Informal document WP.5 (2017) No. 8

Distr.: General
14 August 2017

English only

Economic Commission for Europe

Inland Transport Committee

Working Party on Transport Trends and Economics

Thirtieth session
Geneva, 4-6 September 2017
Item 10 (a) of the provisional agenda
Climate Change and Transport

Group of Experts on Climate Change Impacts and Adaptation for Transport Networks and Nodes

Note by the secretariat

CHAPTER 1

An Overview of Recent Climate Change Trends and projections affecting transportation in the ECE Region

Climate Change: Recent Trends and Projections

2. The information presented here focuses on climatic factors the variability and change of which can have significant implications on transport. Some of the information (climatic factor trends/projections until 2013) has been presented in a previous ECE report (ECE, 2013); in this (draft) report, focus is placed on the most recent 6-year period (2011-2016) as well as on the recent projections on Climate Variability and Change (CV & C)[1].

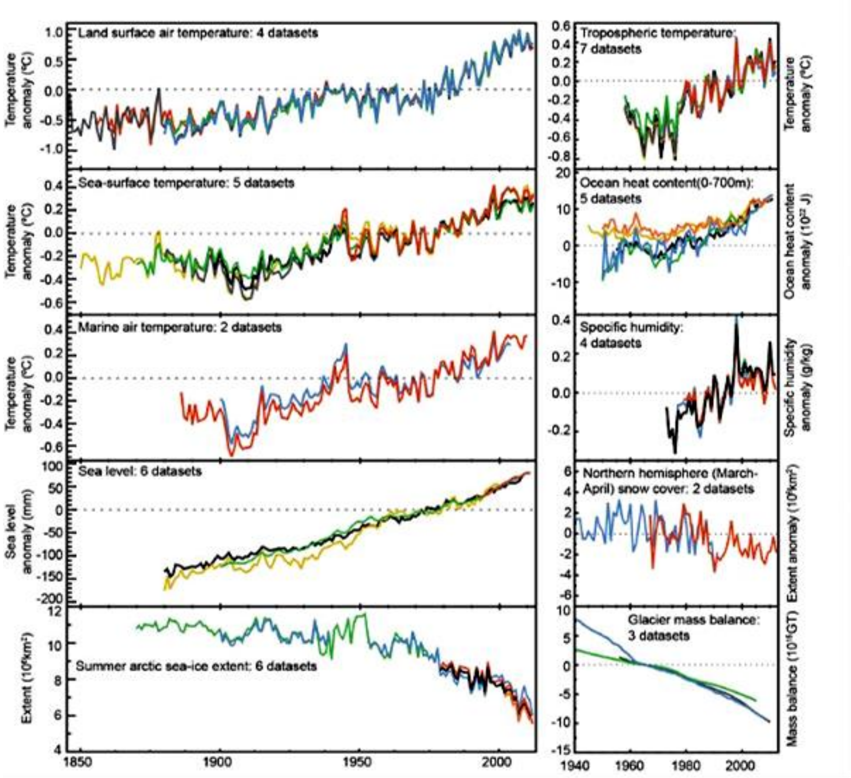
A. Climate Change Trends

3. There is overwhelming evidence for a warming world since the nineteenth century from independent scientific observations in different environments (from the upper atmosphere to the ocean deeps). Nevertheless, in most cases, discussions on Climate Change focus on the land surface temperature increase, 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. In each panel all data sets have been normalized to a common period of record (IPCC, 2013))



4. 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; Dieng et al., 2017);

---

[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 periods at which infrastructure used today has been constructed (e.g. 1961-1990 or 1986-2005).

these have resulted in steric increases of the sea level that are considered as a main driver of sea level rise-SLR (Hanna et al., 2013). At the same time, glacier and sea ice covers have been declining over the last few decades. Arctic sea ice has decreased by > 40 per cent since satellite records began (1979), particularly at the end (in September) of the annual melt season (Melillo et al., 2014; NOAA, 2017a). Glacier ice has been consistently decreasing during the last 20 years and spring snow cover has also shrunk across the Northern Hemisphere-NH since the 1950s (IPCC, 2013; NSIDC, 2017).

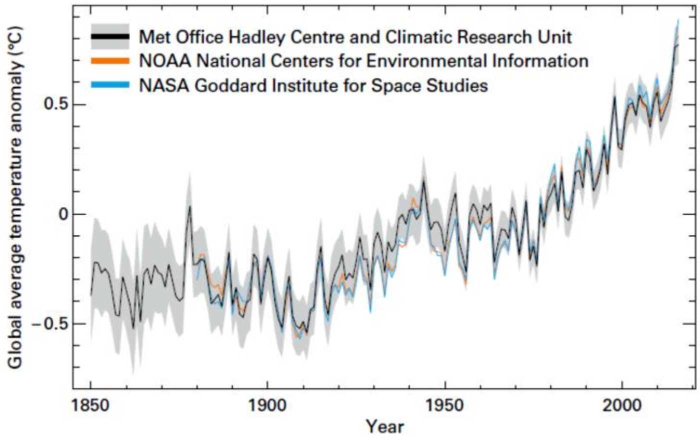
1.1.1 Temperature and precipitation

5. Globally-averaged, near-surface temperature is the most cited climate change indicator as it is directly related to (i) the planetary energy balance (Fourier 1827) and the increase in cumulative Greenhouse Gas-GHG emissions (IPCC, 2013), and (ii) many climatic impacts and risks (Arnell et al., 2014). Although each year (or decade) is not always warmer than the previous, there has been a long-term warming trend (Fig. 2). Most of the warming occurred in the past 35 years (NASA, 2016).

Figure 2

Global average temperature anomalies for the period 1850-2016 relative to the reference period 1961-1990 for 3 major datasets[2]

(Grey shading indicates the uncertainty in the HadCRU dataset (UK Met Office Hadley Centre) (From WMO, 2017))



6. 2016 has been the warmest year in the instrumental record, breaking the previous records of 2015 and 2014, with the data being consistent with a steady global warming trend since the 1970s, superimposed on random, stationary, short-term variability (Rahmstorf et al., 2017). It is the third year in a row that global average surface temperature set a new record, and the fifth time the record has been broken since the start of the twenty-first century (NOAA. 2017b).

7. Warming of the climate system is unequivocal; all observations suggest increases in global average surface air and ocean temperatures (IPCC, 2007; 2013). The planet's average surface temperature has risen by 1.1 ^{0}C since the late nineteenth century, a change largely driven by increased atmospheric concentrations in GHGs. Globally averaged land and ocean surface temperature in 2015 was about

---

[2] In the WMO (2017) analysis, the latest versions of the 3 datasets: GISTEMP, NOAAGlobalTemp and HadCRUT maintained, by NOAA, the US National Air and Space Administration (NASA) and the UK Met Office Hadley Centre have been used. The combined dataset extends back to 1880 (WMO, 2017. http://library.wmo.int/opac/doc_num.php?explnum_id=3414).

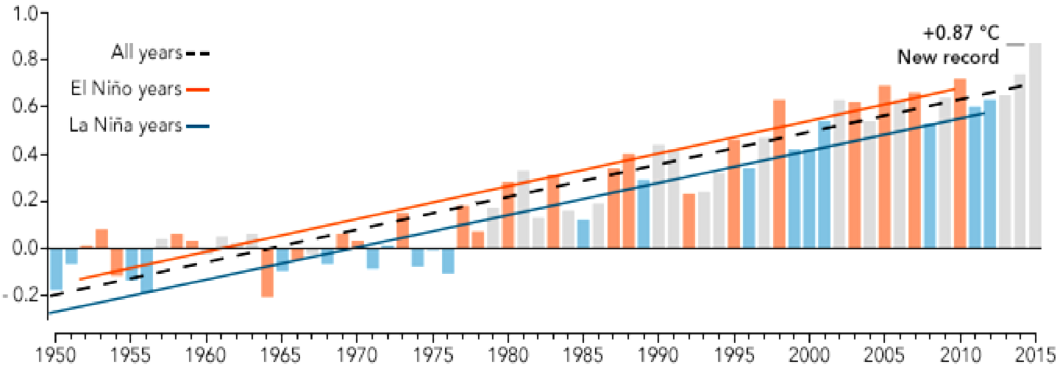
0.76 ± 0.09 ^{0}C above the 1961-1990 average (94 per cent certainty, NASA (2016)), whereas the third in order world breaking record year was 2014 (MetOffice, 2014).

8. Since the beginning of the twenty-first century, there has been a slowdown in the rate of the global mean surface temperature rise compared to global climate model projections. Over the period 2003-2013, both global land and sea surface temperatures increased at a lower rate than in the previous decades (Dieng et al., 2017). This apparent slowdown (termed as '*the global warming hiatus*') has been also attributed to uncertainties in the simulations of the conventional datasets related to external climate forcing, such as volcanic eruptions, stratospheric changes in water vapour and industrial aerosols, heat redistribution within the oceans, solar activity and the inter-annual to decadal variability of ocean cycles (e.g. El Niño and La Niña events) (IPCC, 2013; MetOffice, 2014; Fyfe et al., 2016; Yan et al., 2016). Recent research (e.g. Cowtan and Way, 2014; Karl et al, 2015; Simmons et al., 2017) has questioned the occurrence of *the global warming hiatus* in the rising temperature trend, suggesting that there were biases in surface temperature datasets and that re-analysis of corrected/updated data indicate that recent global temperature trends are higher than those reported in previous studies (e.g. IPCC, 2007; 2013).

Figure 3

Annual temperatures compared to 1951-1980 average

(Blue and red bars represent the annual temperature anomalies in El Niño and La Niña years, respectively. Blue and red lines are the trends; neutral years in grey; the dashed line represents the overall trend (NASA, 2016))



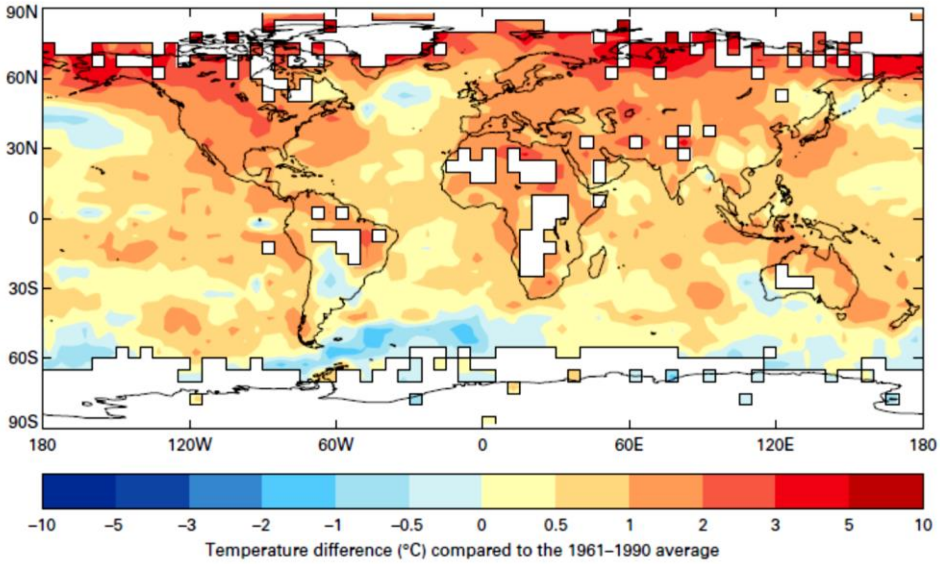
9. Generally, years starting during an El Niño event are warmer than non El Niño years i.e. neutral or La Niña years (Fig. 3). The 2015 and 2016 temperature records were influenced by the strong El Niño conditions in the Pacific (NASA, 2016). In 2014, however, near surface land temperatures were 0.88 ± 0.20 ^{0}C higher than the 1961-1990 average according to NOAA estimates (WMO, 2014), although it was a neutral El Niño year. In 2016, record temperatures were widespread at the Northern Hemisphere (NH), particularly in Arctic regions (Fig. 4). In early 2016, the global temperature was about 1.5 ^{0}C above that recorded in the early industrial revolution and > 0.4 ^{0}C higher than that recorded in 1998 (also a strong El Nino year) (Simmons et al., 2017).[3] Alaska experienced unprecedented, widespread warming (NSIDC, 2017). Globally averaged sea surface temperatures (SSTs) were also the warmest on record, with the anomalies being strongest also in early 2016 (WMO, 2017).

---

[3] An alarming development in view of the 2015 Paris Agreement the aim of which is to 'hold' the global average temperature increase to well below 2 0C above pre-industrial levels (UNFCCC, 2015).

Figure 4

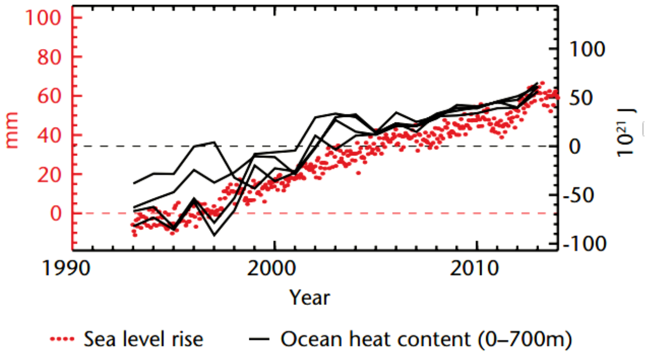
Spatial distribution of the global temperature anomalies in 2016 (relative to the 1961-1990) (WMO, 2017)



10. 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) and 0.5 - 0.65 Wm^{-2} for the period 2003-2013 (Dieng et al., 2017). Water temperature rise has been observed down to depths of 3000 m since 1961 (IPCC, 2013). There is an apparent correlation between the increase in ocean heat content and sea level rise (Fig. 5) which is the presumed to be due to steric effects/thermal expansion (NASA, 2016).

Figure 5

Global average sea level rise and change in ocean heat content for 1993-2013 Sea-level data from TOPEX (1993-2001), Jason-1 (2002-08) and Jason-2 (2008-13) ((http://sealevel.colorado.edu/). Ocean heat content (upper 700 m) relative to the 1993-2012 average. Data from CSIRO/ACE CRC, PMEL/JPL/JIMAR, NODC, and EN4.0.2 (MetOffice, 2014))

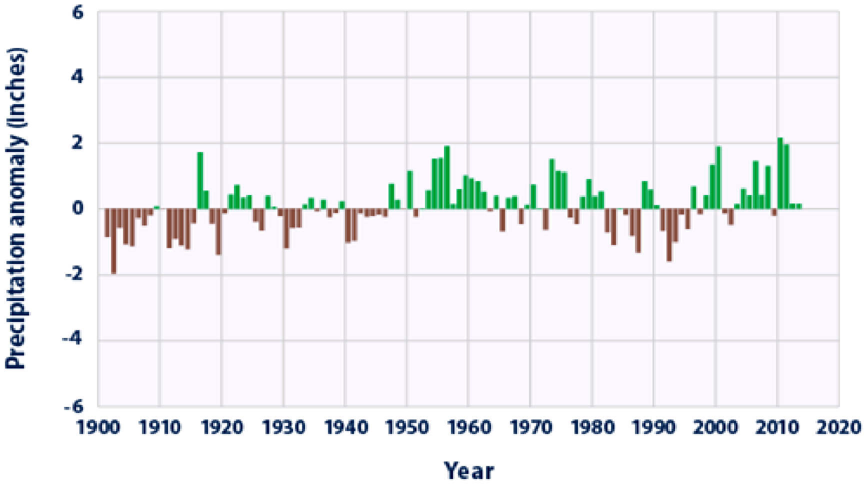


11. Analysis of global precipitation data from land areas reveal that there is an increasing trend in the twentieth century (Fig. 6), especially in middle and high latitudes (low confidence before 1951, medium confidence afterwards). However, when the analysis includes only the NH mid-latitudes, confidence in the precipitation trends for the years after 1951 becomes high. Generally, global

precipitation data show mixed long term trends (IPCC, 2013) and strong regional variability.

