A FRAMEWORK FOR INVESTIGATING THE INTERACTIONS BETWEEN CLIMATE, DUST, SOLAR POWER GENERATION AND WATER DESALINATION IN DESERT CLIMATE

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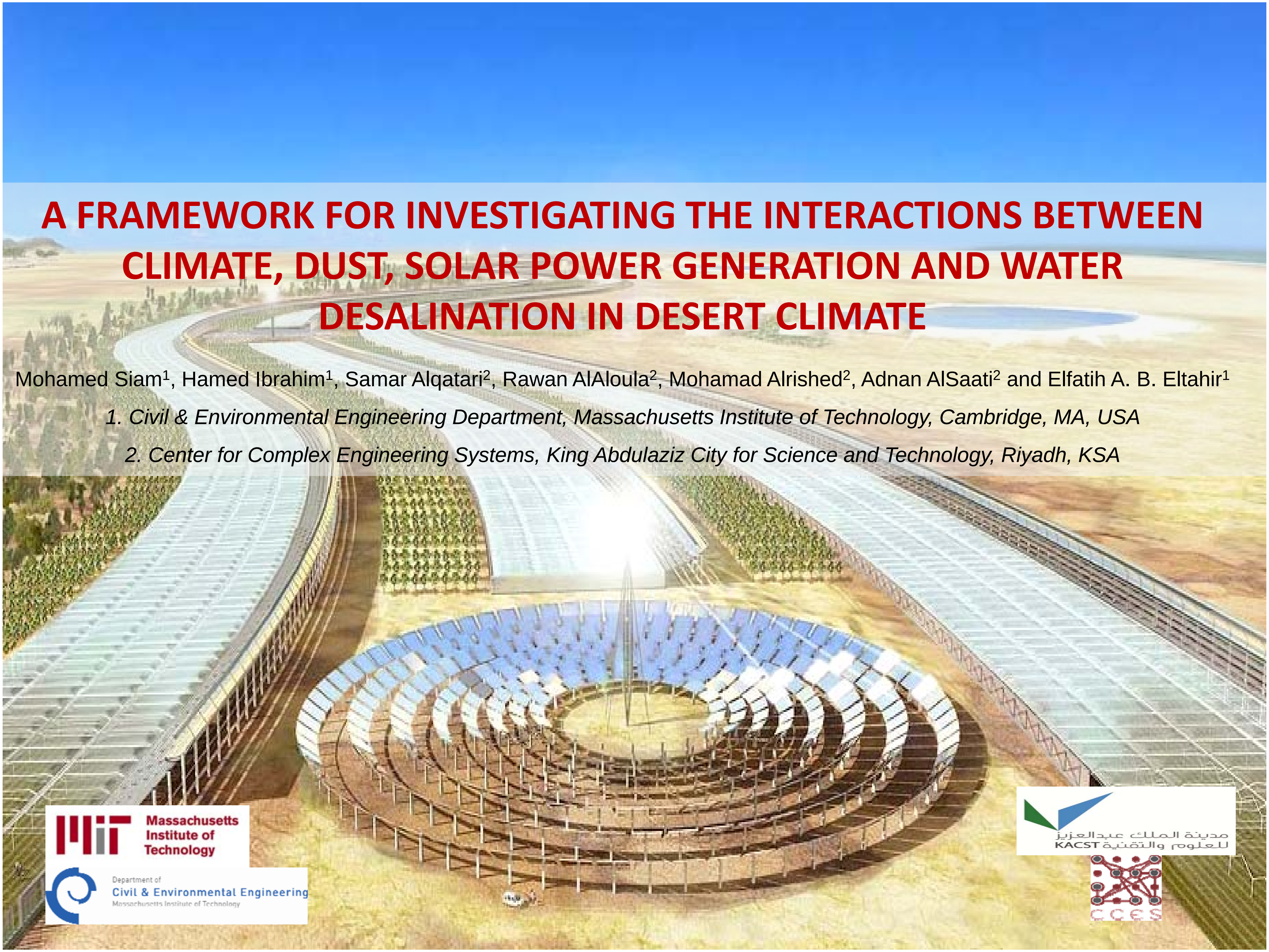

