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Study on the local sea water temperature variation for the industrial water use of Al-Zour coastal area in Kuwait

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ABSTRACT

Ras Al-Zour coastal area, located in southern part of Kuwait, is the region of concentrated industrial water use and sea intake-outfall of existing power plants. There are some of undergoing construction projects such as Al-Zour Refinery, Al-Zour LNG import facility projects, and the expansion planning of existing power plant. The site of Al-Zour LNG import facility project is located close to the power plant in north direction approximately 0.6 km away from the shore between the Sulphur pier and the small boat harbor north of the breakwater. Being located only 3 km away from the massive thermal and brine discharge from power plants, the future water use of LNG regasification facility will be under the direct influence of thermal discharge from power plants and the further development of seawater resources within this area such as Al-Zour North power plant project. There are two issues regarding the seawater temperature in this area to be considered: (1) variations in background water temperature mostly under combined effect of local meteorology and global climate change; (2) increase of temperature due to the expansion of the thermal discharge of expanded power plant. Annual water temperatures of two candidate locations of the seawater intake for Al-Zour LNG regasification facility were measured during 2017, which shows a typical seasonal variation of a local seawater temperature with an added effect of the neighboring thermal outfall. The numerical model study was performed by using MIKE3-DHI to reproduce 2017-measurement of the sea water temperature during June–July based on the meteorological hindcast data from ECMWF (European Centre for Medium-Range Weather Forecasts) and the thermal discharge input from the southern power plants. It was found that the daily sea water temperature at the measurement location is mainly affected by thermal plume dispersion oscillating with the phase of tidal current. Thermal discharge expansion plan in ~10 km area around the new facility should be considered to obtain the exactly estimated intake water temperature limit during the design life of the facility.

Keywords: Al-Zour area; Industrial water use; Thermal discharge; Seawater temperature; Heat exchange

1. Introduction

Along the coastline of Arabian Gulf, increase of demand of industrial water use and sea water intake-outfall is one of the key factors of environmental changes. Nowadays, many construction projects are ongoing along the coastline of Arabian Gulf including the coastal area of Kuwait as well.

Nowadays, industrial plants are developed to be clustered in a specific complex supporting common infrastructures and utilities, thus the additive sea water intakes and outfalls tend to be installed adjacent to those of existing plants. This makes the prediction of local sea water temperature much more complicated. Therefore, it becomes gradually important to assess the sea water temperature of existing condition exactly and predict the future sea water temperature with possible expansion scenarios.

Impact of overall global warming should be considered as well because local coastal water is closely affected by the seasonal and annual variation of regional sea water temperature. Nandkeolyar et al., (2013) reported that a sharp increase (warming) in sea water temperature was found in the Arabian Gulf from 1992 to 2009. Since 1995, it is reported that repeated extended periods of elevated temperature

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in the Gulf have resulted in mass coral bleaching (Coles & Riegl, 2012).

Al-Zour area become one of the major industrial complex in Kuwait, in which many of power and oil refinery plants are developed and still under development. Among them, Al-Zour LNG import facility projects, and the expansion planning of existing power plant are also in progress. The site of Al-Zour LNG import facility project is located near to the power plant in north direction approximately 0.6 km away from the shore between the Sulphur pier and the small boat harbor's north of the breakwater. Being located only 3 km away from the massive thermal and brine discharge from power plants, the future water use of LNG regasification facility will be under the direct influence of thermal discharge from the southern power plants and the further development of seawater resources within this area.

Uddin et al. (2011) provide recorded sea water temperature during 1993 and 2003 by KEPA (Kuwait Environment Public Authority) at Ras Al-Zour station – the seasonal variation of sea water temperature at Al-Zour is reaching 35°C in summer and 14° in winter. Pokavanich et al. (2015) also provide sea water temperature measured data for their model validation at off-Khiran (28°56.805′N, 48°34.397′E). The data are varied from 15°C to 35°C for a year.

Being reviewed ECMWF(European Centre for Medium-Range Weather Forecasts)'s ERA-interim reanalysis climatology data, the hindcast data at 28.66°N, 48.43°E indicated that the annual mean sea water temperature is 25.03°C during year 1979–2015, meanwhile the maximum and minimum sea water temperature was 33.9°C in August and 15.1°C in February. Table 1 shows monthly mean of daily mean climatology of sea water temperature close to Al-Zour area from ERA-interim reanalysis data.

In this study, the sea water temperature variation in 2017 around the Al-Zour LNG Import Facility under construction was reproduced by the numerical modeling. Real water temperature was measured during 2017 in 5 min interval at two candidate points (T1 and T2 in Fig. 1 and Table 2) for the intake head. Together with the marine meteorological condition during the measurement period, thermal discharge from southern power plant was also considered in the reproduction of local water temperature. With those conditions, it was assessed its effect on the temperature variation.

