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LOCAL, NATIONAL, REGIONAL CLIMATE CHANGE PROGRAMME

ARABIAN GULF MODELING

Technical Summary

Climate Change Research Group

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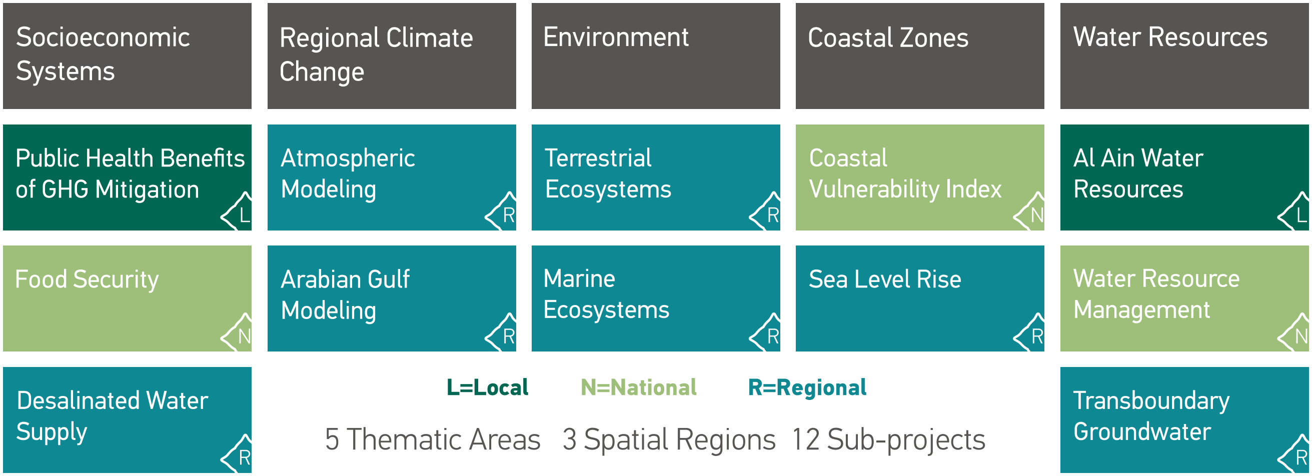
Local, National and Regional Climate Change Programme 2013-2016



12 Sub-projects
Assess the Impacts, Vulnerability & Adaptation to
Climate Change in the Arabian Peninsula

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Introduction

In October 2013, the Abu Dhabi Global Environmental Data Initiative (AGEDI) launched the Local, National, and Regional Climate Change Programme (LNRCCP). Due to be completed by the end of 2016, the aim of this programme is to build upon, expand, and deepen understanding of vulnerability to the impacts of climate change, as well as to identify practical adaptive responses at local (Abu Dhabi), national (UAE), and regional (Arabian Peninsula) levels. The Abu Dhabi Global Environmental Data Initiative (AGEDI), a joint initiative of EAD and the United Nations Environment Programme (UNEP), is managing the Programme.

The design of the LNRCCP is stakeholder-driven, incorporating the perspectives of over 100 local, national, and regional stakeholders in shaping 12 research sub-projects across five strategic themes. As there was significant interest in just how climate change would impact marine biodiversity and Arabian Gulf waters, the topic of Regional Ocean modelling emerged as necessary to carrying out such assessments. The outputs of the study provide a Gulf-specific basis on which to conduct the subsequently planned vulnerability assessments of the LNRCCP regarding marine biodiversity and socioeconomic systems, and will serve as an asset to researchers in the region regarding future climate change and the marine environment.

Background

The study focused on regional ocean modelling under climate change, which is essential to understanding how future climate change will affect specific locations within the world's oceans. The focus for this sub-project was on the Arabian Gulf, a semi-enclosed, highly saline sea between latitudes 24°N and 30°N surrounded by a hyper-arid environment. Its bathymetry shows large areas of shallow water (less than 10 metres deep) with a maximum depth of about 110 metres near central areas. Northwesterly Shamal winds affect Gulf waters in the winter, while southeasterly Shamal winds dominate in the summer. Such winds affect the Gulf's circulation patterns leading to seasonally stratified waters.

What is an RCP?

Representative Concentration Pathways (RCPs) are four GHG concentration (as opposed to emission) trajectories the IPCC used in its 5th Assessment Report. RCPs supersede the previous GHG storylines (e.g., A1, B1). RCP8.5 can be considered analogous to a business-as-usual scenario The other RCPs assume stabilisation of GHG emission concentration in the atmosphere prior to 2100.

