

Current state of knowledge on the evolution of the potential hazards for inland transportation under Climate Variability and Change (CV&C)

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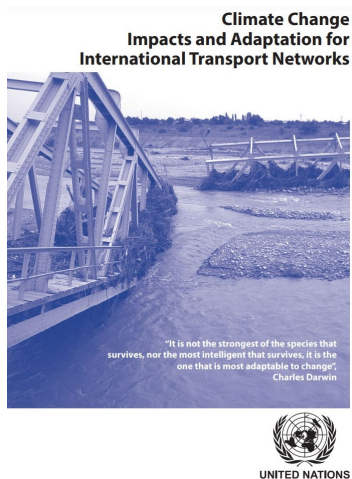
Group of Experts on Assessment of Climate Change (CC) Impacts and Adaptation for Inland Transport (2020-2025)

Key tasks:

- (i) raise awareness, build capacity and integrate knowledge from countries and the scientific community on CC impact assessment and adaptation for transport, and
- (ii) advance the state of knowledge in the analysis of CC impacts on inland transport identify suitable and cost-effective adaptation measures

Expected outputs:

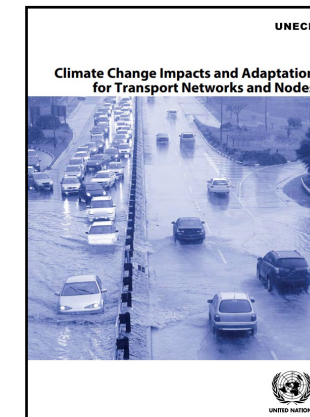
- CC hazard maps for transport networks and assets
- Analysis of potential impacts, areas of vulnerability
- Review of national projects
- Database of (successfully implemented) adaptation measures
- Guidelines for integrating CC considerations in (inland) transport planning and operational practices



http://www.unece.org/fileadmin/DAM/trans/main/wp5/publications/climate_change_2014.pdf






[https://unece.org/DAM/trans/publications/Transport for Sustainable Development UNECE 2015.pdf](https://unece.org/DAM/trans/publications/Transport%20for%20Sustainable%20Development%20UNECE%202015.pdf)



https://reliefweb.int/sites/reliefweb.int/files/resources/ECE-TRANS-283e_0.pdf



Climate change hazards and impacts relevant to transport infrastructure and operations

Temperature			
<ul style="list-style-type: none">• Higher mean temperatures; heat waves/droughts; changes in the numbers of warm and cool days• Reduced snow cover and arctic land and sea ice; permafrost degradation and thawing	 Road	 Rail	 Waterways and ports
	<ul style="list-style-type: none">• Thermal pavement loading and degradation• Asphalt rutting• Thermal damage to bridges• Increased landslides• Reduced integrity of winter roads and shortened operating seasons	<ul style="list-style-type: none">• Track buckling• Infrastructure and rolling stock overheating/failure• Slope failures• Signaling problems• Speed restrictions• Asset lifetime reduction• Higher needs for cooling• Shorter maintenance windows	<ul style="list-style-type: none">• Damage to infrastructure, equipment and cargo• Higher energy consumption for cooling• Potential reductions in snow/ice removal costs• Occupational health and safety issues during extreme temperatures
	Precipitation		
<ul style="list-style-type: none">• Changes in the mean values; changes in intensity, type and/or frequency of extremes	<ul style="list-style-type: none">• Inundation, damage and wash-outs of roads and bridges• Increased landslides• Impacts on bridges	<ul style="list-style-type: none">• Flooding, damage and wash-outs of bridges• Problems with drainage systems and tunnels• Delays	<ul style="list-style-type: none">• Infrastructure inundation• Navigation restrictions in inland waterways due to river water levels changes
Sea levels/storm surges			
<ul style="list-style-type: none">• Mean sea level rise• Increased extreme sea levels	<ul style="list-style-type: none">• Erosion of coastal roads• Flooding, damage and wash-outs of roads and bridges	<ul style="list-style-type: none">• Bridge scour, catenary damage at coastal assets• Disruption of coastal train operation	<ul style="list-style-type: none">• Asset inundation• Navigation channel sedimentation• Maintenance costs

After ECE (2020)



Mean Temperature: Trends

Major driver of climate change: Global warming

Very significant warming since the industrial revolution (about 1.1 °C. In 1979- 2019, temperature appears to accelerate (rise of 0.17 and 0.19 °C per decade

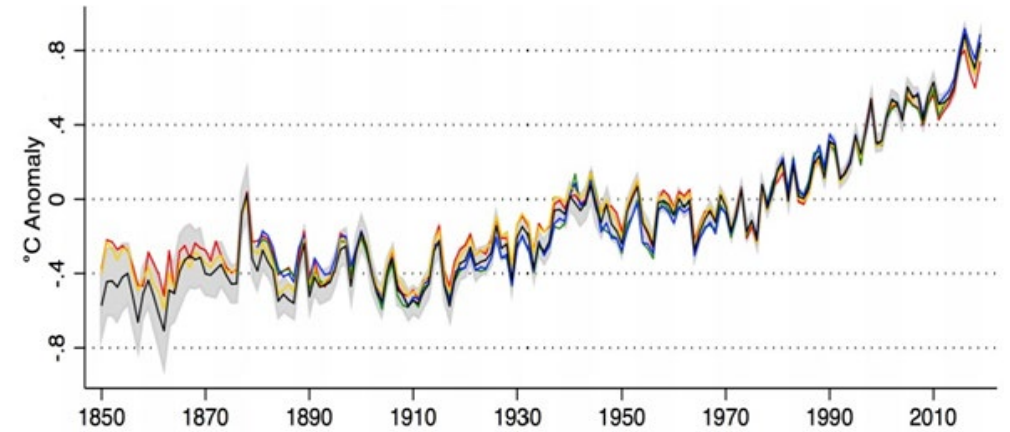
Recent years were the warmest on record (WMO, 2021)

