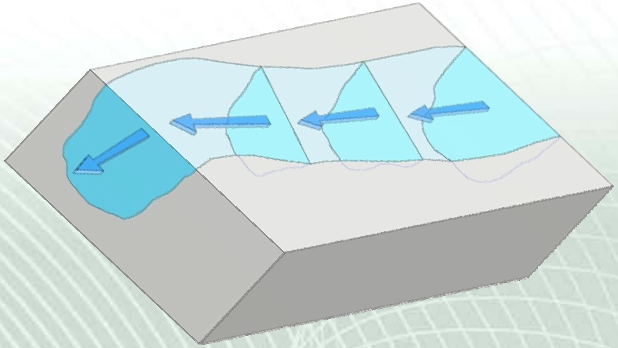
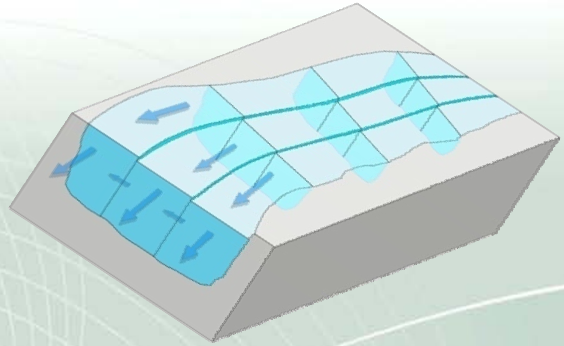
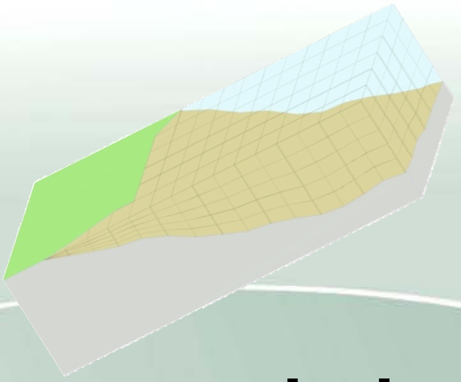




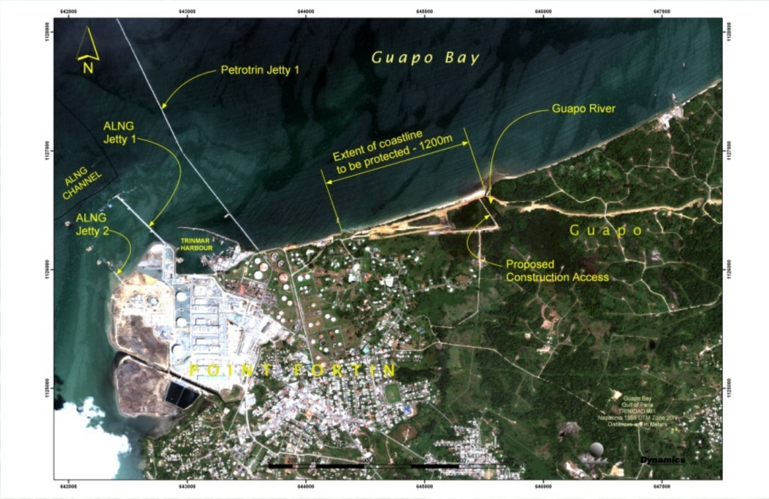
Understanding Ocean Models and their use in EIAs

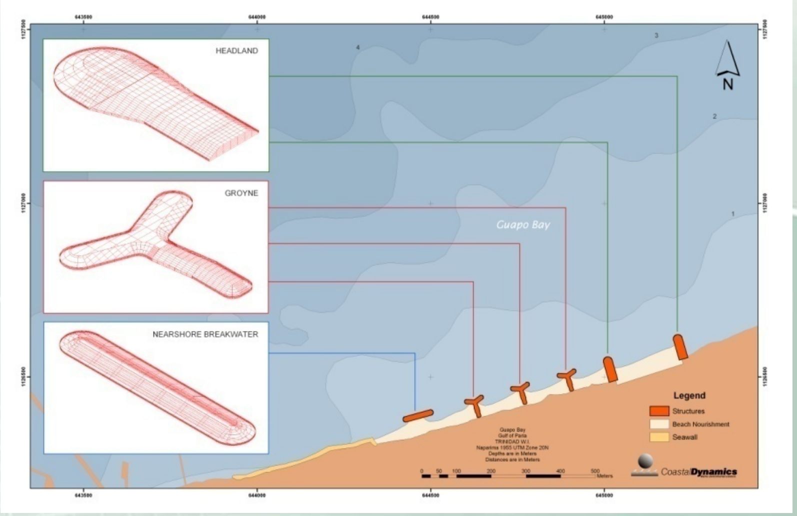
Nazeer Gopaul

Coastal Dynamics

www.coastaldynamics.com

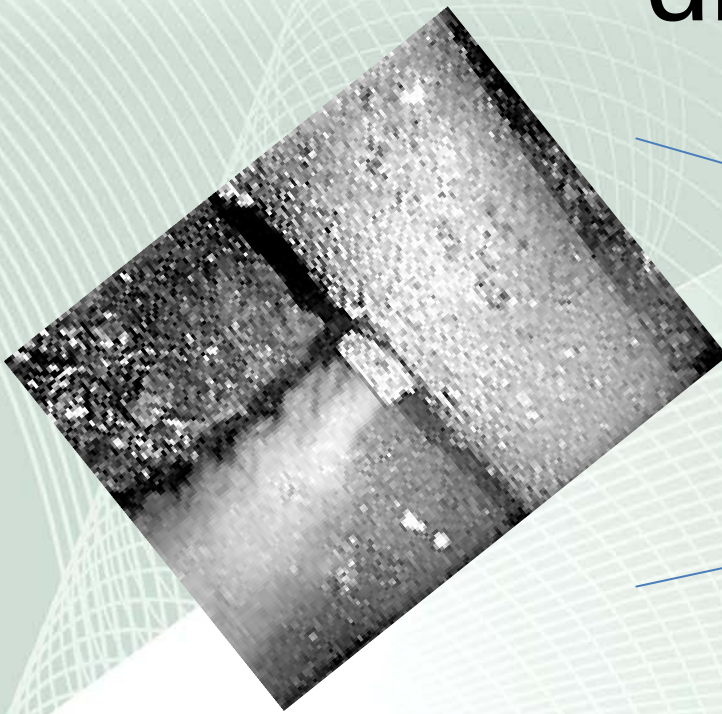
What are models?



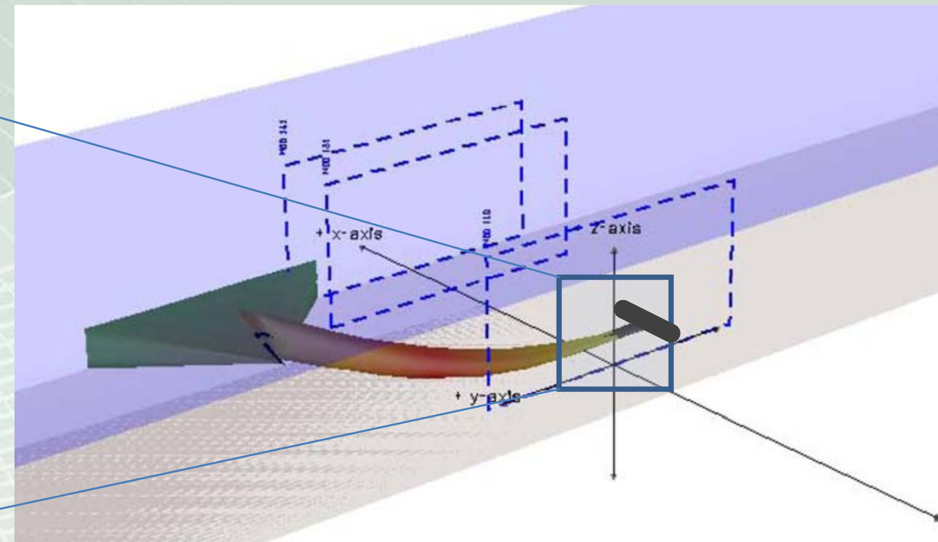


- The models we refer to are representations of the marine environment surrounding us in an electronic format.
- They allow us to be able to predict future changes based on present changes to the environment.
- These models are actually computer programs that are used to calculate the movement of fluids within the model boundaries.
- Our aim in this lecture is to become familiar with the models that are being used at present in EIAs.

