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Observed and Projected Impacts from Climate Change on Transportation Systems

A.F. Velegrakis
University of the Aegean
Greece

Presentation Synopsis

Significance of climate resilient transportation systems for development

Climatic risk assessment of transportation infrastructure/operations

How do climatic factor changes affect transport?
Mean and extreme sea levels and storms

- Extreme precipitation and floods
- Mean and extreme temperature increases and heat waves
- In Arctic areas due to permafrost melt; but also opportunities due to new shipping routes

Multi-hazard exposure

Transportation networks underpin trade and development

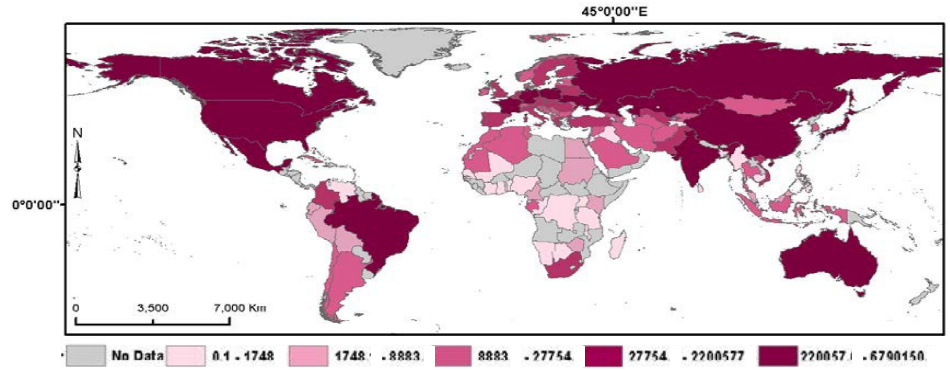
Transport is by itself a huge economic sector requiring large investments; at the same time, transport underpins trade and development

Transport is facilitated by interconnected land, sea (and air) transportation networks

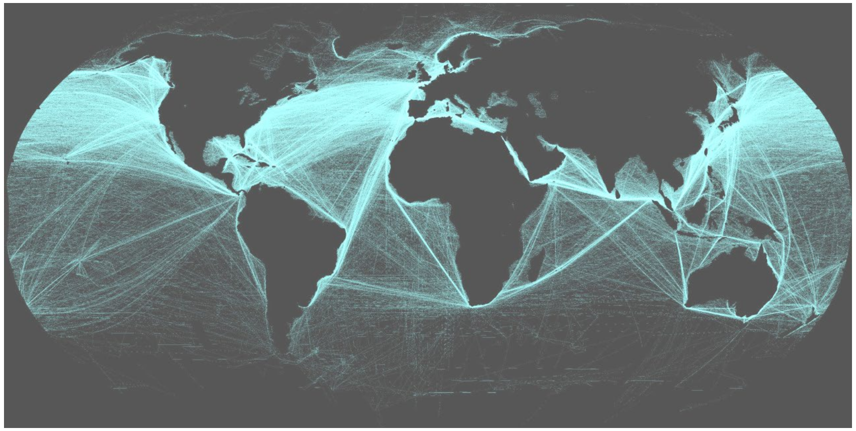
Transport infrastructure and operations span all climatic zones/terrains and can be impacted by different (also combined) climatic hazards

Under a changing climate, the assessment of the climatic risks to infrastructure/operations is pre-requisite for cost effective development of resilient systems (and investments)

Note: Transport is a demand-driven sector; thus, climatic change-driven impacts on other economic sectors (e.g. agriculture, tourism) will also affect transportation (indirect impacts)



Inland freight (railway and road) transport (metric tons x km, ECE, 2015)



Global shipping movements through their emissions (P.Bridge, 2016)

Climatic risk assessment of transportation infrastructure/operations

Risk Assessments should be based on trends and future projections of

(a) the climatic hazards,

(b) the system exposure, and

(c) environmental, socio-economic and governance – ESG vulnerabilities

affecting transportation systems

Trends: Establishment of trends (‘prepare for known risks’) is a difficult exercise, requiring integrated collation/analysis of large, spatio-temporally variable data sets on many climatic factors, transport network distribution, demographics/attitudes

Projections: Estimation of the future risk on transport infrastructure/operations based on projections of future climatic hazards, exposure and other ESG considerations

Important Note:

For transportation infrastructure, in particular, which is expected to be operational well into the future, design should consider projected hazards, exposure and vulnerabilities

There can not be a simple extrapolation of current trends to the future: modeling of future risks under different climatic and socio-economic scenarios is required which as all projections, involves uncertainties.

How do climatic factor changes affect transport?

Factor	Impacts on infrastructure and operations
Sea level (mean and extreme)	
• Mean sea level rise (SLR) • Extreme sea level (ESL) changes • Changes in wave energy/direction • Increased destructiveness of storms/storm surges	Damages to coastal transport infrastructure (open sea/estuarine ports, airports, roads, railroads, and bridges) from incremental and/or catastrophic marine inundation and wave regime changes; higher infrastructure construction/maintenance costs; sedimentation and dredging issues in navigation channels; increased risks for coastal road/railway links; people relocation and insurance issues; operational disruptions and economic losses
Precipitation and windstorms	
• Changes in the mean and the intensity and frequency of precipitation extremes (floods/droughts) • Changes in intensity/frequency of windstorms	Seaport, airport, and road/rail infrastructure inundation; damage to cargo/equipment; navigation restrictions in inland waterways; vital node damage (e.g. bridges); changes in transportation demand Problems in port navigation/berthing; cancellations/delays at airports; damages to transport infrastructure and signage; road/rail obstructions; bridge closures
Temperature	
• Higher mean temperatures, • Heat waves and droughts • Increased spatio-temporal variability in temperature extremes	Damages to infrastructure/cargo; potential asset lifetime reduction; higher energy consumption for cooling; restrictions for inland navigation affecting estuarine ports; reductions in snow/ice removal costs and extension of construction season; lower aircraft payloads-need for runway extension; increased health risks for staff and passengers; rail buckling/restrictions in rail operational speed; asphalt rutting; changes in international transport (freight and passenger) demand
• Permafrost degradation • Reduced arctic ice coverage	Major damage to infrastructure; coastal erosion affecting road/rail links to ports Longer shipping seasons-NSR; new shorter shipping routes-NWP/less fuel costs, but higher support service costs

How do climatic factor changes affect transport?

