Impacts of climate change in Europe:
A focus on road and rail transport infrastructures

Group of Experts on Climate Change impacts and adaptation for international transport networks - Fourth session

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Joint Research Centre

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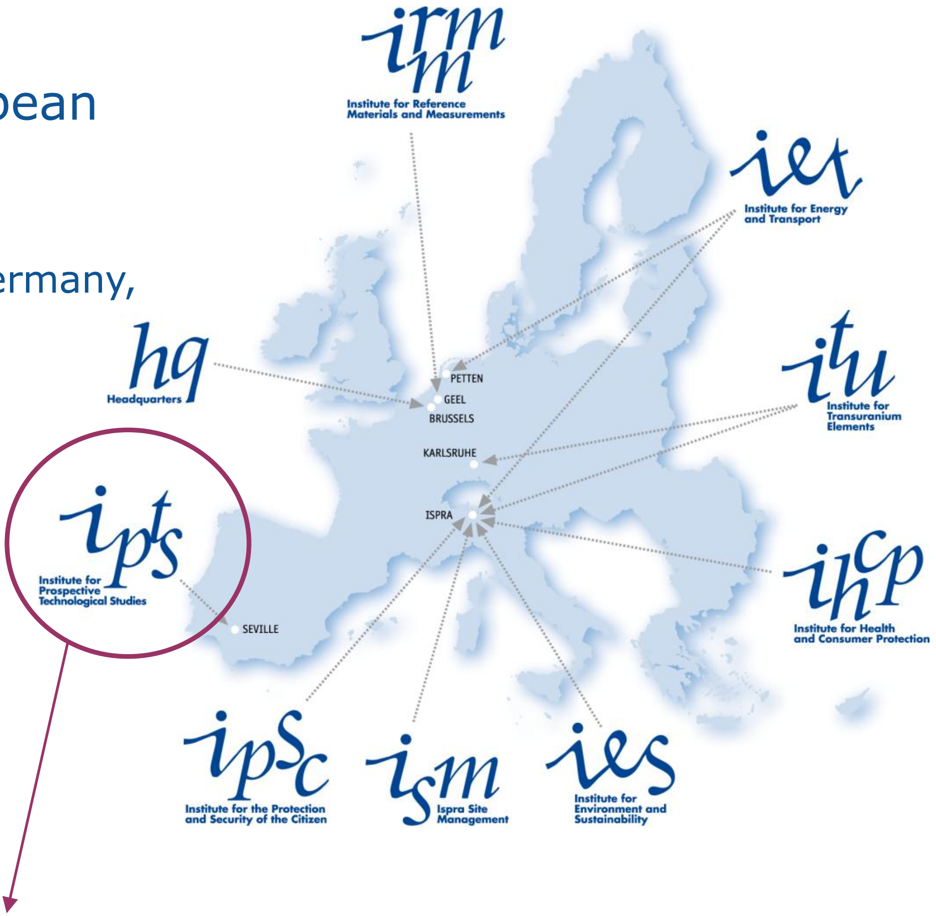


Unit on Economics of Climate Change, Energy and Transport

Outline

A JRC/IPTS research on transport and climate changes

Overview of future impacts for transport

Research focus

Vulnerability and cost assessment method

Current weather associated costs

Adaptation and future vulnerability:

- Bridge scour
- Rail buckling risk
- Road pavement
- Vulnerability to sea level rise

Indicative EU27-wide costs

Discussion

A JRC/IPTS research on transport and climate changes

JRC PESETAII project to analyse and quantify the future impacts and costs of climate changes on:

Biophysical and sectoral impacts:
agriculture, health, energy, river floods, forestry, energy, transport: future costs and adaptation

EU economy as a whole (GEM-E3 macroeconomic model)

Scientific support to EU policy making on adaptation to climate change

Summary report on PESETAII in preparation

Detailed report on Transport study: F. Nemry and H. Demirel, 2012

Overview on future risks and impacts for transport

climate impact	Overview of potential impact on transport system
Increased Summer **Temperatures**	Asphalt rutting, rail track buckling, Low river water levels for navigation, Thermal expansion of bridges, Overheating of diesel engine
Increased Winter **Temperatures**	Reduction in cold weather rail maintenance, Changed construction seasons
Increased **Precipitation** and **floodings**	Flooding of land transport infrastructures, Wet pavements and safety risks. Embankment disruption, Bridge scour, Flooding of underground transist systems. More frequent slushflow avalanches, Landslides and associated risks.
Increased and more frequent **extreme winds**	Damage and safety issue on roads, railways, pipelines, seaports, airports Bridges, signs, overhead cables, railroad signals, tall structures at risk Disturbance to transport electronic infrastructures, signaling, etc
Sea Level Rise and sea storm surges	Erosion of coastal highways Higher tides at ports/harbor facilities Low level aviation infratsructure at risk Regular and permanent inundation Corrosion Bridge scour
Permafrost degradation and thawing	Road, rail, airport, pipeline embankments failures
Reduced **Arctic Ice Cover**	New northern shipping routes (summer) Reduced ice loading on structures, such as bridges or piers
Earlier **River Ice** Breakup	Ice-jam flooding risk

Research focus

Focus on road and rail transport infrastructures and assess:

1. Possible future trends in weather-induced deterioration and damages
2. Adaptation and vulnerability case studies

Mode	Typical infrastructure life	Climate stressor	Adaptation measure	Avoided impacts
road	7-10 years maintenance cycle	Heat	changing asphalt binder	- reduce road pavement degradation (road cracking) - avoid accidents (vehicle damages, fatalities)
rail	50-100 years track life	Heat	speed limitations changing track conditions	- reduce rail track buckling damage - avoid accidents (vehicle damages, injuries, fatalities)
road rail	> 100 yr life	High river discharge	- rip rap, - strenghtening of bridge foundations with concrete	- mitigate bridges scour risk - accidents, fatalities
road	.> 100 yr life	Sea level rise and sea storm surges	*(vulnerability of land transport network to permanent or episodic inundation)*	-

Assessment method

Assessing future exposure to future climate stressor:

- IPCC A1B scenario, by 2040-2070 and 2070-2100 (also E1 and RCP8.5)
- FP7 ENSEMBLE : high resolution projected climate variable (T, p,…) – 25 km*25 km

Global emission scenario	Abbreviation	Scenario	Institute	Regional climate model	Driving GCM
A1B	A1B-KNMI	A1B-KNMI-RACMO2-ECHAM5	KNMI	RACMO2	ECHAM5
	A1B-METO	A1B-METO-HadRM3Q0-HadCM3Q0	METO	HadRM3Q0	HadCM3Q0
	A1B-DMI	A1B-DMI-HIRHAM5-ECHAM5	DMI	HIRHAM5	ECHAM5

Engineer-based technico-economic analysis applied on combined geographical information:

- Climate data and derived climate stress factors for each assessed problem (e.g. rail track temperature, pavement temperature, extreme precipitations and thresholds…)
- Transport information for EU27 (transport network, transport activity): TRANSTOOLS, TELEATLAS, GISCO
- Digital elevation model (e.g. sea level rise)
- Coastal information (e.g. sea storm heights – DIVA databse)
- Hydrological data (JRC/IES)
- Engineering data sources : EU data sources and US data sources (FHWA, EPA,..)

