# Modeling Salinity Changes in the Persian Gulf


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## Introduction and Motivation

- The Persian Gulf is a large semi-enclosed body of water (inverted estuary)
  - Approximately 1000 km in length, 550 km in width and 240,000 km$^2$ surface area) in Western Asia.
  - Connected through the Strait of Hormuz to the Arabian Sea and Indian Ocean.
- Increase in their standard of living in countries.
  - Kuwait, Saudi Arabia, Bahrain, Qatar, Oman and United Arab Emirates.
  - Petroleum and Energy industries.
  - Expansion of desalination plants.
- Water demand is rising due to population growth and rapid development.
  - The ground water resource is diminishing with time.
  - Numerous desalination processes in Gulf are presently the major source of fresh water for all applications.
- The effects of resulting hypersaline discharges, along with shamal winds are considered.
- Distribution of seasonal salinity and its variations due to the effect of the shamal, is investigated using the Delft3D-FLOW hydrodynamic model.

## Objectives

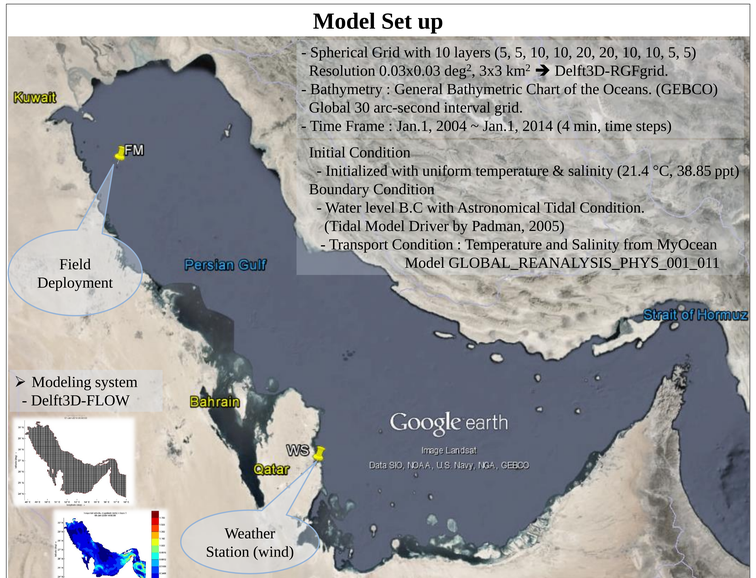
- Using the hydrodynamic model to simulate current, salinity and temperature distributions over the last decade in Persian Gulf.
- Obtain the salinity variations in Gulf. Investigate the seasonal salinity variation due to the shamal effect.
- Investigate the effect of desalination due to salinity changes of ambient conditions from the discharges of desalination plants in Persian Gulf.
- Forecast the future salinity trends for each GCC country nearshore and offshore.

## Model Set up

- Spherical Grid with 10 layers (5, 5, 10, 10, 20, 20, 10, 10, 5, 5)
  Resolution 0.03x0.03 deg$^2$, 3x3 km$^2$ ➔ Delft3D-RGFgrid.
- Bathymetry : General Bathymetric Chart of the Oceans. (GEBCO)
  Global 30 arc-second interval grid.
- Time Frame : Jan.1, 2004 ~ Jan.1, 2014 (4 min, time steps)

Initial Condition
- Initialized with uniform temperature & salinity (21.4 °C, 38.85 ppt)

Boundary Condition
- Water level B.C with Astronomical Tidal Condition.
  (Tidal Model Driver by Padman, 2005)
- Transport Condition : Temperature and Salinity from MyOcean Model GLOBAL_REANALYSIS_PHYS_001_011




- Modeling system
  - Delft3D-FLOW

Figure 1. The location map of Persian Gulf and field deployment [Google Earth, 2016], and description of model set up.

