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

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Presentation Synopsis

Climate Change Implications for Transport

- Impacts on Coastal Areas
- Riverine Floods
- Heat waves and Droughts
- Impacts in polar areas (opening arctic routes and permafrost melt issues)

Climate Change: Recent Trends and Projections

- Phenomenology: in which way is the climate changing?
  - Climatic factor mean trends
  - Extreme event trends
- Forcing Mechanism
- Most recent climate projections

Conclusions

Climate Variability & Change (CV &C) factors affecting transportation

Major CV & C factors include (ECE, 2013):

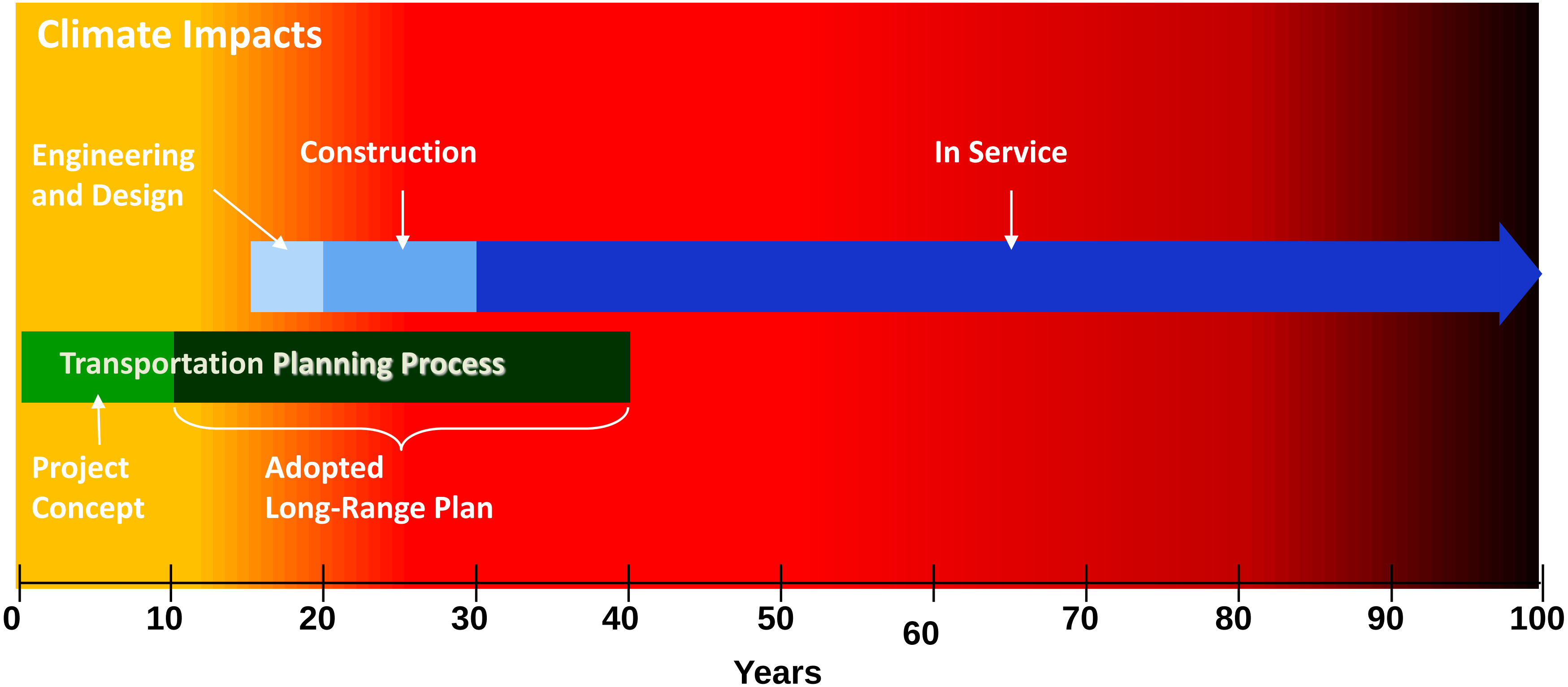
- Rising mean and extreme sea levels;
- More intense precipitation and floods;
- Increase in very hot days and frequency of heat waves; and
- Higher arctic temperatures (opening routes but, also, permafrost melt)

Transport vulnerability to CV & C

- Long lifetimes of key assets, sensitive to climate
- Location of assets at areas exposed to climate impacts (ports, inland waterways, road and rail networks in flood plains etc)
- Interdependence of transport and trade: transport is demand driven (indirect impacts, e.g. from changes in agriculture and tourism patterns; and
- Relatively few studies, particularly in terms of adaptation measures, although large costs are expected

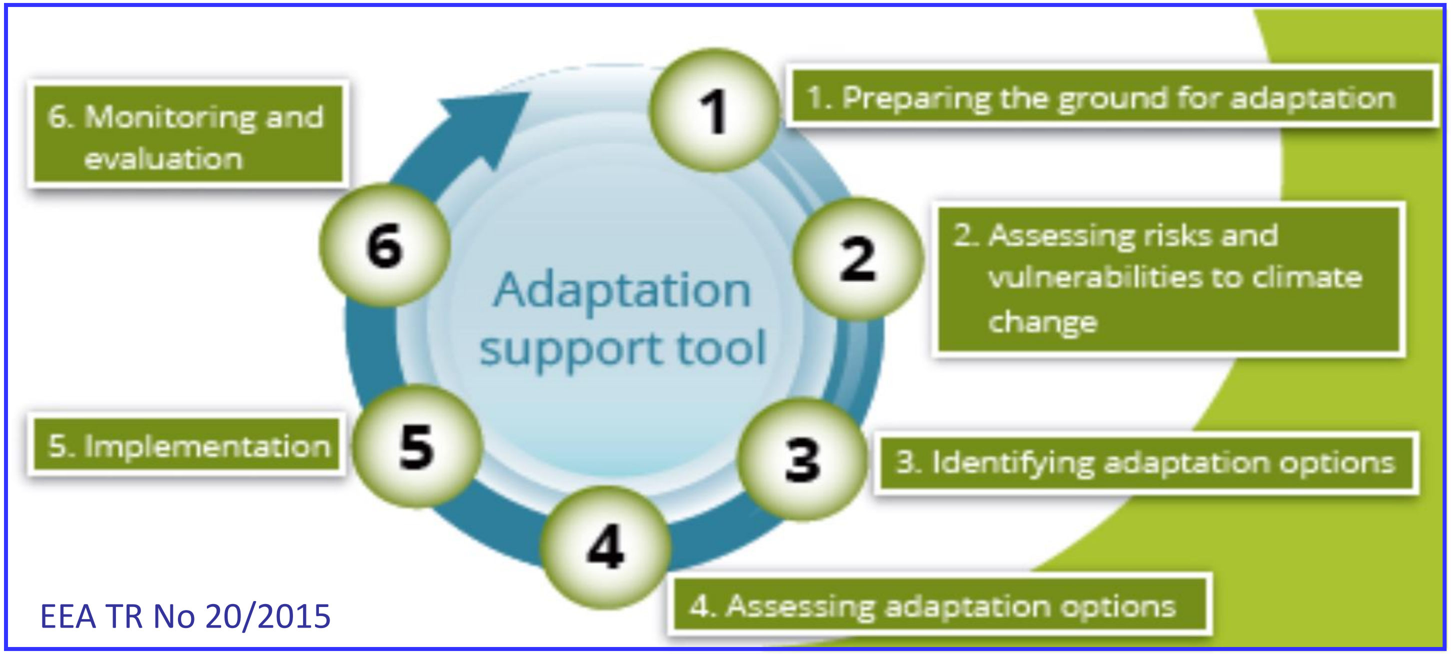
Important: Effective adaptation of transport industry to CV & C requires integrated assessments of key vulnerabilities

Transportation Timeframes vs. Climate Impacts



Source: Savonis, 2011

The European Adaptation Tool



EEA TR No 20/2015

Climate Change challenges for Transport

Significant impacts on transport infrastructure/operations expected in ECE:

In coastal areas due the MSL and storm waves/surges

From extreme precipitation and river floods

From heat waves and droughts

In arctic areas due to permafrost melt, but also opportunities due to longer shipping season and shorter shipping routes

Coastal impacts of MSL Rise and Storms

CV & C can severely impact coastal areas, damaging major transport hubs (ports) and nodal points and, thus, affecting the entire supply chain (ECE, 2013), including by:

- Damaging inland transport connections to ports;
- Increased flood risks and damages to port infrastructure and equipment/cargo
- Increased port construction/maintenance costs
- Socioeconomic impacts (relocation of people/business, and insurance issues)

Until recently, there was a dearth of detailed studies (ECE, 2013).

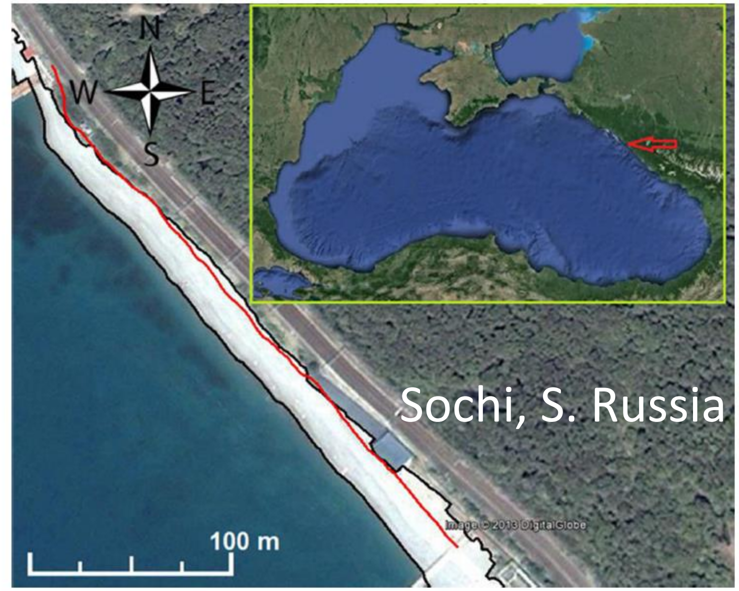
Recently, there has been a modest increase in relevant studies, involving risk and cost assessments based on simulations under different climatic scenarios.

These have been prompted by the significant weather-related impacts on the coastal transport/operations occurred in recent years

Impacts on coastal transport: Roads and Rails

Recorded event

Projection: Simulated risk



(a) Damaged road and rail track from storm surge/waves (Dawlish, SW England, 02/2014 (UNECE, 2015)

(b) Black Sea, Sochi, Russia. The red line shows the maximum beach retreat projected by a model ensemble for 0.5 m SLR. Under storm conditions, the fronting beach will be eroded endangering the main coastal rail network to Sochi (Allenbach et al., 2015).