2. Hydrodynamic model setup

The hydrodynamic and thermal study in Al-Zour site was carried out with MIKE 3-FM (Flexible Mesh) of DHI.

Table 1
Climatology of sea water temperature near Al-Zour location (28.66°N, 48.43°E) during 1979–2015 (extracted from ECMWF ERA-interim atmospheric reanalysis model)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Mean	17.9	17.0	18.2	21.6	25.9	29.1	31.0	32.2	31.4	29.1	25.4	21.1
Max	20.4	18.6	19.9	23.3	27.3	30.5	32.1	33.9	33.1	30.9	26.6	22.9
Min	15.6	15.1	16.0	20.0	24.0	26.4	29.2	29.7	29.4	27.2	23.4	18.3

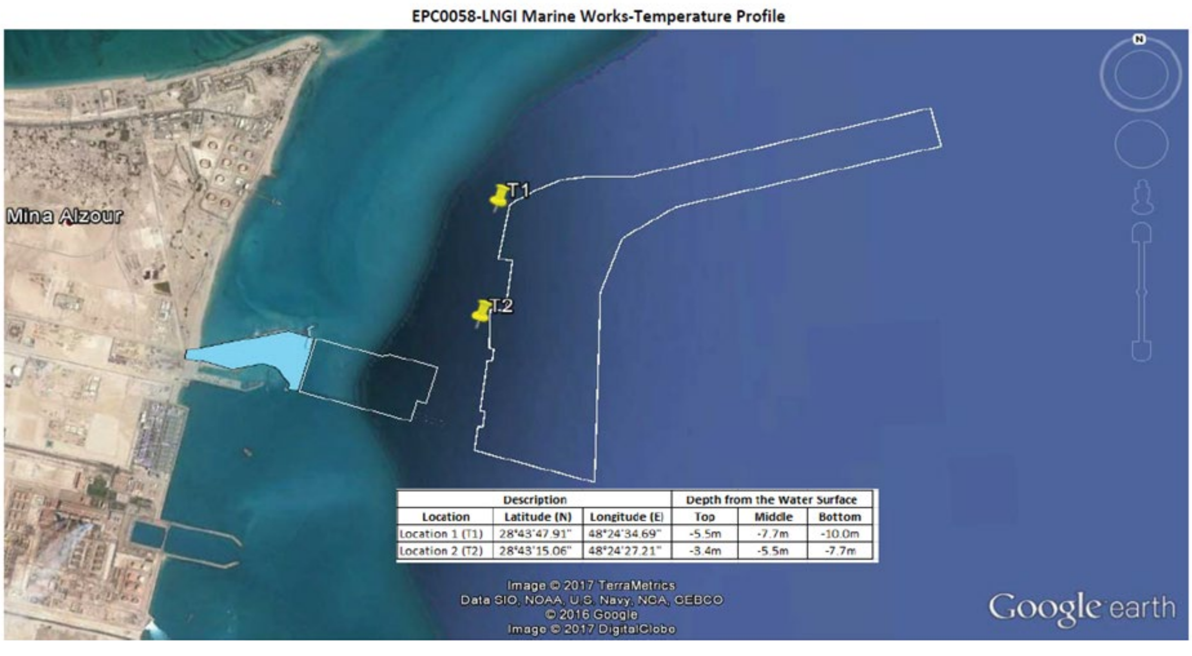


Fig. 1. Schematic layout of Al-Zour LNG site and sea water temperature monitoring points.

Table 2
Coordinate and vertical depth of measurement at each location

No	Description	Coordinate			
		on UTM (39 R)		on Degrees, Minutes, Seconds	
		3,180,820.222 N	246,999.002 E	28°43′47.91″ N	48°24′34.69″ E
1	T1	Surface	Top	Middle	Bottom
		N/A	–5.5 m	–7.7 m	–10.0 m
		3,179,813.336 N	246,774.098 E	28°43′15.06″ N	48°24′27.21″ E
2	T2	Surface	Top	Middle	Bottom
		–3.4 m	–5.5 m	–7.7 m	N/A

