Temperature mapping for climate adaptation

Road Pavement Forum
Presentation

11 November 2021

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CSIR
Touching lives through innovation

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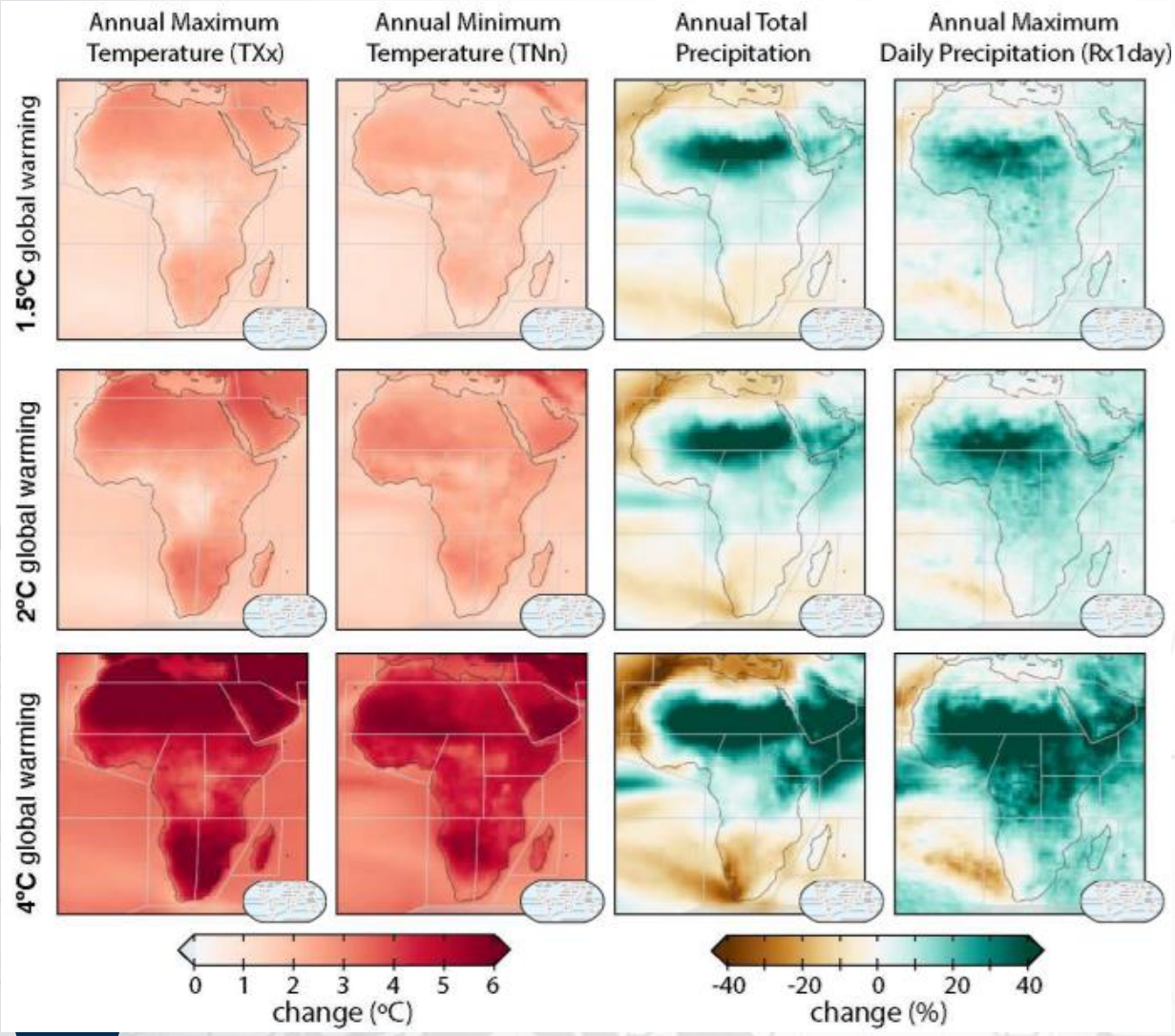
Warning signs of shifts in environmental conditions
Natural environment: Phenological shift
Built environment: Road failures associated with climate extremes

United Nations Climate Change Conference

- COP26 Goals
  - Secure global net zero emissions by mid-century and keep 1.5°C within reach
  - **Adapt to protect communities** and natural habitats
  - Mobilize finance
  - Work together to deliver
- Glasgow Adaptation Imperative
  - Building resilience across all of society
  - Effective Risk Management
  - Transforming Finance
  - Catalyzing Locally Led Action; and
  - Harnessing the power of nature.
- UK's Adaptation Action Coalition

IPCC AR6



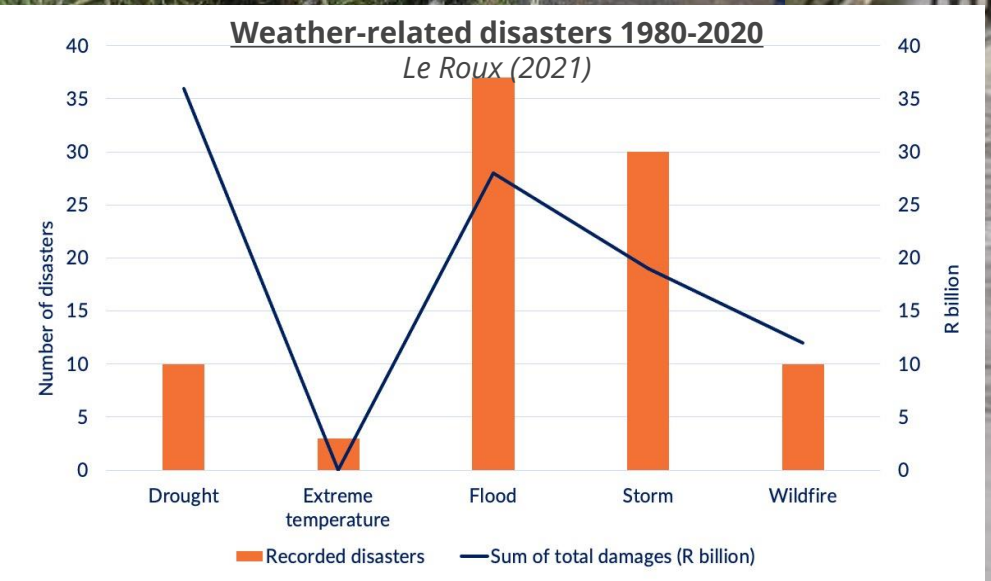
Overview of regional changes

- Mean and extreme temperatures variability
- Increased rate of surface temperature compared to global rates of warming
- Increase in heatwave events
- Decrease in cold temperature extremes
- Increase in frequency and severity of coastal flooding due to sea level rise
- Increase in frequency and intensity of heavy precipitation events

(IPCC Sixth Assessment Report: Regional Fact Sheet, 2021)