Climate Variability and Change (CV& C): variability and sustained change of climatic conditions relative to a reference period (e.g. 1961-1990, 1971-2000, 1986-2005)

The AR5 (2013) and more recent (2018, 2019) reports by the IPCC suggest significant changes ('deterioration') in both trends and projections of climatic factors that can drive climatic hazards with severe impacts on transportation infrastructure and operations:

- Mean and extreme sea levels and storms →
- Extreme precipitation and floods →
- Mean and extreme temperature increases and heat waves →
- In Arctic areas due to permafrost melt, but also opportunities due to longer shipping season and shorter shipping routes →

Transportation infrastructure/operations will be also exposed to combined hazards (multi-hazard exposure) →

Note: Potential feedbacks/tipping points

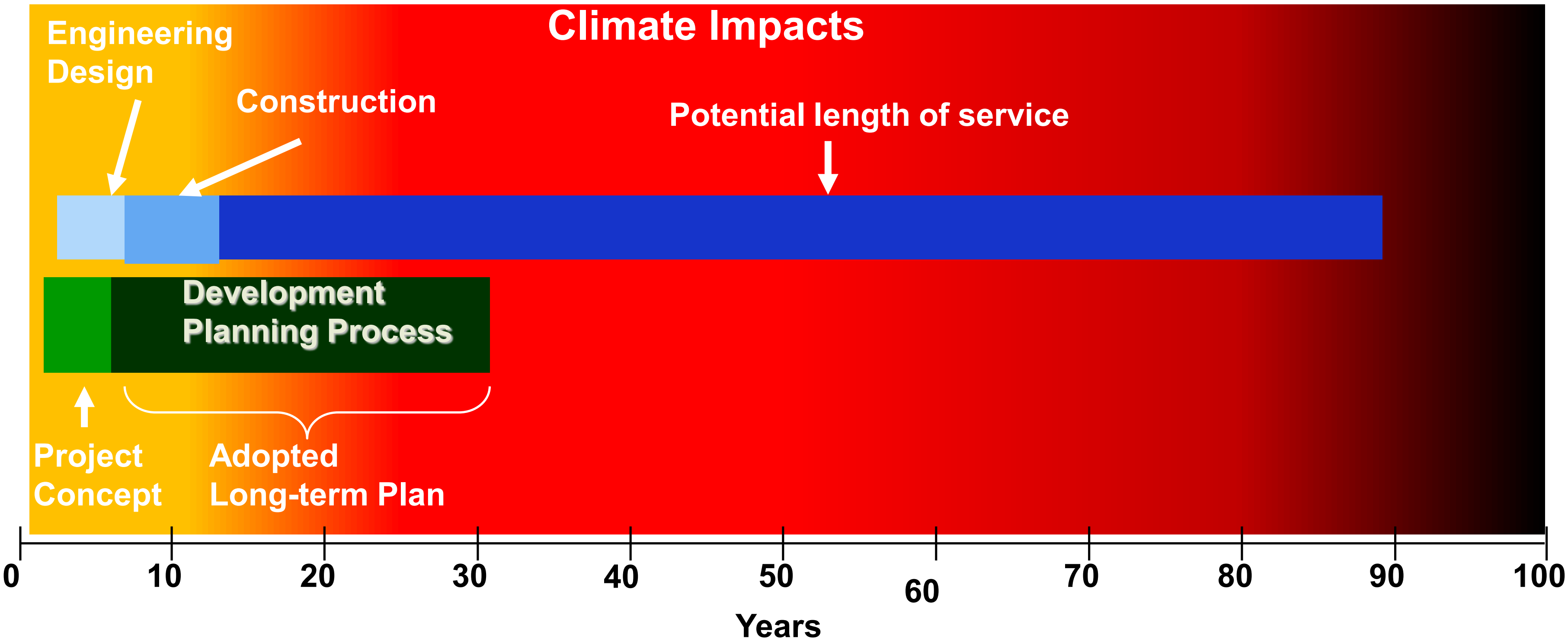
Key message

- The observed and projected impacts of Climate Change affecting transportation indicate that there are very significant challenges ahead for transportation systems/networks and the economic and social activities they underpin

- Urgent action is required

Thank you!