Current weather related costs

Climate resilience costs component in current construction designs

Weather-induced contribution to maintenance & repair costs:
~30%-50% of EU27 road maintenance costs
~10 billion €/yr

Of which **extreme** weather induced damages (FP7 WEATHER)**:**

~1.8 billion €/yr for road transport (80% of all transport)

~0.9 billion €/yr for road infrastructures

~0.65 billion €/yr due to heavy rainfalls & floods

=> How will these cost change with climate change?

Future vulnerability – Road pavement degradation

Average precipitation (road rutting): extra 100 mm annually results in enhanced deterioration of road pavements

⇒ climate models do project such changes only in limited areas (to be assessed in a detailed study)

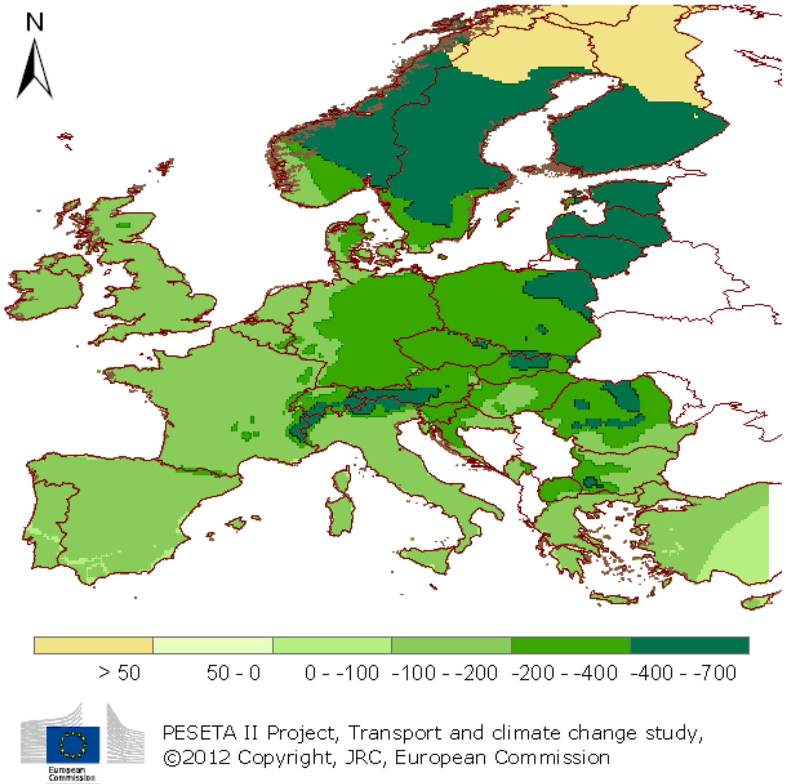
Summer conditions (road cracking):

=> need to adapt asphalt

Winter conditions: cracking and potholes (joint effect of deep frost and thaw-freezing cycle effects, also function of precipitation – FHWA, 2008)

=> ~-500 to -170 million €/yr

Change in Freezing days (by 2070-2100 compared with 1990-2010, A1B- KNMI scenario)



Future vulnerability – Extreme precipitations & floods

1. River floods: Rainfall over an extended period and an extended area can cause major rivers to overflow their banks. Downstream areas may be affected, even when they didn't receive much rain themselves
 => ~5-10% of total rainfall related impacts

2. Prolonged intense rainfalls (7-days heavy precipitation) : e.g. road, rail embankment

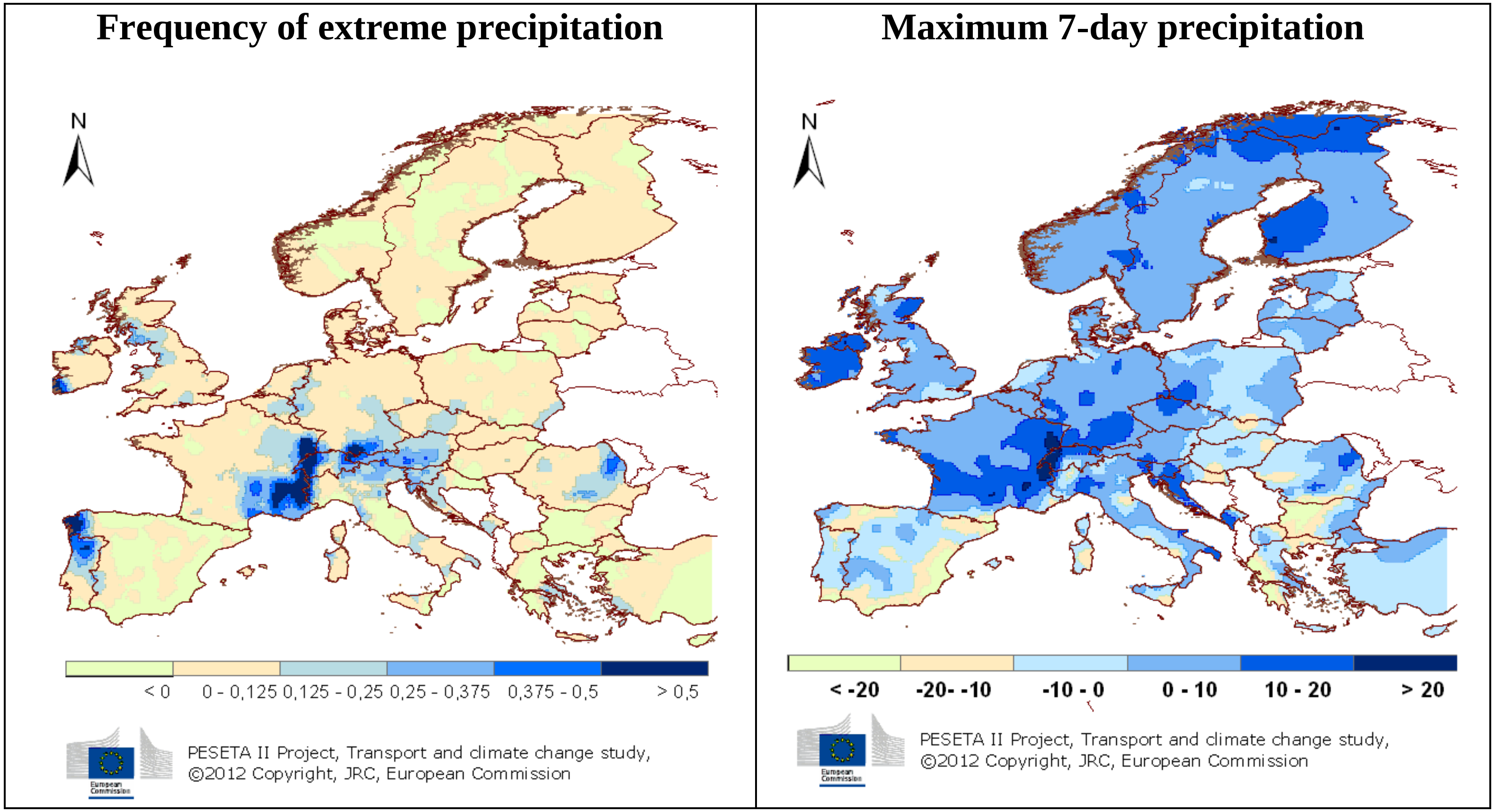
3. Extreme precipitations (>50 mm/day) and possibly induced flash floods or urban floods