Introduction

Photo: eThekwini Municipality



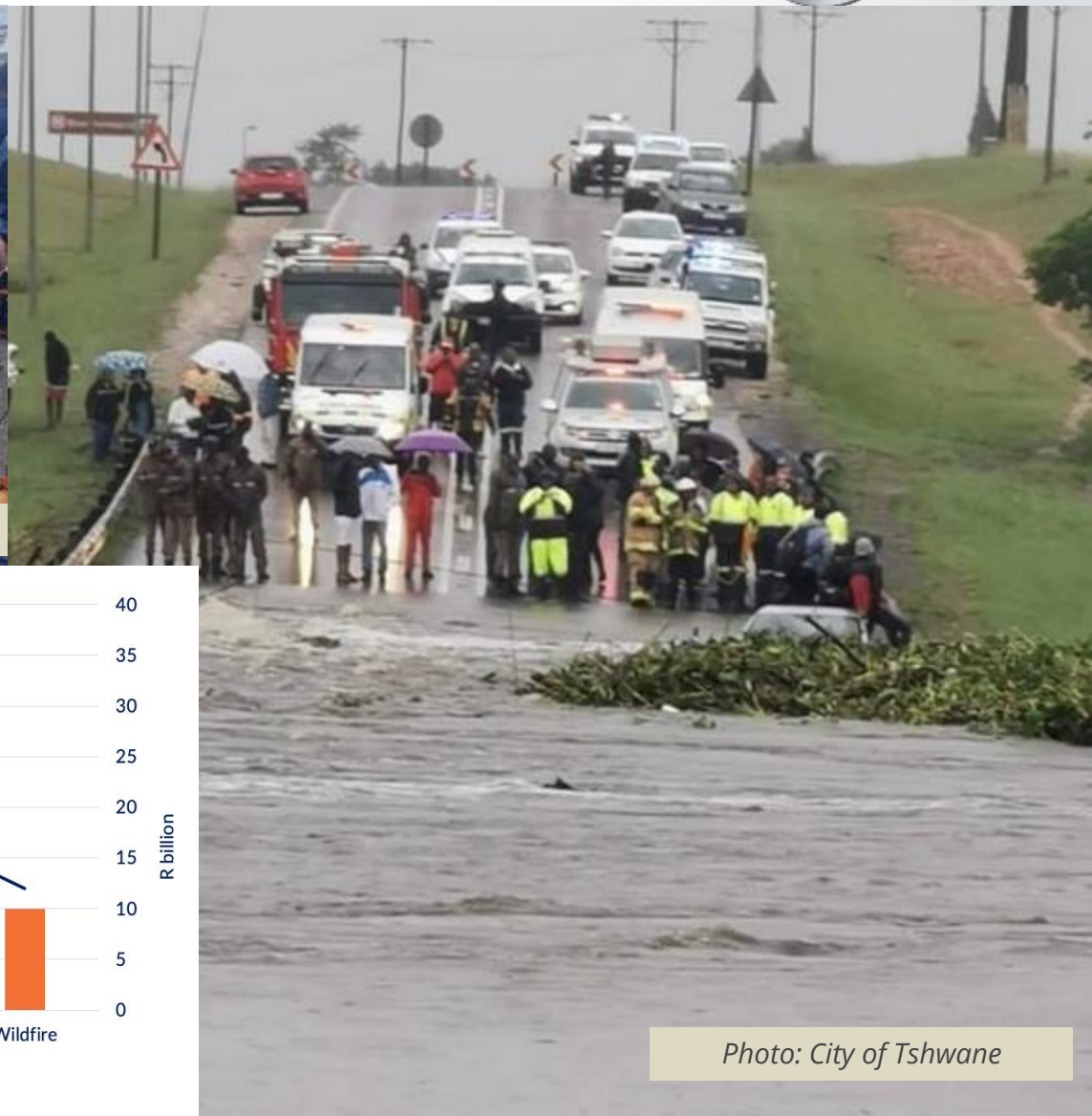


Photo: City of Tshwane

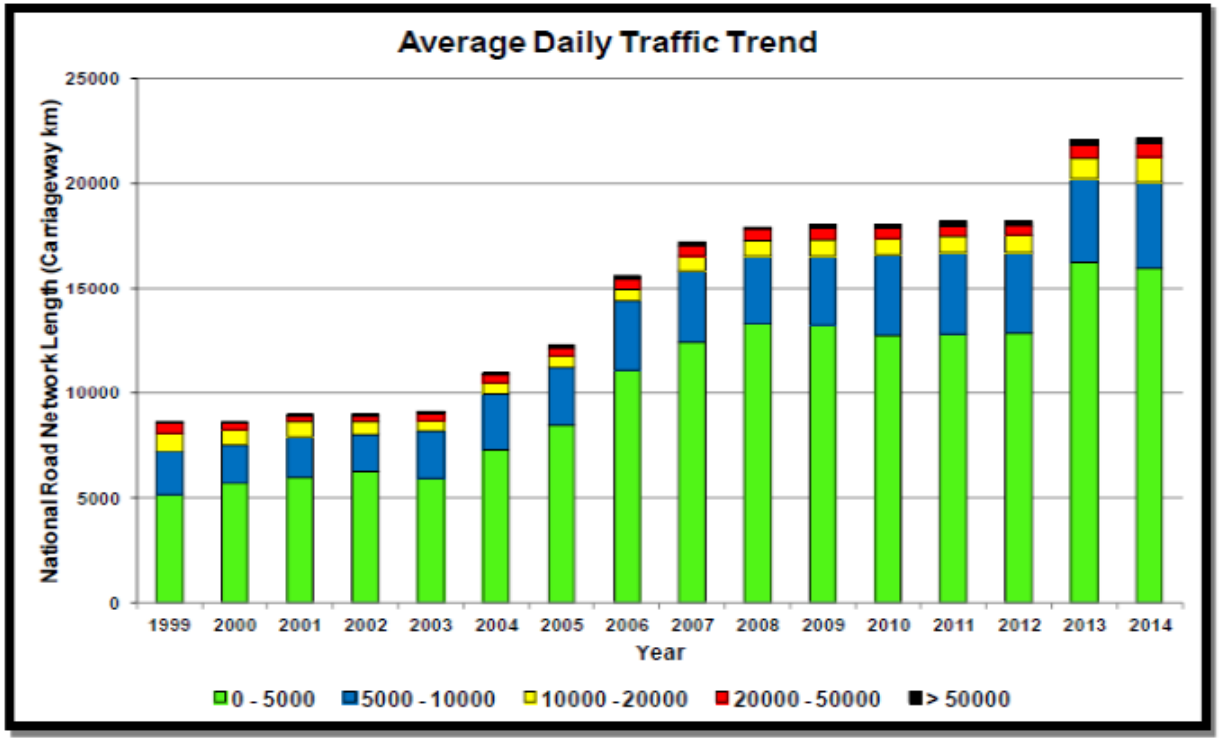
Condition of South African transport infrastructure

- Not coping with demand
- Poorly maintained
- Expected that public will be subjected to severe inconvenience and even danger without prompt action

2017 SAICE Infrastructure Report Card

Apart from National roads, overall condition is poor due to:

- Lack of maintenance
- Vehicle overloading
- High traffic volumes
- Poor stormwater management

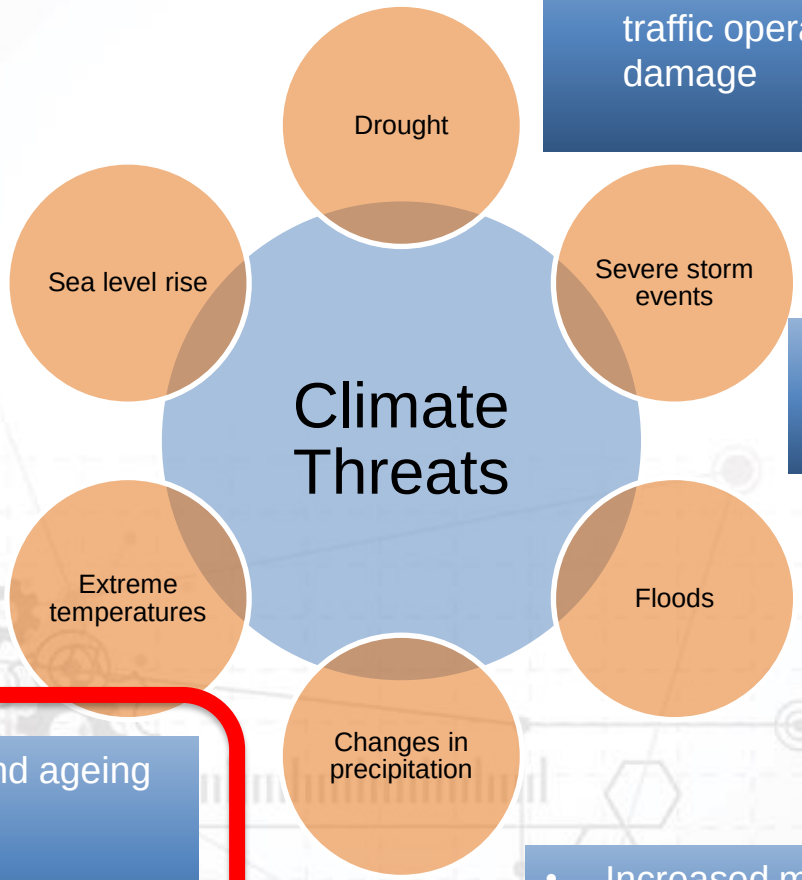


SANRAL Strategic Plan (2016)

Potential climate hazards & impacts

- Loss of structural integrity for gravel roads
- Increased wildfires potentially limiting traffic operations and infrastructure damage

- Submerged roads
- Erosion of coastal road substructure
- Increased flooding of low-lying infrastructure and tunnels



- Road infrastructure damage
- Road closures
- Reduced traffic operations

- Increased risks of landslides and slope failures
- Increased occurrences of pot holes

- Bitumen softening and ageing
- Traffic related rutting
- Surface cracking
- Restrained thermal expansion
- Warping of rigid pavements