Climate does not (and will not) change uniformly: temperatures generally rise faster at high latitudes

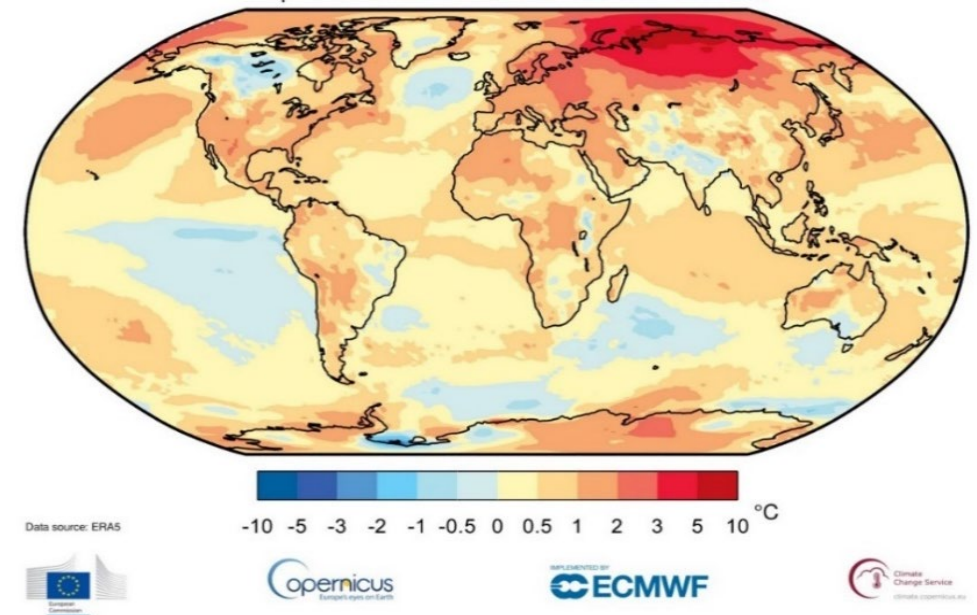
Mean temperature rise affects the dynamics of other climatic factors impacting on transportation, such as:

- the precipitation;
- the cryosphere (snow, ice and permafrost;
- the sea level precipitation

It is also a major control of extreme climatic events



Global Temperature since 1850 (relative to 1961-1999 (Rohde and Hausfather, 2020)



Temperature difference between 2020 and the average temperature of the 1981-2010 period (WMO, 2021)



(Mean) Precipitation: Trends

Global land rainfall data show increasing trends, especially in middle and high latitudes (e.g. IPCC, 2013).

These trends may be linked to the temperature rise; it has been suggested that a global warming of about 1°C relative to pre-industrial time may result to global precipitation increases of about 2 – 3 % (Schneider et al., 2017).

(Land) precipitation shows stronger spatio-temporal variability than temperature due to the large influence of large climatic modulations (e.g. the *El Niño-NSO*).

In the future, precipitation is expected to change in an even more complex manner than temperature



Mean Temperature and Precipitation: Projections

Large temperature increases projected by GCMs and RCMs over the ECE region, particularly for its north