Earth System Models (ESMs), considered in Intergovernmental Panel on Climate Change (IPCC) Assessments, indicate substantial future changes in the world's oceans, and are typically the basis for projecting their large-scale response to rising greenhouse gas concentrations in the atmosphere. While ESM outputs are used to define initial conditions, boundary layers, and external fluxes in Regional Ocean Models (ROMs), due to their complexity, they are formulated at a relatively low spatial resolution of about 100 km, and lack the sufficient spatial resolution to intricately account for bathymetry, circulation, mixing and other characteristics. Therefore, a higher resolution ROM is essential to better understanding how Arabian Gulf conditions may change at specific locations due to climate change, and more realistically capture local oceanographic processes and characteristics including: sea surface temperature profiles, circulation patterns, fresher water influxes, balancing of ocean currents, and topographical features of the ocean bottom.

In this sub-project, the validated ROM for the Arabian Gulf was developed based on ESM boundary conditions and local data, and used to make climate change projections for two future periods in the late 21st century – two 5-year time periods; 2040-2044 and 2095 - 2099. For reporting purposes, the historical period is from 2000 - 2004.

One greenhouse emission scenario was modelled that assumed a business-as-usual trajectory of global greenhouse gas emissions –Representative Concentration Pathway (RCP) 8.5 (see Box). It is the more aggressive greenhouse gas emissions trajectory most similar to humankind's current trajectory, and as such, provides the best basis on which to understand potential climate change implication for the Gulf.

Efforts to model future sea level rise were focused on a single contributor, namely Dynamic Sea Level (DSL) – the smallest of three major factors that contribute to sea level rise (with the other major factors being global thermal expansion and deglaciation) – and the only factor capable of being suitably incorporated in current ESMs.

Several climatic variables were projected, including sea surface temperature, salinity, sea level rise, circulation dynamics, turbulence, and mixing processes. By 2100, the results show sharp changes in the Gulf compared to historical trends, as climate change unevenly disrupts some key processes at specific locations within the Gulf.

A single ensemble from the Mixed Resolution ESM developed by the Max Planck Institute for Meteorology was used to establish initial conditions, boundary layers, and external fluxes for modelling regional climate change in the Arabian Gulf. Extensive data from satellites and other sources were collected on Gulf attributes such as surface temperature, bathymetry, salinity, currents, among others. This region-specific information was used to dynamically downscale ocean fields from the ESM's comparatively coarse-scale resolution to the fine-scale regional domain needed for quantifying the effects of climate change on Gulf waters.

Projected future conditions indicate significant changes in temperature, salinity, mixing processes and circulation patterns in the Arabian Gulf, including:

- Sea surface temperatures are projected to increase throughout the Arabian Gulf, from 1°C by mid-century, to up to 2.8°C by late century
- Sea surface salinity is projected to both decrease and increase, depending on location; by mid-century, an uneven distribution of salinity is observed throughout the Arabian Gulf, and by late century, areas showing decreasing salinity are located along the entire length of the deep channel from the Strait of Hormuz to Iraq, while areas showing modest increases in salinity are located along the UAE coast south of the Northern emirates and in Salwa Dawhat, a bay west of Qatar
- During winter months, salinity on the eastern side of the Gulf is typically higher than summer months
- Sea level is projected to rise throughout the Gulf – by mid-century, dynamic sea level (DSL) rise is highest in the northern area of the Gulf, and by late century, the areas showing the lowest increases are in the central Gulf area. The areas showing the largest are located at the Strait of Hormuz and in Salwa Dawhat
- Annual circulation dynamics are expected to change in two zones – a deep zone located in the central area, and a shallow zone located along the UAE coat
- Seasonal changes in turbulence are anticipated across the entire Arabian Gulf
- Global climate change effects from wind patterns will have impacts on Gulf coastal currents for two locations near Qatar and UAE, with wind effects being more evident in shallow areas, where the coastal currents are well defined and highly correlated with wind, especially regarding Northward winds

Access to regional ocean modelling datasets is being offered through the Climate Inspector, a tool designed to assist in visualization of results and data transfer. Finally, the results of the regional ocean modelling sub-project point to several promising areas of future research.

