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Climate Change Risk and Vulnerability Assessments and Adaptation strategies for South African Ports
R. van Ballegooyen, N. Siyakatshana, F. Engelbrecht. T. Daniels, V. Beakam, M. Rossouw, M. Mateyisi, C. Troch, Nosipho Zwane, G. Smith and N. Mbatha

Climate Change Risk and Vulnerability Assessments and Adaptation strategies for South African Ports

Roy van Ballegooyen[1], Njabulo Siyakatshana[2], Francois Engelbrecht[3], Tania Daniels[4], Vishern Beakam[5], Marius Rossouw[1], Mohau Mateyisi[2], Chris Troch[2], Nosipho Zwane, Geoff Smith[1], and Nelson Mbatha[5live]

1 WSP Group Africa (Pty) Ltd, South Africa; roy.vanballegooyen@wsp.com

2 CSIR, South Africa

3 Global Change Institute, University of Witwatersrand, South Africa

4 South African Weather Services, South Africa

5 Transnet National Port Authority, South Africa

Abstract: South Africa's ports play a major role in the country's economy. Should climate-related infrastructure damage or operational disruption occur, this could have severe "knock-on" effects to the wider economy. Consequently, Transnet, since 2010, has been in the process of developing an integrated Climate Change Strategy across its operations, commencing with a preliminary Risk and Vulnerability assessment for all Transnet Operating divisions in 2010, followed in 2014 by a first-level risk and vulnerability assessment for the Transnet National Port Authority to assess potential drivers of climate-change risk to port infrastructure, operational support systems, activities related to safety and long-term sustainability of the eight ports they presently manage. Only once the climate-related changes in these key environmental drivers are adequately understood and characterised at a local scale, is it possible to assess climate change risks in each port with sufficient rigour to ensure that any proposed adaptation measures are both appropriate and economically justified. Presented here is initial progress with a TNPA-funded, multi-year, collaborative effort by a consortium of scientist and engineers from range of local institutions and consultancies in making such a detailed Climate Change Risk and Vulnerability Assessment informing the development of Adaptation strategies for South African Ports.

Keywords: Climate Change, Risk and Vulnerability Assessment, Climate-Change Adaptation Strategies.

Introduction

South Africa's ports play a major role in the country's economy and therefore should infrastructure damage or operational disruption occur, this could have severe "knock-on" effects to the wider economy whether due to existing or future climate conditions. Any existing infrastructural and operational vulnerabilities to existing climatic conditions, in most cases, are likely to be significantly exacerbated by the effects of climate change (CSIR, 2014).

Recognising such vulnerabilities, Transnet, since 2010, has been in the process of developing an integrated Climate Change Strategy across its operations. The purpose of the strategy is to manage Transnet's exposure to climate change-related risks, and to address Transnet's responsibilities, both as a corporate citizen and as a State-owned Enterprise, in assisting South Africa to meet its international commitments for carbon emission reductions, climate change mitigation and adaptation, as outlined in the National Climate Change Adaptation Strategy approved by the South African Government in August 2020.

As part of the first phase of development of Transnet's Climate Change Strategy, a preliminary Risk and Vulnerability assessment, was conducted in 2010 [22]. This assessment provided a high-level overview of key risks and opportunities for the Transnet Group as a whole, as well as its individual Operating Divisions such as the National Ports Authority. Aspects such as commercial, physical and even reputational risks were addressed, indicating the importance of a holistic understanding the scope and nature of the potential impacts of Climate Change. Of the risks assessed in the study, the greatest identified risk to Transnet National Port Authority (TNPA) was assessed to be the "physical risks" to port infrastructure and operations, a fact re-affirmed by TNPA identifying this as a Priority 1 risk for South African ports in its 2022 Annual Report. A follow-up study was conducted in 2014 [3], comprising a first-level risk and vulnerability assessment of the potential drivers of climate change and the associated implications for identified port elements (*i.e.*, infrastructure and operational support systems) as well as activities related to safety, operations and long-term sustainability of the eight ports presently managed by TNPA. The approach taken in this study was to assess the risk and vulnerability of port infrastructure and operations to changes in key drivers under existing climatic conditions, as well as two potential future climate change scenarios. From this study it became clear that, to ensure a sufficiently robust assessment of the risks associated with climate change for the eight TNPA-managed ports, will require a sufficiently rigorous assessment of how climate change will play out not only for the greater region but specifically within each port. Only once the climate-related changes in the key environmental drivers (i.e., changes in statistical distributions of winds, sea levels, waves currents, *etc.*) are adequately understood and characterised at a local scale, will it be possible to assess the climate change risks in each port with sufficient rigour to ensure that any proposed adaptation measures are both appropriate and economically justified.

