



 TRANSPORTATION RESEARCH BOARD  
*The National Academies of*  
SCIENCES • ENGINEERING • MEDICINE



# Transportation Resilience: Adaptation to Climate Change and Extreme Weather Events

Summary of 4<sup>th</sup> EU-US Symposium on Transportation Research

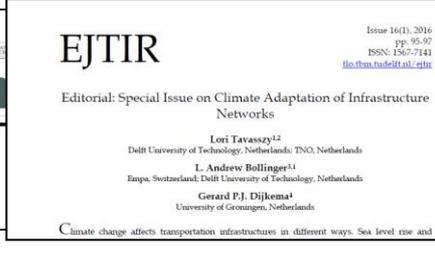
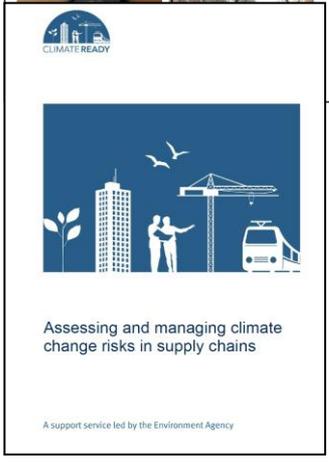
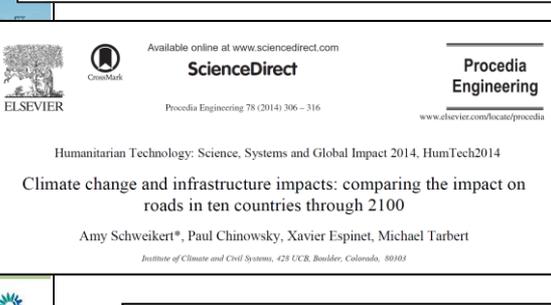
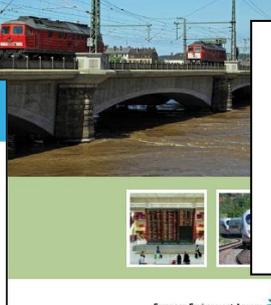
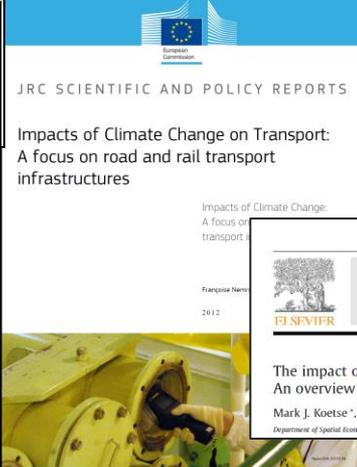
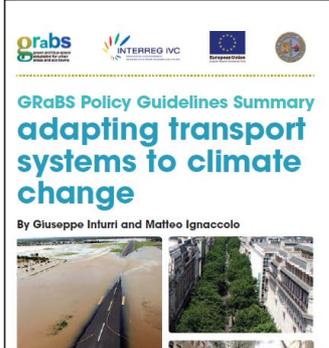
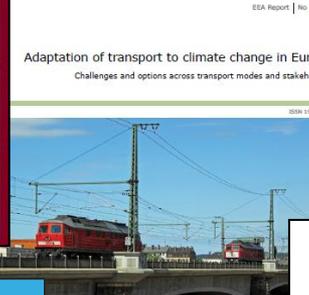
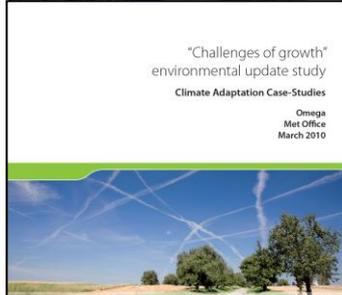
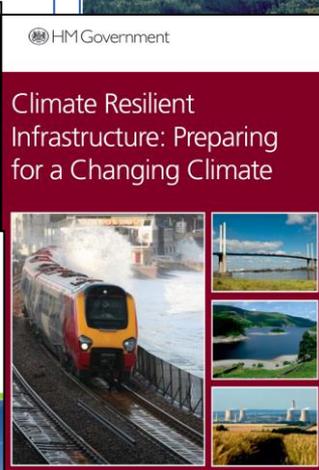
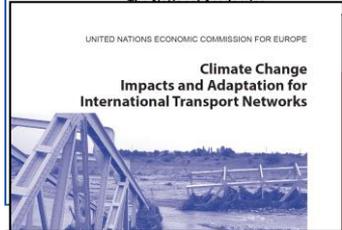
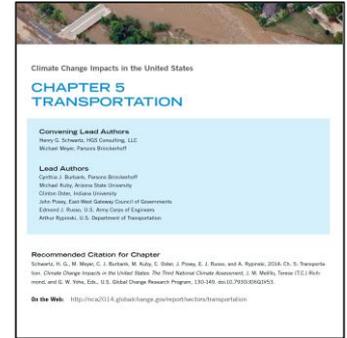
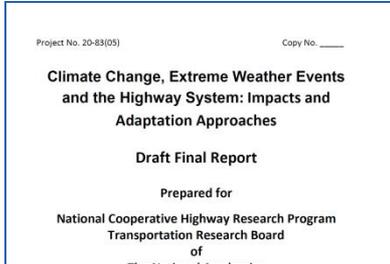
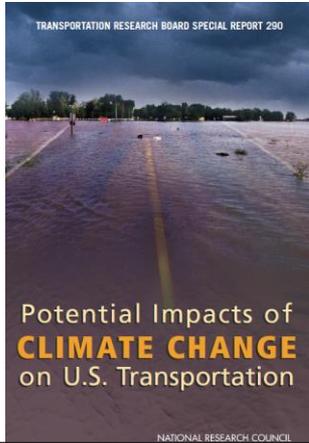
Professor Alan McKinnon, *Kuehne Logistics University*