Time scales of transport infrastructure planning, engineering and use

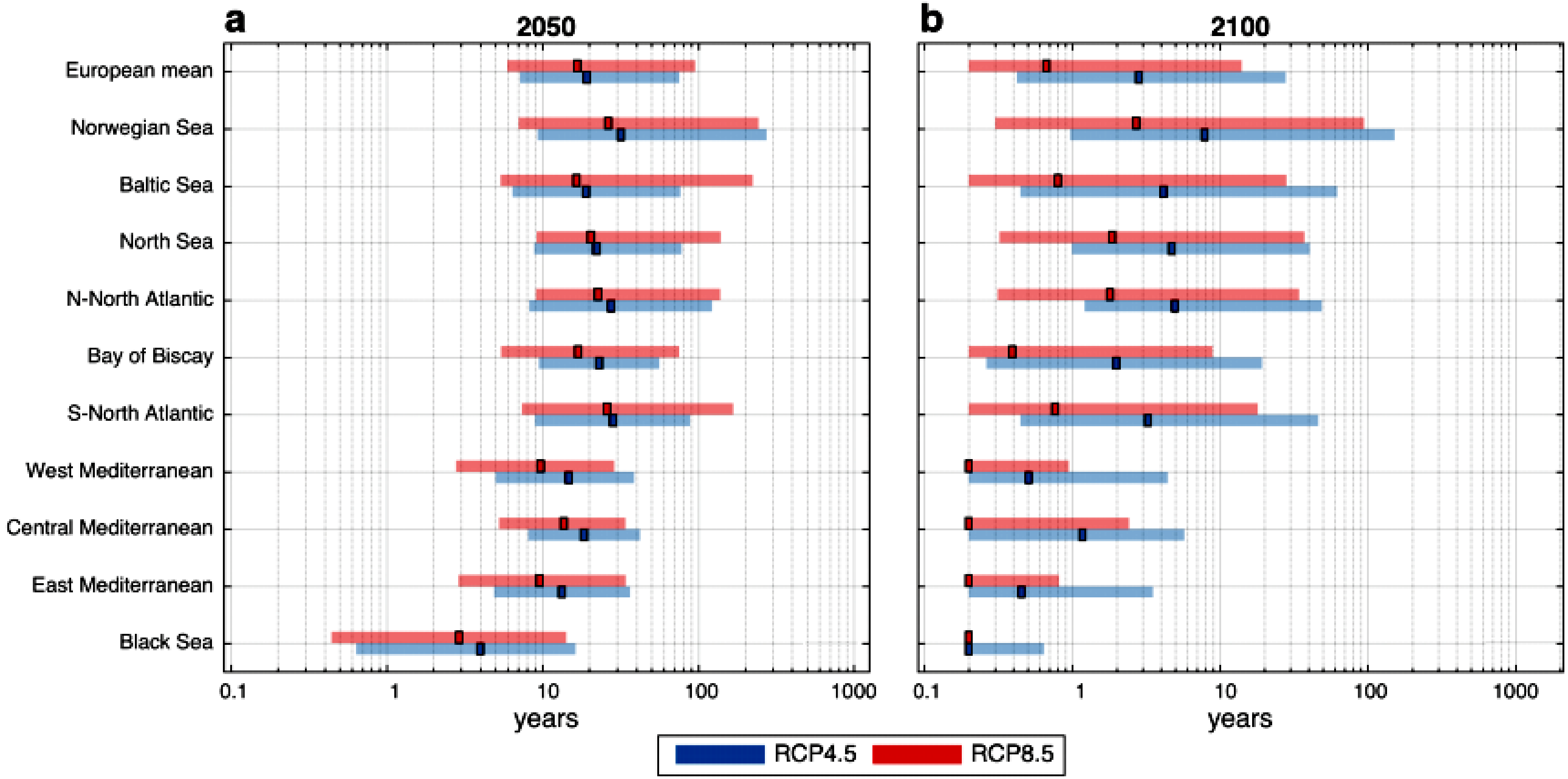


Transportation infrastructure planning/engineering/utilisation time scales: these certainly must take into account future environmental change (after Savonis, 2011)

Evolution of extreme sea level (ESL) recurrence in the future

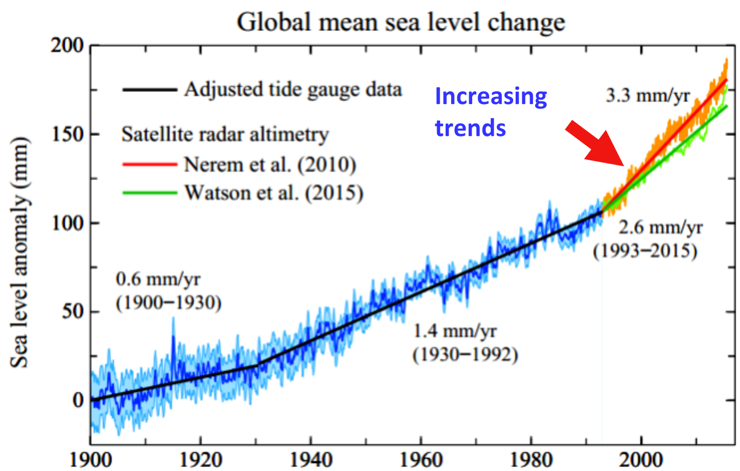
Present ESLs will be much more frequent in the future:

Thus, coastal infrastructure should be designed to be resilient under those events

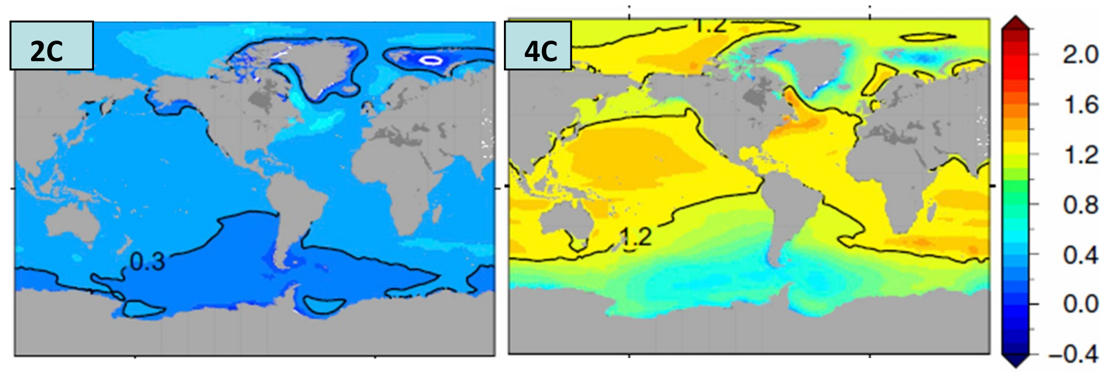


***<u>Projections</u>**: Return periods of the present 1 in a 100-years extreme sea levels ESLs along the European coastline under the 'moderate' RCP4.5 and 'the business as usual' RCP8.5 emission scenarios in 2050 (a) and 2100 (b). Black boxes show the median value of the model ensemble results and colored patches the range of the results (best-worst case) (Vousdoukas et al., 2017).*

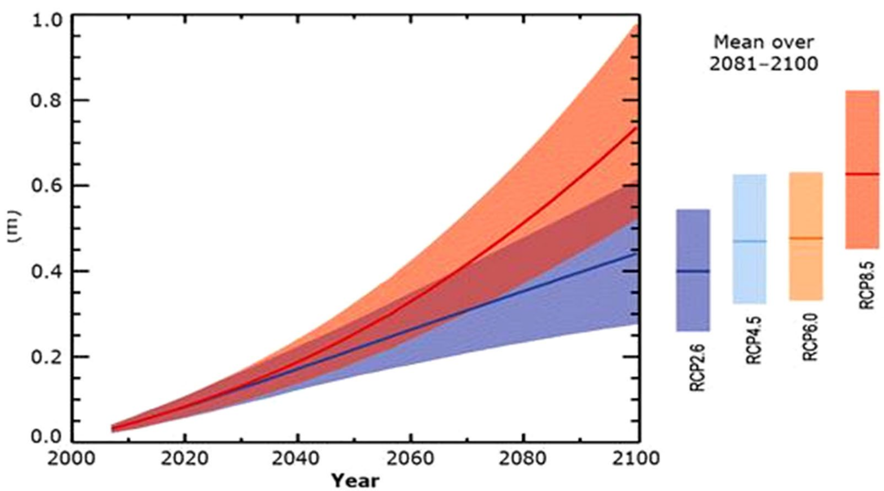
Mean sea level rise (SLR): Trends and Projections



Trends: *Mean sea level rise (mm) since 1900 (Hansen et al., 2016).*



Projections: *SLR under 2 °C and 4 °C warming above pre-industrial times under 'the business as usual scenario' RCP8.5, relative to 1986–2005. High end (95 %) projections.(Jevrejeva et al., 2016).*



Projections: *Global SLR through to 2100 relative to 1986-2005 under different climatic scenarios (IPCC, 2013). Note the range of the projections*