Temperature

Sea surface temperatures are projected to increase throughout the Arabian Gulf. By mid-century, small temperature increases of around 1°C are evenly distributed throughout the Gulf. Meanwhile, by late century, the area showing the lowest increase relative to current conditions, about 1.7°C, is the central Gulf area where most large-scale summer eddies associated with fresher Gulf of Oman waters are concentrated. The areas showing the largest temperature increases relative to current conditions, about 2.8°C, are located at the Strait of Hormuz and along the coastline of Saudi Arabia and Qatar.

Salinity

Sea surface salinity is projected to both decrease and increase, depending on location. By mid-century, an uneven distribution of salinity is observed throughout the Arabian Gulf, with increased levels mostly along the UAE coast and freshening (i.e. lower salinity levels) along the Gulf's main channel. By late century, areas showing decreasing salinity, about 0.2 practical salinity units (psu), are located along the entire length of the deep channel from the Strait of Hormuz to Iraq. Areas showing modest increases in salinity, about 0.5 psu, are located along the UAE coast south of the Northern emirates. The largest increases in salinity, about 1.1 psu, are located in Salwa Dawhat, a bay to the west of Qatar. These changes are due to the Gulf's dilution processes, which progressively flush high-density waters out of the system along the deep channel, but are more constrained in other locations.

During winter months, salinity on the eastern side of the Gulf is typically higher than summer months – although increase is by less than 1 psu during all time periods. This is due to the fact that inflows from the lower-salinity waters of the Arabian Sea are always highest during summer months. By mid-century, fresh water inflow reaches a maximum for this vertical section and result in reduced salinity levels compared to the early period. By late century, more saline and denser waters prevail during summer and winters months when compared to the current period.

Sea level rise

Sea level (DSL) is projected to rise throughout the Gulf. By mid-century, dynamic sea level rise is highest in the northern area of the Gulf. It is important to note that mean comparisons between periods in intervals of 50 years are not particularly conclusive because the intra-annual, inter-annual and decadal variability are of the same order of magnitude. However, by late century, the areas showing the lowest increases, about 2.7 cm, are in the central Gulf area when compared to the early period. The areas showing the largest rise, between 4 cm and 5 cm, are located at the Strait of Hormuz and in Salwa Dawhat. The northern portion of the Gulf shows modest DSL, roughly 3 cm above historic levels.

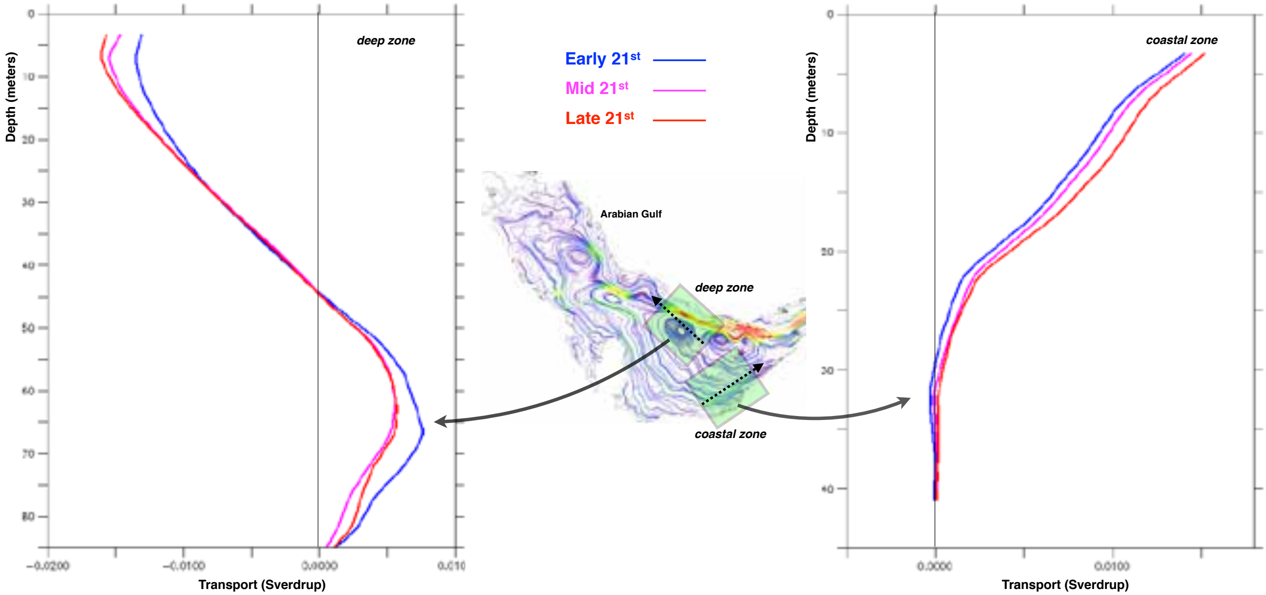

Figure 1: early (blue), mid-century (pink) and late century (red) time averaged climatological net transport along the main circulation direction. The map in the center shows the locations of the zones, with the black dashed arrows point to the circulation direction.