Example 1 – wastewater disposal

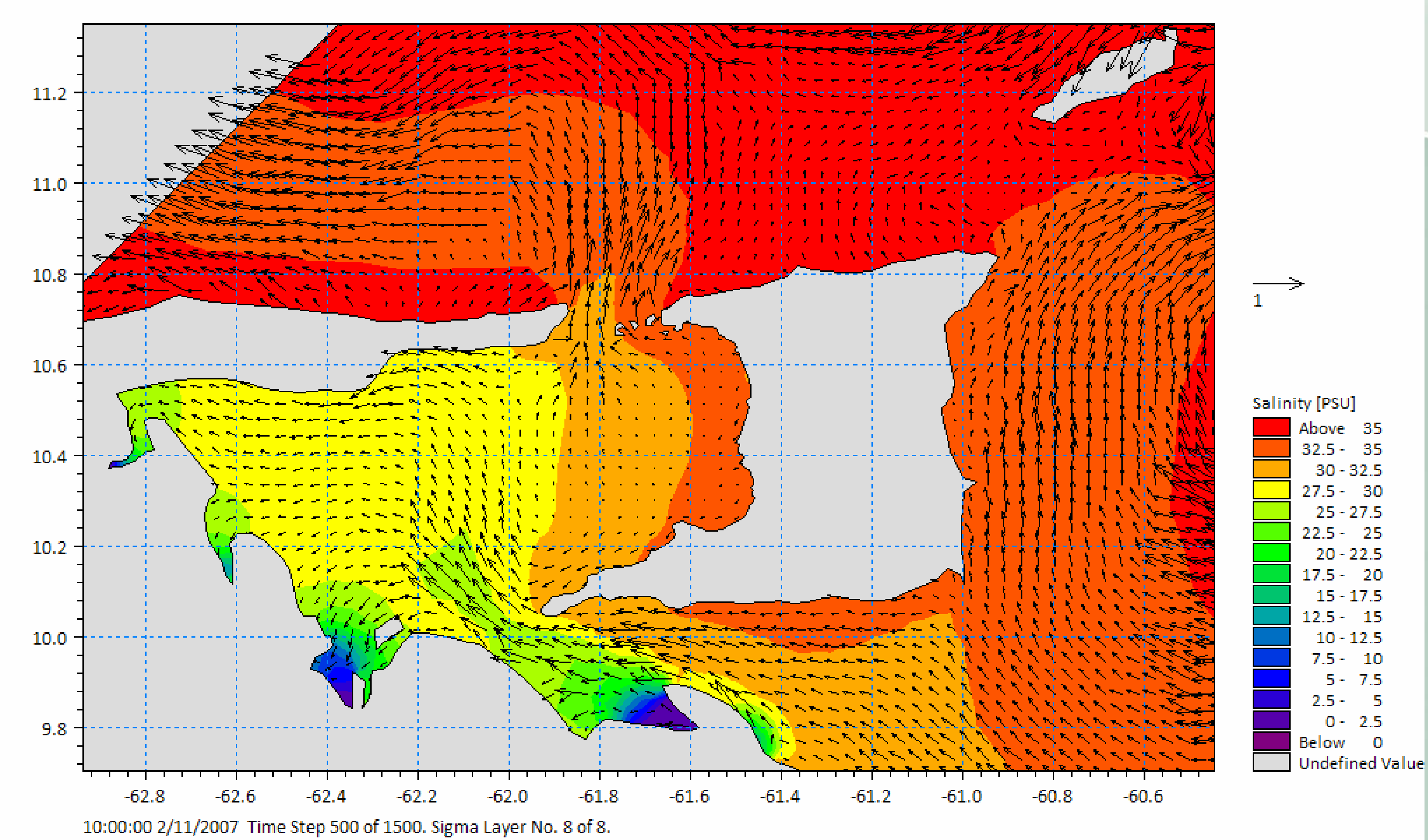


Effluent pipeline

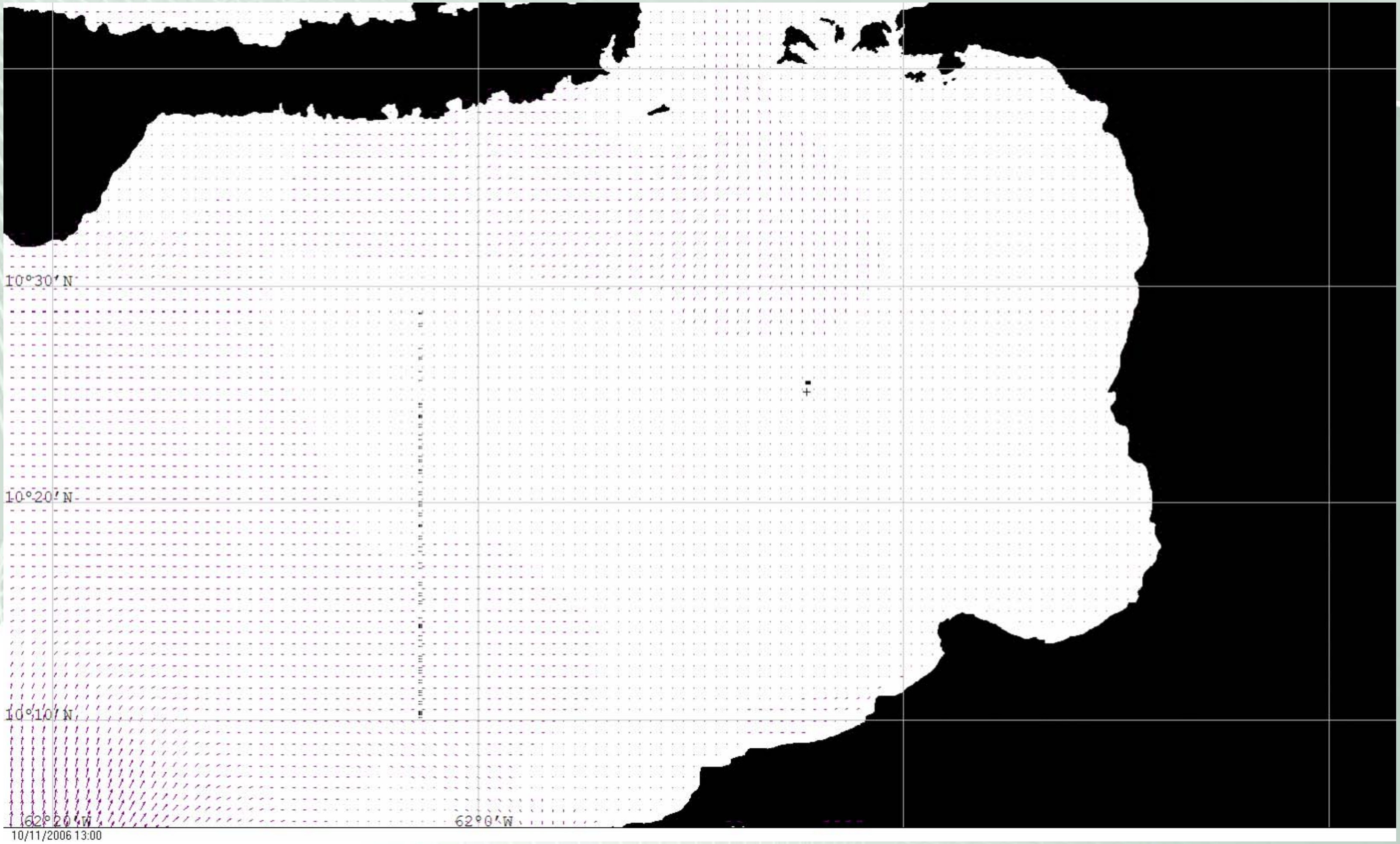


Model Representation of Effluent pipeline

Example 2 – Circulation patterns



Example 3 - Oil Spill



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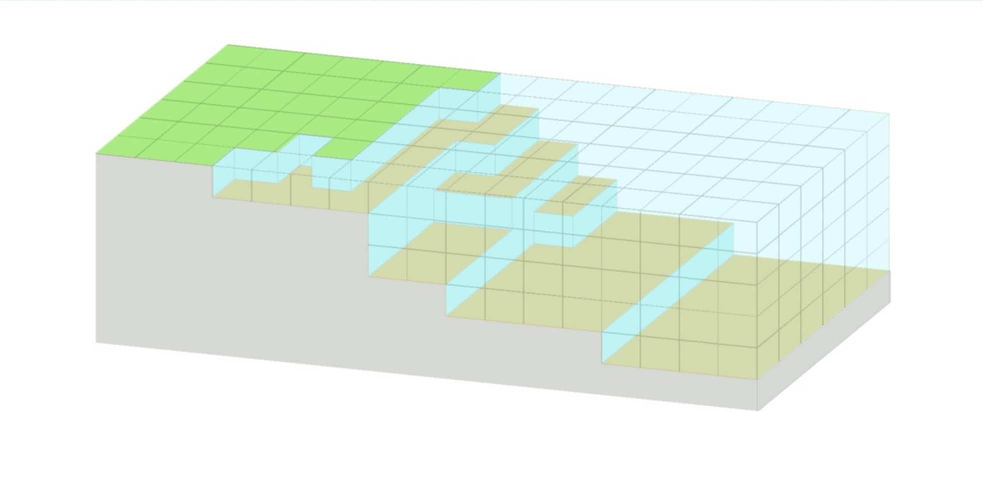
Types of Models

- Two types of models are common – Finite difference and Finite Element.
- Models can represent 1, 2 dimensions or 3 dimensions.
- All models are mathematical models with a time stepping procedure to forecast water conditions over time.
- Other than hydrodynamic models there are, wave models, dispersion models, sediment transport models, water quality models. A good site to have a look at various models is the Danish hydraulics Institute (DHI) website – www.dhigroup.com or www.wldelft.nl

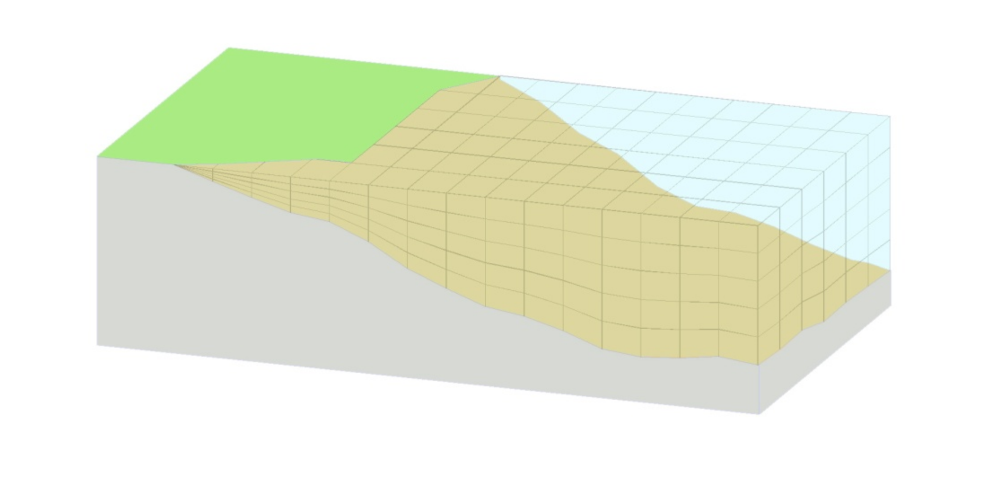
Finite Element or Finite Difference

- With the expense and difficulty that occur at times in collecting direct oceanic measurements, we must incorporate what we know of oceanic physics into numerical models to simulate the ocean (and other parts of the climate system). The ocean models which have been used for the most part so far in oceanography have