## Parameters and Discharges

- Wind Drag coeff. : 0.00063 - Manning Bottom roughness : 0.01
- Horizontal eddy viscosity and diffusivity : 15 m$^2$/s
- Water and air density : 1026 kg.m$^{-3}$ and 1 kg.m$^{-3}$
- Dalton and Stanton number : 0.001 - Secchi depth : 2 m
- Heat Flux : Ocean Model Data from NOAA (1948-2002 : 54 years) - Kampf and Sadrinasab (2006)
- Wind : Space varying wind and Pressure (Climate Forecast System Reanalysis data – http://cfs.ncep.noaa.gov)
- Discharges
  - Rivers : Shatt Al Arab, Hendijan, Hilleh and Mand Rivers. (Kampf and Sadrinasab, 2006)
  - Desalination Plants : 75 energy and desalination plants (MSF, MED, RO types in GCC countries of Gulf) (Abubaker, 2014)
    2004 ~ 2010 : 23 plants operated / 2011 ~2013 : 75 plants operated

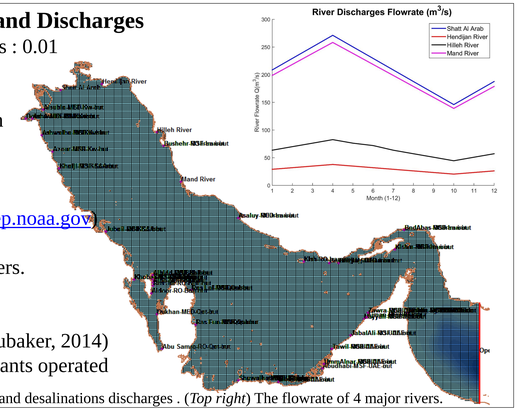



Figure 2. (*Left*) The location of rivers and desalinations discharges . (*Top right*) The flowrate of 4 major rivers.

## Simulation Results

### Results around GCC

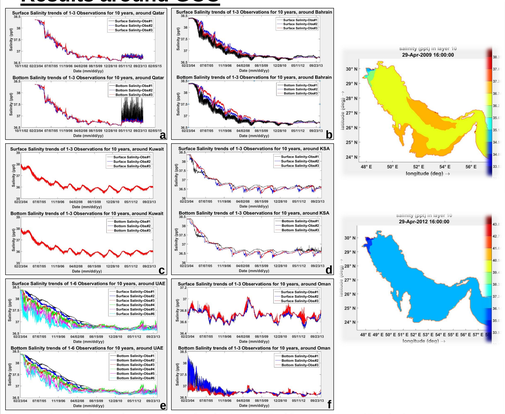


Figure 3. a ~ f are the results of salinity in Gulf countries. (*Right* ) Comparison of salinity distribution in 2009 (April) and 2012 (April).

### Desalination Effect

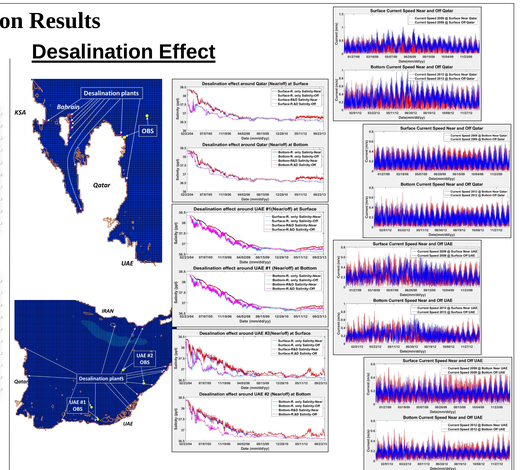



Figure 4. (*Left*) Location of Obs' points in Qatar and UAE. (*Middle*)The results of desalination effects. (*Right*) Comparison of current speed (near and off).

### Seasonal Variation

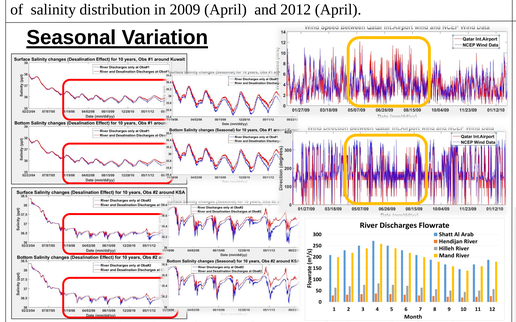



Figure 5. (*Left side*) Salinity changes of Kuwait and KSA, with enlarged view. (*Right*) Wind speed & direction in 2009, and River discharges (m$^3$/s).

