

**Economic and Social Council**Distr.: General
28 April 2016

Original: English

Economic Commission for Europe**Inland Transport Committee****Working Party on Transport Trends and Economics****Group of Experts on Climate Change impacts and adaptation for transport networks and nodes****Tenth session**

Geneva, 7–8 July 2016

Item 4 of the provisional agenda

Discussions on the structure of the final report of the Group of Experts**An Overview of Recent Climate Change Trends and projections affecting transportation in the ECE Region (Part II)****Note by the secretariat****I. Introduction**

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

II. Climate Change: Recent Trends and Projections**A. 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 RCP¹ scenarios. The strongest ocean surface warming is projected for the subtropical and tropical regions. At greater depths, warming is projected to be most pronounced in the Southern Ocean. Best estimates of ocean warming in the upper 100 m are about 0.6°C (RCP2.6) to 2.0°C (RCP8.5), and for the upper 1000 m 0.3°C (RCP2.6) to 0.6°C (RCP8.5) by the end of the 21st century. For RCP4.5, half of the energy taken up by the ocean will be within the uppermost 700 m and 85 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 (IPCC², 2013).

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

Table 1

Forecasts of global mean surface temperature and global mean sea level changes for the period 2081-2100 (means and likely ranges) with respect to the period 1986–2005, according to different scenarios (after IPCC, 2013)

(Predictions are made according to 4 radiative forcing scenarios (Representative Concentration Pathways-RCP)³: RCP 8.5, 6184 Gt CO₂ (2012–2100 cumulative CO₂ emissions); RCP 6.0 3890 Gt CO₂; RCP 4.5, 2863 Gt CO₂; and RCP 2.6, 991 Gt CO₂. Global mean surface temperature changes are based on the CMIP5 ensemble (5–95 per cent model ranges). Sea level rise estimates are based on 21 CMIP5 models (5–95 per 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.⁴)

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

¹ Representative Concentration Pathways

² Intergovernmental Panel on Climate Change

³ 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 CO₂-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.

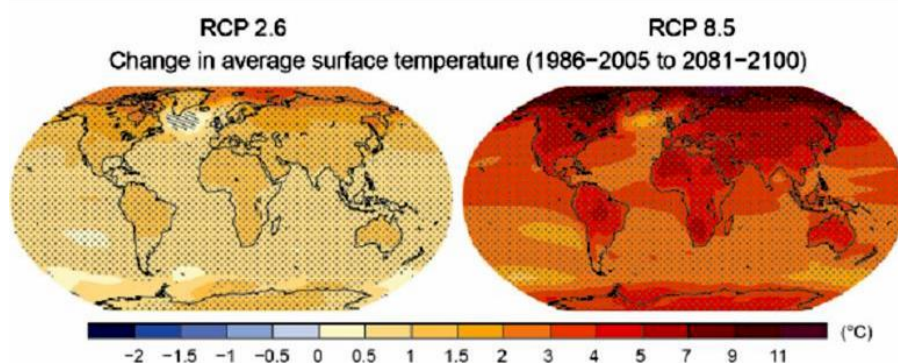
⁴ According to the scenarios the sea level will not stop rising in 2100, but will continue rising during the following centuries; median sea level rises of 1.84 for the lowest and 5.49 m for the highest forcing scenario (RCP 8.5) have been projected for 2500 (Jevrejeva et al., 2012).

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. 15 and 16). Precipitation is changing in a much more complex manner, with some regions becoming wetter and others dryer (ECE, 2013). Such trends are expected to pick up pace in the future, as e.g. in the E. Mediterranean where mean rainfall has been predicted to decrease by up to 25 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).

Figure 15

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

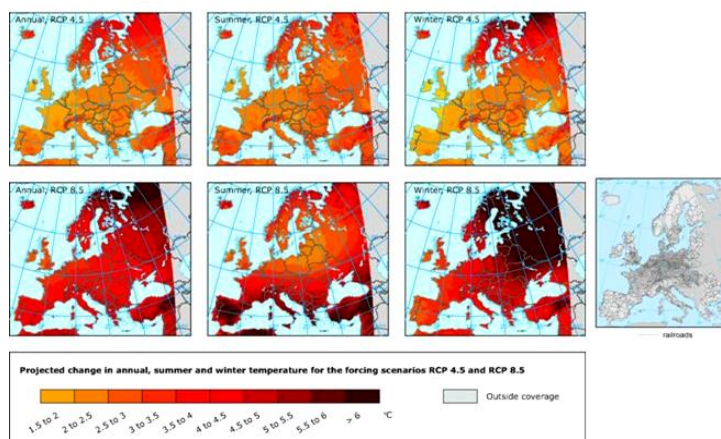


6. Climate model projections suggest widespread droughts across most of southwestern North America and many other subtropical regions by the mid to late 21st century (Milly et al., 2008; IPCC, 2013). In contrast, while summers are expected to become (overall) drier by 2100 over the United Kingdom of 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 more frequent (MetOffice, 2014).

Figure 16

Projected changes in annual (left), summer (middle) and winter (right) surface air temperature (°C) in 2071–2100 compared to 1971–2000 for forcing scenarios RCP4.5 (top) and RCP8.5 (bottom)

(Model simulations from RCMs (EURO-CORDEX initiative). (European Environment Agency (EEA), 2014a))



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 southwestern North America and subtropical regions (IPCC, 2013).

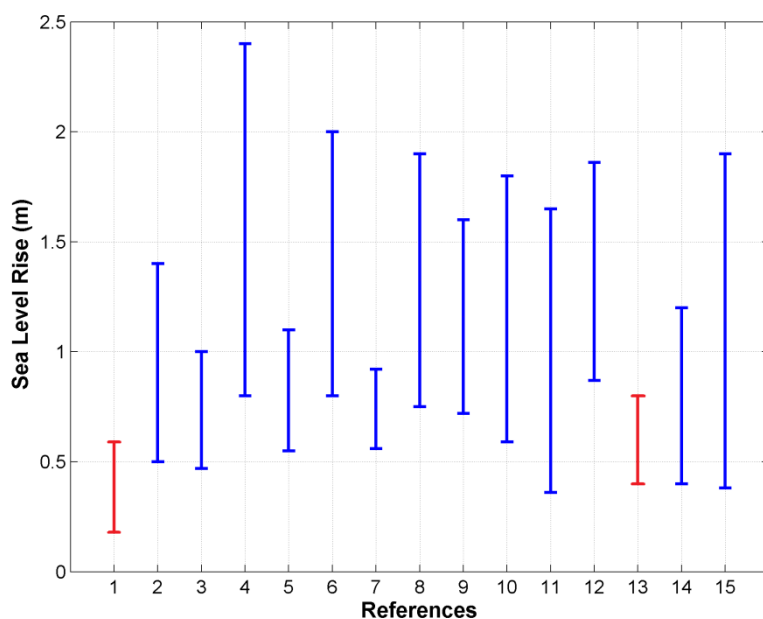
1.2.2 Sea Level Rise

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

Figure 17

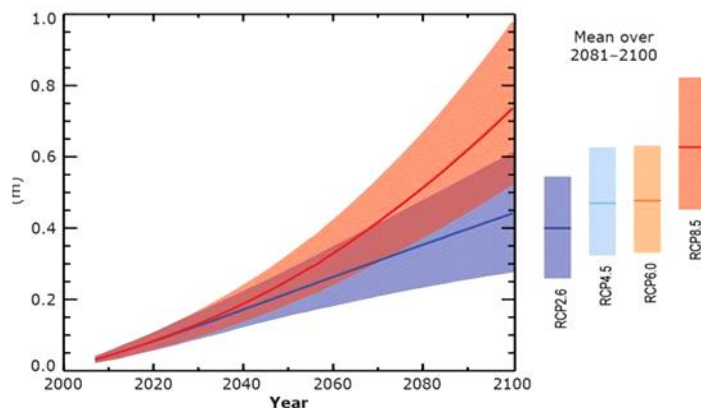
Recent sea level rise projections for 2100 compared to that of IPCC (2007a)