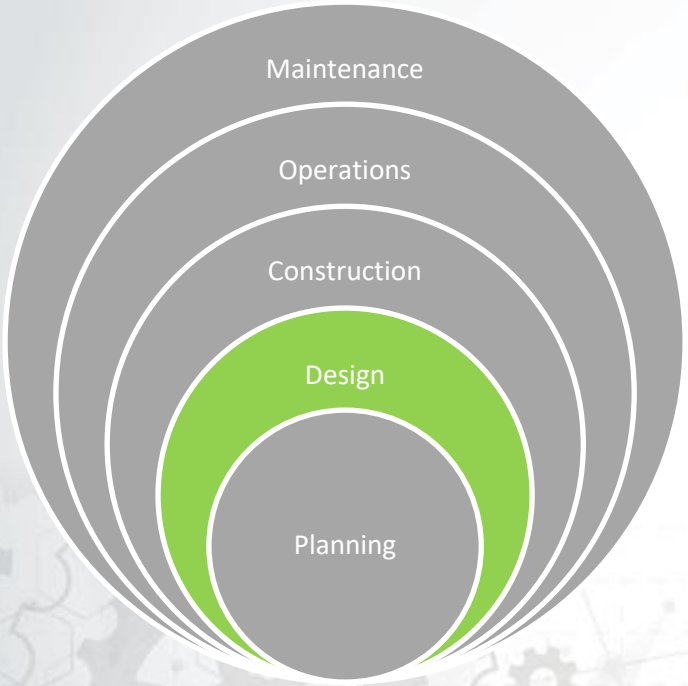
- Increased moisture levels in pavement structures
- Pavement and embankment heave with clay material substructures

(Adapted from Meyer *et al*., 2014)

International best-practice examples

- Internationally various countries have implemented national risk and vulnerability assessments for climate threats with few being implemented into engineering design and materials
- US Federal Highway Administration- NCHRP Report 750
- ASCE: The Committee on Adaptation to a Changing Climate was formed in 2011 to evaluate the technical requirements and civil engineering challenges for adapting to a changing climate
- UK Local Transport Strategy and Funding Division- Climate Change Impacts on Highways
- Italy has investigated effects on performance graded bituminous binders (Viola & Celauro, 2015)
- Canada currently investigating use of climate model data for performance graded bitumen selection
- ReCAP Adaptation Handbook Methodology
- South Africa is yet to introduce pro-active design methods for climate resilience at industry level

Adaptation planning- CoT Climate Action Plan



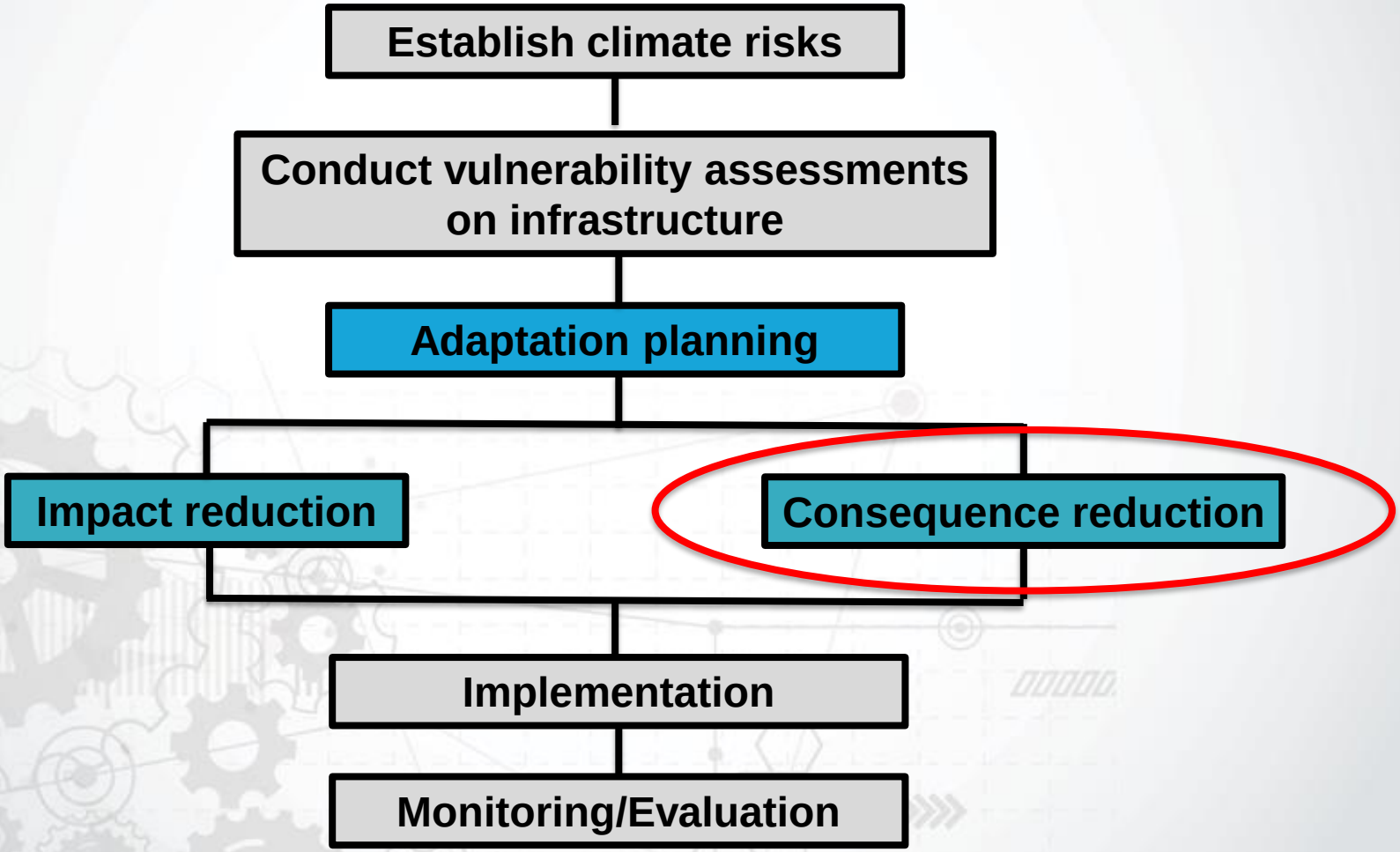
City of Tshwane (2021) Climate Action Plan

https://tshwane-climateactions.greenbook.co.za/

Design climate resilient roads and transport infrastructure

- Identify location of new infrastructure based on climate projections
- Specify appropriate road materials to withstand expected changes in weather events
- Implement revised design standards for roads and transport infrastructure
- Use of vegetation and road geometry to mitigate climate change impacts
- Design capacity to accommodate increased climate demands

Adaptation planning – General framework



Adaptation planning- Consequence reduction

Material specifications

ISBN 978-0-626-37799-1

SATS 3208:2019
Edition 1

South African Bureau of Standards

Technical specification

Performance Grade (PG) specifications for bitumen in South Africa

WARNING
This document references other documents normatively.

This document does not have the status of a South African National Standard.

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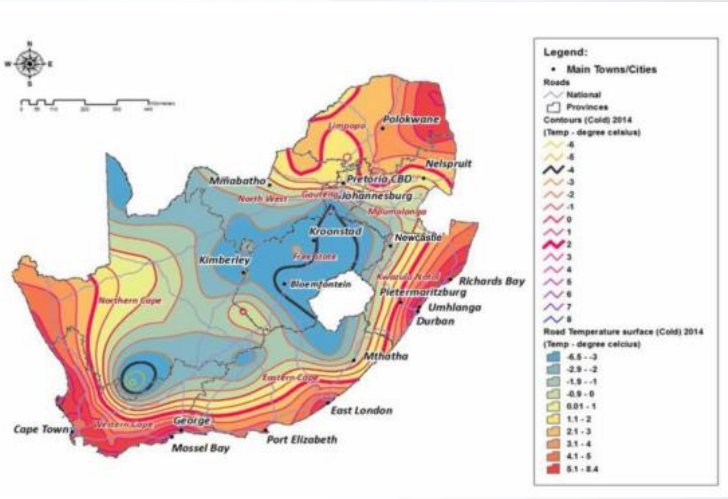
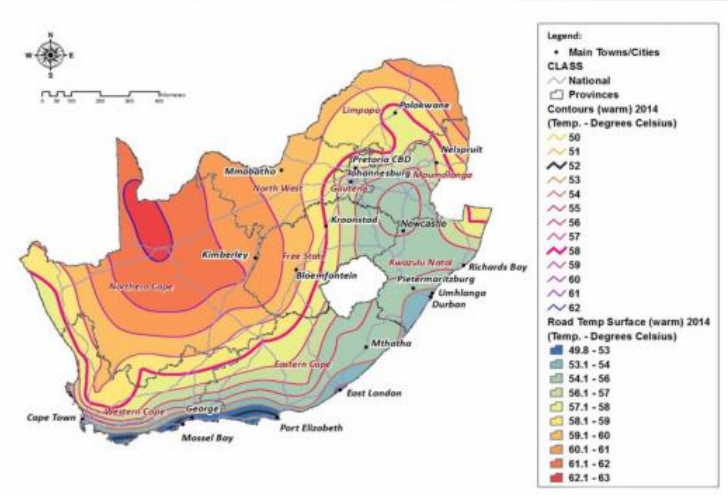