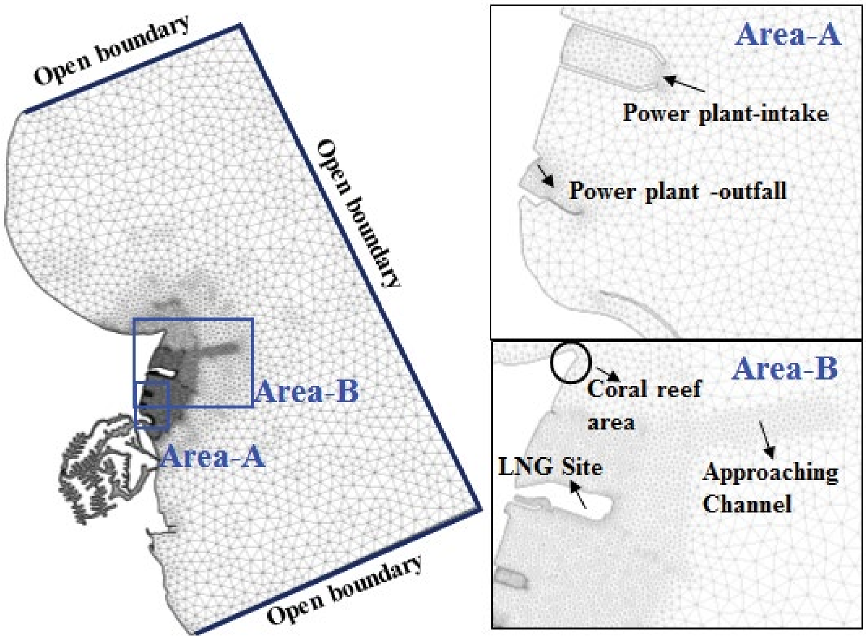


Fig. 2. Al-Zour hydrodynamic model mesh including vicinity facilities.

MIKE 3 is a general numerical modeling system for the simulation of flows in estuaries, bays and coastal areas as well as in oceans. It simulates unsteady three-dimensional flows taking into account density variations, bathymetry and natural forcing such as tide, wind and atmospheric temperature based on the Boussinesq approximation in buoyancy. The model was nested from Arabian Gulf – regional model to provide open-boundary conditions on the nested boundaries. Nested Al-Zour model was developed in 5 sigma vertical layered model with 14,173 elements of horizontal triangular grid. Minimum size of mesh is 20 meters along outfalls and maximum size of mesh is 1 km near open boundaries. The bathymetry information was extracted from MIKE C-MAP. The model covers 20 km towards shoreline and 35 km along-shore line. Fig. 2 shows project area and vicinity facilities.

The simulation period determined 2 months from June to July of 2017 in order to see the model's reproduction of the increasing seawater temperature in this period and to find out the contribution of local thermal discharge from southern power plant. Open boundary condition was extracted from Arabian Gulf – regional model. This regional model has been calibrated in current velocity, current direction and water surface elevation in several coastal locations in Arabian Gulf. Smagorinsky formulation was applied for the horizontal eddy viscosity and k-epsilon formulation was used for the vertical eddy viscosity. Bed resistance was set by the roughness height with constant value 0.05 m. Wind forcing was incorporated with ERA-5 hourly data set provided by ECMWF in timely and spatially varied wind speed and surface pressure.

Latent and sensible heat exchange was based on the given formula in MIKE3. The time series of short wave radiation was included from the extracted data of ERA-interim dataset of ECMWF. The maximum surface short wave was reaching 978 W/m^2 during June–July 2017 in this area. The long wave radiation was calculated with MIKE3 provided formula with using air temperature data input. Air temperature was obtained both from ECMWF hindcast reanalysis data and the hourly records of meteorological observation inside Kuwait City. Applied atmospheric temperature in Kuwait City and sea water temperature measured at T1 surface was compared in Fig. 3. Relative humidity and clearance was set 17% and 70% for whole simulation period. Model parameters related to heat exchange between sea water surface and atmosphere is summarized in Table 3. The open-boundaries sea water temperature was obtained from the surface water temperature in 6 hourly data of ERA-interim dataset (Fig. 4).

3. Simulation without thermal discharge

Model calibration was implemented without introduction of thermal discharge in the domain. Natural sea water temperature was driven by the modeling only with meteorological conditions such as radiation stress, wind and others. In this sense, natural heat transfer in the water body can be described without any interruption of other sources.

Heat exchange parameters are tuned to fit the sea water surface temperature data of ERA-interim. Iteratively, each parameter was tested to check sensitivity of sea water temperature changes. With different parameters, the sensitivity of difference was compared in RMSE base. Calibration sequences are numbered below and its results are shown in Fig. 5.

- *Sequence 1*. Open boundary input of sea surface water temperature from ERA-interim data set + air temperature from ERA-interim data set
- *Sequence 2*. Sequence 1 setup + ERA-interim short wave radiation data
- *Sequence 3*. Sequence 2 setup + heating coefficient calibration
- *Sequence 4*. Sequence 3 + measured air temperature at Kuwait City instead of air temperature from ERA-interim data set in Sequence 1

It is shown that short wave radiation, heating coefficient and air temperature can be major parameter for calibration of water body's temperature (Table 4).