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



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

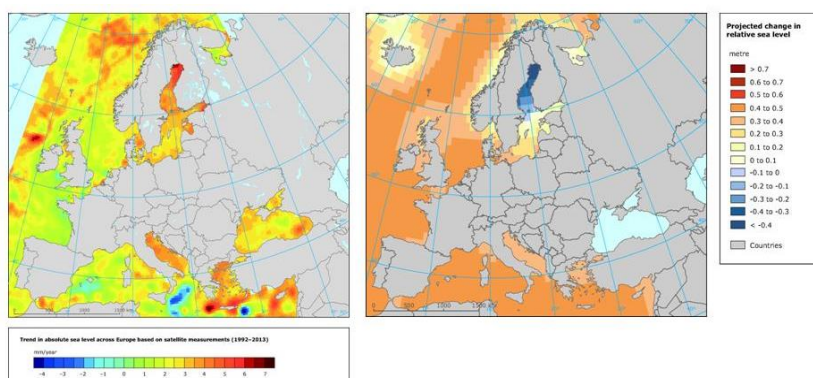
Figure 18
Projected global MSLR over the 21st century relative to 1986-2005 (IPCC, 2013)



10. It should be noted that due to the large spatial variability observed (and projected) in the sea level rise (Fig. 19), regional trends in sea level should be considered when assessing potential impacts along any particular coast (e.g. Carson et al., 2016). In addition to the global processes, regional factors may also contribute to observed coastal sea level changes, such as changes in ocean circulation (e.g. Meridional Overturning Circulation (MOC)) and differential rates in regional glacial melting, and glacio-isostatic adjustment (GIA) and sedimentary deposit subsidence (IPCC, 2013; King et al., 2015; Carson et al., 2016). Palaeoclimate, instrumental and modeling studies have shown that combinations of global and regional factors can cause relatively rapid rates of sea level rise along particular coasts that can exceed significantly the current global rate of about 3 mm yr⁻¹ (e.g. Cronin, 2012). For the UK, sea level rise (excluding land level changes) for the 21st century has been projected to be 0.12–0.76 m depending on the emission scenario, with larger rises predicted in the case of additional ice sheet melting (Lowe et al., 2009). For the North Sea coast of the Netherlands, Katsman et al. (2011) have estimated sea level rises of 0.40–1.05 m for a plausible high end emission scenario. Marcos and Tsimplis (2008) have predicted a temperature-driven sea level rise of 0.03 - 0.61 m in the Mediterranean for the 21st century on the basis of 12 global climate models and for three emission scenarios; this rise should be combined with salinity driven changes of – 0.22–0.31 m (see also EEA, 2012).

Figure 19
Trends in absolute sea level in European Seas from satellite measurements (1992–2013)
(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))

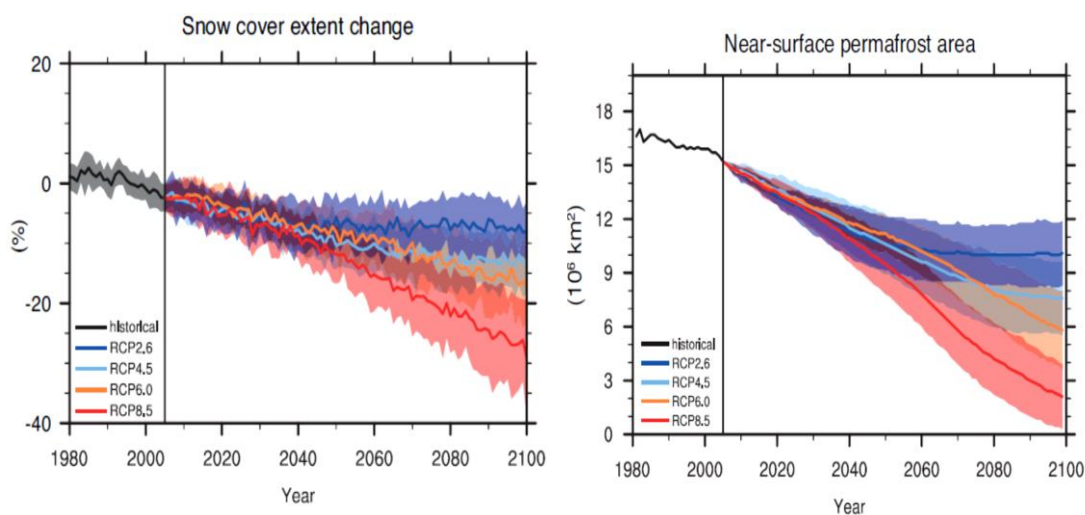


1.2.3 Arctic ice, snow and permafrost melt

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

Figure 20

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

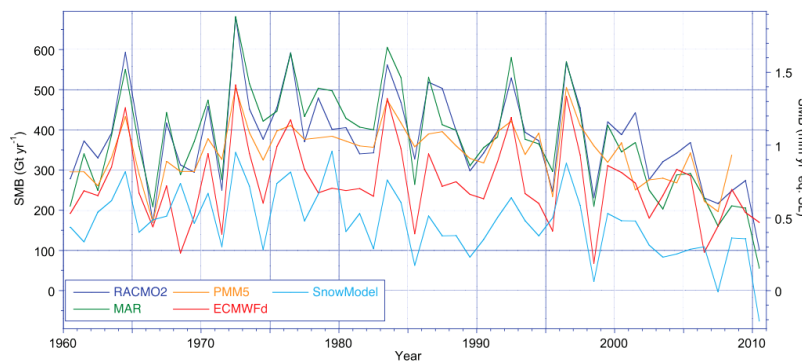


12. In the coming decades it is very likely that the Arctic sea ice will continue to decrease in extent/thickness as global mean surface temperature rises, although there is likely to be considerable inter-annual variability (Fig. 20a). Based on the CMIP5 model ensemble, projections of the Arctic sea ice extent show an average reduction for the period 2081–2100 compared to 1986–2005 from 8 per cent to 34 per cent in February and from 43 per cent to 94 per cent in September (lower and upper limits result from RCP2.6 and RCP8.5 respectively) (IPCC, 2013).