Chairman of the Symposium Planning Committee

TRB Executive Policy Committee meeting  
January 2017

# Adaptation of Transportation Systems to Climate Change

## Already an Extensive Literature



# Specialisms, Transport Modes and Countries Represented at the Symposium

## subjects

Climate science

Civil engineering

Transport planning

Risk analysis

Decision theory

Economics

Hydrology

Logistics

Insurance

Public policy

Coastal adaptation

Infrastructure design, construction, maintenance and management

## transport modes

Highways

Aviation

Rail

Ports

Public transit

Shipping

Inland waterways

United States

+

14 European countries



# Symposium Program

Keynote addresses: **Jan Hendrik Dronkers**, *Rijkswaterstaat*  
**Donald Wuebbles**, *University of Illinois / White House*

White Paper: **Gerry Schwartz and Lori Tavasszy**

Chronology of weather-related transport disruptions: *3 case studies*

## Preparatory phase

*Gordana Petkovic*  
*Jeff Western / Sam Merrill*

Sea-Level Rise

## Disruption phase

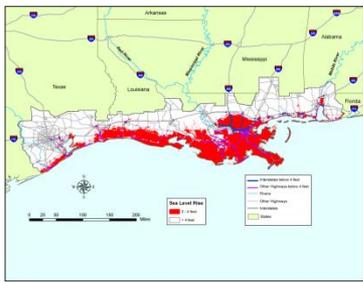
*Jennifer Jacobs*  
*Andre van Lammerer*