   - flash floods in areas with steep slopes, where heavy rain water flows downhill gathering speed and all the water comes together in the river bed
   - urban floods : lack of drainage in an urban area

Trigger point	consequences
>50 mm/24 h	flooded roads, reduced pavement fraction
>100 mm/24 h	– The sewer system fills up, water rises up the streets from drains – Rain water fills the underpasses and lower laying streets – Drain well covers may become detached and cause danger to street traffic – Reduced visibility, flooded underpasses
>150 mm/24 h	– Road structures may collapse – Bridges may be flooded – Vehicle motors damaged and vehicle can be flooded – Roads might be covered by water or transported debris
200 mm/24 h	*Landslides risk in mountainous regions*

Future vulnerability – Extreme precipitations & floods

Future changes in intense precipitation
(2070-2100 compared with 1990-2010 - A1B-KNMI scenario)



Costs to increase from 630 million €/yr today to 712-832 million €/yr (+10% - 30%)

The problem: road cracking

Adaptation: modify the asphalt binder

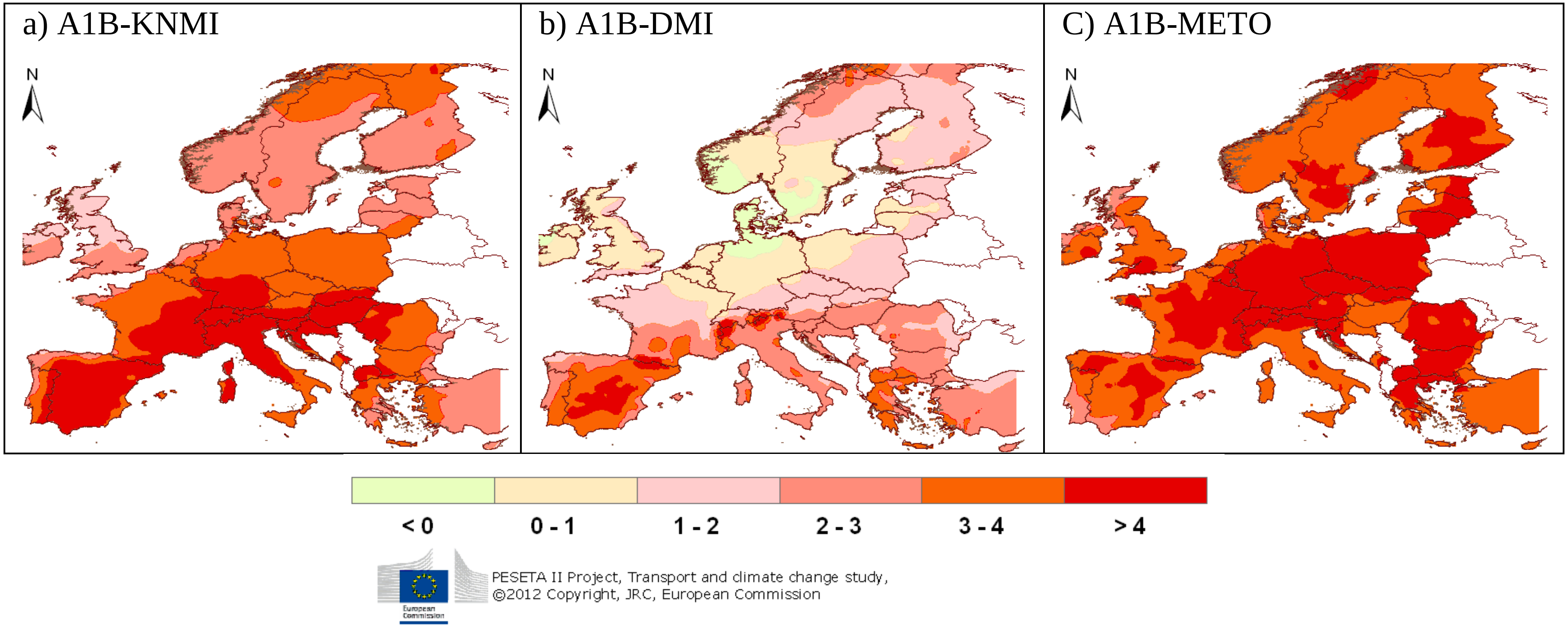
(more costly: ~6000 to 10000 €/km lane for every 4 degree temperature increment)

Remark:

changes in asphalt also dictated by milder winter conditions (-), changing precipitation regimes (+).

Adaptation : Road pavement

Change in average maximum 7-day pavement temperature
(2070-2100 compared with 1990-2010)



~ 52 – 180 million €/yr extra costs over 2040-2100

Adaptation : Rail track buckling

The problem:

Large lateral misalignments in continuous welded rail (CWR) under heat driven compressive forces, especially on tangent and curved tracks.

=> derailment risk (severe events in UK (2003), US, Australia)

Rail tracks anchored under a "stress-free" temperature (SFT; ~23 – 27 C over EU27).
Stress-free temperature reduced as a result of after winter season repairing operations, traffic load, weak track conditions (inadequate ballast e.g. missing ballast, deficient ties).