13. Continuing global warming will have a strong impact on the GIS in the following decades. In the present climate, Greenland Surface Mass Balance (GSMB) is positive but shows a decreasing trend, implying an increasing contribution to MSL rise. Based on the available evidence, it is very unlikely that SMB changes will result in an irreversible decrease of the Greenland Ice Sheet in the 21st century; this decrease is, however, likely on multi-centennial to millennial time scales under the strongest forcing scenarios (IPCC, 2013). The average and standard deviation of accumulation (precipitation minus sublimation) estimates for 1961–1990

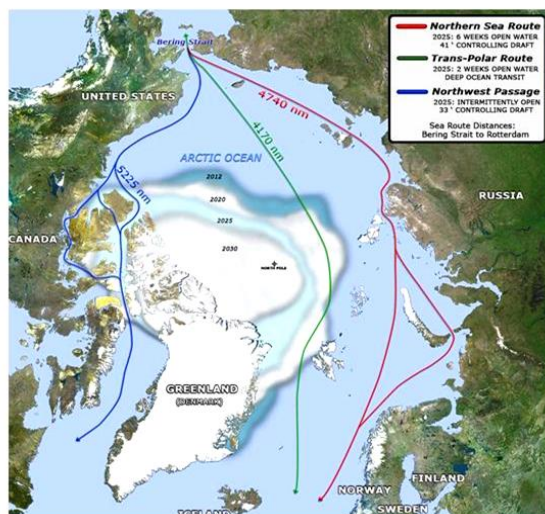
is $-1.62 \pm 0.21 \text{ mm yr}^{-1}$. All information indicates that the GSMB showed no significant trend from the 1960s to the 1980s; it started to become less positive in the early 1990s (on average by 3 per cent yr^{-1}). This results in a statistically significant and increasing contribution to the rate of GMSL rise (Fig. 21). IPCC (2013) suggests that, during the next century, dynamical change of Greenland ice sheet is likely (medium confidence) to contribute to SLR by 20 - 85 mm for RCP8.5, and 14–63 mm for all other scenarios. Other studies project $0.92 \pm 0.26 \text{ mm yr}^{-1}$ SLE compared to the 1961–1990 for SMB (accumulation minus runoff, neglecting drifting snow erosion) (Hansen et al., 2016). In comparison, the SMB of the Antarctic ice sheet is projected to increase under most scenarios due to an increasing snowfall trend; nevertheless, negative Antarctica SMBs have the potential to contribute more than 1 m of sea level rise by 2100 (De Conto and Pollard, 2016).

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



14. Concerning Arctic ice, the US Navy anticipates the development of 3 major shipping routes by 2025 which, however, are associated with several environmental risks (Fig. 22). There may be new economic opportunities for Arctic communities, as reduced ice extent facilitates access to the substantial hydrocarbon deposits (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.

Figure 22
New Arctic shipping routes. (U.S. Climate Resilience Toolkit, 2015)

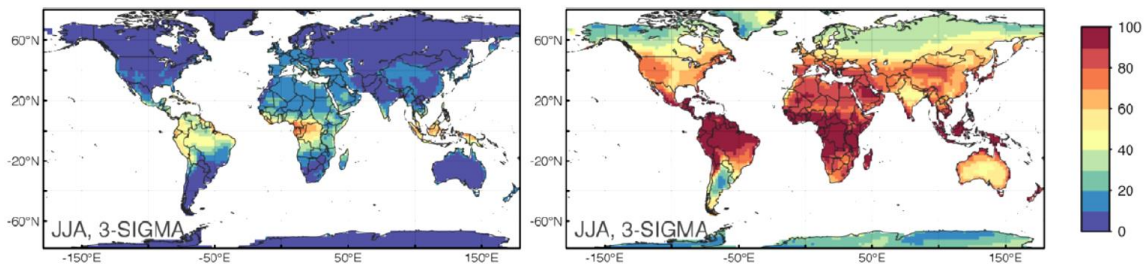


15. Increases in hot extremes and decreases in cold winter extremes are expected by the end of the 21st century, with the frequency, duration and magnitude of the events being affected by anthropogenic forcing (IPCC, 2013). Greater changes in hot days are expected to take place in sub-tropic and mid-latitude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

Figure 23

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

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



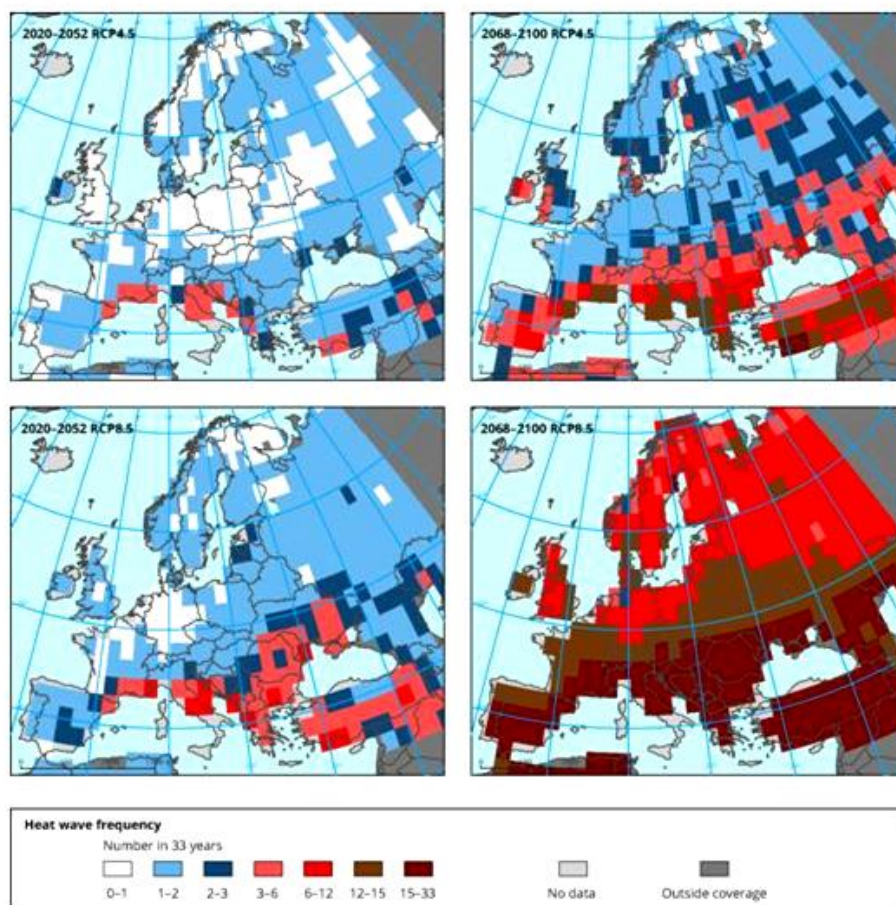
Heat waves

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

17. Heat waves as severe as the one in 2003 is expected to occur about once a century for the current climate; in early 2000s, it was expected to take place approximately once every several thousand years. An attribution study has suggested that anthropogenic influence at least doubled the odds of occurrence of such an event (MetOffice, 2014). Furthermore, recent studies suggest that the probability of occurrence of an extreme heat wave like the one that stroke Russia in 2010 may increase by 5-10 times until 2050 (Dole et al., 2011).