4. Simulation with thermal discharge

Local hydrodynamics during simulation period was reproduced by the tidal elevation change on the open

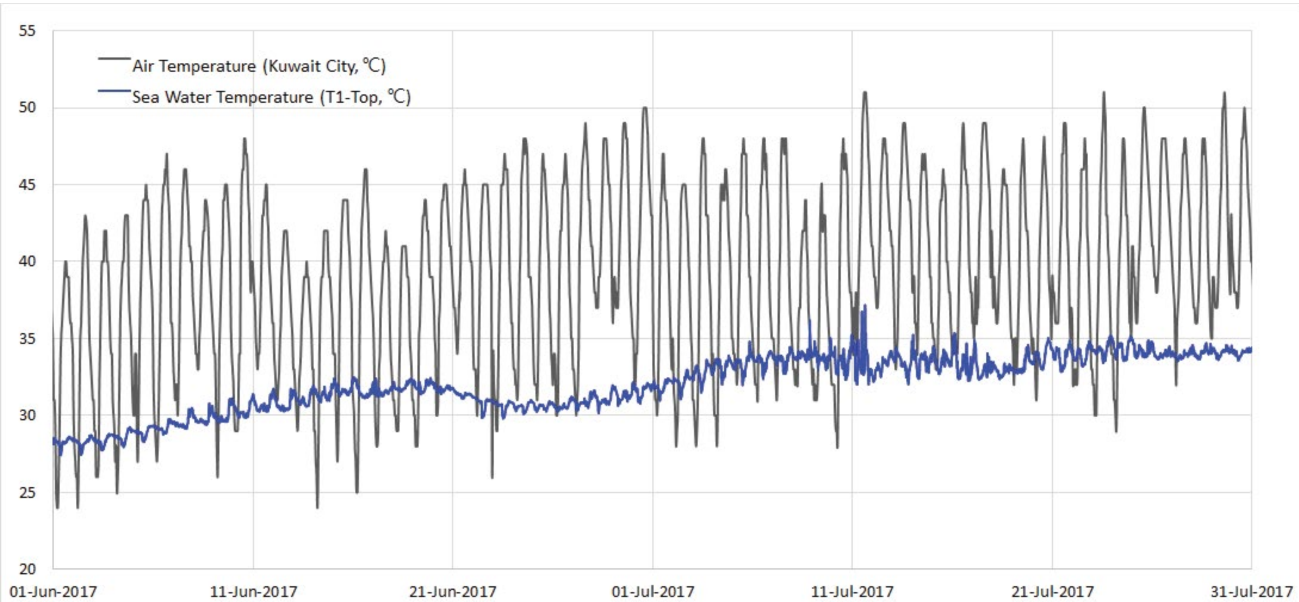


Fig. 3. Sea surface temperature for boundary condition, extracted from ECMWF interim data set.

Table 3
Heat-exchange parameters

Parameter	References or sources	Remarks
Heating coefficient	Calibration factor	Mostly major impact
Short wave radiation	Empirical method, ECMWF dataset	ECMWF dataset was selected
Air temperature	ECMWF dataset, local measurement	Local measurement was selected
Relative humidity	17%	Fixed
Clearance	Calibration factor (Minor impact)	70% was selected
Evaporation rate	Minor impact (almost no changes)	Not included

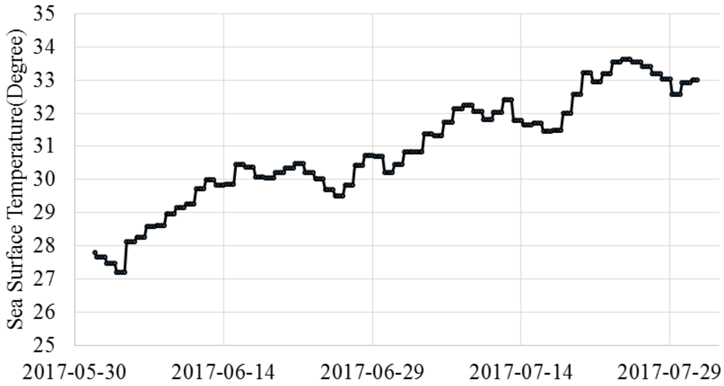
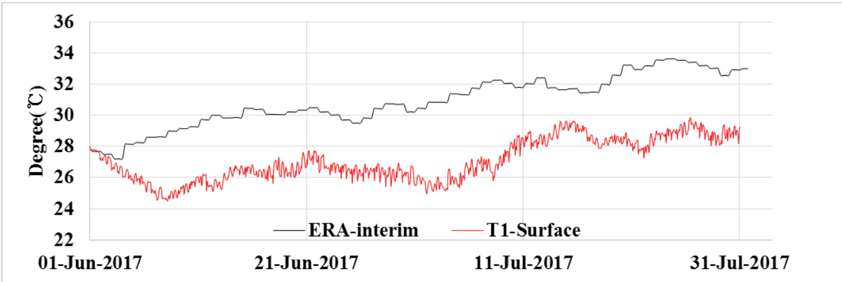
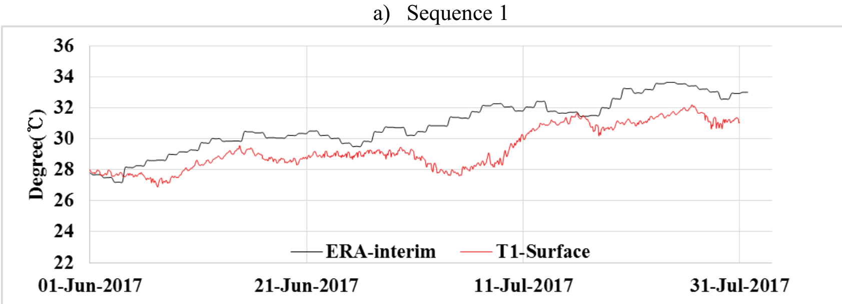