Impacts on Port Assets

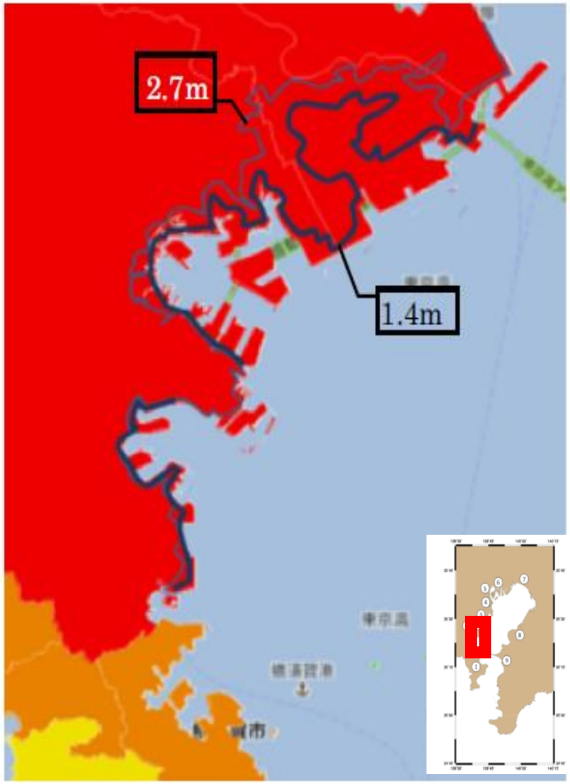
Port of Providence (RI, USA):Flood simulation due to a Category 3 storm surge (26 f of surge) and 0.5 m mean sea level (MSL) rise (Becker et al. 2014, http://dx.doi.org/10.1016/ j.progress.2013.11.002)

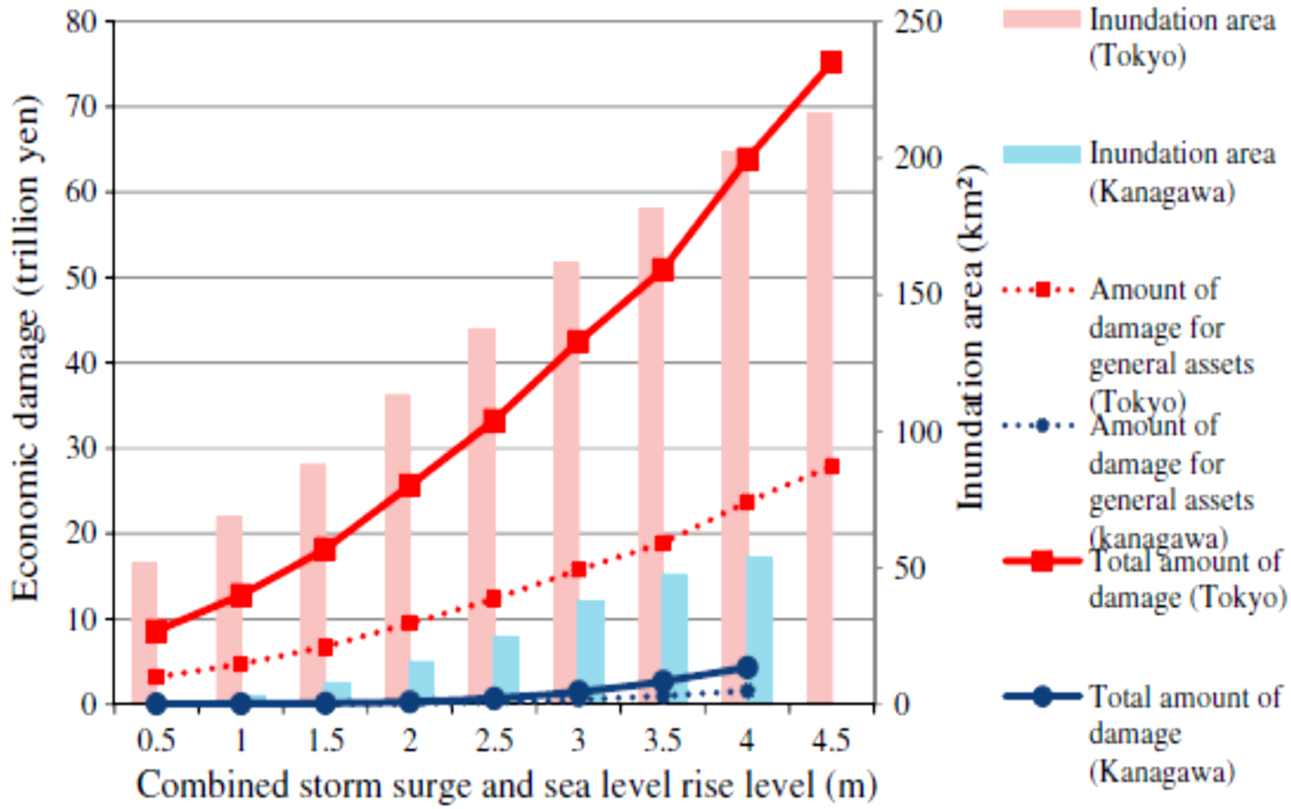
Impacts on Port Operations

Scenario	Port Crane Throughput (PCT)	Total number of trucks served	Truck Queue	Total No. of Containers moved into Yard	Total No. of Containers moved out of Yard
Scenario 1 (baseline)	3346	945	0	3056	1635
Scenario 2 (high temperature)	3310	891	0	3008	1593
Scenario 3 (heavy rain)	2960	891	0	2658	1593
Scenario 4 (high speed wind)	2960	837	54	2646	1551
Scenario 5 (flooding)	3346	765	180	2940	1491

*Simulated decrease in port crane throughput under different extreme events (6-hour event in a 24 hour period). High winds and heavy rains have high impacts on crane throughput, but flooding leads to severe backlogs in servicing trucks. (Chhetri et al., 2016, EJTIR **16**(1), 195-213).*
http://www.tbm.tudelft.nl/fileadmin/Faculteit/TBM/Onderzoek/EJTIR/Back_issues/16.1/2016_01a_06.pdf

Projected port city damages due to combined MSL rise and storm surge

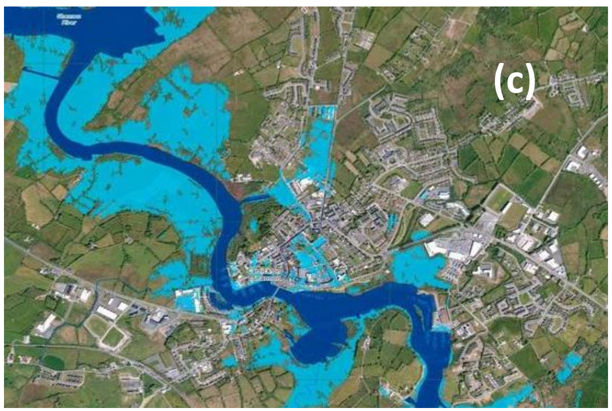


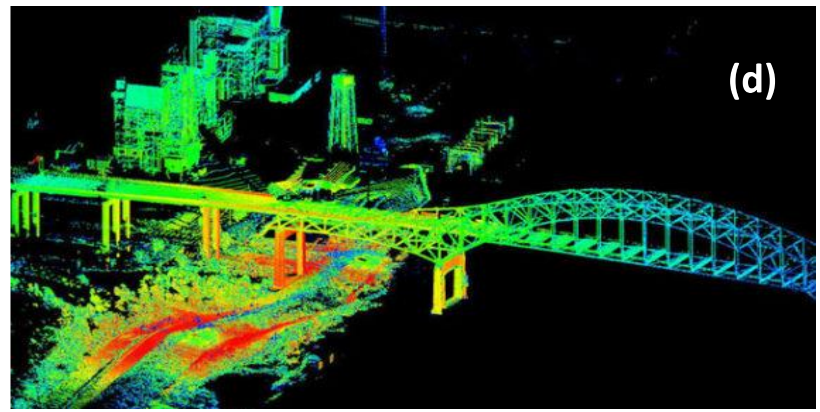


(a) *Areas at <u>flood risk</u> in the Kanagawa area (Tokyo Bay) for the <u>mean expected storm surge due future storm typhoon in the year 2100</u> for a 0.59-m (thick blue line) and 1.9-m (thin blue line) mean sea-level-rise (MSLR) scenarios and*

(b) *<u>Simulated damages</u> for Tokyo and Kanagawa port areas due to combined MSLR and storm surge (Esteban et al., 2015)*

River Flood Impacts





(a) *Sections of the US Highway 34 (black arrows) washed away (S.Platte River fl;oods, Colorado,USA, 09/ 2013) (ECE, 2015).*

(b) *(b) Floods damages in NW UK (10/2012-09/2015). http://waterbucket.ca/gi/2016/01/03/united-kingdom-flooding-december-2015-how-a-town-in-yorkshire-worked-with-nature-to-stay-dry/ .*

(c) (c) Flood projections in Ireland for 01/2016. http://www.independent.ie/irish-news/storms/cold-snap-to-deepen-weather-misery-as-flood-costs-top-60m-34335997.html.

(d) (d) Flood impacts (undercutting, shown by *lidar scan) on the New Orleans' I-510 bridge (Isaac hurricane, 31/08/2012). http://www.huffingtonpost.com/2012/09/06/hurricane-isaac-3d-satellite-photos_n_1860966.html*

Impacts due to Heat Waves: Rail dilatation

http://www3.epa.gov/climatechange/impacts/transportation.html#landtransportation

Melting permafrost impacts on transport

Permafrost degradation will cause damages to:

railways, roads, bridges and pipelines;

building foundations and airports;

coastal infrastructure; and

lead to increased construction and maintenance costs

Climate Change: Recent Trends and Projections

Phenomenology: How does the climate vary and change?

Climate Variability (CV & C): variability and sustained change of climatic conditions relative to a reference period, i.e. :

- the first period with accurate records (1850s-1860s) or
- the average climate of periods with accurate climatic information and construction of infrastructure used today (e.g. 1961-1990 1980-1999)

Evidence presented in the IPCC AR5 (2013) suggests a consistent change of climatic factors

This information and more recent evidence suggest that transport affecting climatic factors (ECE, 2013) are 'deteriorating'

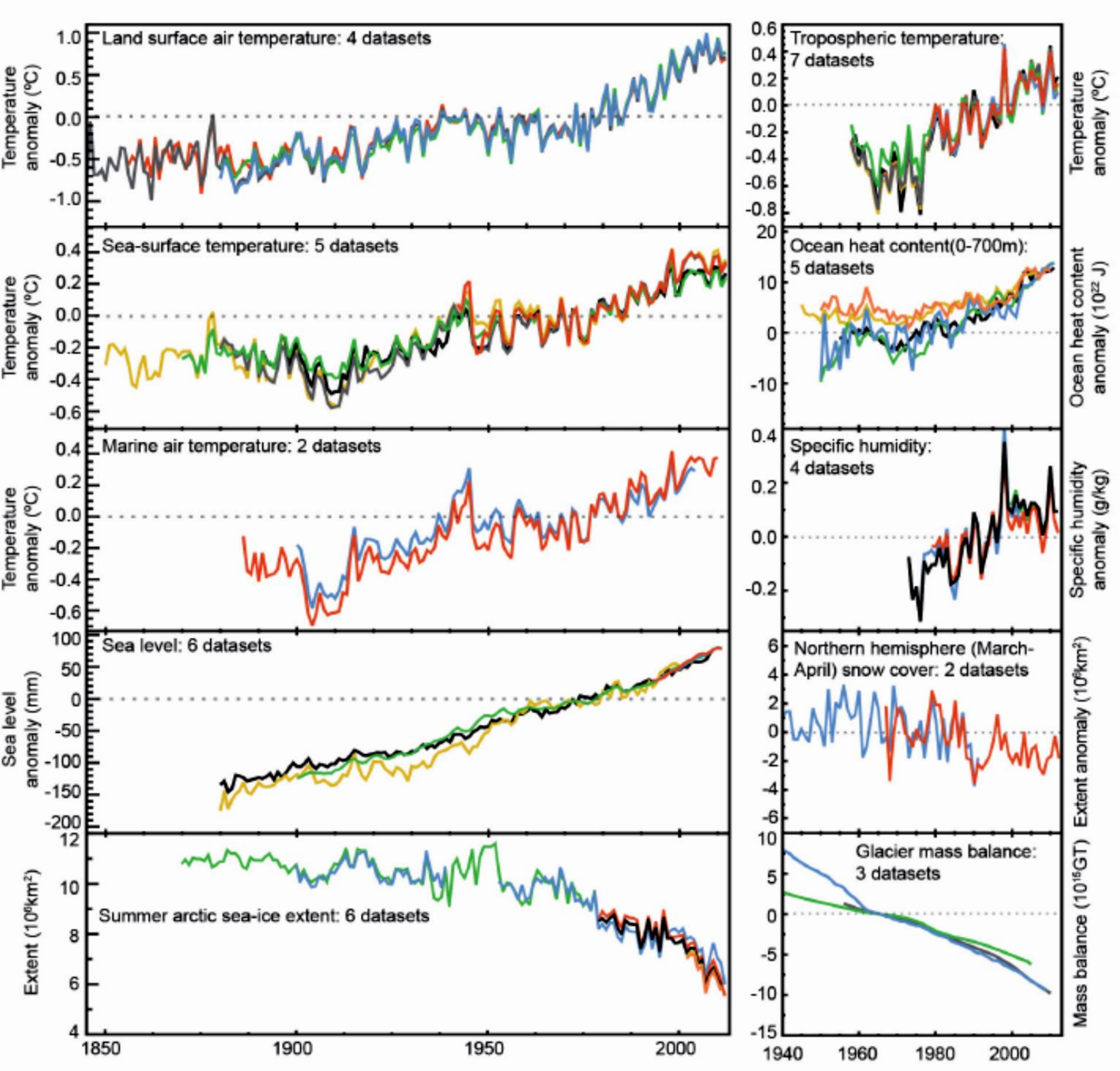
Climatic factor trends

Arctic ice, snow and permafrost melt

Extreme climate events

Note: There are feedbacks/tipping points. i.e trends can be changed by reinforcing or negative feedbacks; if thresholds(?) are crossed, changes might be abrupt, large and (potentially) irreversible in human temporal scales.