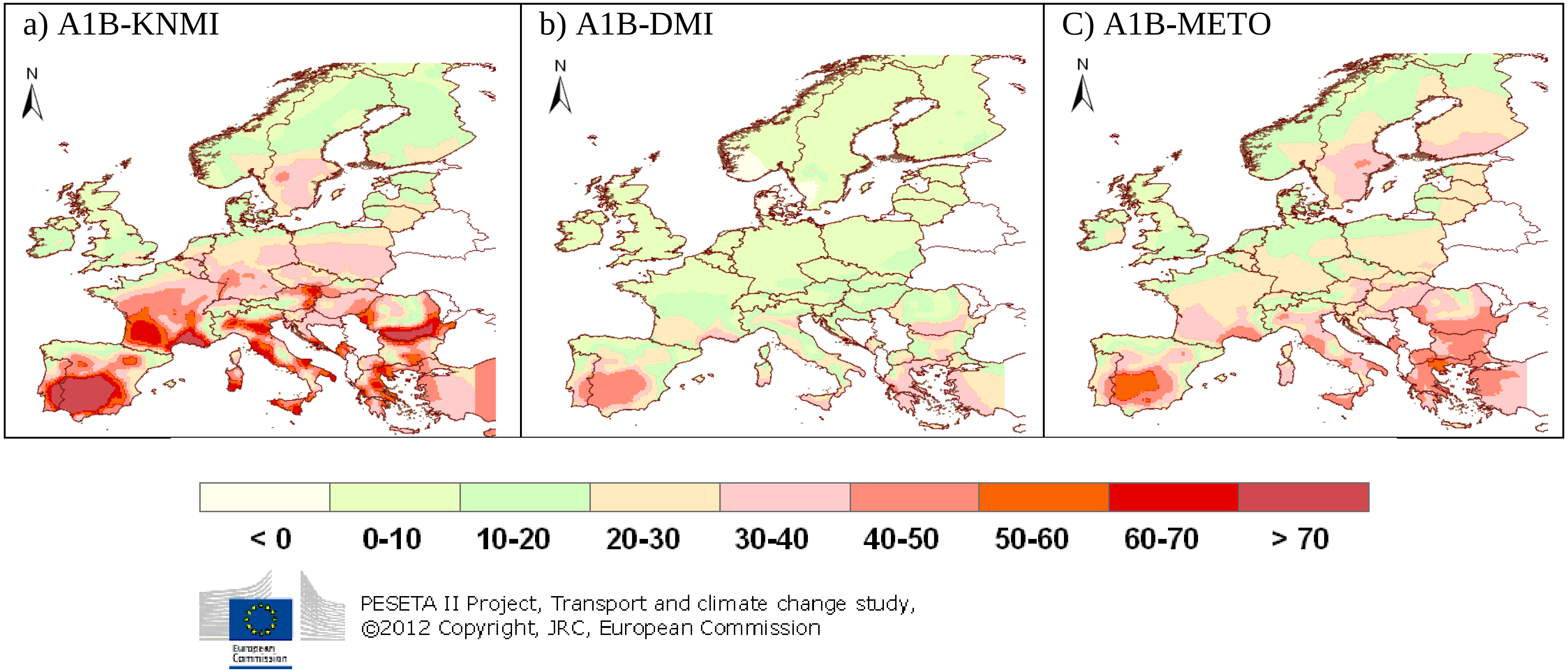
Adaptation measures involve

* Temperature monitoring and speed limits to prevent buckling and derailment risk (critical temperatures)
* Changing stress free temperature (but constraints by inter-season variability)
* Adjusting maintenance and de-stressing regime

Adaptation : Rail track buckling

Extra number of days per year with speed restriction in case of "inadequate ballast"

<5% tracks under "inadequate ballast condition, short distance trip lines, speed limits from ~12:00 – 20:00 => affecting ~<2% of km trips affected during the estimated number of days



Current delays: ~0.012% trip time under free speed flow conditions;

Possibly doubling in the future; +25-48 million €/yr;

Only 50% if changed SFT (but what about feasibility and cost?)

Adaptation : Bridge scour

The problem:

Bridge scour: *removal of river bed sediment from around bridge abutments or piers, potentially scooping out scour holes, and compromising the integrity of the structure.*

Water normally flows faster around piers and abutments making them susceptible to local scour. Enhanced in case of high river flow discharge.

60% of all bridge failures *result from scour and other hydraulic related causes.*

United States*: 46 of 86 major bridge failures resulted from scour near piers from 1961 to 1976.*

Bridge collapse over the River Towy, Wales (UK) in Oct. 1987 resulted in ***4 deaths***

Adaptation:

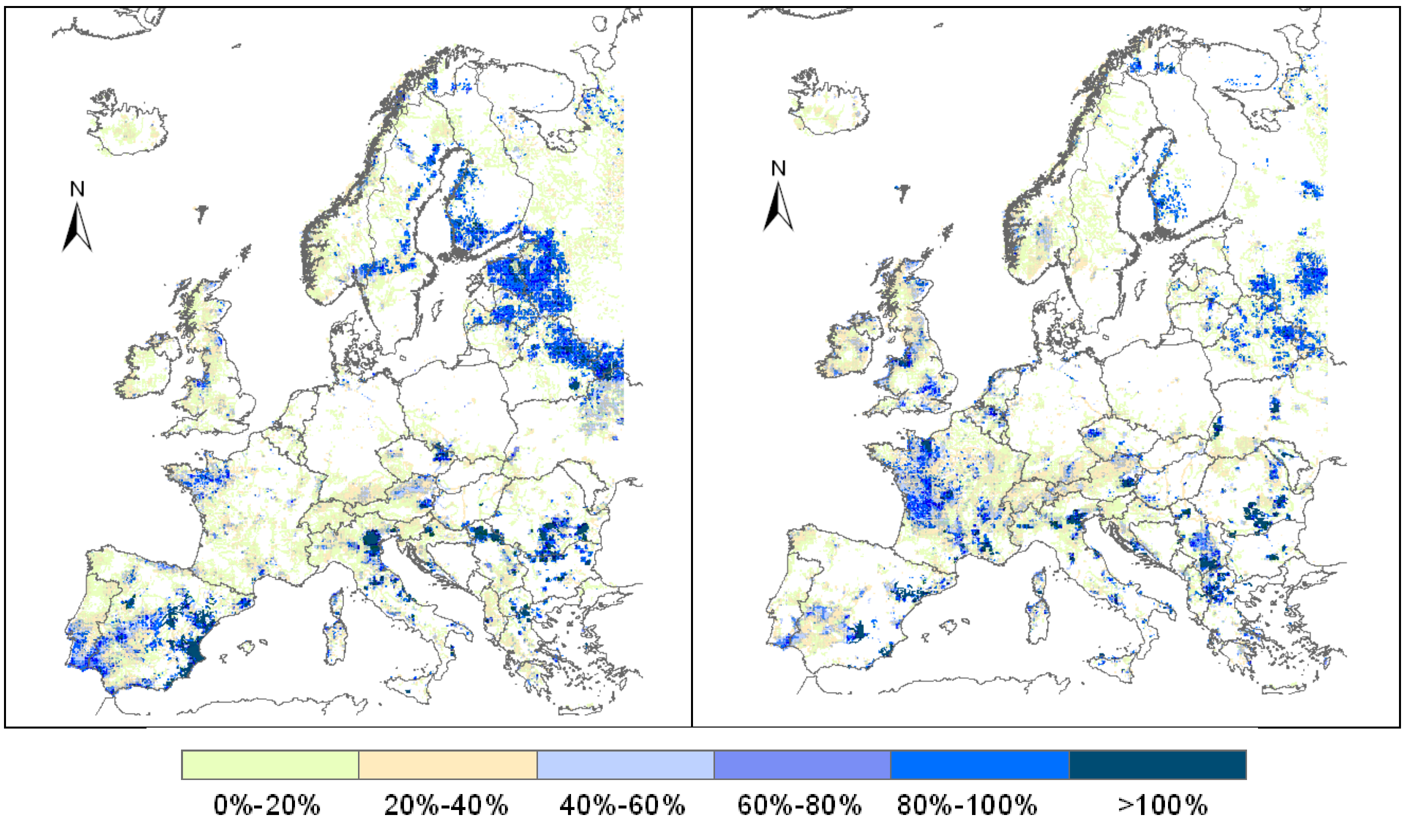
Riprap *: placing large blocks at the base of the bridge piers*