Since these earlier studies, significant progress has been made in predicting future climate change scenarios as well as in the capability to down-scale and model the likely climate--change related shifts in temperature, rainfall, winds, sea level, waves, currents; water quality, sediment transport and ecosystems affecting South African ports infrastructure and operations.

This paper summarises early progress in a TNPA-funded, multi-year, collaborative study by a CSIR led consortium comprising the CSIR, the University of the Witwatersrand, the South African Weather Services and WSP Group Africa, designed to address such issues. The main emphasis of the collaborative study is to provide a more rigorous assessment climate-related changes in key environmental drivers affecting port infrastructure and operations, a pre-requisite for undertaking a risk and vulnerability assessment that adequately informs the selection of adaptation strategies.

Such strategies include the design of suitably resilient infrastructure and port operations, as well as risk management systems to better manage risks associated with climate change.

Approach

The key goals of the overall study are to:

- provide a sufficiently rigorous assessment of the expected changes in atmospheric and ocean forcing likely to occur under appropriately selected future climate change scenarios;
- down-scale these climate-related changes in forcing to accurately represent local conditions both external and within the ports (*i.e.*, characterise locally the shifts in key drivers affecting the construction and maintenance of both present and future port infrastructure and operations);
- use this information to provide a better informed and more rigorous assessment of Risk and Vulnerability to port infrastructure and operations posed by climate-related changes in identified key drivers, and ;
- based on the updated Risk and Vulnerability Assessment, undertake the selection and co-production with TNPA of appropriate adaptation strategies for each of the South African ports managed by TNPA.

The project structure adopted to address these key elements is provided in Figure 1. This paper reports on the progress to date in executing these key project elements.

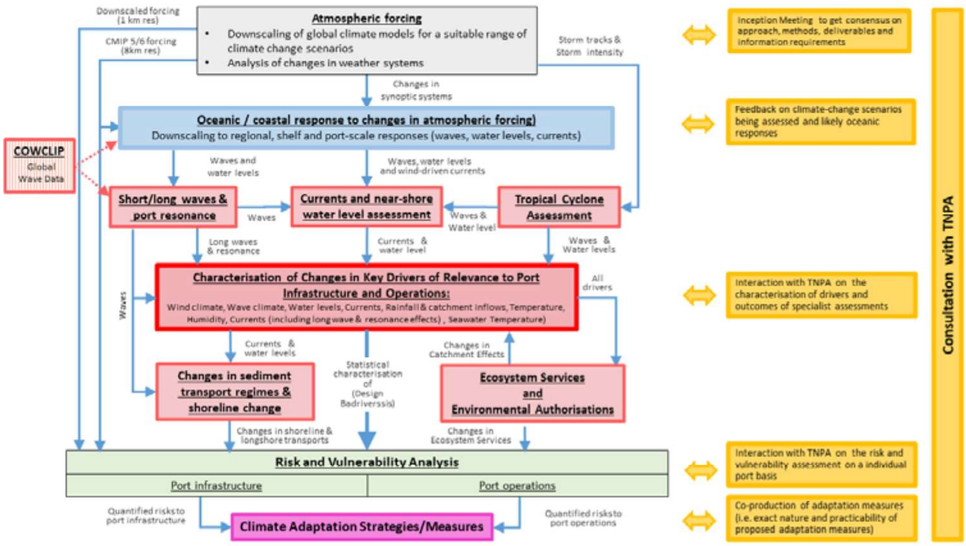

Figure 1: The key elements of the Risk and Vulnerability Assessments and development of Adaptation Strategies, indicating the data and information dependencies between the key project elements and the required consultation to ensure robust and agreed upon outcomes.