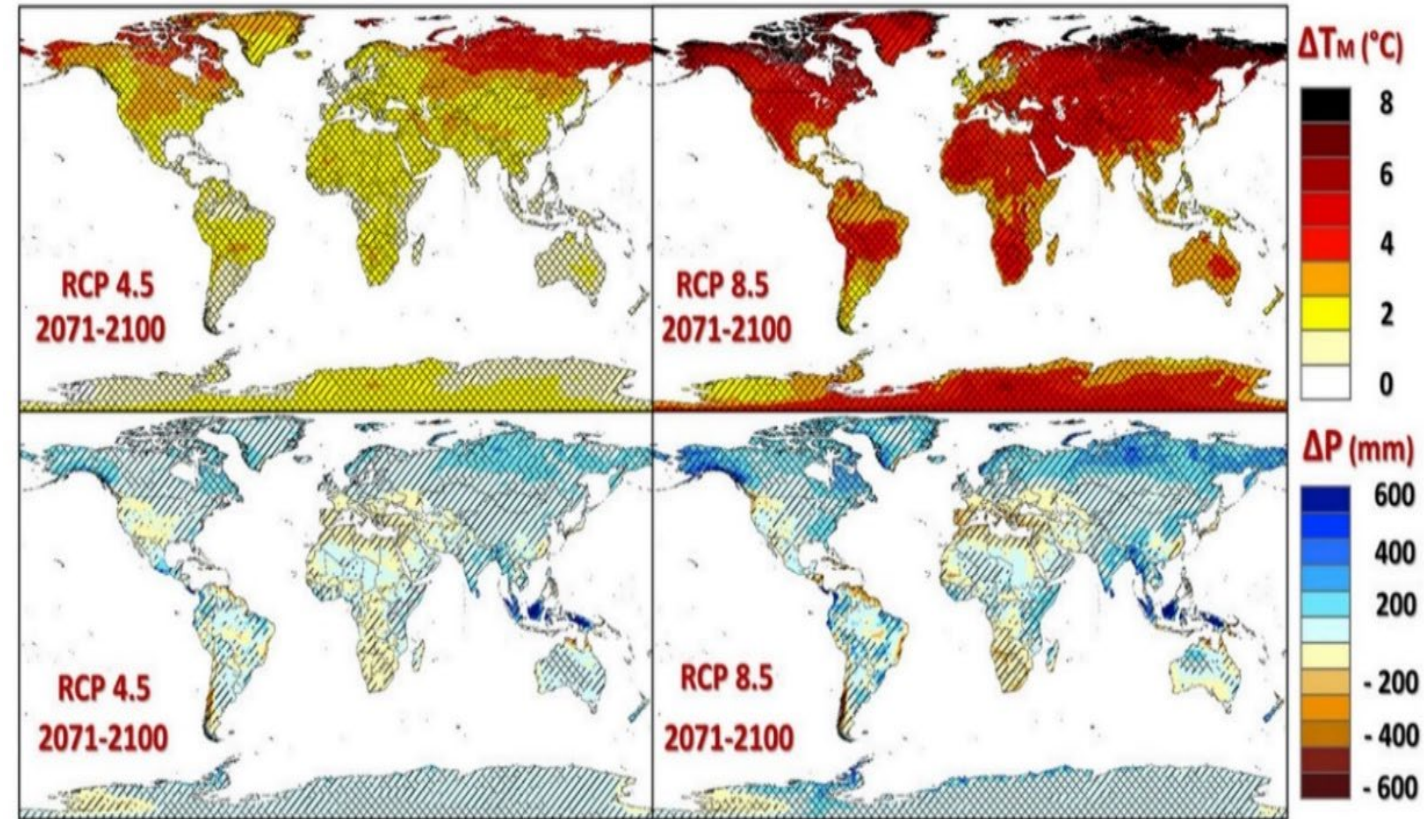
Recent projections indicate increases of $> 4^{\circ}\text{C}$ by 2100 even under RCP4.5.

Extreme magnitudes for northernmost Canada, Alaska and Eastern Siberia

Precipitation expected to change in a more complex manner: both increases and decreases

In the ECE region, the north will generally become wetter and the south drier

Also seasonal differences: In Canada, for example, profound winter increases projected for the north and summer decreases for the south, particularly under RCP8.5)



Changes in mean temperature (ΔT_m , upper panels) and annual precipitation (ΔP , lower panels) between 1981–2010 and 2071–2100 under RCP4.5 and RCP8.5 from CORDEX simulations, . (Spinoni et al., 2020)



Cryosphere dynamics: Trends and Projections

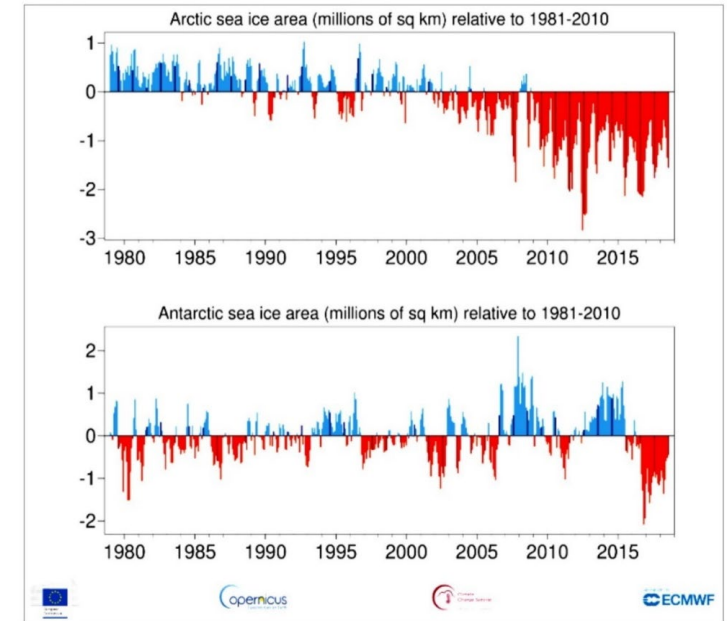
Particularly important for the transport sector in the extensive ECE Arctic regions (Russian Federation, Scandinavia, Canada and the US).