Figure 6

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

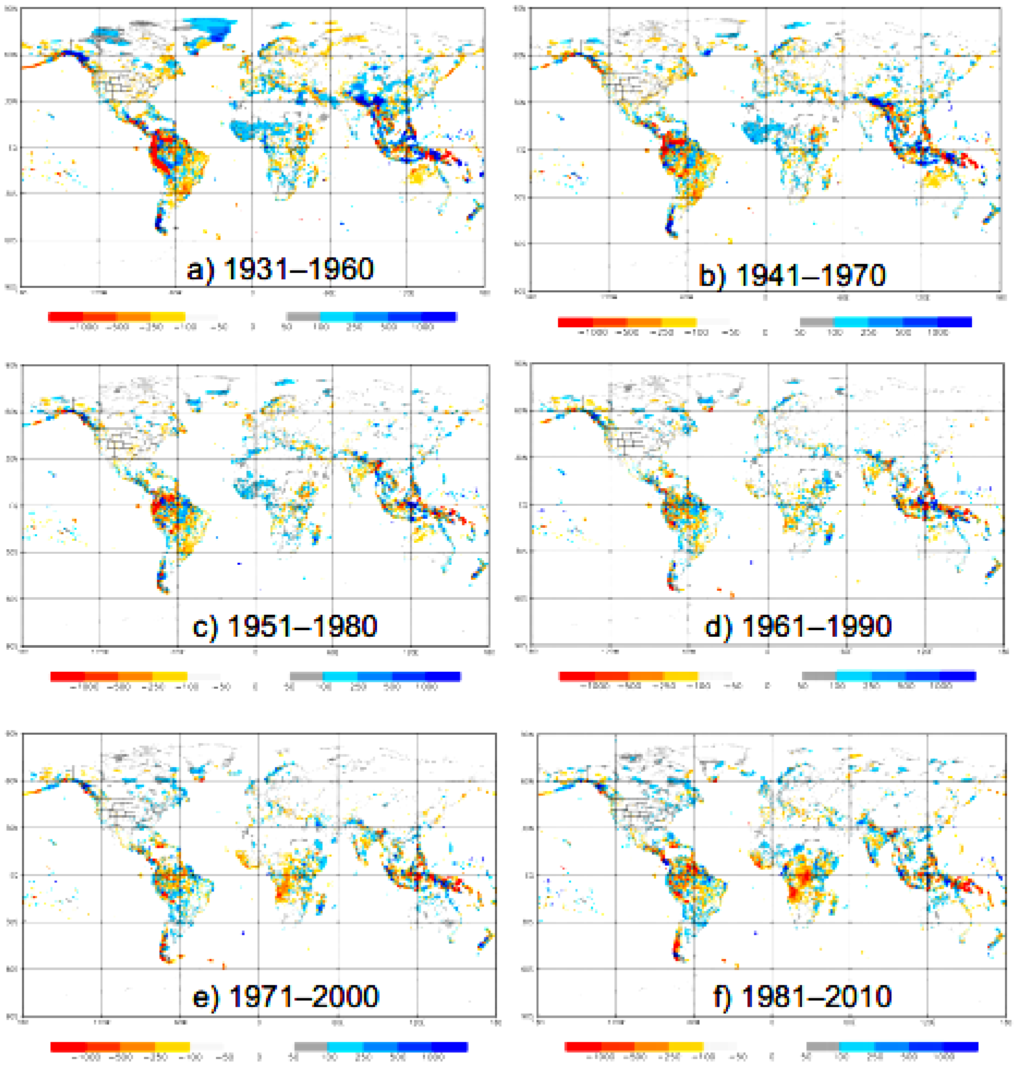


12. Heavy precipitation events have increased in intensity and/or frequency in many parts of Europe and North America, whereas there has been an increased frequency and intensity of drought events in the Mediterranean and parts of Africa (IPCC, 2013). Schneider et al. (2017) applied mean weather-dependent corrections to precipitation data from 75,100 meteorological stations (Global Precipitation Climatology Center-GPCC) and found a mean annual precipitation of about 855 mm (excluding Antarctica) for the period 1951-2000; they also suggested that a warming of about 1 ^{0}C relative to pre-industrial levels could be accompanied by a 2 to 3 per cent increase in global precipitation.

Figure 7

Differences between mean annual land precipitation for different 30-year periods

(a) 1931-1960; (b) 1941-1970; (c) 1951-1980; (d) 1961-1990; (e) 1971-2000 and (f) 1981-2010 to GPCC's precipitation climatology 1951-2000 (Meyer-Christoffer et al., 2015)



13. In the periods 1931-1960 and 1941-1970, there were larger differences compared to those in the 1951-2000 period; more rainfall occurred over West Africa and less over the SE Asia and especially Indonesia (Fig 7). In Europe and N. America, precipitation decreased in the south and increased in the north. In Spain, precipitation patterns appear to have changed substantially in the last 20 years; dry periods became lengthier, annual rainfall decreased by up to 15 per cent, and the number of heavy precipitation events decreased (Valdez- Abellan et al., 2017).

14. Precipitation decreased in the most recent 30 year periods in August, September and October, which might be related to more frequent ENSO events during the last decades and weakened Indian and Southeast Asian summer monsoons (Schneider et al., 2017). Global precipitation in 2016 was strongly influenced by the transition from El Niño conditions in the early year to neutral or weak La Niña conditions in the second half. This resulted in strong seasonal contrasts. Some regions experienced post-El Niño heavy rainfall, resulting in annual totals that were well above average. Indonesia and Australia, which were influenced by a negative IOD,

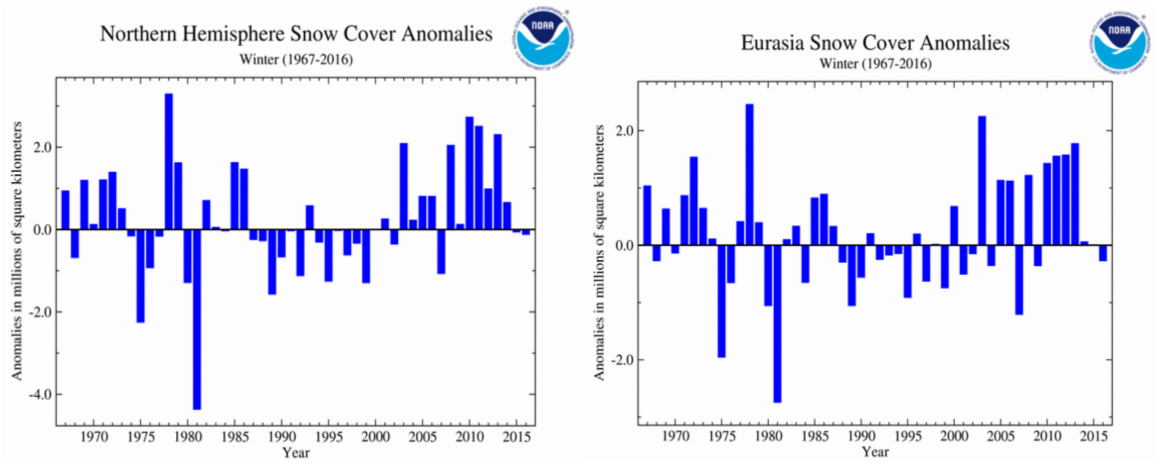
had extensive areas with rainfall above the ninetieth percentile (wettest 10 per cent of all years). It was also a wet year in many NH high-latitude areas.

1.1.2 Snow and sea ice

15. The warming trend also affects the cryosphere. Snow cover in the North Hemisphere (NH), i.e. about the 98per cent of the global snow cover, has declined by 11.7 per cent per decade in June (EEA, 2015a) over the period 1967-2012. 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). Over the past few decades, research shows a downward trend in the extent and duration of snow cover in the Arctic region.

Figure 8

Winter Snow Cover Extent in North America (left) and Eurasia (right) (NOAA 2017a)

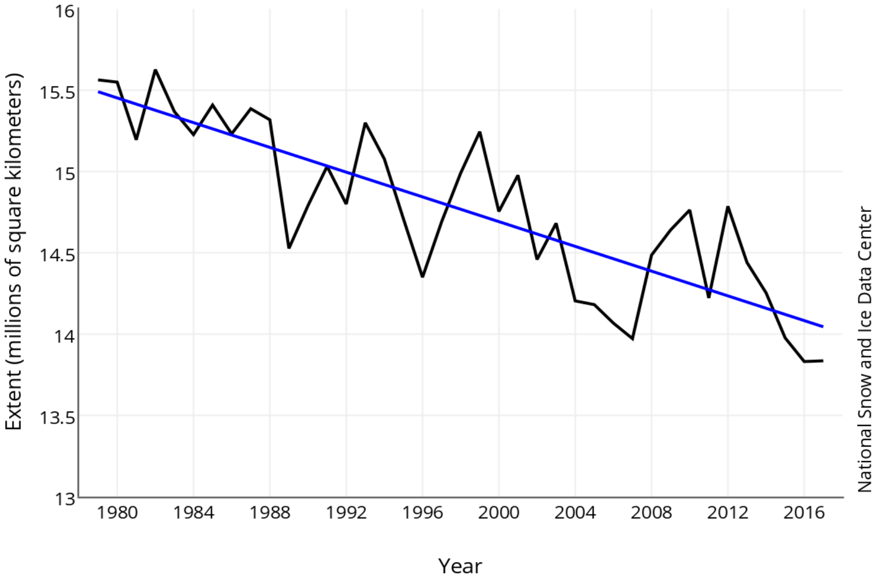


16. NH winter snow cover extent (SCE) has changed slightly in the 50-year record (NOAA, 2017a). In 2016, the winter SCE (December 2015-February 2016) was about 120,000 km^2 below the 1981-2010 average, although several winter storms moved across N. America in January 2016 increasing significantly the monthly snow cover to about 810,000 km^2 above the 1981-2010 average. (Fig. 8). In Eurasia, the winter SCE for 2015-16 was 270,000 km^2 below average. This was the smallest winter SCE since 2006/07. Similarly to North America, the Eurasian SCE was below average during December and February and above-average during January.

17. Arctic sea ice is in decline (Fig. 9). Sea ice usually expands during the cold season to a March-April maximum, and then contracts during the warm season to a September minimum; in contrast, Antarctic sea ice typically contracts during the SH warm season to a minimum extent in February-March (late summer) and expands during the cold season to a September maximum. Minimum Arctic sea ice extent has declined by about 40 per cent since 1979 and most September (minimum) records have occurred in the last decade.

Figure 9

Trend in the monthly Arctic sea ice extent in April during 1979-2017 (NSIDC, 2017)

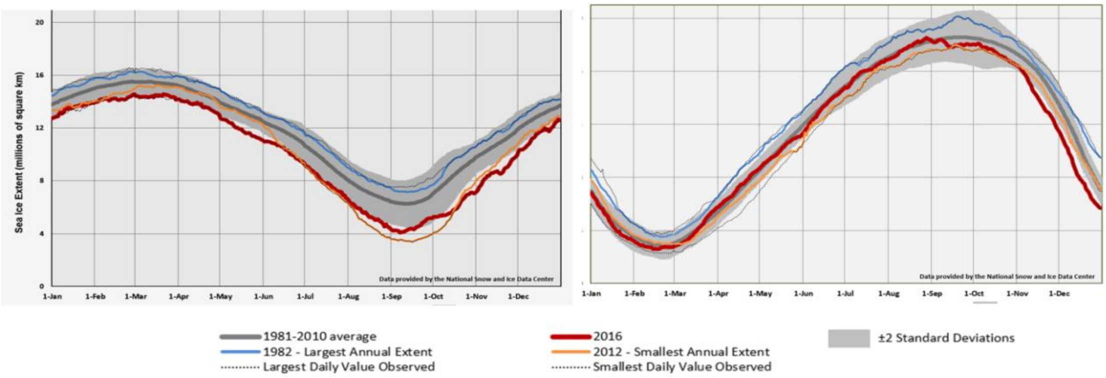


18. In November 2016, Arctic and Antarctic sea ice extents had dropped to record lows; ice conditions were so unusual, that were described as a “black swan” event (NSIDC, 2017). During each month of 2016, Arctic sea ice extent was below average. Seven months in 2016 had record lows in Arctic sea ice extent (Fig. 11). When averaged for the entire year, Arctic sea ice extent was 12.6 per cent below average.

19. The 2016 annual maximum sea ice extent in the Arctic was the lowest in the satellite record over most Arctic regions, with notable exceptions in the Labrador Sea, Baffin Bay and Hudson Bay. Maximum and minimum sea ice extent was 1.12 and 2.08 million km^2 below the 1981-2010 average, respectively. Large areas of the open ocean, which are typically ice-covered in mid-September, were observed with an ice extent minimum (e.g. large areas of the Beaufort, Chukch, Laptev and East Siberian Seas). Antarctic sea ice was near average during the first 8 months of 2016. In early September 2016, Antarctic sea ice extent began a rapid decline and was near record low levels for the rest of the year (Fig. 10).

Figure 10

Daily Arctic (left) and Antarctic (right) sea ice extent in 2016 (NOAA, 2017, data from NSIDC)



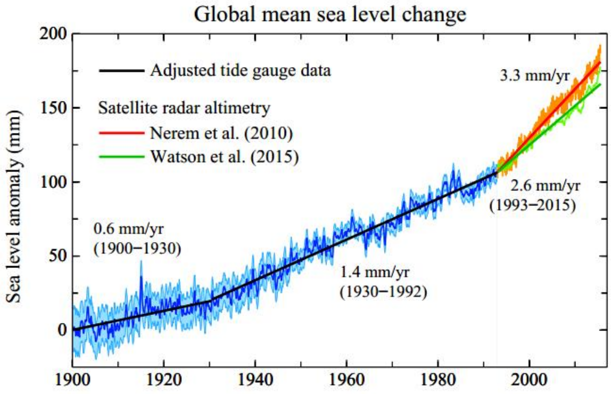
20. When averaged for the entire year, the Antarctic sea ice extent was 4.2 per cent below average, the second smallest on record. In August 2016, the Antarctic sea ice reached its maximum extent at 18.44 million km^2; this was the earliest occurrence of the maximum extent since 1979.Arctic sea ice has not been declining as rapidly in winter as it has been in summer (WMO, 2016). Greenland's ice sheet mass was measured by Velicogna et al. (2014); they found a loss of 280 ± 58 Gt year^{-1}, accelerating by 25.4 ± 1.2 Gt year^{-1}. On the same study, 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^{-1}.[4]

1.1.3 Sea level

21. 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-SLR 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, global sea level has increased by about 0.20 m; during this period, global SLR rates averaged 1.3 to 1.8 cm per decade (Church et al., 2013; Hay et al., 2015). However, the rate of increase becomes progressively greater; there is a discernible acceleration in the global sea level since the 1900s (Fig. 11). 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 century and much of the 1960s and 1970s; sea level increased more rapidly during the 1930s and through the 1950s. Currently, satellite and tide gauge observations suggest a global sea level rise of 3.3 ± 0.25 cm per decade since 1993 (Church et al., 2013).

Figure 11

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)



---

[4] These processes have had significant effects on global SLR. Observations indicate that the contribution of Greenland's ice loss has increased from 0.09 (-0.02 - 0.20) mm yr-1 in 1992-2001 to 0.59 (0.43 - 0.76) mm yr-1 in 2002-2011, while the contribution of Antarctica's ice sheet melt increased from 0.08 (-0.10 to 0.27) mm yr-1 in 1992-2001 to 0.40 (0.20 to 0.61) mm yr-1 in 2002-2011. Altogether, ice sheet melt contribution to SLR is estimated as 0.60 (0.42 - 0.78) mm yr-1 for the period 1993-2010 (IPCC, 2013).

22. Mean sea level trends and variations in regional climate have led to changes in the trends of extreme high water levels in the late twentieth century. There is considerable regional (spatial) variability in the coastal sea level rise trends (Menendez and Woodworth, 2010). In Europe, sea levels have increased along most of its coast in the last 40 odd years, with the exception of the N. Baltic coast (EEA, 2012). Some regions experience greater sea-level rise than others. In the tropical western Pacific some of the highest rising sea-level rates over the period 1993-2015 are observed, which may have been an additional contributing factor in the devastation of several areas of the Philippines during the storm surge of the typhoon Haiyan (November 2013).

1.1.4 Extreme climate events

23. Climate change is often characterized in the public discourse by the increase in global mean temperature. However, for society, economy and the environment, regional impacts and changes in extremes, such as heat waves, droughts, or floods, are generally most relevant (Vogel et al., 2017). It is essential to understand and communicate the actual implications of such events on the infrastructure/activities for a given global temperature target (Seneviratne et al., 2016). Changes in the mean climate can 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 be located within the ‘tails’ of the present conditions (IPCC, 2013).

24. 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, since they may induce abrupt and 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, 2014). In USA, extreme hydro-meteorological event events cause on average about 650 deaths and $15 billion in damages annually and are responsible for some 90 per cent of all declared by the President disasters. In addition, about one-third of the economy (around $3 trillion) appears to be sensitive to weather and climate; since 1980, the USA has sustained 208 hydro-meteorological disasters with a total cost exceeding $1.1 trillion (NOAA, 2017c).

25. Many indicators of climate extremes 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 have become warmer and cold extremes less cold in many regions (IPCC, 2013). Evidence suggests 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). A slight global mean decrease in the annual number of mild days (i.e. days with maximum temperature between 18-30 ^{0}C and precipitation < 1 mm) is projected in the near future (4 days/year for the 2016-2035 period and 10 days/year for the 2081-2100 period) (Van der Wiel et al., 2017).

26. 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 and costly impacts on infrastructure. 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

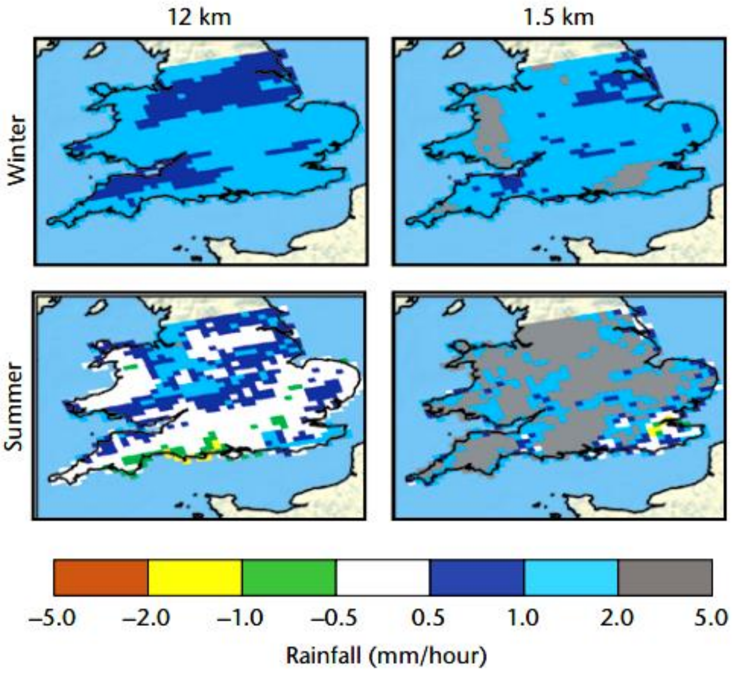
destructive (Category 5) cyclones (e.g. Steffen, 2009). The implications of these extreme events for e.g. the coastal communities and infrastructure could be severe, as they may increase the likelihood of extreme sea levels (ESLs) from storm surges and waves (e.g. Stockdon et al., 2012) and consequently of coastal floods, especially if combined with the projected increases in the mean sea level (Hallegate et al., 2013).