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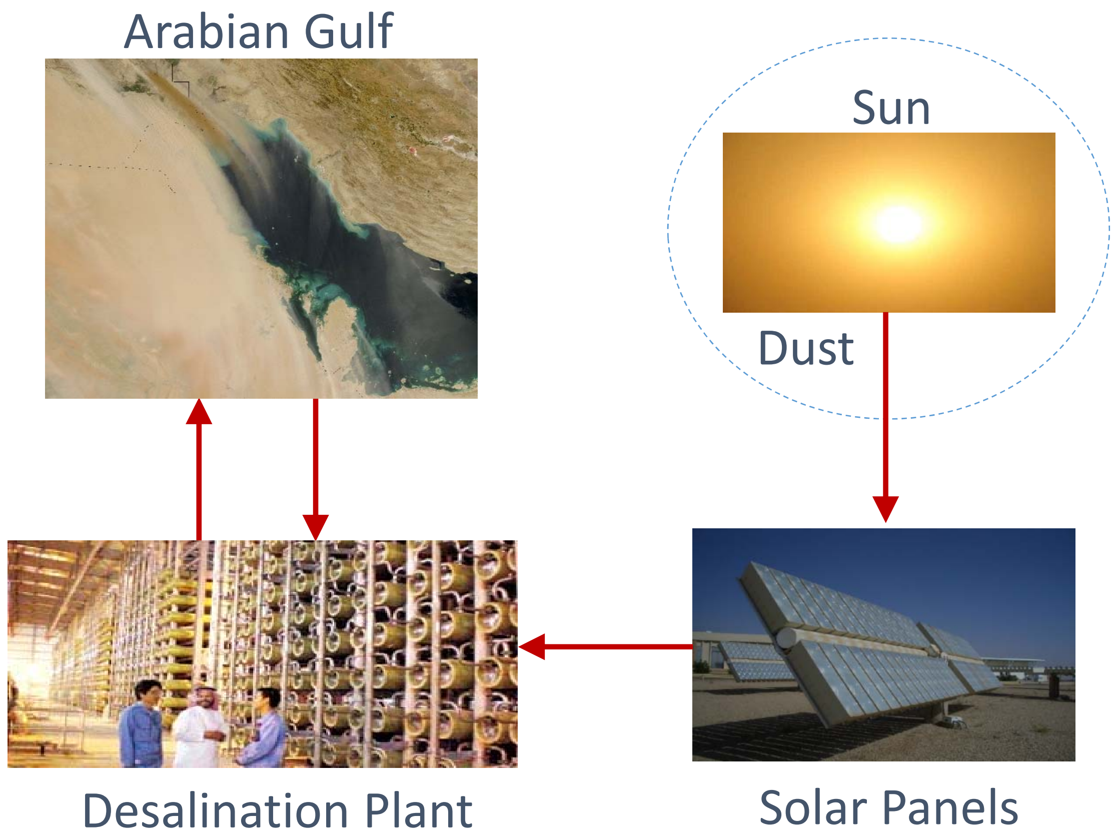
Introduction

Increasing water demand in Saudi Arabia due to rapid population growth has forced the rapid expansion of seawater desalination plants in order to meet both current and future freshwater needs. Saudi Arabia has a huge potential for solar energy, hence, solar powered desalination plants provide an opportunity to sustainably address the freshwater demand in the kingdom without relying on fossil fuels energy. However, the desert climate of Saudi Arabia and limited access to the open ocean imposes several challenges to the expansion and sustainability of solar powered desalination plants. For example, the frequent and intense dust storms that occur in the region can degrade solar panels and significantly reduce their efficiency. Moreover, the high salinity Arabian Gulf in both the source of feedwater and sink of hypersaline discharge (brine) for many plants in the east of the Kingdom, and the brine may alter the salinity, temperature and movement of the water thereby reducing the quality of the feedwater to the desalination plants.