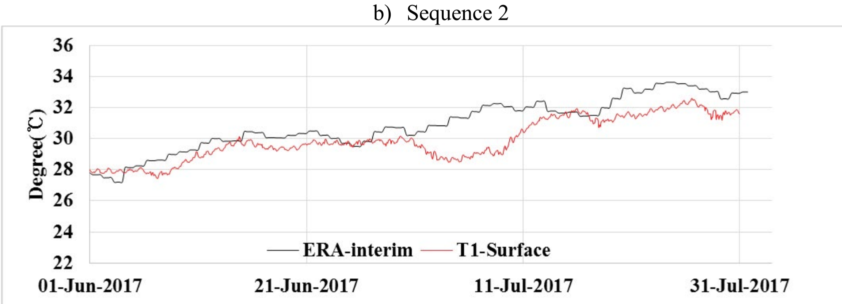
Fig. 4. Sea surface temperature for boundary condition, extracted from ERA-interim data set.



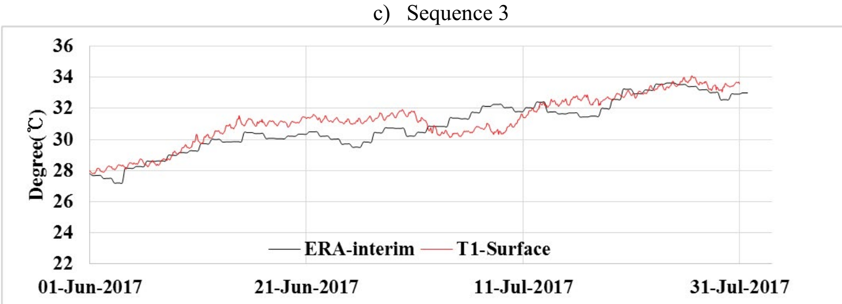
a) Sequence 1



b) Sequence 2



c) Sequence 3



d) Sequence 4

Fig. 5. Comparison result of heat-exchange in different parameter setting. (a) Sequence 1, (b) sequence 2, (c) sequence 3, (d) sequence 4.

Table 4
Comparison of calibration result, subtracted in series

Sequence	RMSE (°C)	NRMSE (%)
1	3.95	78.5
2	1.76	34.0
3	1.27	25.2
4	0.80	13.6

boundaries and the wind forcing on the surface. Thermal discharge from the surface outfall of southern power plant was defined in the model with 131 m^3/s of flowrate and 6°C of excess water temperature in the one-through cooling system but this is roughly averaged discharge scenario due to the absence of detailed operation record of the power plant. The resultant mean current speed around the LNG site is varied in 0.1 to 0.15 m/s whereas Ras-Al Zour reef area (Northern part of Kuwait LNG Import site) reaches by

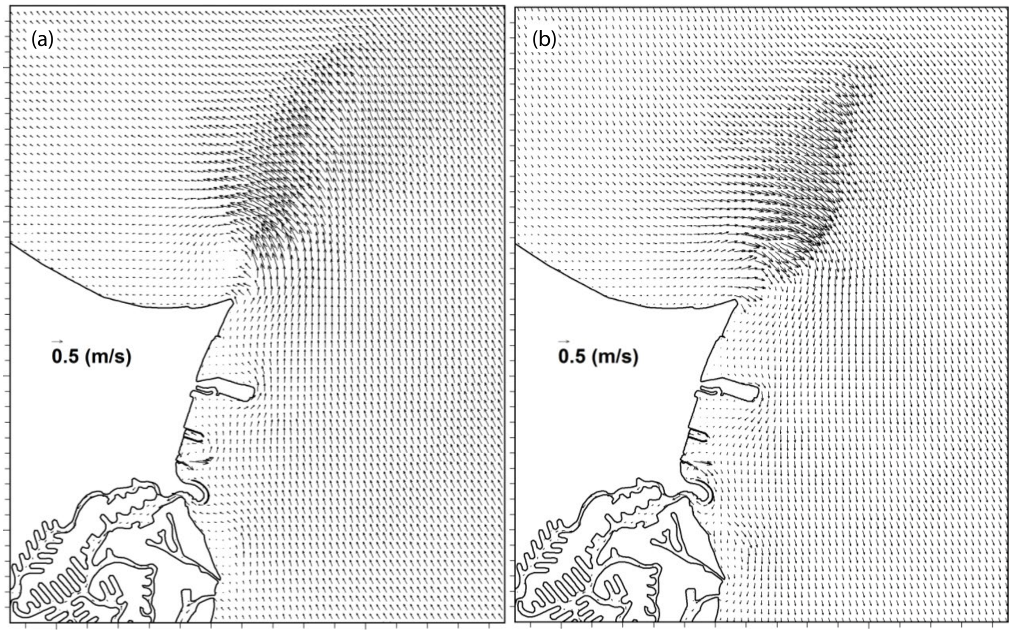


Fig. 6. Local hydrodynamic in flood (a) and ebb (b) tide.