27. 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; Mentaschi et al., 2017) will also induce, at least temporarily, coastal erosion or inundation, particularly when combined with increasing mean sea levels (e.g. Losada et al., 2013; Vousdoukas et al., 2017). 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). In Southern Europe, analysis of the extreme coastal sea level/storm surges recorded by tide gauges has 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; Vousdoukas et al., 2017). The projected rise in extreme sea levels (ESLs) constitutes a serious threat to global coastal societies. Their safety and resilience depends on the effectiveness of natural and man-made coastal flood protection, i.e. the capacity of the coast to act as a buffer and absorb ocean energy through wave shoaling and breaking processes (e.g. Vousdoukas et al., 2012).

Figure 12

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 RCP8.5 (Met Office, 2014))



28. 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 UK summers are to become drier by 2100, summer downpours will be heavier (Fig. 12). It is likely that the frequency of such events will increase over many regions in the twenty-first 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).

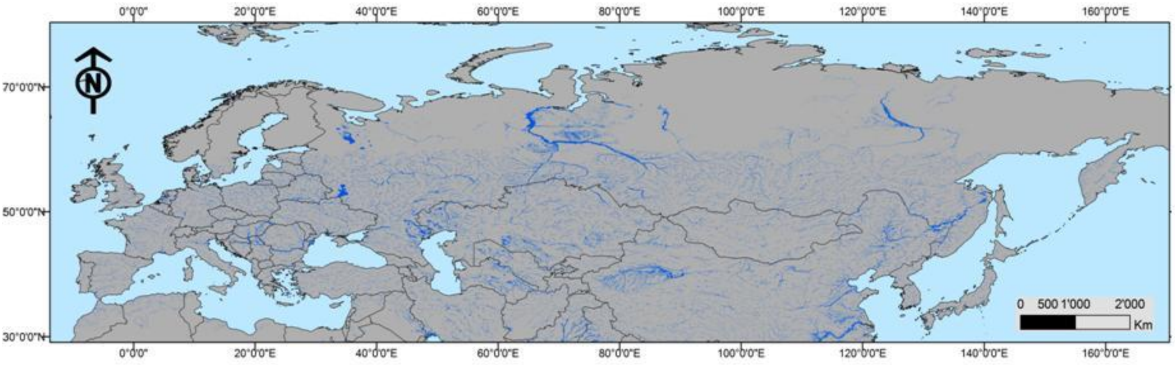
29. River flooding is the most serious and widespread weather hazard (King et al., 2015). Between 1980 and 2014 river floods accounted for 41 per cent of all loss events, 27 per cent of fatalities and 32 per cent of losses (Munich Re, 2015). Riverine floods involve both physical and socio- economic factors. The former depend on the hydrological cycle, which is influenced by changes in temperature, precipitation and glacier/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.

30. 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. 13). 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 13

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 ^{0}N are not fully covered (From UNEP-GRID and UNISDR, 2008). (ECE, 2013))



31. 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 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 twenty-first century (IPCC, 2013).

1.1.5 The 2011-2016 period

Temperature and precipitation

32. The last 6-year period (2011-2016) has been the warmest on record. Temperatures were more than 1 ^{0}C above the 1961-90 average (over most of Europe, northern Asia and the southwest US) and reaching about 3 ^{0}C above average in regions of the Russian Arctic. 2016 was the warmest year on record (1.1 ^{0}C higher than the 1901-2000 average of 14.0 ^{0}C), surpassing the previous records of 2015 and 2014, with the average land surface temperature at record high (Fig. 14).

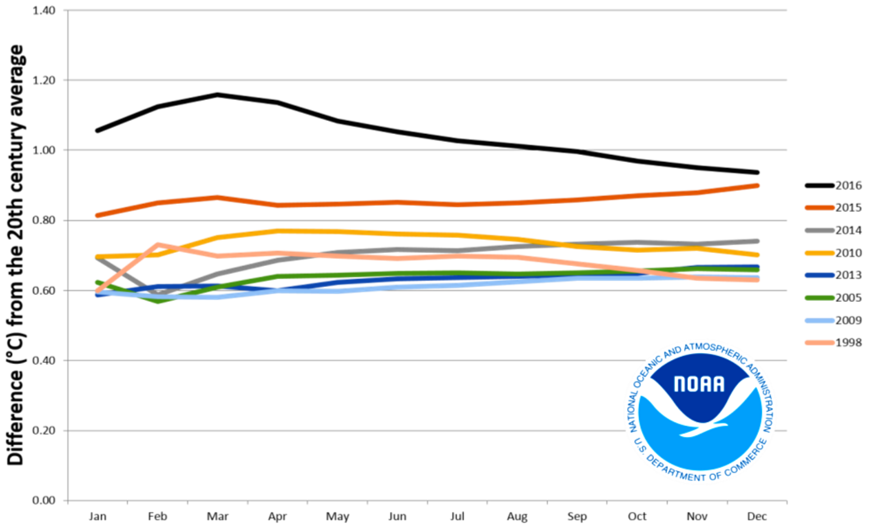
33. In 2016, the global average temperature was 0.83 ± 0.10 ^{0}C warmer than the average for the 1961-1990 reference period and about 1.1 ^{0}C above the pre-industrial period. It was the warmest year on record for both land and oceans and for both hemispheres. The 5-year mean temperatures also reached their highest values on record, with the 2012-2016 period being 0.65 ^{0}C above the 1961-1990 average. Global temperatures continued to be consistent with a warming trend of 0.1 °C to 0.2 ^{0}C per decade (WMO, 2017). Nearly all of Eurasia was much warmer than average. Noteworthy were 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 ^{0}C or more above the 1880-1899 average, a trend that continued in 2016 (NOAA, 2017b). Globally, may of the warmest years have occurred since 1998 (Fig. 14).

34. Phenomena, such as El Niño (or La Niña) that can warm or cool the tropical Pacific Ocean, may be responsible for short-term variability in the global temperature. An El Niño event occurred in 2015 and the first part of 2016. Research suggests direct impacts of the 2015/2016 El Niño; warming in the tropical Pacific (Fig. 15) increased the annual global temperature anomaly for 2016 by almost 0.1 ^{0}C (NOAA, 2017b).

35. Sea surface temperatures (SSTs) for the period were above average in most of the oceans, with the exception of some 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 previous time according to 5 different data sets (NOAA, 2016). There were two notable ocean temperature anomalies in late 2013: (i) a large area of very warm water (> 2 ^{0}C above average) in eastern North Pacific; and (ii) a persistent pool of water exhibiting SSTs below-normal in eastern North Atlantic.

Figure 14

The 2011-16 period was the warmest period on record, with temperatures 0.57 ^{0}C above the 1961-1990 average and 0.51 ^{0}C above the 2006-2010 average. Land temperatures were > 1 ^{0}C above the 1961-90 average over most of Europe, the southwestern US and the Asian sector of the Russian Federation and most areas to the north of 60 ^{0}N (NOAA, 2017b).

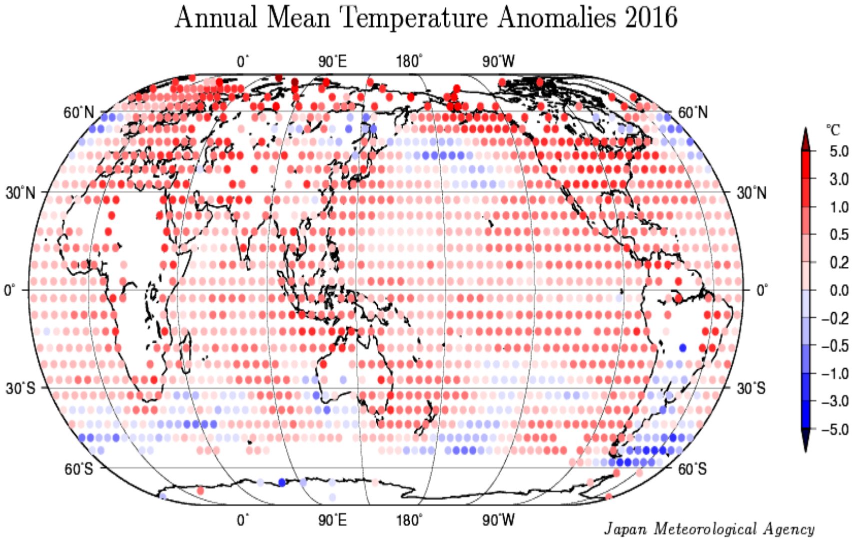


36. Land precipitation was strongly influenced early and late in the 2011-2016 period by the El Niño-Southern Oscillation (ENSO), with La Niña conditions for much of 2011 and early 2012, and a strong El Niño at the 2015-early 2016. 2011 was assessed by NOAA as being the world’s second-wettest year on record, with 2012, 2013 and 2014 all close to the long-term average. A major feature of the 6-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. In 2016, global precipitation was strongly influenced by the transition from El Niño conditions in the early year to neutral or weak La Niña conditions in the second half of the year. This resulted in strong seasonal contrasts (but annual totals close to the average conditions) in many regions. In other regions, however, heavy rainfall occurred in the post-El Niño period, resulting in annual totals well above average (WMO, 2017).

37. 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 also regions where precipitation exceeded the 90th percentile (e.g. in eastern Russia). Regarding Europe, there was a marked north/south split, with very wet conditions in Scandinavia and very dry conditions in much of the central and SE Europe. Major annual precipitation anomalies were less common in the years 2012-2014, with significant anomalies observed in NE Europe, parts of China and Argentina (2012) and SE Europe (2014); in the ECE region, very dry conditions occurred over much of the central US and central (2012) and western Russia (2014).

Figure 15

Temperature anomalies in 2016 (JMA, 2017)



Japan Meteorological Agency

The circles indicate temperature anomalies from 1981-2010 baseline averaged in 5°x 5° grid boxes.

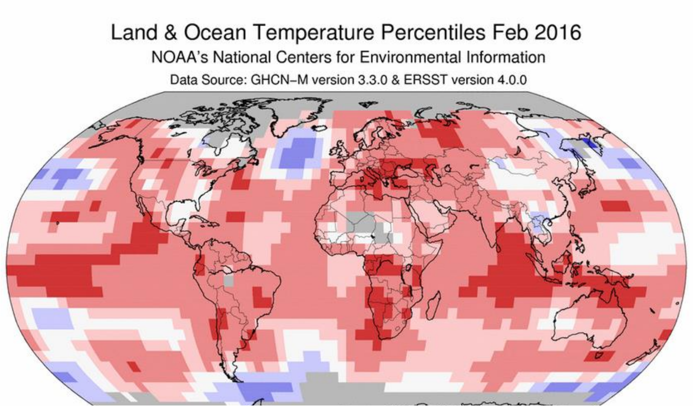
38. 2016 was a wet year in many high-latitude NH areas. Precipitation above the 90th percentile was observed in a large swath extending from Kazakhstan across the western Russian Federation into Finland, northern Sweden and Norway. However, large areas of the northern-central Russian Federation were dry, with much of the region between the Urals and Lake Baikal and to the north of 55 ^{0}N having precipitation below the 10th percentile. The tropical west coast of S. America, which normally experiences heavy rains during strong El Niño years, had only patchy rainfall in early 2016 (seasonal rainfall generally close to average). Another non-typical region was California, where the 2015-2016 seasonal rainfall was near average (after 4 very dry years), increasing towards the end of the year.

39. Precipitation was close to average over most of central and western Europe, with a very wet first half and a dry second half of the year. The 2015/2016 winter was wet across the western Europe, with the UK having its second-wettest year. May and June were also very wet in western and central European regions, causing significant flooding in France and Germany. However, the July-September period was dry, with France having its driest July/August on record. December was also extremely dry, with many areas having less than 20 per cent of normal precipitation. Lowland Switzerland had its driest December and third driest month on record. One particular example of the high variability in the precipitation of 2016 was at Belgium; Uccle had its wettest January-June on record (62 per cent above average), followed by its third-driest July-December (36per cent below average) (WMO, 2017).

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 twentieth 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.



Snow and ice

40. The cryosphere component of the Earth system includes solid precipitation, snow cover, sea ice, lake and river ice, glaciers, ice caps, ice sheets, permafrost and seasonally frozen ground. The cryosphere provides some of the most useful indicators of climate change, yet is one of the most under-sampled domains of the Earth system. There are at least 30 cryospheric properties that should be (ideally) measured. Many of these properties are measured at the surface, but spatial coverage is generally poor. However, some of these properties have been measured for years from space. The major cryosphere elements for which assessment is provided for 2016 include snow cover, sea ice, glaciers and ice sheets.

41. Despite the overall high temperatures of the 6-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 areas of the central and western Europe, with temperatures remaining below 0 ^{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 temperatures in Montreal, Toronto and Syracuse did not rise above 0 ^{0}C. In coastal regions there were frequent snowfalls, resulting in Boston experiencing its greatest seasonal snowfall on record (WMO, 2016).

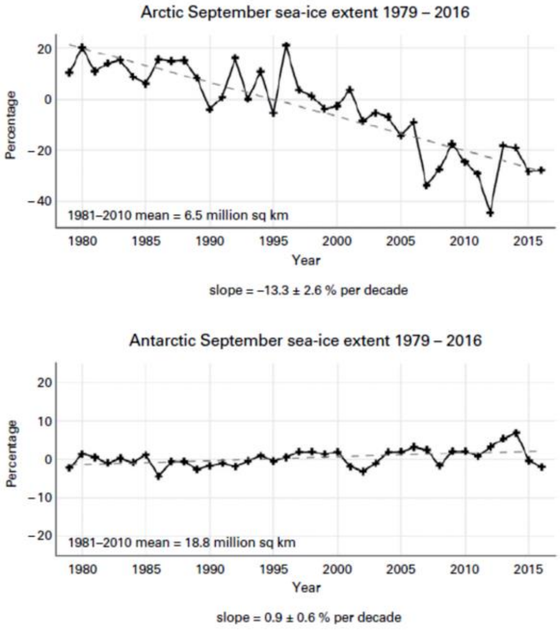
42. Northern hemisphere mean annual snow cover extent for 2016 was 24.6 million km^2, 0.5 million km^2 below the 1967-2015 average; this was very similar to 2015 (see also Fig. 8). After above-average snow cover in January, snow cover was well

below average from February to June, with cover between 2.4 million km^2 and 3.3 million km^2 below average. The April mean snow-cover extent was the lowest on record, with March ranking second, February and June third and May fourth. Autumn snow cover, however, was above average, as it had been in the previous three years. There were positive anomalies from September and each month from October to December. There are no comparable snow-cover records for the southern hemisphere, where (except for the Antarctic) snow is generally rare outside high mountain regions. In Australia, peak seasonal snow depths at Spencers Creek in the Snowy Mountains were slightly below average, but high precipitation and below-average temperatures in September and October led to a late finish to the season (WMO, 2017).

43. Arctic sea-ice extent was well below average in 2016 and at record low levels for large parts of the year. The seasonal maximum of 14.52 million km^2 (on the 24 March) was the lowest seasonal maximum in the 1979-2016 satellite record (Fig. 16), just below that of 2015. Sea-ice extent again dropped to record lows in May and June but a relatively slow summer melt resulted in a seasonal minimum (4.14 million km^2) being above the 2012 record. The 2016 autumn freeze was slow. The mean November extent of 9.08 million km^2 was 0.8 million km^2 below the previous record low. Antarctic sea-ice extent was close to the 1979-2015 average for the first 8 months of 2016, reaching a seasonal maximum of 18.44 million km^2 in late August; this was the earliest seasonal maximum on record. The spring melt was exceptionally rapid, resulting in a November mean extent of 14.54 million km^2, by far the lowest on record (1.0 million km^2 below the previous record). The reasons behind the collapse of the sea ice in late 2016 are not yet understood, although local winds might have been a factor (WMO, 2017).

Figure 16

(a) September sea-ice extent for the Arctic and (b) September sea-ice extent for the Antarctic: Percentage of long-term average of the reference period 1981-2010 (Source: prepared by WMO, data from the US National Snow and Ice Data Center) (WMO, 2017)



44. With Arctic and Antarctic sea-ice extent at record low levels, global sea ice extent in November was also far below average. After being more than 1 million km^2 below the 1979-2015 average for most of the year, it dropped to more than 4 million km^2 below average in November - an unprecedented anomaly - before a slight recovery in December.

45. During the last years (2011-2016), Arctic sea ice continued a decline that exceeded the 1981-2010 mean value, particularly for the winter maximum. In comparison, 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 in spring (maximum in early October of 18.83 million km^2, only 0.7 per cent above the 1981-2010 average (WMO, 2017).

46. Mountain glaciers also continued their decline during the last 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 in the period 2011-2016. 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).

47. Data from the World Glacier Monitoring Service indicate that mountain glaciers continued to melt in 2016. Reference glaciers for which 2015/2016 data are available show a mean mass balance of -858 mm, with only one of 26 glaciers showing a positive mass balance. This mean mass balance deficit is less extreme than that of 2014/2015, but above the 2003-2015 average. The loss of Greenland ice sheets in the 12 months to August 2016 had a similar rate to that of recent means. The surface mass balance for this period was close to the 1990-2013 average, with above-average accumulation during the colder months being offset by above-average melting in summer. The loss of glacier area was the largest since 2012 (WMO, 2017).

Sea level rise

48. In 2011-2016, 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 the 2015/2016 El Niño developed), with sea levels being of about 10 mm above the long-term trend.

49. SLR rend over the full satellite record (1993-2015, 3 mm year^{-1}) has been considerably higher than the average of the 1900-2010 (1.7 mm year^{-1}). There is evidence suggesting that the contribution to SLR from the continental ice sheet melt (particularly from those of Greenland (GIS) and west Antarctica (WAIS)) has been increasing. The contribution of GIS melting to global SLR 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^{-1}estimated for the period 2002-2011 (IPCC, 2013).