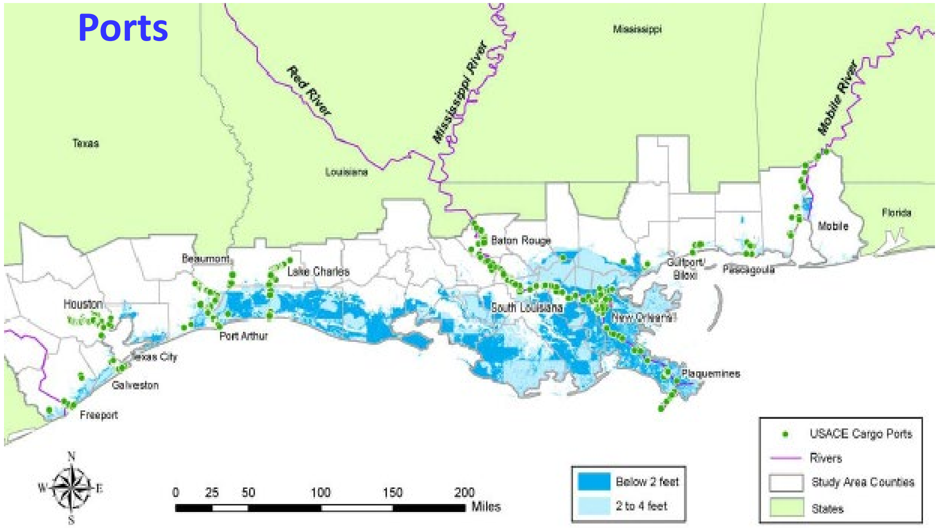
Mean sea level rise (SLR) is a most significant hazard for (international) transport networks

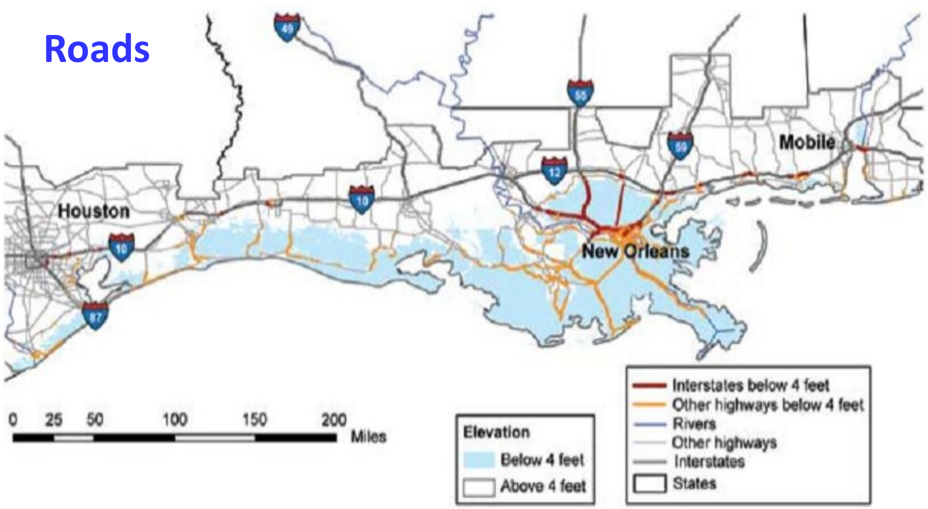
SLR is projected to be spatially variable and increasing with global warming

Note: SLR was projected to be up to 1 m relative to 1986-2005 in 2100 (IPCC, 2013).

However, due to uncertainties involving the ice sheet melting, these projections may be considered conservative

US Gulf Coast: Flood exposure under SLR





SLR of about 1.2 m (4 feet) can flood permanently:

- over 70% of existing port facilities
- 3 airports
- more than 2400 miles of roads, and
- 9% of the railway lines

Note: Some areas exhibit much higher than average SLR trends (up to 10 mm/yr) due to deltaic subsidence

Temporary storm flooding (from hurricanes) can be devastating (Katrina, 2005)

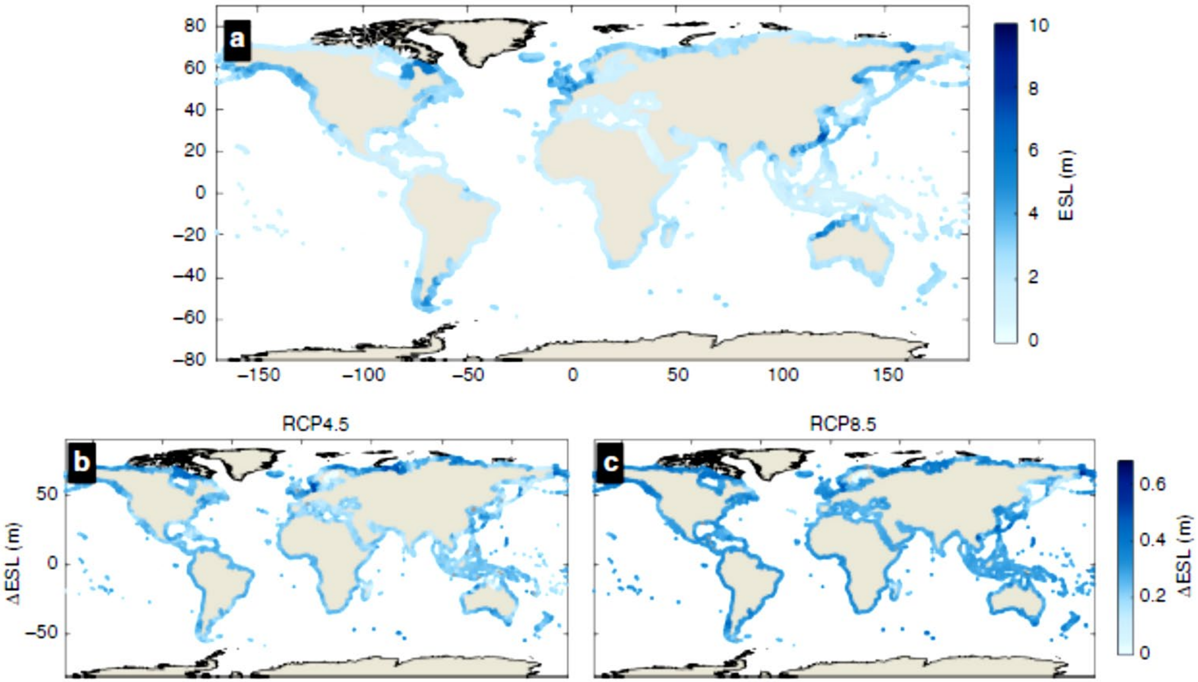
Large increase in infrastructure exposure in recent years(due to e.g. new LNG terminals)

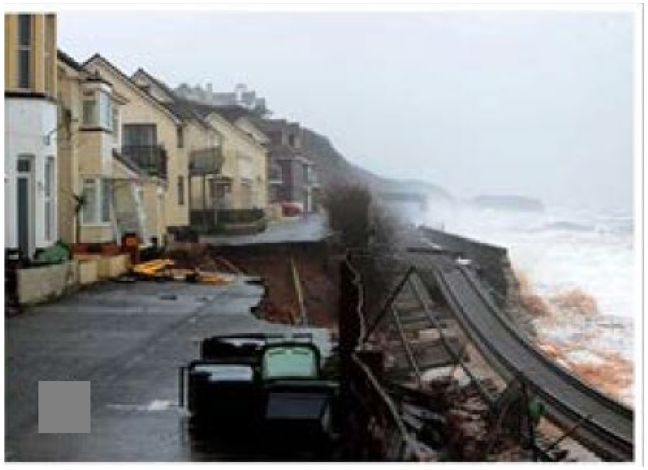
Flood exposure of US Gulf coast transportaion infrastructure under mean sea level rise (SLR) of 0.6 - 1.2 m (US DOT, 2009).