Flooding

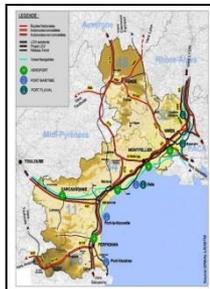
## Recovery phase

*Michael Meyer*  
*Alan O'Connor*

Extreme Heat



US Gulf Coast



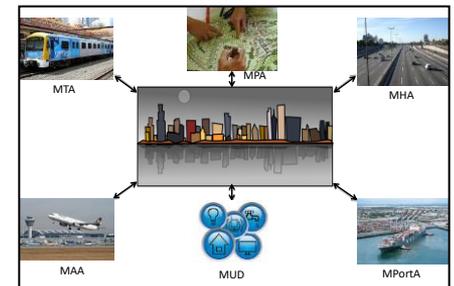
Langedoc -  
Mediterranean



Vermont 2011



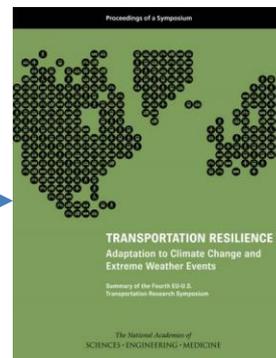
Central Europe 2011



Metropolis  
100°F for 30 days

Plenaries  
 Break-out  
 Panel discussion

*Rapporteur*  
 Katie Turnbull



potential portfolio of  
 EU-US research

38 research topics

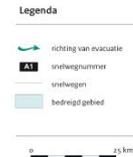
Strong Dutch presence at the Symposium: for good reason...

## Snelwegen bij een evacuatie (highways for evacuation)

**Dreiging zee**  
(flood risk from sea)



**Dreiging rivieren**  
(flood risk from rivers)



# Essence of Climate Change Adaptation in the Transportation Sector

## Climate Changes

- Extreme precipitation
- Rising sea levels
- Temperature spikes

## Impacts on Transportation

- Roadway flooding
- Damage to or destruction of bridges
- Pavement and rail buckling
- Subway flooding
- Seaport and airport flooding
- Slope failures
- Curtailment of barge operations

## Consequences

- Freight traffic disrupted for days or weeks
- Power plants, water facilities, homes, businesses, hospitals cut off
- Passenger travel delays
- Higher transportation costs for government, businesses, and households
- Evacuation of urban areas

## Adaptive Strategies to Reduce Impacts

- Retrofit facilities
- Relocate facilities
- Upgrade stormwater drainage facilities
- Build new facilities to climate-ready standards
- Protect existing infrastructure
- Incorporate climate change into maintenance cycles

## Adaptive Strategies to Reduce Consequences

- Reroute freight and passenger flows
- Shift to alternative modes
- Land use regulations relating to development in vulnerable areas
- Evacuation and contingency strategies
- Building in network flexibility
- Traveler information systems
- Rapid rebuilding of damaged facilities
- Improved air traffic management

Where do you draw the boundary around the wider socio-economic consequences?

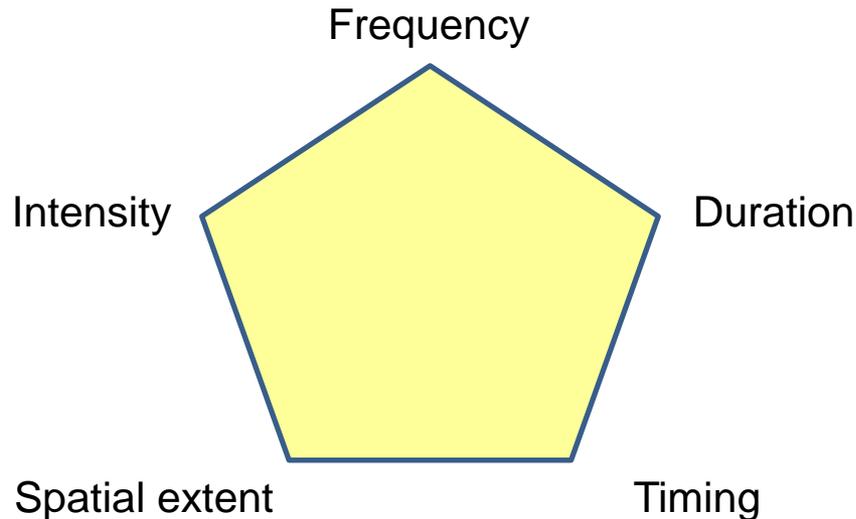
EU EWENT project estimated cost of extreme weather on the transport system of the EU 27 in 2010: €15.5-21.5 bn

## Analysing and planning for extreme weather event is inherently difficult

- By definition, extreme events occur rarely; frequency based on historical records
- Rare occurrence makes datasets small and sparse
- Extremes are hard to measure -*instrumentation often performs poorly under extreme conditions*
- Processes that generate extremes are highly complex and difficult to model.

