excess energy associated with the increased emissions since the 1970s) show significant increases in heat content (IPCC, 2013; NCA, 2014), which has resulted in steric increases 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% since satellite records began (1978), particularly at the end (September) of the annual melt season (NCA, 2014). Spring snow cover has shrunk across the NH since the 1950s and glacier ice has been consistently decreasing during the last 20 years (IPCC, 2013).

1.1.1 Temperature and precipitation

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). 15 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% certainty) (GISTEMP/NASA-NOAA, 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, 2015). Record temperatures were widespread in the western part of N. America, the northern, southern and eastern Europe, western Asia, the Indian Ocean, parts of the Arctic Ocean and the western North Atlantic.

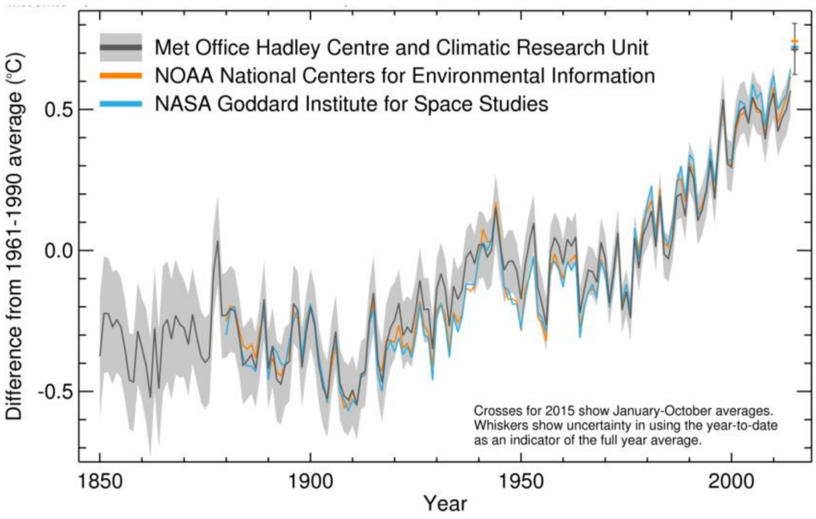

***Figure 2**. Average global near-surface temperature for the period 1850-October 2015, including uncertainties (grey shading). Source: HadCRUT4, NOAA-GlobalTemp, NASA-GISS (Met Office, 2015).*

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 vapor changes, industrial aerosols, solar activity and inter-annual to decadal variability of ocean cycles (e.g. El Niño and La Niña events) (MetOffice, 2015).

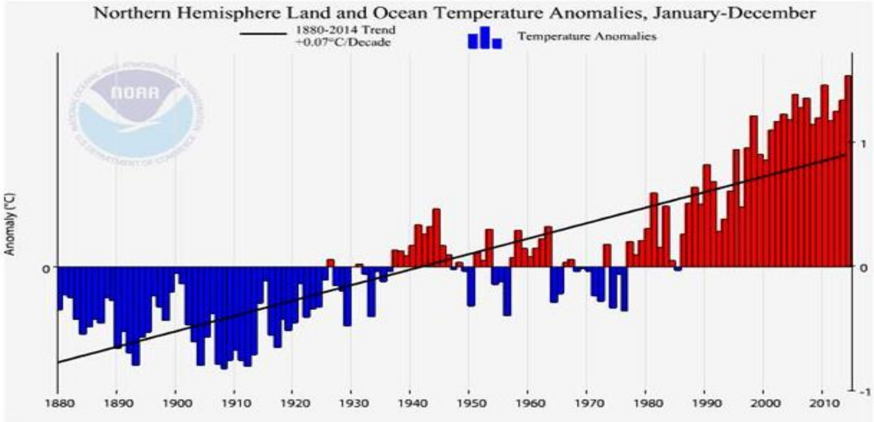

Figure 3. Trends: Land and ocean temperature anomalies 1880-2014. (http://www.ncdc.noaa.gov/cag/time-series/global/nhem/land_ocean/ytd/12/1880-2015?trend=true&trend_base=10&firsttrendyear=1880&lasttrendyear=2015)

It has been observed that years starting during El Niño 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 temepartyiures are predicted to be also high in 2016 (NASA, 2016 http://www.giss.nasa.gov/research/news/20160120/). In comparison, although 2014 was a neutral El Niño year, near surface land temperatures were 0 88 ± 0 20 °C > 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 these suggestions for decreasing rising temperature trends, 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).

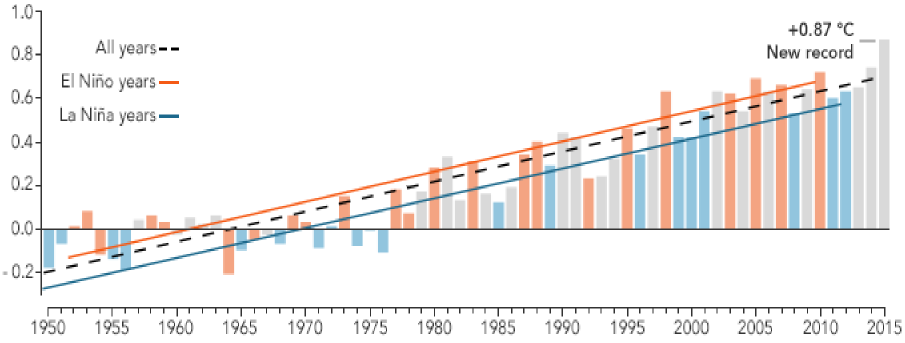

***Figure 4.** Annual temperatures compared to 1951-1980 average. Blue and red bars represent the annual temperature anomalies in El Niño and La Niña years, respectively while blue and red lines represent the trend. Neutral years shown in gray; the dashed line represents the overall average trend since 1950. (NASA/GSFC/Earth Observatory; fig. upd. 2016-01-25)*

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 % 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, 2015).

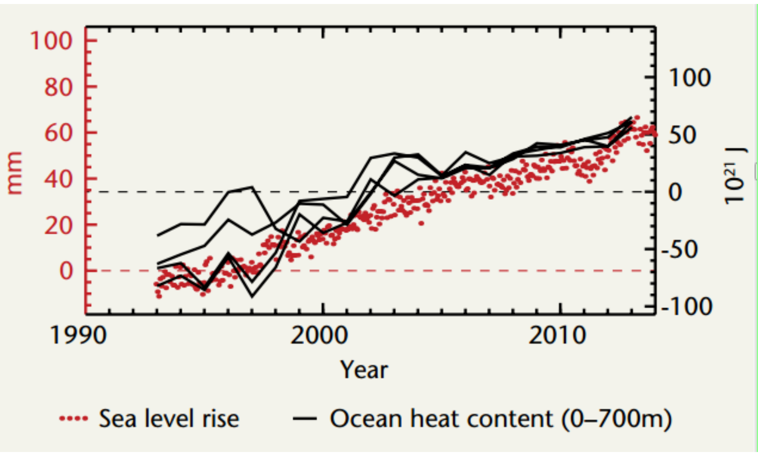

Figure 5:. Observed global average sea level rise and change in ocean heat content for a 20 year period (1993-2013). Sea-level data from a combination of TOPEX (1993–2001), Jason-1 (2002–08) and Jason-2 (2008–13) (available from http://sealevel.colorado.edu/). Ocean heat content is for the top 700 m relative to the 1993–2012 average: data from CSIRO/ACE CRC; PMEL/JPL/JIMAR; NODC; and EN4.0.2 (Met Office, 2015)

Analyses 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 North Hemisphere (NH), confidence in the precipitation trends for the 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).

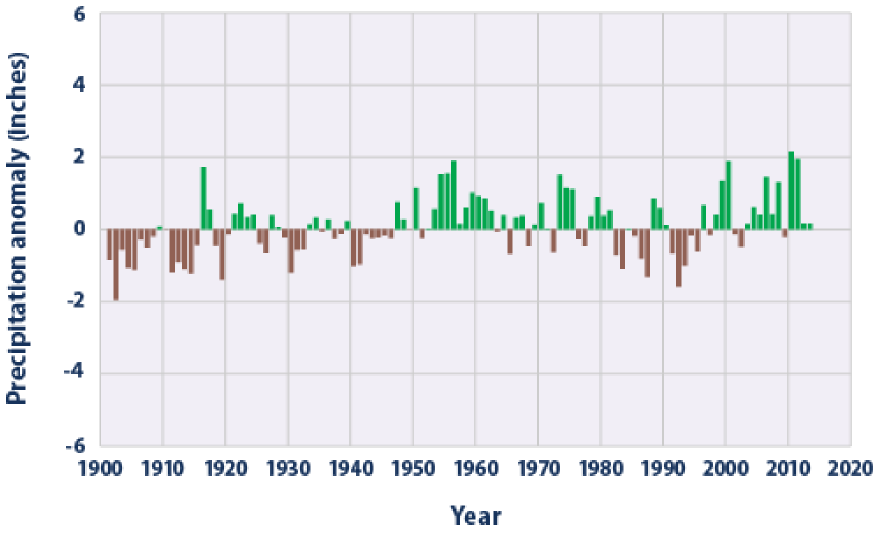

Figure 6. *Total annual global precipitation over land for the period 1901-2013 in relation to the 1901-2000 (www.epa.gov/climatechange/indicators)*

1.1.2 Sea Level

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 ise of □3.3 ± 0.25 cm per decade (Church et al., 2013) and there are discernible accelerations in global sea level acceleration since the 1900s (Fig. 7).

Mean sea level trends and variations in regional climate have led to worldwide 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, 2012).