Recent evidence of climatic change

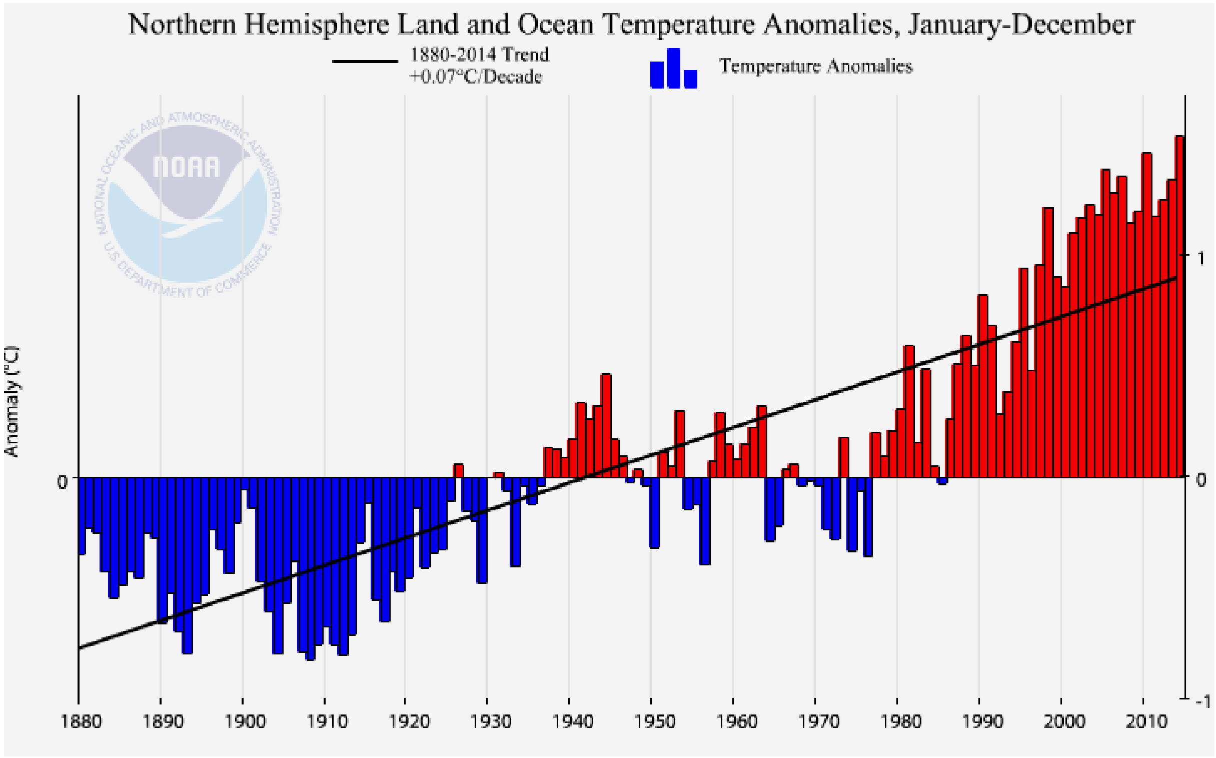


Source: IPCC, 2013

The now better recorded and understood dynamics of several climatic factors (e.g. land/sea surface temperature, sea level, arctic ice extent, glacier mass balance) suggest:

A significant and, in some cases, accelerating climatic change

Trends: Land and ocean temperature anomalies 1880-2014

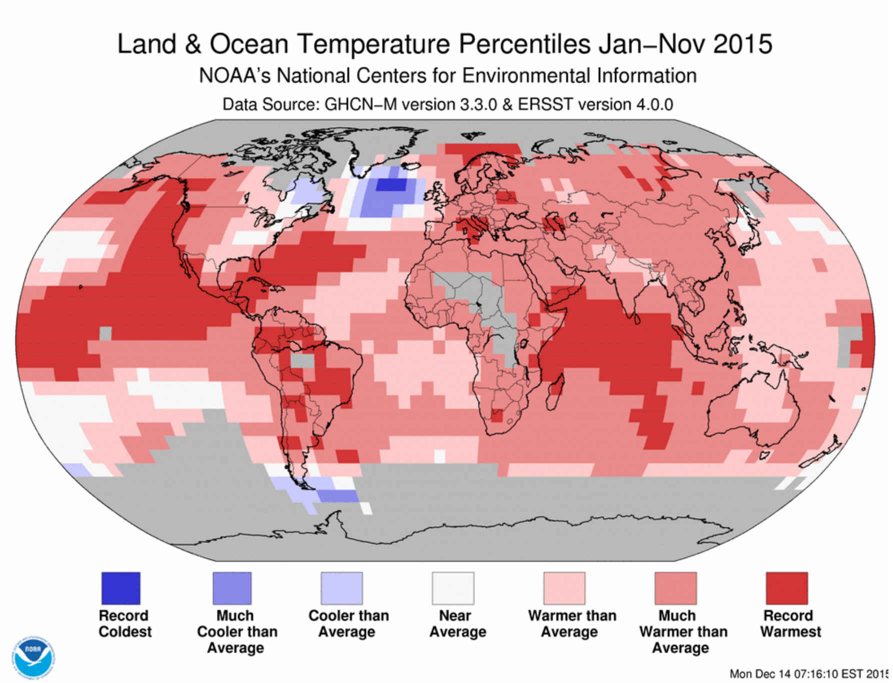


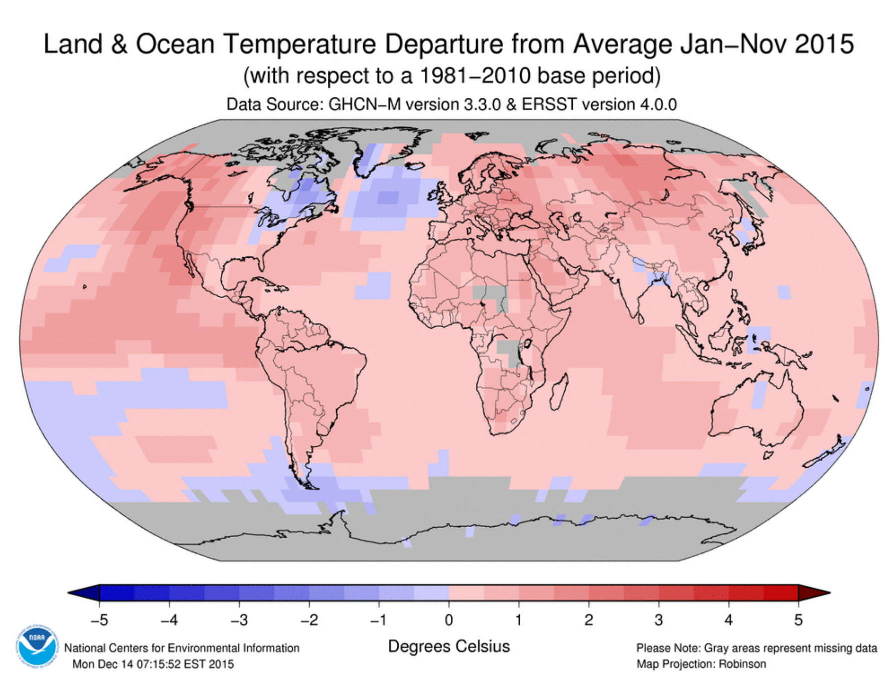
Detectable accelerating trend of rising temperatures in recent decades

Source: NOAA, 2015

: http://www.ncdc.noaa.gov/cag/time-series/global/nhem/land_ocean/ytd/12/1880-2015?trend=true&trend_base=10&firsttrendyear=1880&lasttrendyear=2015

Trends: 2015 Temperature anomalies



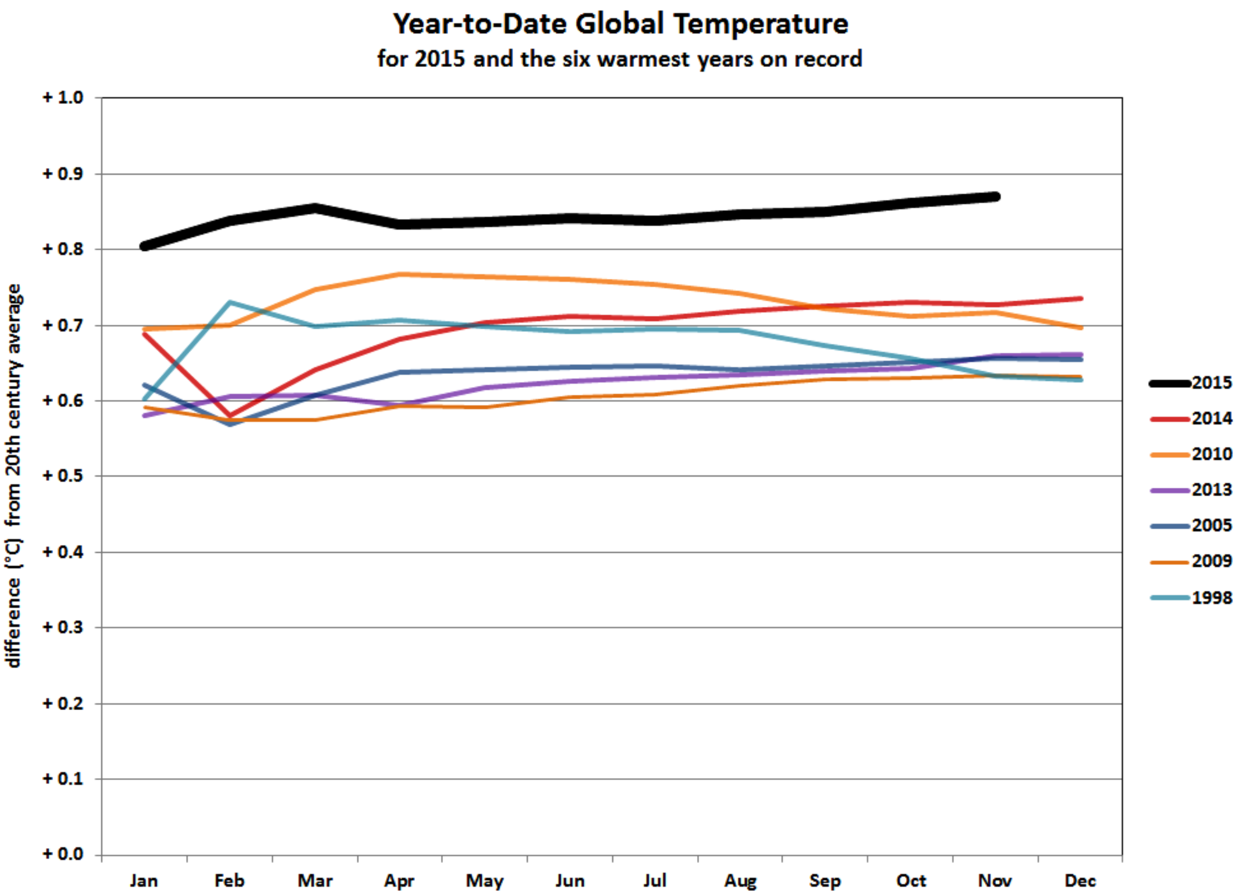


Source NOAA 1015

<u>2015 was the warmest year on record</u> (0.87°C > the 1901-2000 average of 14.0°C), surpassing the previous record (2014).