Minimum temperature at 97,5 % confidence level on the road surface



Maximum temperature at 97,5 % confidence level for 7 d annual average at a depth of 20 mm below the road surface

Adaptation planning- Consequence reduction

ThermalPADS

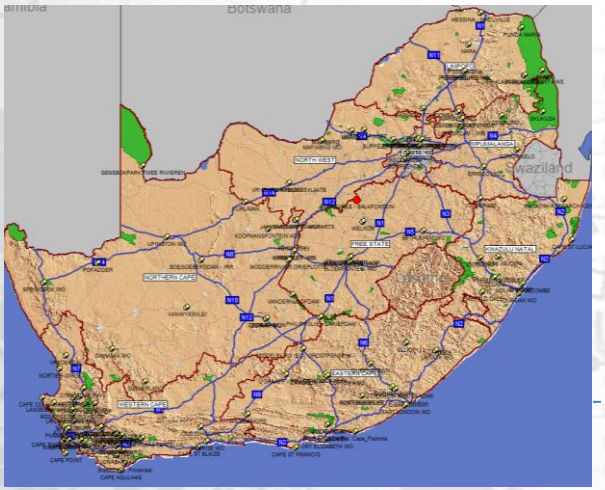
CSIR

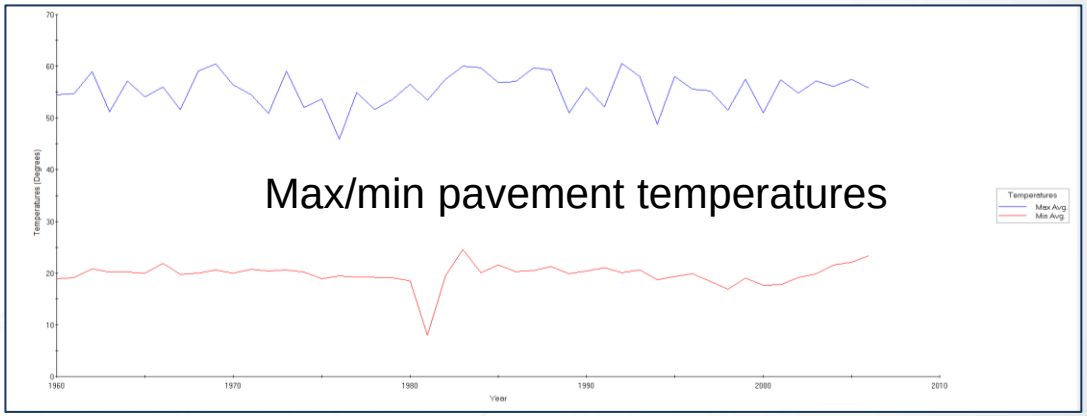
Key weather parameters

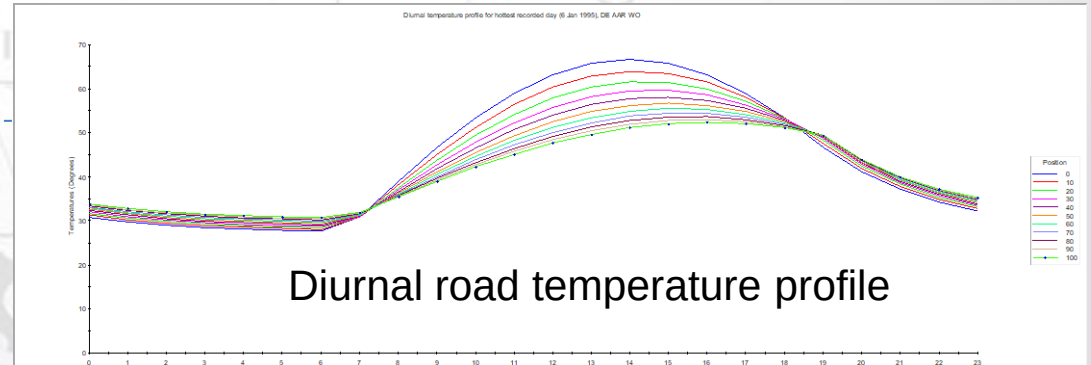
- Ambient temperature
- Cloud cover

Considerations

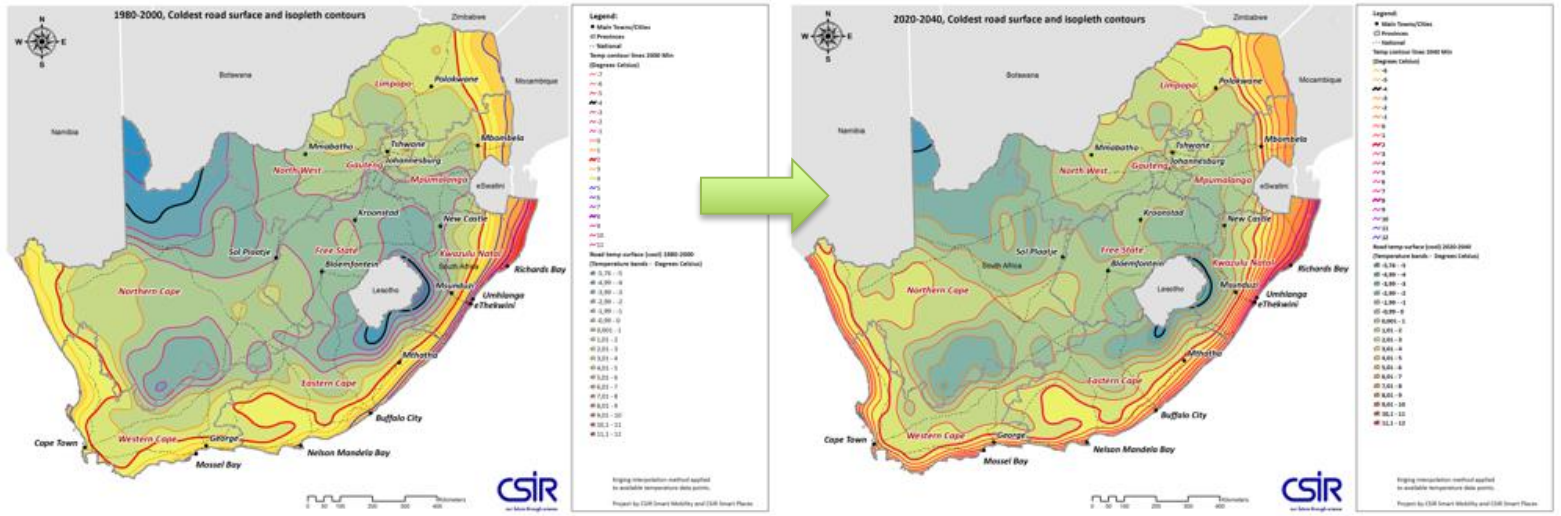
- Zenith angle
- Geographical location



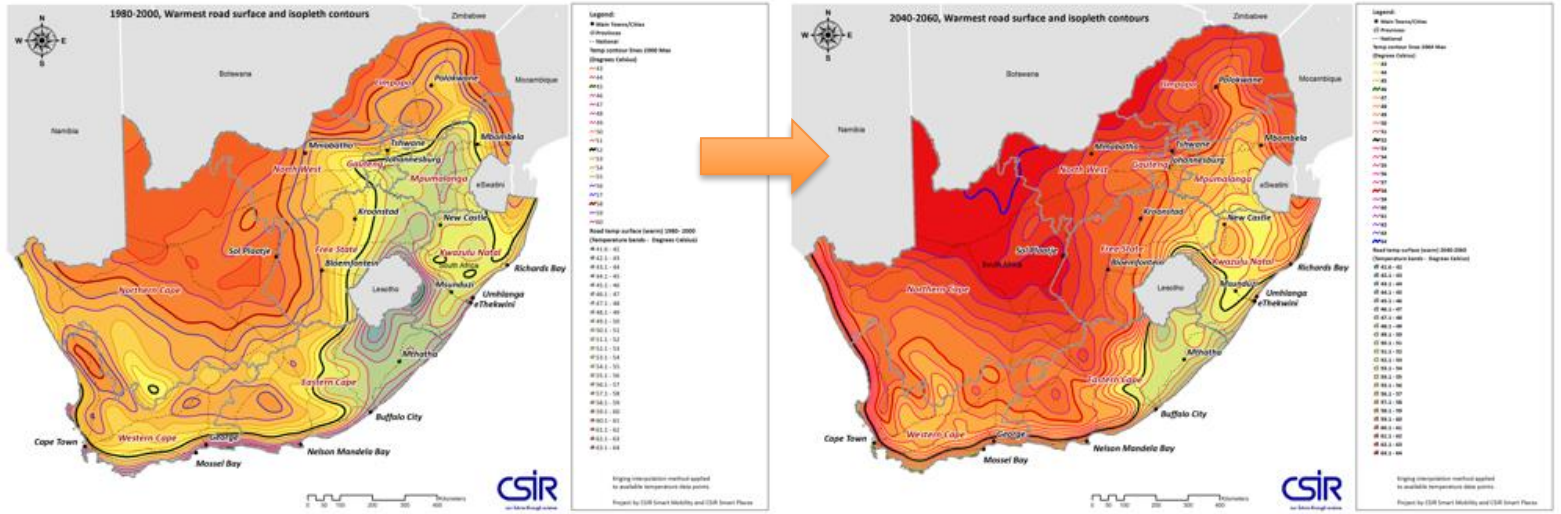




Adaptation planning- Consequence reduction



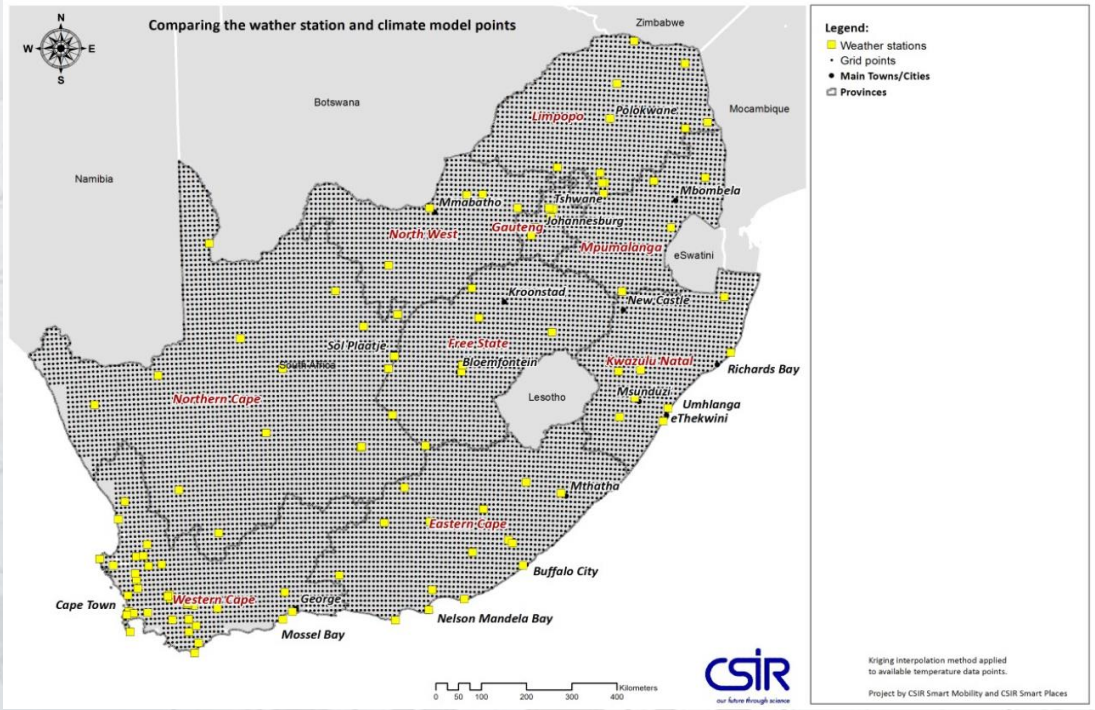
Minimum pavement surface temperature progression between 1980 and 2060 (Mokoena et al., 2019)



