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Invited Papers**

**The Role of Spatial Data in Understanding Climate  
Change Risk \***

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# **The Role of Spatial Data in Understanding Climate Change Risk**

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## **Summary**

The development of climate change adaptation policies must be underpinned by a sound understanding of climate change risk. As part of the Hyogo Framework for Action, governments have agreed to incorporate climate change adaptation into the risk reduction process. This paper explores the nature of climate change risk assessment in the context of human assets and the built environment. More specifically, the paper's focus is on the role of spatial data which is fundamental to the analysis. The fundamental link in all of these examples is the National Exposure Information System (NEXIS) which has been developed as a national database of Australia's built infrastructure and associated demographic information. The first illustrations of the use of NEXIS are through post-disaster impact assessments of a recent flood and bushfire. While these specific events can not be said to be the result of climate change, flood and bushfire risks will certainly increase if rainfall or drought become more prevalent, as most climate change models indicate. The second example is from Australia's National Coastal Vulnerability Assessment which is addressing the impact of sea-level rise and increased storms on coastal communities on a national scale. This study required access to or the development of several other spatial databases covering coastal landforms, digital elevation models and tidal/storm surge. Together, these examples serve to illustrate the importance of spatial data to the assessment of climate change risk and, ultimately, to making informed, cost-effective decisions to adapt to climate change.

## **1. Introduction**

The development of policies and strategies for adapting to climate change requires information about the nature of the risks posed to society. Arguably, the better the knowledge base available to assess these risks, the more informed the decisions about adaptation are likely to be. Although it is desirable to have a comprehensive database available, clearly some decisions can be made without extensive information or can simply be made on an ad hoc basis in response to changes in temperature or increased severity of storms and so on. After all, while severe storms and heat waves are rapid-onset events that come with warnings of only hours or days, many manifestations of climate change, such as sea level rise, occur slowly over years and decades. Nevertheless, many decisions about urban infrastructure and land use, for instance, require years of planning for developments that will endure for decades. Moreover, some of the impacts of climate change may be very costly, such as from increases in droughts or bush fires, or even irreversible, such as accelerated droughts or bush fires and the irreversible effects of eroded coast lines or degraded marine habitats.

The premise of this paper is that if we better understand the risk, we can actually make changes that will reduce the risk and thereby reduce the cost and the loss of life. As discussed in a complementary paper for this conference<sup>1</sup>, the Hyogo Framework for Action 2005-2015<sup>2</sup> articulates five priorities for reducing disaster losses which includes "know the risks and take action". Moreover, within this UN framework, governments have agreed to incorporate climate

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<sup>1</sup> Scott, G. and Simpson, A. (2009): Disaster risk reduction and climate change adaptation in the Australia-Pacific Region, 18<sup>th</sup> UNRCC-AP, Bangkok, 13 p.

<sup>2</sup> Document available online at UNISDR: <http://www.unisdr.org/eng/hfa/hfa.htm>

change adaptation into the risk reduction process by identifying climate-related disaster risks, designing risk reduction measures, and improving the use of climate risk information by planners, engineers, and other decision makers.

This paper explores the nature of climate change risk assessment in the context of human assets and the built environment. First we define what it means to assess risk, and then we present several examples of risk or impact analyses, focussing on the spatial data sets that are critical to the analysis. The fundamental link in all of these examples is the National Exposure Information System (NEXIS) which has been developed as a national database of Australia's built infrastructure and associated demographic information. The first application of NEXIS is to post-disaster impact assessments of a recent flood and bushfire. The second application is for the National Coastal Vulnerability Assessment which is addressing the impact of sea-level rise and increased storms on coastal communities on a national scale. This study required access to or the development of several other spatial databases covering coastal landforms, digital elevation models and tidal/storm surge. Together, these examples serve to illustrate the importance of spatial data to the assessment of climate change risk and, ultimately, to inform decisions about climate change adaptation.