The <u>average land surface temperature was also record high, at 1.27°C above average</u>, surpassing the previous record of 2010 by 0.15°C. Nearly all of Eurasia were much warmer than average

Trends: 2011-2015 Temperature anomalies

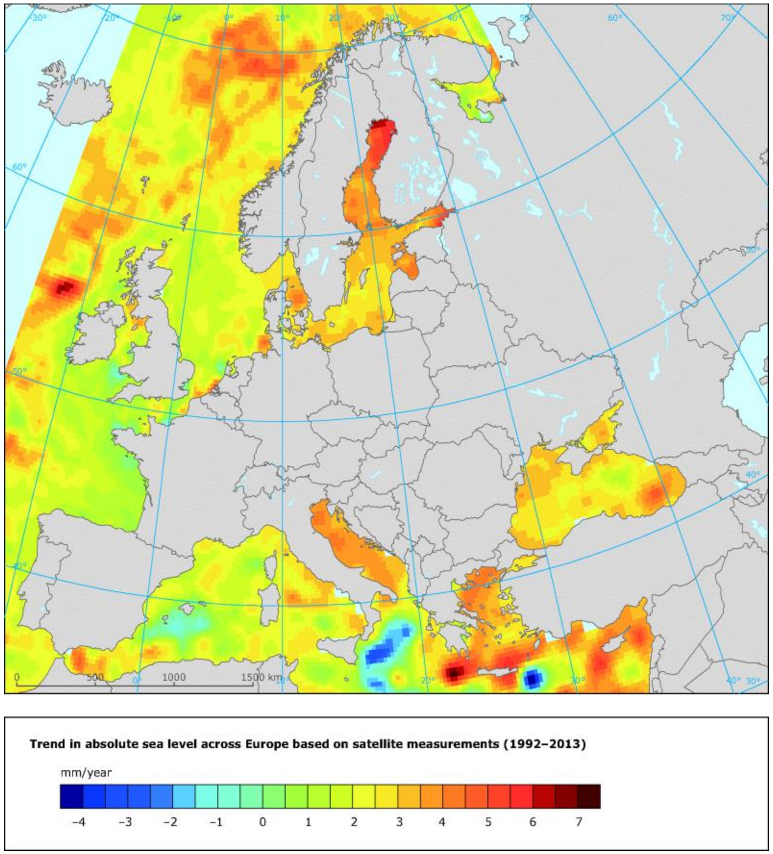


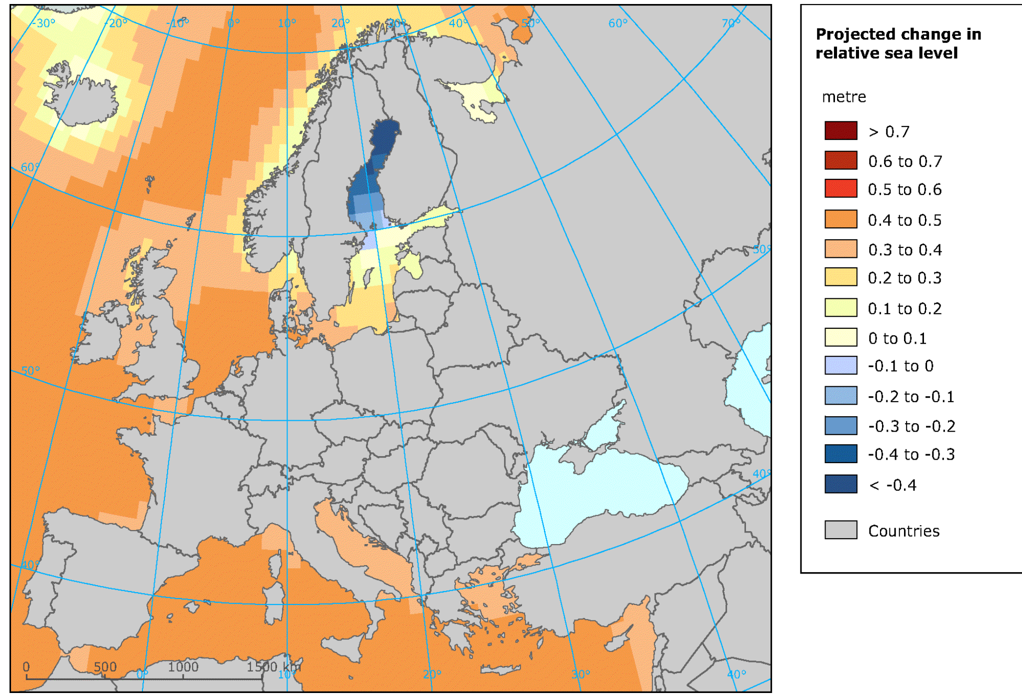
2011-15 was the warmest 5-year period on record, with temperatures 0.57°C above the 1961-1990 average and 0.51°C the 2006-2010 period

Land temperatures were > 1°C above the 1961-90 average over most of Europe, the SW United States and the Asian sector of the Russian Federation and most areas north of 60°N (NOAA, 2016)

Global ocean temperatures were also unprecedented

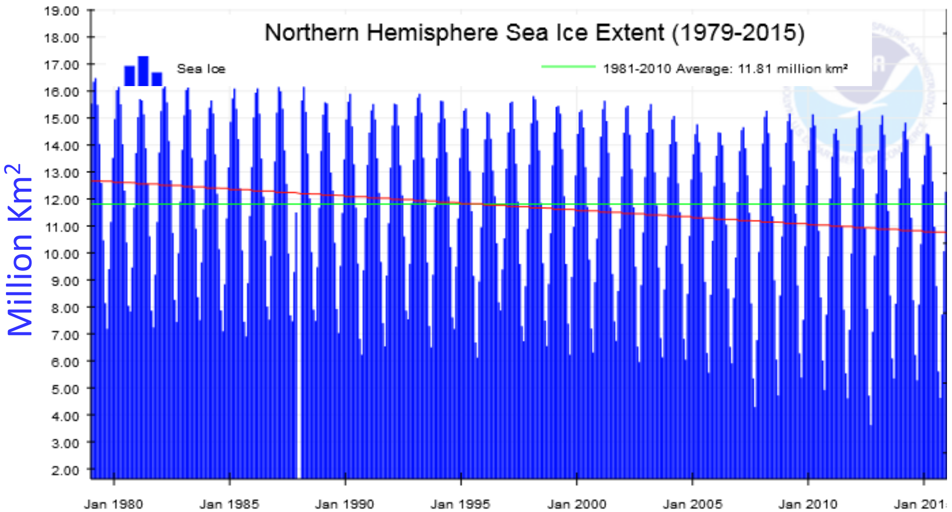
Sea level rise trends: Absolute and Relative SLR along the European coastline

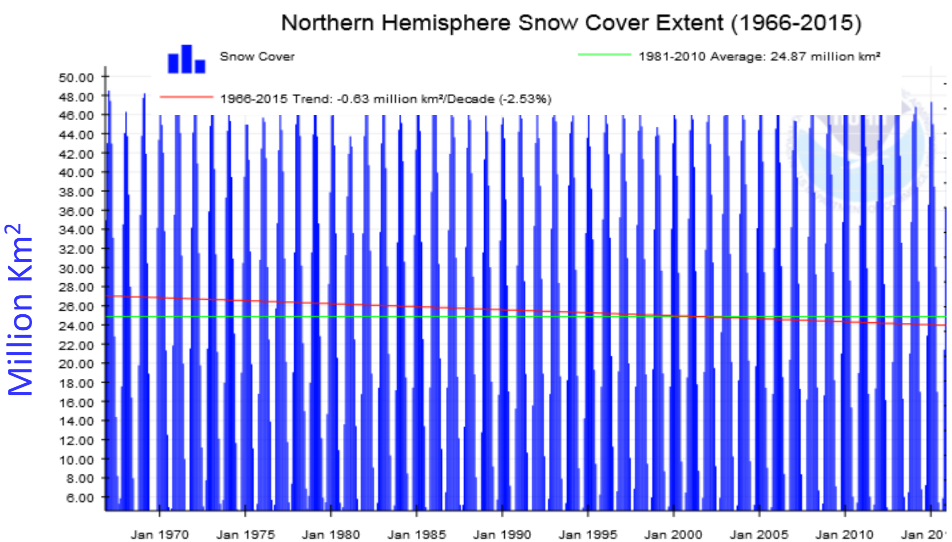




Trends in absolute sea level in European Seas from satellite measurements (1992–2013) http://www.eea.europa.eu/data-and-maps/figures/sea-level-changes-in-europe-october-1992-may-1 Projected change in relative sea level in 2081-2100 compared to 1986-2005 for the medium-low emission scenario RCP4.5 (from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

Trends: Sea ice and snow

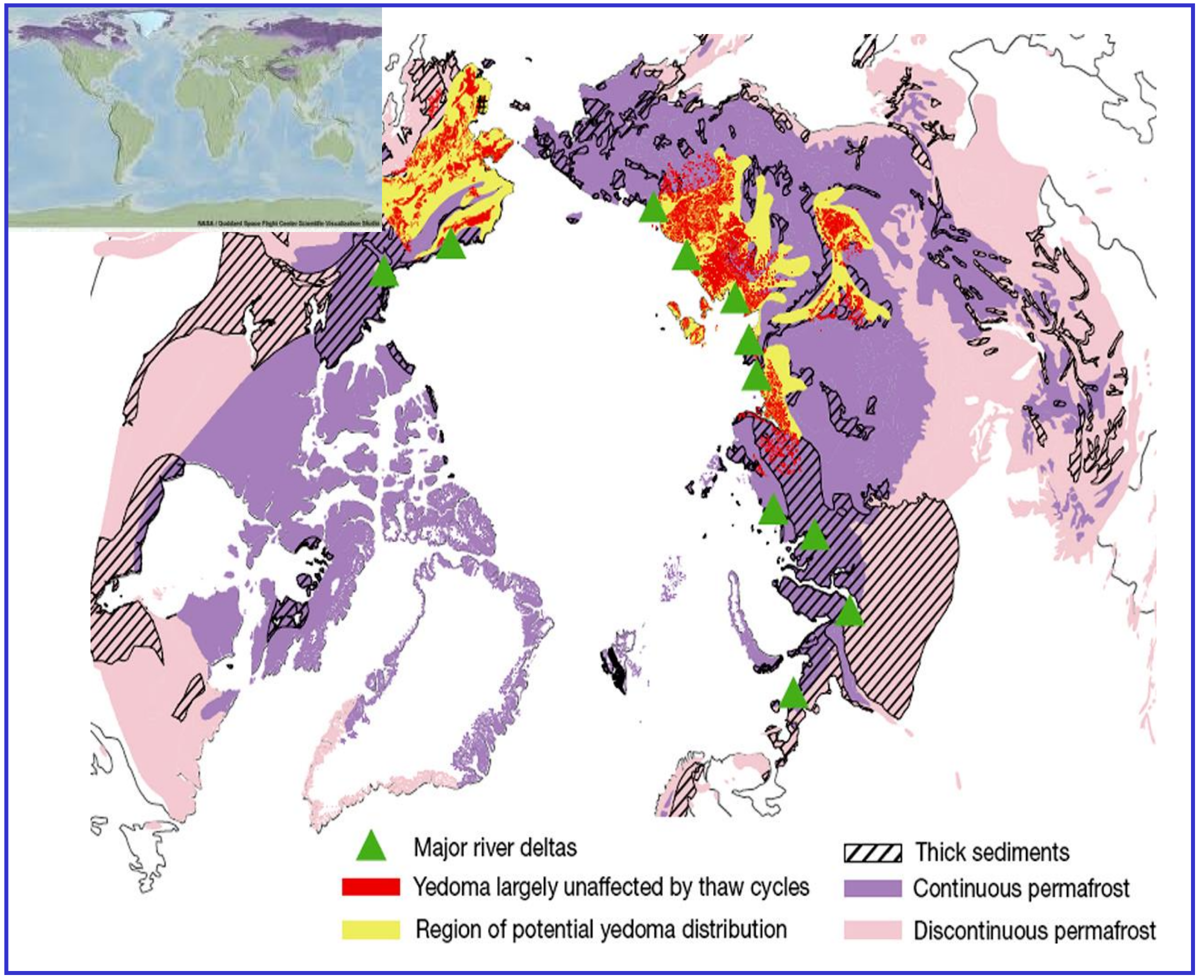




Sea ice and, to a lesser extent, snow cover have been decreasing

Source: NOAA, 2015

Permafrost distribution



Map of the northern circumpolar permafrost zone, highlighting the extent of the yedoma type of permafrost soil (yellow and red) that accounts for significant portion of the permafrost carbon pool (Schuur et al., 2015 doi:10.1038/nature14338)

Extreme events 2011-2015

Many extreme weather/climate events, including hurricanes, heat/cold waves, floods and droughts

Events caused large economic losses (> 20 billion US$): Hurricane *Sandy (2012)*, the 2011 SE Asian floods, droughts in the southern/central United States (2012-2013), and floods in central Europe (2013) and the UK (2014-2015)