Figure 24

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

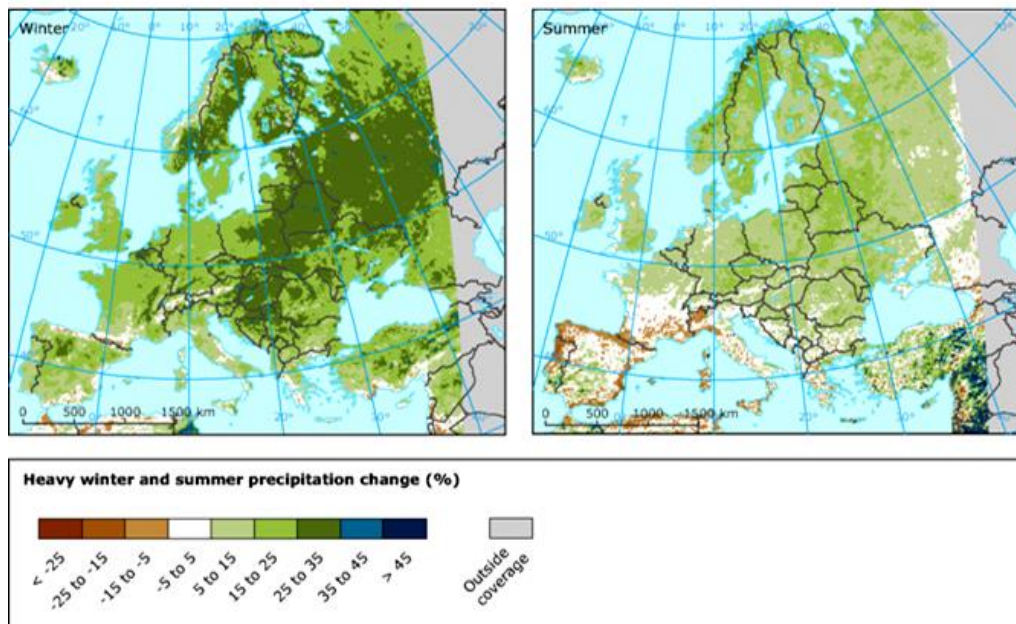


Downpours

18. Extremes linked to the water cycle -such as droughts, heavy rainfall and floods- are already causing substantial damages. As temperature rises, average precipitation will exhibit substantial spatial variation; it is likely that precipitation will increase in high and mid latitude land regions and decrease in subtropical arid and semi-arid regions by the end of this century under the RCP8.5 scenario. Extreme precipitation events will very likely be more intense over most of the mid-latitude and wet tropical regions (IPCC, 2013). For central and NE Europe, projections demonstrate large increases (25 per cent) in heavy precipitation by the end of the 21st century (Fig. 25). 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 25

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)



Storm surges and riverine floods

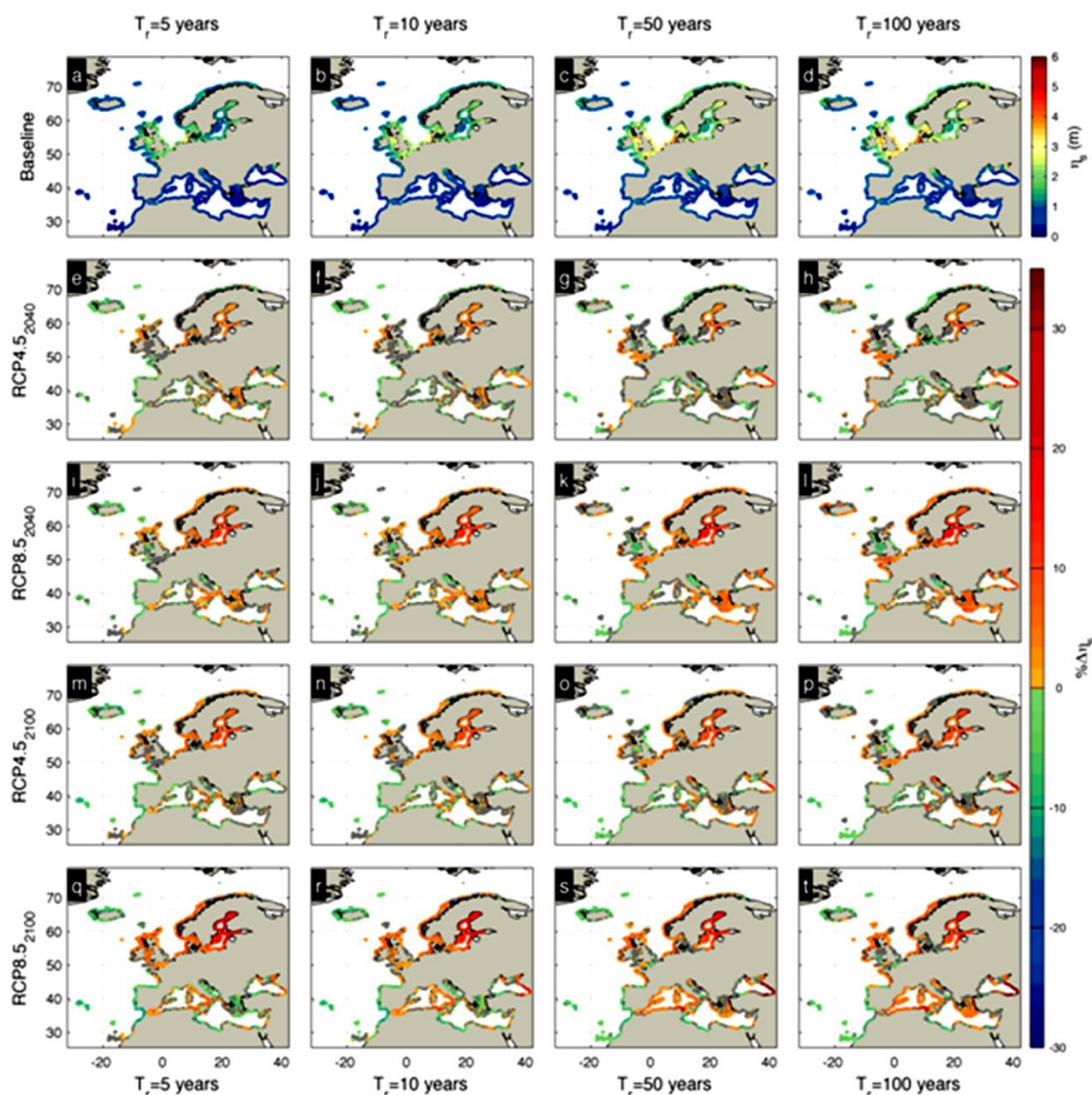
19. Despite the emerging risks associated with the changes in extreme coastal water levels, there is still limited, if any, information on storm surge levels (SSL) projections under the Representative Concentration Pathways (RCPs) (IPCC 2013). That's mainly because most previous studies are at local/regional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

20. For Europe, projections show larger storm surge levels for the Atlantic and Baltic coast/ports under all scenarios and extreme storm events tested (Vousdoukas et al., 2016). The North Sea is an area subject to some of the highest SSL in Europe (Fig. 26), with the projections indicating an increase in the extremes, especially along the eastern coast. Storm surge projections showed an increase along the Atlantic coast of the UK and Ireland, due mostly to a consistent increase of the winter extremes. The Atlantic coast of France, Spain and Portugal is also exposed to very energetic waves generated in the North Atlantic (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., 2016). The North Adriatic is a region which has been studied more thoroughly due to the highly vulnerable (and socio-economically important) Venice area, with most previous projections reporting no statistically significant change, or even decreases (Mel et al. 2013), even though

Lionello et al. (2012) projected increases in the frequency of extreme events around Venice, under a B2 SRES scenario.