Here, we propose a framework to investigate the different interactions between climate, dust, solar power generation and seawater desalination and their impact on water quality in the Arabian Gulf using several numerical models including regional climate, hydrodynamics, Photovoltaics (PV) and Photovoltaic-Reverse Osmosis (PVRO) models that are used to investigate these interactions for a solar powered desalination plant at AlKhafji on the Northeastern coast of Saudi Arabia.

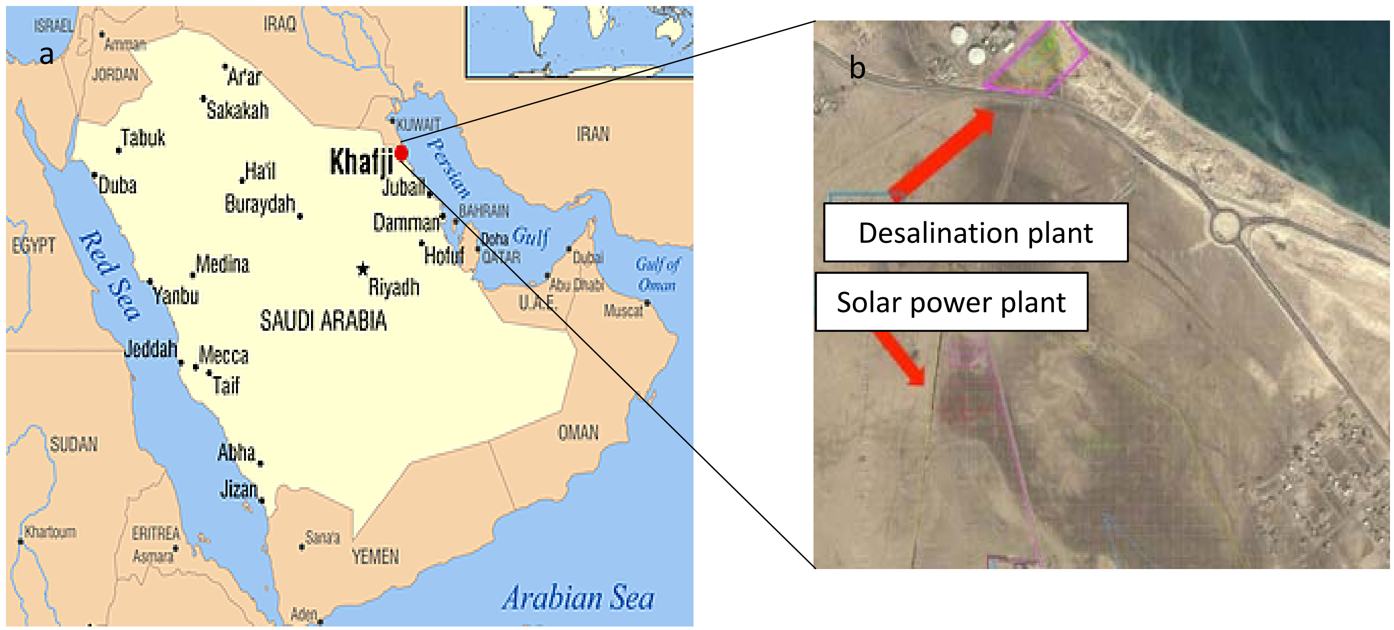
Description of the Framework



Schematic of the different interactions between the solar energy from sun, dust in the atmosphere, generation of electricity from the solar panels, water desalination plants and their impacts on the salinity and temperature of water in the Arabian Gulf.