Extreme Sea level (ESL) projections

The already high (in many areas) extreme sea levels (ESLs) under storms <u>will increase further under climate change</u>, requiring substantial upgrading of the coastal transportation networks

Particularly vulnerable are coastal assets (e.g. ports), critical for the global supply chain



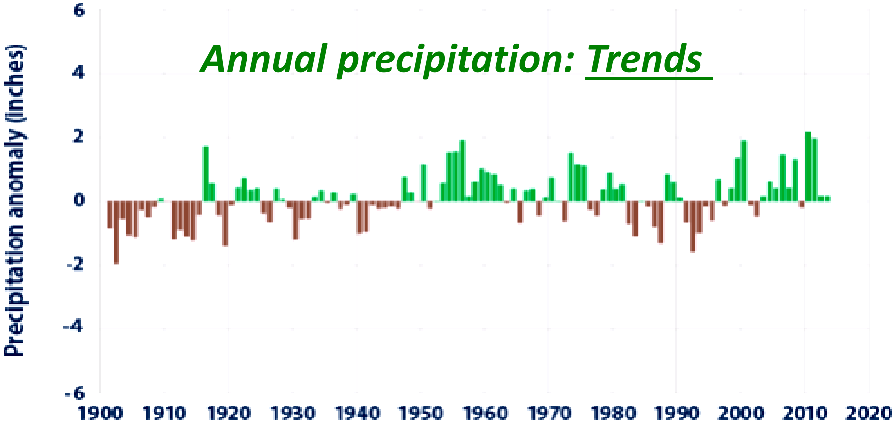


Storm destruction of the coastal railway in SW England (2013)

<u>Trends and Projections</u>: *(a) Present-day extreme sea level (ESL, in m) and projected changes in the magnitude of the 1 in 100 years event under (b) RCP4.5 and (c) RCP8.5 by 2100, (Vousdoukas et al., 2018). .*

Precipitation: Trends and projections

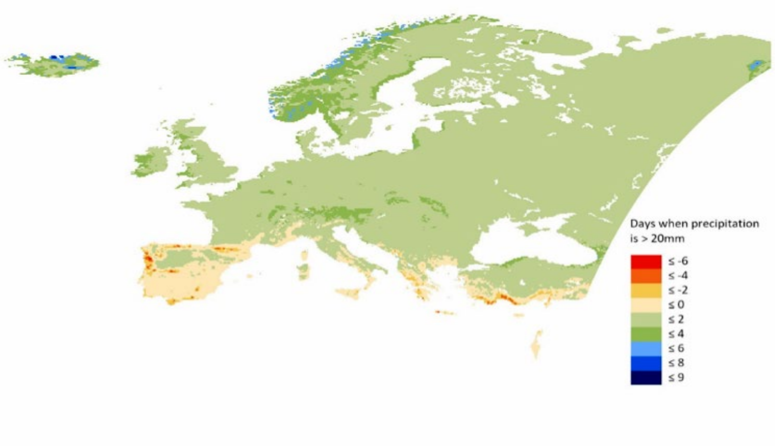
Annual precipitation: Trends



Annual global precipitation anomaly for 1901-2013 in relation to the 1901-2000 average (EPA, 2015).

Transport infrastructure during the 2017 Harvey downpour in (a) downtown and (b) highways of Houston (USA)

Heavy precipitation: Projections



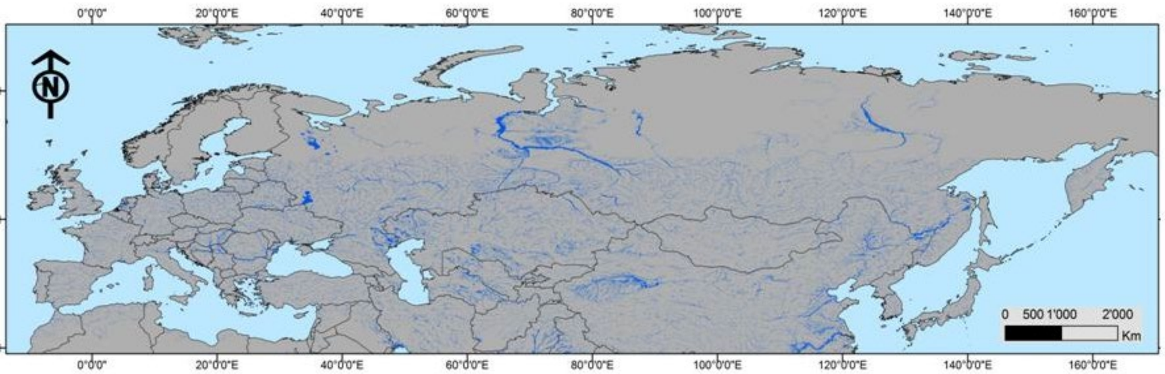
Change in the number of days per year with precipitation above 20 mm (R20mm) in 2051-2080 under RCP8.5 relative to 1971–2000. Multi-model means (UNECE, 2019)

Annual (averaged) precipitation shows large spatio-temporal variability (stronly influenced by ENSO

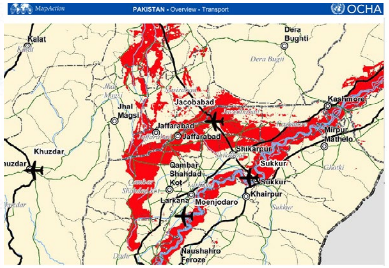
Extreme precipitation (downpours) affecting infrastructure and operations (damages/delays) are projected to generally increase