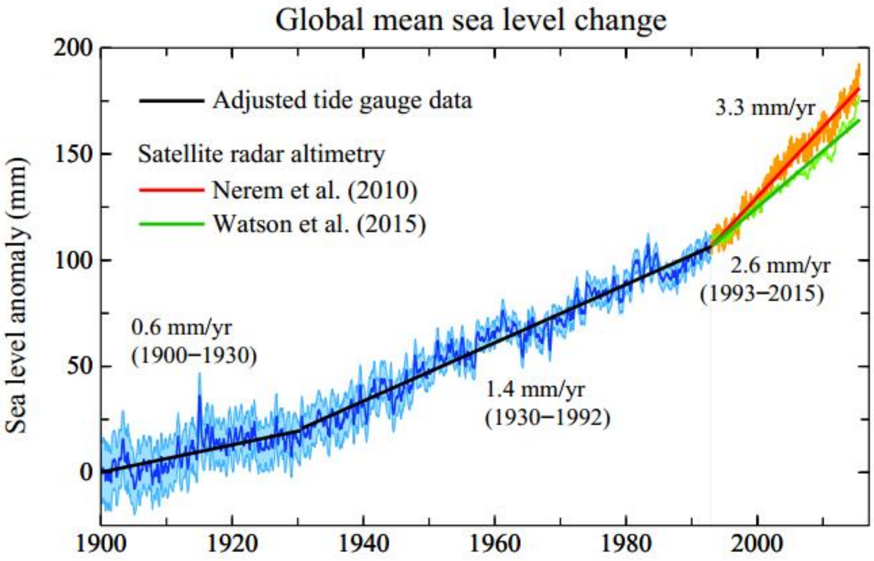

Figure 7. Estimated sea level change (mm) since 1900. Data through 1992 are the tide-gauge record of Church and White (2011) with the change rate multiplied by 0.78, so as to yield a mean 1901–1990 change rate of 1.2 mm year^{-1} (Hansen et al., 2016).

1.1.3 Arctic Ice, Snow and Permafrost

The warming trend affects the cryosphere. Snow cover in the North Hemisphere (which equals to the 98% of the global snow cover) has declined by 11.7 % per decade in June (EEA, 2015b) over the period 1967-2012 (Fig. 8). However, this trend is not uniform with some regions (e.g. the Alps and Scandinavia) which 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).

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 % since 1979 and the 9 lowest September ice extents during the period 1979-2015 have all occurred in the last 9 years (NSIDC, 2015 http://nsidc.org/news/newsroom/PR_2015meltseason). The extent of summer arctic sea ice in 2012 has been estimated at 3.39 million km^2, which is the lowest value ever recorded, while summer surface melting of Greenland ice sheet was above the average in the period 2011-2015 (WMO, 2015). 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 km^2 (WMO, 2015). 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}.

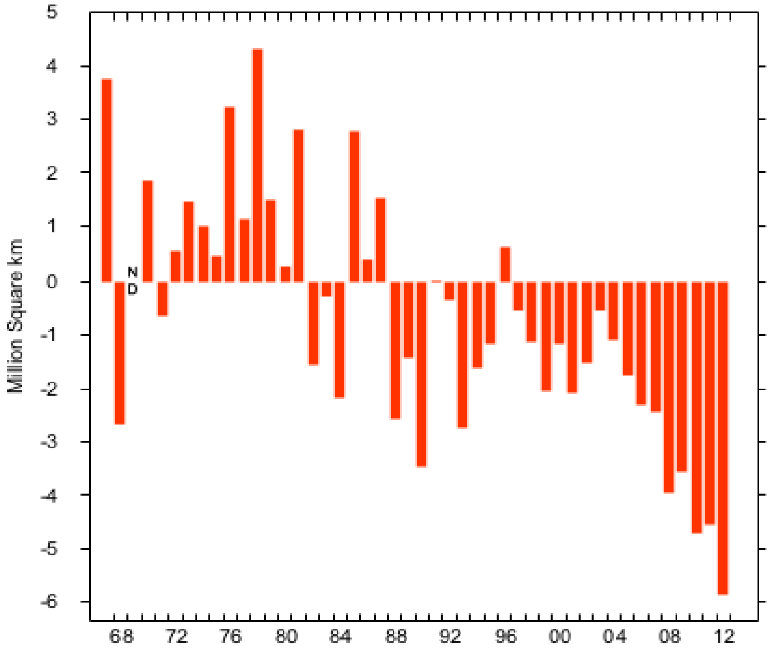

Figure 8: Northern Hemispere snow cover extent for Junes from 1967-2012 (NSIDC, 2012. http://nsidc.org/arcticseaicenews/2012/07/rapid-sea-ice-retreat-in-june/)

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; altogether, ice sheet contribution to SLR is 0.60 (0.42 to 0.78) mm yr^{-1} for the period 1993-2010 (IPCC, 2013).

During the last 5 years (2011-2015), Arctic sea ice continued its decline being above the 1981-2010 mean value, particularly for the winter maximum. In contrast, ice extent in the Southern Ocean reached 20.16 million km^2 in September 2014, 1.45 million km^2 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 km^2, only 0.7 % above the 1981-2010 average (WMO, 2015). 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 (WMO, 2015). Permafrost temperature has increased in most regions by up to 2 ºC since 1980, leading to significant infrastructure damages; thickness of the NH permafrost has decreased by 0.32 m since 1930 (IPCC, 2013a). 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 differences, 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, 2015).

1.1.4 Extreme Climate Events

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 - such as storms, floods, droughts and heat waves - as well as changes in the patterns of particular climatic systems - such as the monsoons - (King et al., 2015) can be, at smaller spatio-temporal scales, the most impacting climatic phenomena (IPCC, 2013) as they may induce more severe effects/natural disasters than changes in the mean variables. Moreover, societies are rarely prepared to face efficiently extreme weather events, having become dependent on predictable, long-term climatic patterns (MetOffice, 2015).

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, 2015).

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 release 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; Met Office, 2015). 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 may 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).

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 deltas 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).

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 (Met Office, 2015) projected that whereas 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).

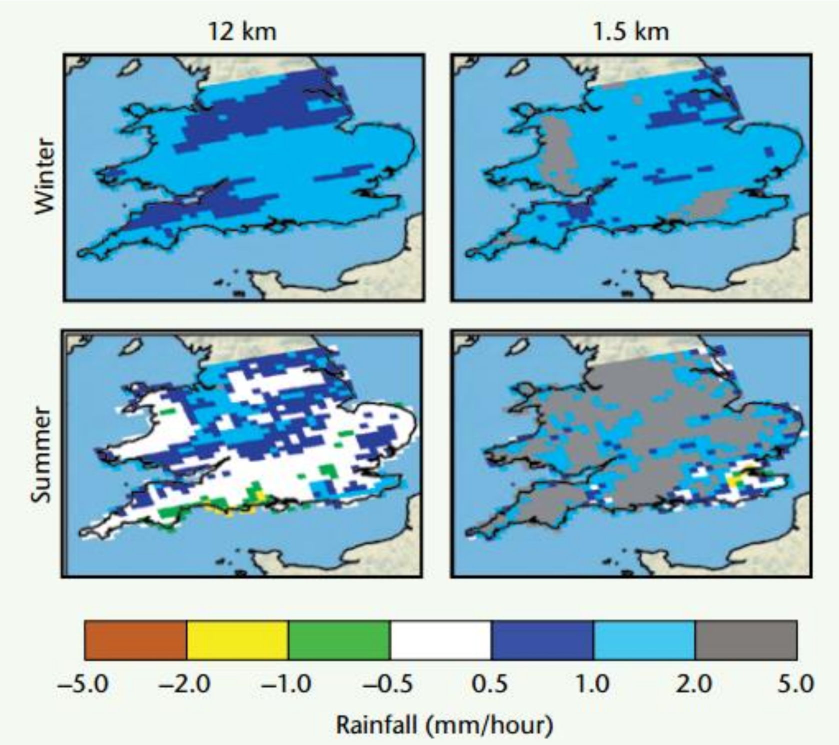

***Figure 9**. Future changes in heavy rainfall in the 12 km (left) and 1.5 km (right) resolution models, for winter (top) and summer (bottom). Both models show increased hourly rainfall intensity during winter, but the 1.5 km model also reveals significant increases in short-duration rain intensity during summer. Changes are for 2100 under high emissions scenario RCP8.5* (Met Office, 2015)

River flooding is the most serious and widespread weather hazard (King et al., 2015). Between 1980 and 2014 river floods accounted for 41 % of all loss events, 27 % of fatalities and 32 % 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 (Feyen et al., 2010). By the 2050, there is at least a 50 % chance that climate change alone would lead to a 50 % increase in flooded people across sub-Saharan Africa, and a 30 to 70 % chance for such an increase in Asia; by 2100 the risks have been projected to be greater (King et al., 2015).

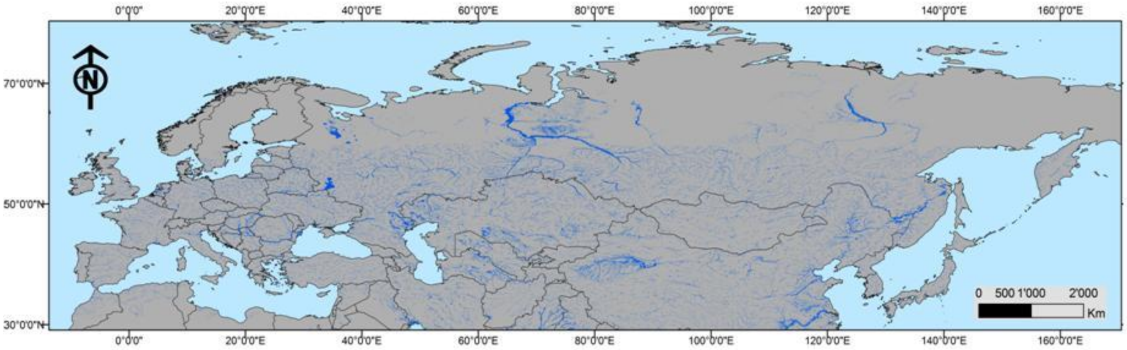

Figure 10. *Current flood hazard (95 % probability) in the Eurasian region of the ECE for the 100-year flood from a global GIS model based on river discharge time-series. DEM resolution 90 m. Areas over 600 N are not fully covered (From UNEP-GRID and UNISDR, 2008). (ECE,2014)*

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 (http://ies.jrc.ec.europa.eu/). 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 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

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 greater 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 N. America (2012) and Europe (2014), whereas the hottest summer on record for N. America was in 2012. The year 2015 was the first time the global average temperatures were 1 ^{o}C or more above the 1880-1899 average http://www.nasa.gov/press-release/nasa-noaa-analyses-reveal-record-shattering-global-warm-temperatures-in-2015). Phenomena such as El Niño (or La Niña) that can warm or cool the tropical Pacific Ocean, can be responsible for such short-term variability in the global temperature and a warming El Niño event occurred for most of 2015. Globally, the 10 warmest years have all occurred since 1998, with 8 of these since 2005 (GISTEMP, 2015).