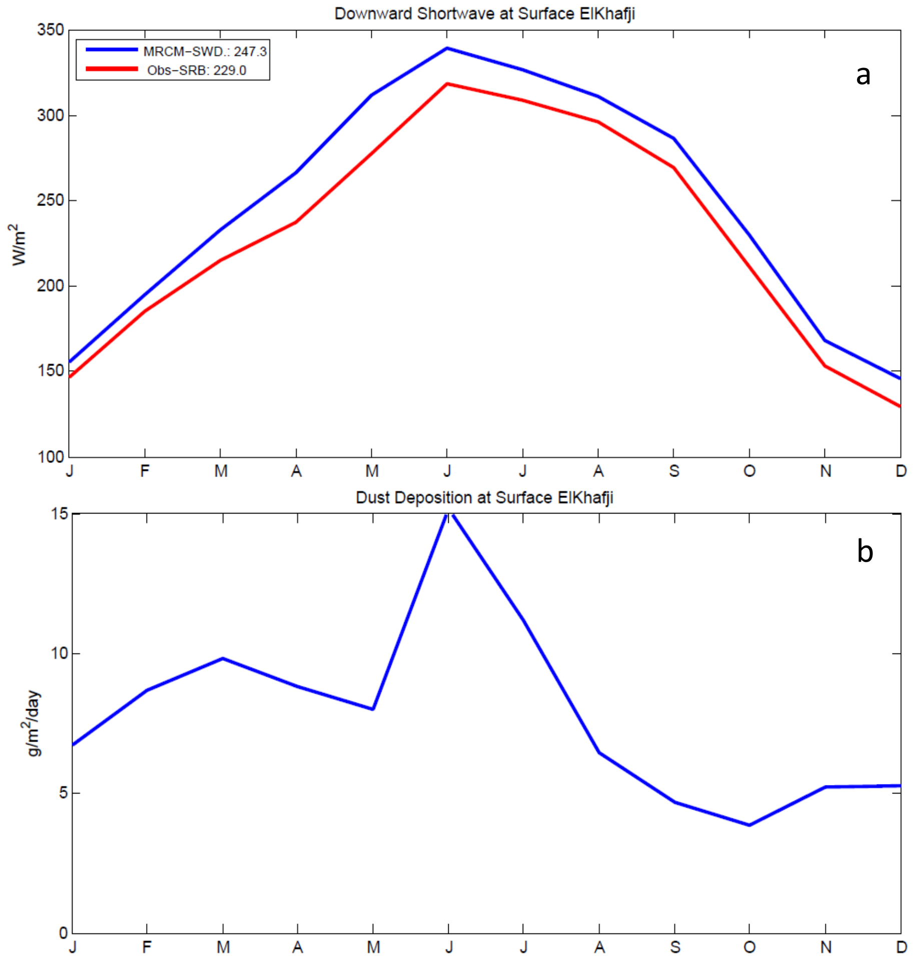
The performance of solar panels is directly related to the amount of solar energy reaching the surface of the panels, but dust deposition on the surface of solar panels reduces their performance. The electricity generated from solar panels is used to power the Reverse Osmosis (RO) desalination plant, and the efficiency of the plant also depends on the salinity and temperature of intake water from the Gulf. Moreover, the brine discharge from the plant into the Gulf affects the temperature, salinity and water movement in the Gulf. Thus, an understanding of these different interactions is required in order to have optimum performance of the solar powered desalination plant and minimum impact on the environment.