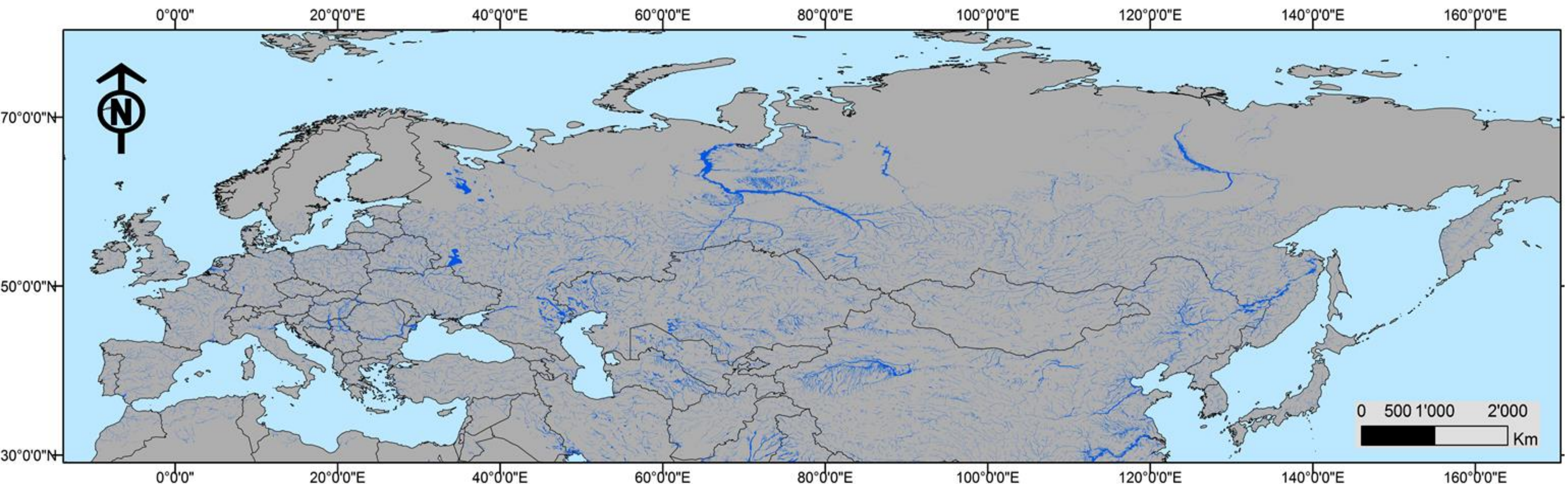
Significant annual wet anomalies in NE Europe (2012) and SE Europe (in 2014)

Major heatwaves (July 2015 set several records in Europe)

Prolonged period of extreme cold in Europe (February 2012)-temperatures remained below 0°C continuously for 2 weeks or more in most of central Europe

Flooding in the Danube and Elbe basins (May-June 2013) caused huge economic losses

Extreme river floods: Current hazard in Eurasia



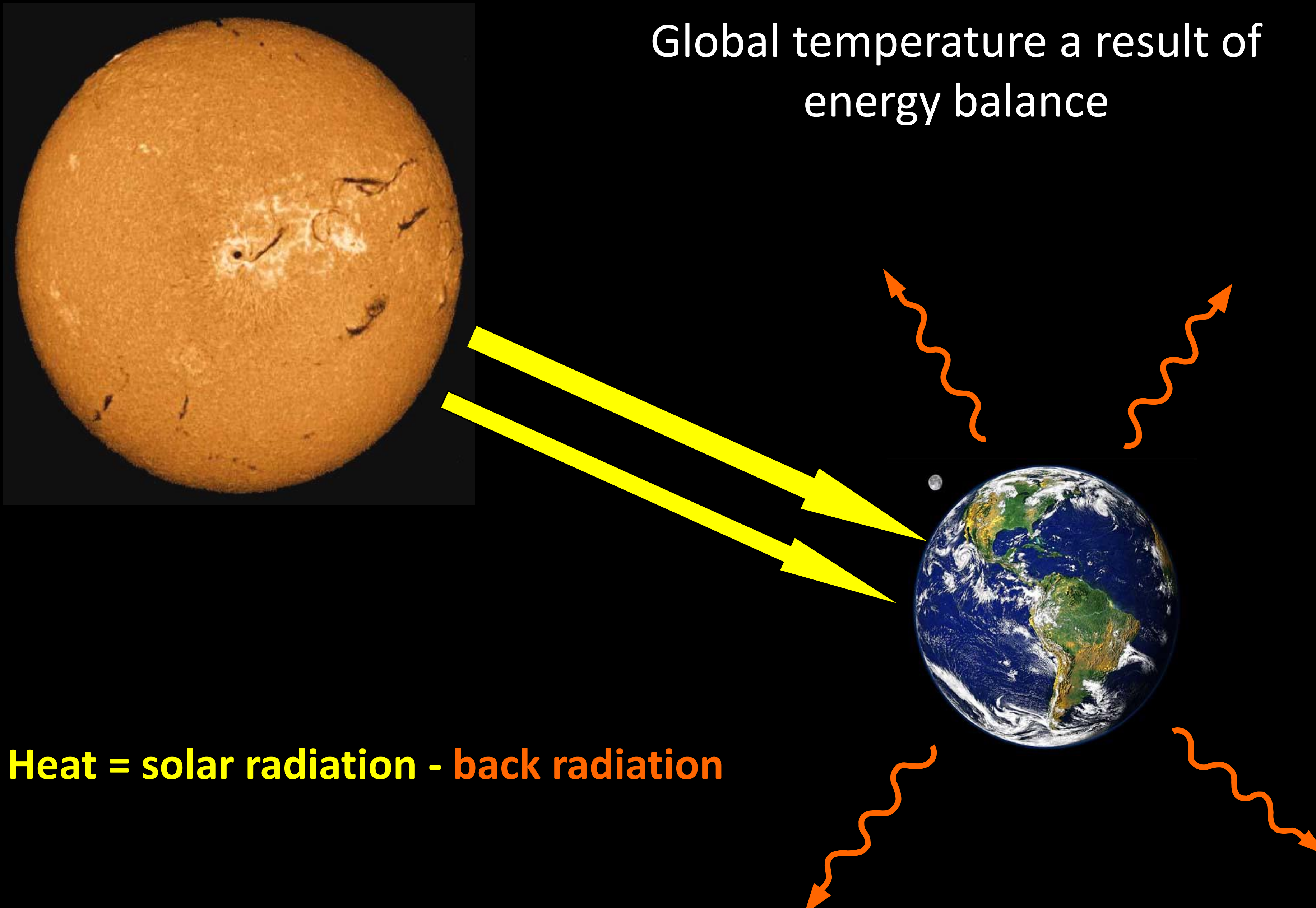
<u>Current flood hazard</u> (95 % probability) in the Eurasian region of the ECE for the 100-year flood from a global GIS model based on river discharge time-series. DEM resolution 90 m. Areas over 60^0 N are not fully covered (From UNEP-GRID and UNISDR, 2008). (ECE,2013)

Forcing Mechanism: what are the processes involved?

Climate is controlled by solar heat inflows/outflows

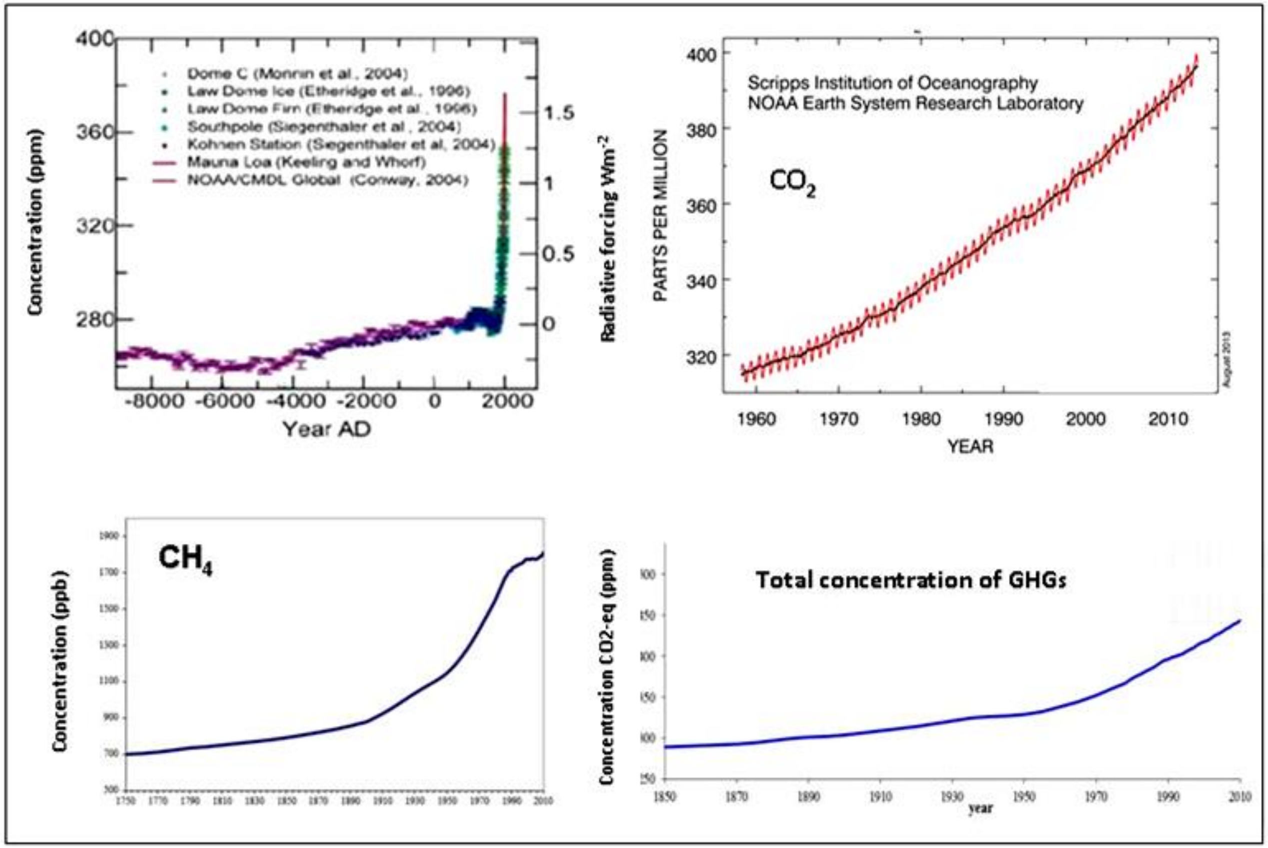
The observed increase in heat content is probably (at least partly) due to the increasing atmospheric concentrations of greenhouse gases (GHGs), that absorb heat reflected back from the Earth's surface (IPCC, 2013)

Global temperature a result of energy balance



Heat = solar radiation - back radiation

Atmospheric concentrations of Greenhouse Gases-GHGs



[Recent large, non-linear and accelerating increases of GHGs (ECE, 2013)]()

CO2 concentration passed the 400 ppm milestone for the first time in the last 800000 years in 09/05/2013 (http://www.esrl.noaa.gov/gmd/ccgg/trends).

CO2 concentration (parts per million-ppm) in the last 11000 years (Rahmstorf, 2011) and the last 50 years (Mauna Loa data, (www.esrl.noaa.gov/gmd/ccgg/trends/).
Also shown are the CH4 concentrations (ppb- parts per billion) and the total concentration of the 6 GHGs of the Kyoto Protocol (in ppm CO2 Equivalent) which has increased by 60 % compared to pre-industrial levels (http://www.eea.europa.eu/data-andmaps/figures/observed-trends-in-the-kyoto-gases-1) .