been largely based on traditional **finite-difference** techniques. Although possessing advantages in terms of simplicity and ease of use, these techniques often have difficulty in resolving land boundaries, straits and narrow active regions such as boundary currents, all of which are play very important roles in the large scale oceanic circulation.
- An alternative numerical technique is the **finite element** method, which has recently been gaining in interest in oceanography. Among its many advantageous properties is the fact that irregularly structured grids are simple to use, without any loss of computational accuracy. One is thus able to provide high resolution in areas that are of importance for a given problem while limiting it elsewhere (and thus reducing the computational expense of the problem).

Finite Difference Grids



Finite Difference with a regular size grid size over depth. There is no variation in grid size over the entire model 3D space.



Finite Difference with a variation in grid size over depth. These are referred to as (sigma coordinate grids)

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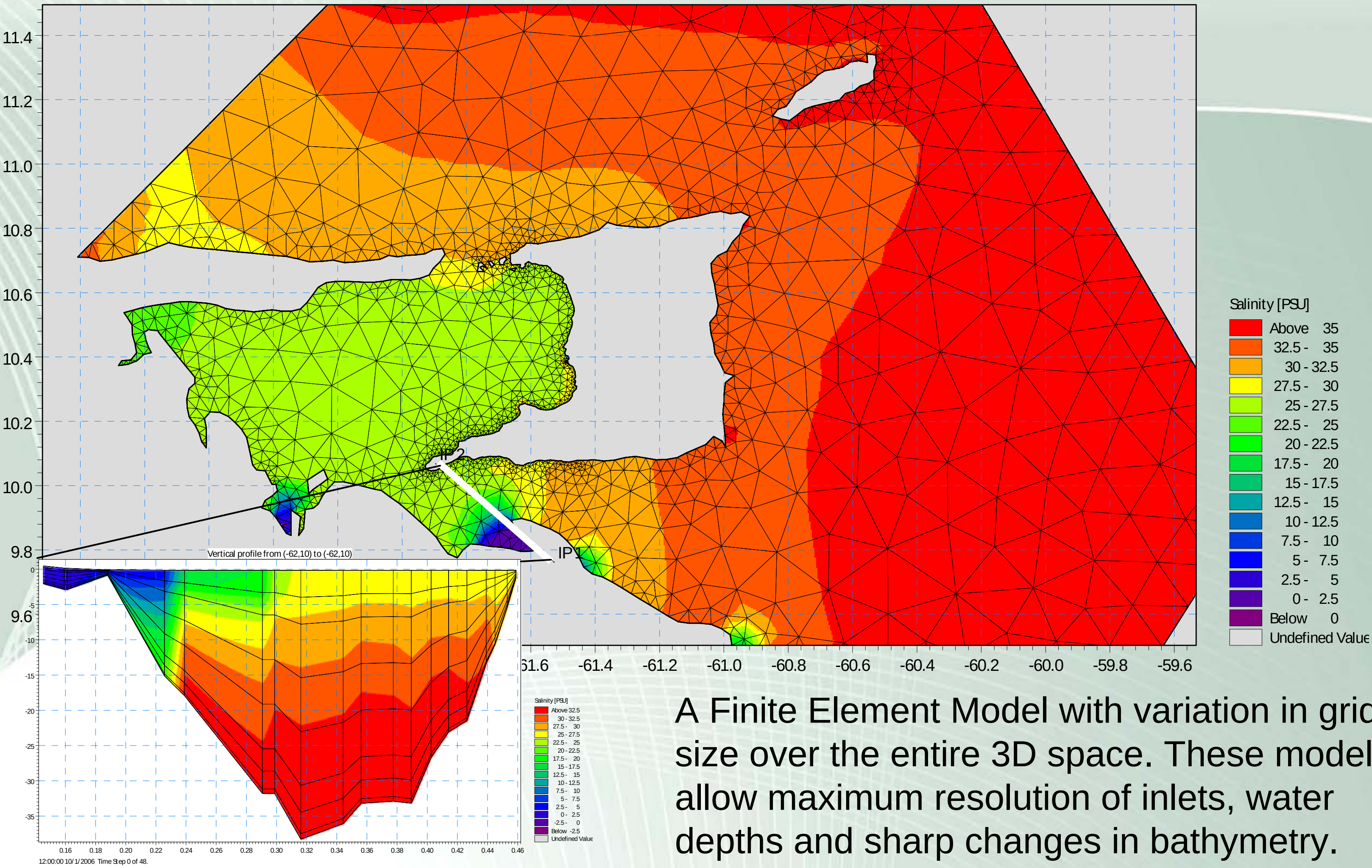
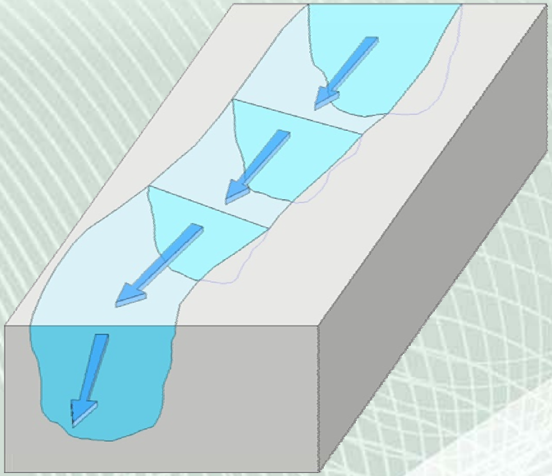
Finite Element Grids