50. Regarding the Pacific Ocean, strong regional differences were apparent in 1993-2014; these have been attributed to El Niño and La Niña events. The western Pacific has shown the world’s fastest SLR rates over this period (> 10 mm year^{-1} in places), compared to the eastern Pacific. Sea level rise has been more consistent in the Atlantic and Indian Oceans with most areas in both oceans showing rates similar to the global average. Global sea levels rose strongly during the 2015/2016 El Niño, rising about 15 mm between November 2014 and February 2016, well above the post-1993 trend of 3 mm year^{-1}.

Extreme events in the 2011-2016 period

51. In 2011-2016 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 Caribbean and the US (2012), droughts in the southern

and central US (2012 and 2013), and floods in central Europe in May-June 2013 (Fig. 17).

Figure 17

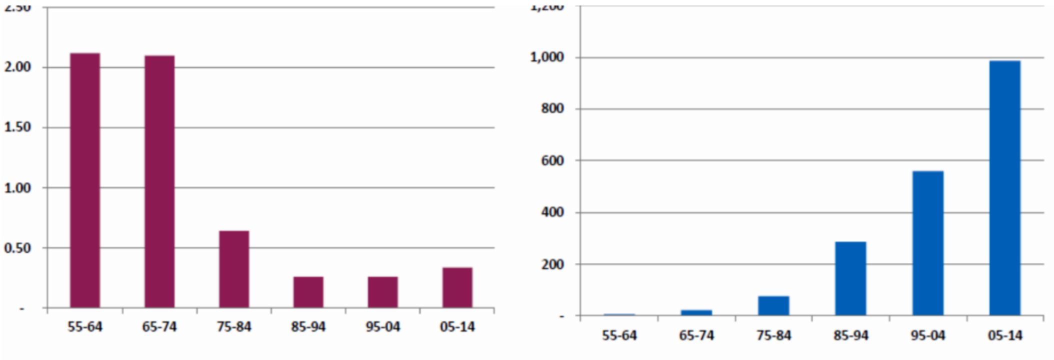
Flood damages on European roads in June 2013: (a) Highway 8 in Grabenstaett, S. Germany ((Matthias Schrader, AP); (b) Tyrol, Austria (Kerstin Joensson, AP)

52. Fortunately, human loss does not follow the upward trend in economic losses (Fig. 18). 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 13,600 deaths (2013). More than 3,700 people 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 that was responsible for 258,000 excess deaths (WMO, 2016).

Figure 18

Human losses (left) and economic losses by decade

(Economic losses in US$ billions, adjusted to 2013 (NOAA, 2017c))



53. Generally, the 1980-2016 average has been 5.5 US$ billion disaster events (CPI-adjusted) per year, with the annual average for the most recent 5 years (2012-2016) being 10.6 such events (NOAA, 2017c).

54. 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 ^{0}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 ^{0}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 ^{0}C were also recorded in Germany.

55. Severe droughts have occurred in the period 2011-2016. N. America (US and N. 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 2011-2016 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 rainfall (June-September) was about 10 per cent below normal in both 2014 and 2015. In April and May 2016, India experienced a major heat wave. A record high temperature of 51.0 ^{0}C was set in the town of Phalodi. 160 people died and 330 million were affected.

56. High winds and tornadoes caused major destruction. The number of cyclones characterized by high intensity winds increased during the 6-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 third 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 extremely intense with recorded wind speeds up to 322 km/h at Mexico.

57. 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 in this period. In 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, 2016).

58. In 2016, severe thunderstorms and tornadoes triggered significant losses in many parts of the world. The worst single incident occurred in Yancheng, Jiangsu province, China, when a tornado was associated with 99 deaths. It was one of the most destructive tornadoes in recorded Chinese history, at a time when the region was also experiencing severe flooding. Tornado activity in the United States was below the long-term average for the fifth consecutive year, with a preliminary count of 985 tornadoes, about 10 per cent below the post-1990 average. There were, however other severe thunderstorms. Two major hailstorms in Texas resulted in combined damage of more than US$5 billion. A notable hailstorm occurred in Brabant (Netherlands), with losses estimated at €500 million. Flash floods occurred in many parts of the NH, with notable episodes in Houston (Texas) and Tunisia. Unusually early heavy snowfalls affected Scandinavia in early November. Significant early snowfalls also affected Japan, with Tokyo receiving its first measurable November snow since records began in 1875 (WMO, 2017; NSIDC, 2017).

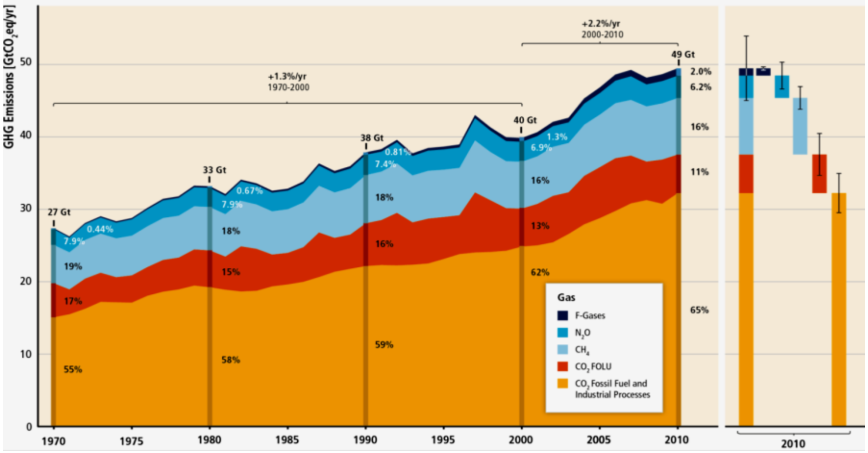
1.1.6 Forcing mechanism

59. 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 nineteenth 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).

Figure 19

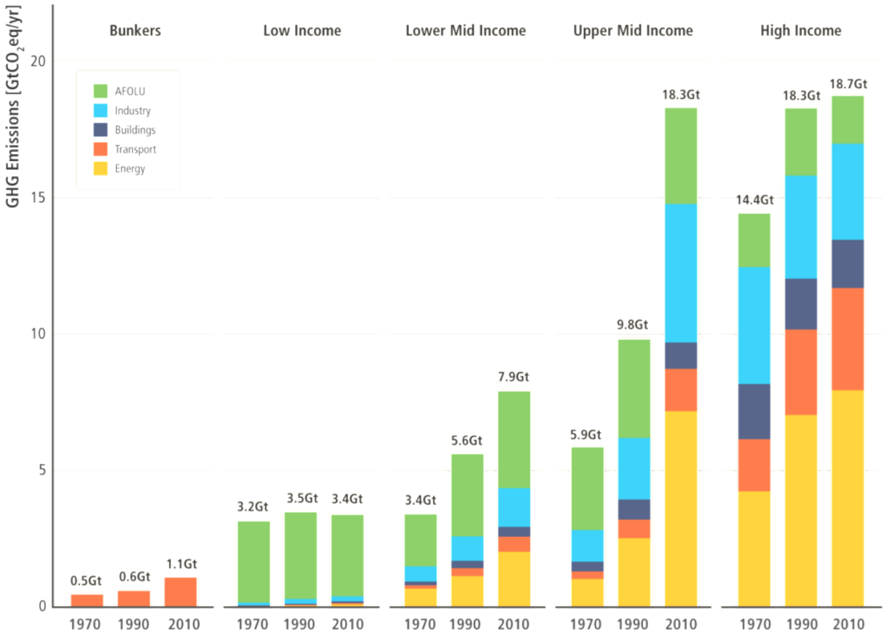
Total annual anthropogenic GHG for the period 1970-2010 (IPCC, 2014)



60. 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 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).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).

Figure 20

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



61. 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. 19); this trend continued in 2011-2016 (WMO, 2016).

62. In 2011-14, CO_2 and N_2O concentration had growth rates slightly higher than the 1995-2014 average. CH_4 concentration also showed growth, following a period of little change in 1999-2006 (WMO, 2016). During the 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, 2015). Approximately 44 per cent of the total CO_2 emitted by human activities from 2004 to 2013 may remain in the atmosphere, with the remaining 56 per cent stored in the oceans and the terrestrial biosphere (WMO, 2014, 2016).

63. Breakdown of the total anthropogenic GHG emissions in 2010 revealed that CO2 accounted for 76 per cent (65 per cent due to fossil fuel combustion/industry and 11per cent due to land-use), CH4 for 16 per cent, N2O for 6 per cent and fluorinated gases for 2per cent of the emissions (IPCC, 2014). Analysis of the total CO2 emissions from combustion for the period 1971-2010 showed 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 (e.g. the US and most EU countries) (Fig. 20). A notable increase of CO2 emissions was also found in lower-mid-income countries (IPCC, 2014).

Recent Climate Projections

2. 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’.

3. 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 1,000 m 0.3 °C (RCP2.6) to 0.6 °C (RCP8.5) by the end of the twenty-first century. For RCP4.5, half of the energy taken up by the ocean will be within the uppermost 700 m and 85 per cent 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).

4. With regard to the atmospheric air temperature, a long-term increasing trend is clear. Concerning temperature projections for the end of the twenty-first 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 twenty-first 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)[5]: 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 (5-95per cent model ranges). Sea level rise estimates are based on 21 CMIP5 models (5-95per cent 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.[6])

	Temperature		*Sea level rise*	
Scenario	*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

---

[5] 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 (Moss et al., 2010).

[6] 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).

	Temperature		*Sea level rise*	
Scenario	*Mean (°C)*	*Likely Range (°C)*	*Mean (m)*	*Likely Range (m)*
RCP 8.5	3.7	2.6-4.8	0.63	0.45-0.82

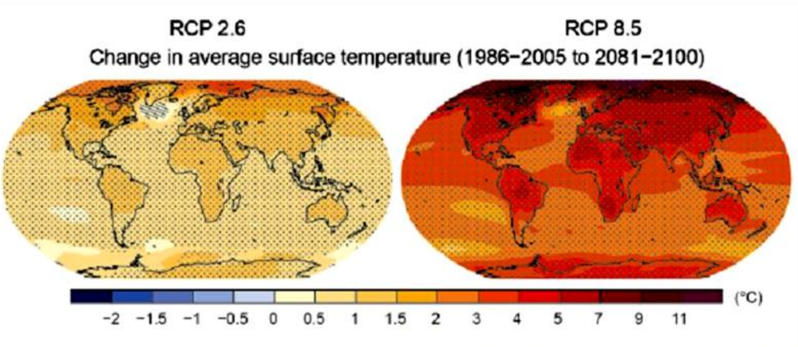
1.2.1 Temperature and Precipitation

5. Climate does not change uniformly, with temperatures close to the poles rising faster than at the equator (Figs. 21 and 22). 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 per cent in the decade 2020-2029 compared to that of the decade 1990-1999 (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).

6. Climate model projections suggest widespread droughts across most of South-Western North America and many other subtropical regions by the mid to late twenty-first century (Milly et al., 2008; IPCC, 2013). In contrast, while summers are expected to become (overall) drier by 2100 over the United Kingdom of Great Britain and Northern Ireland (UK), precipitation events may become heavier. Model simulations suggest that intense rainfall associated with flash flooding (more than 30 mm in an hour) could become almost 5 times more frequent (MetOffice, 2014)

Figure 21

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

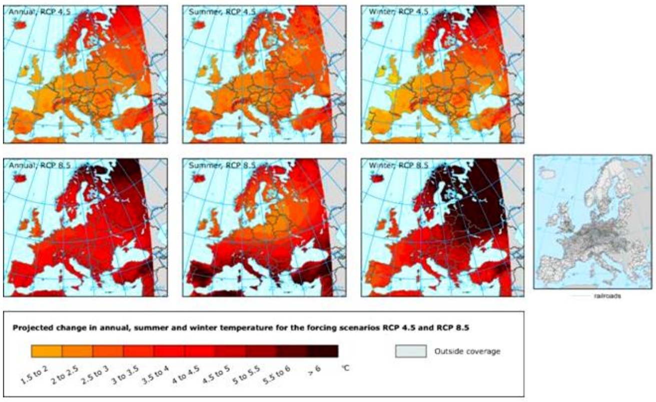


7. Studies also project decreases in the duration/intensity of droughts in the South Europe and the Mediterranean, the central Europe and parts of the North America (e.g. IPCC, 2013). At the same time, recent studies suggest severe/widespread droughts for the next 30-90 years (Dai, 2013) for most of South-Western North America and subtropical regions (IPCC, 2013). Vogel et al. (2017) have suggested that the multimode mean of daily maximum temperature (TX_X) increases globally in simulations (CTL and SM20c models) until the end of the century.

Figure 22

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). (EEA, 2014a))



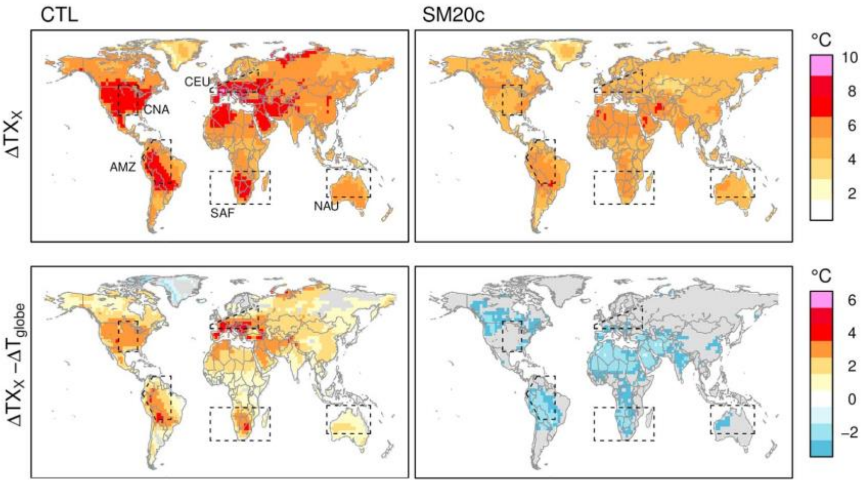
8. Projected changes are more pronounced in CTL, with regional increases of up to 10 °C, whereas in SM20c simulations temperature changes vary between 1°C and 6°C

(Fig. 23, top). There also appear to be large regional differences between the projected TX_X increase in Central Europe, Central North America, Northern Australia and Southern Africa. Such differences may indicate soil moisture-climate feedbacks for extreme temperatures in these regions.

Figure 23

Projected changes in TX_X (top row) between 2081-2100 and 1951-1970 and additional increase of TX_X versus Tglobe (bottom row) between 2081-2100 and 1951-1970 for CTL (left) and SM20c (right)

(Grey colour denotes insufficient model agreement; i.e. fewer than 4 models show the same change signal. The upper colour bar corresponds to top row, the lower colour bar to bottom row (Vogel et al., 2017))



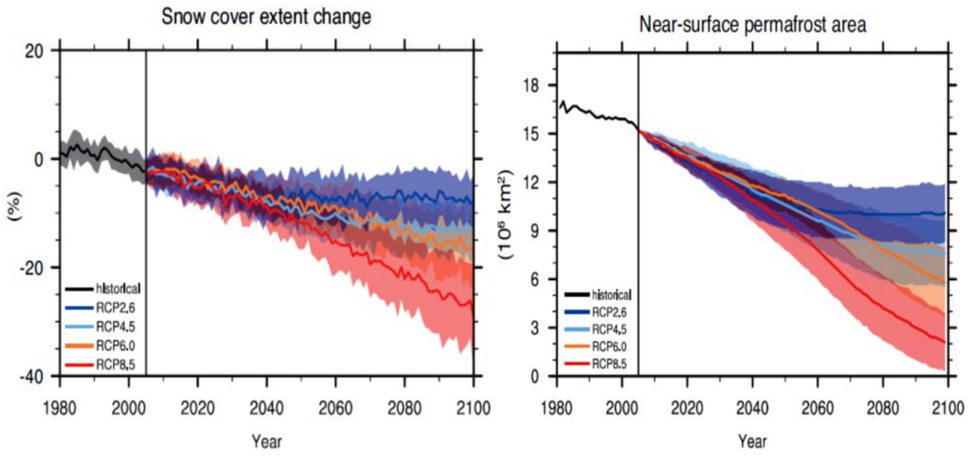
1.2.2 Arctic ice, snow and permafrost melt

9. Snowfall and rainfall are projected to increase in all seasons in the Arctic regions, mostly in winter; thus winter maximum snow depth over many areas is projected to increase, with the most significant increase (15 to 30per cent by 2050) taking place in Siberia. However, snow will tend to stand for 10 to 20 per cent less time each year over most of the Arctic regions, due to earlier spring melting

(AMAP, 2012). Spring snow cover in the North Hemisphere (NH) will decrease by 7 per cent (RCP2.6) and 25 per cent (RCP8.5), by 2100 (Fig. 24a). As for mountain glaciers and ice caps, climate model projections show 10 to 30 per cent mass reduction by the end of the century (AMAP, 2012). Models also 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 ^{0}C yr^{-1} (EEA, 2015a). Although there are challenges in assessing the magnitude of permafrost change, including those related to soil processes, climate forcing scenarios and model physics, permafrost extent is expected to decrease by 37 per cent and 81 per cent for RCP2.6 and RCP8.5 scenarios, respectively, by the end of the twenty-first century (medium confidence) (Fig. 24b).