7-day maximum pavement temperature progression between 1980 and 2060 (Mokoena et al., 2019)

Adaptation planning- Consequence reduction

- **Key findings:**
  - Established changes in average air temperatures and subsequent changes in pavement temperatures
  - Indication of change in PG high temperature requirements (particularly inland regions)
  - Conservative estimates



Mokoena *et. al., 2021*

Weather station data

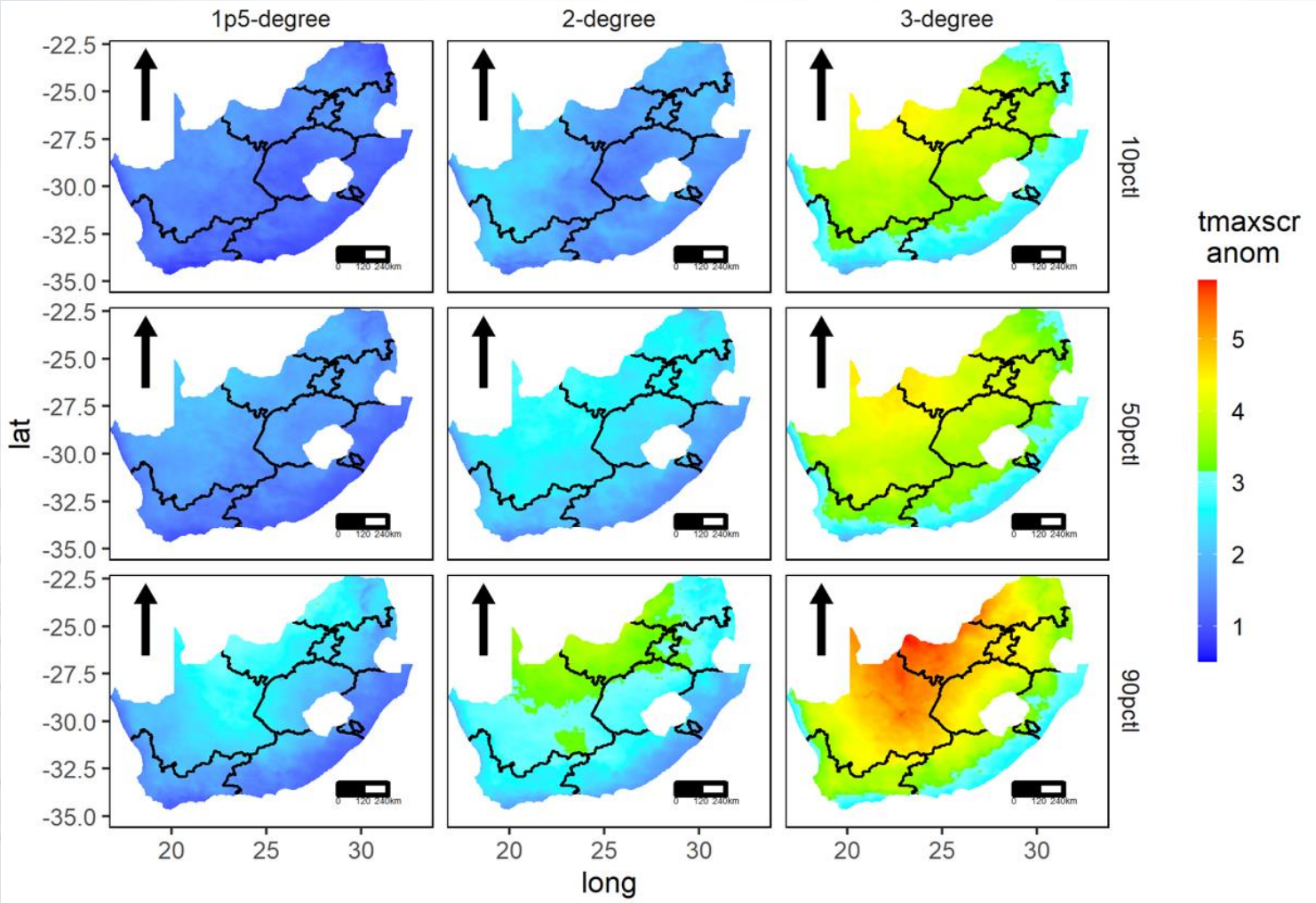
- Measured temperatures
- Actual weather station readings
- Incomplete datasets
- Sparsely situated

vs

Climate model data

- Projected temperatures
- Use of climate models
- Complete datasets
- High resolution