Most recent climate projections

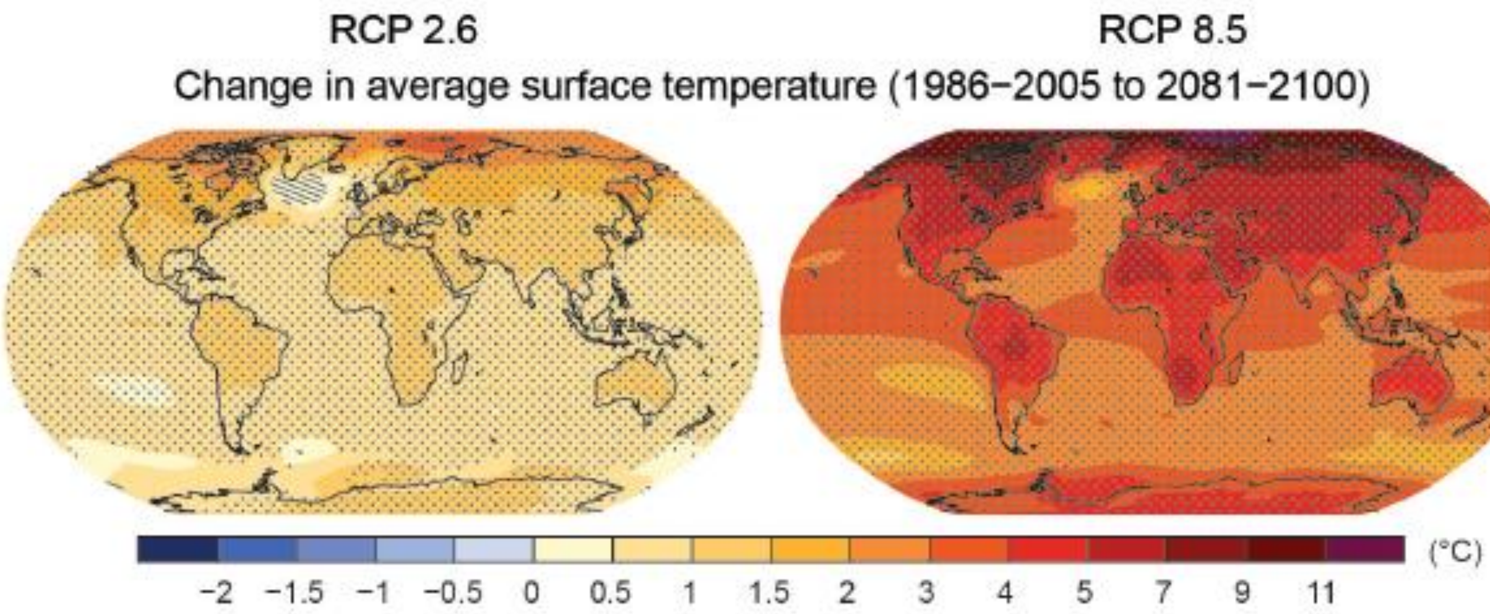
Temperature projections

Mean sea level projections

Extreme event dynamics

Permafrost and Arctic ice projections

Projections: Temperature

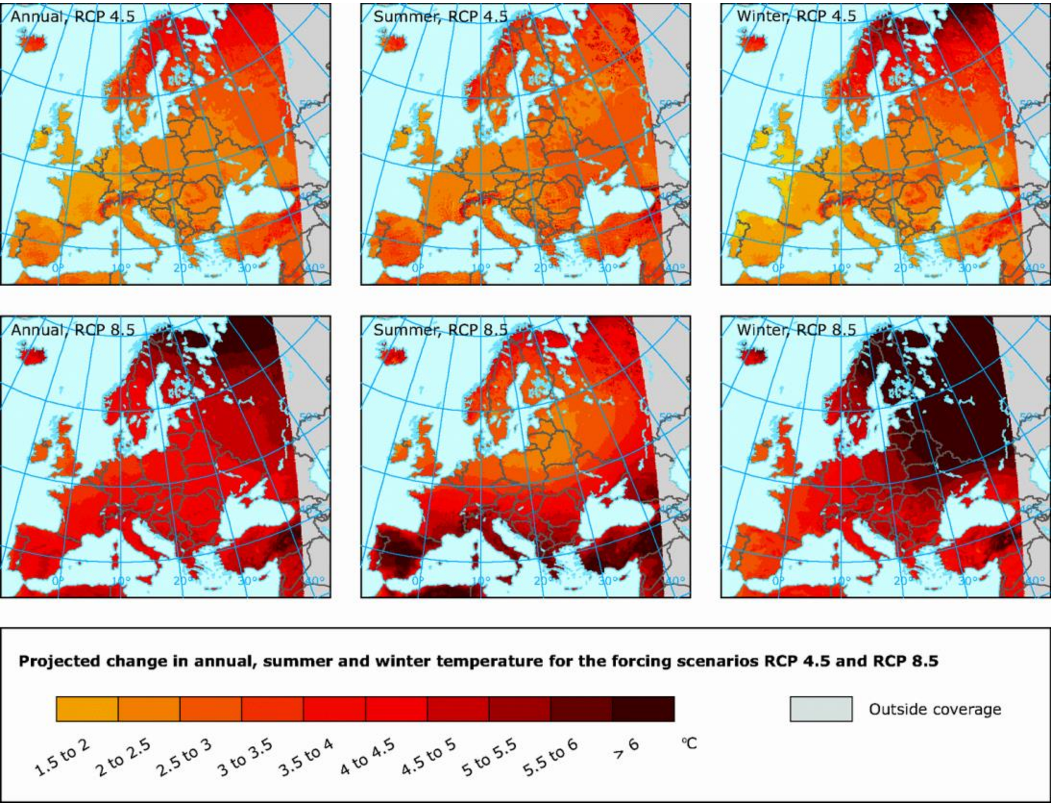


Projected changes in average temperatures in 2081-2100 relative to 1986-2005 for low (RCP2.6) and high emission (RCP8.5) scenatios (IPCC, 2013)

Under both low-moderate (RCP 4.5) and high emission (RCP8.5) scenarios, large increases in surface temperatures

Temperature increases are projected to be higher in the northern ECE region

Land temperature: Projections for Europe

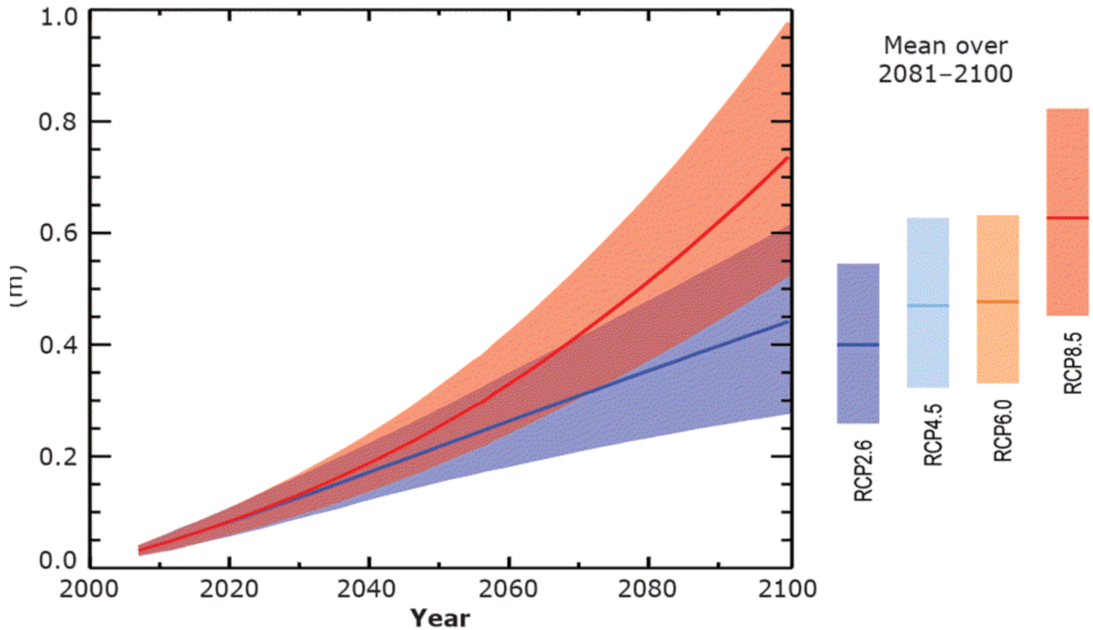


Large increases in land surface temperatures projected for all Europe

Greater increases in N/NE Europe, particularly in winter (ice and permafrost melt implications).

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

Projections: Mean sea level rise



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

Global MSL has risen by 0.19 m in 1901-2013 (average rate 1.7 mm/year). In the last two decades, the <u>rate has accelerated to 3.2 mm/year</u>

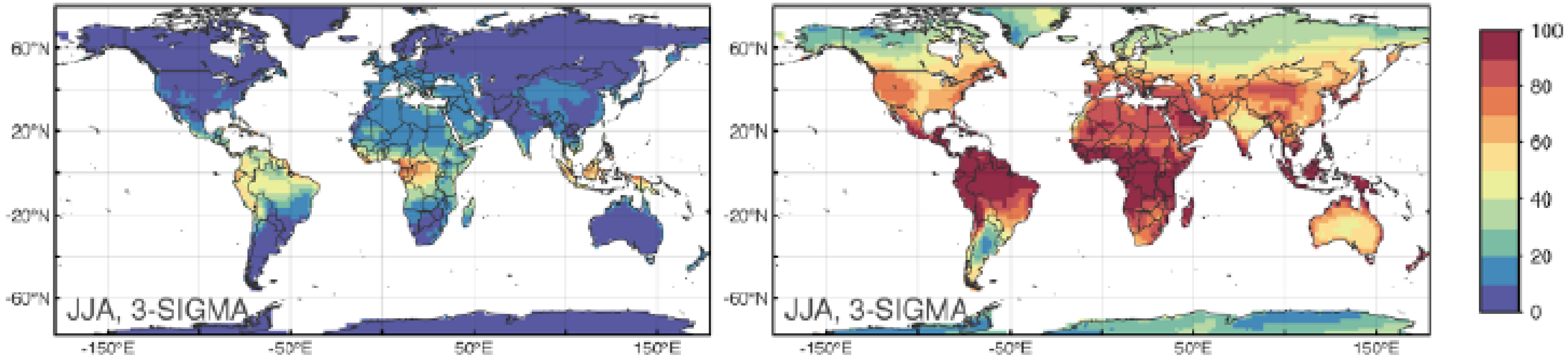
Model project a likely rise in 2081–2100 (compared to 1986–2005) in the range <u>0.26–0.54 m for RCP2.6</u> and <u>0.45–0.82 m for RCP8.5.</u>

<u>Significant spatial variability</u> along the global coast

Projections of Extremes: Temperature

Projections show that a very hot summers will occur much more frequently in the future under all CC scenarios.

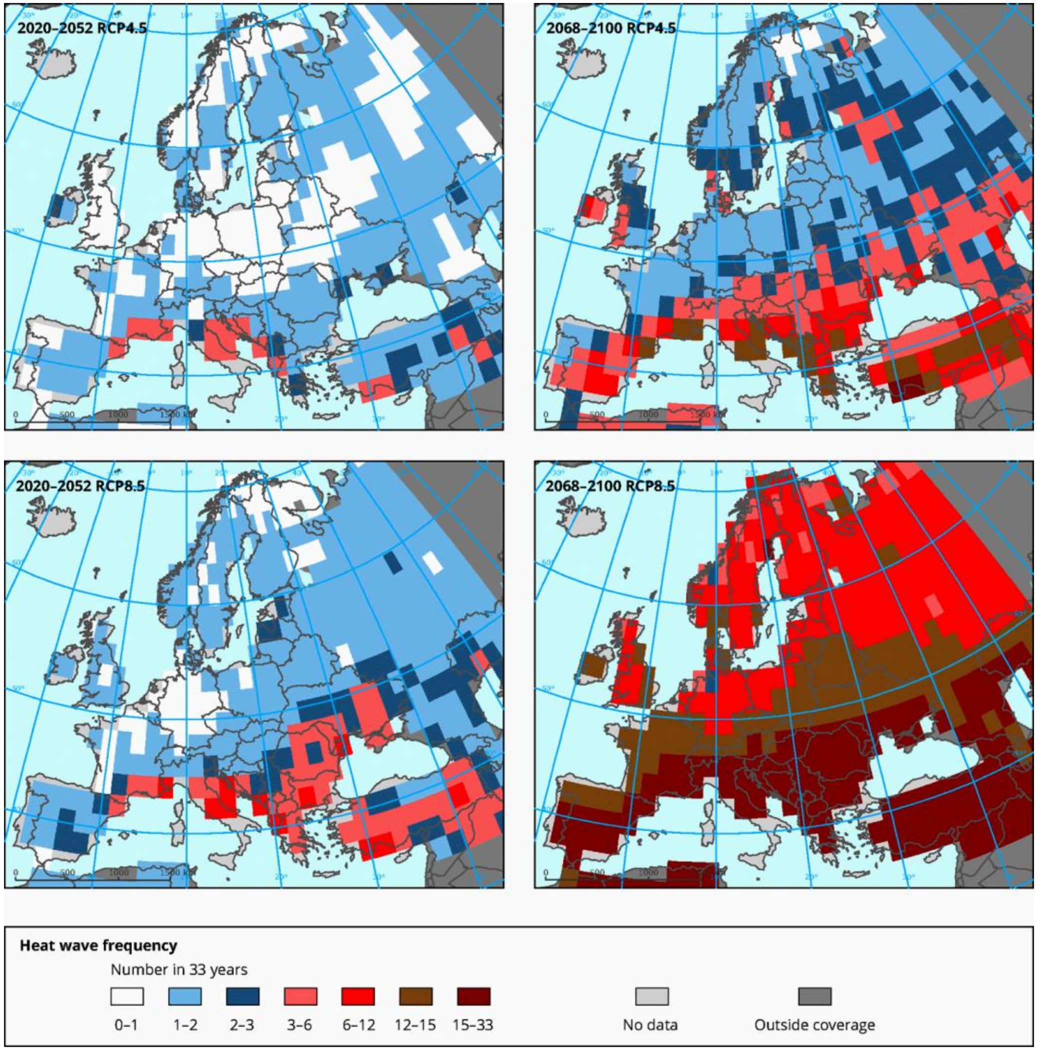
Yellow, orange/red areas in the maps show regions where (at least) 1 every 2 summers will be warmer that the warmest summer in 1901-2000