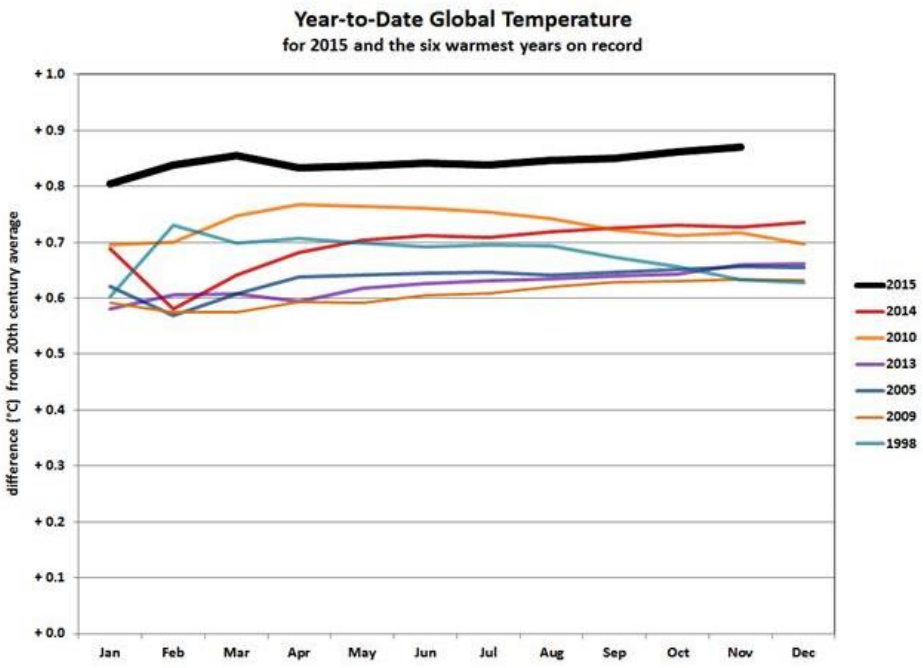

Figure 11 *2011-15 was the warmest 5-year period on record, with temperatures 0.57°C above the 1961-1990 average and 0.51°C the 2006-2010 period Land temperatures were > 1°C above the 1961-90 average over most of Europe, the SW United States and the Asian sector of the Russian Federation and most areas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

Sea surface temperatures for the same 5-year period were above average in most of the world oceans, with the exception of parts of 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 from late 2013: (i) a large area of very warm water (> 2 °C above average) in locations of the eastern North Pacific; and (ii) a persistent pool of below-normal sea surface temperatures in the eastern North Atlantic.

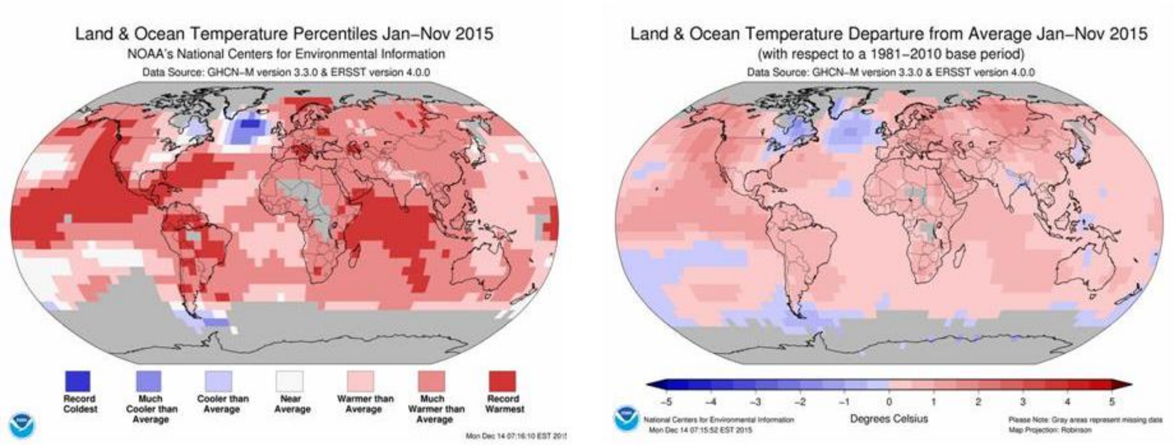

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Figure 12 Temperature anomalies in 2015 (NOAA, 2015)

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.

Three regions (eastern half of Brazil, western US, and parts of eastern Australia) contained 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. southeast Europe and 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, 2016). 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 (and 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).

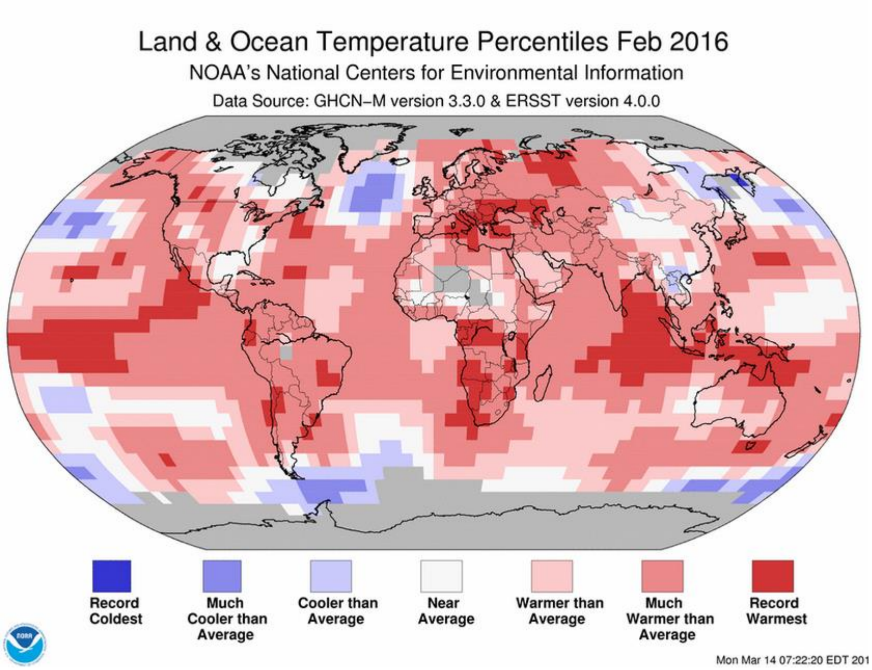

Figure B.1. Land/Ocean Temperature anomalies for February 2016 compared to the global

Sea Level Rise

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 2002-11 period (IPCC, 2013). Regarding the Pacific Ocean, strong regional differences are apparent for the 1993-2014 period that have 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

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 damages/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, 2015). 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 N. India resulted in 13600 deaths (2013). More than 3,700 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 which has been suggested that has caused famine in Somalia (late 2010-early 2012) responsible for 258,000 excess deaths (WMO, 2015).

Heat waves and droughts

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 recorded in Germany.

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

Cold and snow

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 parts of the US and southern Canada, with persistent low temperatures over the region for extended periods (although again 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, 2015).

High winds and tornadoes

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 Joplin (Missouri) there were 157 deaths. During 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 damages, 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

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 the UK, France, Germany, Netherlands and Sweden). The highest storm surge levels since 1953 were recorded in Netherlands and the UK. During the 2013-2014 winter, a sequence of storms led to the UK having its wettest winter on record, causing also significant wind damage and coastal erosion (WMO, 2015).

1.1.6 Forcing Mechanism

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 vapor 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 vapor 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 vapor is strongly dependent on temperature, atmospheric water vapor is regulated by the Earth's temperature itself, increasing with global warming. Thus, water vapor 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).

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 ^{o}C (i.e. about 34 ^{o}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 ^{o}C) of Venus can be 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)

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). At the same time, there is mounting evidence for a link between GHGs concentration and climate. For example, covariation 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 from air trapped in ice show that GHGs have increased by about 40 % since 1800, with most of the increase occurring since the 1970s when global energy consumption accelerated (EEA, 2015b). Furthermore, measurements from ice cores suggest that current CO2 concentrations are higher than at any time in the last 800 000 years http://www.esrl.noaa.gov/gmd/ccgg/trends. The 400 ppm milestone was reached in 09/05/2013 (NAS and RS, 2014). 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, 2015).