Risk and Vulnerability Assessment Framework

As noted in the introduction, an initial review (WSP, 2010) of the key risks and opportunities for the individual Operating Divisions (such as the National Ports Authority) and the Transnet Group as a whole, identified the greatest risk to be due to ”physical risk”. This led to the more detailed risk and vulnerability assessment undertaken in 2014 (CSIR, 2014) that focussed solely on such “physical risks”. Specifically issues such the development of port infrastructure and ongoing port operations and shipping on GHG emissions were excluded from this study.

This study undertook a risk and vulnerability assessment for the eight ports presently managed by Transnet, under the following three scenarios:

- Scenario A: Existing conditions, *i.e.,* a no climate change scenario;
- Scenario B: A sea level rise of 0.5 m and a 10% increase in all other drivers considered, and
- Scenario C: A more extreme sea level rise of 1.0 m and a 20% increase in all other drivers considered.

The results of two of these scenarios are presented in Figure 2.

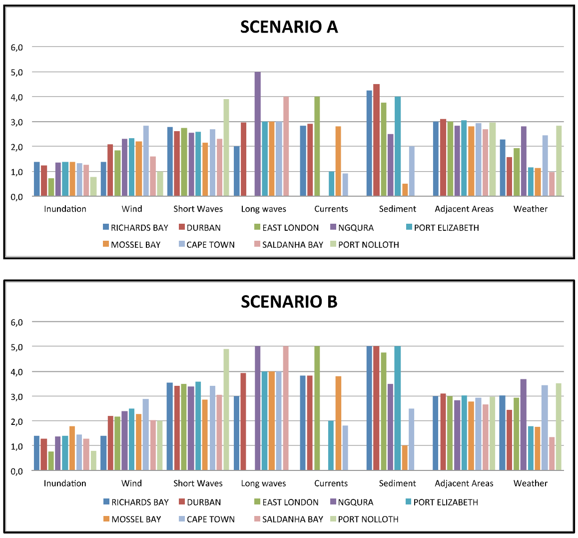

Figure 2: Vulnerability rating of ports under Scnerio A (no climate change) and Scenario B (moderate climate change) [3].

Issues around changes in sediment transport regimes, together with changes in wave climate, are highlighted as constituting the major risks to ports in terms of climate change. It is for this region that the detailed modelling proposed for the present study focusses on the detailed down-scaling of climate-related changes in large-scale forcing to inform resultant changes in the key drivers of waves, water levels and sediment transport.

A more recent global assessment provides context to these results [6], particularly in terms of multi-hazard risks due to climate change. The study reports a particular vulnerability of South African east coast ports to such multi-hazard risks associated with climate change.

Early guidance on risk and vulnerability assessments was provided by PIANC [11], that was followed by a more comprehensive guidance document in 2020 [12]. Subsequently additional guidance was provided by PIANC on climate change risks [15] and resilience of port infrastructures [13, 14]. The study undertaken for TNPA in 2014 [3] included the first three of the key elements identified in PIANC guidance document for “Climate Change Adaptation Planning for Ports and Inland Waterways” [12], namely:

- The identification of key infrastructure and operations at risk due to climates change, the exact nature of the vulnerabilities and required adaptation and resilience objectives;
- The robust and detailed characterisation risk parameters (wind, waves, currents, *etc.*) at the local port scales both under present and future climatic conditions;
- A risk analysis based on an agreed upon approach, that included identification of hazards, detailed characterisation of the risks, *i.e.,* the nature of impact, the vulnerability to such impacts and the likelihood and consequence of such impacts.