Jennifer Jacobs.

### 5 dimensions of extreme weather

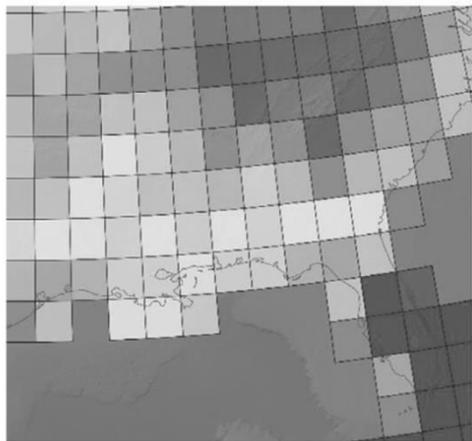


Source: IPCC SREX (2011)

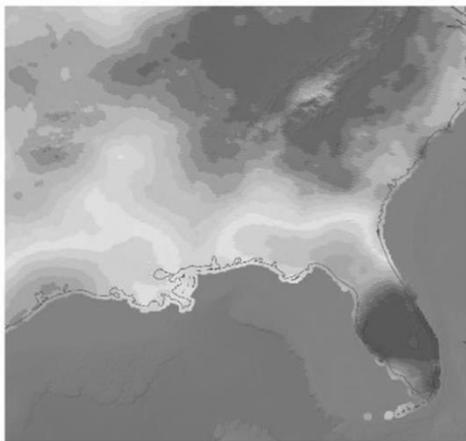
# Translating Climate Science Data into Useful Information for Transport Planning