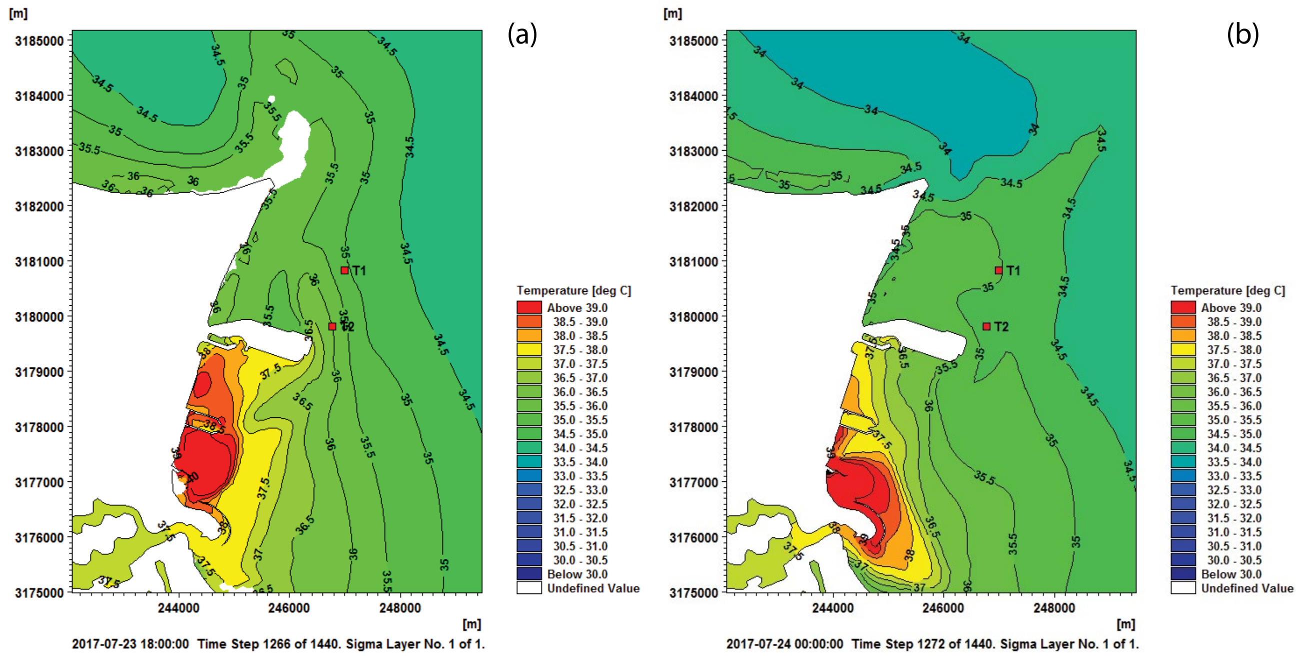


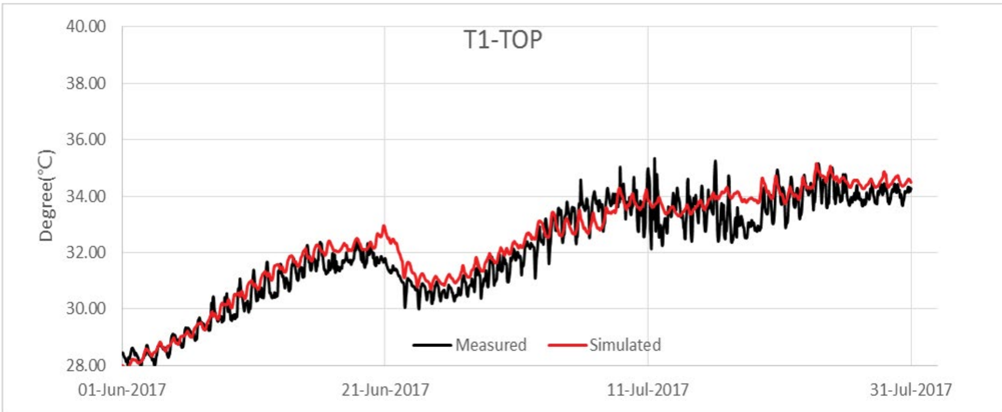
Fig. 7. Sea water temperature distribution with thermal discharge in flood (a) and ebb (b) tide.