Figure 24

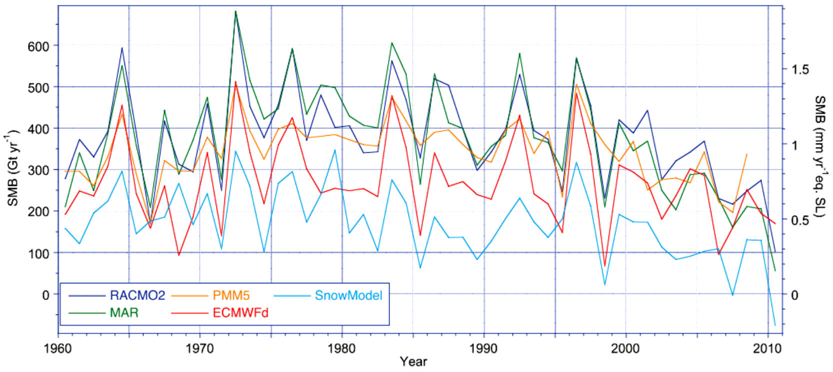
Projected (a) snow cover extent and (b) near-surface permafrost changes for 4 Representative Concentration Pathways-RCPs (from CMIP5 model ensemble) (IPCC, 2013)



10. Such changes could impose substantial problems in the development/maintenance of transport infrastructure in the Arctic regions (ECE, 2013), that could constrain the development of transport networks to take advantage of new Arctic Ocean routes made possible by the projected Arctic sea ice thaw.

Figure 25

Annual mean Surface Mass Balance (SMB) for the Greenland Ice Sheet (GIS), simulated by 5 regional climate models for the period 1960-2010 (Hansen et al., 2016)

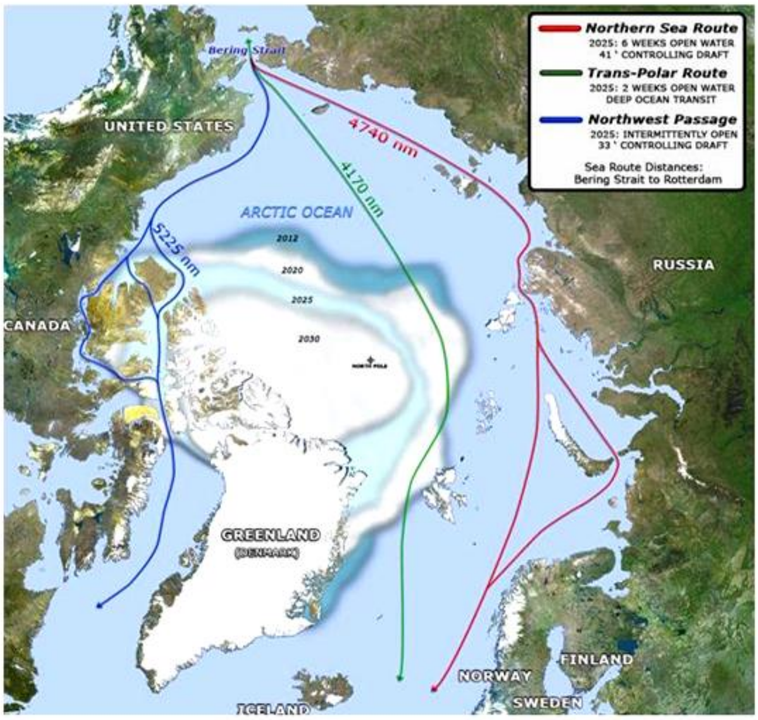


11. It is likely that the Arctic sea ice will continue to decrease in extent/thickness as global mean surface temperature rises, although there will be considerable inter-annual variability. Based on the CMIP5 model ensemble, Arctic sea ice extent is projected to decrease considerably. In the period 2081-2100, reductions of 8 to 34

per cent (in February) and of 43 to 94 per cent (in September) compared to the average extents in 1986-2005 are projected; the lower and upper projections refer to the RCP2.6 and RCP8.5, respectively (IPCC, 2013).

12. Continuing global warming will have a strong impact on the Greenland Ice Sheet (GIS) in the following decades. In the present climate, Greenland Surface Mass Balance (SMB) is positive but shows a decreasing trend, implying an increasing contribution to mean SLR. Based on the available evidence, it is unlikely that SMB changes will result in a collapse of the GIS in the twenty-first century, but likely on multi-centennial to millennial time scales (IPCC, 2013). The average and standard deviation of accumulation (precipitation minus sublimation) estimates for 1961-1990 is -1.62 ± 0.21 mm yr^{-1}. All information indicates that the Greenland SMB showed no significant trend from the 1960s to the 1980s, but started to become less positive in the early 1990s (on average by 3 per cent per year). This results in a statistically significant and increasing contribution to the rate of mean SLR (Fig. 25). IPCC (2013) has suggested that, during the next century, dynamical change of GIS could contribute to SLR by 20 to 85 mm (RCP8.5), and 14 to 63 mm for all other scenarios (medium confidence). Other studies project SMBs of 0.92 ± 0.26 mm yr^{-1} (compared to the 1961-1990) (Hansen et al., 2016). In comparison, the Antarctic ice sheet SMB is projected to increase under most scenarios due to an increasing snowfall trend. Nevertheless, it should be noted that negative Antarctica SMBs have the potential to contribute more than 1 m of sea level rise by 2100 (De Conto and Pollard, 2016).

Figure 26
New Arctic shipping routes. (U.S. Climate Resilience Toolkit, 2015)



13. Concerning Arctic ice, the US Navy anticipates the development of 3 major shipping routes by 2025 (Fig. 26); these are, however, associated with several environmental risks and development challenges. There may be new economic opportunities for Arctic communities, as reduced ice extent facilitates access to the substantial hydrocarbon deposits (at 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 (see below).

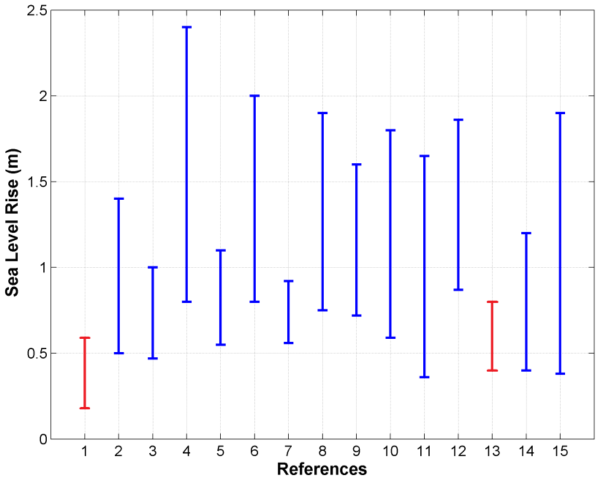
1.2.3 Sea level

14. Process-based predictions of sea-level rise (SLR) 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). Antarctic ice sheet melting could potentially contribute by more than 1 m of SLR by 2100 (De Conto and Pollard, 2016).

Figure 27

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, Dutton et al., 2015. The variability of the projections reflects differences in assumptions and approaches.)



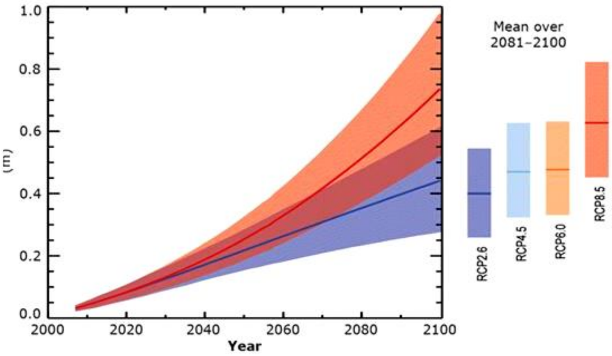
15. Global mean sea level has risen by 0.19 m between 1901 and 2013 (average rate 1.7 mm yr^{-1}), whereas in the last two decades, the rate has accelerated to almost 3.2 mm yr^{-1}. Models project a likely rise in 2081-2100 (compared to 1986-2005) in the range 0.26-0.54 m for RCP2.6 and 0.45-0.82 m for RCP8.5. It is thought that the steepening of the curve of the SLR in recent decades is mostly due to the increasing contribution of ice loss from the Greenland and Antarctic ice sheets (e.g. Rignot et al., 2011; Hanna et al., 2013; IPCC, 2013). Sea level estimates based on alternative approaches project a mean SLR much higher than that predicted a decade earlier (IPCC, 2007); it must be noted that the IPPC consistently provides conservative estimates (Fig. 27). Sea-level rise (Fig. 28) will not cease in 2100 (e.g. Jevrejeva et al., 2012), as changes in ocean heat content could affect thermal expansion for (at least) several centuries, whereas melting and dynamic ice loss in Antarctica and Greenland will also continue well into the future.

16. It should be noted that due to the large spatial variability observed (and projected) in sea level rise (Fig. 29), the regional trends should be considered when assessing potential impacts along any particular coast (e.g. Carson et al., 2016).

17. 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 coastal sediment subsidence (IPCC, 2013; King et al., 2015; Carson et al., 2016). Palaoclimatic, instrumental and modelling studies have shown that combinations of global and regional factors can cause relatively rapid rates of SLR along particular coasts that can exceed significantly the current global rate of about 3 mm yr^{-1} (e.g. Cronin, 2012).

Figure 28

Projected global MSLR over the twenty-first century relative to 1986-2005 (IPCC, 2013)

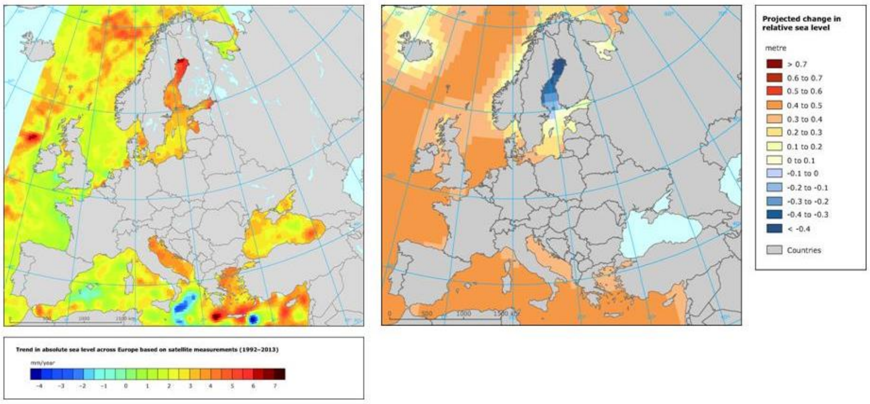


18. Sea level rise for the UK for the twenty-first century has been projected to be 0.12 - 0.76 m (excluding land level changes) depending on the emission scenario, with greater rises predicted in the case of additional ice sheet melting (Lowe et al., 2009). For the Netherlands coast, Katsman et al. (2011) have estimated sea level rises of 0.40-1.05 m for a plausible high end emission scenario. Marcos and Tsimplis (2008) have predicted a temperature-driven sea level rise of 0.03-0.61 m in the Mediterranean for the twenty-first century on the basis of 12 global climate models and for 3 emission scenarios; this rise should be combined with salinity driven changes of up to 0.31 m (see also EEA, 2012).

Figure 29

Trends in absolute sea level in European Seas from satellite measurements (1992-2013) (EEA, 2014b)

(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. (EEA, 2014c))



1.2.4 Extreme events

Heat waves

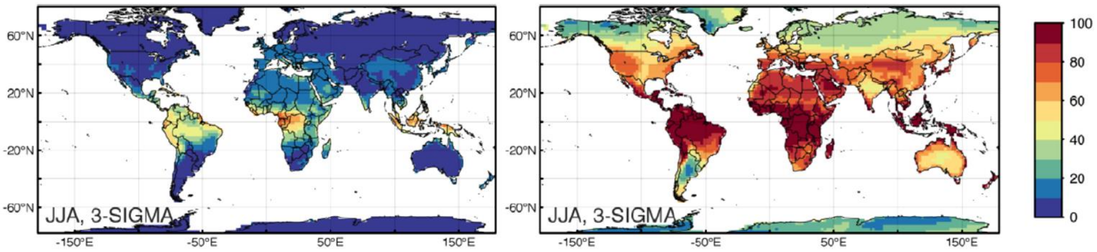
19. Increases in hot extremes and decreases in cold winter extremes are expected by the end of the twenty-first century, with the frequency, duration and magnitude of the events being affected by anthropogenic forcing (IPCC, 2013). Greater changes in hot days are expected to take place in sub-tropic and mid-latitude regions (Fig. 30), 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.

20. 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. 31). 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. 30).

Figure 30

Projected changes in hot seasonal temperature extremes in 2071-2100 for RCPs 2.6 and 8.5

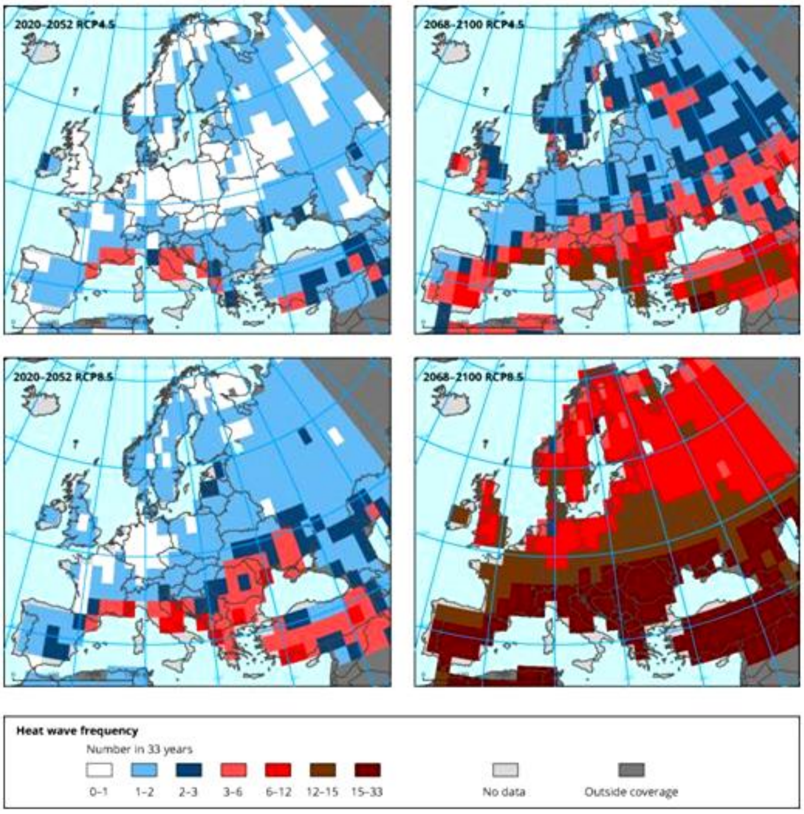
(Yellow, orange/red areas show regions where (at least) 1 every 2 summers will be warmer that the warmest summer in 1901-2100 (Coumou and Robinson, 2013))



21. Heat waves as severe as that of 2003 are 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 events (MetOffice, 2014). Furthermore, recent studies suggest that the probability of occurrence of an extreme heat wave like that occurred in the Russian Federation in 2010 may increase by 5 to 10 times until 2050 (Dole et al., 2011).

Figure 31

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, 2015b)

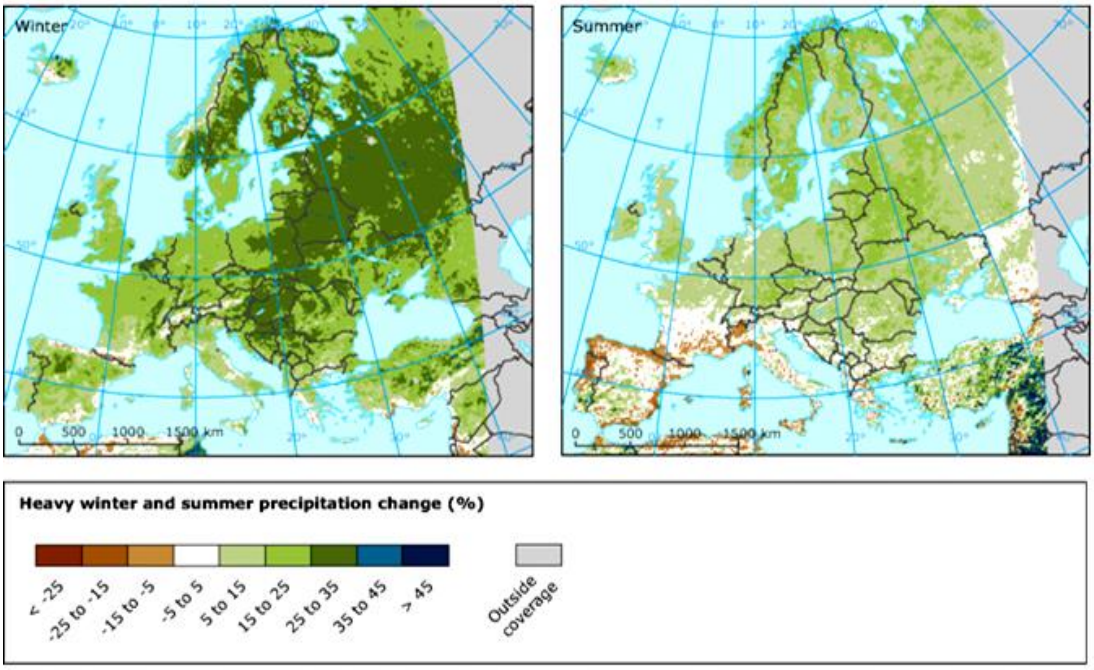


Downpours

22. 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 the century under the RCP8.5 scenario. Extreme precipitation events will 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 per cent) in heavy precipitation by the end of the century (Fig. 32). High resolution climate models indicate that extreme summer rainfalls could intensify with climate change (MetOffice, 2014). 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, 2014).