Methodology- Ensemble approach



- 50th percentile of 7 downscaled Global Circulation Models

Methodology - Bias-correction

"Bias-correction is the process of scaling climate model outputs to account for their systematic errors, in order to improve their fitting to observations." – (Teutschbein & Seibert, 2010)

- Main objective is to incorporate bias-correction techniques to climate data output

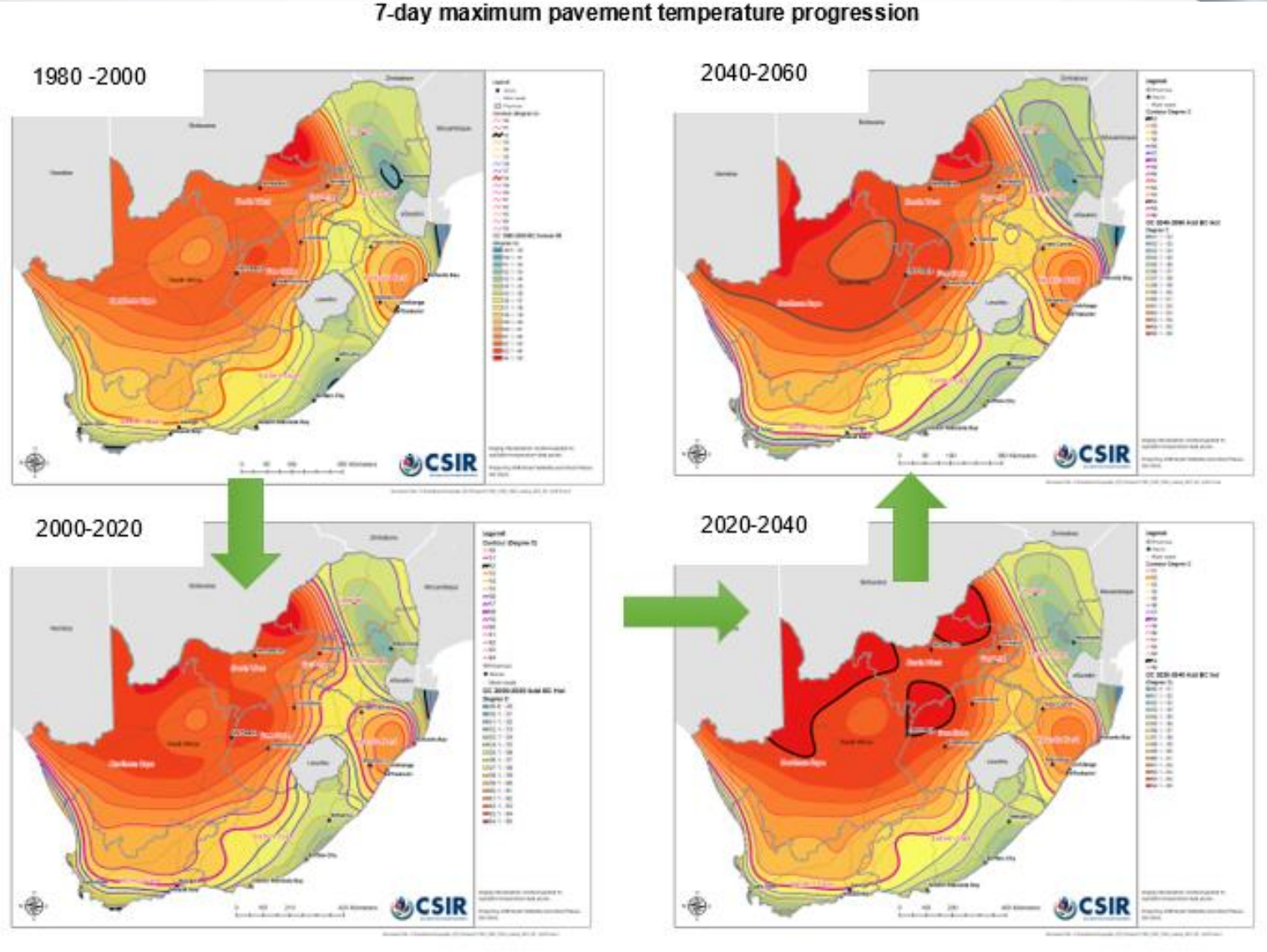
7 GCMs

Precipitation	Temperature
Linear Scaling (LS)	Linear Scaling (LS)
Daily Translation (DS)	Daily Translation (DT)
Local Intensity Scaling (LOCI)	Variance scaling (VARI)
Daily Bias Correction (DBC)	Distribution Mapping (DM)
Power Transformation (PT)	Empirical Quantile Mapping (EQM)
Distribution Mapping (DM)	
Empirical Quantile Mapping (EQM)	

Linear Scaling (LS)	Variance scaling (VARI)
ACC.CCSP85	ACC.CCSP85
ACC.RCP85	ACC.RCP85
CCS.RCP85	CCS.RCP85
CNR.RCP85	CNR.RCP85
GFD.RCP85	GFD.RCP85
MPI.RCP85	MPI.RCP85
NOR.RCP85	NOR.RCP85

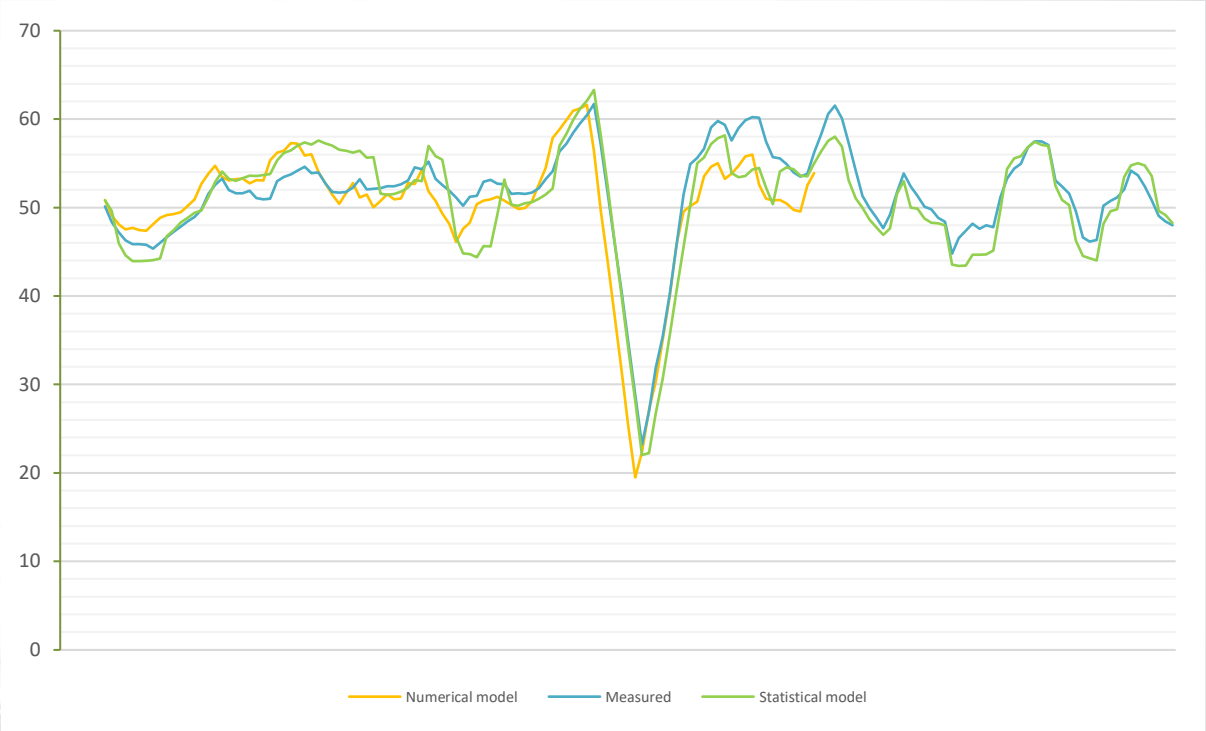
Luo et al., 2018

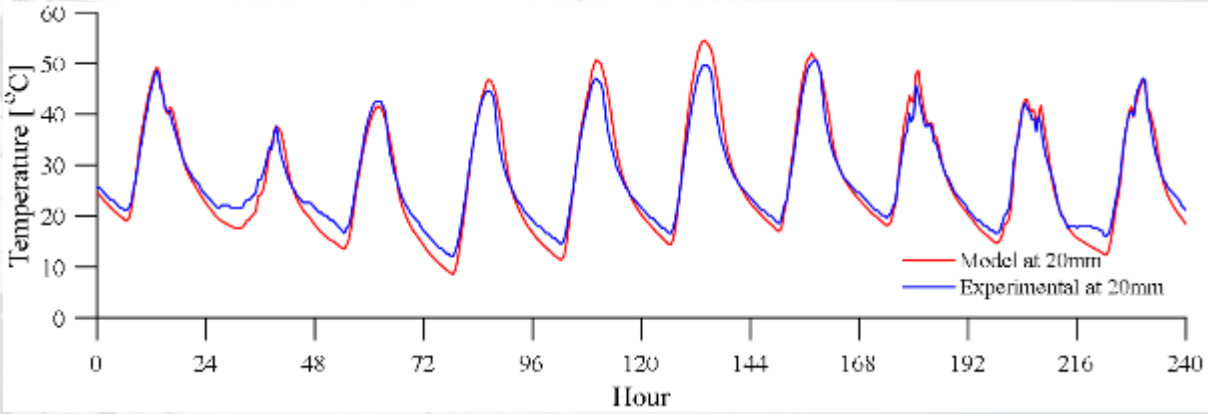
Bias-corrected pavement temperature maps