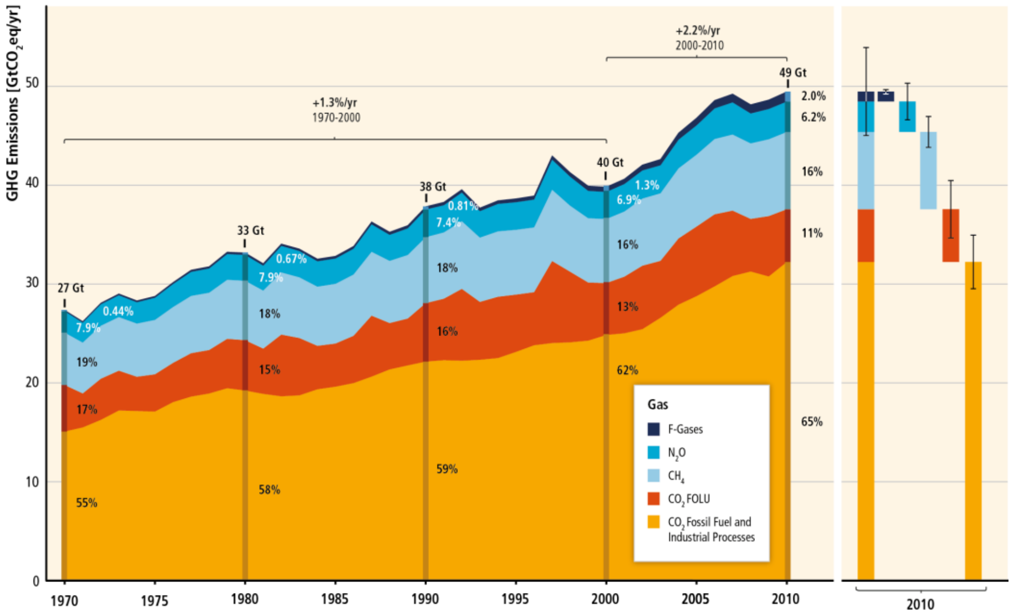

Figure 13 Total annual anthropogenic GHG for the period 1970-2010 (IPCC, 2014b)

CO_2 and N_2O concentration had growth rates in 2011-14 slightly higher than those the 1995-2014 average. CH_4 concentration also showed a renewed period of growth, following a period of little change in 1999-2006 (WMO, 2015). During the last 2 years (2014 and 2015), the annual mean concentrations of GHGs increased. In 2014, CO_2, CH_4 and N_2O concentrations were 397 ppm, 1833 ppb, and 327.1 ppb, respectively (NOAA, 2016). Approximately 44 % of the total CO_2 emitted by human activities from 2004 to 2013 remained in the atmosphere, with the remaining 56 % being removed into the oceans and the terrestrial biosphere (WMO, 2015).

Breakdown of the total anthropogenic GHG emissions in 2010 revealed that CO2 accounted for 76 % of them (65 % due to fossil fuel combustion/industry and 11% due to land-use), CH4 for 16 %, N2O for 6 % and fluorinated gases for 2% (IPCC, 2014b). 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, 2014b). 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, 2014b).

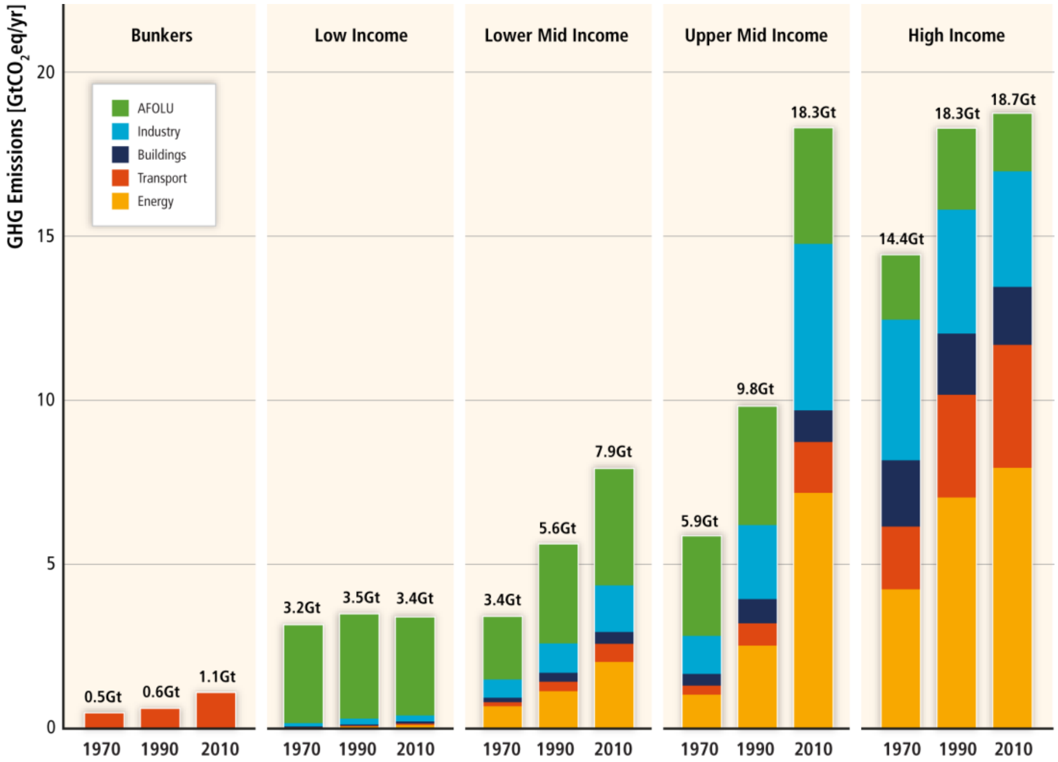

Figure 14 *Total anthropogenic GHGs in 1970, 1990 and 2010 by economic sector and country income groups (IPCC, 2014b)*

1.2 Recent Climate Projections

The now better recorded/understood climatic factor dynamics (e.g. land/sea surface temperature, sea level, arctic ice extent, glacier mass balance) suggest a significant and, in some cases, accelerating climatic change . This information and more recent evidence suggest that transport affecting climatic factors (ECE, 2013) are ‘deteriorating’.

The ocean will warm in all RCP scenarios. The strongest ocean surface warming is projected for the subtropical and tropical regions. At greater depths, warming is projected to be most pronounced in the Southern Ocean. Best estimates of ocean warming in the upper 100 m are about 0.6 °C (RCP2.6) to 2.0 °C (RCP8.5), and for the upper 1000 m 0.3 °C (RCP2.6) to 0.6 °C (RCP8.5) by the end of the 21st century. For RCP4.5, half of the energy taken up by the ocean will be within the uppermost 700 m and 85 % in the uppermost 2000 m. Due to the long time scales of this heat transfer from the surface to deeper waters, ocean warming will continue for centuries, even if GHG emissions were stabilized (IPCC, 2013).

With regard to the atmospheric air temperature, a long-term increasing trend is clear. Concerning temperature projections for the end of the 21st century, it is expected that the atmospheric temperature will increase between 1.0 and 3.7 °C (mean estimates, see Table 1), depending on the scenario. Forced by a range of possible Greenhouse Gas (GHG) concentration scenarios (IPCC, 2013), the central (mean) estimate for the warming has been predicted to be 1.0 - 2.0°C for the period 2046–2065 compared to the mean of the period 1986–2005, whereas by the late 21st century (2081–2100) increases of 1.0 - 3.7 °C are projected. However, the range of the projections broadens to 0.3 - 4.8 °C when model uncertainty is included.

Table 1. Forecasts of global mean surface temperature and global mean sea level changes for the period 2081-2100 (means and likely ranges) with respect to the period 1986–2005, according to different scenarios (after IPCC, 2013). Predictions are made according to 4 radiative forcing scenarios (Representative Concentration Pathways-RCP)[2]: RCP 8.5, 6184 Gt C02 (2012-2100 cumulative CO2 emissions); RCP 6.0 3890 Gt C02; RCP 4.5, 2863 Gt CO2; and RCP 2.6, 991 Gt CO2. Global mean surface temperature changes are based on the CMIP5 ensemble (5–95% model ranges). Sea level rise estimates are based on 21 CMIP5 models (5–95% model ranges). The contributions from ice sheet rapid dynamical change and anthropogenic land water storage are treated as having uniform probability distributions, and as largely independent of scenario, as the current knowledge state does not permit quantitative assessments of the dependence[3].

Scenario	Temperature		Sea Level Rise	
	Mean (°C)	Likely Range (°C)	Mean (m)	Likely Range (m)
RCP 2.6	1.0	0.3-1.7	0.40	0.26-0.55
RCP 4.5	1.8	1.1-2.6	0.47	0.32-0.63
RCP 6.0	2.2	1.4-3.1	0.48	0.33-0.63
RCP 8.5	3.7	2.6-4.8	0.63	0.45-0.82

1.2.1 Temperature and Precipitation

Climate does not change uniformly, with temperatures close to the poles rising faster than at the equator (Figs. 15 and 16). Precipitation is changing in a much more complex manner, with some regions becoming wetter and others dryer (ECE, 2013). Such trends are expected to pick up pace in the future, as e.g. in the E. Mediterranean where mean rainfall has been predicted to decrease by up to 25 % in the decade 2020-2029 compared to that of the decade 1990-1999

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[2] 2 The recent IPCC Assessment Report AR5 (2013) forecasts are made on the basis of the Representative Concentration Pathways-RCP scenarios and not the IPCC SRES scenarios. The CO2 equivalent concentrations have been set to (e.g. Moss et al., 2010): RCP 8.5, 1370 C02-equivalent in 2100; RCP 6.0 850 CO2-equivalent in 2100; RCP 4.5, 650 CO2-equivalent in 2100; and RCP 2.6, peak at 490 CO2-equivalent before 2100.

3 According to the scenarios the sea level will not stop rising in 2100, but will continue rising during the following centuries; median sea level rises of 1.84 for the lowest and 5.49 m for the highest forcing scenario (RCP 8.5) have been projected for 2500 (Jevrejeva et al., 2012).

(IPCC, 2007). Under both low-moderate (RCP 4.5) and high emission (RCP8.5) scenarios, large increases in surface temperatures are projected, particularly for the northern ECE region (IPCC, 2013).