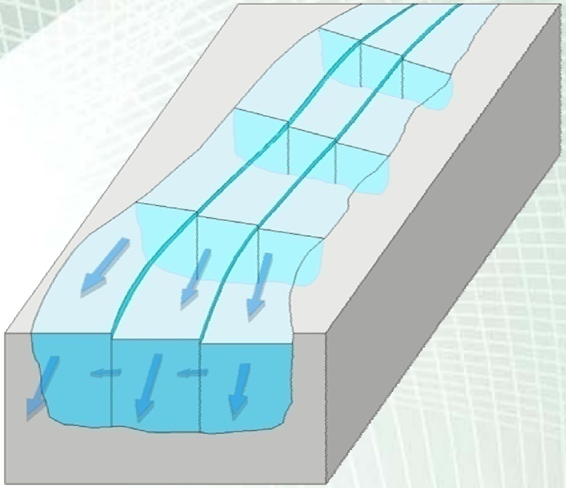


A Finite Element Model with variation in grid size over the entire 3D space. These models allow maximum resolution of inlets, water depths and sharp changes in bathymetry.

1D and 2D models



One dimensional models are simple approximations that can be used to look at flow, such as, in rivers, pipelines, channels.



Two dimensional models add an extra dimension so that variations in shape is better accounted for in the model.

Making the model useful and trustworthy

- In order to make useful and to be able to trust model results we need to do two things:
- 1. Calibrate
  - This involves adding information to the model so that it knows how the water behaves.
- 2. Validate
  - This involves checking the model output to ensure that what is modelled is real.

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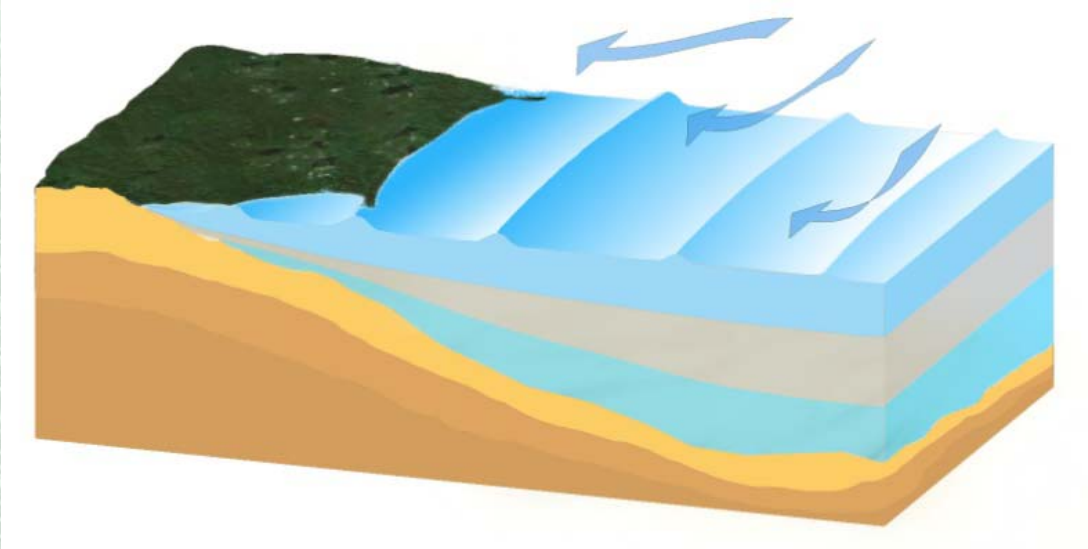
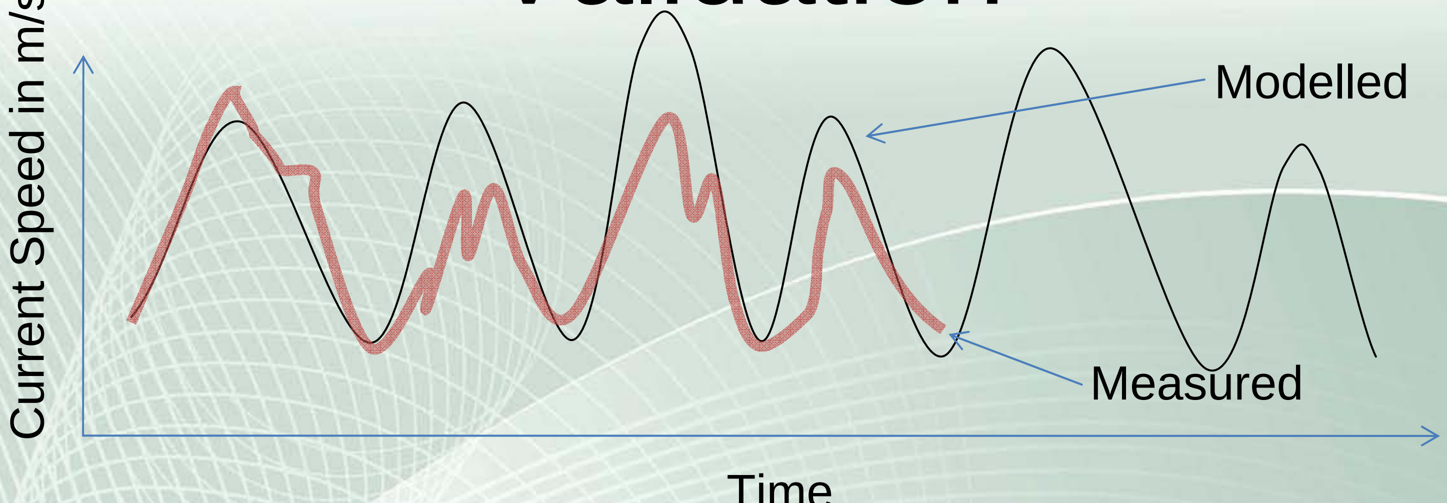
Calibration



- We put data into the model to tell it how to behave, so we recreate the natural environment in a computer-based model:
- We tell the model, how the wind behaves, how the water levels change and what the water “feels like”. How sticky is the water, how hot/cold, how salty, how turbid, resistance of flow over the seabed? And so on…
- This is a very important step in the model setup since the accuracy of the model is dependent on the data that goes into it. If we were to judge how well a model is setup typically in a hydrodynamic model we would like to for what actual data has been inputted to the model to generate the scenarios being modelled.