Excluded from this initial study was the identification and assessment of the likely efficacy and desirability of adaptation measures and associated adaptation pathways. The study did not explicitly consider adaptation measures due to insufficient rigour in the characterisation of many of the risk parameters at the local port scale, the very issue that the present study seeks to address.

The risk and vulnerability method proposed for the present study largely mirror that of the initial 2014 assessment, with some minor modifications and enhancements to ensure consistency with more recent similar assessments [6].

Atmospheric Forcing

The objectives of this component of the study are:

- the identification of a range of climate change scenarios under likely emissions scenarios that need to be considered and the effect that such changes will have on large-scale atmospheric circulation;
- the detailed characterisation of key weather systems such as cut-off lows and cyclones that presently, or will in future, pose significant threat to existing port infrastructure and

operations, and how these weather systems will change under future climate change;

- downscaling of global climate model outputs for the selected climate change scenarios to provide high resolution characterisations of local conditions at each of the ports. This information is required for both direct hazard assessment (*e.g.,* highly variable wind conditions affecting operations in the Port of Cape Town and flooding effects on the Port of Durban), as well as inputs to the other study components.

Based on a ranking of Coupled Model Intercomparison Project Phase 6 (CMIP6) global climate models in southern Africa [8], an ensemble of the three best performing global climate models (GCMs) , namely FGOALS-g3, MPI-ESM1-2-HR and NorESM2-LM, has been selected for the development of methodologies to track both cut-off lows and tropical cyclones, as well as investigating the frequencies and intensities of these weather phenomena in future. A tracker previously developed and utilized for the identification and tracking of cut-off lows over southern Africa in reanalysis data and climate change projection scenarios [5], is being used determine cut-off low attributes such as frequency of occurrence and geographical location under both present and future climates. A similar effort is being undertaken for the tracking of tropical cyclones [5, 9, 10], under existing and future climate scenarios. The findings of this analysis, once available, will be utilised in detailed modelling of tropical cyclones at the relevant east coast ports.

Downscaling efforts include the characterisation of down-scaled winds, temperature and rainfall that will directly inform the Risk and Vulnerability Assessment. For example, extreme rainfall events are projected to increase in their frequency of occurrence over eastern South Africa, including at the ports of Durban and Richards Bay.

However, more important is that the downscaled atmospheric drivers from this component of the study will inform the modelling undertaken in the remaining project elements, particularly the characterisation of changes in local winds, water levels and wave conditions that, in turn, will influence strongly the sediment transport regimes and the natural systems (and associated ecosystem services) in the ports. It is planned to generate 8 km resolution wind data for the planned regional wave and water level modelling to be undertaken for this study.

Statistical downscaling of extremes is planned, based on measured data for the ports and well as measured data from the South African Weather Services. This downscaling will commence once all relevant measured data have been collated.

Regional Wave and Water level modelling.
The characterisation of wave and water level climates under both present day and future climate conditions is important, particularly insofar as providing joint probabilities of occurrence of high wave conditions and increased water level due to wind-driven flows (storm surges.

The data to be used in these regional model simulations include:

- wave boundary conditions for the low mitigation greenhouse gas emission scenario, SSP5-8.5 from two climate models forced by EC-Earth3 and ACCESS-CM2 for the period 1961–2100, and
- 8 km resolution downscaled atmospheric forcing data from the same two models.

This modelling study presently is its early stages of implementation. The planned model outputs are important inputs into higher resolution modelling to be undertaken within the immediate environs pt the ports and as well within the ports (see section on Nearshore and Port Wave Modelling).

The legacy forecasting systems from this endeavour are likely to form an integral part of the risk managements systems to be embedded in adaptation strategy pathways being developed as part of this study.

Nearshore and Port Wave Modelling.
Waves and water level changes (storm surges) arguably pose the most important and persistent risks for port infrastructure and operations.

High resolution nested SWAN models for each of the ports have been setup and refined to a resolution of approximately 20m in each of the 8 port regions. Test frameworks and events have been run for offshore wave and wind events. An example of the high-resolution output from a nested grid for the port region of the port of Cape Town is shown in Figure 3.