## 2. Assessing Risk

Risk represents the combination of probability and consequence. In the context of the impact of climate change on human settlements or communities, the measurement of risk is a function of three main factors expressed as follows:

$$\text{Risk} = \text{Hazard} \times \text{Exposure} \times \text{Vulnerability}$$

The hazard is the underlying physical phenomenon, such as a tropical cyclone or sea-level rise; the exposure represents the human assets (e.g., buildings and infrastructure) and population at risk; and the vulnerability represents the extent to which the exposure may be damaged or lost or other attributes such as the economy or quality of life may be impacted as a result of the imposed hazard or hazard event. In theory, a reduction in risk can be achieved by reducing one or more of the factors that contributes to risk. For instance, reducing carbon emissions may reduce the likelihood of sea level rise and associated storm surge or coastal erosion hazards; moving communities from coastal areas may reduce their exposure to these hazards; and, finally, building stronger structures or creating better warning systems may reduce the vulnerability. In the parlance of climate change policy, reducing the hazard is referred to as mitigation, while reducing the exposure and vulnerability are the domain of adaptation.

## 3. The Australian National Exposure Information System (NEXIS)

Geoscience Australia has developed the National Exposure Information System (NEXIS) as a fundamental source of information for assessing the impacts of natural and man-made hazards on Australian communities<sup>3</sup>. It is derived primarily from reliable and publicly available datasets.

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<sup>3</sup> Nadimpalli, N., Edwards, M. and Mullaly, D. (2007): National Exposure Information System (NEXIS) for Australia: Risk Assessment Opportunities, in Oxley, L. and Kulasiri, D. (eds) MODSIM 2007 International Congress on Modelling and Simulation, December 2007, pp. 1674-1680. ISBN: 978-0-9758400-4-7.

NEXIS maintains information at building level that is required as input to vulnerability models for a wide range of hazards (inter alia, earthquake, severe wind, tsunami, flood, bushfire, landslide). Exposure information includes population demographics, income demographics, number and construction type of buildings (residential, commercial, industrial and institutions), age of buildings, type of businesses, financial turnover, employees, usage of institutions (education, health, community halls, stadia etc.) and infrastructure associated with sectors such as transportation (roads, railway, tunnels, bridges, airports, sea ports).

Exposure information is highly diverse and must be extracted from more than one dataset. It must take into account vulnerability from many perspectives: economic, social, and built infrastructure, all subjected to the potential cascading effects of a hazardous event. NEXIS information is categorised into residential, business, institutions and infrastructure exposure (Figure 1). In the absence of data on each individual structure, the information is collated using reasonable and logical assumptions and expressions to achieve an exposure definition that is consistent with available aggregated data.

Exposure information is in varied resolutions (state, post code, census collection district, buildings or personal) and is impractical to collect and collate for the entire nation. Therefore, a statistical approach was adopted for the NEXIS framework, whereby the information is derived from a number of basic datasets and distributed to individual assets in a representative manner. The assumptions and statistical models for this mapping process are modified and improved as more data are acquired. The four NEXIS components are as follows:

- NEXIS Residential. The data sources include: demographic (census) information from the Australian Bureau of Statistics; geographic location (geocoded addresses) from the Geo-Coding National Framework (GNAF); and structural information from a range of housing surveys.
- NEXIS Business. This component is further divided into commercial and industrial buildings based on the construction type and usage of the building. A commercial database called Cityscope provides information about the size, number of stories, refurbishment and usage. Business activity is derived from Australian Business Registry and SENSIS (Yellow Pages).
- NEXIS Institutions. This component includes information about childcare, aged care, education, health, government, community, sports and emergency related buildings and their associated populations. A primary school, for example, contains children aged five to eleven years, between nine and three o'clock on a typical working day, while the crowd in a sport stadium will be based on the event at the time.
- NEXIS Infrastructure. This component comprises publicly available information about different sectors including transport (roads, railway, airports, sea ports, bridges and tunnels), communication (radio antenna, mobile antenna, and towers), energy (power and fuel) and water.



Figure 1: Spatial location of residential, commercial and industrial buildings in Gold Coast, Australia.

NEXIS Residential is presently the most advanced component of the database and has been used for a number of natural hazard risk assessment applications. Two salient examples are post-disaster assessments of a 2007 flood and 2009 bushfire.

### 3.1 *The June 2007 Hunter Region Flood*

In June 2007, the Hunter Region and Central Coast of New South Wales were extensively flooded by an intense low pressure system which developed off the coast. Rainfall exceeded 300mm in some areas and vital support services were cut off or disrupted. Japan's ALOS satellite imagery was acquired for the flooded region following the event, fortuitously finding a time window with no cloud cover. The satellite imagery was augmented with water height interpretations using a one-second DEM (digital elevation model) to prepare a preliminary disaster footprint (flood extent map). Finally, NEXIS Residential data were extracted over the disaster footprint, including residential building locations and value, building types, number of people exposed in the inundation zone (Figure 2). The total number of residential buildings affected was 69,627 with 216,566 inhabitants. This information was extremely value to emergency response efforts and disaster recovery and relief operations.