Study Area



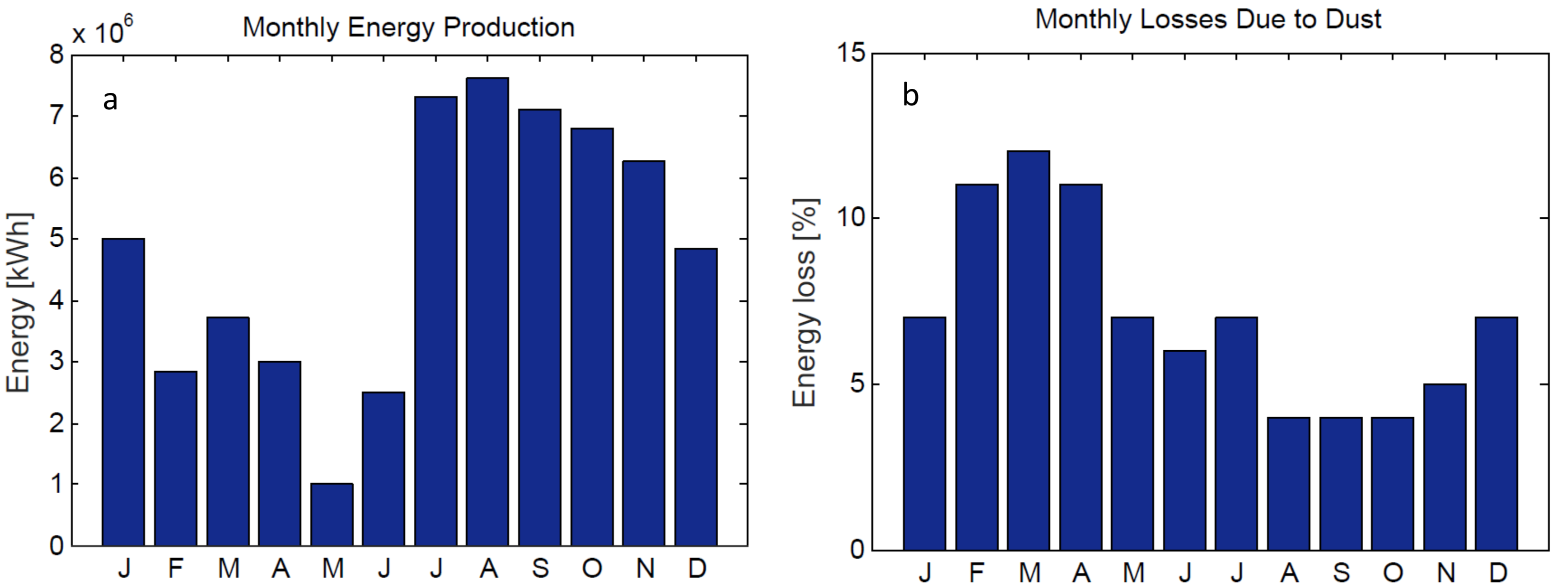
The proposed framework is applied for a solar-powered desalination plant using photovoltaic cells for solar power generation and reverse osmosis desalination technologies at AlKhafji in the northeastern coast of Saudi Arabia. The solar power plant has a capacity of 38 MW and it is located 1 km away from the desalination plant, which has a capacity of 60,000 m3/day.

Simulation of Dust and Solar Energy



The MIT-Regional Climate Model (MRCM) is used in this study to investigate the different interactions between climate, solar energy and dust over the Saudi Arabia using 30 years simulation from 1983 to 2013. Furthermore, the model provide the downward shortwave (blue line in top figure, red line is observation from NASA-SRB product) radiation and dust deposition (bottom figure) data to run the PV model.