Once the outputs from the regional wave modelling for existing and future climate changes scenarios are available, the models will be used to generate the statistical analyses that can be used as the "design basis" for assessing the risk of both present and future climate.

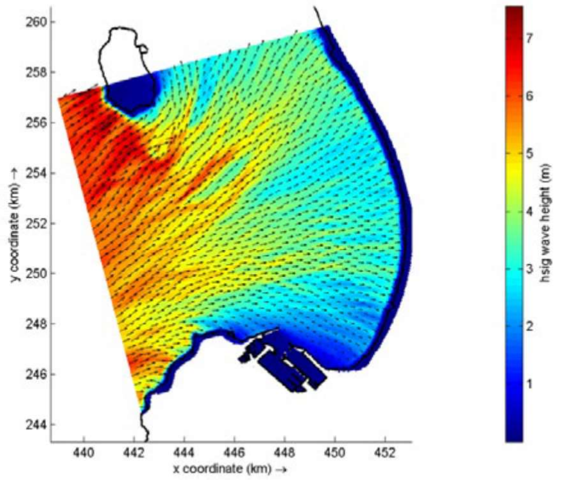

Figure 3: An example of high-resolution SWAN wave model output for the port of Cape Town showing significant wave height, and peak wave direction (vectors).

Also planned are wave penetration studies for the Ports of Richards Bay Durban and Cape Town, using the Mike 21 Boussinesq Wave model to assess whether wave conditions will get worse inside ports under climate change.

Challenges associated with the effects of long waves exist in the Ports of Saldanha, Cape Town and Ngqura. Therefore, it is important to quantify the long wave effect to determine if these will be exacerbated by climate change. Presently, running of long waves frameworks are complete for these 3 ports. Figure 4 provides a comparison of measured and modelled long wave conditions obtained applying the Port of Cape Town framework.

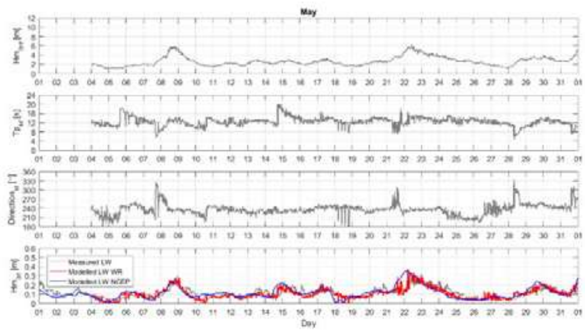

Figure 4: A comparison of measured and modelled long wave parameters applying the Slangkop and NCEP hindcast data for the month of May 2018.

Tropical cyclones assessment

Tropical Cyclones (TC) can generate severe wave conditions, as was the case with TC Imboa off Richards Bay in February 1984 when a significant wave height of approximately 8 m was recorded off the port. Although rare events, TC's pose high risk events ports. TC activity is not uncommon to the region north of Richards Bay. Given the rarity of such events, South African ports are likely to be ill-prepared should such events occur more frequently.

Based on predictions from the tropical cyclone tracker utilised to assess existing and future climate change scenarios, model simulation will be undertaken to determine water levels and wave conditions extremes associated with such events. The information generated will be used to quantify the risk and vulnerability of both existing and future port infrastructure and operations for the two most severe tropical cyclones events identified for future climates.

Sediment Transport Regime Assessments

The primary influences from climate change on sediment transport regimes are related to changes in water level and wave conditions (both in extremes and average climate conditions), The resultant climate-related changes in sediment transport regimes could result in:

- erosion/accretion effects of ports on neighbouring shorelines due to wave sheltering effects and/or changes in sand supply;
- altered maintenance dredging (*e.g.,* changes in the accumulation of sediments in sand traps, due to changing longshore sediment transport) [4, 16] and associated beach nourishment requirements [18];
- Increased erosion or sedimentation within ports due to changes in hydrodynamic conditions within the port [20]
- Changes to the stability of sandy shorelines within ports (the south bank of the Richards Bay port entrance which is managed by a series of groynes) [17];
- the integrity of environmentally sensitive habitat within ports (i.e. the Central Sandbank in Port of Durban) [21];

The intention is to quantify, as best possible:

- potential changes in sediment transport regimes and associated impacts as described above for the most likely climate change scenarios, and
- possible adaptation and/or mitigation measures that are likely to require significant modification of existing dredging and sand-bypassing activities.