Figure 26

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



21. It should be noted that more than 200 million people worldwide live along coastlines less than 5 m above sea level; this figure is estimated to increase to 400–500 million by the end of the 21st century. Growing exposure (population and assets), rising sea levels due to climate change, and in some regions, significant coastal subsidence due to human coastal water drainage/groundwater withdrawals will increase the flood risk to varying degrees. For instance, a 1 m rise in relative sea-level increases the frequency of current 100 year flood

events by about 40 times in Shanghai, about 200 times in New York, and about 1000 times in Kolkata (WMO⁵, 2014). For the next 50 years or so, Hallegatte et al. (2013) suggested that for the 136 largest coastal cities: (i) damages could rise from US\$ 6 billion/year to US\$ 52 billion/year solely due to increase in population and assets; (ii) annual losses could approach US\$ 1 trillion or more per year if flood defenses are not upgraded; (iii) even if defenses would be upgraded, losses could increase as flood events could become more intense due to the water depths increasing with relative sea-level rise. This raises the question of whether there are potential thresholds which, if passed, could reverse the current and projected trends of coastal population growth (King et al., 2015).

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

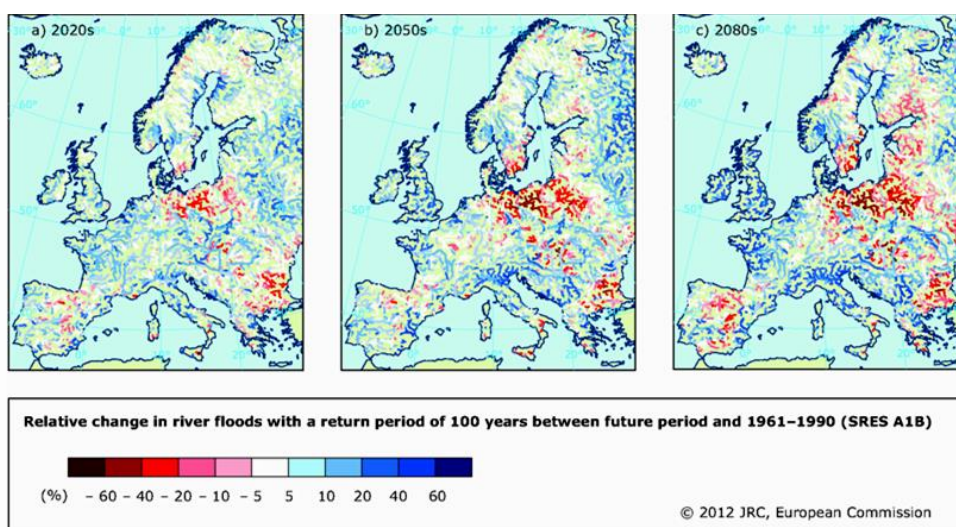


Figure 27 Relative change in minimum river flow for a) 2020s, b) 2050s and c) 2080s compared to 1961-1990 for SRES A1B scenario (EEA, 2012)

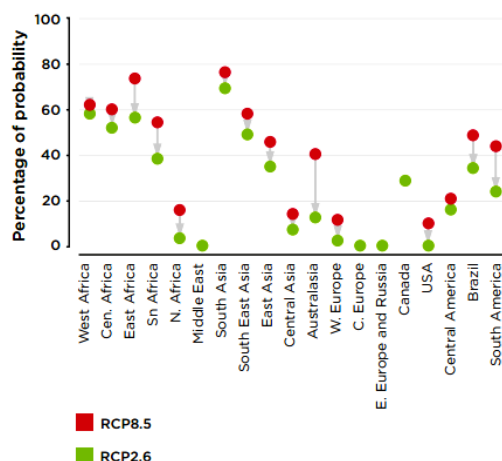
23. Fig. 28 shows the flood risk by region that climate change increases by more than 50 per cent the numbers of people affected by a current 30-year flood, relative to the situation without climate change. By the 2050s, there is at least a 50 per cent chance that climate change alone would lead to a 50 per cent increase in flooded people across sub-Saharan Africa, and a 30-70 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, Southeast and East Asia (King et al., 2015).

⁵ World Meteorological Organization

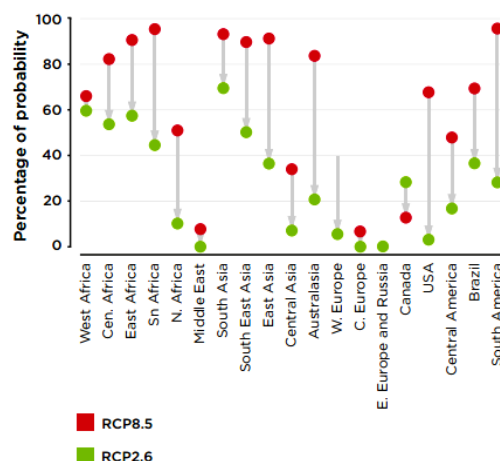
Figure 28

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

2050: probability of number of people affected by flooding increasing by >50%



2100: probability of number of people affected by flooding increasing by >50%



References

AMAP, 2012. Arctic Climate Issues 2011: Changes in Arctic Snow, Water, Ice and Permafrost. SWIPA 2011. Overview Report.

Alfieri, L., Feyen, L., Dottori, F. and Bianchi A., 2015. Ensemble flood risk assessment in Europe under high end climate scenarios. *Global Environmental Change*, 35, pp. 199–212. (doi:10.1016/j.gloenvcha.2015.09.004)

Androulidakis, Y.S., Kombiadou, K.D., Makris, C.H., Baltikas, V.N. and Krestenitis, Y.N. 2015 Storm surges in the Mediterranean Sea: Variability and trends under future climatic conditions, *Dynamics of Atmospheres and Oceans*, 71, pp. 56–82.

Beniston, M. and Diaz, H.F. 2004. The 2003 heat wave as an example of summers in a greenhouse climate? Observations and climate model simulations for Basel, Switzerland. *Global and Planetary Change*, 44, pp. 73–81.

Bertin, X., Prouteau, E. and Letetrel, C. 2013. A significant increase in wave height in the North Atlantic Ocean over the 20th century. *Global and Planetary Change*, 106, pp. 77–83.