Concrete reinforcement *of foundation: Beyond water velocities of 12 and 10 km/h for sand and non sandy material respectively*

Adaptation : Bridge scour

Bridges exposed to a 100-yr return period river peak discharge as % of historical period (A1B-KNMI)

2040-2070 and 2070-2100



PESETA II Project, Transport and climate change study,

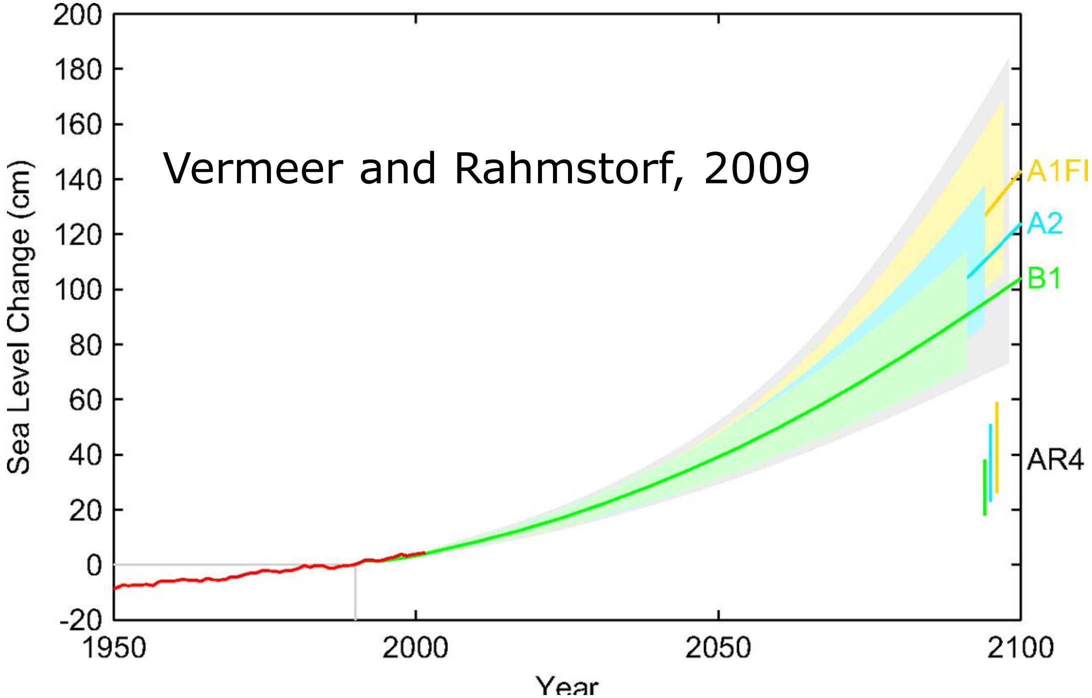
~20% of bridges vulnerable

325–475 million €/yr (2040-2100)

Vulnerability : Sea Level Rise

European Commission

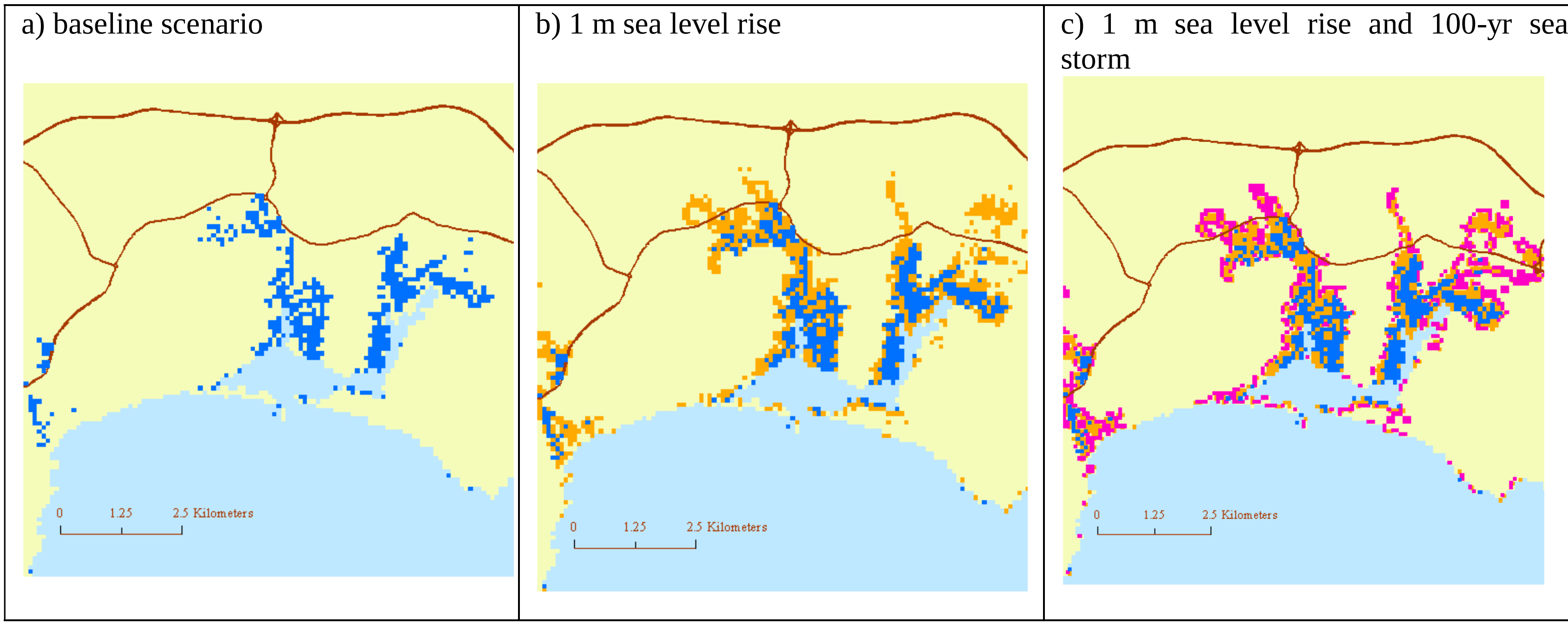
The problem



⇒ How much transport infrastructure at risk of permanent (1 meter sea level rise) or episodic inundation (sea storm surges) by 2100

Sea level rise and sea storm surges

Inundation map
Areas at risk of permanent or temporary inundation (example in Portugal)



~4% coastal infrastructure (in a 10 km coastal band) at risk of permanent or episodic inundation,

Triple in low lying zones

~18 billion € asset under risk at EU27 level

Indicative EU27-wide costs

Road infrastructures

Estimated **costs:**

		Current costs		Future costs changes	
		million €/yr	% MC	million €/yr	% MC
Damages and deterioration	Weather-induced wear&tear	10 405	40.0%	-339	-1.3%
	Extreme weather damage costs			145	0.6%
Adaptation	River bridges scour protection			322	0.6%
	Road pavement (asphalt binder)			116	0.4%
	Other measures (slope protection, infrastructure elavation,…)			?	?
Total estimated costs		**10 405**		**242**	**0.9%**
avoided cost (bridge scour)				*-1 185*	*-4.6%*

Road infrastructure at risk of future SLR and sea storm surges	*18 460*

Other adaptation measures: ?