Projected changes in hot seasonal temperature extremes in 2071-2100 for RCPs 2.6 and 8.5. (Coumou and Robinson, 2013)

Projections of Extremes: Heat waves

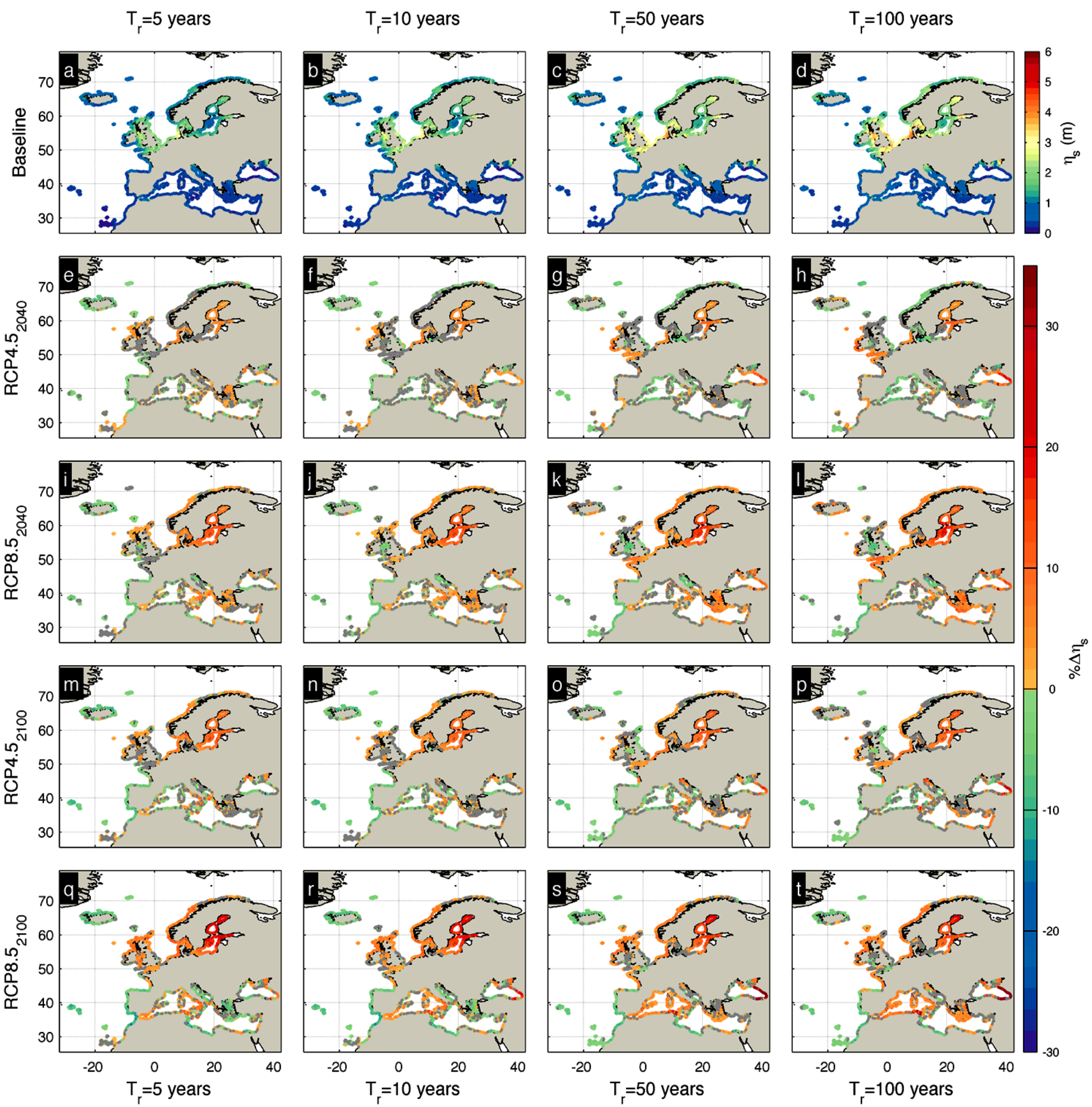
Large increase in heat waves projected for Europe, particularly under RCP8.5

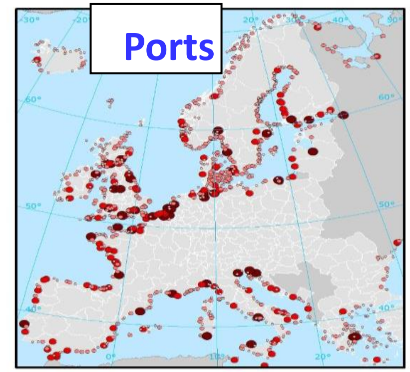


Median of the projected number of heat waves (from a model ensemble) in the near (2020–2052) and long (2068–2100) term under the RCP4.5 scenario (EEA, 2015).

The same, but under RCP8.5

Storm surge levels under Climate change: Projections for Europe

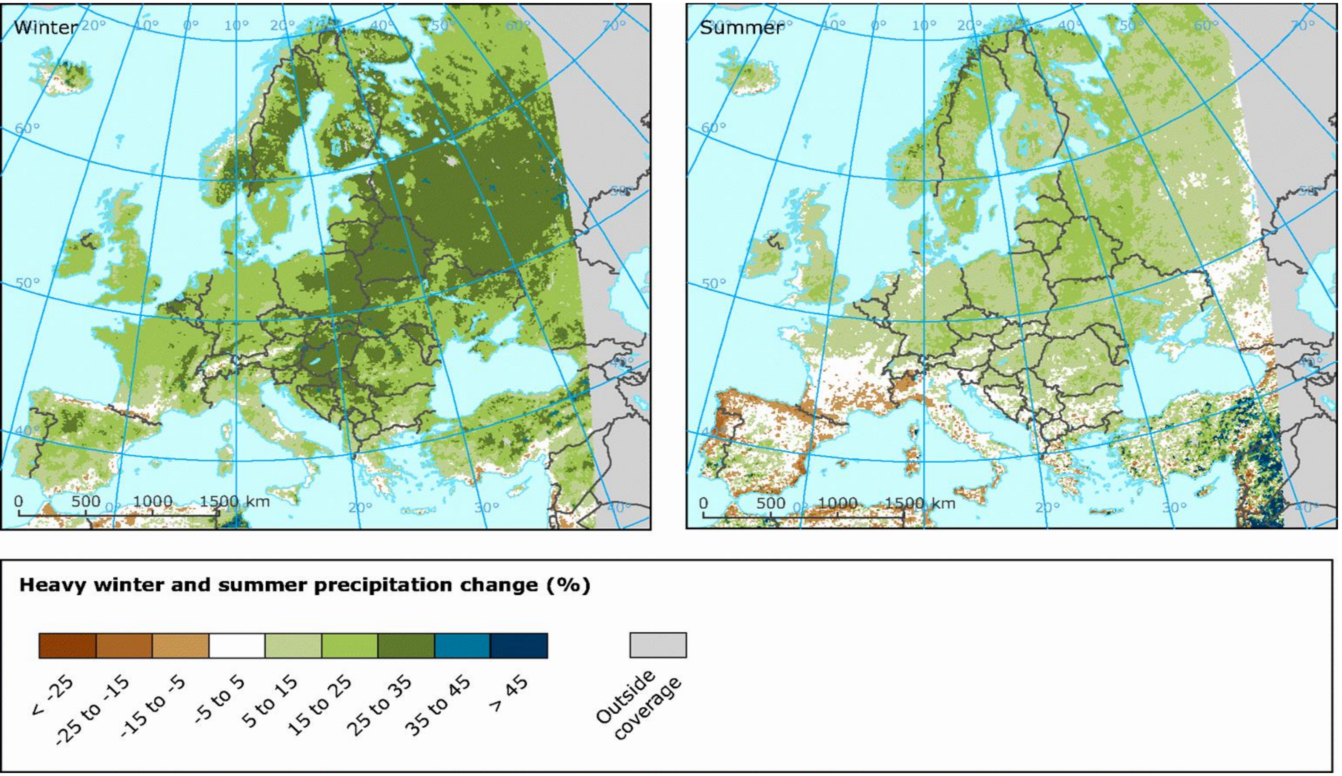




Projection show larger storm surge levels for the Atlantic and Baltic coast/ports under all scenarios and extreme storm events tested

Trends and model projections (as percentage of the present level) (Vousdoukas et al., 2015) of storm surge levels in 2040 and 2100 under RCP4.5 and RCP8.5 scenarios for the 5, 10, 50 and 100 year event.

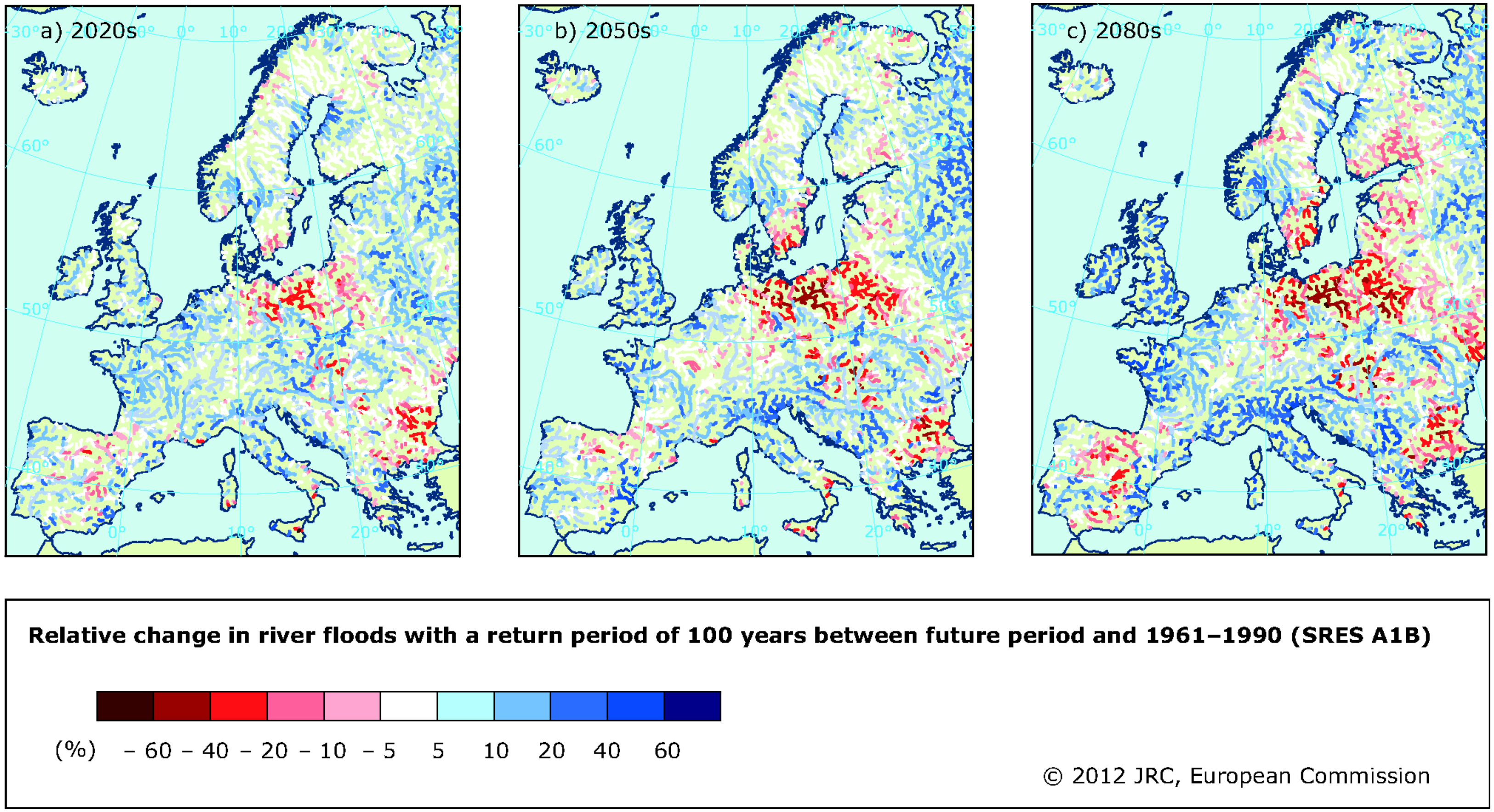
Projections of Extremes: Precipitation



Large increases (25 %) in heavy precipitation projected for central and NE Europe, for the end of the 21st century