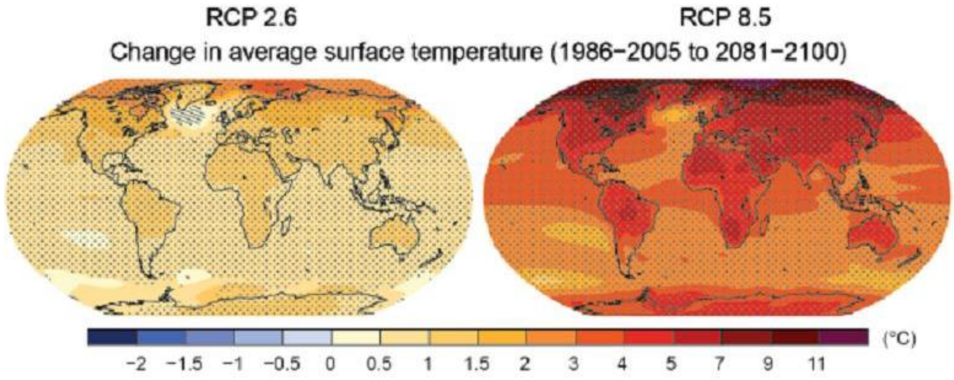


***Figure 15** Projected changes in average temperatures in 2081-2100 relative to 1986-2005 for low (RCP2.6) and high emission (RCP8.5) scenarios (IPCC, 2013)*

Climate model projections suggest widespread droughts across most of southwestern North America and many other subtropical regions by the mid to late 21st century (Milly et al., 2008; IPCC, 2013). In contrast, while summers are expected to become (overall) drier by 2100 over the UK, precipitation events may become heavier. In particular, model simulations suggest that intense rainfall associated with flash flooding (more than 30 mm in an hour) could become almost 5 more frequent (Met Office, 2015).

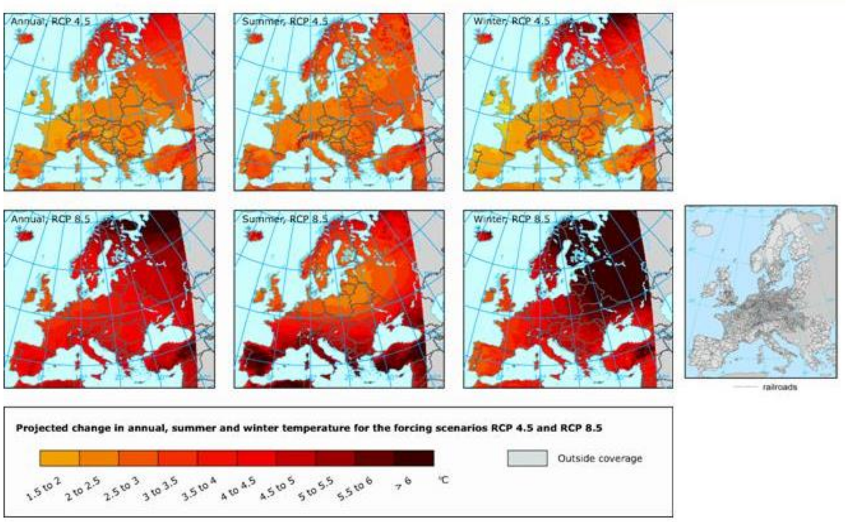


***Figure 16** Projected changes in annual (left), summer (middle) and winter (right) surface air temperature (°C) in 2071-2100 compared to 1971-2000 for forcing scenarios RCP4.5 (top) and RCP8.5 (bottom). Model simulations from RCMs (EURO-CORDEX initiative). http://www.eea.europa.eu/data-and-maps/figures/projected-changes-in-annual-summer-1*

Studies also project decreases in the duration/intensity of droughts in the South Europe and the Mediterranean, the central Europe and parts of the North America (e.g. IPCC, 2013). At the same time, recent studies suggest severe/widespread droughts for the next 30–90 years (Dai et al., 2013) for most of southwestern North America and subtropical regions (IPCC, 2013).

1.2.2 Sea Level Rise

Process-based predictions of sea-level rise are limited by uncertainties surrounding the response of the GIS and WAIS (Pritchard et al., 2012), steric changes (Domingues et al., 2008), contributions from mountain glaciers (Raper and Braithwaite, 2009), as well as from groundwater pumping for irrigation purposes and storage of water in reservoirs (Wada et al., 2012). Antarctica has the potential to contribute by > 1 m of sea level rise by 2100 (De Conto and Pollard, 2016).

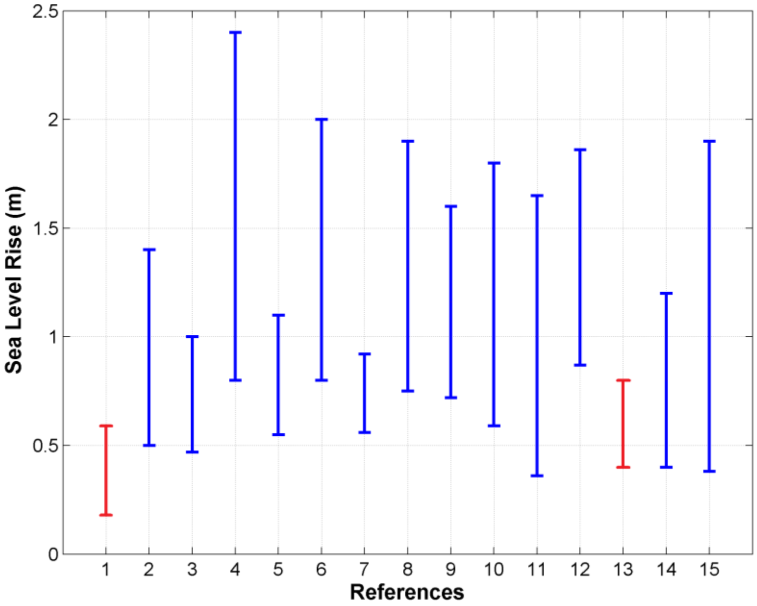


Figure 17 *Recent sea level rise projections for 2100 compared to that of IPCC (2007a). Key: 1, IPCC (2007a), 0.18-0.59 m; 2, Rahmstorf et al. (2007); 3, Horton et al. (2008); 4, Rohling et al. (2008); 5, Vellinga et al. (2008); 6, Pfeffer et al. (2008); 7, Kopp et al. (2009); 8, Vermeer and Rahmstorf (2009); 9, Grinsted et al. (2010); 10, Jevrejeva et al. (2010); 11, Jevrejeva et al. (2012); 12, Mori et al. (2013); 13, IPCC (2013); 14, Horton et al., 2014; and 15, Horton et al., 2015. The variability of the projections reflects differences in assumptions and approaches.*

Global MSL has risen by 0.19 m in 1901-2013 (average rate 1.7 mm/year), whereas in the last two decades, the rate has accelerated to 3.2 mm/year. Model project a likely rise in 2081–2100 (compared to 1986–2005) in the range 0.26–0.54 m for RCP2.6 and 0.45–0.82 m for RCP8.5 (Fig. 18). It is thought that the steepening of the curve of the sea level rise during the last decades is mostly due to the increasing contribution of ice loss from the Greenland and Antarctica ice sheets (e.g. Rignot et al., 2011; Hanna et al., 2013; IPCC, 2013). Sea level estimates based on alternative approaches project a mean sea level rise much larger than that predicted a decade earlier (IPCC, 2007); it must be also noted that IPPC gives consistently more conservative estimates (Fig. 17). Sea-level rise will not cease in 2100 (see e.g. Jevrejeva et al., 2012), as the changes in ocean heat content could affect thermal expansion for several centuries at least, whereas melting and dynamic ice loss in Antarctica and Greenland will also continue well into the future.

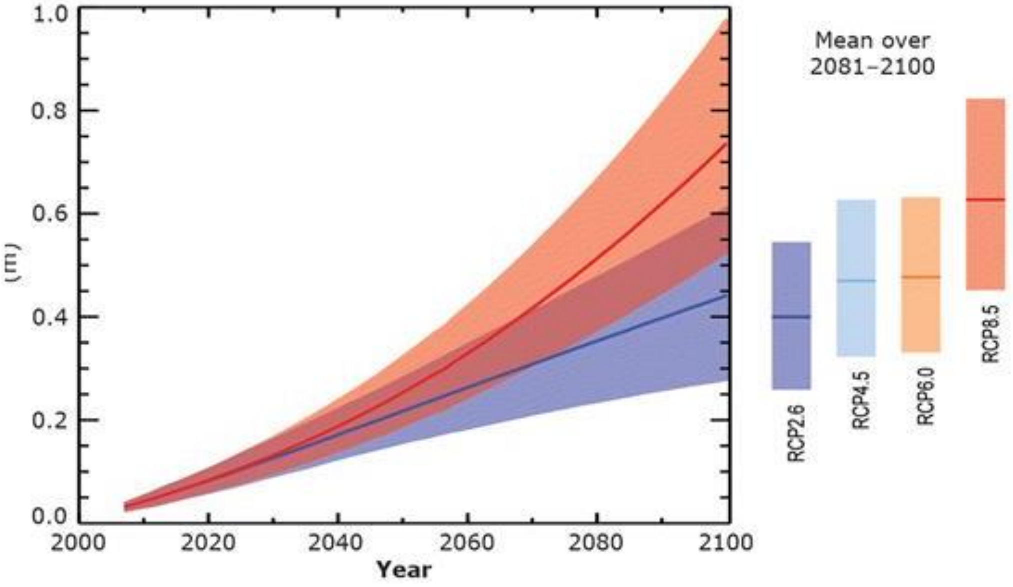


Figure 18 *Projected global MSLR over the 21st century relative to 1986-2005 (http://www.eea.europa.eu/data-and-maps/figures/projected-change-of-global-mean)*

It should be noted that due to the large spatial variability observed (and projected) in the sea level rise (Fig. 19), regional trends in sea level should be considered when assessing potential impacts along any particular coast (e.g. Carson et al., 2016). In addition to the global processes, regional factors may also contribute to observed coastal sea level changes, such as changes in ocean circulation (e.g. Meridional Overturning Circulation (MOC)) and differential rates in regional glacial melting, and glacio-isostatic adjustment (GIA) and sedimentary deposit subsidence (IPCC, 2013; King et al., 2015; Carson et al., 2016). Palaoclimate, instrumental and modeling studies have shown that combinations of global and regional factors can cause relatively rapid rates of sea level rise along particular coasts that can exceed the current global rate of about 3 mm yr^{-1} significantly (e.g. Cronin, 2012). For the UK, sea level rise (excluding land level changes) for the 21st century has been projected to be 0.12 - 0.76 m depending on the emission scenario, with larger rises predicted in the case of additional ice sheet melting (Lowe et al., 2009). For the North Sea coast of the Netherlands, Katsman et al. (2011) have estimated sea level rises of 0.40 - 1.05 m for a plausible high end emission scenario. However, Marcos and

Tsimplis (2008) have predicted a temperature-driven sea level rise of 0.03 - 0.61 m in the Mediterranean for the 21st century on the basis of 12 global climate models and for three emission scenarios; this rise should be combined with salinity driven changes of - 0.22 - 0.31 m (see also EEA, 2012).