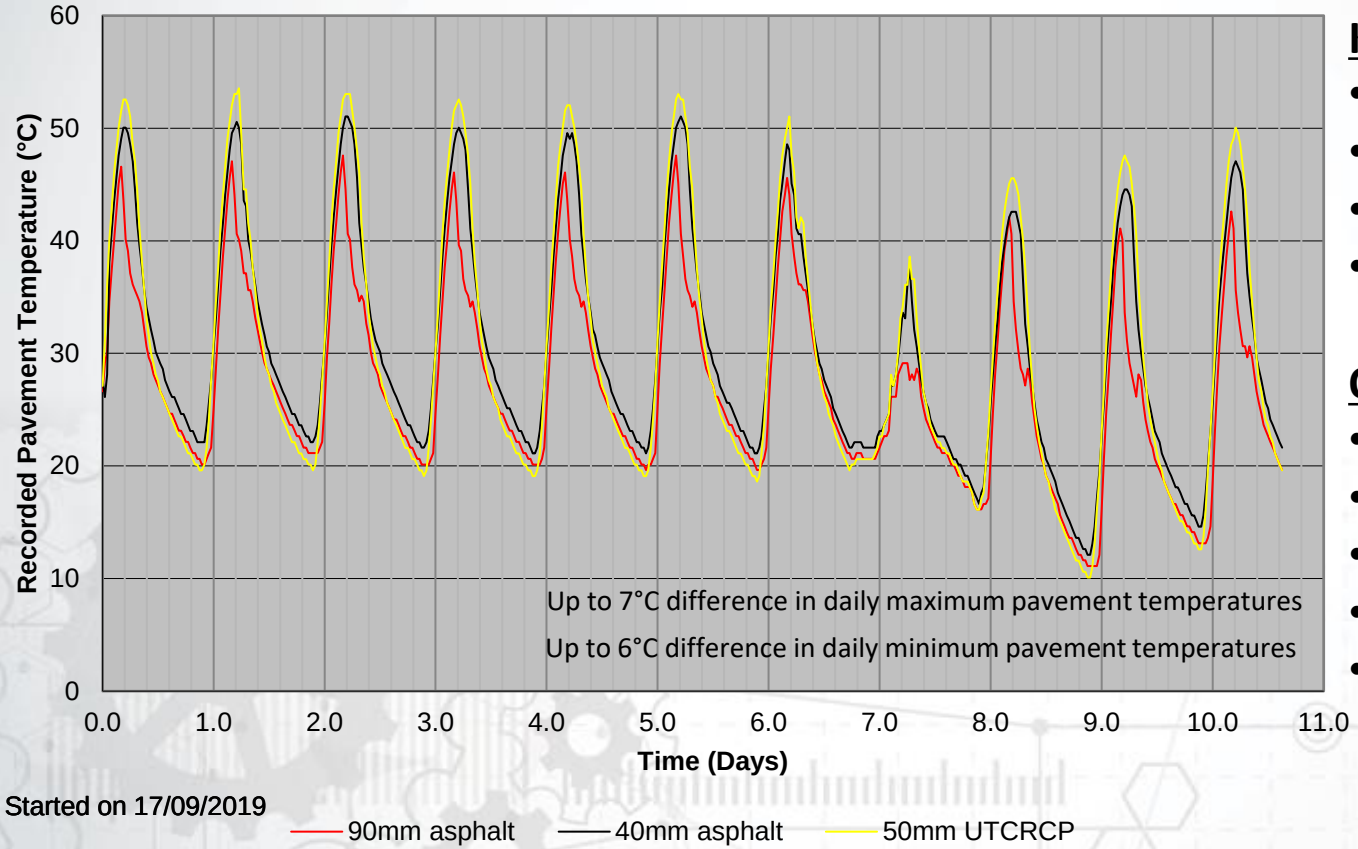
Other considerations – Pavement models

- Analytical models
  - Obtaining an exact solution
- Numerical models
  - Use of reasonable estimates to arrive at solution
- Empirical models
  - Usually based on a regression analysis of the measured results





Other considerations – Pavement materials



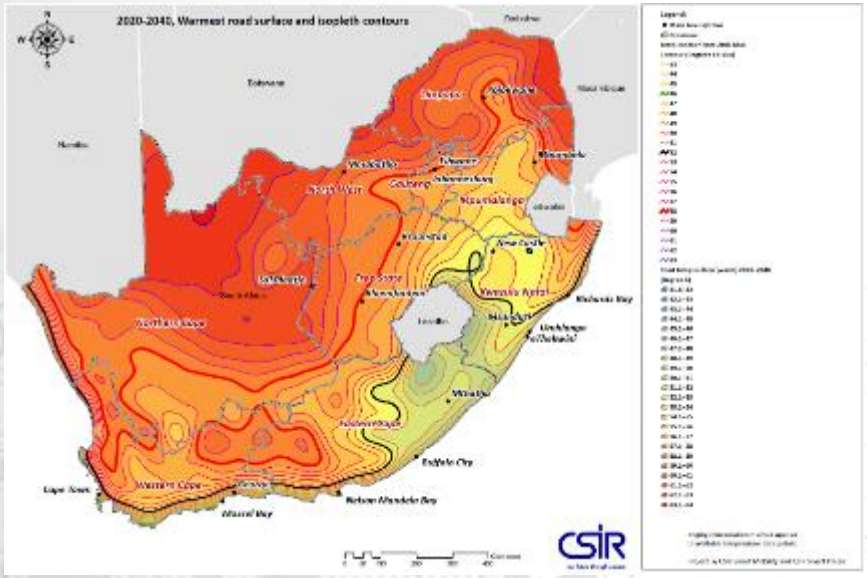
Key Weather parameters

- Solar irradiance
- Ambient temperature
- Wind speed
- Cloud cover

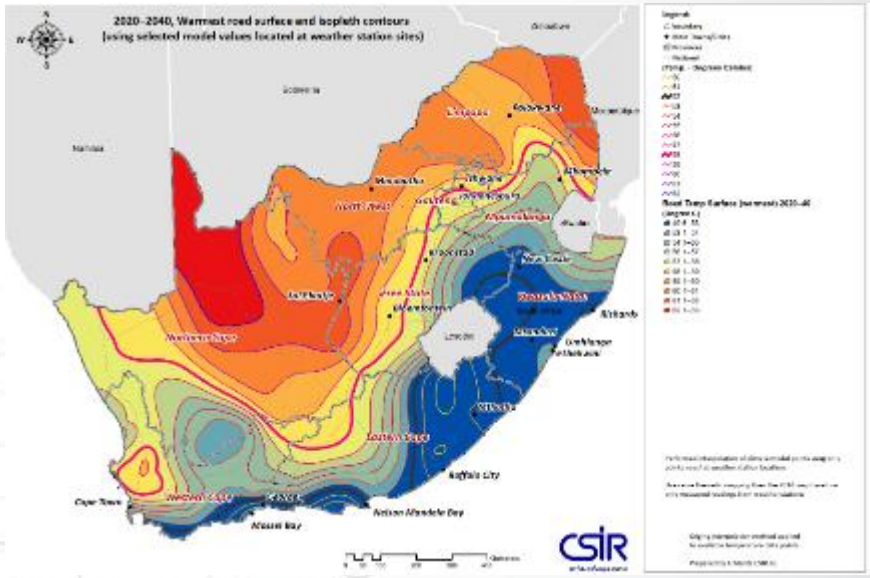
Other considerations

- Material properties
- Pavement structure
- Geographical location
- Surrounding terrain
- Micro- and meso-climates