Other transport modes, components?

Discussion

Current and future weather-induced damage costs

- Still fragmented costs estimates for transport infrastructure and operation
- Unaccounted indirect impacts (propagation of through the economy in case of severe traffic disruption)
- Weather together with other important stressors (e.g. growing traffic load, rail bridges)
- EU-wide and, even country-wide costs masking regional and local disparity
- High uncertainty in climate models => high uncertainty about adaptation needs and costs

Adaptation

- Short to long infrastructure life versus uncertain future climate changes
  - => short life maintenance cycle (e.g. pavement): gradual and iterative adaptation
  - => long-life infrastructures: one-off adaptation or adaptative management strategy (e.g. sea port infrastructure elevation)
- Changing maintenance practices
- Engineering design standards (revision as a long process; public / private / EU initiative?)
- Regional impacts and planning and EU-wide transfer of experience (e.g. rail buckling)
- Case-by-case assessment

First insight that avoided costs significantly higher than adaptation costs

Research efforts to be continued

European Commission

Notably in relation with abrupt climate changes:

Sea Ports: sea level and sea storm surges

(and possibly changing storm tracks)

Opening of the Arctic maritime road

New infrastructure designs (guidelines)

Traffic disruption and impacts on the whole economy

International cooperation

European Commission

Thank You!

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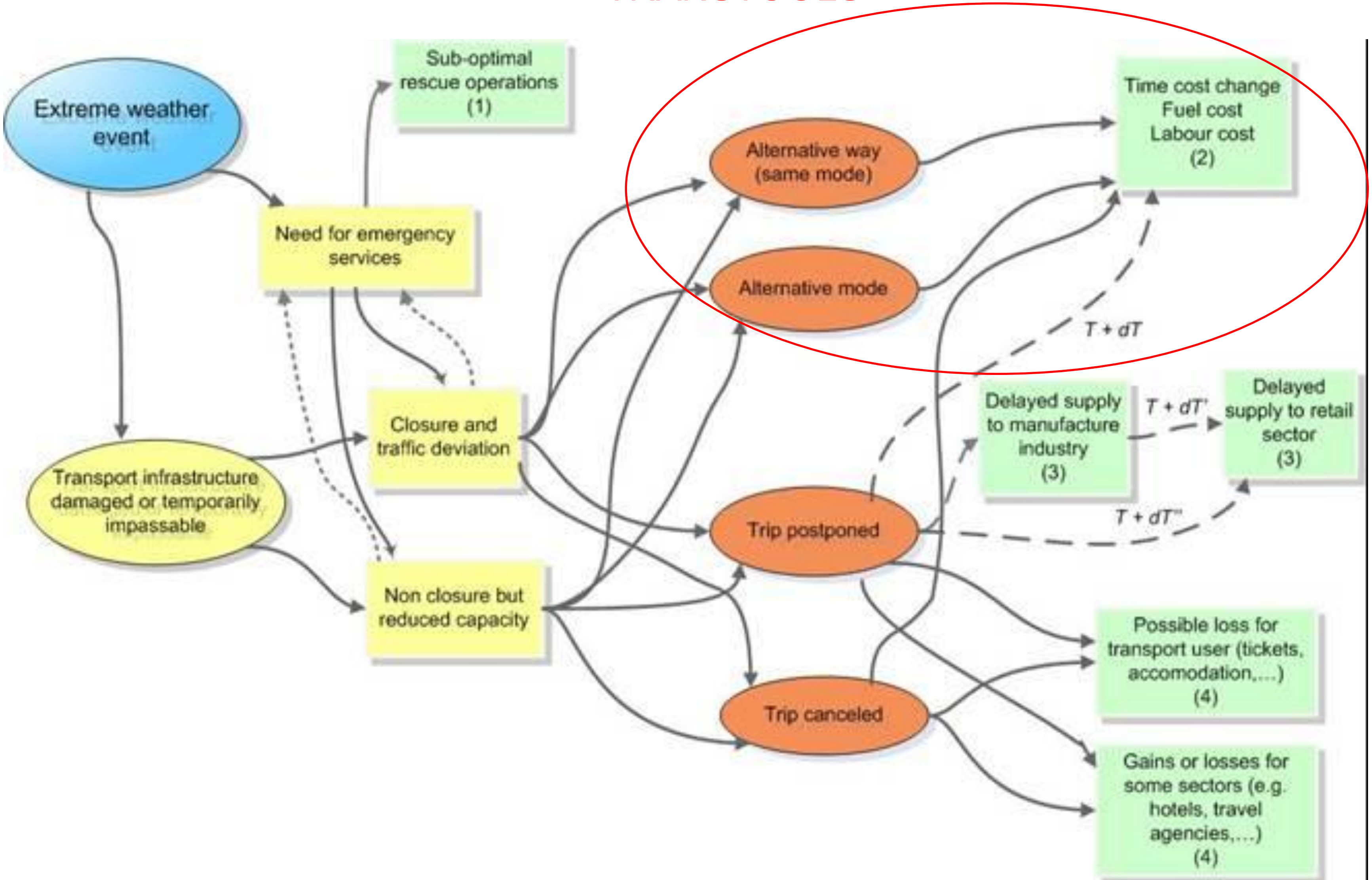
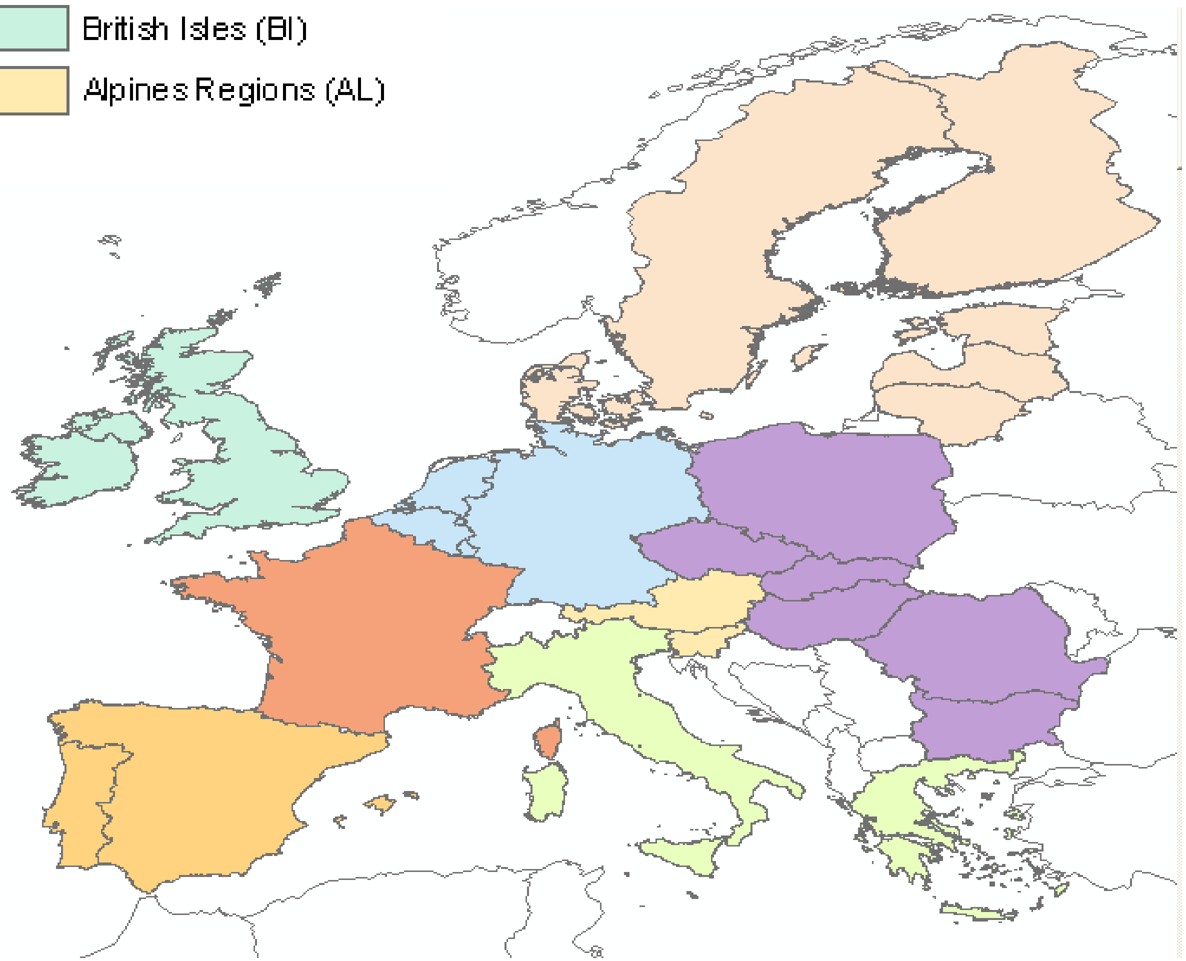
TRANSTOOLS