## Geographical downscaling of climate data

Model ~155 km (1.4°) grid output

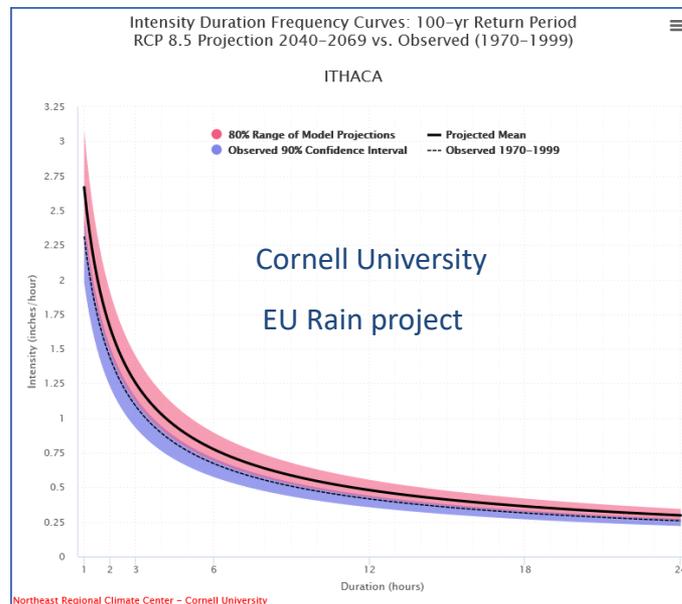


Statistically downsampled ~4.5 km grid output

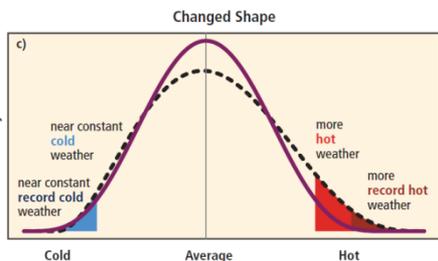
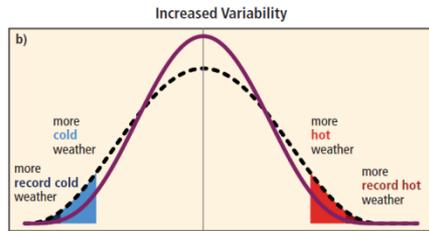
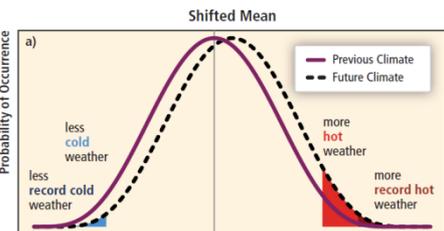


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Source: Data from National Center for Atmospheric Research.

## Incorporating downscaled climate data into transport engineering models



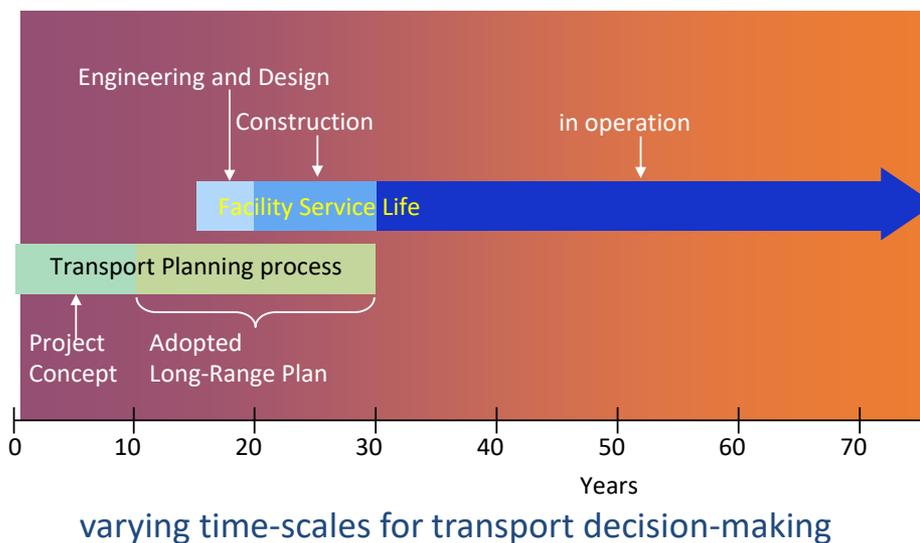
## Relaxing 'stationarity' assumptions



can no longer extrapolate from historic data

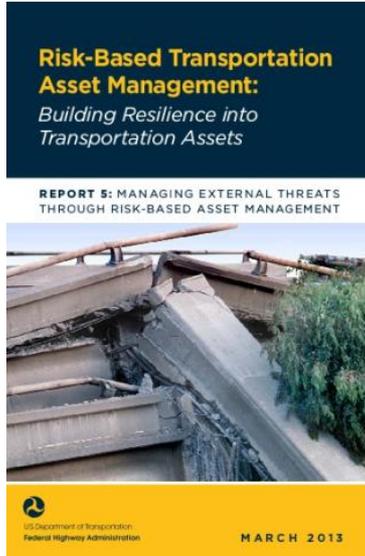
rate of climate change accelerating – need regular recalibration

trends may prove non-linear if 'tipping points' are crossed



# Risk Assessments, Stress Tests and Benefit-Cost Analyses (BCA)

Integrating climate risk assessment into the management of transportation assets



New BCA methodologies with risk-adjusted discounted rates and life-cycle costing of transport assets

Determining the 'right' level of transportation resilience

Measuring and benchmarking the relative cost-effectiveness of an extended range of adaptation options

Analysing the inter-relationship between mitigation and adaptation measures in the transportation sector:

*How can we minimise the carbon intensity of infrastructural 'climate proofing'?*

*Are some mitigation and adaptation measures in conflict?*

Modal shift from road to rail and canal networks  
- *with higher risk of weather-related disruption?*