### Other Effects

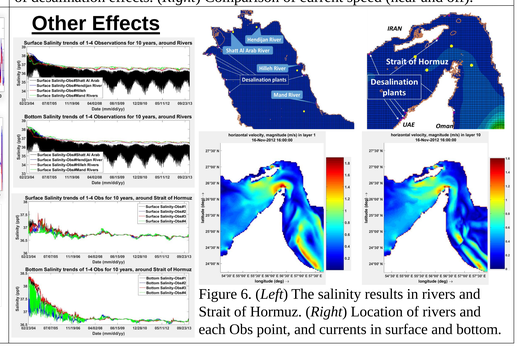



Figure 6. (*Left*) The salinity results in rivers and Strait of Hormuz. (*Right*) Location of rivers and each Obs point, and currents in surface and bottom.

## Model Validations

- Field data from TAMUG Microstructure Group in 2013 (Jan.17 ~ Apr.23, 2013).
  - Location : 28 50.938'N, 48 47.534'E Offshore of Kuwait (FM in Figure 1)
  - Data : Temperature and Current at the bottom layer.
- Field wind from the weather station of Doha INTL. Airport (Jan.1, ~ Dec.31, 2010)
  - Location : 25 16'1.2''N, 51 32'60''E (WM in Figure 1)

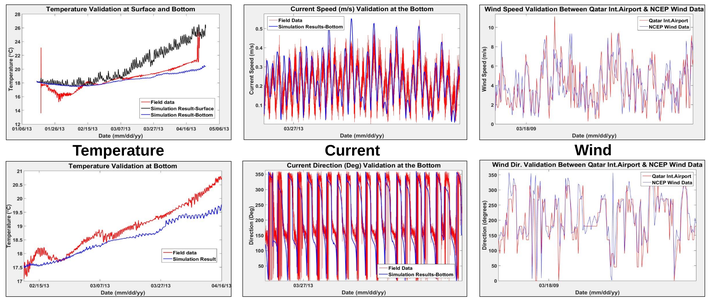



Figure 7. (*Left side*) The Validations of temperature at FM of Figure 1. (*Middle*) Validation of current speed and direction in FM. (*Right side*) Validations of wind speed and direction at WM of Figure 1.

## Summary of Results

- Salinity changes surrounding Kuwait, KSA, Bahrain, Qatar, Oman and UAE
- Desalination effect
  - Comparison salinity changes between two cases with and without desalination discharges surrounding Qatar and UAE.
  - Due to increasing fresh water demands today, numerous desalination plants have been built in Gulf. The salinity has apparently increased since 2011.
  - Desalination led to higher salinity near the coastal area close to desalination plants, so that it can be environmental impacts in water circulation of Gulf.
- Seasonal variation of salinity
  - Surrounding Kuwait and KSA, the minimum salinity shows in April ~ July, and maximum salinity attains in October ~ January.
  - Effect of rivers run-off and seasonal wind shamal are considered over entire Gulf scale. As inflows of low-salinity and varying sinusoidally with minimum value in October and maximum in April, it shows a good agreement with seasonal and decreased salinity changes in simulation results.
  - The larger variations of salinity are shown on the surface during the shamal season.
- Other effects
  - Due to the river discharges, low-salinity is shown surrounding 4 major rivers.
  - Inflow and outflow are strongly dynamic throughout the Strait of Hormuz; desalination effect and seasonal characteristics are thus less evident.

## Future Plans

- Transport boundary condition : Decrease trends of salinity in this study.
- Need further model validation and new source of desalination in Gulf.
- Developments in modeling to forecast the future salinity trends in Persian Gulf.


Acknowledgements

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