The Med region will be less affected than the northern regionas

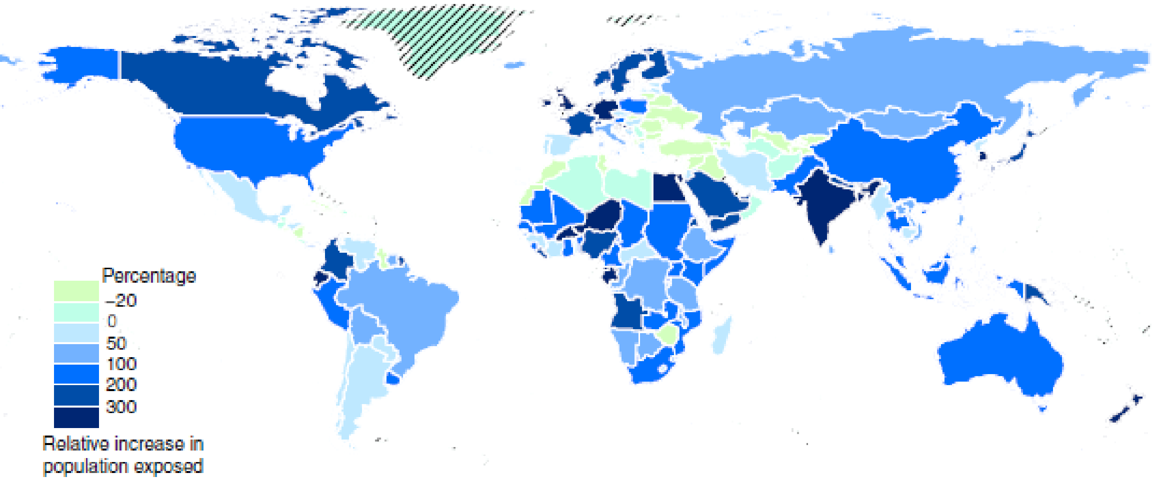
Floods and droughts: Trends and projections



__Trends:__ Current flood hazard in the Eurasian ECE region for the 1 in 100 years flood event. Areas > 60 ^{0}N not covered (UNEP-GRID, UNISDR, 2008).



Pakistan, 2010)



__Projections:__ Increase in the population exposure to floods. Alfieri et al. 2017; Dottori et al., 2018)

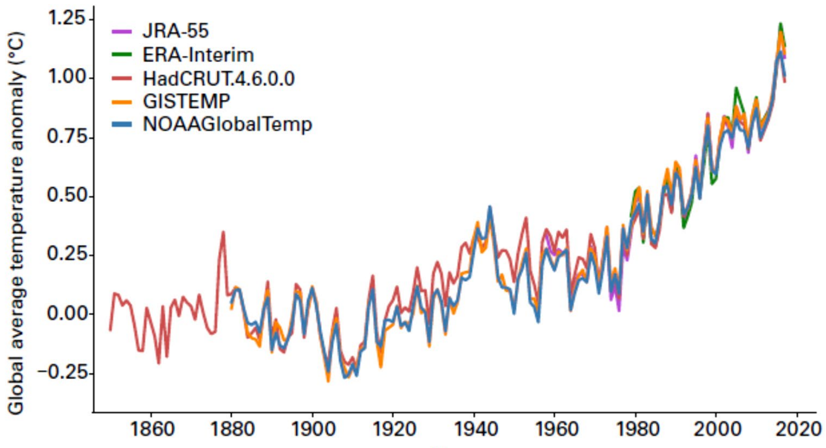
Population/infrastructure flood exposure will rise in most areas

Impacts will increase with warming; higher losses projected for Asia

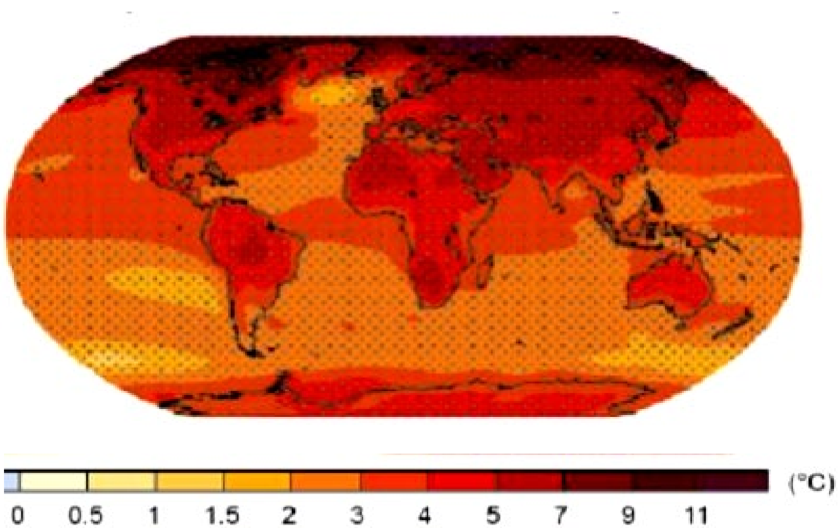
Also, increases in droughts with

- direct impacts (e.g. in inland waterways-IWWs) and
- indirect impacts (e.g. through changes in agriculture)

Global temperature: Trends and Projections I



<u>Trends:</u> Global mean temperature anomaly relative to 1850–1900 (UK Met Office)



<u>Projections:</u> Average temperatures in 2081-2100 relative to 1986-2005 under RCP8.5 (IPCC, 2013)

Increasing temperature trends

The recent 5-year mean temperature (2013–2017) the highest on modern record (about 1 °C above pre-industrial values)

Temperature projected to increase by up to 3.7°C (mean estimates) until 2100, under 'the business as usual' emission scenario (RCP8.5)