Caldeira, K. 2009. Ocean acidification: Humanity and the environment in geologic time, IOP Conference Series: Earth and Environmental Sciences, 6(3), 462004

Canadell, J.G., Le Quere, C., Raupach, M.R., Field, C.R., Buitenhuis, E., Ciais, P., Conway, T.J., Gillett, N.P., Houghton, R.A. and Marland, G. 2007. Contributions to accelerating atmospheric CO₂ growth from economic activity, carbon intensity, and efficiency of natural sinks. *Proceedings of the National Academy of Sciences*, 104, pp. 18866–18870.

Carson, M., Kohl, A., Stammer, D., Slangen, A.B.A., Katsman, C.A., van de Wal, R.S.W., Church, J. and White, N. 2016. Coastal sea level changes, observed and projected during the 20th and 21st century. *Climatic Change*, 134, pp. 269–281. (doi: 10.1007/s10584-015-1520-1).

- Church, J. A. and White, N. J. 2006. A 20th century acceleration in global sea-level rise. *Geophysical Research Letters*, 33, L01602. (doi:10.1029/2005GL024826)
- Church, J.A.; Clark, P.U.; Cazenave, A.; Gregory, J.M.; Jevrejeva, S.; Levermann, A.; Merrifield, M.A.; Milne, G.A.; Nerem, R.S.; Nunn, P.D.; Payne, A.J.; Pfeffer, W.T.; Stammer, D.; Unnikrishnan, A.S., 2013. Sea level change. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. ed. by: Stocker, T.F.; Qin, D.; Plattner, G.-K.; Tignor, M.; Allen, S.K.; Boschung, J.; Nauels, A.; Xia, Y.; Bex, V.; Midgley, P.M.; Cambridge; UK; 2013; 1137-1216.
- Conte, D. and Lionello, P. 2014. Storm Surge Distribution Along the Mediterranean Coast: Characteristics and Evolution , *Procedia -Social and Behavioral Sciences* , 120, pp. 110–115. (ISSN 1877-0428)
- Coumou, D. and Rahmstorf, S. 2012. A decade of weather extremes. *Nature Climate Change*, 29, pp. 491-496. (doi:10.1038/nclimate1452).
- Coumou D. and Robinson A., 2013. Historic and future increase in the global land area affected by monthly heat extremes. *Environmental Research Letters* 8 (3) <http://iopscience.iop.org/article/10.1088/1748-9326/8/3/034018/meta>
- Cowtan, K. and Way, R. G. 2014. Coverage bias in the HadCRUT4 temperature series and its impact on recent temperature trends. *Q.J.R. Meteorol. Soc.*, 140, pp. 1935–1944. (doi: 10.1002/qj.2297)
- Cronin, T.M. 2012. Rapid sea-level rise. *Quaternary Science Reviews*, 56, pp. 11-30.
- Dai, A. 2013. Increasing drought under global warming in observations and models. *Nature Clim. Change*, 3, pp. 52–58.
- De Conto, R.M. and Pollard, D. 2016. Contribution of Antarctica to past and future sea-level rise. *Nature*, 531, pp. 591–596. (doi: 10.1038/nature17145)
- Dole et al., 2011. Was there a basis for anticipating the 2010 Russian heat wave? *Geophys. Res. Lett.*, 38, L06702.
- Domingues, C.M., Church, J.A., White, N.J., Gleckler, P.J., Wijffels, S.E., Barker, P.M. and Dunn, J.R. 2008. Improved estimates of upper-ocean warming and multi-decadal sea-level rise. *Nature*, 453, pp. 1090–1094.
- Dutton A., A. E. Carlson, A. J. Long, G. A. Milne, P. U. Clark, R. DeConto, B. P. Horton, S. Rahmstorf, and M. E. Raymo, 2015. Sea-level rise due to polar ice-sheet mass loss during past warm periods. *Science*, 349, 6244 <https://marine.rutgers.edu/pubs/private/Science-2015-Dutton.pdf>
- ECE, 2013. *Climate Change Impacts and Adaptation for International Transport Networks*, United Nations Economic Commission for Europe, New York and Geneva, 2013, 225 pp.
- EEA, 2010. *The European environment: State and outlook 2010, Adapting to climate change*. European Environmental Agency, Copenhagen. (ISBN 978-92-9213-159-3).
- EEA, 2012. *Climate change, impacts and vulnerability in Europe 2012. An indicator-based report*. European Environmental Agency (EEA), Copenhagen, Denmark, 300 pp. (ISBN 978-92-9213-346-7)
- EEA, 2014a. *Projected changes in annual, summer and winter temperature*. [Online image]. European Environment Agency (EEA). Available from: <http://www.eea.europa.eu/data-and-maps/figures/projected-changes-in-annual-summer-1> [Accessed 01/03/2016].

EEA, 2014b. Trend in absolute sea level in European Seas based on satellite measurements (1992–2013). [Online image]. European Environment Agency (EEA). Available from: <http://www.eea.europa.eu/data-and-maps/figures/sea-level-changes-in-europe-october-1992-may-1> [Accessed 01/03/2016].

EEA, 2014c. Projected change in relative sea level. [Online image]. European Environment Agency (EEA). Available from: <http://www.eea.europa.eu/data-and-maps/figures/projected-change-in-sea-level> [Accessed 01/03/2016].

EEA, 2015a, Global megatrends assessment: Extended background analysis complementing the SOER 2015 'Assessment of global megatrends'. European Environmental Agency, Copenhagen. (ISSN 1725-2237).

EEA, 2015b. Number of extreme heat waves in future climates under two different climate forcing scenarios. Available from: <http://www.eea.europa.eu/data-and-maps/figures/number-of-extreme-heat-waves> [Accessed 13/07/2015].

EEA, 2015c. 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 different regional climate models (RCMs) nested in different general circulation models (GCMs). Available from: <http://www.eea.europa.eu/data-and-maps/figures/projected-changes-in-20-year-2> [Accessed 21/03/2016].

Emanuel, K. 2005. Increasing destructiveness of tropical cyclones over the past 30 years. *Nature*, 436, pp. 686–688.

Engelhart, S.E., Horton, B.P., Douglas, B.C., Peltier, W.R. and Törnqvist, T.E. 2009. Spatial variability of late Holocene and 20th century sea-level rise along the Atlantic coast of the United States. *Geology*, 37, pp. 1115–1118.

EPA, 2015. Precipitation Worldwide, 1901–2013 [Online image]. Available from: <https://www3.epa.gov/climatechange/science/indicators/weather-climate/precipitation.html> [Accessed 03/02/2016].

Feyen L, Dankers R and Bodis K, 2010. Climate warming and future flood risk in Europe. *Climatic Change*.

Gehrels, W.R. and Woodworth, P.L. 2012. When did modern rates of sea-level rise start? *Global Planet Change*, 100, pp. 263–277.

GISTEMP, 2016: NASA Goddard Institute for Space Studies - GISS Surface Temperature Analysis (GISTEMP). Available from: <http://data.giss.nasa.gov/gistemp/>.