Validation

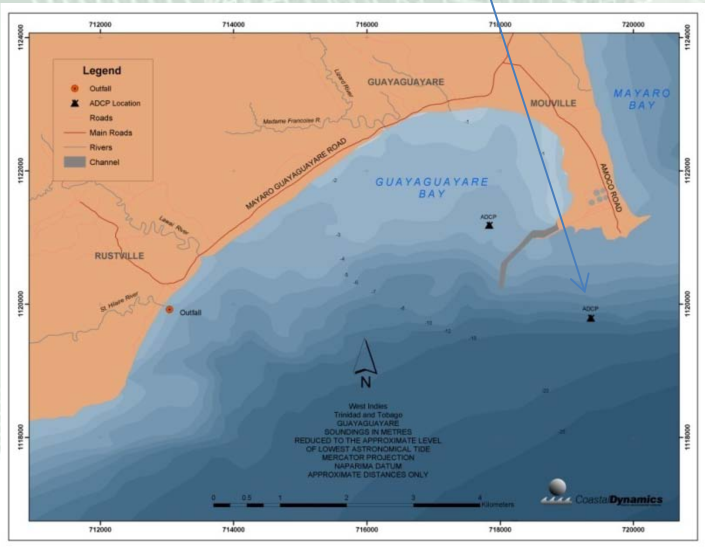


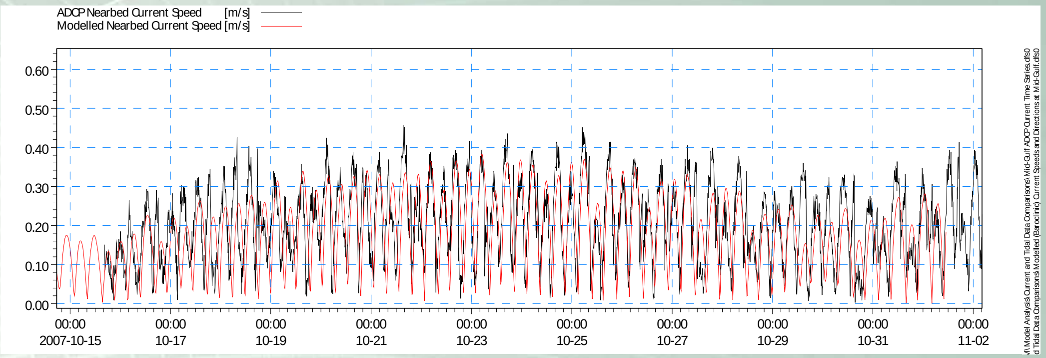
- Once the model takes all the information and forwards the calculations in time we want to check these values with measured values to see how good it performs.
- We can usually have a look at the results and can provide an initial estimate of how good the model performs at predicting the parameter (speed, direction etc.).
- Nature tends to be more complicated than we can model but we still get a good approximation in many cases if we have the physics described correctly.
- Physics may include : winds blowing near the surface, tidal currents, background currents flowing through the area (oceanic type currents), variations in temperature and salinity in the water column. Once these are entered into the model and we apply the laws of physics then we should get a good estimate of the flow.

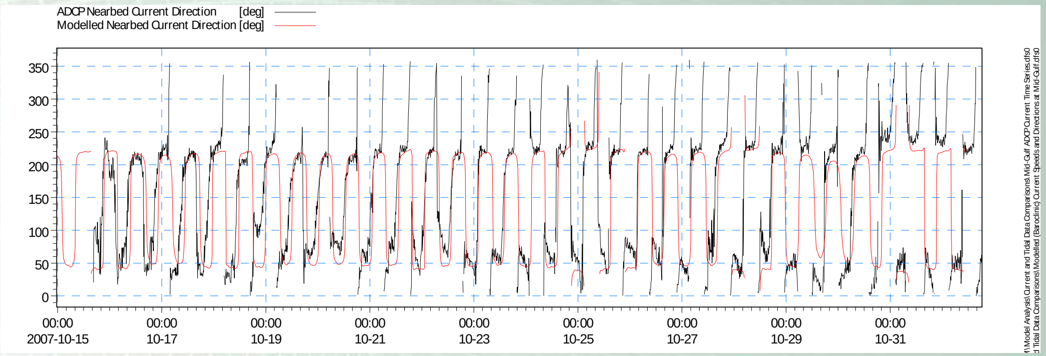
How do I validate the model?

We take measurements at sea and compare these to the modelled values. As shown in the adjacent graphs the comparisons of model and measured tend to be good but the complexity of the natural flow is very difficult to mimic and often too costly to attempt to do. At any rate, is it even necessary to replicate these?