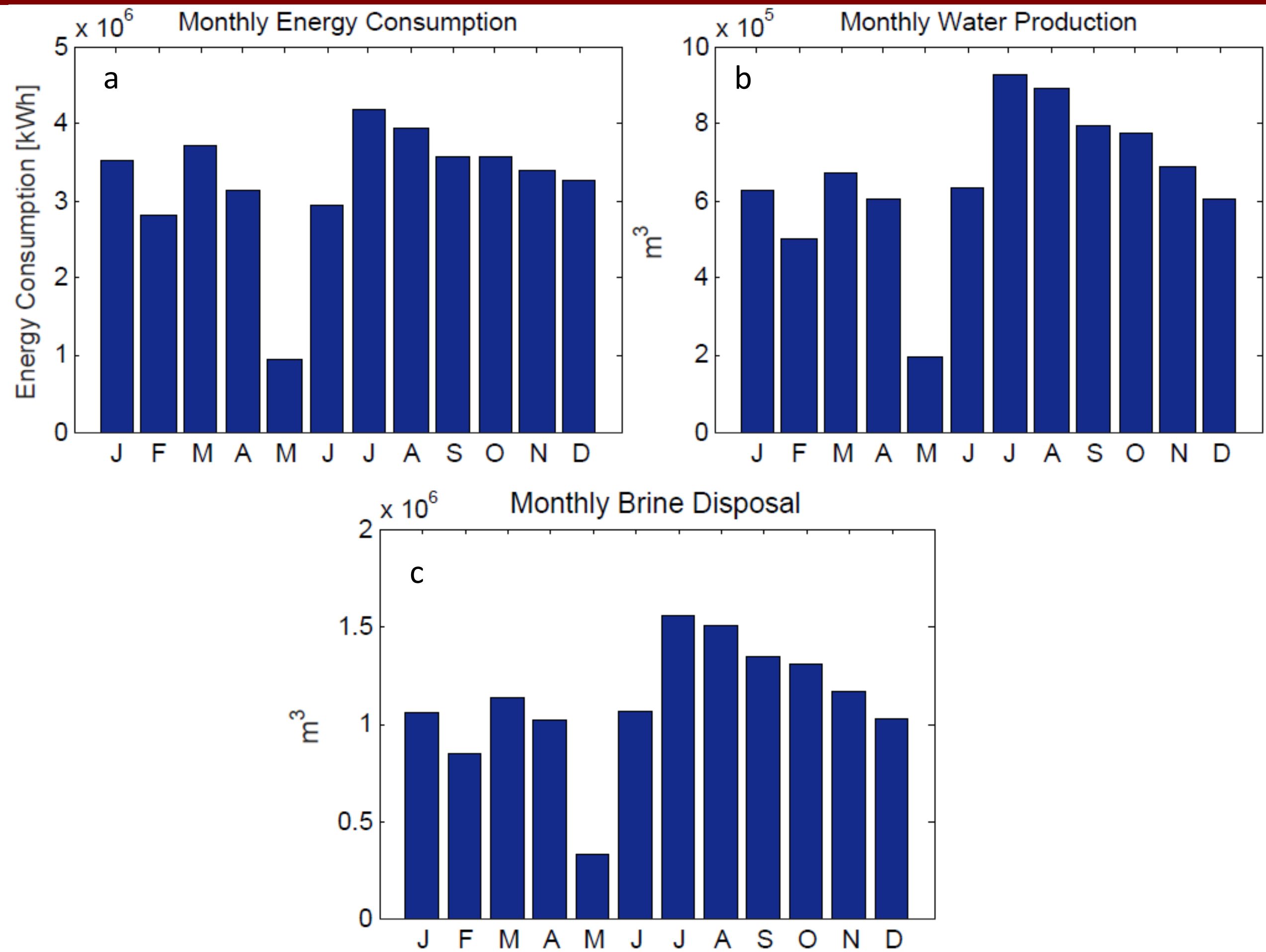
Impacts of Dust on the Performance of Solar Panels



Average monthly: (a) energy produced from the PV panels, and (b) percent of energy lost due to dust at AlKhafji site. The panels are cleaned at the end of each month.

The electricity is produced using Photovoltaics (PV) technology. A PV model is developed to simulate the amount of electricity produced by the panels based on solar energy and dust deposition provided by MRCM. The PV model accounts for the various factors that impact the performance of the panels including solar energy, dust, temperature and difference in performance of panels from different manufactures.