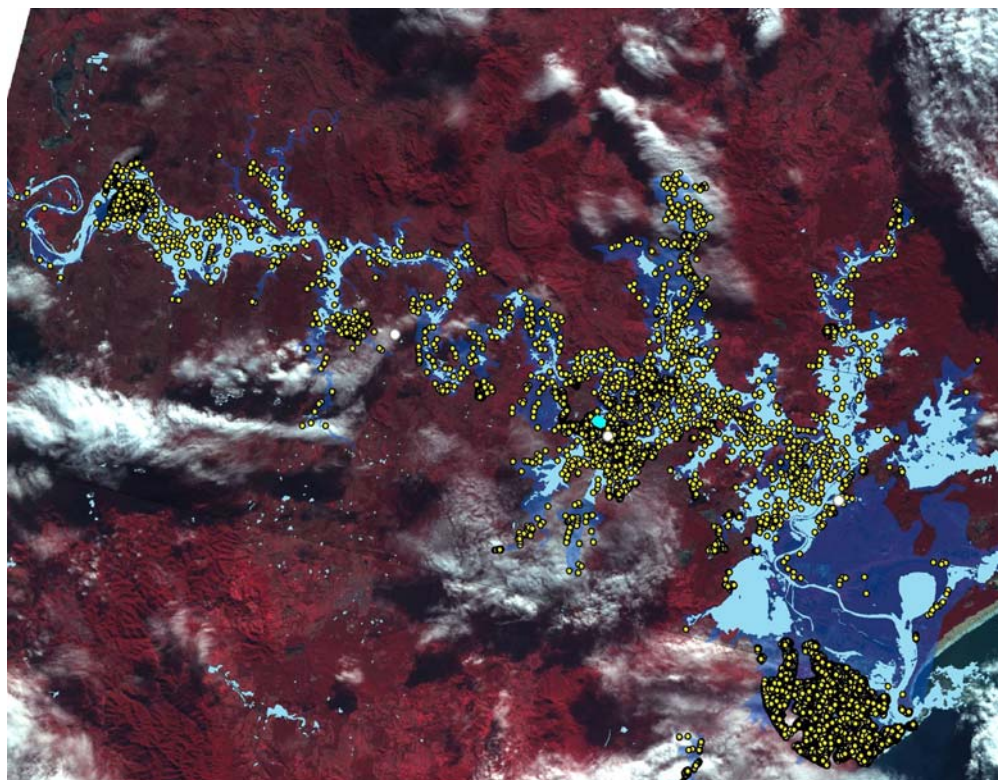


Figure 2: Newcastle disaster footprint displaying inundation immediately after the storm (blue) and riverine (cyan) floods overlying ALOS data on 10 June 2007. Yellow points indicate affected residential buildings.

### 3.2 *The February 2009 Victoria Bushfires*

On 7 February 2009, Black Saturday, several communities near Melbourne, Victoria were struck by a devastating series of bushfires (aka wild fires). The fires resulted in nearly 200 deaths and over 2000 buildings destroyed. A week after the fires, the extent of the damage and death toll were still poorly known. Figure 3 shows NEXIS Residential data superimposed on a map of the fire scar (provided by the Department of Sustainability & Environment, Victoria) assembled about 10 days after the fire. The map is for the Kinglake fire footprint, which accounted for about two-thirds of the damage and loss of life overall. The residential exposure within the Kinglake – Marysville fire scar includes 5,700 residences, over 15,000 inhabitants, and over \$2 billion (Aus) in replacement value. Although these numbers substantially exceed the total building loss and loss of life, they did provide accurate estimates of the affected population and asset values.