Other considerations – Mapping procedure

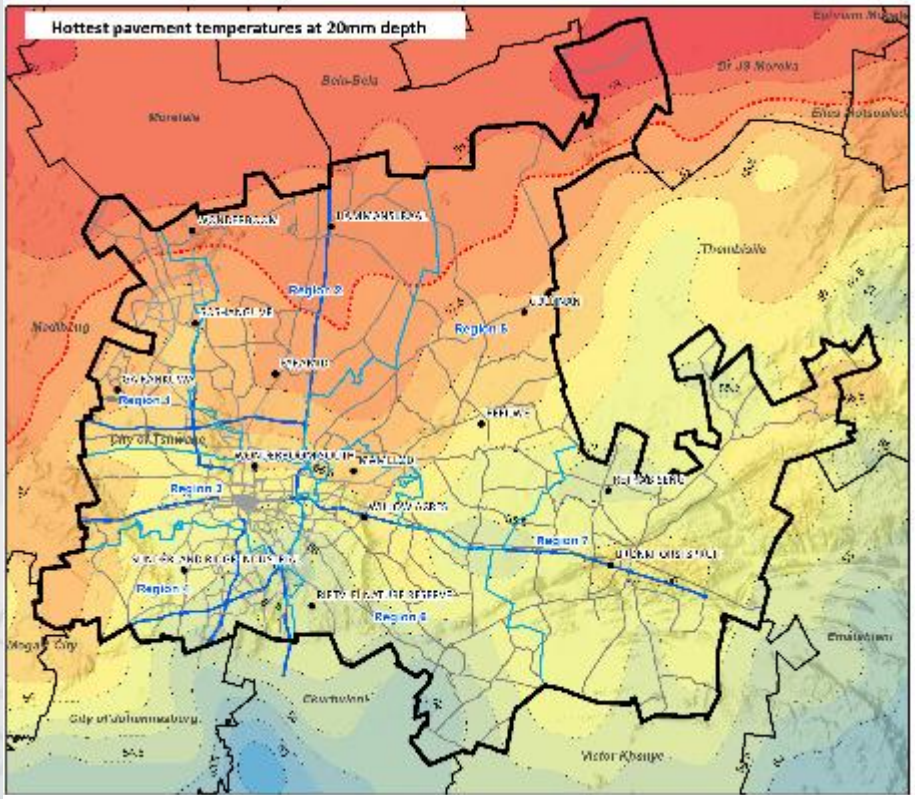


2020–2040 map and national road network from the 8 × 8 km grid (Mokoena *et. al.*, in press)

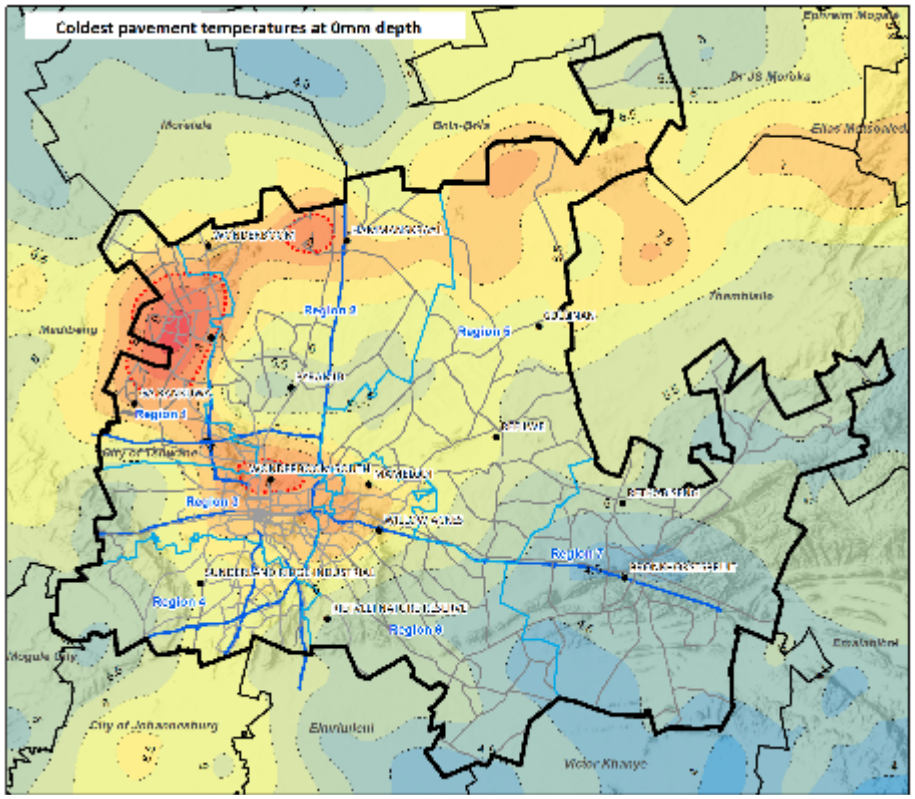


2020–2040 map and national road network generated using limited climate model points (Mokoena *et. al.*, in press)

Other considerations – Urban heat islands



Tshwane 7-day hottest road temperature at 20 mm depth (Mokoena *et. al.*, in press)



Tshwane coldest road surface temperature (Mokoena *et. al.*, in press)

- PG specification at municipal level
- Clear hotspots in North eastern sections of Tshwane
- Higher impact on low pavement temperatures material selection for performance graded bituminous binder

SATC Climate Change Workshop (7 July 2021)

- Proceedings
  - Southern Africa as a climate change hotspot
  - Importance of roads for evacuations and crisis management
  - The CSIR Green Book
  - Infrastructure and Climate Network
  - City of Tshwane's Climate Change Policy
  - National Climate Change Adaptation Strategy

SATC Climate Change Workshop (7 July 2021)

- Recommendations
  - Need to create an interface between existing structures aimed at transport infrastructure and climate change adaptation
  - The Department of Transport is best positioned to take the lead in mainstreaming climate change into transport sector policies and strategic plans that can cascade to provincial and municipal levels with the necessary research
  - Industry forums will also play an important role in enforcing this message across all its members for effective implementation
  - National Risk & Vulnerability Assessments, Engineering & Non-engineering Adaptation Options are recommended for dealing with the climate adaptation of South Africa's transport corridors

Way forward

Vulnerability assessment → Adaptation options → Adaptation planning → Implementation → Review

Planning, design, construction, monitoring and maintenance

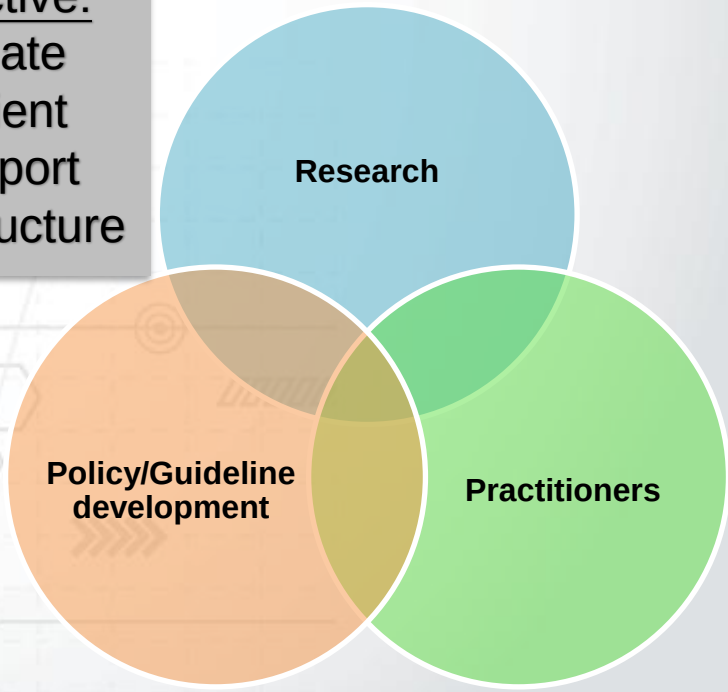
Lessons learnt:

- Customized requirements for use in engineering design
  - Temperature based material selection
  - Stormwater infrastructure design

Way forward:

- Similar approach for similar key weather parameters
- Tools development for infrastructure design, construction, monitoring and maintenance
- Climate dependent performance testing
- Incorporation to existing technical standards and maintenance systems

Objective: Climate resilient transport infrastructure



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