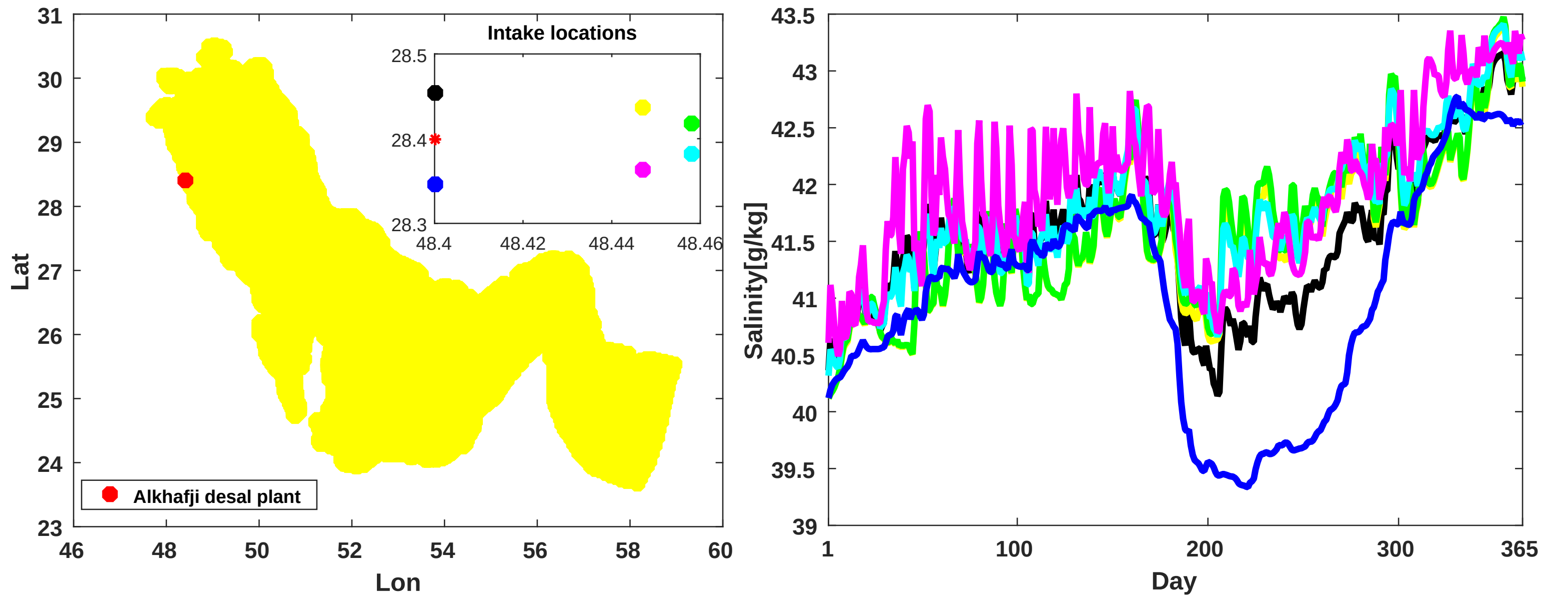
Desalination Processes



Average monthly: (a) energy consumption from the PV panels, (b) water production, and (c) brine discharged to the Gulf from the desalination plant at AlKhafji site.

The water is desalinated using the Reverse Osmosis (RO) technology. An RO model is developed that is capable of simulating in detail the main physical processes necessary to describe the operation of an RO plant. The performance of the plant is determined by the amount of energy available from the PV panels and temperature and salinity of a plant's intake water from the Gulf provided by the Gulf model described in the next section.

Optimizing Sea Water Intake Location



The hydrodynamics of the Gulf is simulated with the Gulf-Atmosphere Regional Model (GARM). The atmosphere component of GARM is MRCM and the ocean component of GARM is the Finite Volume Community Ocean Model (FVCOM). The coupling between MRCM and FVCOM is done with OASIS every six hours (Xue and Eltahir, 2015).

Summary

1. A framework is proposed to investigate the different interactions between climate, dust, solar desalination processes and water salinity in the Gulf. This framework includes different models simulating the details of each of these processes. The MIT-Regional Climate Model (MRCM) is used to simulate the amount of dust and shortwave radiation reaching the solar panels, a Photovoltaics (PV) model is developed to simulate the loss in energy produced due to dust, a Reverse Osmosis (RO) model is used to simulate the amount of water desalinated and the corresponding energy consumed and brine discharged from the desalination plant, and Gulf-Atmosphere Regional Model (GARM) is used to simulate the impacts of discharged brine the desalination plant on the hydrodynamics of the Gulf.

2. The framework was applied for AlKhafji solar desalination plant on the northeast coast of Saudi Arabia. Moreover, it can expanded to analyze the interactions between climate, dust, solar desalination processes and water salinity of other locations in the Gulf. In addition, it can be used to optimally design solar desalination plants by locating regions with maximum potential solar energy, minimum dust deposition rates and have low impacts on the salinity of the Gulf.