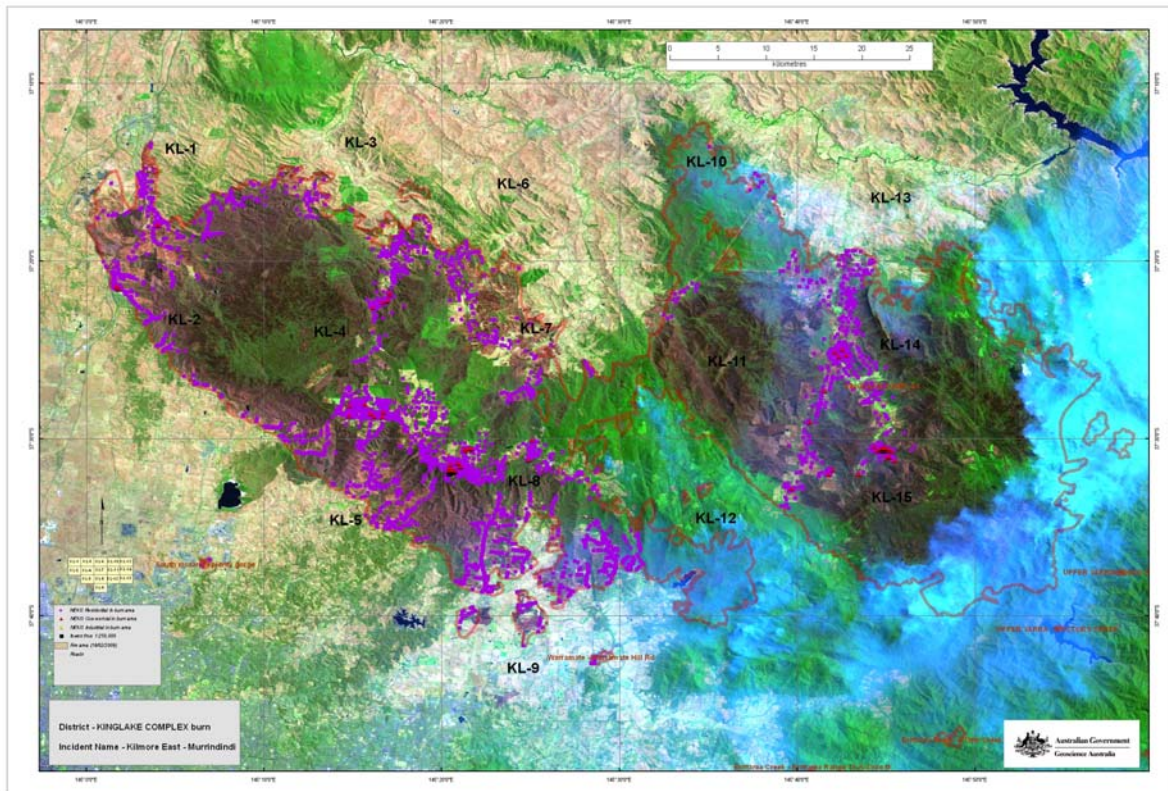


Figure 3. NEXIS Residential and Commercial data for the 2009 bushfires in the vicinity of King Lake and Marysville, Victoria.

#### 4. Australia’s National Coastal Vulnerability Assessment

Australia, through the federal Department of Climate Change (DCC), has undertaken a national-scale analysis of the potential impacts of climate change on coastal communities as part of the National Coastal Vulnerability Assessment (NCVA). Geoscience Australia is contributing to the NCVA by assessing the potential effects of sea-level rise, and increased storms on coastal buildings and infrastructure. We focus here on two hazards arising from this analysis: coastal erosion and coastal inundation. The process has followed the following key steps:

- Determine the storm surge hazard: Assess potential physical effects of sea-level rise on the potential for increased storm surge. The method combines estimates of the rise in mean sea level, together with the tidal range and storm surge (defined as the 1-in-100 year surge heights). This information is modelled using a digital elevation model (DEM) to calculate a spatial grid around the coast, from which the most likely positions of future shorelines can be extracted. In other words, the combination of sea-level rise and tide/storm surge forms an elevated level or “bath-tub” ring around the coast, thereby identifying areas at risk.
- Determine the coastal erosion hazard: Identify the attributes of coastal landforms in terms of fabric (from soft sand to hard rock), form (from flat lying beaches to vertical

- cliffs), coastal setting (from open coast to inlet); and geomorphic setting (susceptibility to erosion). This information is used to determine “zones of potential instability”, with coastal recession of 50 to 100 times the sea-level rise in areas most susceptible to erosion. For instance, if the sea level were to rise 1 metre adjacent to a soft, sandy beach, the beach would potentially recede inland by 50 to 100 metres.
- Estimate the impact on the built environment: Using NEXIS, map the buildings and key infrastructure (roads, rail, ports, airports) that may be exposed to the erosion or inundation hazard. In simple terms this is determined by measuring the intersection of the exposure derived from NEXIS with the hazard footprints derived from the hazard modeling.