0.4 m/s. Maximum current speed around LNG site is 0.2 to 0.3 m/s, whereas Ras Al-Zour coral reef area is over 0.7 m/s. The overall circulation pattern is tidally driven oscillatory current in alongshore direction.

Discharged plume from the southern power plant's outfall is moving back and forth in north and south direction forming a large thermal cloud reaches from the entrance of Al Khiran to the corner of coral reef area (Fig. 7).

The overall rise of measured water temperatures during simulation period were compared with simulation results at corresponding points in Figs. 8 and 9. Simulation results correspond well with the daily mean temperature increase in measurement especially on the top measurement point. Crests in temperature fluctuation occur when the sea current direction is toward north. The amplification of fluctuations is higher in measurement than in simulation results, especially in the bottom layer.

The water temperature at T2 is more dependent on the thermal dispersion from power plant than the temperature at T1 because of its closer distance from outfall point. Temperature fluctuation is also more severe in T2 than T1, which is under direct tidal fluctuation depending on the thermal plume movement. Fluctuation in simulation results reaches to 2°C at T2 whereas it was reduced to 1°C level



a)

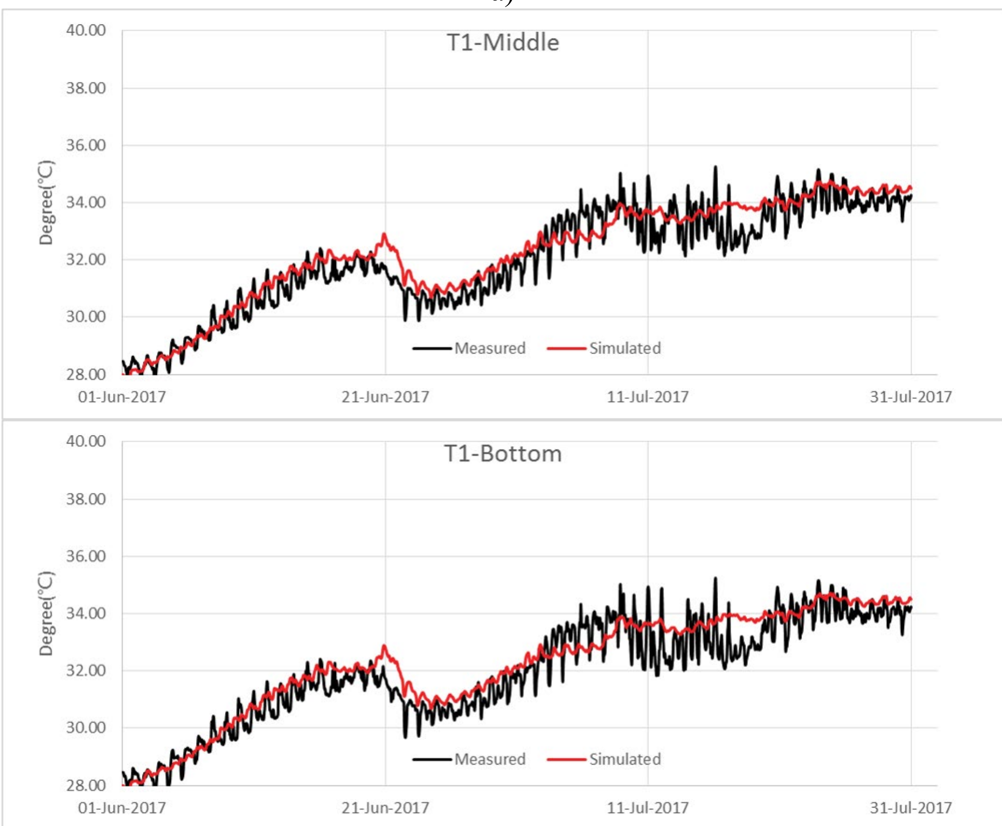


Fig. 8. Comparison of simulation result and measured data at T1 during simulation period Jun–July 2016 (Top:–5.5 m, middle: –7.7 m and bottom –10 m from the sea surface).

