

## Hydrodynamic modelling of the Arabian Gulf

### introduction

The Arabian Gulf is a large and relatively shallow sea basin. The motion of water within the Gulf is complex and mainly related to the tide. Besides the tide, the wind (storms) and water density differences affect the water motion in the Gulf.

WL | Delft Hydraulics has developed a hydrodynamic model of the Arabian Gulf. This model was set up and extensively calibrated in 1994 and has been updated each time new depth, water level or current measurements became available.

The model computes the tidal and wind-induced water level elevations and currents for the entire Arabian Gulf at any pre-described period in time. The model is set up in WL | Delft Hydraulics' hydrodynamic modelling package Delft3D-FLOW. Besides computing the water levels and currents, the model is used to compute the wave fields on basis of the input winds using the SWAN programme.

Both the *flow* and the *wave* models of the Arabian Gulf are developed to support various kinds of local studies by providing the necessary boundary conditions. In the course of the last decade, numerous nested models were developed and further calibrated on basis of local measurements and applied in different types of studies (see Figure 1).

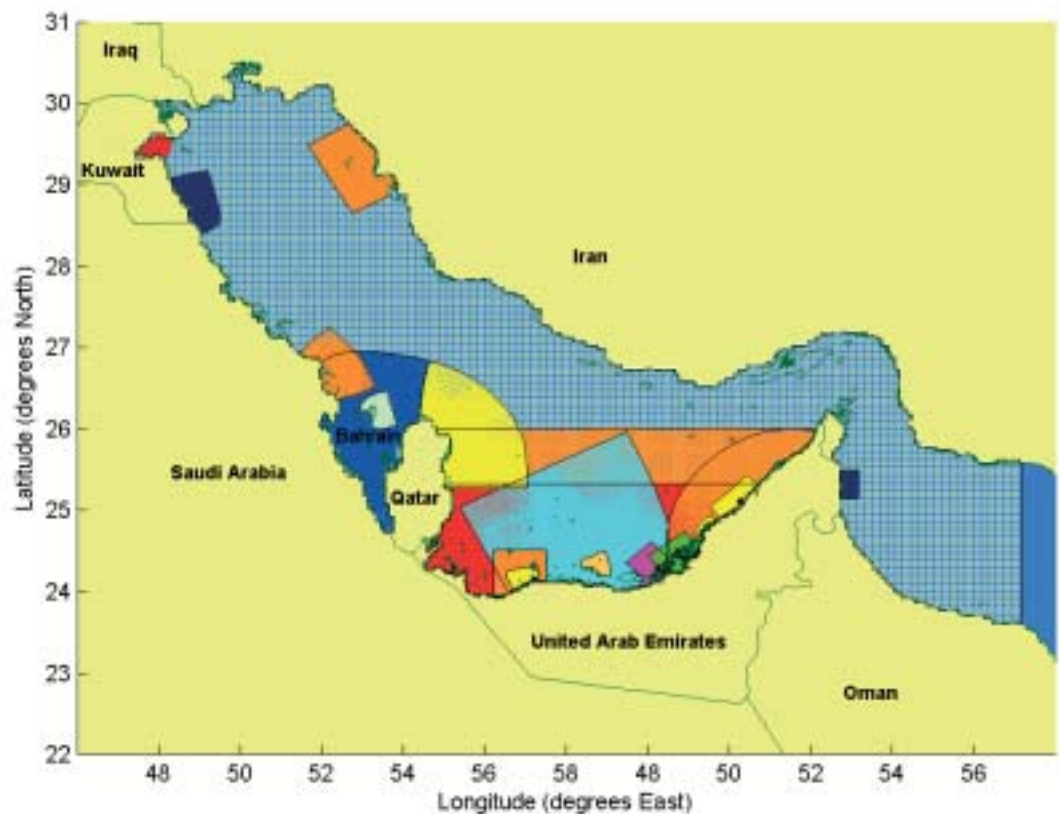


Figure 1: The Arabian Gulf Model and several nested, more detailed flow models

keywords:  
Arabian Gulf Model  
numerical simulations  
Delft3D-FLOW  
Delft3D-WAVE (SWAN)



### Arabian Gulf Flow Model - model description

The Arabian Gulf model covers the entire Gulf, the Strait of Hormuz and the inner part of the Gulf of Oman. The model is defined in a spherical coordinate system with a resolution of 1/20 degree latitude and longitude (approximately 4.5 km), resulting in a total of about 10,600 active computational grid points. The depth schematisation of the model of this relatively shallow and largely enclosed basin is shown in Figure 2. At the open sea boundary of the model, situated in the deep waters of the Gulf of Oman, tidal forcing is described in the form of amplitudes and phases of the 10 principal tidal constituents. This enables the computation of the actual tidal conditions in the Arabian Gulf for any requested period in the future or the past.