Figure 32

Projected changes in heavy precipitation (in per cent) 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, 2015c)



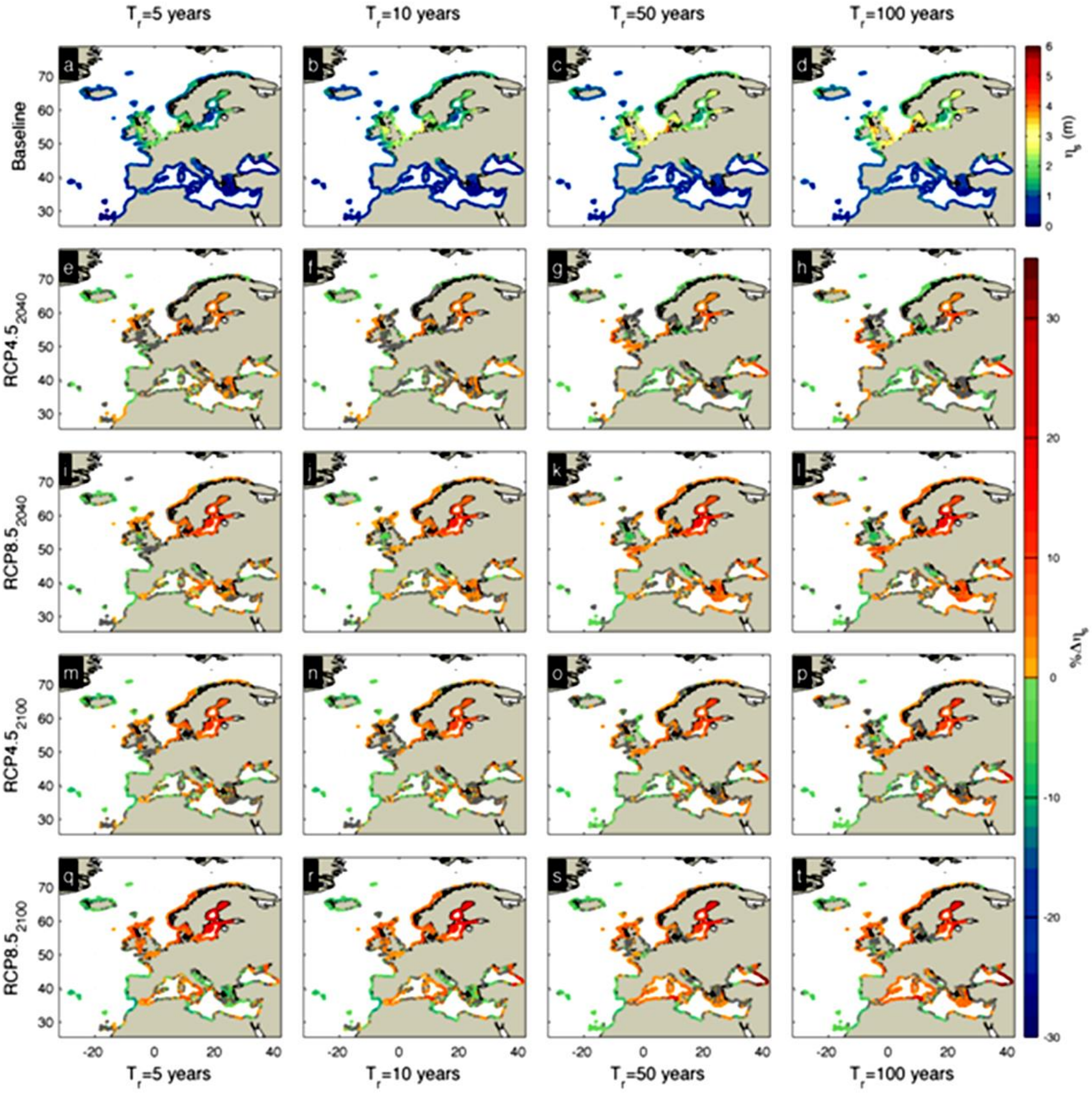
Sea storm and riverine floods

23. Despite the emerging risks associated with the changes in extreme coastal water levels, there is still limited information on storm surge levels (SSLs) 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.

Figure 33

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 colours express increase/decrease, respectively; while points with high model disagreement are shown with grey colours (Vousdoukas et al., 2016a))



24. 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., 2016a; Vousdoukas et al., 2017). The North Sea is an area subject to some of the highest SSLs in Europe (Fig. 33), with the projections indicating an increase in the extremes, especially along its eastern coast. Storm surges are projected to increase along the Atlantic coast of the UK and Ireland, due mostly to a consistent increase in the winter extremes. The Atlantic coast of France, Spain and Portugal is also exposed to very energetic waves (Pérez et al. 2014). The Mediterranean Sea has been studied 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

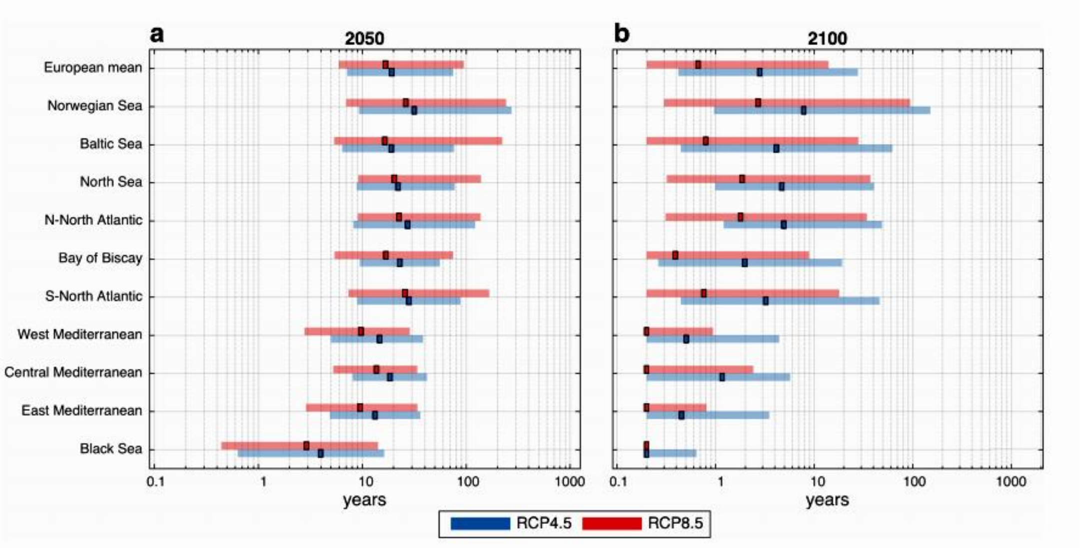
Woodworth 2010), as well as with more recent findings, projecting changes mostly in the ±5 per cent band, either positive or negative (Vousdoukas et al., 2016a). The North Adriatic is a region which has been studied more thoroughly due to the highly vulnerable (and socio-economically important) Venice 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.

25. 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 twenty-first 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 can increase 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).

Figure 34

Return period of the present day 100-year ESLs under RCP4.5 and RCP8.5 in 2050 (a) and 2100 (b). Coloured boxes express the ensemble mean value and coloured patches the inter-model variability (best-worst case)

(The values shown are averages along the European coastline as well as along the coasts of 10 geographical regions (Vousdoukas et al., 2017))

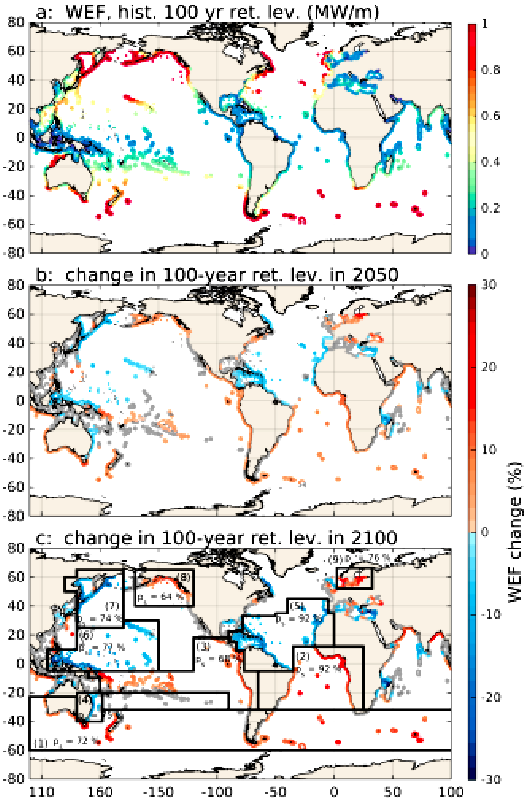


26. For the next 50 years or so, Hallegatte et al. (2013) suggested that for the 136 largest coastal cities: (i) damages could rise from US$ 6 billion/year to US$ 52 billion/year solely due to increase in population and assets; (ii) annual losses could approach US$ 1 trillion or more per year if flood defences are not upgraded; (iii) even if defences 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). Taking into account the standards of coastal flood protection works and uncertainties concerning the probability of their failure, about 5 million people in Europe could potentially be affected by the present day 100-year extreme sea level-ESL (Vousdoukas et al., 2016b).

Figure 35

Projections of wave energy flux-WEF along the global coastline: (a) baseline 100-year return level and relative change of the 100-year WEF for the year (b) 2050, and (c) 2100

(Grey dots correspond to locations with no significant change. In (c), areas of significant change are reported together with the percentage ps of points where increase is significant. (1) Southern temperate zone, (2) S. Atlantic, (3) sub-equatorial-tropical E. Pacific, (4) E. Australia, (5) N. tropical Atlantic, (6) NW tropical Pacific, (7) NW Pacific, (8) NE Pacific, and (9) Baltic Sea (Mentaschi et al., 2017))



27. Averaged over Europe’s coastlines, the present 100-year ESL[7] is projected to occur approximately every 11 years by 2050, and every 3 and 1 years by 2100 under RCP4.5 and RCP8.5, respectively (Fig. 34). Hence, the 5 million Europeans currently at risk once every 100 years, may be flooded at an almost annual basis by the end of the century (Vousdoukas et al., 2017). Some regions are projected to experience an even higher increase in the frequency of occurrence of extreme events, most notably along the Mediterranean and the Black Sea, where the present day 100-year ESL is projected to occur even more often.

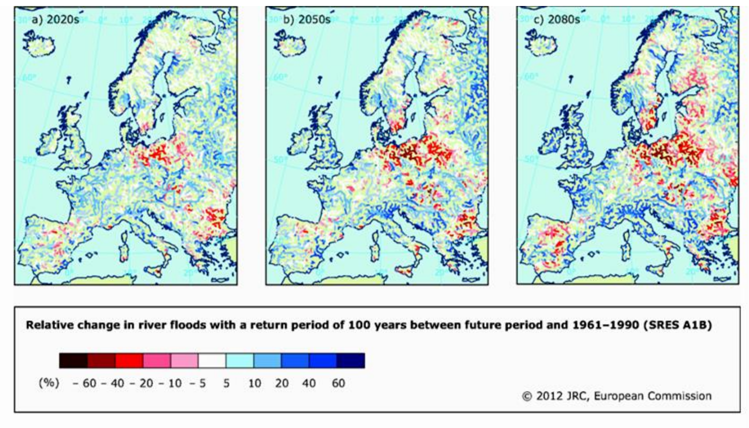
28. For the end of the twenty-first century, recent modelling results under a high emission scenario (RCP8.5) suggest a significant increase of up to 30 per cent in the 100 year return level wave energy fluxes (WEF) for the majority of the coastal areas of the southern temperate zone, with the exception of Eastern Australia, the Southern Atlantic, and the sub-equatorial-tropical E. Pacific (Mentaschi et al., 2017). In comparison, large coastal areas in the NH are projected to have a negative trend, with the exception of the NE Pacific and the Baltic Sea (Fig. 35) which are projected to show positive trends (rises of up to 30 per cent).

Figure 36

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

---

[7] The extreme sea level (ESL) is the combination of mean sea level, the tide, the storm surge level (SSL) and the wave set up (Losada et al., 2013).

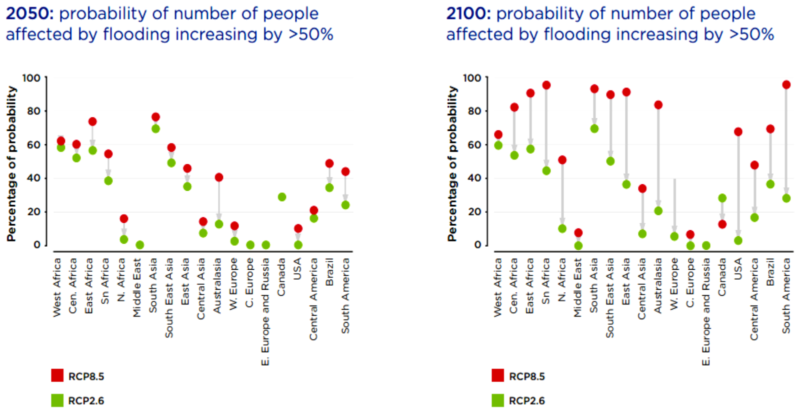


29. River flooding also poses a significant threat to the global population with observed increases in extreme runoffs being well documented (Feyen et al., 2010). Damage magnitude is mainly due to increasing human and infrastructure exposure in flood risk areas (IPCC, 2013). Changes in river floods projected for Europe are presented in Fig. 36).

30. Fig. 37 shows the flood risk by region that climate change increases by more than 50per cent 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 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 that such an increase would also take place in Asia. By 2100, risks will be higher (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, South-East and East Asia (King et al., 2015). Concerning the ECE region, flood impacts in 2050 are projected to be milder than in the other regions; nevertheless the situation for some ECE regions is projected to deteriorate significantly in 2100 (Fig. 37).

Figure 37

Probability that climate change will increase by more than 50per cent 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)



1.3 Implications for Transport: A short review

31. With regard to the sensitivity of transport networks to CV & C, a recent review (ECE, 2013) has found that: (a) transportation assets tend to be more sensitive to

extreme events, such as storm surges, heavy precipitation events, heat waves and high wind events than to incremental changes in the mean of the climate variables; (b) maintenance, traffic conveyance and safety are generally more sensitive to climate forcing than physical assets, as thresholds for e.g. delaying/cancelling transport services are generally lower than those for damages to infrastructure and (c) transport assets are sensitive to stressors whose occurrence is relatively unlikely in comparison to typical weather variability. For example, the superstructure of the US Gulf Coast bridges proved to be vulnerable to loading from direct wave impacts due to the unprecedented coastal sea levels induced by the storm surge of the Katrina (2005) hurricane (USDOT, 2012).

32. Hydro-meteorological extremes, such as heavy rainfall/floods and droughts are already causing substantial damages to transport infrastructure and services. Changes in extreme precipitation may result in river floods that might be particularly costly for inland transport networks (Hooper and Chapman, 2012), as major roadways and railways are located within and/or crossing flood plains; they can also have significant effects on bus/coach stations, train terminal facilities and inland waterway operations. There can be direct damages during, and immediately after, a heavy precipitation event that require emergency response as well as measures to support the structural integrity and maintenance of roads, bridges, drainage systems, and tunnels (USDOT, 2012).

33. Road and railway networks are projected to face significant risks of flooding as well as bridge scouring, whereas the projected increases in downpours/floods will also cause more rain-related road accidents (due to vehicle and road damages and poor visibility), delays, and traffic disruptions (e.g. Hambly et al., 2012). Road networks are expected to be severely affected by the projected increases in heavy downpours and flooding, through diverse impacts on the different types of pavement, asphalt and concrete; these would require adaptive maintenance practices such as construction of adequate drainage and the use of permeable pavements and polymer modified binders (e.g. Willway et al., 2008). Regions where flooding is already common will face more frequent and severe problems. Standing flood waters could have severe impacts and high costs; for example, the costs due to long-term road submersion in Louisiana have been estimated as US$50 million for 200 miles of the state highways (Karl et al., 2009). In the USA, adaptation costs for (road and rail) bridges vulnerable to river flooding have been estimated as $140-$ 250 billion through the twenty-first century (Wright et al., 2012). For the EU27 cost estimations are lower: future costs for bridge protection against flooding have been estimated as up to €0.54 billion per year (EC, 2012; ECE, 2015).

34. Railway infrastructure could be also impacted severely, with impacts including track and line side equipment failure, flood scours at bridges and embankments due to high river levels and culvert washouts, landslides, as well as problems associated with personnel safety and the accessibility of fleet and maintenance depots. In the UK, costs related to extreme precipitation/floods and other extreme events, which are already estimated as £50 million a year, might increase to up to £500 million a year by the 2040s (Rona, 2011). Extreme winds are also projected to be more catastrophic in the future (e.g. Rahmstorf, 2012), particularly at coastal areas where they can cause coastal defence overtopping and flooding of coastal/estuarine railways. Extreme winds could also cause infrastructure failures and service interruptions though wind-generated debris (e.g. (PIARC, 2012; ECE, 2013; 2015).

35. The projected increase in the frequency of heat waves may also pose substantial challenges in the railway, road (and airport) operations and services, due to rail buckling, road pavement damages and necessary reductions on aircraft payloads. The projected increases in the number of days with temperatures above about 38 ^{0}C (Vogel et al., 2017) can lead to increasing road infrastructure failures. Drier and hotter summers will cause pavement deterioration and/or subsidence, affecting performance and resilience (PIARC, 2012). Model predictions (EC, 2012) have estimated the additional annual costs for the upgrade of asphalt binder for the EU27

under the SRES scenario A1B[8] as €38.5-135 million in the period 2040-2070 and €65-210 million in 2070-2100. Nevertheless, it should be noted that as road surfaces are typically replaced every 20 years, such climate change impacts could be considered at the time of replacement.