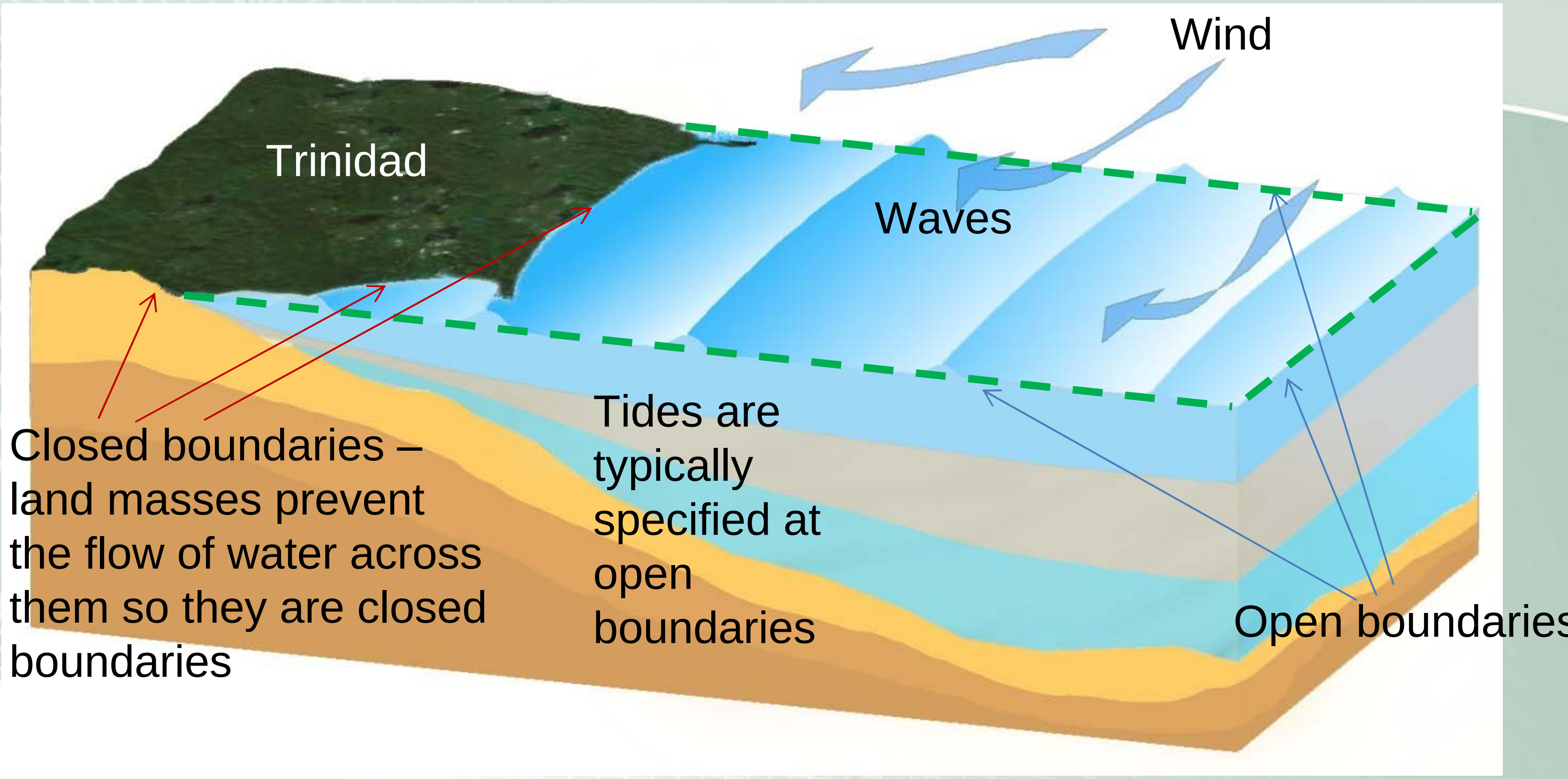
Current data collection point





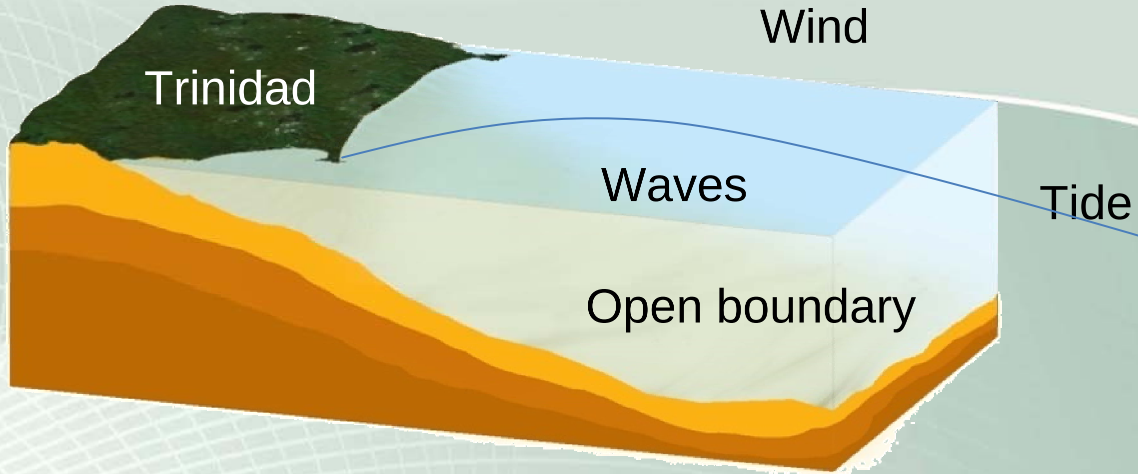


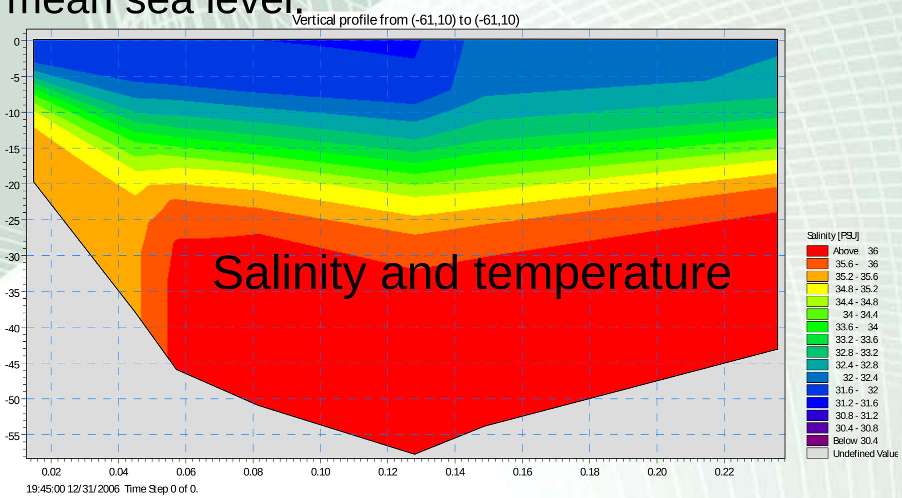
Some Definitions



Modelling the Flow

The information for the study area is converted to gridded sets of numbers which describe numerous parameters. The first parameter to be setup is generally the bathymetry or water depths. To this we add water levels above the mean sea level.





This information is typically added in the form of tidal elevations at the open boundaries in our local case. Winds are also added together with the salinity and temperature variations over the model area at the start of the model run and from then on by setting the values at the boundaries.

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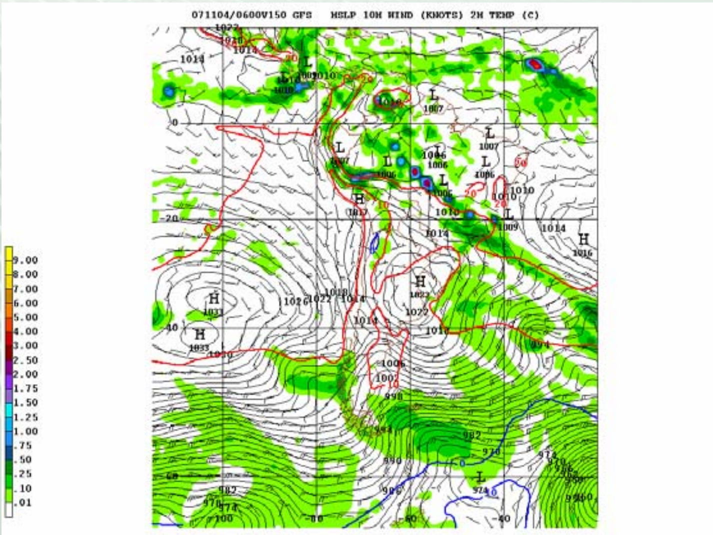
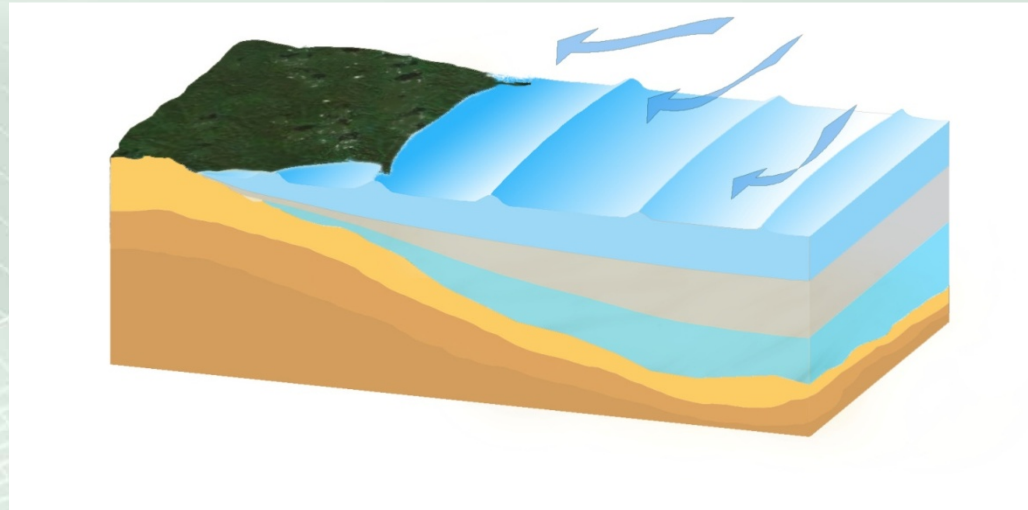
Moving Water - 1





- To force the water to move through the model we must add the forcing factors from various sources. Some come from agencies such as The Admiralty (Tides), NOAA (winds) or UKMO (winds), Local Meteorological Stations (Piarco).
- We can add winds, waves, currents, tides and differences in density.
- The forces cause water to move and we are interested in understanding and predicting how the water moves.

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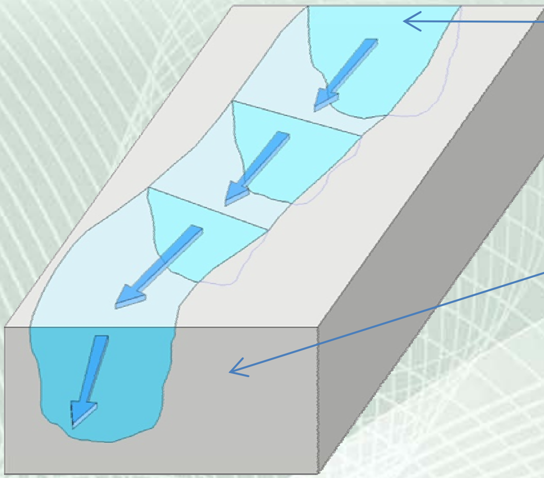
Moving Water - 2



What goes in must come out

Simply put this is the continuity equation

- To implement these forcing factors into the model we need to use Mathematics
- Mathematics can be used to describe the Laws of Physics – which sets rules that tell us how the water will behave.
- The Laws are described in the model in the form of equations. The basic equations are as follows:
- The equations of motion – the equation that we need to solve in order to describe the dynamics of the ocean is simply put : **Newton's Second Law of Motion** – **Force = mass x acceleration**
- The second important equation is **the Continuity Equation** – simply put it means – mass must be conserved or that the mass of water flowing into a given space must equal to the mass flowing out of that space. So if a mass of let's say 6 flowing through a wide channel is narrowed the for the 6 to flow through their speed must increase to prevent the piling up of water and to allow 6 to leave at the other end.
- In the models that we use these equations are described in more detail taking into account several forces and resistance factors so that we can describe the environment.