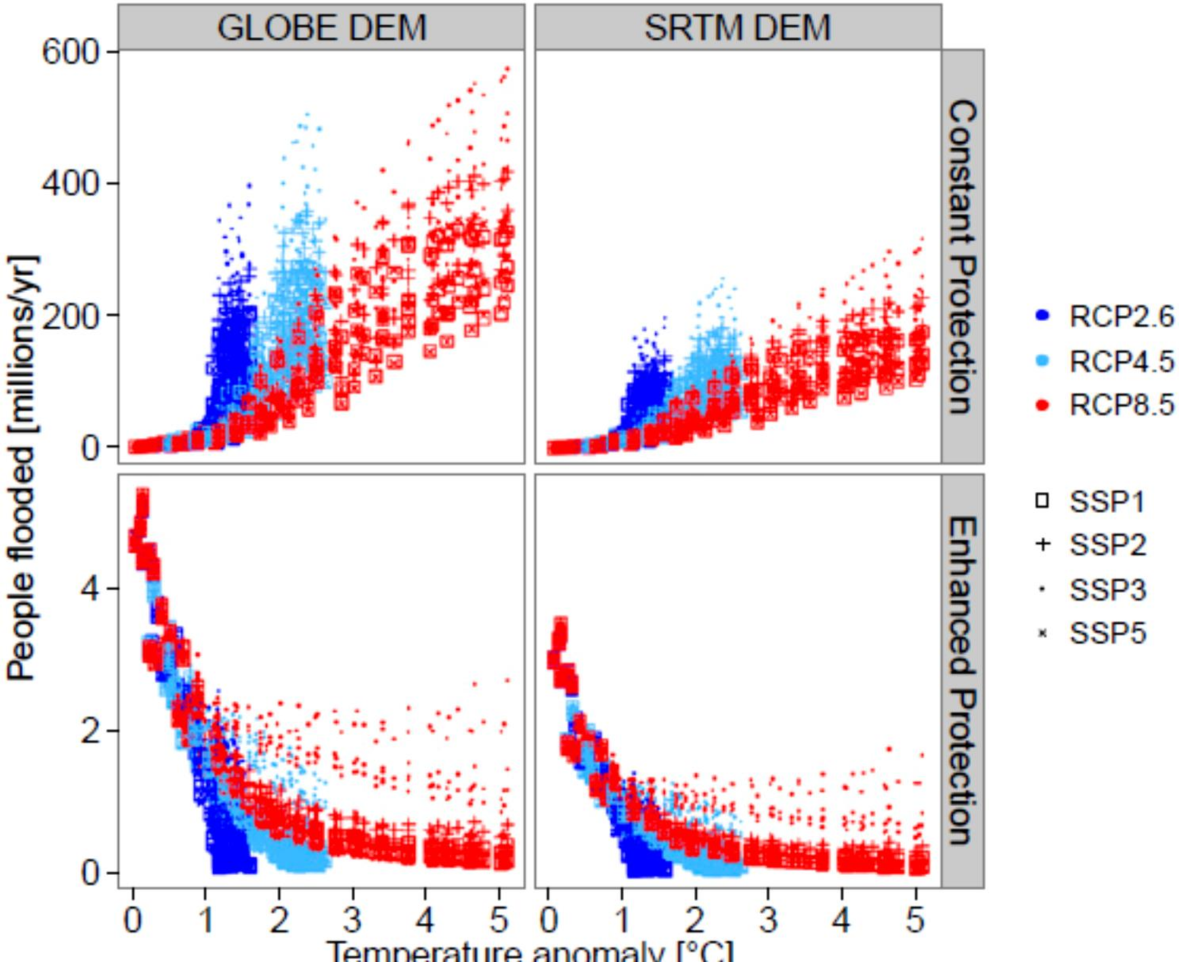
Projected changes in heavy precipitation (in %) in winter and summer from 1971-2000 to 2071–2100 for the RCP8.5 scenario based on the ensemble mean ofregional climate models (RCMs) nested in general circulation models (GCMs).

Projections of Extremes: River floods



Increases in river floods projected for most of the Europe

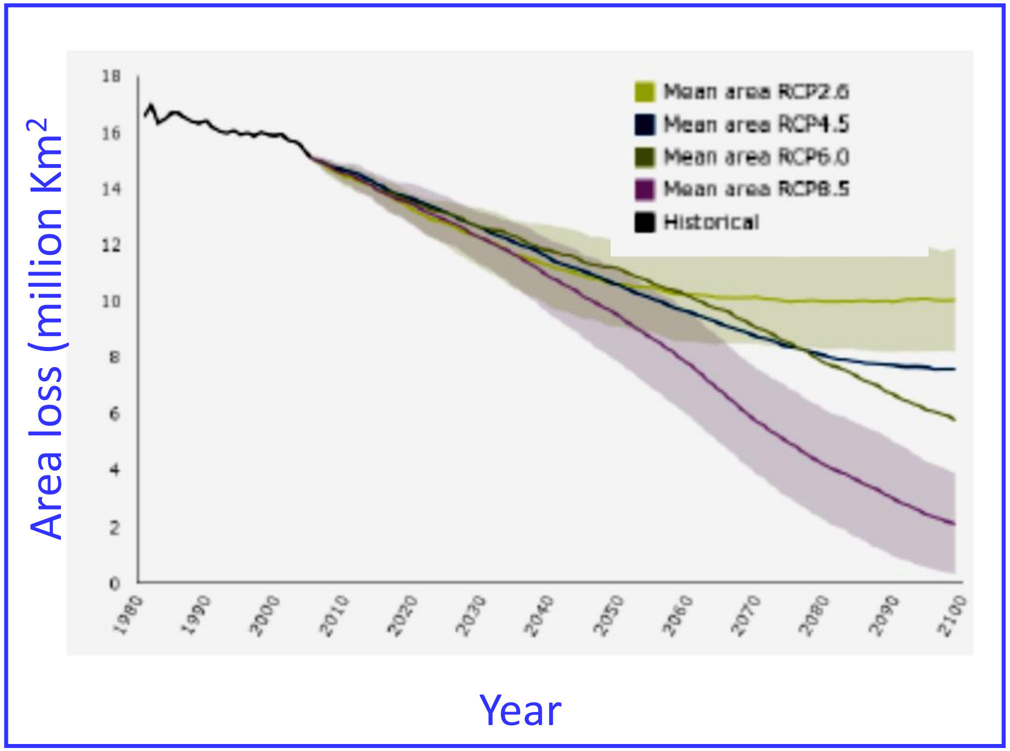
Projections of Extremes: Impacts of River floods



Global expected annual number of people flooded in the period 2000-2100 versus the Global mean temperature anomaly relative to 1986-2005.

SSP scenarios are socioeconomic scenarios based on population and gross domestic product (GDP) growth. (https://secure.iiasa.ac.at/web-apps/ene/SspDb).

Projections: Melting permafrost and Arctic ice



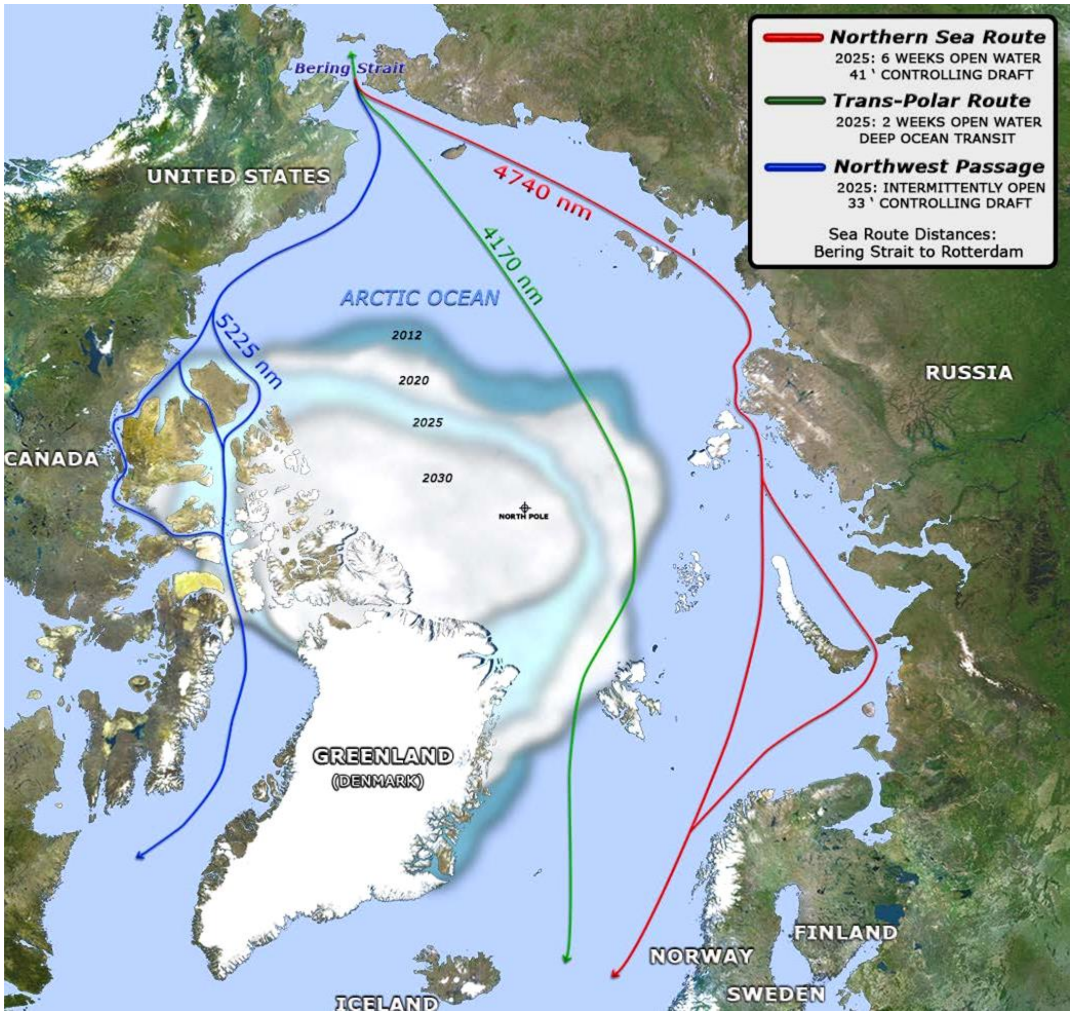
Projected near-surface (n-s) permafost changes, for 4 Representative Concentration Pathways-RCPs (from CMIP5 model ensemble). (EEA, 2015)

Current warming rates at the permafrost surface of 0.04–0.07 °C/year.

Simulated reduction in (n-s) permafrost area (N. Hemisphere, 2100) between 37 ± 11% (RCP2.6) and 81 ± 12% (RCP8.5)

Fennoscandia *palsa mires* (a special case of Arctic permafrost) may respond more rapidly to warming, potentially leading to a complete palsa loss in N. Fennoscandia by 2100

Projections of Arctic ice extent: Challenges and opportunities



The U.S. Navy anticipates 3 major shipping routes by 2025, which however are associated with environmental risks.

There may be new economic opportunities for Arctic communities, as reduced ice extent facilitates access to the substantial hydrocarbon deposits (Beaufort and Chukchi seas) and international trade.

At the same time, CV & C will affect existing infrastructure and all future development due to thawing permafrost and coastal wave activity

https://toolkit.climate.gov/topics/arctic/arctic-development-and-transport

Conclusions

- There is now ample evidence to suggest a significant and, in some cases, accelerating change of several climatic factors
- The period 2011-15 was the warmest 5-year period on record; land surface temperatures were > 1°C above the 1961-90 average for most of the ECE region
- Changes are likely to be (at least partly) due to non-linear and accelerating increases of GHG concentrations; CO2 concentration passed 400 ppm for the first time in the last 800000 years in 2013
- Under both low-moderate and high emission scenarios, large increases in surface temperatures are projected, particularly for the northern ECE region
- Global MSL rise in 2081–2100 (compared to 1986–2005) is projected as 0.26–0.82 m for all scenarios; however there will be significant spatial variability
- The already diminishing sea ice/permafrost areas will be very significantly reduced till 2100
- In the ECE region, very hot summers will occur much more frequently under all CC scenarios
- Large increases (25 %) in heavy precipitation projected for central and NE Europe for 2100; increases in river flooding are also projected for most of Europe
- Large increase in heat wave frequency are projected for Europe
- Projections show higher storm surge levels for the Atlantic and Baltic coast/ports under all scenarios
- Finally, since 2013 there has been a modest increase in risk and cost assessment studies on climate change-related impacts on transportation; nevertheless, much more relevant studies are needed

Thank you!