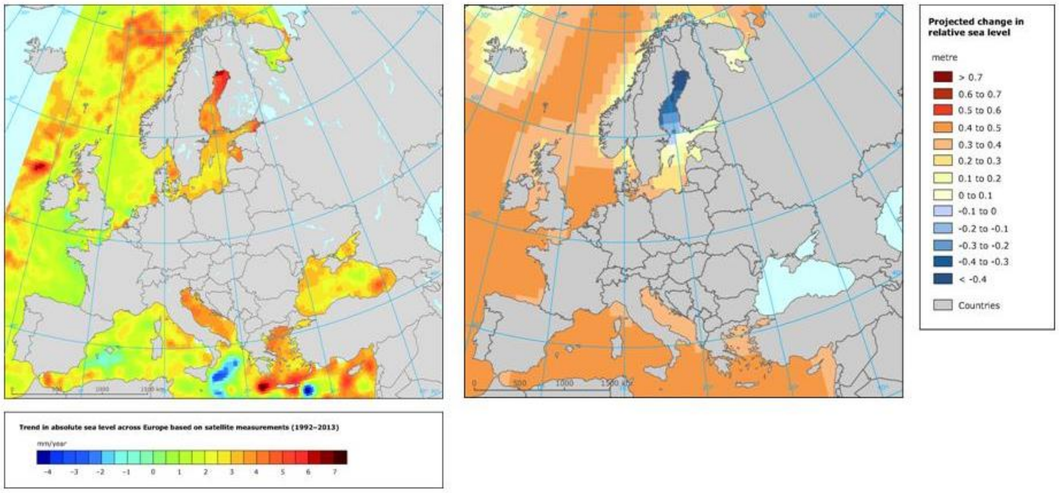


Figure 19 *Trends in absolute sea level in European Seas from satellite measurements (1992–2013) (http://www.eea.europa.eu/data-and-maps/figures/sea-level-changes-in-europe-october-1992-may-1). Projected change in relative sea level in 2081-2100 compared to 1986-2005 for the medium-low emission scenario RCP4.5 (from an ensemble of CMIP5 climate models). No projections are available for the Black Sea. (http://www.eea.europa.eu/data-and-maps/figures/projected-change-in-sea-level).*

1.2.3 Arctic ice, snow and permafrost melt

Arctic snowfall and rainfall are projected to increase in all seasons, but mostly in winter; thus maximum snow depth during winter over many areas is projected will increase, with the most significant trend (15 – 30% by 2050) taking place in Siberia. However, snow will tend to lie on the ground for 10 – 20 % less time each year over most of the Arctic, due to earlier melting in spring (AMAP, 2012). Spring snow cover in the North Hemisphere will decrease by 7% (RCP2.6) and 25% (RCP8.5), by 2100 (Figure 20a). Models project continued thawing of permafrost due to rising global temperatures and changes in snow cover (AMAP, 2012). Current warming rates at the European permafrost surface are 0.04 – 0.07 °C/year (EEA, 2015b). Although there are many implications regarding the magnitude of permafrost change, including soil processes, climate forcing scenarios and model physics, permafrost extend is expected to decrease by 37 % and 81 % for RCP2.6 and RCP8.5 scenarios respectively by the end of the 21st century (medium confidence) (Figure 20b). As for mountain glaciers and ice caps, climate model projections show also a 10 – 30 % mass reduction by the end of the century (AMAP, 2012).

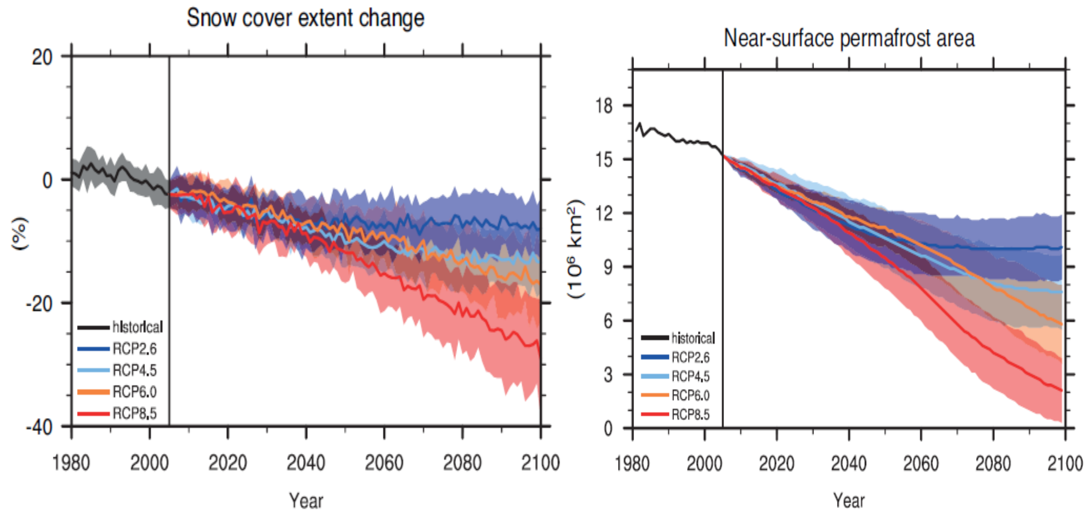


***Figure 20** Projected snow cover extent and near-surface permafrost changes, for 4 Representative Concentration Pathways-RCPs (from CMIP5 model ensemble) (IPCC, 2013)*

In the coming decades it is very likely that the Arctic sea ice will continue to reduce in extent/thickness as global mean surface temperature rises, although considerable variation from year to year will remain (Figure 20a). Based on the CMIP5 model ensemble, projections of the Arctic sea ice extend show an average reduction for the period 2081-2100 compared to 1986-2005 from 8 % to 34 % in February and from 43 % to 94 % in September (lower and upper limits result from RCP2.6 and RCP8.5 respectively) (IPCC, 2013).

Continuing global warming will have a strong impact on the GIS in the following decades. In the present climate, Greenland Surface Mass Balance (GSMB) is positive but shows a decreasing trend, implying an increasing contribution to MSL rise. Based on the available evidence, it is very unlikely that SMB changes will result in an irreversible decrease of the Greenland ice sheet in the 21st century but likely on multi-centennial to millennial time scales in the strongest forcing scenarios (IPCC, 2013). The average and standard deviation of accumulation (precipitation minus sublimation) estimates for 1961–1990 is –1.62 ± 0.21 mm yr^{-1} SLE. All information indicates that the GSMB showed no significant trend from the 1960s to the 1980s, then started becoming less positive in the early 1990s, on average by 3 % yr^{-1}. This results in a statistically significant and increasing contribution to the rate of GMSL rise (Fig. 21). IPCC (2013) suggest that, during the next century, dynamical change of Greenland ice sheet is likely (medium confidence) to contribute to SLR by 20 - 85 mm for RCP8.5, and 14 - 63 mm for all other scenarios. Other studies project 0.92 ± 0.26 mm yr^{-1} SLE compared to the 1961–1990.for SMB (accumulation minus runoff, neglecting drifting snow erosion) (Hansen et al., 2016). In comparison, the SMB of the Antarctic ice sheet is projected to increase under most scenarios due to an increasing snowfall trend; however, a negative Antarctica SMB has the potential to contribute more than 1 m of sea level rise by 2100 (De Conto and Pollard, 2016).

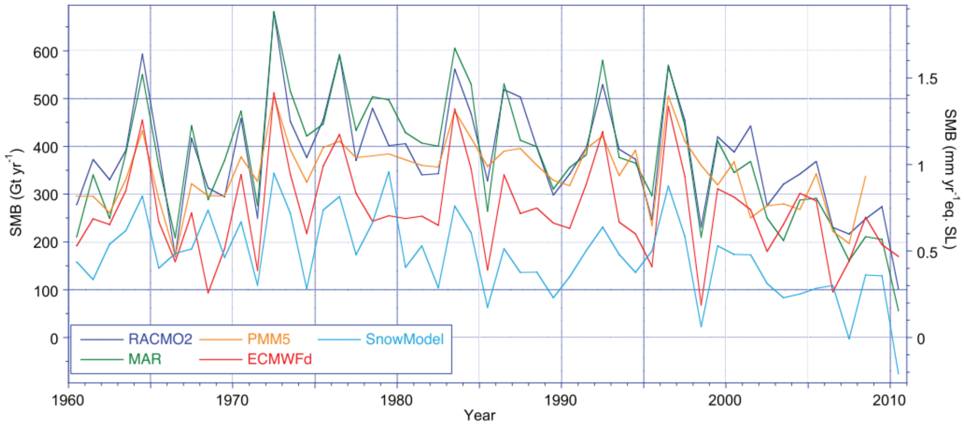
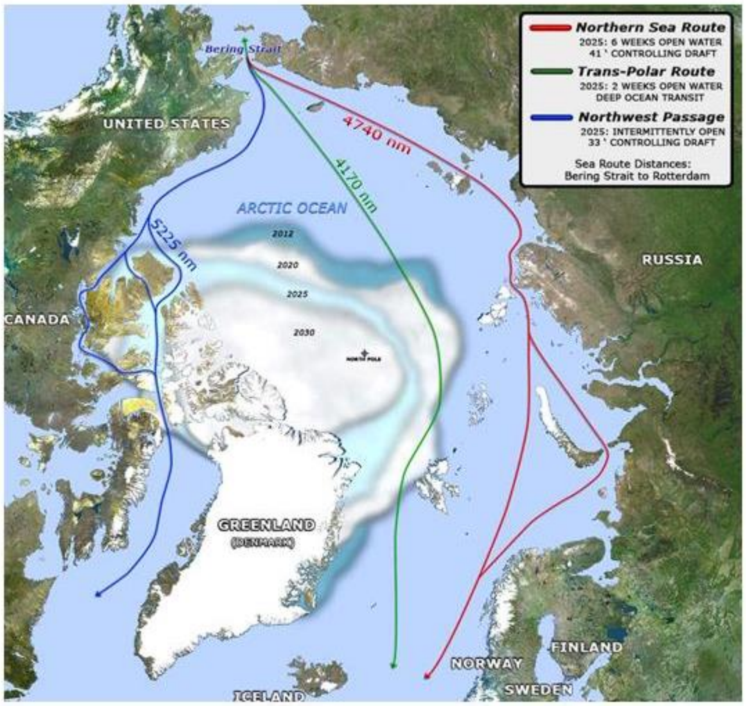


Figure 21 *Annual mean Surface Mass Balance for the Greenland ice sheet, simulated by five regional climate models for the period 1960–2010 (Hansen et al., 2016)*

Concerning Arctic ice, the US Navy anticipates the development of 3 major shipping routes by 2025, which however are associated with several environmental risks (Fig. 22). There may be new economic opportunities for Arctic communities, as reduced ice extent facilitates access to the substantial hydrocarbon deposits (Beaufort and Chukchi seas) and international trade. At the same time, CV & C will affect existing infrastructure and all future development due to thawing permafrost and coastal wave activity.