In order to do the analysis outlined above, two specific spatial data sets (in addition to NEXIS) were identified as being important on a national scale for the entire Australian coast: digital elevation model (DEM) and coastal landform. In addition, a national model for the High Water Surface was required in order to make estimates of the storm surge inundation potential. These three data sets or data models are briefly described below. Finally, an example of the coastal impact on the built environment is provided.

#### *4.1 National elevation data*

The vertical height datum must be sufficiently accurate to allow for estimates of flooding and sea level rise, and to assess resulting changes in coastal processes such as storm surge inundation and coastal erosion. As outlined in a complementary paper<sup>4</sup>, the DCC is supporting the development of high resolution Urban Digital Elevation Models for key urban areas. There are also now available so-called mid-resolution DEMs such as the SPOT High Resolution Stereoscopic Reference3D DEM (SPOT HRS) and the Shuttle Radar Topographic Mission (SRTM) DEM (1 arc second). The results of inundation modelling using the SRTM 3 arc second data and LIDAR DEMs are compared in Figure 4. The higher resolution LIDAR data, with 0.15 m vertical accuracy and 1 m horizontal resolution, is better able to resolve the extent of potential coastal inundation. Figure 5 shows a comparison of inundation modelling using the SPOT HRS data and LIDAR for another location on the Australian coast. In this case, although the LIDAR-based analysis has much higher resolution, the SPOT HRS data provides a reasonable estimate of the potential inundation. For a national-scale analysis of the potential for coastal inundation resulting from sea-level rise, the SPOT HRS data provides an adequate basis for broad-scale assessment of the inundation risk.

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<sup>4</sup> Scott, G. and A. Simpson (2009): Disaster risk reduction and climate change adaptation in the Australia-Pacific Region, 18<sup>th</sup> UNRCC-AP, Bangkok, 13 p.



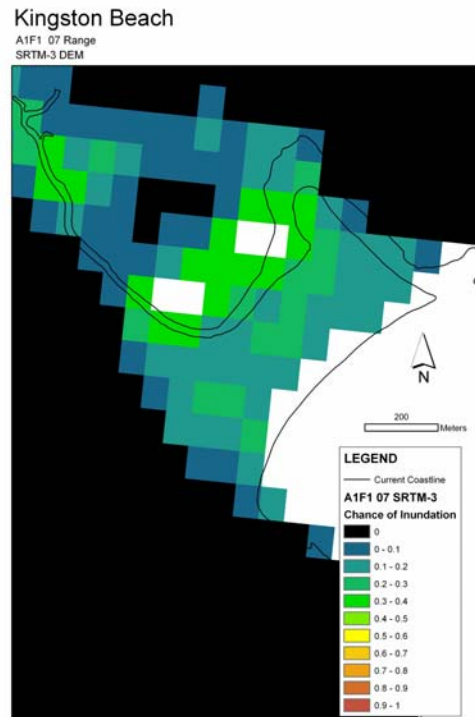
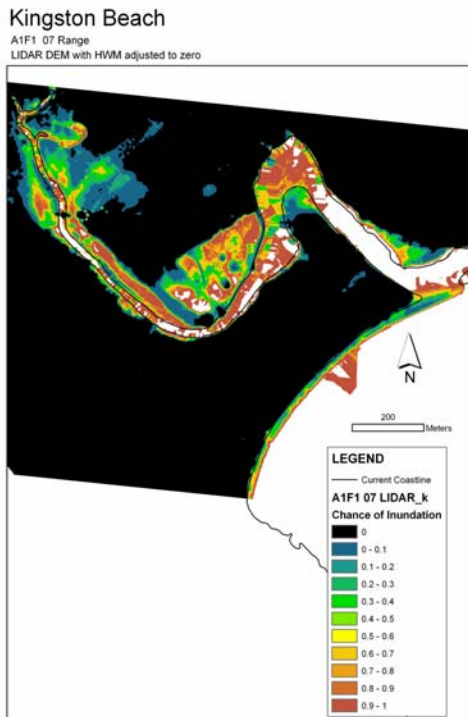


Figure 4. Comparison of coastal inundation modelled for a coastal location in Australia for 1.1 m rise in sea level: Left) LIDAR DEM; Right) SRTM DEM (3 arc sec).