Since the 1950's, spring NH snow cover has decreased (in June by 12 % per decade in 1967 - 2012); projections suggest further decreases (but regional differences)

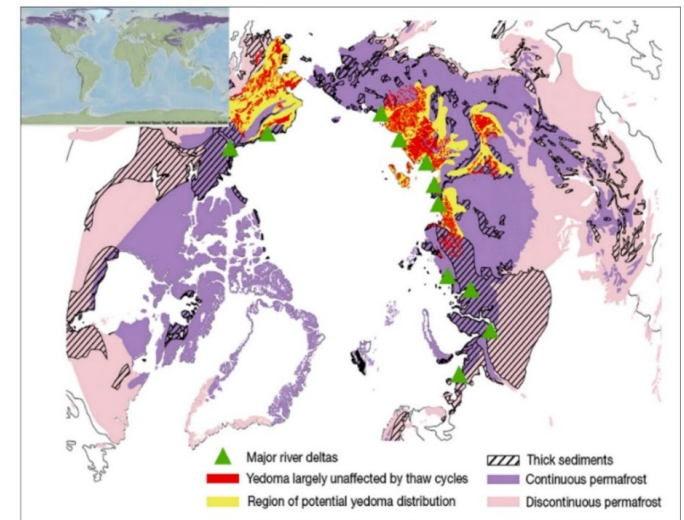
Arctic (minimum) SIE in decline (40% since 1979, -12.8 ± 2.3 % per decade in 1979 – 2018), but Antarctic SIE shows variability; large implications for shipping and facilitating inland transportation; SIE decreases projected for the future

Mountain/polar glaciers declined and will retreat further (small glaciers will disappear); significant effects for mountainous infrastructure and IWWs

The NH polar permafrost decreased by 0.32 m since the 1930; mountainous permafrost has warmed by 0.19 ± 0.05 °C per decade (2007-2016); by 2100, near-surface permafrost area will decrease by 2 – 66 % (RCP2.6) and 30 – 99 % (RCP8.5); serious challenges for the development/maintenance of Arctic transport infrastructure



Arctic and Antarctic sea ice extent (SIE) evolution 1979-2019 (Taalas, 2019)



.NH permafrost zone (Schuur et al., 2015).

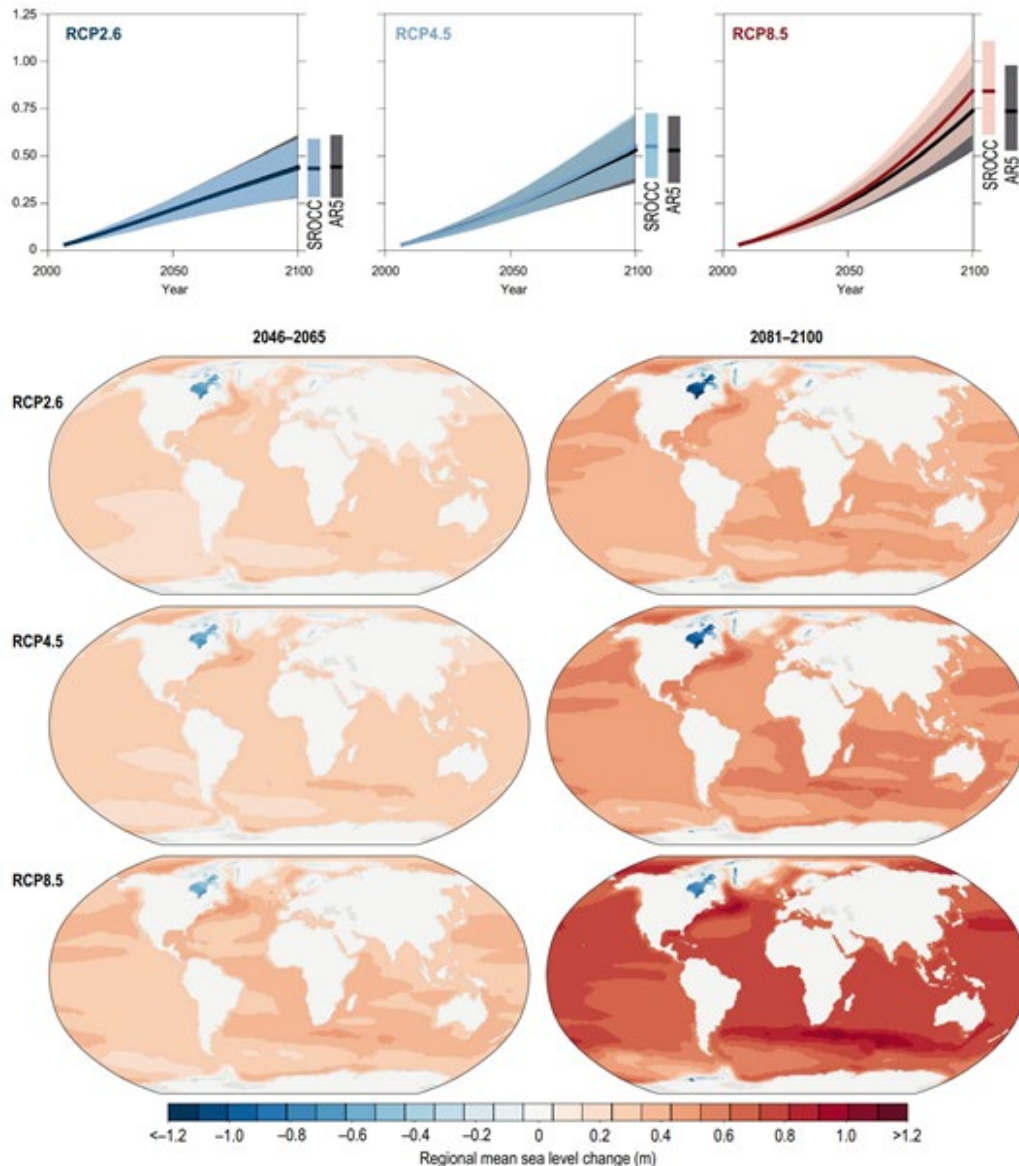


Sea level rise (Trends and projections)

In recent decades, global SLR increased sharply above the background rates (to 3.29 ± 0.3 mm/year peaking in 2020) .