Figur 22. New Arctic shipping routes. (https://toolkit.climate.gov/topics/arctic/arctic-development-and-transport)

1.2.4 Extreme climate events

Increases in hot extremes and decreases in cold winter extremes are expected by the end of the 21th century, with the frequency, duration and magnitude of the events being affected by anthropogenic forcing (IPCC, 2013). Greater changes in hot days are expected to take place in sub-tropic and mid-latitude regions (Fig. 23), whereas the frequency of cold days will decrease in all regions. Projections show that very hot summers will occur much more frequently in the future under all Climate Change scenarios.

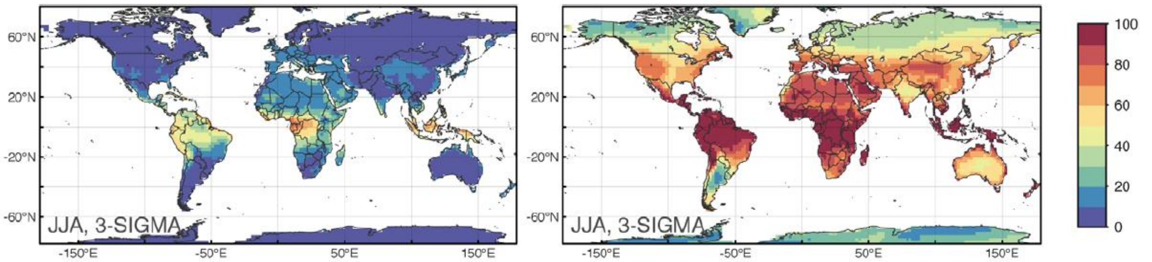


__Figure 23__ Projected changes in hot seasonal temperature extremes in 2071-2100 for RCPs 2.6 and 8.5. Yellow, orange/red areas show regions where (at least) 1 every 2 summers will be warmer that the warmest summer in 1901-2100 (Coumou and Robinson, 2013)

Heat waves

It is also likely that the frequency and duration of heat waves (prolonged period of excessive heat) will increase, mainly due to the increasing seasonal mean temperature trends (Fig. 23). For most land regions it is likely that the frequency of a current 20-year hot event will be doubled (though in many regions it might even occur every 1-2 years), while the occurrence of a current 20-year cold event will dramatically be reduced, under the RCP8.5 scenario (IPCC, 2013). Large increases in heat waves are projected for Europe along with the probability of high summer temperatures particularly under RCP8.5 (Fig. 24).

Heat waves as severe as the one in 2003 is expected to occur about once a century for the current climate; in early 2000s, it was expected to take place approximately once every several thousand years. An attribution study has suggested that anthropogenic influence at least doubled the odds of occurrence of such an event (MetOffice, 2015). Furthermore, recent studies suggest that the probability of occurrence of an extreme heat wave like the one that stroke Russia in 2010 may increase by 5-10 times until 2050 (Dole et al., 2011).

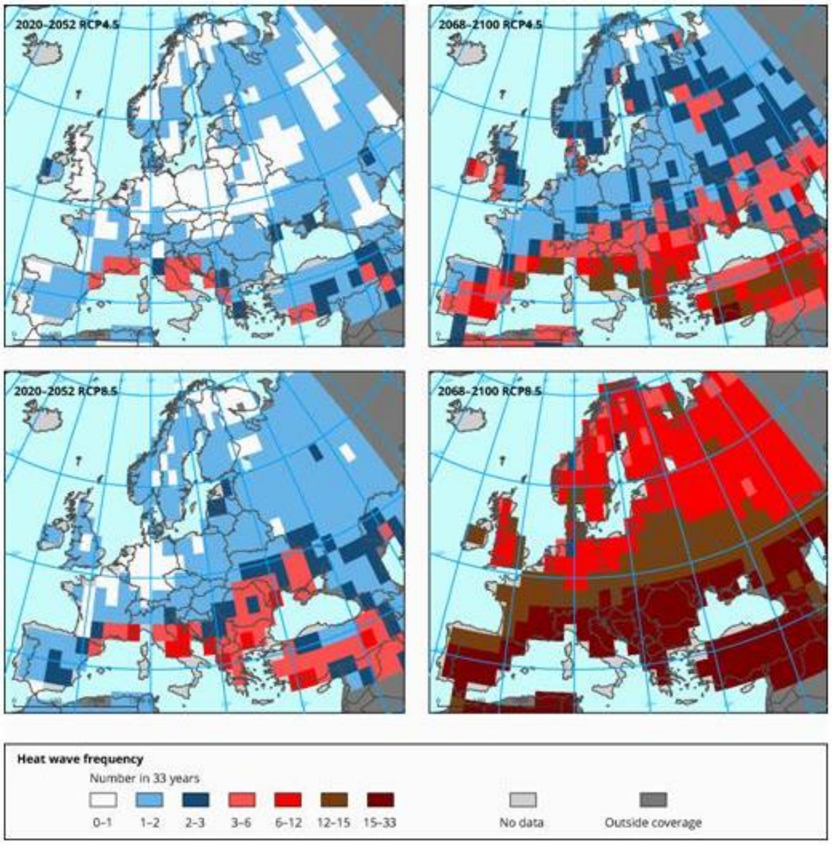


Figure 24 Median of the projected number of heat waves (from a model ensemble) in the near (2020–2052) and long (2068–2100) term under the RCP4.5 and RCP 8.5 scenario (EEA, 2015).

Downpours

Extremes linked to the water cycle -such as droughts, heavy rainfall and floods- are already causing substantial damages. As temperature rises, average precipitation will exhibit substantial spatial variation; it is likely that precipitation will increase in high and mid latitude land regions and decrease in subtropical arid and semi-arid regions by the end of this century under the RCP8.5 scenario. Extreme precipitation events will very likely be more intense over most of the mid-latitude and wet tropical regions (IPCC, 2013). For central and NE Europe, projections demonstrate large increases (25 %) in heavy precipitation by the end of the 21st century (Figure 25). High resolution climate models indicate that extreme summer rainfalls could intensify with climate change (MetOffice, 2015). For the UK, although summers will become drier overall, the occurrence of heavy summer downpours (more than 30 mm in an hour) could increase almost 5 times (MetOffice, 2015).

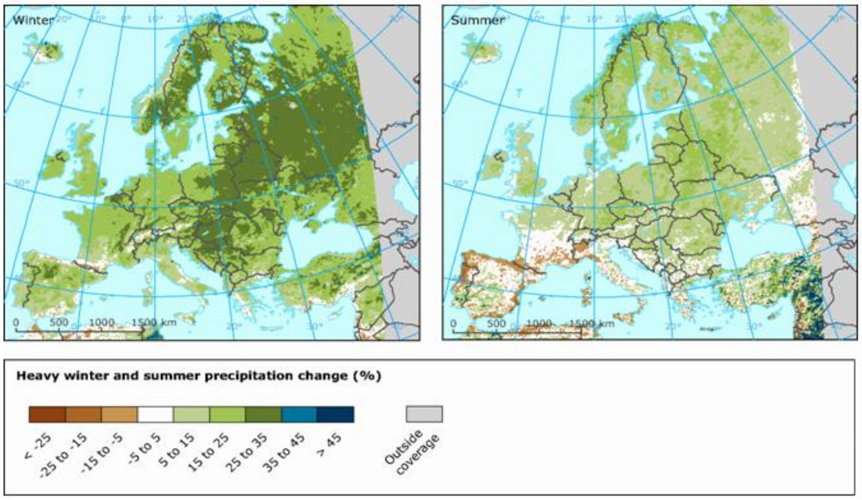


***Figure 25** Projected changes in heavy precipitation (in %) in winter and summer from 1971-2000 to 2071–2100 for the RCP8.5 scenario based on the ensemble mean of regional climate models (RCMs) nested in general circulation models (GCMs) (EEA, 2015)*

Storm surges and riverine floods

Despite the emerging risks associated with the changes in extreme coastal water levels, there is still limited, if any, information on storm surge levels (SSL) projections under the Representative Concentration Pathways (RCPs) (IPCC 2013). That's mainly because most previous studies are at local/regional scale which implies that (a) there are several regions for which there is no information on projected SSL and (b) the use of different GHG emission scenarios, climate and ocean models, as well as the diversity of the coastal environments make it difficult to draw general conclusions at global or regional scales.