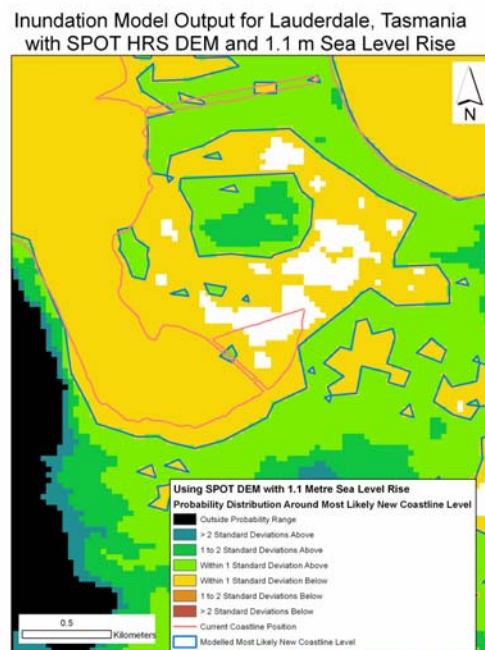
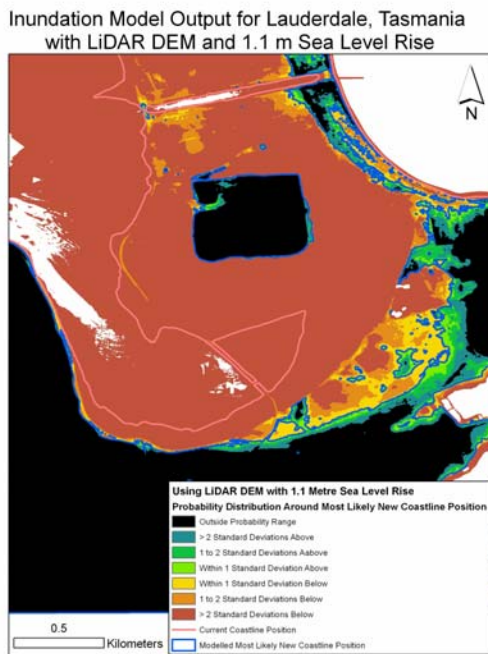


Figure 5. Comparison of coastal inundation modelled for a coastal location in Australia for 1.1 m rise in sea level: Left) LIDAR DEM; Right) SPOT HRS DEM (1 arc sec).

#### 4.2 Coastal Geomorphology (*Smartline*)

One of the expected impacts from climate change is the potential for accelerated erosion due to rising sea levels around the Australian coastline. In order to get some indication of the potential for accelerated erosion it is necessary to understand the shape and composition of the landscape (or geomorphology) of the Australian coastline. In regions where the coastline has soft sandy beaches, there is an increased potential for accelerated erosion; whereas where the coastline has hard rocky cliffs, erosion may not be a significant issue. A single nationally-consistent coastal geomorphology classification was developed called *Smartline*<sup>5</sup> in order to inform a national assessment of the extent of the Australian coastline that may be susceptible to increased rates of erosion.

*Smartline* was devised based on existing geomorphic, geological and physical data, available in a variety of formats, classifications and scales. The data has been captured in a line-map format wherein the national coastline is tagged with multiple attributes describing the types of landforms present along the coast (Figure 6). The line mapping achieves a high degree of detail in the along-shore direction; being segmented wherever any significant change in any of the mapped attributes occurs. *Smartline* provides a detailed map of the coastal geomorphology of continental Australia and most adjacent islands and can be accessed via the OzCoasts website ([www.ozcoasts.org.au](http://www.ozcoasts.org.au)).



Figure 6. Landforms of the coastal zone are described in terms of landform types found in three shore-parallel tidally-defined zones.

#### 4.3 High Water Surface and Storm Tide Model

The calculation of storm surge inundation involves the combination of a number of disparate data sets, all of which have their own issues with data gaps and errors. In addition to the DEM model described above, key additional data sources for this analysis include:

- Sea-level rise estimates;
- Mean high-tide estimates;

<sup>5</sup> Sharples, C and Mount, RE and Pedersen, TK and Lacey, MJ and Newton, JB and Jaskierniak, D and Wallace, L (2009): *The Australian Coastal Smartline Geomorphic and Stability Map Version 1: Project Report*, Australian Government, Geoscience Australia, 1.

- Storm tide/surge modelling (only available for Tasmania, Victoria and New South Wales); and
- Height datum (Australian Height Datum, 1971).

