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Hydrodynamic evaluation of long term impacts of climate change and coastal effluents in the Arabian Gulf

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A B S T R A C T

A comprehensive basin wide hydrodynamic evaluation has been carried out to assess the long term impacts of climate change and coastal effluents on the salinity and seawater temperature of the Arabian Gulf (AG) using Delft3D-Flow model. The long term impacts of climate change scenarios A2 and B1 of the IPCC-AR4 on the AG hydrodynamics were evaluated. Using the current capacity and production rates of coastal desalination, power, and refinery plants, two projection scenarios until the year 2080 with 30 year intervals were developed namely the realistic and the optimistic discharge scenarios. Simulations of the individual climate change scenarios ascertained overall increase of the AG salinity and temperature and decrease of precipitation. The changes varied spatially with different scenarios as per the depth, proximity to exchange with ocean water, flushing, vertical mixing, and flow restriction. The individual tested scenarios of coastal projected discharges showed significant effects but within 10–20 km from the outfalls.

1. Introduction

The Arabian Gulf (AG) is a semi-enclosed extension of the Indian Ocean located in the subtropical, hyper-arid region between 24 and 30° latitudes occupying an approximate surface area of 240,000 km^2 and connecting directly with the deep Gulf of Oman through the Strait of Hormuz which is a narrow 60 km wide passage. The AG is bordered by 6 countries i.e. Kuwait, Saudi Arabia, Bahrain, Qatar, United Arab Emirates, and Iran. The widest section of the Gulf spans over 340 km between the coasts of the United Arab Emirates (UAE) and Iran, and the bathymetry is shallow with an average depth of 36 m asymmetric along its axis with a deeper zone close to the Iranian coast and a broad, shallower shelf off the UAE coast. The AG forms an inverse estuary that experiences salinities higher than the adjacent Indian Ocean. The circulation of the AG is driven principally by the tides (Elshorbagy et al., 2008; Elshorbagy et al., 2006; Azam et al., 2006; Reynolds, 1993). The tides in the AG are complex standing waves and the dominant pattern varies from primarily semi-diurnal to diurnal. The tidal range has values greater than 1 m (Lehr, 1984). The residual circulation in the AG is density-dominated in the central and southern regions while it shows frictional-balanced, wind-dominated circulation in the NW Region (Hunter, 1983). The open waters of the Arabian Gulf experience evaporation rates of 2 m/yr (Privett, 1959; Meshal and Hassan, 1986; Ahmad and Sultan, 1991) which considerably surpass the net freshwater input by precipitation (0.15 m/yr) (Johns et al., 2003) and the river discharges of 0.15–0.19 m/yr (Johns et al., 2003; Reynolds, 1993). The temperature and salinity of the AG was best described by the Mt. Mitchell expedition (Reynolds, 1993). The data showed that the southern shallow areas are more saline, with values up to 43 psu in winter. Reynolds (1993) showed that the surface salinity near the Straits of Hormuz was lower, with values of about 36–38 psu in both summer and winter due to the effect of the Indian Ocean surface water (IOSW). A stratified bottom layer with higher salinity and colder temperature was observed during both summer and winter. The lower summer salinity is attributed to the intensification of the Indian Ocean Surface Water (IOSW) inflow along the Iranian coastline in spring. In autumn and winter, together with a weakening of the IOSW inflow, the low-salinity surface signature partially disappears (Kämpf and Sadrinasab, 2006). In most Gulf waters, salinity greater than 39 psu occurs (Alessi et al., 1999) and salinities of over 70 psu are observed at low flushing major embayment in its central and southern parts (Kämpf and Sadrinasab, 2006). The rate of exchange between the AG and the Gulf of Oman via the Strait of Hormuz that determines the residence time for the AG basin has been studied by a number of scientists. Older studies showed that the residence time falls in the range of 2–5 years (Hughes and Hunter 1979; Hunter 1983).

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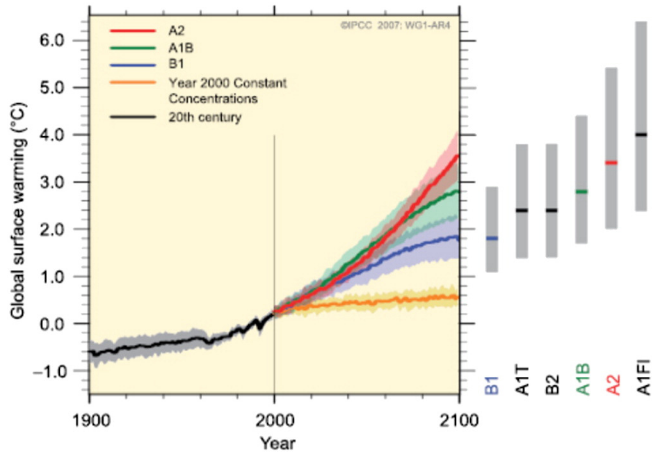

Fig. 1. Multi-model averages and assessed ranges for surface warming (source: IPCC, 2007).