Extreme weather event
Sub-optimal rescue operations (1)
Need for emergency services
Transport infrastructure damaged or temporarily impassable
Closure and traffic deviation
Non closure but reduced capacity
Alternative way (same mode)
Alternative mode
Trip postponed
Trip canceled
Time cost change
Fuel cost
Labour cost
(2)
T + dT
Delayed supply to manufacture industry (3)
T + dT'
Delayed supply to retail sector (3)
T + dT''
Possible loss for transport user (tickets, accomodation,...) (4)
Gains or losses for some sectors (e.g. hotels, travel agencies,...) (4)

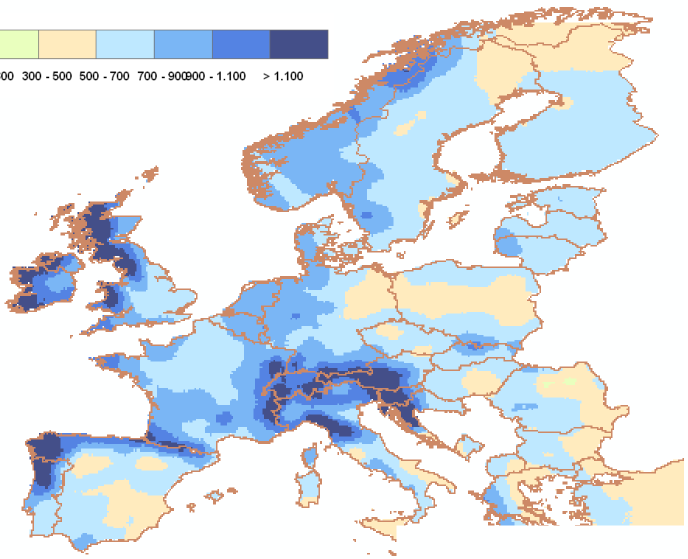
Climate zones:

- Scandinavia (SC)
- Middle Europe (ME)
- Mediterranea (MD)
- Iberian Peninsula (IP)
- France (FR)
- Eastern Europe (EA)
- British Isles (BI)
- Alpines Regions (AL)

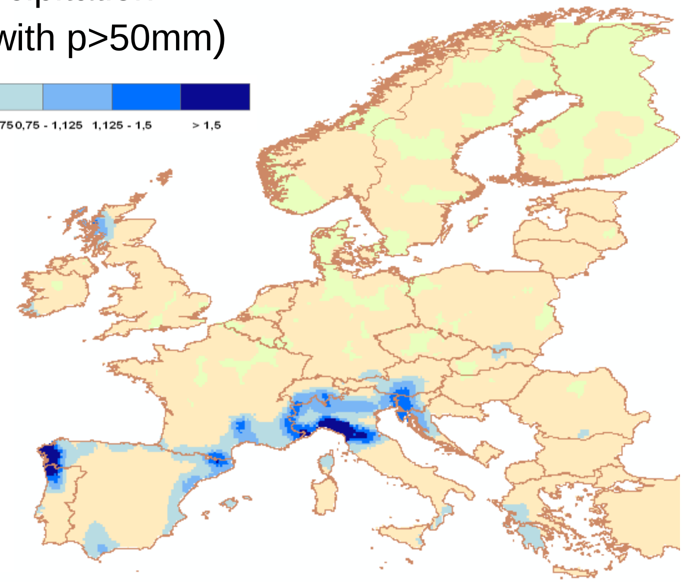


Current vulnerability to heavy precipitation

Annual precipitation (mm)

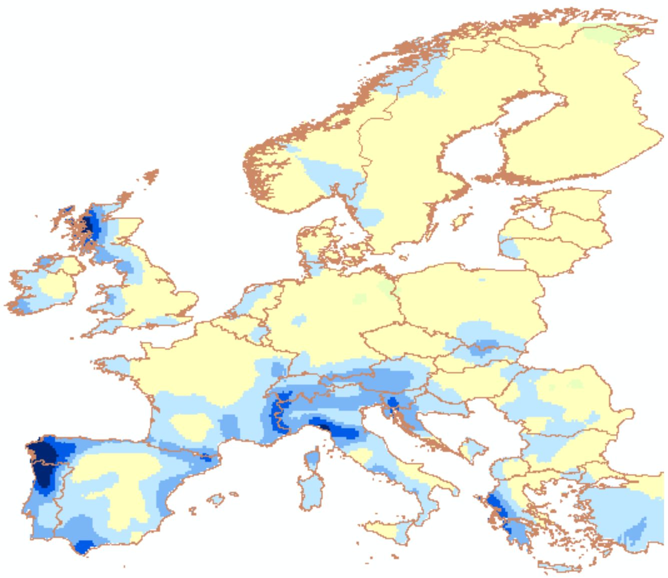


Heavy precipitation
(nb days with p>50mm)