### Arabian Gulf Flow Model - calibration

The calibration of the Arabian Gulf Model focused primarily on the correct reproduction of the tidal wave propagation and dissipation characteristics. The calibration of the tidal motion in the model has been based on tidal constants available from various sources. For this calibration, simulation runs of 35 days were carried out, enabling the tidal analysis of the results. Modelled amplitudes and phases of the tidal constituents were compared with observed amplitudes and phases at over 130 coastal and offshore stations. A high level of agreement has been achieved, see Figure 2. This calibration in the frequency domain enables an objective and quantified model skill assessment independent of the selected calibration period.

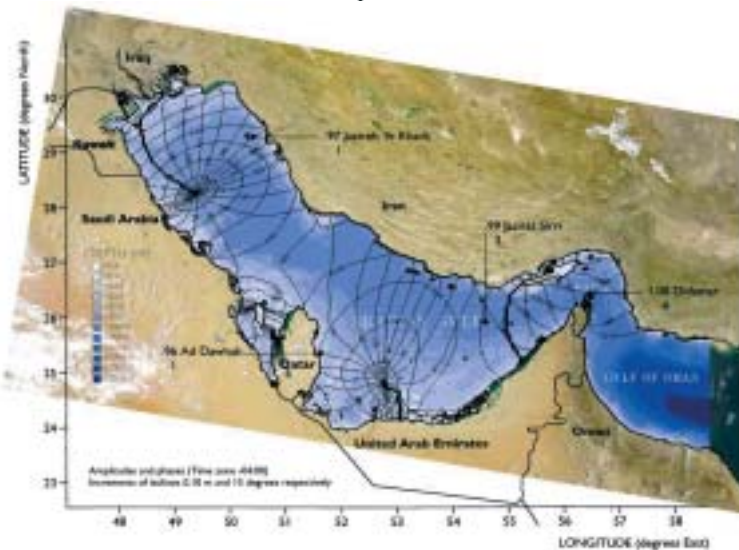


Figure 2: Depth schematisation of the Arabian Gulf Model. The overlaying black lines indicate the computed co-tidal map of the M2 constituent and the numbers near the monitoring station names denote the amplitude ratio (above) and the phase difference in degrees (below) of the modelled versus observed M2 tidal constituent.

### tidal characteristics in the Arabian Gulf

The dimensions and layout of the Arabian Gulf are such that a system of “standing waves” is generated between the Strait of Hormuz and the Kuwait/Iraq end of it. Two primary standing waves, one with a diurnal period of nearly 25 hours occupying the full length of the Gulf and the other with a semi-diurnal period of nearly 12½ hours occupying half the length of the Gulf, interfere and get mutated by the Coriolis effect due to the rotation of the earth, producing a complex pattern of vertical and horizontal tides (see Figure 3).

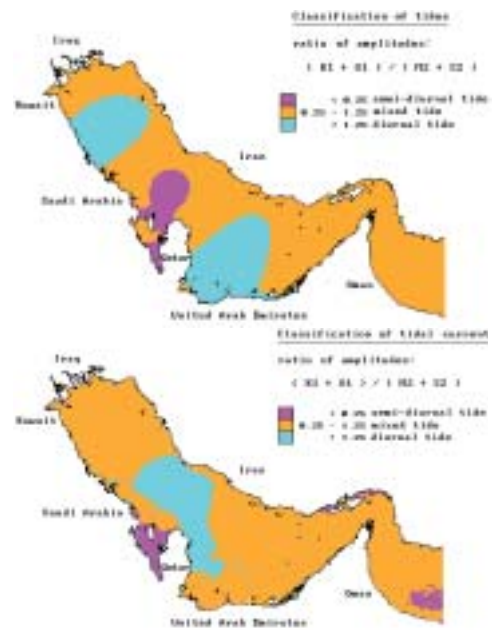


Figure 3: Patterns of vertical and horizontal tide

The resulting tidal characteristics within the Gulf vary considerably from area to area. Around Bahrain, for example, both the vertical and the horizontal tide are predominantly semi-diurnal. Offshore Ras Laffan, Qatar, the tide is of the mixed type (see Figure 4).

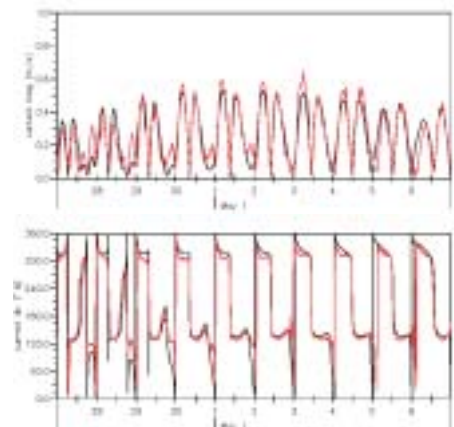


Figure 4: Measured (red) versus computed (black) current magnitude (top) and direction (bottom) at 10m water depth just offshore Ras Laffan in Qatar.