SLR of 0.26 – 0.54 m (RCP2.6) to 0.45 – 0.82 m (RCP8.5) have been projected for 2081–2100 as compared to 1986–2005 (IPCC, 2013); these were upgraded in the IPCC SROCC (2019) report.

It has been and will be large spatial variability
Mean sea level rise has and will have large effects on coastal sea extreme sea levels and waves



Global Mean Sea Level for RCP2.6, RCP4.5 and RCP8.5, showing also a comparison between the IPCC AR5 (IPCC, 2013) and the IPCC SROCC (IPCC, 2019) projections.. Median values. Left: slices 2046–2065; Right slices 2081–2100 (IPCC, 2019).



Extreme events and the transport industry

In the public discourse, climate change is often associated with increases in the mean values of the climatic variables

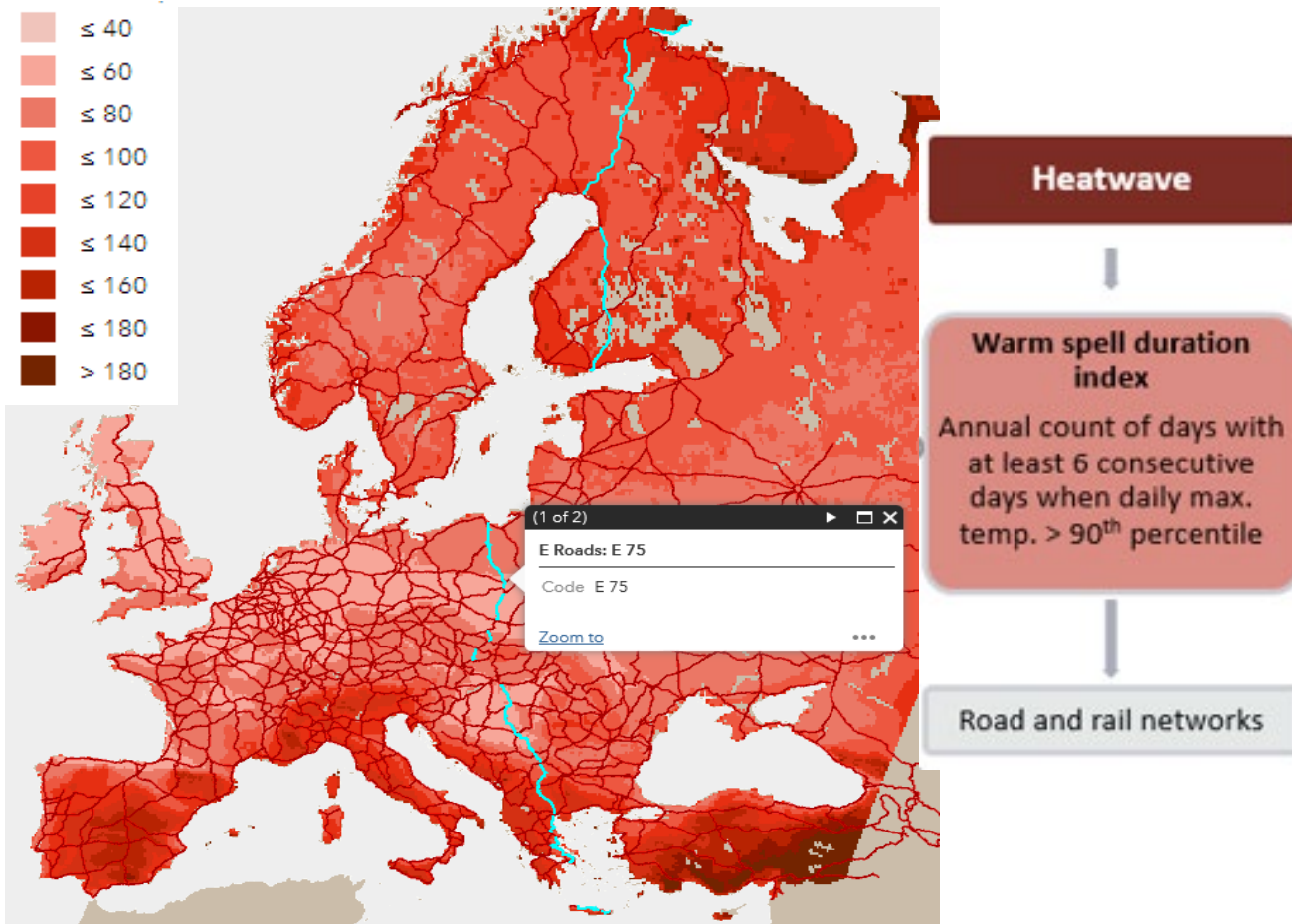
For the transport industry as well as for the broader society, economy and environment, regional conditions and changes in climatic extremes can be more relevant; extreme hydro-meteorological events accounted for about 72 % of natural disasters in 1998 – 2017

Extreme events cover a large spectrum: heat waves; high precipitation events (downpours) or droughts; rapid sea ice retreats, sudden water releases from melting glaciers; permafrost slumping; and storm waves and surges.