Powering transport with low carbon electricity  
- *increased dependence on electrical infrastructure?*

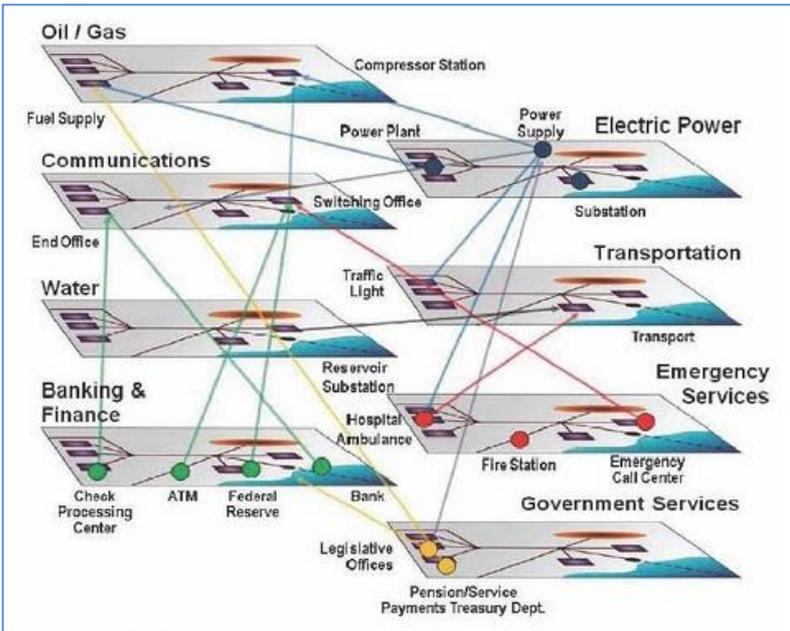
Stress testing to determine vulnerability of transport infrastructure and services



Measuring 'adaptive capacity' of transport users as well as the infrastructure.

# Developing Holistic Resilience Strategies

## across critical infrastructures



infrastructural interconnections cause propagation of disruptive effects

## across stakeholders

not simply an infrastructural responsibility  
sharing of information, risks and costs  
with service providers and users

need new communication strategies and support tools to facilitate multi-agency and multi-level co-ordination

## across transport modes



modal substitution as a resilience option

## across jurisdictions

effects of extreme weather and response mechanisms cross political boundaries

presents particular challenges in the EU, e.g. for the aviation sector

## across disciplines

Climate science

Civil engineering

Transport planning

Economics

Logistics

Behavioural sciences

Insurance

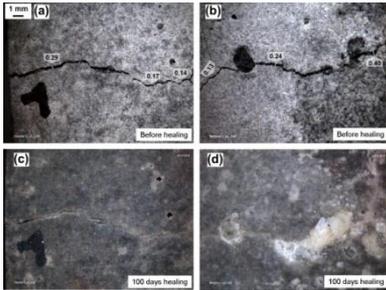
Aiming for system-level resilience - but how do we define the system?

# Impact of Technology

Technology in support of adaptation and resilience

Transport technologies creating new adaptation challenges

smart materials: e.g. self-healing concrete

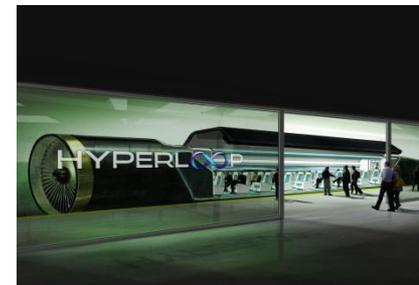


new sensors

big data / IoT



social media



## Some fertile areas for future research

Integration of climate data more effectively into transportation planning models.

Deployment of latest thinking on risk analysis, decision science and organizational learning.

Upgrading of 'sense-and-response' capabilities to manage the transportation system more effectively during extreme weather events and to accelerate recovery times.

Improving our understanding of the behavioral responses of transport users (both personal and corporate) during weather-related disruptions and how they can be modified.

## **Professor Alan McKinnon**

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