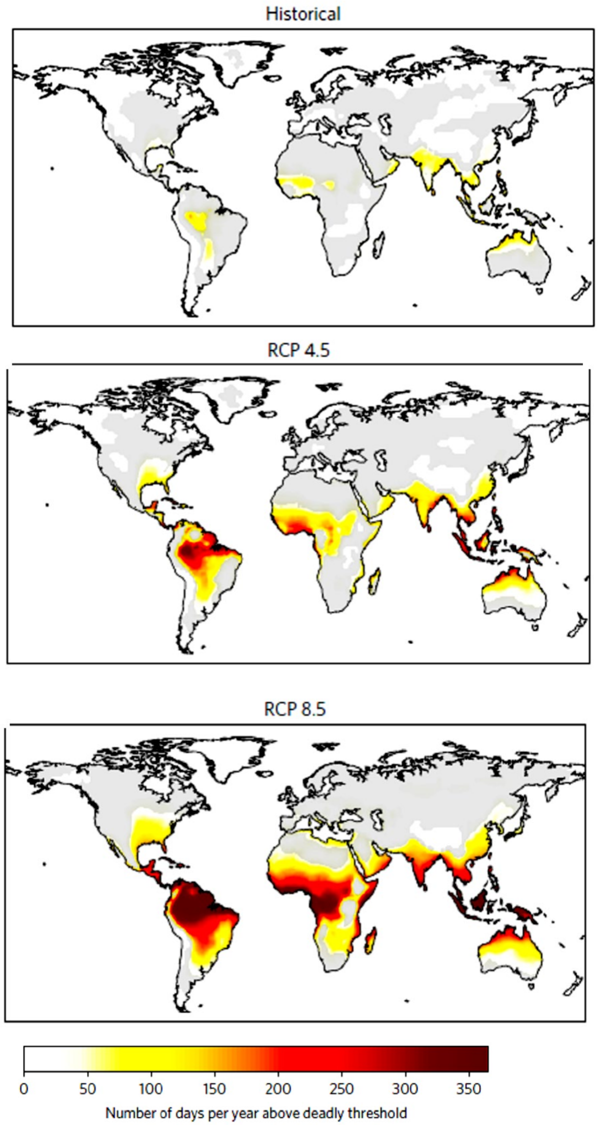
Temperatures <u>rise faster at higher latitudes</u>.

Under global warming of 1.5°C and 1.5–2°C above pre-industrial levels, <u>increases in hot extremes are projected for most areas</u> with high confidence (IPCC, 2018)

Heat waves: Trends and Projections

Extreme heat waves can impact both infrastructure (e.g,, road surfaces and railway lines), operations and staff and passenger health and safety

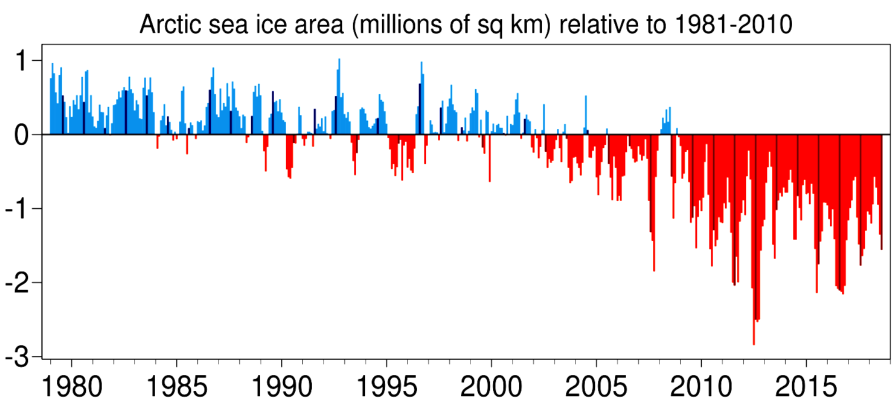
Increases in the Heat Index (combined temperature and humidity) will have severe direct and indirect impacts



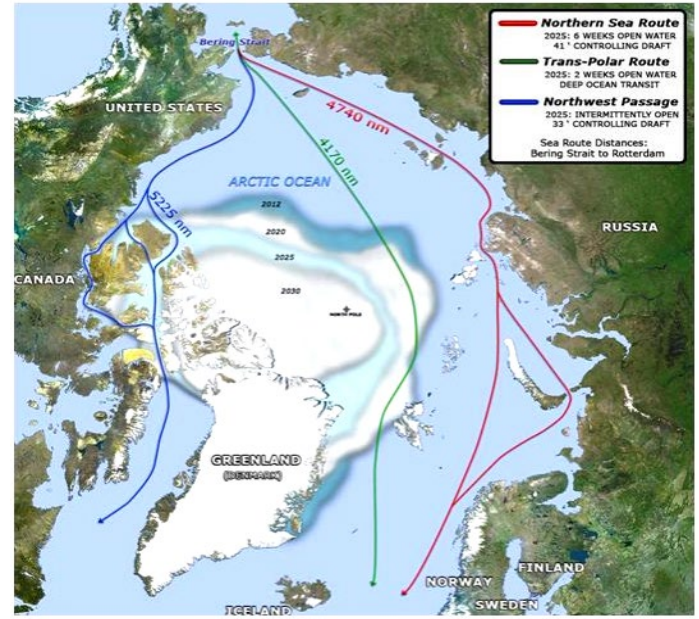
Days/year exceeding the deadly temperature and humidity threshold in 1995-2005 (historical experiment), and 2090 -2100 under RCP4.5 and RCP8.5 (multi-model medians) (Mora et al., 2017).

Change in the number of very hot days (> 30 °C) under RCP8.5 relative to 1971-2000 period in 2051-2080. (multi-model mean values) (UNECE, 2019)

Sea ice: Trends and Projections



<u>Trends:</u> Arctic sea ice extent (ASIE) (P. Taalas, WMO, 2019) .



Potential new Arctic shipping routes by 2025 (US Climate Resilience Toolkit, 2015)

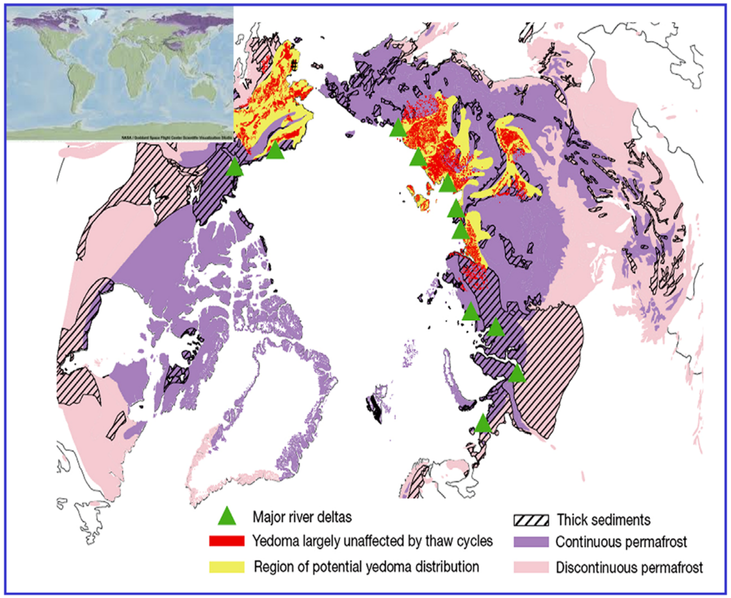
<u>Projections:</u> For 2081-2100, ASIE will decrease by 8 - 34 % (February) and 43 - 94 % (September) relative to the average ASIE of 1986–2005, depending on the emission scenario (IPCC, 2013)

Arctic sea ice melt may <u>provide opportunities for the Arctic UNECE areas</u>, though the opening of sea routes, development of resources and related transport infrastructure (ports and inland links).