To achieve the above requires an understanding of the natural transport regimes as modified by existing dredging, sand-bypassing, shoreline management and catchment flow management activities. Thus, in addition to information on existing sediment transport regimes, required is a robust characterisation of existing (capital and maintenance) dredging and shoreline management activities.

The review of such activities is largely desktop but will be supplemented by a limited modelling effort for ports where there exist major concerns. This is expected to include one or more of the Ports of Durban, Richards Bay and Ngqura.

Currents And Near-Shore Water Level
For most of the east coast ports, wave- and wind driven flows, and even the influence of the Agulhas Current on occasion, make for potentially challenging conditions at the port entrances. This was particularly true for the Port of Durban prior to the widening of the port entrance channel.

Climate change is expected to result in changes in large-scale ocean circulations, that together with changes in the wave climate, could change both the flows and water quality over the adjacent shelf and in the vicinity of port entrances. While predicted increases in mesoscale activity in the Agulhas Current [2] could influence inshore currents [1, 7], by far the greatest effect on navigation is expected the wave-and wind-driven flows at the port entrances [19]. These risks associated with climate change will be assessed once the changes in wave- and wind-driven flows have been more robustly characterised for the climate change scenarios considered in this study.

Ecosystem Services and Environmental authorisations.
A key factor in future port development and existing operations is the utilisation of the ports by other users as well as ecosystem services derived from the port environments. Ports can no longer operate without acknowledging and incorporating societal and environmental considerations in their planning and management. There exist uncertainties (changing baselines and vectors of change), associated with the effects of climate of port ecosystems that hamper assessments undertaken to achieve environmental authorisation for proposed port developments.

A broad review of the current and likely future ecosystem services derived from natural infrastructure in ports (inclusive of those that benefit port operations) as well as current and likely future threats to these services, will be undertaken. This will be based on the predicted climate-related changes in key drivers such as changing water levels, changing catchment stormwater and sediment inflows and to the ports, erosion and inundation of habitats, amongst others.

Updated Risk and Vulnerability Assessment
An updated risk and vulnerability assessment will be completed based on the more robust characterisation of the key drivers generated by this study. Depending on the type of risks identified and the associated uncertainties, the most appropriate and cost-effective adaptation measures are likely to include changes in one or more of the following:

- infrastructure design,
- port operations,
- management systems,
- maintenance activities; and
- general behaviours.

Given the inherent uncertainty in the assessed risks and likely efficacy of proposed adaptation measures,' it is best to adopt an adaptation pathway which itself can change and adapt to new knowledge or evidence over time. It may also prove cost-effective to undertake short-term measures to buy time. More expensive or longer-term solutions can then be adopted, designed and implemented as data availability and understanding (e.g. of local rates of change) improve. Furthermore:

- no- or low-regret solutions that deliver benefits irrespective of how the climate changes, and
- nature-based solutions that capitalise on nature's resilience,

can play an important role in accommodating uncertainty.

It is planned to identify and develop adaptation strategies in a co-production mode with TNPA, ultimately resulting in an adaptation strategy based on identified adaptations measures, their likely efficacy and whether they are deemed cost-effective.

Project Legacy
The project will conclude with quantitative, probabilistic estimates of the main risks over time, and the formulation of suitable adaptation options for each key risk identified. This is expected to include a "design basis" for climate change that can be utilised in future design and or detailed assessment of proposed developments within the Transnet ports. Whilst, in general, risk is best managed by including resilience to climate-change resilience in the design of port infrastructure and operations, a likely legacy of the project is an improved measurement and predictive modelling capability to actively manage risk to port operations and shipping.

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