Grinsted A, Moore JC and Jervejeva S, 2010. Reconstructing sea level from paleo and projected temperatures 200 to 2100 AD. *Climate Dynamics* 34, 461- 472.

Hallegatte, S., Green, C., Nicholls, R. J. and Corfee-Morlot, J. 2013. Future flood losses in major coastal cities, *Nature Climate Change*, 3, pp. 802–806. (doi:10.1038/NCLIMATE1979)

Hanna, E. et al., 2013. Ice sheet mass balance and climate change. *Nature*, 498, pp. 51–59.

Hansen, J., Sato, M., Hearty, P., Ruedy, R., Kelley, M., Masson-Delmotte, V., Russell, G., Tselioudis, G., Cao, J., Rignot, E., Velicogna, I., Tormey, B., Donovan, B., Kandiano, E., von Schuckmann, K., Kharecha, P., LeGrande, A.N., Bauer, M. and K.-W. Lo. 2016. Ice melt, sea level rise and superstorms: Evidence from paleoclimate data, climate modeling, and modern observations that 2°C global warming could be dangerous. *Atmos. Chem. Phys.*, 16, pp. 3761-3812. (doi:10.5194/acp-16-3761-2016)

Hay, C.C., Morrow, E., Kopp, R.E. and Mitrovica, J.X. 2015. Probabilistic reanalysis of twentieth-century sea-level rise, *Nature*, 517, pp. 481–484.

Horton R., Herweijer C, Rosenzweig C, Liu J, Gornitz V, and Ruane AC, 2008. Sea level rise projections for current generation CGCMs based on the semi-empirical method. *Geophysical Research Letters* 35 DOI:10.1029/2007GL032486.

Horton, B.P., Rahmstorf, S., Engelhart, S.E. and Kemp, A.C. 2014. Expert assessment of sea-level rise by AD 2100 and AD 2300, *Quaternary Science Reviews*, 84, pp. 1–6.

IPCC, 2007. *Climate Change 2007. The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Solomon S, D Qin, M Manning, Z Chen, M Marquis, KB Averyt, M Tignor and HL Miller (eds)). Cambridge University Press, Cambridge, UK and New York, NY, USA, 996 pp.

IPCC, 2013. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2014. Summary for policy makers. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1–32.

Jevrejeva S, Moore JC and Grinsted A, 2010. How will sea level respond to changes in natural and anthropogenic forcings by 2100? *Geophysical Research Letters* 37. DOI: 10.1029/2010GL042947.

Jevrejeva, S., Moore, J.C. and Grinsted, A. 2012. Sea level projections to AD2500 with a new generation of climate change scenarios. *Global and Planetary Change*, 80-81, pp. 14–20. (doi:10.1016/j.gloplacha.2011.09.006)

Karl, T.R., Arguez, A., Huang, B., Lawrimore, J.H., McMahon, J.R., Menne, M.J., Peterson, T.C., Vose, R.S. and Zhang, H. 2015. Possible artifacts of data biases in the recent global surface warming hiatus, *Science*, 348, pp. 1469–1472.

Karl, T.R., Melillo, J. T. and Peterson, T. C. 2009. *Global Climate Change Impacts in the United States*. Cambridge University Press, 189 pp.

Katsman, C.A., Sterl, A., Beersma, J.J., Brink, H.W., Church, J.A., Hazeleger, W., Kopp, R.E., Kroon, D., Kwadijk, J., Lammersen, R., Lowe, J., Oppenheimer, M., Plag, H.P., Ridley, J., Storch, H. et al., 2011. Exploring high end scenarios for local sea level rise to develop flood protection strategies for a low-lying delta. The Netherlands as an example. *Climatic Change*. 109 (3–4), pp. 617–645. (doi:10.1007/s10584-011-00375)

King, D., Schrag, D., Dadi, Z., Ye, Q. and Ghosh, A. 2015. *Climate Change: A Risk Assessment*. Centre for Science and Policy, University of Cambridge. (<http://www.csap.cam.ac.uk/media/uploads/files/1/climate-change--a-risk-assessment-v9-spreads.pdf>)

Kopp R, Simons F, Mitrovica J, Maloof A and Oppenheimer M. 2009. Probabilistic assessment of sea level during the last interglacial stage. *Nature* 462, 863–867. (doi:10.1038/nature08686).

Lionello, P., Galati, M.B. and Elvini, E. 2012. Extreme storm surge and wind wave climate scenario simulations at the Venetian littoral. *Phys Chem Earth Parts A/B/C*, 40–41, pp. 86–92.

- Losada, I.J., Reguero, B.J., Mendez, F.G., Castanedo, S., Abascal, A.J. and Minguez, R. 2013. Long-term changes in sea level components in Latin America and the Caribbean. *Global and Planetary Change*, 104, pp. 34–50.
- Lowe, J.A., Howard, T., Jenkins, G., Ridley, J., Dye, S. and Bradley, S. 2009. UK Climate Projections science report: Marine and coastal projections. Met. Office Hadley Centre, Exeter, United Kingdom.
- Lyman, J. M. et al. 2010. Robust warming of the global upper ocean, *Nature*, 465, pp. 334–337.
- Marcos, M. and Tsimplis, M.N. 2008. Comparison of results of AOGCMs in the Mediterranean Sea during the 21st century. *Journal of Geophysical Research*, 113 (C12). (doi:10.1029/2008JC004820)
- Marcos, M., Jorda, G., Gomis, D. and Perez, B. 2011. Changes in storm surges in southern Europe from a regional model under climate change scenarios. *Global and Planetary Change*, 77(3–4), pp. 116–128. (doi:10.1016/j.gloplacha.2011.04.002)
- Mel, R., Sterl, A. and Lionello, P. 2013. High resolution climate projection of storm surge at the Venetian coast. *Nat Hazards Earth System Science*, 13, pp. 1135–1142.
- Melillo, J.M., Richmond, T.T.C., Yohe, G.W. 2014. Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, NCA, pp. 841.
- Menendez, M. and Woodworth, P.L. 2010. Changes in extreme high water levels based on a quasi-global tidegauge data set. *Journal of Geophysical Research*, 115, C10011. (doi:10.1029/2009JC005997).
- MetOffice, 2014. Climate risk An update on the science. Met Office, Handley Center, Devon, UK, 9 pp.
- Milly, P.C.D., Betancourt, J., Falkenmark, M., Hirsch, R.M., Kundzewicz, Z.W., Lettenmaier D.P. and Stouffer, R.J. 2008. Stationarity is dead: Whither water management? *Science*, 319, pp. 573-574.
- Mori N, Shimura T, Yasuda T and Mase H, 2013. Multi-model climate projections of ocean surface variables under different climate scenarios—Future change of waves, sea level and wind. *Ocean Engineering*, <http://dx.doi.org/10.1016/j.oceaneng.2013.02.016>
- Moss R, et al., 2010. The next generation of scenarios for climate change research and assessment. *Nature* 463, 747–756
- Munich Re (2015) NatCatSERVICE: Loss events worldwide 1980–2014.
- NASA, 2016. NOAA Analyses Reveal Record-Shattering Global Warm Temperatures in 2015 [WWW] Goddard Institute for Space Studies. Available from: <http://www.giss.nasa.gov/research/news/20160120/> [Accessed 13/02/2016]
- NOAA, 2016a. Global Analysis - Annual 2015: 2015 year-to-date temperatures versus previous years [WWW] National Centers for Environmental Information. Available from: <https://www.ncdc.noaa.gov/sotc/global/2015/13/supplemental/page-3> [Accessed 12/02/2016]
- NOAA, 2016b. Global Analysis - November 2015 [WWW] National Centers for Environmental Information. Available from: <https://www.ncdc.noaa.gov/sotc/global/201511> [Accessed 12/02/2016]
- NOAA, 2016c. Global Analysis – February 2016 [WWW] National Centers for Environmental Information. Available from: <https://www.ncdc.noaa.gov/sotc/global/201602> [Accessed 12/02/2016].