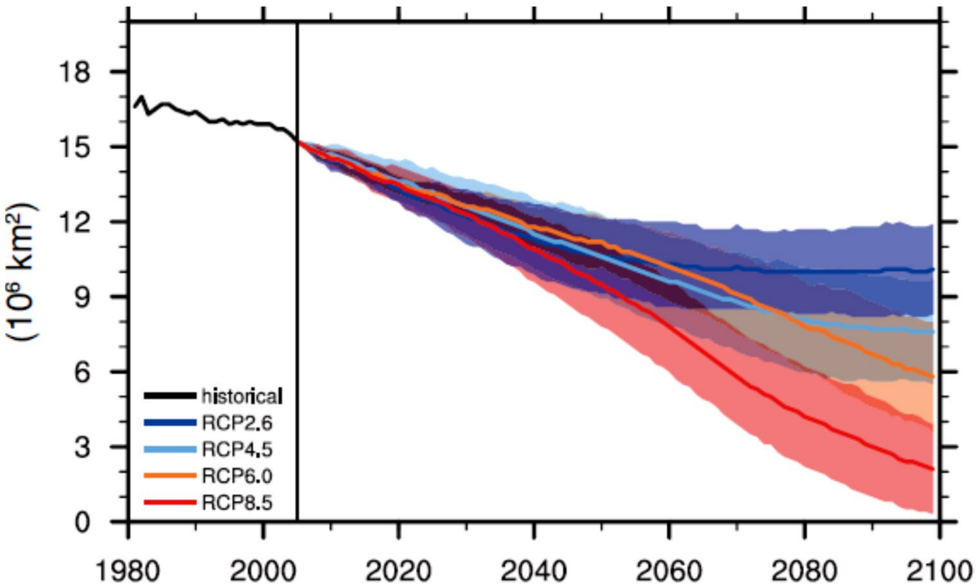
In 2017 cargo turnover in the Arctic seaports of the Russian Federation has already reached 73 million tons; by <u>2030, turnover is projected to increase to 140 million tons</u> (Egorshev, 2018).

However, development/maintenance of (coastal) transport infrastructure in these areas faces <u>increasing challenges (and costs) due to the increasing permafrost (frozen soil) melt</u>

Permafrost: Trends and Projections



Permafrost extent (yedoma permafrost in yellow/red) (Schuur et al., 2015)



<u>Trend and Projections:</u> Surface permafrost extent changes under 4 emission scenarios (IPCC, 2013)

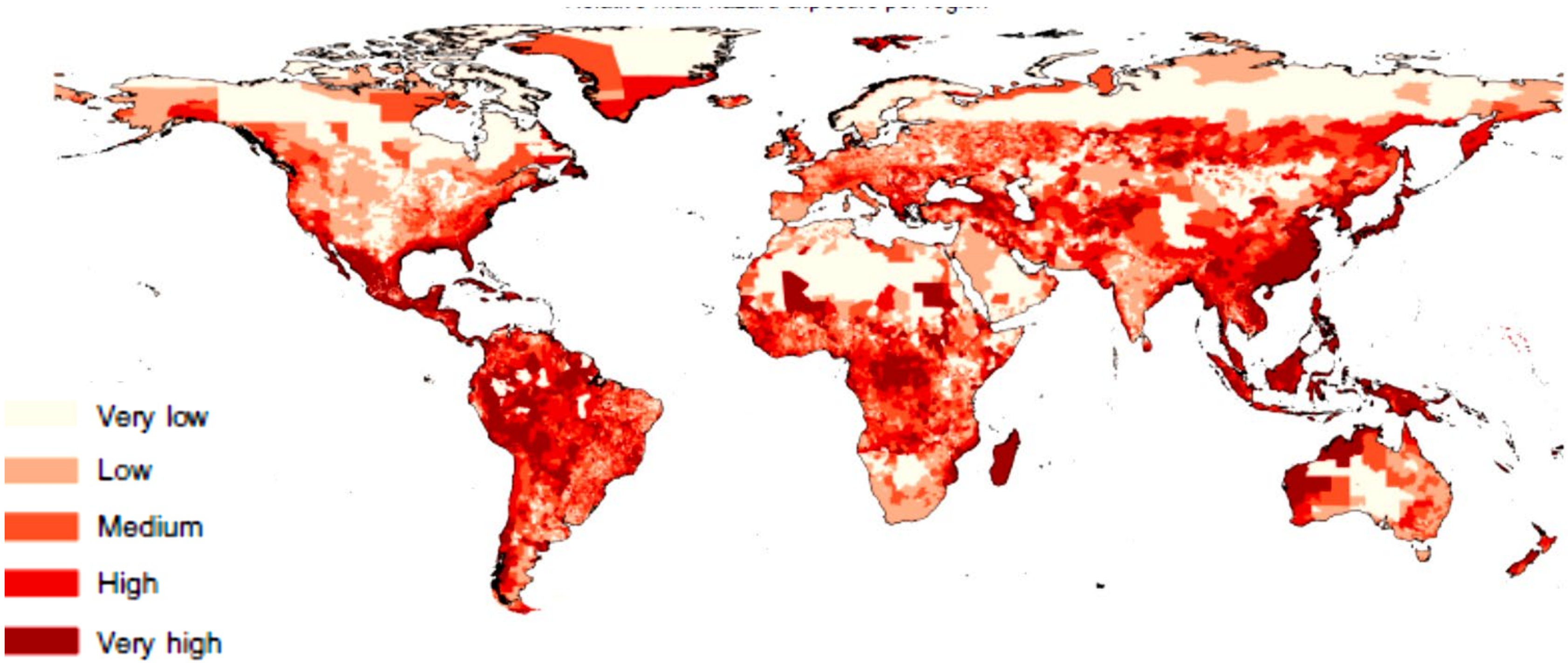
Warming down to 20 m depth with temperature increases of up to 2 °C since 1980 observed n many permafrost areas. Generally, <u>the thickness of the NH permafrost has decreased by 0.32 m since 1930s</u> (IPCC, 2013)

Permafrost thawing has already incurred significant damages; infrastructure damages, construction and maintenance costs are expected to rise in the future

Global multi-hazard road and railway infrastructure exposure

Presently, global Expected Annual Damages (EAD) to roads and railways can reach up to 22 billion USD; about 73 % of those are caused by flooding.

Many coastal areas show high exposure to risk



Trends: *Global multi-hazard transport infrastructure exposure due to cyclones, earthquakes, river and surface flooding and coastal flooding. Exposure does not include cryosphere impacts (Koks et al., 2019)*