All these, by themselves or in combination, can cause large damages/losses on the (inland) transport infrastructure/operations.



Extreme heat events (inland transportation)



Projected (median) warm spell duration (in days) under RCP 8.5 in 2051-2080, superimposed on the road network

In the ECE region, severe heat waves were recorded in recent years e.g. 2015, 2017 and 2018)

Further increases expected in the probability of very hot summers and heatwaves (high spatial variability)

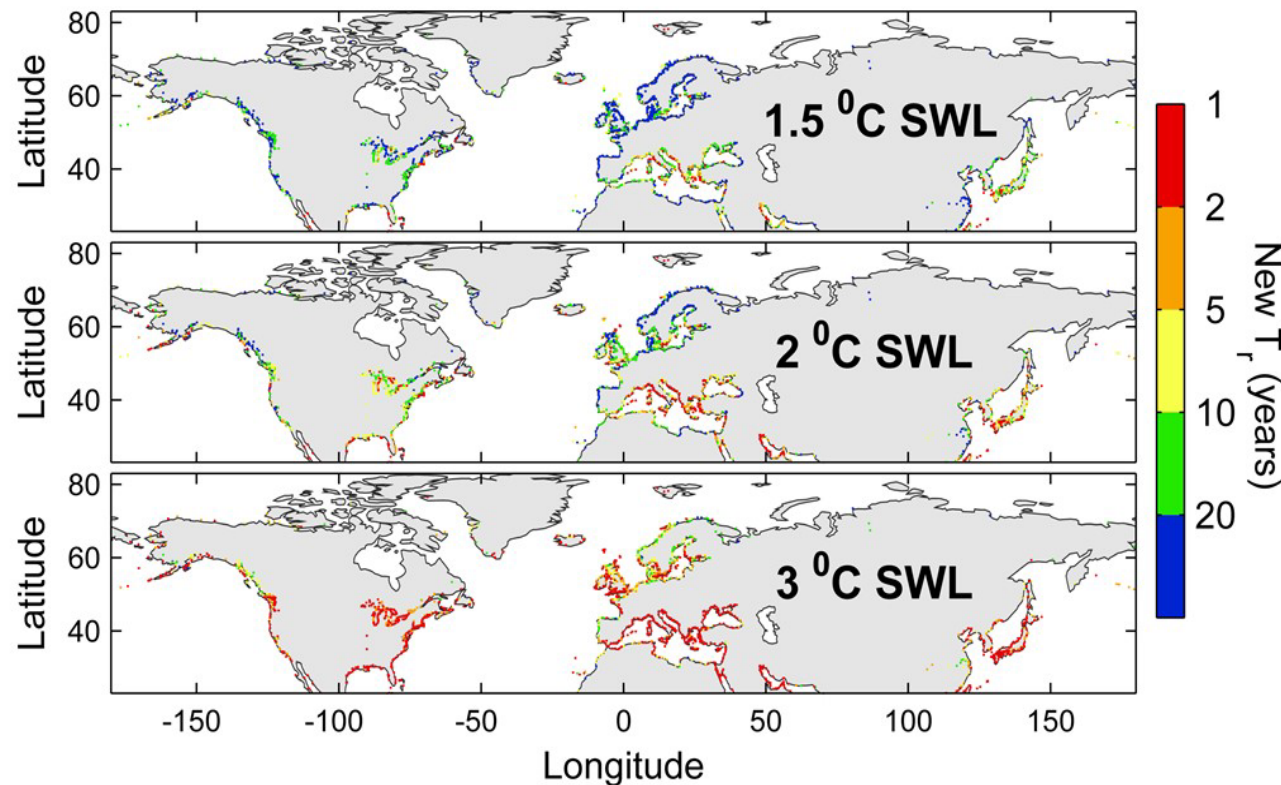
RCM ensembles (EURO-CORDEX) project increases in warm warm days across Europe and cold nights decreases; heatwave amplitudes increases projected, particularly in the south (Cardell et al., Jeuken et al.2020)

Projections (ECE, 2020) indicate substantial increases in warm spell duration for 2051-2080 under RCP8.5 for the southern Europe and the Eastern Mediterranean

The number of very hot days projected to also increase across Canada (highest projected increases of 40 - 50 days/yr in southern Alberta, Saskatchewan, Manitoba, Ontario and Quebec