36. Arctic warming may lengthen the arctic shipping season and introduce new shipping routes. There may be new economic opportunities for Arctic communities, as reduced ice extent facilitates access to the substantial hydrocarbon deposits (at Beaufort and Chukchi Seas) and international trade. At the same time, Arctic warming will result in (a) greater coastal erosion due to increased wave activity at the polar shorelines of Canada, the Russian Federation and the USA (e.g. Lantuit and Pollard, 2008) and (b) increasing costs in the development and maintenance of transport infrastructure due to thawing permafrost (ECE, 2015). Permafrost thawing (e.g. Streletskiy et al., 2012) presents serious challenges for transportation, such as settling and/or frost heaves that can affect road structural integrity and load-carrying capacity (ECE, 2013). In Arctic areas many highways are located in areas with already discontinuous, patchy permafrost, resulting in substantial maintenance costs as well as usage restrictions (Karl et al., 2009). Such disruptions are projected to increase substantially under the predicted increases in the extent/depth of permafrost thaw (EEA, 2015a).

37. Inland waterways can also be affected by both floods and droughts. Floods can have major impacts such as suspension of navigation, silting, changes in the river morphology and damage of banks and flood protection works (ECE, 2013). Inland waterways can also be affected by low water levels during droughts. Recent research[9], which has used the Rhine-Main-Danube (RMD) corridor as a case study, has found that over a period of 20 years, average annual losses due to low water levels were about €28 million (see also Jonkeren et al., 2007). Projections from different climate models, however, do not show significant effects of the low flow conditions on the RMD corridor until 2050; nevertheless, ‘dry’ years may lead to a 6-7 per cent increase in total transport costs compared to "wet" years.

38. Impacts of CV & C on the European transport systems were studied in two recent European projects[10]. Both projects found that there is a lack of reliable information relevant to the vulnerability of the different transport modes. Direct costs borne by the transport sector, such as those from infrastructure repair/maintenance and vehicle damage and increased operational costs, have been estimated for the period 1998-2010 as € 2.5 billion annually, and indirect costs from transport disruptions as €1 billion annually. Rail has been the most affected transport mode, with ‘hot spots’ in E. Europe and Scandinavia, whereas the effects on roads (mainly from weather related road accidents) have been found to be more evenly distributed.

39. Coastal transport infrastructure (coastal roads, railways, seaports and airports) will be dis-proportionally impacted by the CV & C as, in addition to the above challenges, they will have to adapt to increasing marine coastal flooding. In the ECE region, mean SLR and increasing storm surges and waves, particularly along the NW Europe, the Baltic Sea and the NE Pacific coast the of US and Canada (e.g. Vousdoukas et al., 2016a; Mentaschi et al., 2017), may induce major impacts, including flooding of roads, rail lines and tunnels in coastal areas. Coastal inundation can render transportation systems unusable for the duration of the event and damage terminals, intermodal facilities, freight villages, storage areas and cargo and, thus, disrupt supply chains for longer periods (ECE, 2013; 2015). Pecherin et al. (2010) have estimated that one meter increase in the ESLs above the inundation

---

[8] This scenario is roughly equivalent to the IPCC AR5 scenario RCP6.0.

[9] EU FP7-ECCONET Project, www.tmleuven.be/project/ecconet/home.htm

[10] The EU-FP7 WEATHER www.weather-project.eu and EWENT Projects (www.weather-project.eu/weather/inhalte/research-network/ewent.php)

level of the current 1-in 100 year-storm event[11], would result in damages and repair costs of up to €2 billion for mainland French A-roads, excluding operational and connectivity costs. Another study (EC, 2012) has provided an initial estimate of the future risk of the European coastal transport infrastructure due to mean sea level rise-SLR and storm surges on the basis of a comparison between the coastal infrastructure elevation and the combined level of 1 m mean SLR and the 100-year storm surge height; it was found that coastal transport infrastructure (e.g. coastal roads) at risk represents the 4.1 per cent of the total, with an asset value of about €18.5 billion. As however, more detailed projections on future extreme sea levels-ESLs and coastal wave power are starting to become available (Vousdoukas et al., 2016b; 2017; Mentaschi et al., 2017) for the ECE region (and beyond), it will be a worthwhile exercise to assess again the potential inundation impacts on the ECE transport infrastructure under different CV & C scenarios.

40. Finally, it should be noted that the transport industry is a demand-driven industry. Climate Variability and Change can have significant effects in, almost all, sectors of economy, and thus affect indirectly transport services through e.g. changes in commodity demand and tourism transportation (ECE, 2015).

1.4. Summary

41. In this Chapter a review of the long-term and recent trends and variability of different climatic factors that can affect transportation has been presented, together with a review of the recent projections on the evolution of these factors in the twenty-first century under different emission scenarios. The major findings are summarized below.

Trends

42. There is overwhelming evidence for a warming world since the nineteenth century from scientific observations from the upper atmosphere to the ocean deeps. The global average surface temperature has risen by 1.1 ^{0}C since the late nineteenth century, with the most recent 6-year period (2011-2016) being the warmest on record. 2016 has also been the hottest year on record (1.1 ^{0}C higher than the 1901-2000 average of 14.0 ^{0}C). In the ECE region, temperatures were more than 1 ^{0}C above the 1961-1990 average over most of Europe, Northern Asia and the South-Western US and reaching about 3 ^{0}C above average in regions of the Russian Arctic. The integrated ocean heat content within the 0-700 m layer was higher than any previous time and sea surface temperatures (SSTs) were above average in most of the oceans. Evidence suggests that warm extremes have become warmer and cold extremes less cold in many regions.

43. Land precipitation data reveal an increasing trend in the twentieth century, especially in mid and high latitudes and a strong regional variability which, in many cases, appears to be influenced by the large climatic modulations such as the ENSO and NAO. Land precipitation in the most recent period (2011-2016) was strongly influenced by the ENSO, i.e. the La Niña conditions in 2011-2012, and the strong El Niño of 2015-2016. In 2016, precipitation above the 90th percentile was observed in a large swath of land extending from Kazakhstan across the Western Russian Federation into Finland, N. Sweden and Norway; at the same time, large areas of the Northern and Central Russian Federation were dry, with much of the region between the Urals and Lake Baikal and to the north of 55 ^{0}N showing precipitation below the 10th percentile.

44. There has been also an increase in heavy precipitation events (in intensity and/or frequency) in many areas of the ECE region. One of the clearest trends

---

[11] Costs assumed in the study: average linear property cost at €10 million/km of road surface; repair costs at about €250 thousands/km

appears to be the increasing frequency/intensity of heavy downpours in areas that there is already a significant flood risk (for the 1 in a 100-year events), such as the Central and Eastern Europe, Central Asia and along the large S-N drainage basins of Siberia. Consequently, flood damages are expected to rise considerably by the end of the century, being generally higher in the north than in the south. In some regions, there is also evidence to suggest increases in the frequency/intensity of heat waves, as well as of droughts (e.g. in the Mediterranean).

45. Over the past few decades, there appears to be a downward trend in the extent/duration of snow cover in the Arctic. Snow cover has declined (in the month of June) by 11.7 per cent per decade over the period 1967-2012. However, this trend is not uniform; some regions (e.g. the Alps and Scandinavia) show consistent decreases at low elevations but increases at high elevations, whereas other regions (e.g. the Carpathians, Pyrenees, and Caucasus) show no consistent trends. There has been a decrease in the number of frost days in mid-latitude regions. Arctic sea ice continued its steep decline. In 2016, sea ice extent was well below average and at record low levels for large parts of the year; March seasonal maximum was 14.52 million km^2, the lowest seasonal maximum in the 1979-2016 satellite record. Mountain glaciers also continued to decline. Permafrost extent also continued to decrease; recently, there has been warming down to 20 m depth in Arctic permafrost regions.

46. Since 1860, sea level has increased by about 0.20 m, with the rate of increase becoming progressively greater, particularly since the 1990s. SLR trend over the satellite record (1993-2015) has been 3-3.2 mm yr^{-1}, considerably higher than the 1900-2010 average (1.7 mm year^{-1}).

47. Extreme hydro-meteorological events (e.g. heat and cold waves, tropical cyclones, floods, droughts and intense storms) causing significant losses/damages also appear to be on the rise; fortunately, human loss did not follow the steep upward trend of the economic losses associated with these extreme events.

Projections

48. Recent projections on the climatic factors that could impact transport infrastructure and operations are presented below. Generally, challenges that are already imposed by certain climatic factors on the present day transport infrastructure will increase significantly.

49. By the end of the twenty-first century, the mean atmospheric temperature is projected to increase between 1.0 and 3.7 ^{0}C above the mean temperature of the period 1986-2005, depending on the RCP scenario. Oceans will warm under all scenarios, with the highest SSTs projected for the subtropical and tropical regions. Increases in hot extremes and decreases in cold extremes are expected by the end of the twenty-first century, particularly in mid-latitude regions. Large regional differences are projected for temperature maxima (TX_X); these may increase in central Europe, central N. America and N. Australia. The frequency/duration of heat waves is projected to increase for many regions (and in Europe), particularly under high emission scenarios. For most land regions it is considered likely that the frequency of the current 20-year hot event will be doubled; in some areas, such an event might even occur every 1-2 years. At the same time, the occurrence of the current 20-year cold event will substantially decrease in the future.

50. As temperature rises, average precipitation will exhibit substantial spatial variation in its patterns. Land precipitation is projected to increase in high and mid latitudes and decrease in sub-tropical arid and semi-arid regions. Extreme precipitation events will likely be more intense over most of the mid-latitude and wet tropical regions. For central and NE Europe, projections demonstrate large increases (by 25 per cent) in heavy precipitation events by the end of the century. At the same time, widespread droughts across most of South-Western North America are projected for the mid to late twenty-first century. In comparison, decreases are

projected for the duration/intensity of droughts in Southern Europe and the Mediterranean, central Europe and other areas of North America.

51. Snowfall and rainfall are projected to increase in the Arctic regions, mostly in winter. However, although winter maximum snow depth will likely increase (particularly in Siberia), early melt will result in considerable decreases (by up to 25 per cent) in spring snow cover in the Northern Hemisphere (NH). Mountain glaciers and ice caps are projected to show a 10 to 30 per cent mass reduction by the end of the century. Models also project accelerating thawing of permafrost, due to rising temperatures and changes in snow cover. Current rates of warming of the European permafrost surface are 0.04 - 0.07 ^{0}C yr^{-1} and, although there are challenges in assessing permafrost change, its extent in 2100 is expected (medium confidence) to decrease by 37 per cent and 81 per cent for the RCP2.6 and RCP8.5 scenarios, respectively.

52. It is also likely that the Arctic sea ice will continue to decrease in extent/thickness, although there will be considerable inter-annual variability. In the period 2081-2100, reductions in Arctic ice extent of 8 to 34 per cent (in February) and of 43 to 94 per cent (in September) are projected (compared to the average extents in 1986-2005) for RCP2.6 and RCP8.5. These may result in the development of major Arctic shipping routes which, however, could be associated with environmental risks and development difficulties, such as those imposed by the projected permafrost thaw on the development/maintenance of the necessary coastal and land transport infrastructure to service these routes.

53. CV & C risks to ECE coastal transport infrastructure are also expected to rise. Sea level rise for the ECE region depends on the emission scenario, with greater rises predicted in the case of additional ice sheet melting. For the North Sea coast, for instance, mean sea level rises of 0.40 to 1.05 m are expected, with slightly lower rates projected for the Mediterranean coast. Larger storm surge levels are projected for the Atlantic, North Sea and Baltic coasts (and ports) under all scenarios and extreme storm events. For Southern Europe, however, projections are better, with expected changes in the storm surge levels mostly in the ±5 per cent band.

54. Recent research suggests a negative trend in the wave energy fluxes-WEF (for the 100-year return event) along the ECE coast, with the exception of the NE Pacific and the Baltic coasts which are projected to show increases in the WEF of up to 30 per cent. With regard to the extreme sea levels (ESLs) and taking into account the presence/standards of coastal flood protection works and uncertainties concerning the probability of their failure, about 5 million people in Europe could potentially be affected by the present day 100-year ESL. Averaged over Europe’s coastlines, such an event is projected to occur approximately every 11 years by 2050, and every 1 to 3 years by 2100 (RCP4.5 and RCP8.5). Hence, the millions of Europeans currently at risk once every 100 years may face flooding at an almost annual basis by the end of the century. Some regions are projected to experience an even higher increase in the frequency of occurrence of extreme events, most notably along the Mediterranean and the Black Sea; in these areas, such events are projected to occur even more often. It appears that the effects of these events on the coastal transportation infrastructure (and related supply chains) should be urgently assessed in more detail.

CHAPTER II

SUMMARY OF NATIONAL STRATEGIES, GOOD PRACTICES, AND CASE STUDIES

Introduction

As part of the activities of the Group of Experts on Climate Change Impacts and Adaptation for Transport Networks and Nodes, a questionnaire was send to the UNECE member states. In their reply some Governments provided links to their National strategies, action plans as well as policies already implemented. Also, during the Groups' sessions, Governments and Organizations representatives presented various good practices and actions implemented.

This chapter provides a short overview of the information presented. This overview might possibly serve as entry to further in-depth bilateral consultations.

Additional information provided by governments in reply to the questionnaire.

STRATEGY & PLANNING

SYNOPSIS

Many countries have or are developing both a strategy on climate change adaptation and a strategy on transport and mobility. In general, climate change strategies drive from climate scenarios. In developed countries regionalized climate scenarios are available or under construction, while for developing countries the global IPCC scenarios -complemented by an expert assessment- act as starting point for conclusions.

Transport strategies focus in most cases on the main infrastructure and include -broadly speaking- an assessment of the corridors, connections and interchanges that are vulnerable already in our current climate.

In most cases the climate change strategy and the transport strategy are complementary, meaning that transport is not or hardly addressed in the adaptation strategy and vice versa. Combining the two strategies would bring the effects of climate change and the vulnerability of the network together and may be considered as the next step to a climate resilient infrastructure and transport system. All in all, the basis for swift progress on this matter is already available!

EUROPEAN UNION

At the EU level

The 2009 White Paper 'Adapting to climate change: Towards a European framework for action' set out a number of measures that have largely been implemented12. A key deliverable was the web-based European Climate Adaptation Platform (Climate-ADAPT13), launched in March 2012. It incorporates the latest data on adaptation action in the EU, together with several useful policy support tools.

In 2013 the EU published their 'Strategy on adaptation to climate change'14 and invited all EU Member States to prepare and finalise a National Adaptation Strategy by 2017.

To date, 15 EU Member States have adopted an adaptation strategy15. Others are under preparation. Some of the adopted strategies have been followed up by action plans, and some progress was made in integrating adaptation measures into sectoral policies. However, in most cases adaptation on transport is still at an early stage,

---

[12] COM(2009) 147 Final. See the impact assessment for a full review of implementation

[13] http://climate-adapt.eea.europa.eu/ focuses on EU-level information, with links to national action. Several Member States have developed national information platforms

[14] COM (2013) 216 final

[15] See http://climate-adapt.eea.europa.eu/web/guest/adaptation-strategies

with relatively few concrete measures on the ground. Some Member States have developed sector-specific plans, such as plans to cope with heat waves and droughts, but only a third carried out a comprehensive vulnerability assessment to underpin policy. Monitoring and evaluation is proving to be particularly difficult, as indicators and monitoring methodologies have hardly been developed.

One priority and responsibility for the EU Commission is to mainstream adaptation measures into EU policies and programmes, as the way to 'climate-proof' EU action. Adaptation has already been mainstreamed in legislation in such sectors as marine waters16 and transport17; and in important policy instruments such as inland water18 and mobility19. In addition, the Commission has tabled legislative proposals on integrating adaptation in a number of sectors including transport20. These moves to mainstream climate change adaptation into EU policies will be pursued in priority fields such as energy and transport.

Infrastructure projects, which are characterised by a long life span and high costs, need to withstand the current and future impacts of climate change. Building on the recent mandate to assess the climate change implications for Eurocodes21, it is intended that the EU work with standardisation organisations, financial institutions and project managers needs to analyse to what extent standards, technical specifications, codes and safety provisions for physical infrastructure is strengthened to cope with extreme events and other climate impacts.

Monitoring and evaluating climate change adaptation policies are crucial. The emphasis is still on monitoring impacts rather than adaptation action and its effectiveness. The EU Commission will develop indicators to help evaluate adaptation efforts and vulnerabilities across the EU. In 2017 the Commission will report to the European Parliament and the Council on the state of implementation of the Strategy and propose its review if needed. The report will amongst others be based on information provided by Member States under the Monitoring Mechanism Regulation22 on national adaptation planning and strategies.

The EU developed guidance describing how to integrate provisions regarding effects of climate change in the product standard, covering each life cycle stage23. It is concluded that transportation needs to be considered at all stages of the life cycle. Climate change related impacts to products during transportation (including transport of raw materials, product to market or product at the end of its life) include:

weather events cause disruption to transport infrastructure leading to delays, in particular if travelling over long distances or through affected regions;

product is damaged or degraded during transport due to temperature or humidity.

Examples of provisions in standards	Choices, limitations or win-wins
Traffic planning (not	Longer delivery routes

---

[16] Council Directive 2008/56/EC and EU Regulation No 1255/2011

[17] Decision 661/2010/EC

[18] COM(2012)673 final

[19] COM(2011) 743 final

[20] COM(2011) 650/2 final

[21] Eurocodes are a set of harmonised technical rules for the structural design of construction works in the EU developed by the European Committee for Standardisation

[22] http://ec.europa.eu/clima/policies/g-gas/monitoring/

[23] CEN-CENELEC Guide 32: addressing climate change adaptation in standards. Edition 1, 2016-04

through vulnerable regions)	may lead to delay and higher costs
Consider the location of raw material production	
Choose the most resilient way of transport.	Choose the optimum between resilience and reduction of GHG emissions
Choose new/ alternative ways of packaging.	Balance between waste and GHG emissions

Recommendations for climate change adaptation provisions related to transportation.

At the member states level

Countries in the European Economic Area (EEA) are at different stages of preparing, developing and implementing national adaptation strategies and plans. Through the CLIMATE ADAPT portal (http://climate-adapt.eea.europa.eu), information is provided by each Member State of the European Union as part of the obligations under the European mechanism for monitoring and reporting information on climate change. For other EEA Member countries, the information provided is based on voluntary submissions to EEA.