Circulation Dynamics

Figure 1 illustrates changes in annual circulation dynamics in the Arabian Gulf for the two zones – a deep zone located in the central area, and a shallow zone located along the UAE coast.

Circulation changes are typically measured by the net mass transport metric and are highly related to salinity change, the key driver for most of the internal density balances and mixing processes in the Gulf. Net mass transport occurs unevenly, depending on season. Moreover, there is a systematic increase in net mass transport in the mid and late century results as indicated by the pink and red lines, respectively, that is sustained yearlong. Notably, there is a clear contrast in net mass transport extremes in the channel (deep zone, left side) and in the shallow areas (coastal zone, right side).

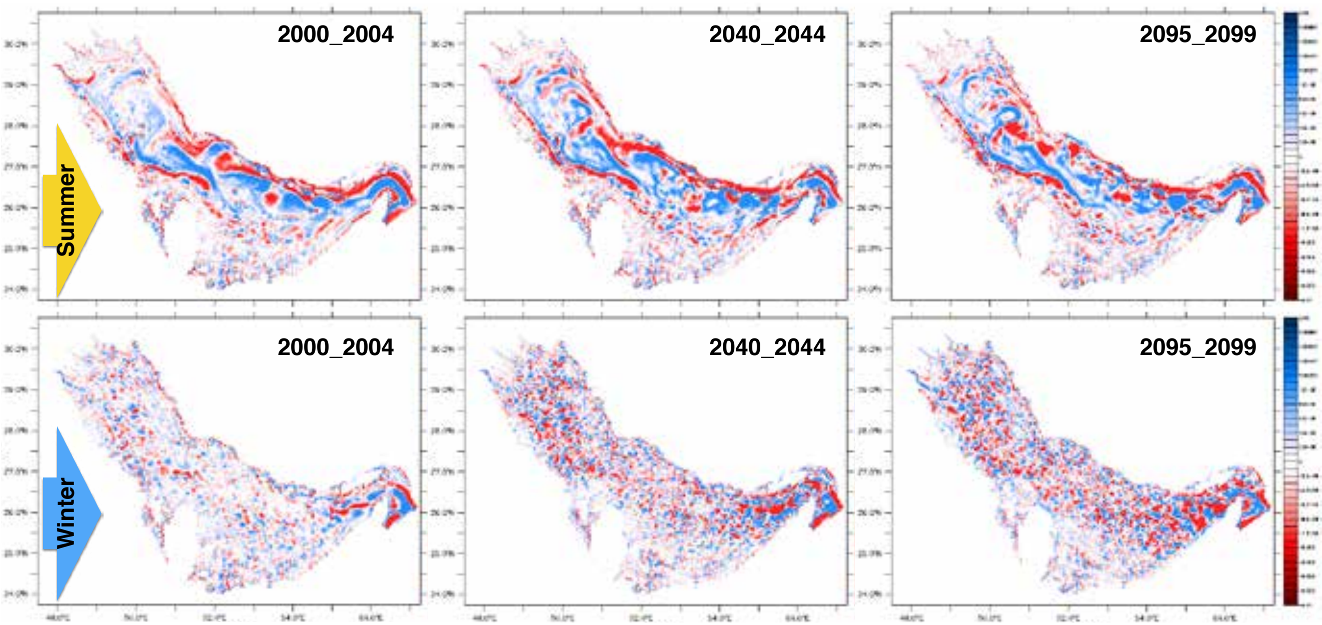

Figure 2: arabian gulf vorticity in the early, mid and late 21st century periods. The scale (1/s) is the same for all the vorticity plots.

Turbulence

Figure 2 illustrates seasonal changes in turbulence over the entire Arabian Gulf. Turbulence is typically measured by the vorticity metric and is highly related to salt fingering and mixing processes. Vorticity changes significantly with climate change due to an increase of overturning kinetic energy and a decrease in the average duration of the small-scale eddy period. By mid-century, low salinity levels along the eastern side of the Gulf coast, together with unbalances in the cyclonic gyre, will cause significant changes in the mixing processes. By late century, there is an increase in the average duration of the larger-scale eddies due to the influx of Arabian Sea low salinity waters during summer months. Also, more high frequency eddies will become evident in the North due to the effect of warmer atmospheric conditions on dense water formation zones.