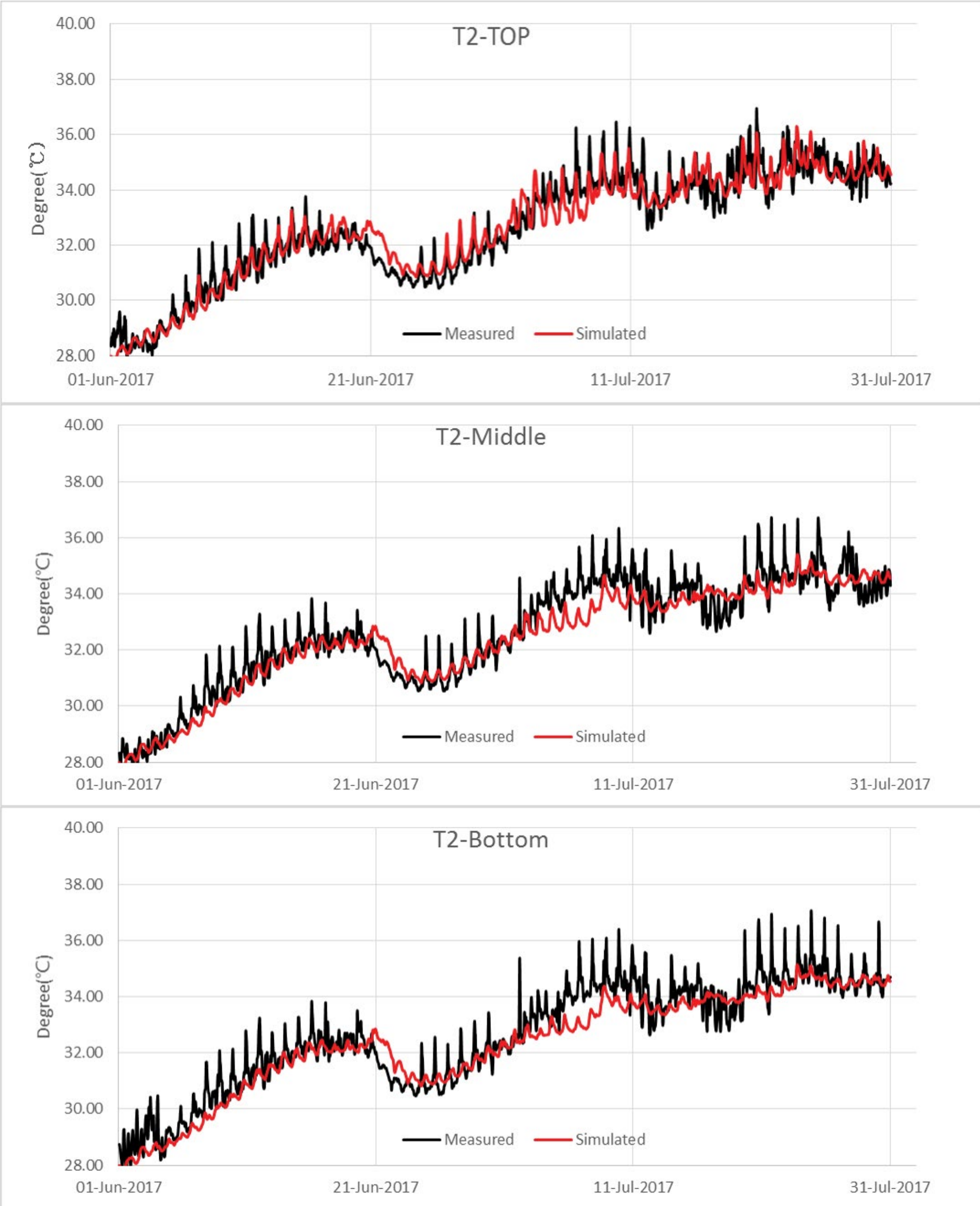


Fig. 9. Comparison of simulation result and measured data at T1 during simulation period Jun–July 2016 (Top:–3.5 m, middle: –5.5 m and bottom –7.7 m from the sea surface).

at T1. This amplification is 2–4 times larger than the 0.5°C fluctuation of thermal plume temperature of simulation without local discharge (Fig. 5).

The maximum temperature of measurement and simulation results during June–July was listed in Table 5. Compared with the regional maximum surface water temperature from ERA-interim hindcast data was 33.63°C (Fig. 4), the effect of thermal discharge on the local water temperature can be estimated at least 1.7°C at T1 and 3.3°C at T2. The simulation results underestimated the maximum

Table 5
Comparison of maximum temperatures

	Measurement (°C)		Simulation (°C)	
	T1	T2	T1	T2
Top	35.34	36.91	35.15	36.29
Middle	35.25	36.72	34.76	35.40
Bottom	35.23	37.03	34.72	35.14

temperature in a range of 0.2°C–0.6°C in top layer, whereas 0.5°C–1.9°C in bottom layer. Model simulation result could approximate measurement more closely through input of the detailed thermal outfall operation record and the more elaborate calibration of physical parameter related to heat exchange and hydrodynamic dispersion.

The measured temperature at T2 bottom has maximum value of temperature distribution. Considering normal thermal stratification of discharged water on the surface, this weak vertical stratification in measurement show that there exists strong vertical mixing in the initial mixing zone due to the strong discharge momentum.

4. Conclusion and discussion

Through the simulation with thermal discharge input, it was found that the daily sea water temperature distribution in this specific area can be greatly affected by the local thermal plume dispersion oscillating with the phase of tidal current. The regional meteorological condition also provided major contribution as a baseline condition of sea water temperature. Thus the long-term variation of water temperature around Al-Zour Site due to the global warming also needs to be considered. In the planning of the future water use in the Al-Zour industrial site, it will be necessary to consider major outfall discharges to be planned in adjacent facility in ~10 km area.

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