Modelling Flow

- The equations are represented in the model and they use the grids of information that we previously described to calculate the currents, water elevations and other parameters at each grid cell.
- We apply rules for flow across different areas of the model, some boundaries allow water to flow through while others prevent flow. Typically the boundaries that allow flow (or open boundaries) are water boundaries while the boundaries that do not allow flow through them are considered closed. Closed boundaries are typically found at the seabed and at the land masses.
- Sometimes the differences between modelled and measured data shows great discrepancies and this is also useful as it indentifies something missing in the physics used to describe the flow. A good example of this is boundary currents that were not observed in Stommel’s (famous oceanographer) model. These were later found to be a result of the Coriolis Force which changes with latitude. The Coriolis Force is caused by the rotation of the earth and is responsible for the direction of the rotation of large cyclones: winds around the center of a cyclone rotate counterclockwise on the northern hemisphere and clockwise on the southern hemisphere.

Forecast Models

- Water forecast models are available similar to wind and weather forecast models – they provide a prediction of what the expected currents will be at a future date. We are able to do this because we can provide a mathematical model description of the area and the forcings and use these to predict the movement of water. We know how the tides will behave and we can use the forecasts for winds. River flow data can be estimated and we can add other estimated factors that are less important. Coastal Dynamics has a forecast model which is operational.

Forecast Model

Coastal Dynamics has a new operational 3D forecast model for Trinidad and Tobago. The model is Danish Hydraulics Institute (DHI) MIKE3 Flexible Mesh (FM) hydrodynamic model. The system provides 7.5 day forecasts and publishes the data in a web page format. In addition the hindcast data is archived and is available for use by anyone wishing to have current and tide data within the model region.

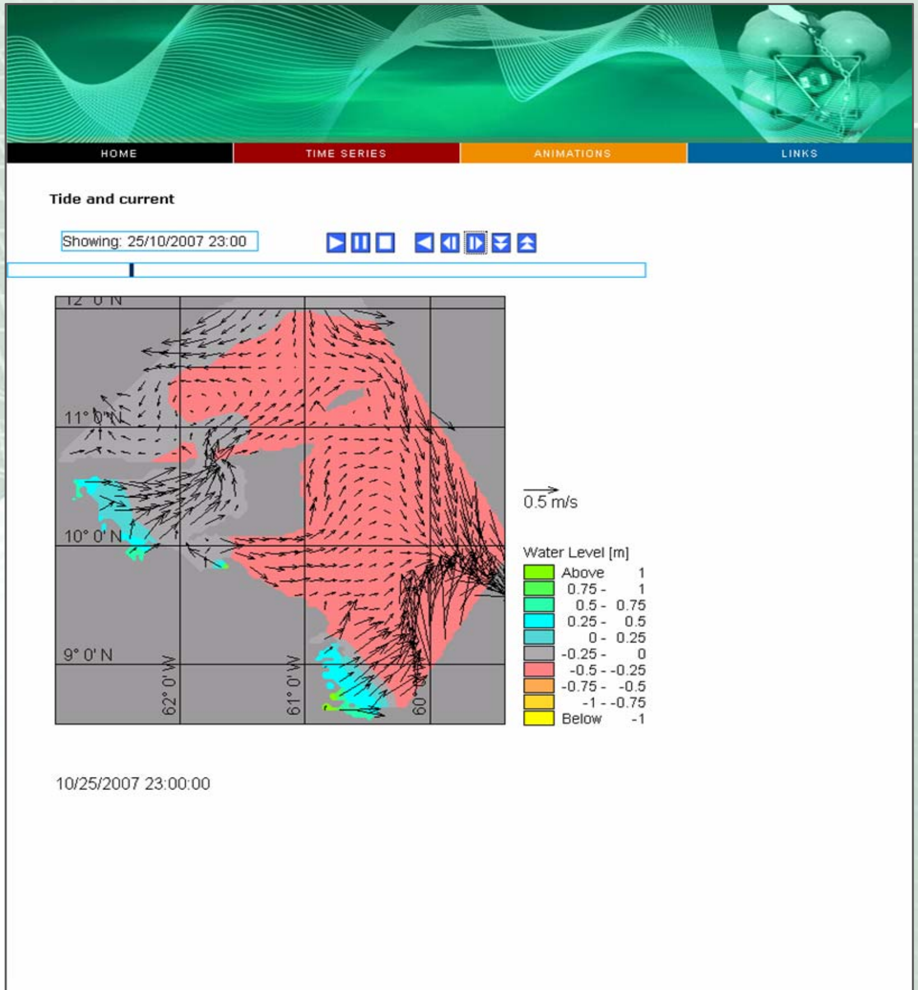
The model has been quality checked (validated) for several locations around Trinidad.

We are currently conducting extensive validation exercises for various sites within the model area to provide better accuracy in output data for our clients.

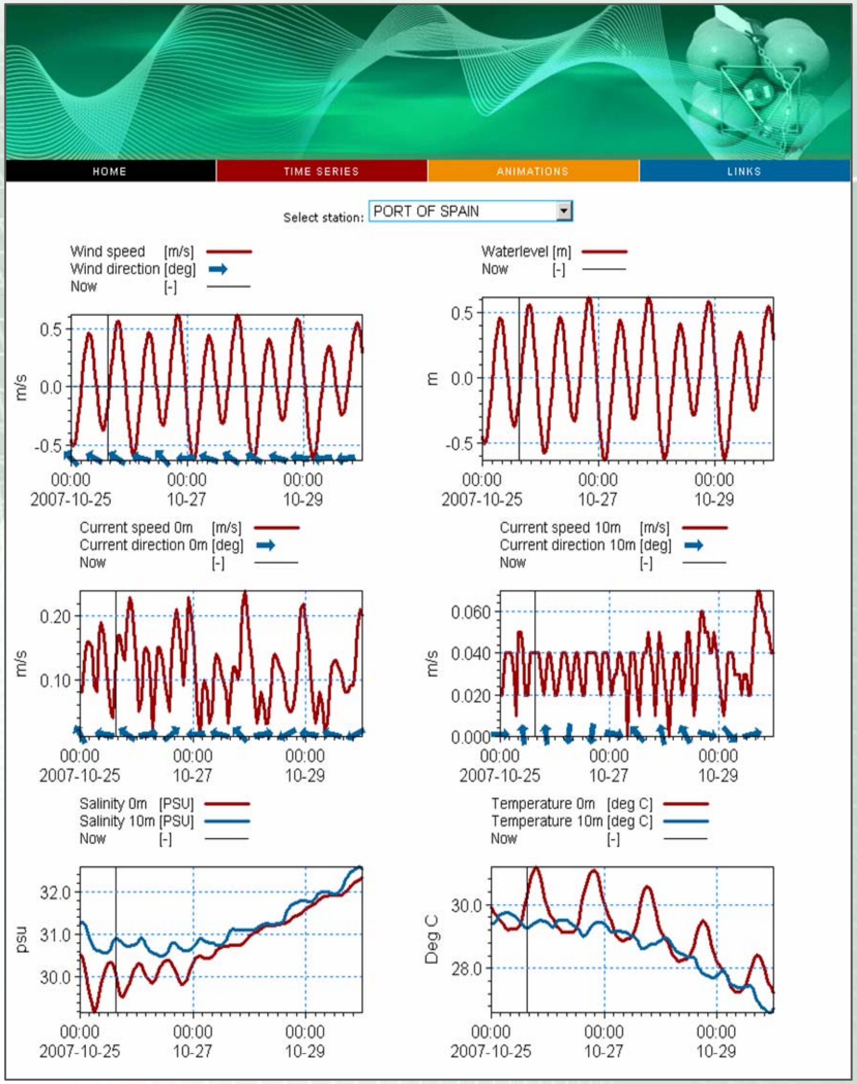
The model has 8 vertical layers and can therefore provide currents near the surface and near the seabed and for 6 layers between the surface and seabed. The datasets will allow us to offer a fast track to client projects when there is a need for quicker access to long term data for approvals or for use in other types of modeling such as sediment/effluent transport.