Impacts of future wind patterns on currents

Figure 3 illustrates global climate change effects from wind patterns on Gulf coastal currents for two locations near Qatar and UAE. Wind patterns by mid and late 21st century have no significant impact on currents when compared to the early 21st century period. The current polar histogram shown for the shallow areas where currents are very sensitive to wind changes. Figure 3 results are consistent with the shallow water transport profiles discussed earlier. Wind plays an important role in the general circulation system in the Arabian Gulf. The Gulf functions as a low frequency gyre system and historical winds have a Southeastward predominant direction. With climate change, the combination of both systems increases the shallow and high saline coastal flow southward and reduces the northward low saline waters from Gulf of Oman. Wind effects are more evident in shallow areas, where the coastal currents are well defined and highly correlated with wind, especially regarding Northward winds.

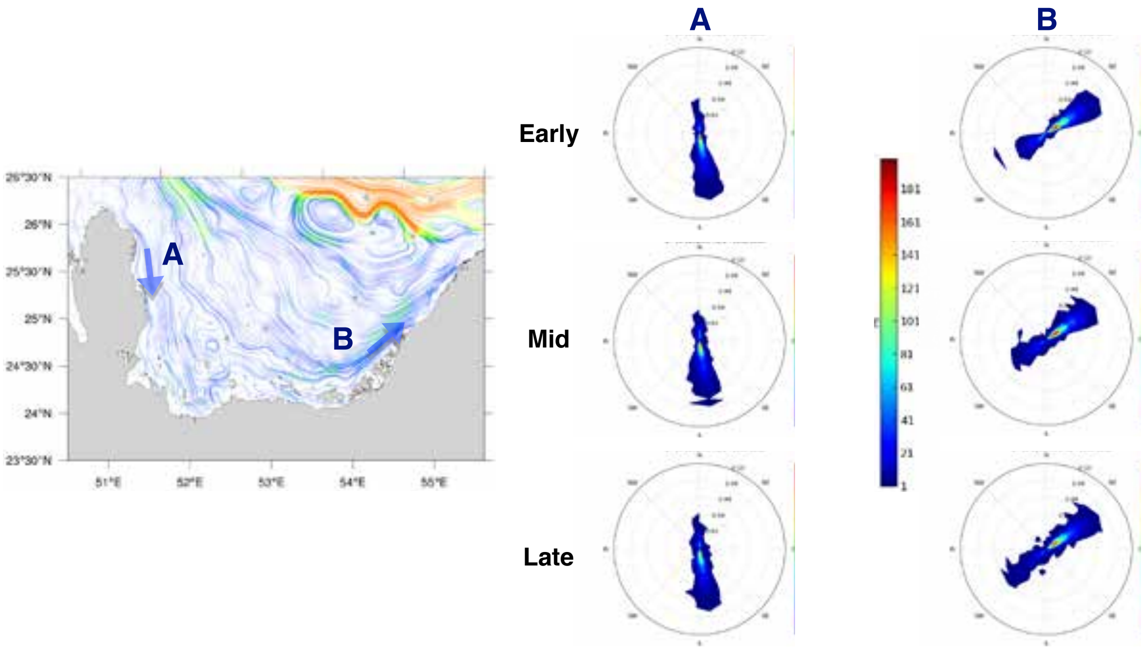

Figure 3: coastal currents near qatar ("a") and the uae ("b"). The map at left shows residual currents. The polar histograms at right show cumulative current frequencies near qatar and the uae, for the early, mid and late 21st century periods.

Outputs

The outputs of the study provide a Gulf region-specific basis on which to conduct subsequent planned vulnerability assessments under the LNRCCP regarding terrestrial biodiversity, water resources, coastal zones and socioeconomic systems.

A large data archive of nearly 20 Terra-Bytes has been generated. A web-based data explorer, known as the Climate Inspector, is currently under development to enhance access and availability to this dataset. It will allow for those interested to readily generate maps for specific locations of interest and/or obtain detailed or summarised data regarding future sea surface temperature, salinity, circulation, and numerous other variables describing current and future conditions in the Arabian Gulf.