On the basis of country specific climate projections and a vulnerability assessment, an evaluation is made of the consequences of climate change and possible adaptation actions per sector are recognized.

In most cases however transport is not addressed in the adaptation strategy or -in best cases- as a side effect of actions in other sectors, for instance on water. Nevertheless, in can be concluded that the climate projections and vulnerability analyses can very well serve as a basis for adaptation action planning on transport and mobility.

In addition to the above, some EU Member States provided information on their adaptation strategy to the Group of Experts:

BELGIUM

The Belgian National Climate Change Adaptation Strategy originates from 2010.

In Belgium a substantial part of initiatives to adapt to climate change has been initiated from the bottom up. On the regional and local level as well as on sector specific level, the sense of urgency has inspired many people to take action in diverse fields as health, tourism, agriculture, forestry, biodiversity, ecosystems, water, coastal, marine and tidal areas, production systems and physical infrastructure.

To cope with climate change, people started to construct monitoring schemes, to build physical barriers and to induce changes in people’s behavior. It is interesting to note that the actions are not only based on the defense against threats, but also on finding new possibilities and capitalizing on favorable changes.

In the adaptation strategy the attention is focused on sectors as water, agriculture and health. Adaptation in the transport sector is not explicitly addressed. However, the thorough analyses of effects and possible actions in the field of spatial planning, flood and drought protection and water management provides a solid basis for a transport and mobility specific assessment of adaptation options.

BULGARIA

In Bulgaria, climate-related risks are expected to increase due to the changing climate in the next decades. (http://www.preventionweb.net/countries/bgr/data).

Several institutes are actively involved in monitoring and research on climate, including the Bulgarian Academy of Science, the National Institute of Meteorology and Hydrology (NIMH-BAS) and the National Institute of Geophysics, Geodesy and Geography. In the context of the EU WEATHER program, several studies were undertaken regarding the environmental and economic impacts from climate change in the field of transport: Impact of natural Disasters on Transport Systems – Case studies from Bulgaria. (http://www.weather-project.eu/weather/downloads/Deliverables/WEATHER-IP_BG-Karagyozov_pub.pdf)

Bulgaria is in the process of completing a National Adaptation Strategy, for the period up to 2030. As a first step a "National Climate Change Risk and Vulnerability Assessment for the Sectors of the Bulgarian Economy" was prepared (2014), covering amongst others, transport and infrastructure. In this document each sector is assessed by a system of indicators regarding vulnerability to future climate change in the time frame 2016 - 2035.

The main conclusions from the analysis on the transport sector are:

There is no drastic impact of climate change on the transport system expected on the short-term;

Climate change will significantly affect the development and costs of road and railway transport on the mid- and long-term;

In summer, the impact is mainly related to increased infrastructure maintenance due to the expected increase of "thermal stress" on road and railway infrastructure;

For the period 2040-2070 an annual reduction of 2.4% for winter maintenance of road infrastructure is expected due to milder winter conditions.

Extreme weather events are dominantly of local importance, but trends outlined by the climate scenarios indicate a significant effect on operations and the system's functioning.

Adaptation to Climate Change is closely related to Disaster Risk Management. Several reports were made on reducing vulnerability and adaptation measures. (http://www.moew.government.bg/files/file/Climate/Insurance_Against_Climate_Change.pdf and http://www.preventionweb.net/countries/bgr/data/). The findings are also relevant for the transport sector, but no transport specific conclusions were drawn.

CROATIA

The Republic of Croatia developed a Transport Development Strategy setting out the basic guidelines for the development of the transport sector within the Republic of Croatia over a medium and long-term horizon (2014-2030). The general goal of this Strategy is to achieve an efficient and sustainable transport system in the territory of the Republic of Croatia, taking into account its new role after its accession to the European Union in July 2013. The Strategy aims to define an overall and coherent framework to ensure the linkage of infrastructure and transport policy and enabling decision making. (http://www.mppi.hr/default.aspx?id=16279)

Although the strategy takes environmental concerns into account, including changes in climatic patterns, the consequences of climate change and hence adaptation are not explicitly part of the way forward. However, the strategy provides an exhaustive analysis of the transport system, including vulnerabilities, that easily can serve as starting point for further work.

FINLAND

In 2005 Finland adopted a ‘National Strategy for Adaptation to Climate Change’ covering land use planning, transport, infrastructure and other important sectors of society. It was recognized that adaptation should be part of the visions, long term planning and R&D of the transport sector. To implement the national strategy and support ‘the EU Strategy on adaptation to climate change’, the ‘National Adaptation Plan 2022’ was adopted in 2014.

This National Adaptation Plan aims at mainstreaming adaptation into all sectors and at assuring that sufficient tools are available to estimate risks related to climate change. In the context of the National Adaptation Plan, the transport sector assessed the impacts of climate change to transport infrastructure and recognized the need for adaptation.

Consequently, adaptation measures were implemented and co-operation between different transport-related sectors started. Adaptation in the transport sector covers:

proactive adaptation in design of the infrastructure,

structural adaptation (measures undertaken in building and maintenance),

proactive (or reactive) adaptation in maintenance and

planning and preparing for emergency situations.

Flood risk areas are taken into account when designing roads. The Finnish Transport Agency mapped these risk areas a few years ago and this information is publicly available at http://paikkatieto.ymparisto.fi/tulvakartat/SL/Viewer.html?Viewer=Tulvakarttapalvelu.

The available adaptation plans for floods can be assessed through

http://www.ymparisto.fi/fiFI/Vesi/Tulviin_varautuminen/Tulvariskien_hallinta/Tulvariskien_hallinnan_suunnittelu/Tulvariskien_hallintasuunnitelmat.

Further it is recognized that land use planning can reduce climate related impacts on the road and railway networks. Risks from the surrounding areas may affect a railway or a road under planning and in Finland impacts from the surrounding area - including flood risks- have to be assessed in the design phase. In this way the effects of climate change are taken into account in the structural design of railways and in proactive maintenance;

In Finland a lot of climate change related research has been done, including studies concerning climate change impacts to agriculture, transport, energy production etc.. They provide an overarching picture, but it is difficult to draw conclusions on what the results would mean for the critical infrastructure at a specific location.

Overall, winters are getting warmer what affects road maintenance, but it is not clear whether the change will be positive or negative. It seems that in Southern Finland maintenance work will decrease, while elsewhere in Finland possibly more maintenance will be needed. But as a whole, it is expected that the total costs of road maintenance in Finland will increase because of climate change.

The indirect impacts of climate change on transport are even more difficult to assess. It proved to be very difficult for instance to draw reliable conclusions on what certain changes to agriculture would mean for our TEN-T network. These kind of indirect impacts are still very speculative and need further research.

IRELAND

Ireland’s approach to transport adaptation is currently being developed at a more strategic level. Accordingly, Ireland’s approach to adaptation is focused on assessing our vulnerability to key climate variables and the likely impacts of such on our transport system.

In order to focus the analysis, five subsectors were selected (road, bus, rail, aviation and port services) for assessment and impacts were identified on the basis of infrastructure, modes and staff and passengers. The impacts and vulnerability analysis was categorised by changes (observed and projected) in climate variables (e.g. increasing temperatures) and extreme weather event type (e.g. cold snap). Importantly, the observed and projected impacts of changes in climate variables and extreme weather events were determined with reference to the recorded impacts of recent extreme weather events and observed changes in Ireland’s climate.

Further, the analysis was focused on impacts which have occurred due to observed changes in Ireland’s climate and also due to recent extreme weather events, i.e. weather related events that had directly or indirectly affected the agriculture and forest sector. On this basis, potential future impacts and vulnerabilities will be identified and prioritised (although this has yet to be done) with adaptation options proposed.

While it will be difficult to determine the extent to which climate change will impact on the Irish transport system in the coming years, the sector has been collating baseline data in relation to the impacts of severe weather events on transport infrastructure and services, particularly since 2009. We have undertaken a screening exercise to identify the wide range of impacts of observed and projected changes in key climate parameters as well as extreme weather events for the transport sector. This screening exercise was undertaken to identify priority climate changes and impacts for the transport sector (in general terms).

NETHERLANDS

The Netherlands have two complementary plans for adaptation, the DELTAPROGRAMMA and the NATIONAL ADAPTATION STRATEGY.

In 2010 the Delta Programme started with the aim to ensure that freshwater supply, flood risk management and spatial planning will be climate-proof and water-resilient by 2050. (https://english.deltacommissaris.nl) The Delta Programme means a new approach to working on the delta, in concert with other organisations, focusing on three areas:

New flood protection standards will be set: these will not only be linked to the probability of flooding, but also to the impact of a flood (risk-based approach). The scope of the impact is the decisive factor in setting the standard;

The availability of freshwater for agriculture, industry and Nature will become more predictable;

Spatial planning will become more climate-proof and water-resilient.

In the Delta Programme it is investigated what short-term and long-term solutions are needed to protect the Netherlands from flooding, ensure an adequate supply of freshwater, climate-proof our country and make it water-resilient. Finalising measures for fifty to a hundred years ahead is difficult and in most cases not advisable. After all, solutions must be able to grow along with new insights and circumstances. On the other hand, planning and implementation of major works take time: it took several decades to complete the Delta Works. Guiding principle is therefore: take the right steps at the right time: adaptive delta management. This to ensure that sensible measures are taken now, while at the same time keeping sufficient options open in the future.

In 2016 the Netherlands government approved the National Adaptation Strategy (NAS) that builds upon a decade of climate adaptation policy and, in combination with the Delta Programme, sets out the Netherlands' response to climate change. (http://ruimtelijkeadaptatie.nl/english/nas)

The NAS uses four diagrams ('Hotter', 'Wetter', 'Drier' and 'Rising Sea Level') to visualize the effects of climate change in nine sectors, including water and spatial management and infrastructure (road, rail, water and aviation. Six climate effects which call for immediate action have been identified, of which two are of direct relevance for the transport sector :

more frequent failure of vital systems;

cumulative effects whereby a systems failure in one sector or at one location triggers further problems elsewhere.

Attention must also be devoted to climate effects which are not expected to emerge until somewhat later this century, but which call for urgent attention due to their high impact. They include the failure of the electricity supply grid due to extreme weather, restriction of shipping due to unusually high or low water levels, large-scale failure of IT systems. There may also be ground subsidence causing damage to buildings and infrastructure and safety risks further to the fracture of pipes and cables.

Rising temperatures might also have positive economic and societal effects. Effects on transport may come from warmer weather that could increase yields of some crops or allow the cultivation of new crops. The Dutch weather might become more attractive than that elsewhere in Europe and this could have a positive effect on tourism.

SPAIN

In 2006 the Spanish ‘National Climate Change Adaptation Plan’ (PNACC) was proposed, to start assessing the vulnerability and possibilities for adaptation of the transport sector and system. In addition, an initiative was launched in September 2012 to conduct a ‘preliminary analysis of the needs to adapt the core network of transport infrastructure in Spain to climate change’24.

An overall assessment of the adaptation measures suggests that the greatest short-term challenge in adapting the core network of Spanish transport infrastructure to climate change, will be to promote awareness among those responsible for the network, that climate change must be included as an additional determining factor in its design and operation. Climate change should also serve as a spur to strengthen some of the current infrastructure management practices related to some weather events.

In Spain, the adaptation needs are significantly influenced by the latitude of the country and its effect on the maximum temperatures, by its size (which means more nodal infrastructure, with specific design and operational requirements against weather conditions), and by its topography and the strong variability of its rainfall and hydrological regimes (which give rise to an abundance of slopes and structures on linear infrastructure and a large number of sites affected by high runoff and flash floods).

Further, when taking climate change into account in the design and operation of infrastructure, it is important to remember to contextualize climate risks within a broader set of non- climatic conditions (including demographic, economic, technological and institutional conditions, etc.), since it is possible that some indirect effects (e.g. changes in population density, changes in transport demand, changes in vehicle fleet, etc.) may generate greater impacts on the transport network than climate change itself.

Finally, it is necessary to tailor climate change forecasts in Spain to the analysis of adaptation needs. Firstly, to align the variables provided by climate models with the parameters with which infrastructure managers are familiar (in transport, for example, parameters on indirect phenomena, such as the water table and the hydrological regime). Secondly, models and climate scenarios should include wind conditions and fog, being particularly relevant variables for transport, and pay attention to changes in the intensity and frequency of extreme weather events. The damage from such events may be considerable and hard to accept from a social point of view. Lastly, there is a need for local predictions when assessing the vulnerability of nodal infrastructure and to reduce the uncertainties in the predictions.

SWITZERLAND

The climate in Switzerland is changing. In order to provide decision-makers with the best possible basis for making their decisions, Switzerland needs updated and reliable climate scenarios. Based on the latest climate models, results from user surveys, and in close collaboration with the scientific community, new climate change scenarios are developed as part of CH2018.

---

[24] "Climate change adaptation needs of the core network of transport infrastructure in Spain", final report September 2013, Working Group for the analysis of the Climate change adaptation needs of the core network of transport infrastructure in Spain

The CH2018 scenarios will replace the current Swiss climate scenarios dating from 2011 (CH2011).

(http://www.meteoschweiz.admin.ch/content/dam/meteoswiss/de/Ungebundene-Seiten/Publikationen/Fachberichte/doc/fb243klimaszenarien.pdf)

In CH2018, detailed regional and local climate scenarios are developed that shed light on future climate in Switzerland. These scenarios are used by government authorities as well as the political and private sectors to study the impact of climate change on individual sectors such as hydrology, agriculture and health, and to minimise the risks with targeted measures. The goal is to publish the CH2018 climate scenarios in 2018 to ensure that its findings are included in Switzerland's second action plan for the adaptation to climate change strategy. There a no specific adaptation strategies developed yet for the transportsector

TECHNOLOGY, GOOD PRACTICES AND CASE STUDIES

Climate Scenarios

WMO/Hamburg institute

The ClimaCor Pre-Scan', A Methodology for Quickly Assessing Climate Threats to Inland Transport Corridors

With support of the Netherlands Government the Hungary based Regional Environmental Center (REC) developed the 'ClimaCor Pre-Scan', A Methodology for Quickly Assessing Climate Threats to Inland Transport Corridors. The report of the project is a practioner's guide to support quick "snapshot" assessments of overall climate resilience of transport infrastructure along a specific corridor. Through goal-directed questions, the transport practitioner will:

inventory current climate threats, transport infrastructure and its capacity to withstand those (climate resilience);

rank the climatic threats based on their likelihood and magnitude over time (vulnerability);

identify general categories of adaptive measures, from the improvement of infrastructure maintenance, to updating travel information to investments in infrastructure (response).

The ClimaCor Pre-Scan is not an empirical method requiring reams of climatic and transportation data. Instead, it is based on expert opinion from transport authorities, climate scientists and others who – owing to their knowledge and familiarity with the particular corridor under study – are best placed to make the assessment. The method describes a structured procedure for these experts to work together in identifying and ranking threats according to risk. The aim is to see how threats compare to one another so that transport agencies have a better grasp of how follow-up climate adaptation measures should be prioritised.

The ClimaCor Pre-Scan -- as the name infers -- isn't a substitute but rather a supplement to data-based analysis. It can give transport managers a preliminary, broad-brush picture of their main climate-related challenges and which of them merit deeper scrutiny. The method is particularly useful for corridors where little climate analysis has been carried out, and where authorities might not know where to begin. In this context, the ClimaCor method has these key selling points:

it is quick and inexpensive

the workshop takes just a day

data isn’t required

consensus is built-in

The ClimaCor method borrows from several existing procedures devised mainly in Europe and the United States (for details, see section on “Survey of existing methodologies”). Most notably, it borrowed the expert workshop approach of the Quick Scan method of the ROADAPT project. But while ROADAPT dealt solely with road-based transport, ClimaCor broadens the view to look at entire transport corridors, including roads, railways and inland waterways. In addition, it streamlines the Quick Scan’s already minimalist approach so that the main feature of the procedure, the threat-assessment workshop, can be concluded in one day.

Tresholds as Indicator

The direct impacts on the transport infrastructure become pertinent when exceeding thresholds for heavy rains, wind or temperatures. Concerning the railway network, it is relevant that the Finnish TEN-T network is already very resilient to fluctuation of temperatures, including extreme temperatures. There are no thresholds indicated so far that alert extra maintenance; preparing for extreme weather events would be initiated by expert evaluation of the actual situation.

For roads, flood areas are mapped and the information is quite reliable and site-specific. The impacts of climate change on both the railway network and navigation are assessed in a broad scale. This means that we have a big picture of the impacts of climate change and the possible impact on railway infrastructure etc. There is no estimation of impacts on specific locations, except locations situated in the flood risk areas.

The maps for the flood risk areas of TEN-T core network show flood risk areas on the E75 near Jyväskylä and Pyhäjärvi (http://paikkatieto.ymparisto.fi/tulvakartat/html5/). There are also flood risk areas on E 18 near Espoonjoki, Kotka-Hamina and in the Kotka-Hamina ports. Unfortunately, there is no reliable estimate available of how much the lake/sea water level should rise to cause flooding in these areas. The Finnish Traffic Agency has guidelines for designing road drainage (5/2013). Research showed that the impacts of climate change will cause the biggest disturbances in the parts of the traffic system which at the moment already

are critical,

have problems with capacity

do not have replacing connections.

It was concluded that focusing investments to these parts of the infrastructure network would efficiently reduce impacts of climate change. There is no analysis available yet of these critical parts.

AT weather company

other

https://wiki.unece.org/login.action?os_destination=%2Fpages%2Fviewpage.action%3FspaceKey%3DWP5%26title%3DClimate%2BChange%2BAdaptation%2B-%2BOnline%2BWorkspace&permissionViolation=true