In the area between western Abu Dhabi and Qatar the vertical tide is predominantly diurnal whereas the horizontal tide is predominantly semi-diurnal (see Fig. 5).

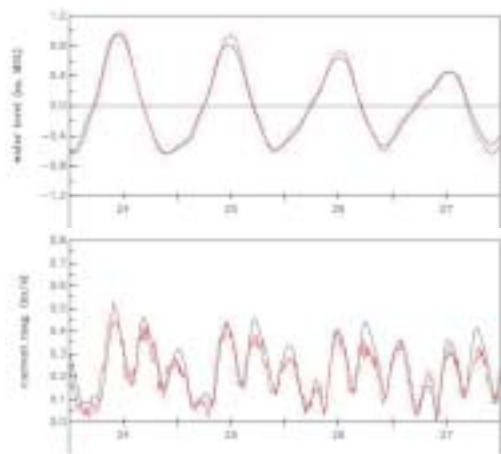


Figure 5: Measured (red) versus computed (black) water level (diurnal) and Flow velocity (semi-diurnal) at Ras Al-Qila, western Abu Dhabi

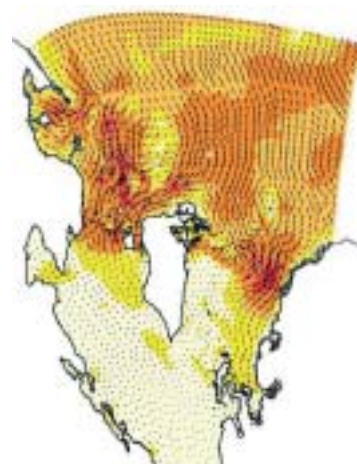


Figure 7: Detail model of Bahrain waters, operated through boundary conditions derived from the Arabian Gulf Flow Model

Hindcasting of Shamal storm events to determine meteorologically induced variations in water levels and flows as input for determining extreme design conditions, see Figure 8.

### applications of the Arabian Gulf Flow Model

The Arabian Gulf Model has been instrumental in understanding the tidal dynamics as well as storm surges in the Arabian Gulf, and has enabled WL | Delft Hydraulics to build an extensive and readily applicable database. The model is frequently updated with the latest field data, ensuring that the results of the model are always in line with current situation of the Arabian Gulf.

The Arabian Gulf Model has been and is used for various consultancy and research applications, such as:

- Analysis of tidal characteristics at any location in the Arabian Gulf.
- Generation of tide and wind driven flow fields for large scale water quality studies and oil spill studies.
- Generation of boundary conditions for detailed models, see examples in Figures 6 and 7.



Figure 6: Numerical modelling was undertaken to investigate the flushing of the Palm Island scheme and to assess the impact of the land reclamation on the seabed and coastline.

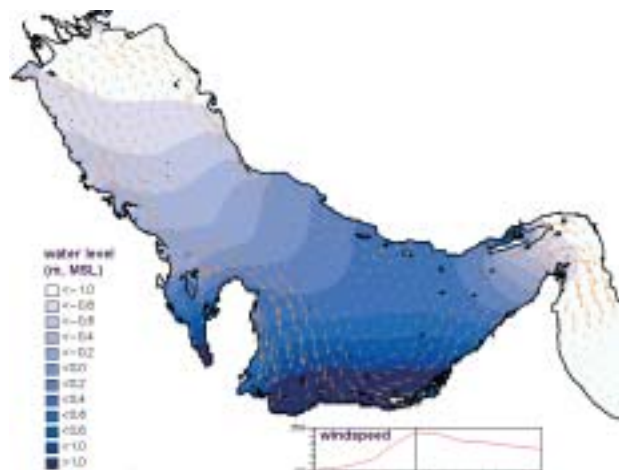


Figure 8: Water levels and flow field during peak of the extreme Shamal storm of January 1964

### instrument to reduce field measurements

Traditionally, site specific (hydrodynamic) data to operate and calibrate/verify models were, and are still, obtained through field measurements. Not long ago, this has been a considerable problem for marine area models due to the huge logistic efforts and high costs involved.

Large scale overall models, such as the Arabian Gulf Model with a considerable degree of detail and high accuracy, paved the way to an optimum approach in which a combination of the overall (numerical) model and limited field measurements are utilised.

The local model, schematised in more detail as appropriate, is nested within the overall model from where it obtains its boundary conditions. However, local field measurements are still needed to fine-tune the detailed model and optimise its accuracy. These local field measurements are much more local and are of a shorter duration than those which would be needed in the absence of the overall model.

## Arabian Gulf Wave Model – model description

For wave computations, the layout (extent, resolution and depth schematization) of the model is the same as that for the flow computations.