1990-2010,
A1B-KNMI

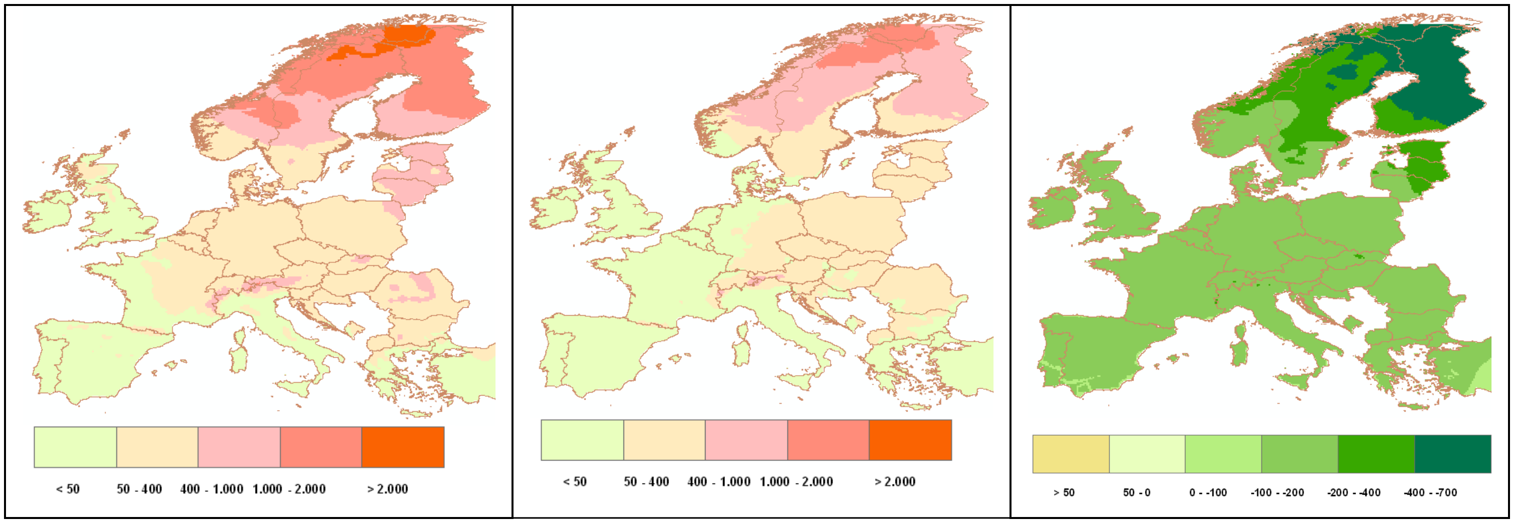
Prolonged intense precipitation:
max 7-day precipitation (mm)



Future vulnerability (road infrastructures)

Winter conditions *(current costs: 248 million €/yr)*

Changes by 2070-2100 compared with 1990-2010 (Freezing Day Index - FDI)



1990-2010 | 2070-2100 | 2070-2100 minus 1990-2010

Adaptation : Road pavement

Methodology, data, assumptions

	parameter	comment
technico-economic assumptions and parameters	Pavement grade performance as a function of 7-day maximum pavement temperature	based on Superpave (US), similar in Europe
	Cost for asphalt binder per performance class	based on Superpave (US), similar in Europe
climate indices	average maximum 7-day temperature	scenarios DMI, KNMI, METO
transport data	road infrastructure (motorways	NUTS3 resolution

Remark:

Following approach implemented by EPA

Adaptation : Rail track buckling

	parameter	comment
technico-economic assumptions and parameters	Stress Free temperature per country	~ available for 10 countries others: SFT~3/4 Tmax
	Critical temperature for speed limits CRT70 ~ SFT + 2 degrees CRT30 ~ SFT + 13 degrees	only for " inadequate ballast" (VOLPE)
	relation ambiant temperature and track temperature	Ttrack ~ 3/2 Tambiant
climate indices	dayly maximum temperatures	scenarios DMI, KNMI, METO
	number of days with Tmax > critical levels	
transport data	transport activity (pkm / tkm) long distance vs short distance	NUTS3 resolution
	free flow speeds	NUTS3 resolution
	value of time (euro/hour delay per passenger and per ton)	~ 8 euros/hour*pass ~ 1 euros/hour*ton

Adaptation : Bridge scour

	parameter	comment
technico-economic assumptions and parameters	Stock of river passing bridges (rail, main roads) and geographical location	Very fragmented data on stock (COST project, partial) GIS based method to infer stock (roads, rail lines (TELEATLAS) crossing main rivers (GISCO))
	Characterization of bridges	Inexistent data per bridge available for Europe (contrary to US : NBI database (e.g. physical conditions on substructure, water flow and channel, waterway opening, vulnerability to scour). => assumed average deficiency factor assumed to be comparable to US (~27% bridges)
	costs data (rip rap, concrete reinforcement)	same assumptions as EPA study
	river bed material (sand vs other)	European Soil Database (ESDB)
Hyrdological variable	river discharge peak flows	scenarios KNMI as produced by IES (River Flood study)

Key assumptions (similar to EPA) :

- Under less than 20% change in 100-yr return peak flow by the beginning of the period, the initial bridge design is still adequate and no measure is needed.
- Under changes higher than 20%, measures are required to prevent bridge scour and this depends on the river bed material:
  - Riprap is the first adaptation measure and it is adequate up to a certain flow change (60% and 100% change for non sandy and sandy soils respectively).
  - Beyond these thresholds, the foundation needs to be reinforced with concrete.

Adaptation : Sea Level rise

Methodology, data, assumptions

Digital Elevation Model (DEM): Shuttle Radar Topography Mission (SRTM) data from NASA (USA). 90 m horizontal resolution. Not available for Finland (GTOPO30 global Digital Elevation Model was applied).

Sea storm surge: Dynamic Interactive Vulnerability Assessment (DIVA) database. Surge heights for several return periods (1, 10, 100, 1000 yr).

Transport infrastructure:

- Road infrastructures: Teleatlas
- Airports, ports and railways: Eurostat spatial database, Geographical Information System at the Commission (GISCO).

Adaptation : Sea Level rise

European Commission

Methodology, data, assumptions

1 meter SLR individually or combined with sea storm surge height (e.g. 100-yr return)
=> Two new water levels

"Bucket fill" approach projects the new water height inland and inundates all land areas at an elevation below this level.

The two types of areas at risk of (permanent or temporary inundation) are then overlaid with the transport network infrastructure, to identify the linear distance in kilometers affected within each scenario (*also airports, runways and port areas*)

Caveats:

Data inaccuracy (protections, infrastructure elevation)
Bucket fill approach versus a more realistic approach (hydraulic processes, water pathway)

- **=> less accurate for low lying zones**
- **=> first rough assessment to be followed by much more detailed analysis (LIDAR data, water pathway approach)**