For Europe, projections show larger storm surge levels for the Atlantic and Baltic coast/ports under all scenarios and extreme storm events tested (Vousdoukas et al., 2016). The North Sea is an area subject to some of the highest SSL in Europe (Fig. 26), with the projections indicating an increase in the extremes, especially along the eastern coast. Storm surge projections showed an increase along the Atlantic coast of the UK and Ireland, due mostly to a consistent increase of the winter extremes. The Atlantic coast of France, Spain and Portugal is exposed to very energetic waves generated along the North Atlantic (Pérez et al. 2014). The Mediterranean Sea has been studied extensively in terms of projected storm surge dynamics and there is consensus among studies based on SRES scenarios for no changes, or even a decrease in the frequency and intensity of extreme events (Conte and Lionello 2013; Androulidakis et al. 2015). This is in agreement with reported historical trends (Menéndez and Woodworth 2010), as well as with more recent findings, projecting changes mostly in the ±5 % band, either positive or negative (Vousdoukas et al., 2016). The North Adriatic is a region which has been studied more thoroughly due to the highly vulnerable (and socio-economically important) Venice area, with most previous projections reporting no statistically significant change, or even decreases (Mel et al. 2013), even though Lionello et al. (2012) projected increases in the frequency of extreme events around Venice, under a B2 SRES scenario.

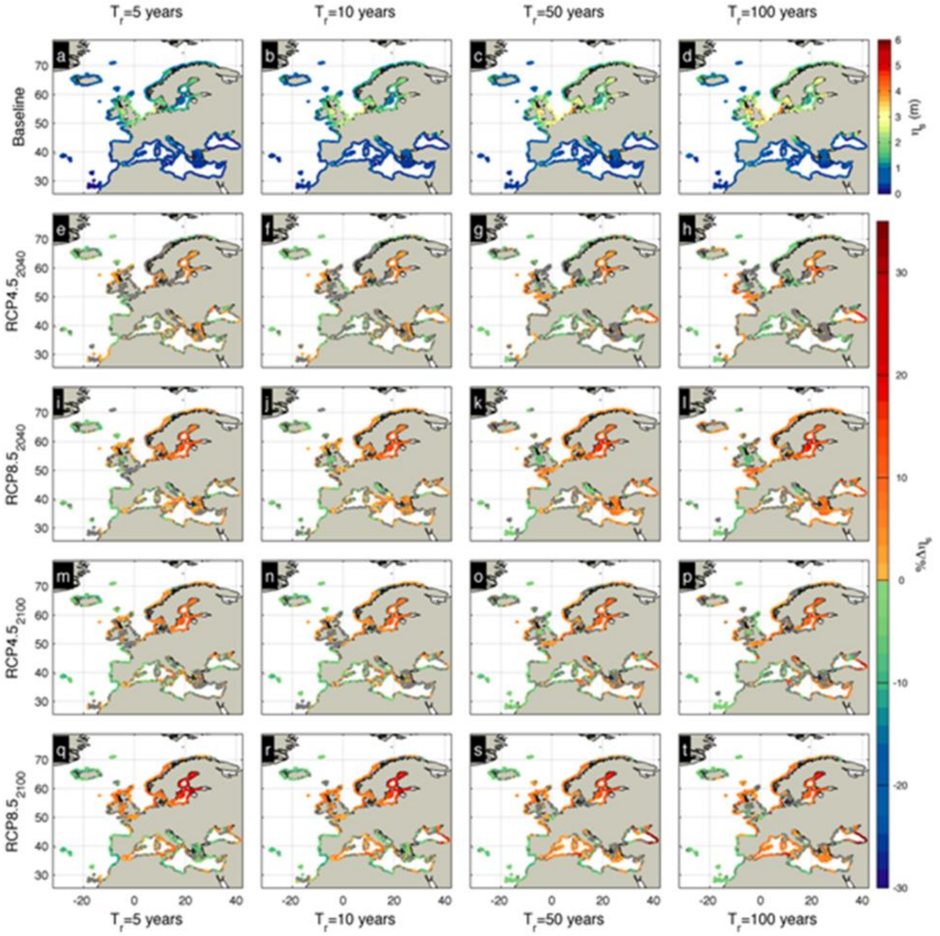


***Figure 26** Ensemble mean of extreme SSL (**m**) along the European coastline obtained for 5, 10, 50, and 100 years return periods (shown in different columns), for the baseline period (**a**–**d**), as well as their projected relative changes under RCP4.52040 (**e**–**h**), RCP8.52040 (**i**–**l**), RCP4.5 2100 (**m**–**p**), RCP8.52100 (**q**–**t**) scenarios (shown in different lines). Warm/cold colors express increase/decrease, respectively; while points with high model disagreement are shown with gray colors (Vousdoukas et al., 2016).*

It should be noted that more than 200 million people worldwide live along coastlines less than 5 m above sea level; this figure is estimated to increase to 400 - 500 million by the end of the 21st century. Growing exposure (population and assets), rising sea levels due to climate change, and in some regions, significant coastal subsidence due to human coastal water drainage/groundwater withdrawals will increase the flood risk to varying degrees. For instance, a 1 m rise in relative sea-level increases the frequency of current 100 year flood events by about 40 times in Shanghai, about 200 times in New York, and about 1000 times in Kolkata (WMO, 2014). For the next 50 years or so, Hallegatte et al. (2013) suggested that for the 136 largest coastal cities: (i) Damages could rise from US$ 6 billion/year to US$ 52 billion/year solely due to increase in population and assets; (ii) annual losses could approach US$ 1 trillion or more per year if flood defenses are not upgraded; (iii) even if defenses would be upgraded, losses could increase as flood events could become more intense due to the water depths increasing with relative sea-level rise. This raises the question of whether there are potential thresholds which, if passed, could reverse the current and projected trends of coastal population growth (King et al., 2015).

River flooding also poses a significant threat to the global population with observed increases in extreme runoffs being well documented. Damage magnitude is mainly due to increasing human and infrastructure exposure in flood risk areas (IPCC, 2013). Changes in river floods projected for Europe are presented in Figure 27.

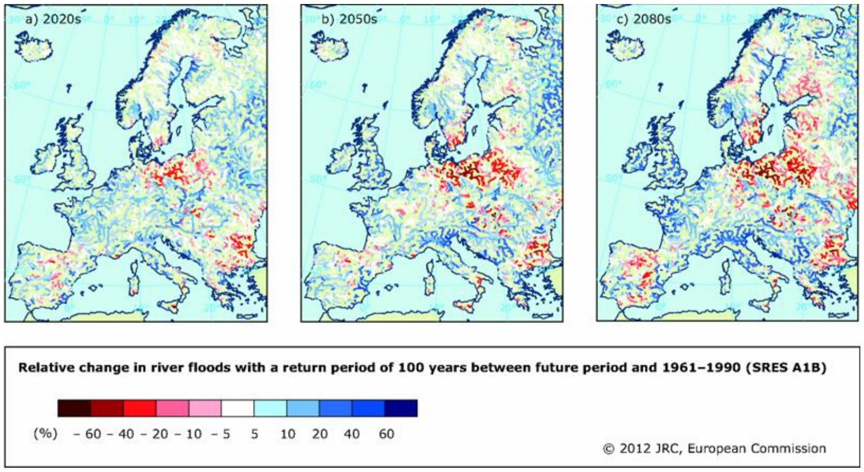


Figure 27 *Relative change in minimum river flow for a) 2020s, b) 2050s and c) 2080s compared to 1961-1990 for SRES A1B scenario (EEA, 2012)*

Figure 28 shows the flood risk by region that climate change increases by more than 50% the numbers of people affected by a current 30-year flood, relative to the situation without climate change. By the 2050s, there is at least a 50 % chance that climate change alone would lead to a 50 % increase in flooded people across sub-Saharan Africa, and a 30-70% chance that such an increase would also take place in Asia. By 2100, risks will be greater (King et al., 2015). Population change alone will increase the numbers of people affected by flooding. Global total increases very substantially – by around 5-6 times over the course of the century for the high emissions pathway (RCP8.5), mainly due to increases in South, southeast and East Asia (King et al., 2015).

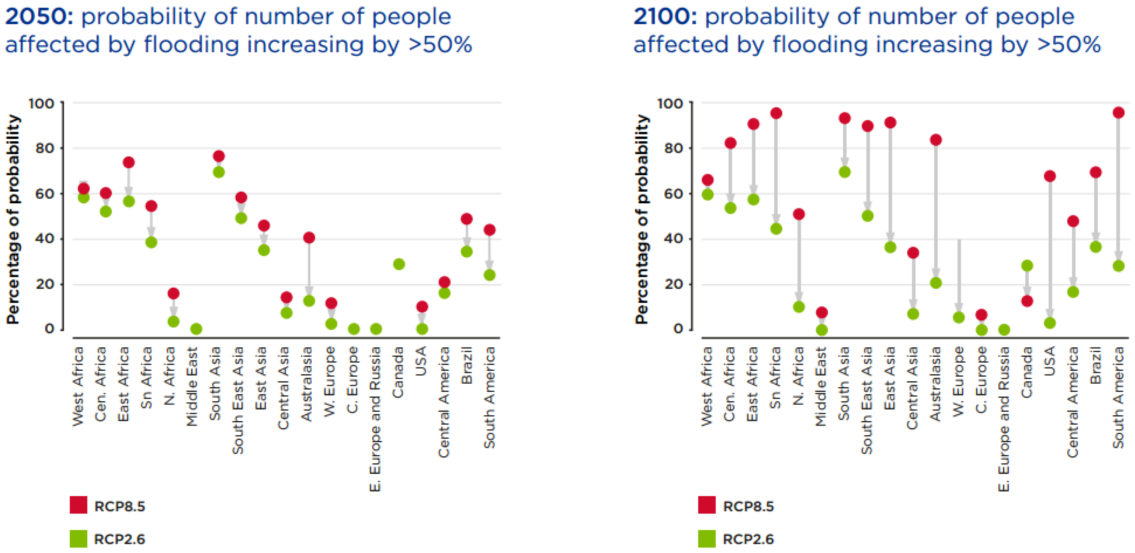


Figure 28 *Probability that climate change will increase by more than 50% the number of people affected by the current 30-year flood, relative to the situation with no climate change, under two RCPs. Medium growth population projection is assumed (King et al., 2015)*

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