- NOAA, 2016d. Global Analysis - February 2016 [WWW] National Centers for Environmental Information. Available from: <https://www.ncdc.noaa.gov/sotc/global/201602> [Accessed 12/02/2016]
- NOAA, 2015. 2014 State of the Climate: Carbon Dioxide [WWW] Available from: <https://www.climate.gov/news-features/understanding-climate/2014-state-climate-carbon-dioxide>
- NSIDC, 2012. Rapid sea ice retreat in June [WWW] National Snow & Ice Data Center. Available from: <http://nsidc.org/arcticseaicenews/2012/07/rapid-sea-ice-retreat-in-june/> [Accessed 15/02/2016]
- Pérez, J., Menendez, M., Mendez, F. and Losada, I. 2014. Evaluating the performance of CMIP3 and CMIP5 global climate models over the north-east Atlantic region. *Clim Dyn.*, 43, pp. 2663–2680.
- Pfeffer W, Harper J and O' Neel S, 2008. Kinematic constraints on glacier contributions to 21st century sea levelrise. *Science* 321, 1340–1343. (doi:10.1126/science.1159099).
- Pritchard, H.D., Ligtenberg, S.R.M., Fricker, H.A., Vaughan, D.G., van den Broeke, M.R. and Padman, L. 2012. Antarctic ice-sheet loss driven by basal melting of ice shelves. *Nature*, 484, pp. 502–505.
- Rahmstorf S, Cazenave A, Church JA, Hansen JE, Keeling RF, Parker DE, and RCJ Somerville, 2007. Recent climate observations compared to projections. *Science* 316, 709-709.
- Raper, S.C.B. and Braithwaite, R. J. 2009. Glacier volume response time and its links to climate and topography based on a conceptual model of glacier hypsometry. *The Cryosphere*, 3, pp. 183-194, (ISSN 1994-0416)
- Richardson, K., Steffen, W., Schellnhuber, H.J., Alcamo, J., Barker, T., Kammen, D.M., Leemans, R., Liverman, D., Munasinghe, M., Osman-Elasha, B., Stern, N. and O Ole W.ver., 2009. Synthesis Report. *Climate change: Global Risks, Challenges and Decisions*. University of Copenhagen, 39 pp.
- Rignot, E., Velicogna, I., van den Broeke, M.R., Monagha, A. and Lenaerts, J. 2011. Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise. *Geophysical Research Letters*, (38), 5 pp. (doi:10.1029/2011GL046583)
- Rohling E, Grant K, Hemleben C, Siddall M, Hoogakker B, Bolshaw M and Kucera M, 2008. High rates of sea levelrise during the last interglacial period. *Nature Geosciences* 1, 38–42. (doi:10.1038/ngeo.2007.28).
- Ruggiero, P., Komar, P.D. and Allan, J.C. 2010. Increasing wave heights and extreme value projections: The wave climate of the U.S. Pacific Northwest. *Coastal Engineering*, 57, pp. 539–552.
- Ruggiero, P. 2013. Is the intensifying wave climate of the U.S. Pacific Northwest increasing flooding and erosion risk faster than sea-level rise? *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 139 (2), pp. 88–97.
- Shakun, J.D., Clark, P.U., He, F., Marcott, S.A., Mix, A.C., Liu, Z., Otto-Bliesner, B., Schmittner, A. and Bard, E. 2012. Global warming preceded by increasing carbon dioxide concentrations during the last deglaciation, *Nature*, 484, pp. 49–55.
- Steffen, W. 2009. *Climate Change 2009: Faster Change and More Serious Risks*. Report to the Department of Climate Change, Australian Government.
- Stockdon, H.F., Doran, K.J., Thompson, D.M., Sopkin, K.L., Plant, N.G. and Sallenger, A.H. 2012. National assessment of hurricane-induced coastal erosion hazards: Gulf of Mexico: U.S. Geological Survey Open-File Report 2012-1084, 51 pp.

U.S. Climate Resilience Toolkit, 2015. Arctic Development and Transport. [WWW] Available from: <https://toolkit.climate.gov/content/about-climate-resilience-toolkit> [Accessed 15/01/2016]

Velicogna, I., Sutterley, T. C. and van den Broeke, M. R. 2014. Regional acceleration in ice mass loss from Greenland and Antarctica using GRACE time-variable gravity data. *Geophys. Res. Lett.*, 41(22), pp. 8130–8137.

Vermeer M and Rahmstorf S 2009 Global sea level linked to global temperature. *Proceedings of the National Academy of Sciences USA* 106, 21527–21532. (doi:10.1073/pnas.0907765106).

Vousdoukas, M.I., Voukouvalas, E., Annunziato, A., Giardino, A. and Feyen, L. 2016. Projections of extreme storm surge levels along Europe. *Climate Dynamics*, 20 pp. (in press) (doi: 10.1007/s00382-016-3019-5)

Wada, Y., van Beek, L.P.H., Weiland, F.C.S., Chao, B.F., Wu, Y-H. and Bierkens, MFP. 2012. Past and future contribution of global groundwater depletion to sea-level rise. *Geophys Res Lett.*, 39, L09402. (doi: 10.1029/2012GL051230)

Vellinga P et al. 2008. Exploring high-end climate change scenarios for flood protection of the Netherlands. *International Scientific Assessment for the Delta Committee*. SR WR-2009-05. KNMI, Alterra, The Netherlands. <http://www.knmi.nl/bibliotheek/knmipubWR/WR2009-05.pdf>.

WMO, 2014. *Statement on the status of the global climate in 2014*, World Meteorological Organization, WMO-No. 1152, Chairperson, Publications Board, Geneva, Switzerland, 22 pp. (ISBN: 978-92-63-11152-4.)

WMO, 2016. *WMO Statement on the Status of the Global Climate in 2015*, World Meteorological Organization, WMO-No. 1167, Chairperson, Publications Board, Geneva, Switzerland, 26 pp. (ISBN: 978-92-63-11167-8.). See also <http://www.indiaenvironmentportal.org.in/content/421694/provisional-statement-on-the-status-of-global-climate-in-2011-2015/>