1.1. Climate variability in the AG

The region is expected to be under higher stresses due to the anticipated climate change impacts. The Intergovernmental Panel for Climate Change

Fourth Assessment Report (IPCC, 2007) mentioned that by the middle of the 21st century, the Middle East region is expected to get warmer across all seasons. It also stated that "For the next two decades a warming of about 0.2 °C per decade is the average projected according to the special report on emission scenarios (SRES). Even if the concentrations of all greenhouse gases (GHG) and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1 °C per decade would be expected."

Climate modeling results for the Middle East and Gulf region predicts an increase between 2.5 to 3.7 °C in summer, and 2.0 to 3.1 °C in winter by 2100 (Hemming et al., 2007). Higher temperatures will increase the vapor pressure which along with the changes in atmospheric circulation patterns will likely have a considerable effect on the intensity, frequency and spatial variability of precipitation. With less than 66% agreement of the climate model results on the sign of the change, the region will likely get drier, with significant rainfall declines in the wet season outweighing slight increases during the drier summer months (IPCC, 2007). The weather is also likely to become more unpredictable, with the region experiencing an increase in extreme rainfall events (Tolba and Saab, 2009). Using long-term historical climate records for the Arabian Peninsula Nasrallah and Balling (1996) indicated a linear increase of temperature of 0.63 °C and an insignificant decrease in precipitation over the last 100 years. More recently, Al Sarmi and Washington (2011) examined trends in temperature and precipitation parameters for the Arabian Peninsula (AP) during the last 2 to 3 decades using recorded measurements from 21 stations and concluded a general warming pattern of the Arabian Peninsula mean annual temperature with the UAE (Dubai) showing an increasing rate of 0.81 °C per decade. In their study they showed that the mean annual precipitation changes were insignificant showing a decreasing trend.

Most recently Elhakeem et al. (2015a,b) used statistical downscaling (SD) and proposed an improved systematic approach to select influential predictors to downscale the Hadley Model (HadCM3) projections using local observations at two stations representing the dominating bioclimatic zones in the UAE. The tested climate change scenarios revealed a range of increase of the annual mean maximum temperature of 2.79–3.80 °C and a range of reduction of annual precipitation between 16.80–37.00% by 2080 at the considered stations.

Table 2
AOGCM in order of their skill for air temperature.

	Model	Total rank
1	MIROC-HI	8
2	MPIECH-5	8
3	CCSM−30	7
4	MRI-232A	6
5	UKHADCM3	6
6	GISS−ER	4
7	MIROCMED	4
8	ECHO−G	3
9	CCCMA-31	2
10	GFDLCM20	2
11	GFDLCM21	2
12	GISS−EH	2
13	CNRM-CM3	1
14	UKHADGEM	1
15	BCCRBCM2	0
16	CSIR0-30	0
17	FGOALS1G	0
18	INMCM-30	0
19	IPSL_CM4	0
20	NCARPCM1	0

Table 1
Statistical analysis of Middle-East and global modeled and observed temperature.

Model	CORR (ME)	CORR (G)	RMSE (ME)	RMSE (G)	BIAS (ME)	BIAS (G)	CORR-RMSE (ME)	CORR-RMSE (G)
	°C	°C	°C	°C	°C	°C		
BCCRBCM2	0.954	0.988	4.233	3.274	−3.862	−2.216	1.732	2.411
CCCMA-31	0.957	0.99	3.794	3.011	−3.426	−1.805	1.631	2.411
CCSM−30	0.973	0.995	1.943	1.396	−1.415	−0.294	1.332	1.364
CNRM-CM3	0.961	0.99	4.36	2.68	−3.961	−1.756	1.823	2.025
CSIR0-30	0.941	0.991	4.541	2.649	−4.131	−1.772	1.886	1.969
ECHO−G	0.929	0.99	2.199	2.029	−0.715	0.307	2.08	2.006
FGOALS1G	0.931	0.973	3.285	4.393	−2.407	−1.994	2.235	3.915
GFDLCM20	0.963	0.989	4.273	3.12	−3.974	−2.278	1.572	2.132
GFDLCM21	0.938	0.992	3.244	2.299	−2.61	−1.47	1.927	1.767
GISS−EH	0.929	0.983	3.033	2.71	2.223	0.62	2.063	2.638
GISS−ER	0.956	0.988	1.637	2.296	0.069	−0.499	1.636	2.241
INMCM-30	0.906	0.987	5.221	3.019	−4.638	−1.969	2.397	2.288
IPSL_CM4	0.949	0.989	3.563	2.782	−3.1	−1.789	1.755	2.13
MIROC-HI	0.976	0.994	1.222	1.665	−0.057	−0.536	1.22	1.576
MIROCMED	0.944	0.991	2.109	2.198	0.159	−1.059	2.104	1.926
MPIECH-5	0.977	0.996	1.218	1.473	−0.231	−0.257	1.196	1.45
MRI-232A	0.938	0.995	2.01	1.889	0.201	−0.811	2	1.706
NCARPCM1	0.919	0.99	7.007	2.977	−6.641	−2.138	2.234	2.071
UKHADCM3	0.98	0.994	2.159	2.051	−1.849	−0.901	1.115	1.842
UKHADGEM	0.934	0.992	5.533	2.9	−5.159	−2.109	2	1.991

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