Heatwaves at the coastal transport assets: Projections



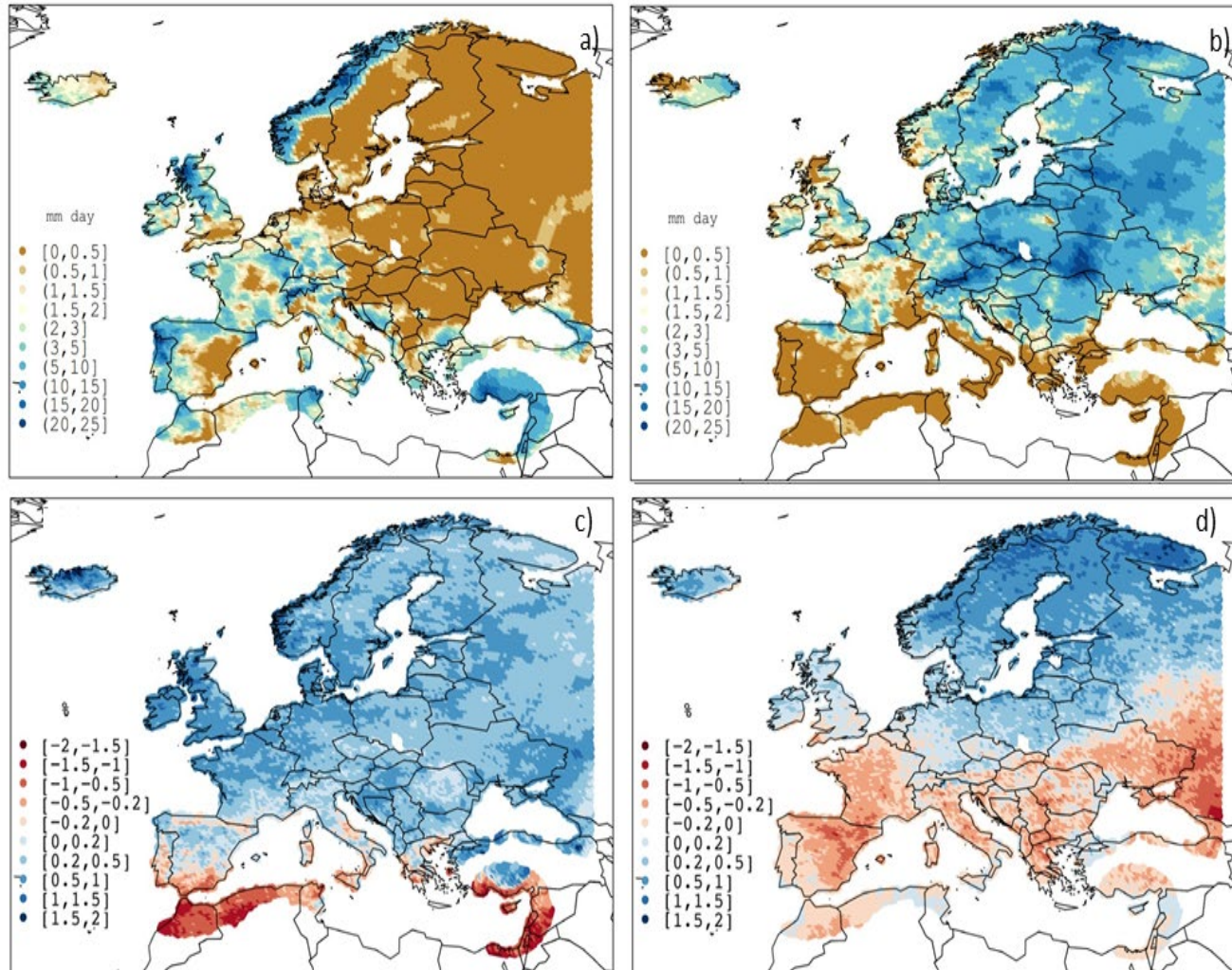
Projected changes in the future return periods (T_r) of the 1 in 100 year event with the magnitude of that of the baseline (1976-2005) period (Dosio et al., 2018) for the major ECE seaports under Specific Warming Levels-SWLs (IPCC, 2018) of 1.5, 2.0 and 3.0 °C. Port data from the World Port Index.

Results (based on global models) provide an insight on the increasing challenges for seaports, their connecting transport networks and the associated large urban conglomerates

Under a SWL of 1.5 °C (expected by 2030s), seaports will experience more frequent heat waves, particularly in the American and south European regions of the ECE. Conditions will worsen under a SWL of 2 °C (expected by 2050s - 2060s) and, particularly, under a SWL of 3 °C (expected by about 2100 under RCP8.5).

In the latter scenario, most ECE seaports are projected to experience heatwaves with the magnitudes of the 1 in a 100 years heatwaves of the baseline (1976-2005) period once or two times per year

Downpours (Projections)



Recent studies show a spatial divide in the European ECE region in both winter and summer

In winter, the western and most of southern Europe experience heavier events than the northeastern Europe, whereas this pattern reverses in summer

Climate change will alter significantly these (baseline) patterns

In 2071-2100 (RCP8.5) increases in the heavy precipitation magnitude projected for most of the Europe in winter; in summer, increases are expected in northern and decreases in southern Europe