Where storm tide/surge surfaces were not available, the standard High Water Surface modelled by the National Tidal Centre (NTC) was used. This model represents tidal amplitudes in metres between Mean Sea Level and Indian Spring Low Water multiplied by two to give an estimate of the complete tidal range. The results of this modelling are shown in Figure 7. Note the much higher tidal variation on the northern coasts of Australia and central coast of Queensland where the broad and shallow continental shelf amplifies the tides.

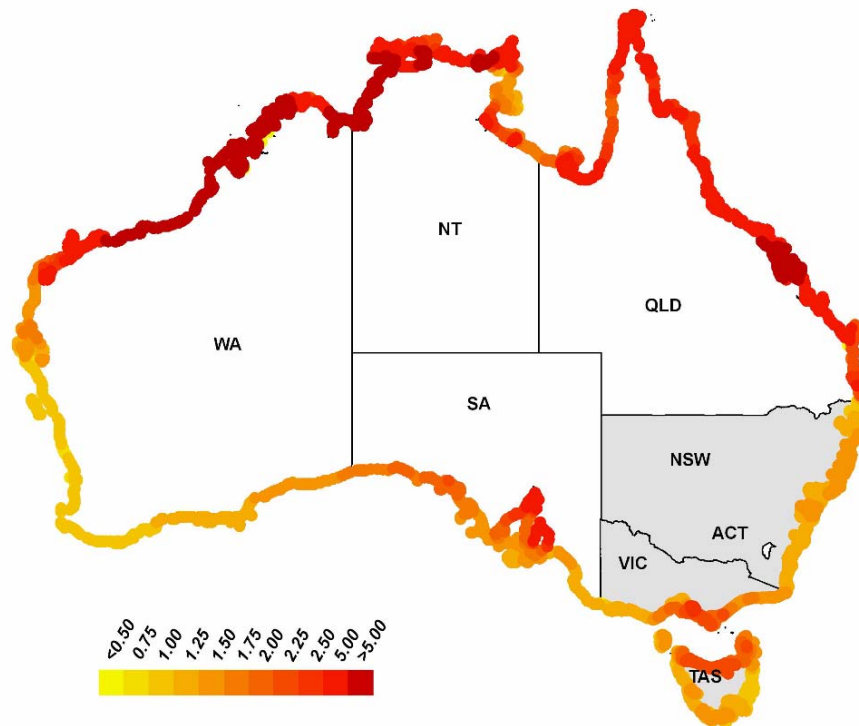


Figure 7. High Water Surface Storm/tide model for Australia showing areas which include 1-in-100 storm surge estimates in metres (grey area), and the modelled High Water Surface elsewhere.

#### 4.4 Impact Analysis

Figure 8 illustrates the results of combining the storm surge and coastal erosion analyses with the NEXIS exposure data. The areas shaded in blue indicate the extent of the built environment that would be susceptible to coastal inundation for a 1.1 metre sea-level rise. This is an upper-bound estimate of the rise in sea level for the highest CO<sub>2</sub> model (A1FI) provided by the International Panel on Climate Change in their 2007 assessment<sup>6</sup>. The resulting inundation estimates represent a practical upper bound to the climate change risk to coastal communities from present to 2100.

<sup>6</sup> IPCC (2007): Climate Change 2007. Fourth Assessment Report, Cambridge University Press.



Figure 8. Sample result of combined modelling of a 1-in-100 year storm surge with a projected sea-level rise of 1.1 metre. Commercial (blue) and residential (red) buildings are from the NEXIS database.



John Schneider is the Group Leader of the Risk & Impact Analysis Group at Geoscience Australia. This Group, which comprises about 60 hazard scientists, engineers, mathematicians, geographers and economists, develops a wide range of tools, databases and methods for assessing the impact and risk of natural and man-made hazards in Australia and the Australasian region. John and his team advise government and private industry on risk management issues including emergency preparedness, critical infrastructure protection, climate change, land-use planning, and building regulation.

John is an internationally recognised expert in natural hazard risk assessment. Prior to his arrival in Australia in 2000, John was Chief Scientist at Aon Corporation's Impact Forecasting in Chicago, Illinois, specialising in catastrophic risk assessment for corporate and insurance applications (1995 to 2000). He has an MS (1981) and PhD (1984) in geophysics from the University of Wisconsin, USA.

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