The execution of the wave computations is performed by the SWAN module. The SWAN wave module is incorporated in the Delft3D modelling package and is a state-of-the-art, third generation, fully-spectral, two-dimensional, stationary wave propagation model that computes the wave conditions on a regular grid.

At the open sea boundary, wave conditions (height, period, direction) are enforced. A space-varying wind field (speed and direction) can be prescribed over the whole area of the Gulf. In this way, every possible combination of wind and waves can be applied and computed by the SWAN module. If desirable, water levels and currents computed by the flow model can also be used as input for the wave model. In this way, the influence of the flow is included in the computations of the wave parameters.

The output of the wave model exists of wave conditions (wave height, period and direction, directional spreading of the waves) in every grid point. An output example is given in Figure 9.

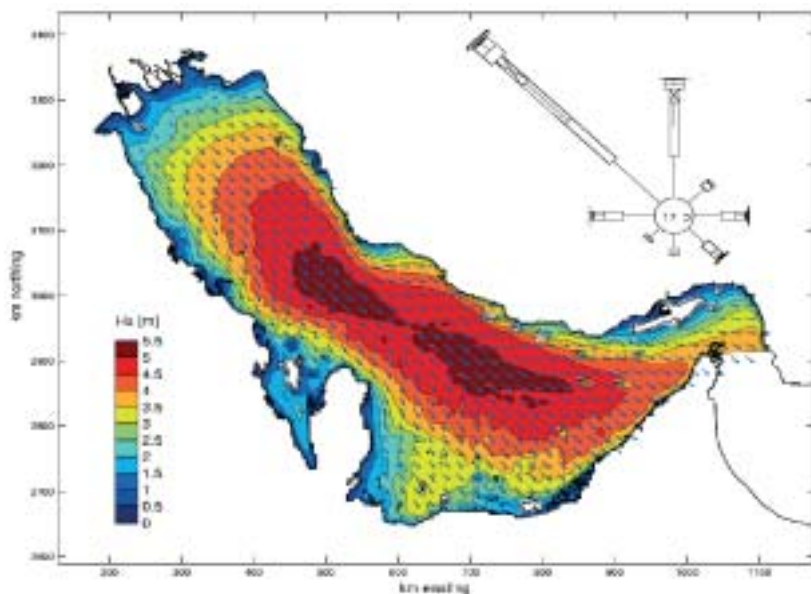


Figure 9: Contour plot of the significant wave height plus the direction of the waves during an extreme Shamal storm event. Also an output example in the form of a wave rose is given.

## applications

A Regional large scale model, nested within the Arabian Gulf Wave Model has been applied in investigations for determining wave conditions in large scale area, e.g. a gas pipeline offshore Qatar (see Figure 10).

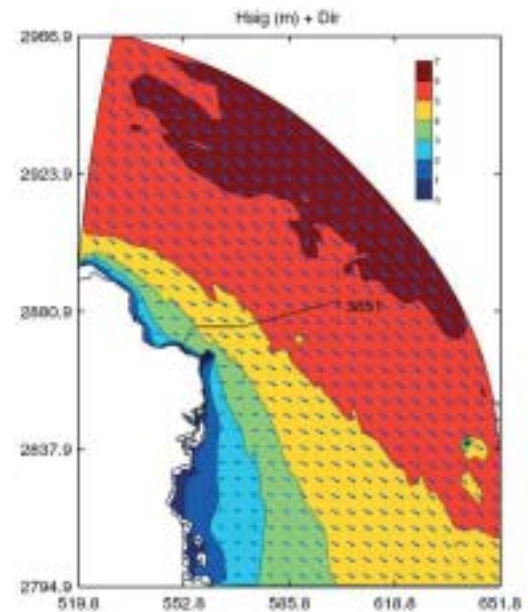


Figure 10: Computed significant wave heights and wave vectors offshore Ras laffan, Qatar

Similar to the Arabian Gulf Flow Model, the Arabian Gulf Wave Model has also often been used as an overall model in which smaller and fine grid models are nested. The fine grid models include a more detailed schematisation of the seabed and as a result a more detailed simulation of the wave propagation in a certain area, see Figure 11.

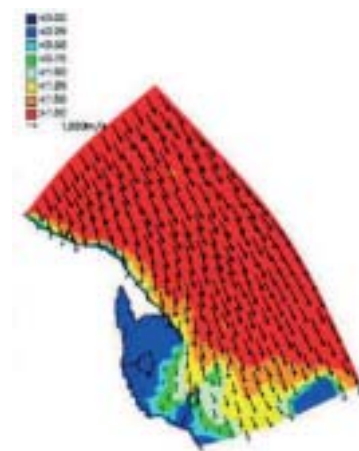


Figure 11: Detail wave model, Ras Tanura, Saudi Arabia

### WL | Delft Hydraulics

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