Summary & future directions

The Arabian Gulf Modelling sub-project has provided insights into key changes in the conditions of the Arabian Gulf due to climate change. The modelling process consisted of a number of key stages, starting with the selection of the MPI-MR model as the ESM that displayed the best fit with historical conditions in the Gulf over the 1950-2005 period, and hence the most suitable model for providing oceanographic forcing fields.

The outputs of MPI-MR were dynamically downscaled into a high-resolution regional ocean model that adequately captured unique local characteristics for a historical period. The validated regional model was then used to project future conditions in the Gulf consistent with a business-as-usual global greenhouse gas emission trajectory. The regional ocean model was run with a spatial resolution of 2.8 km and with 20 levels for the vertical resolution. Model projections for two time slices up to about 2100 confirm that Gulf conditions will change significantly from historical conditions relative to temperature, salinity, circulation, and mixing processes.

Several areas of future research have been identified and can build directly from the ocean datasets generated by the study. These include:

- **Addressing uncertainty.** Numerical ocean modelling is a complementary tool to field observations and theoretical knowledge for a specific area. However, modelling raises important questions about confidence intervals and uncertainty levels associated with outputs. The present yearlong research study has yielded some key insights on future conditions in the Gulf while pointing to interesting research themes to address the inherent uncertainties involved.

- **Regional atmospheric-ocean coupling.** As the regional atmospheric and regional ocean modelling sub-projects were carried out concurrently, attempts were made to undertake one-way coupling. Given the complexity and timing of such a framework, only a limited set of results could be considered. Future research would benefits from direct coupling of the models in either dynamic or one-way coupling.

- **Future anthropogenic salinity influxes.** Highly saline brine discharges from desalinization plants should be incorporated into the model dynamics. Such plants may have a significant impact on the AG circulation, if considered as salt sources that grow consistent with projected economic growth.

- **Large-scale phenomena.** Factors outside the immediate Arabian Gulf could be considered. For example, the Indian Ocean Dipole could produce important effects in the Gulf area, which have not been accounted for in the current study. Because of its larger spatial and temporal scales, this is a research topic that could be directly investigated within the CMIP5 models themselves.

- **Model updates.** The outputs of the regional ocean modelling sub-project has confirmed that significant change in Arabian Gulf waters due to global warming are very likely. It will be important to update the regional modelling framework to account for future improvements in the modelling capabilities of next generation ESMs. This will help to shed more light on critical issues for the Gulf, such as sea level rise, as these next generation models are able to incorporate other major factors contributing to global sea level rise.

NOTES:

This Executive Summary is based on the final Technical Report entitled: “A Numerical Study of the Changes in the Arabian Gulf due to Climate Change - Final Report for AGEDI’s Local, National, and Regional Climate Change Programme” authored by José Edson (Principal Investigator), Ilana Wainer, and Bruno Ferrero of the Oceanography Institute at the University of Sao Paulo in Brazil.

For the most part, the degree of certainty in key findings is expressed qualitatively, based on the authors’ expert judgment. Where possible, degree of certainty in key findings is expressed probabilistically in terms of statistical significance. Ultimately, confidence in the validity of regional modelling results is based on the authors’ expert judgment after their assessment of the overall consistency of the data, evidence, and other factors.

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AGEDI

Under the guidance and patronage of His Highness Sheikh Khalifa bin Zayed Al Nahyan, President of the United Arab Emirates, the Abu Dhabi Global Environmental Data Initiative (AGEDI) was formed in 2002 to address responses to the critical need for readily accessible, accurate environmental data and information for all those who need it.

With the Arab region as a priority area of focus, AGEDI facilitates access to quality environmental data that equips policy-makers with actionable, timely information to inform and guide critical decisions. AGEDI is supported by Environment Agency – Abu Dhabi (EAD) on a local level, and by the United Nations Environment Programme (UNEP), regionally and internationally.

For more information, visit www.agedi.org.

The Environment Agency-Abu Dhabi

The Environment Agency – Abu Dhabi (EAD) was established in 1996 to preserve Abu Dhabi's natural heritage, protect our future, and raise awareness about environmental issues. EAD is Abu Dhabi's environmental regulator and advises the government on environmental policy. It works to create sustainable communities, and protect and conserve wildlife and natural resources. EAD also works to ensure integrated and sustainable water resources management, to ensure clean air and minimize climate change and its impacts.

For more information, visit www.ead.ae.

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Climate Change Research Group

CCR Group

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