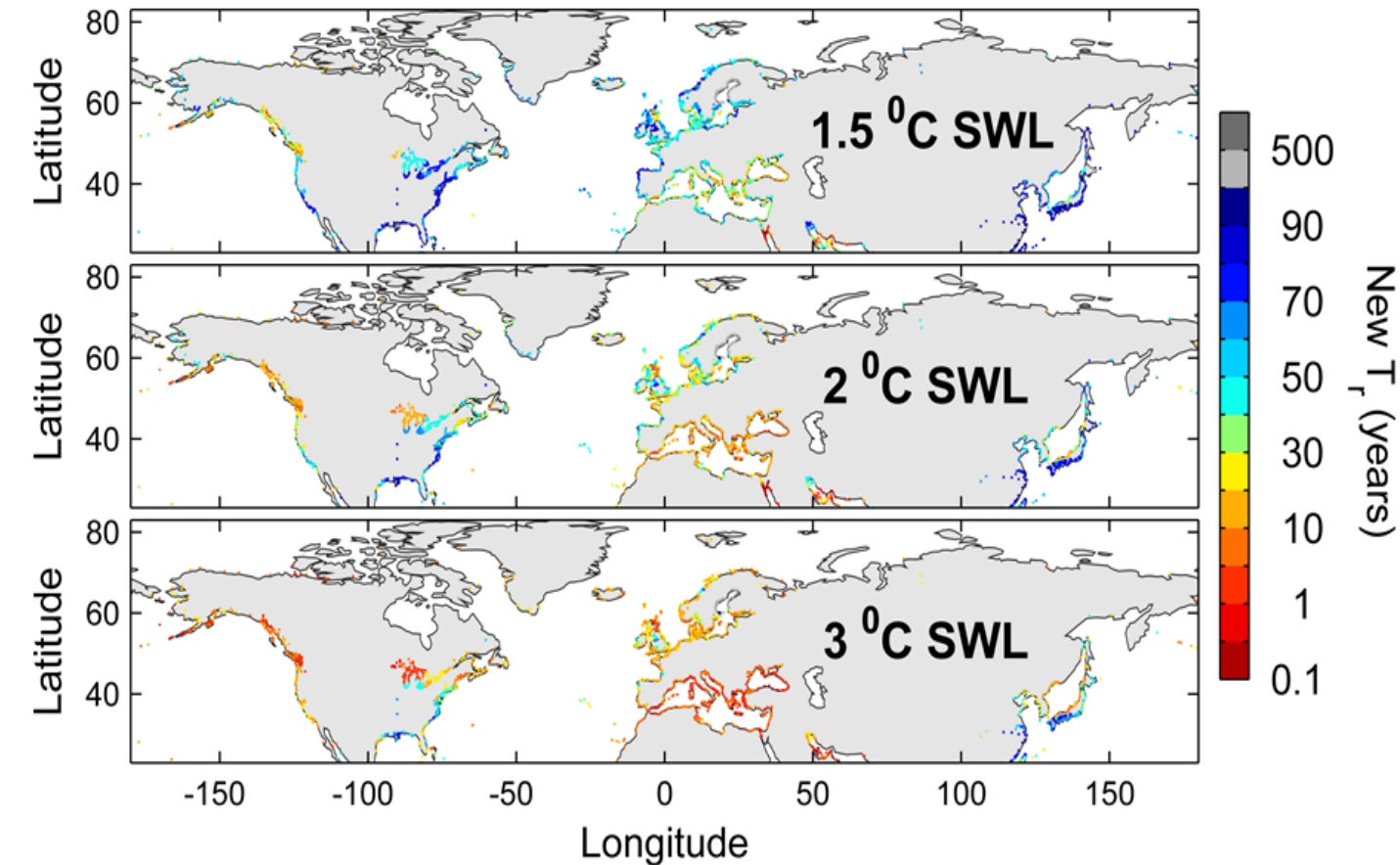
Substantial increase in downpours projected also for Canada (2051-2080, RCP8.5), particularly for the southwestern and southeastern Canada (ECE, 2020)

Important implications for pluvial/fluvial flooding of transport infrastructure; however hydrological and hydrodynamic modelling of higher resolution is required

Observed baseline (1981-2005) downpour amplitude (mm/day) in a) winter and b) summer. Future (2071-2095) changes in the percentage of heavy precipitation days relative to the baseline values in c) winter and d) summer (Cardell et al., 2020)



Extreme sea levels at seaports: Projections



Projected changes in the future return periods (T_r) of the 1 in a 100 years extreme sea level events ($ESLs_{100}$) at the ports of the ECE region, under with the magnitude of the baseline (1980-2014) events under Specific Warming Levels-SWLs of 1.5, 2, and 3 °C. Coastal extreme sea level data from JRC-EC and port data from the World Port Index.

Very substantial effects for seaports.

Evolution of the return periods of the baseline (mean of the 1980 - 2014) 1 in 100 years extreme sea levels ($ESLs_{100}$) shows significant reductions across the board

Even under a SWL of 1.5 °C, some ports along the Mediterranean coastline will be experiencing the baseline $ESLs_{100}$ once every 10 to 20 years.

Under higher SWLs, further deterioration is projected for all ECE seaports, with those in the Mediterranean, Black Sea and the Pacific Canada coast facing the worst conditions



Concluding remarks

Recent research suggests that the ECE inland transportation faces large threats from a plethora of climatic hazards under CV&C.

Results show high and increasing potential impacts involving e.g. flooding and operational disruptions from e.g. the increasing magnitude and frequency of extreme heat waves

In the light of these projections, there is an urgent need for detailed risk assessments/management plans; this is particularly important due to implications for disaster risk reduction, transport accessibility and international and national trade.

Main hazards affecting transportation have been presented. However, in order to assess risk, relevant information on all risk determinants is required, i.e hazards, exposure and vulnerability

It is noteworthy that the most higher resolution studies cover only part of the ECE region due to the spatial coverage of the RCMs used.

It is submitted that, notwithstanding the modelling challenges and requirements in human, computational and financial resources, extension of such modelling approaches to the whole (Eurasian) ECE region will provide a large added value for inland transportation