The forecasted tides, current and wind data (via NOAA GSF data) can also be used to model oil spill forecast scenarios, for marine navigation, search and rescue, or for marine operators scheduling works at sea.

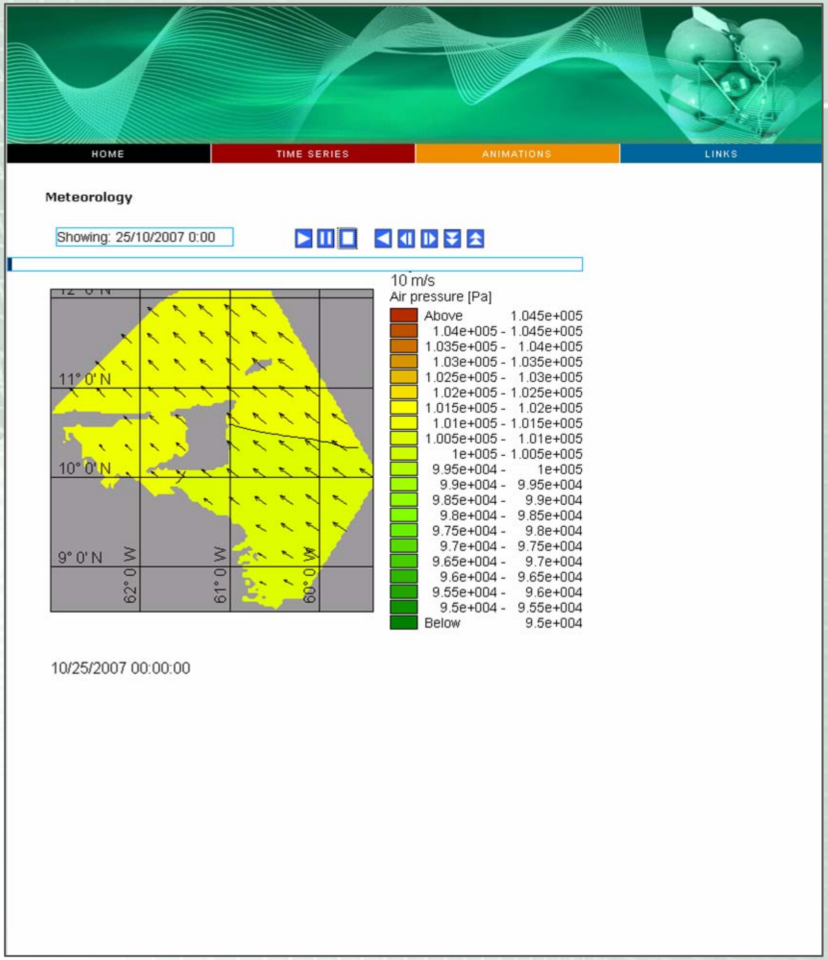
Surface layer Current Flows



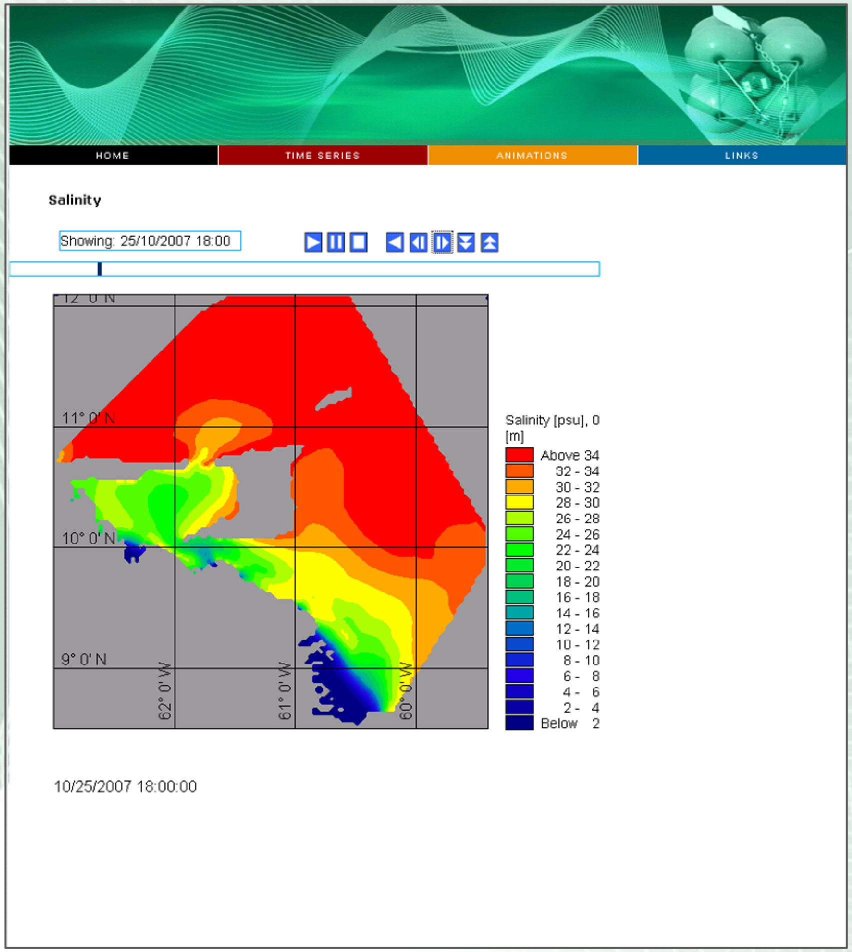
Site Specific Forecasts

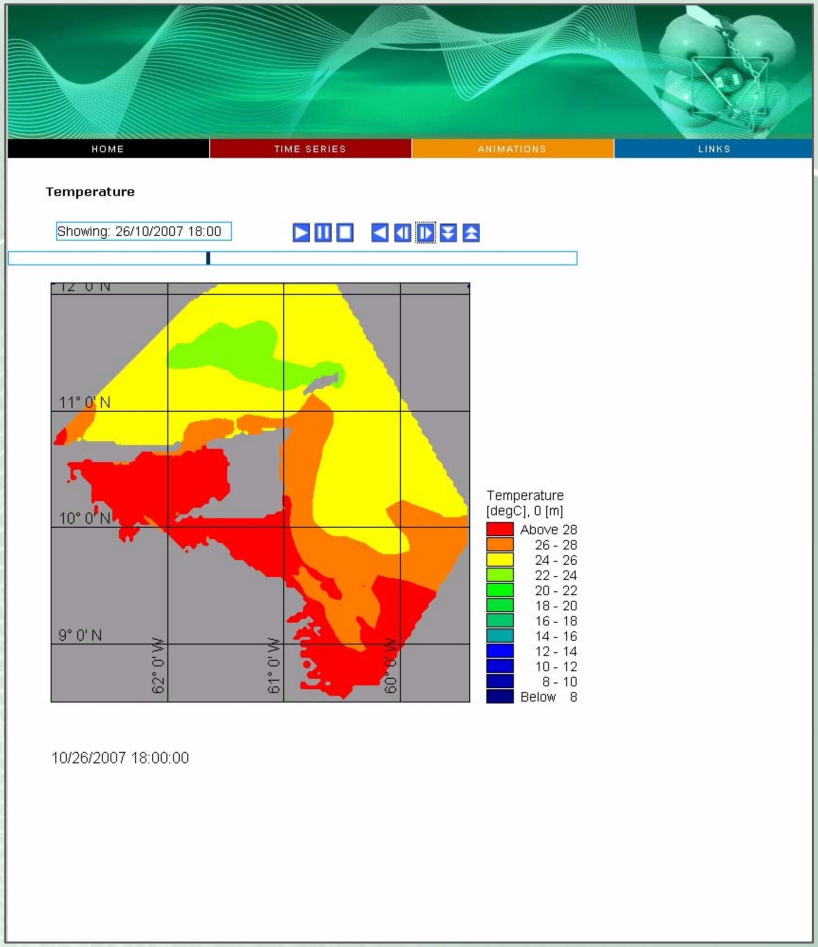


Wind Data from NOAA GSF Forecasts



Salinity and Temperature





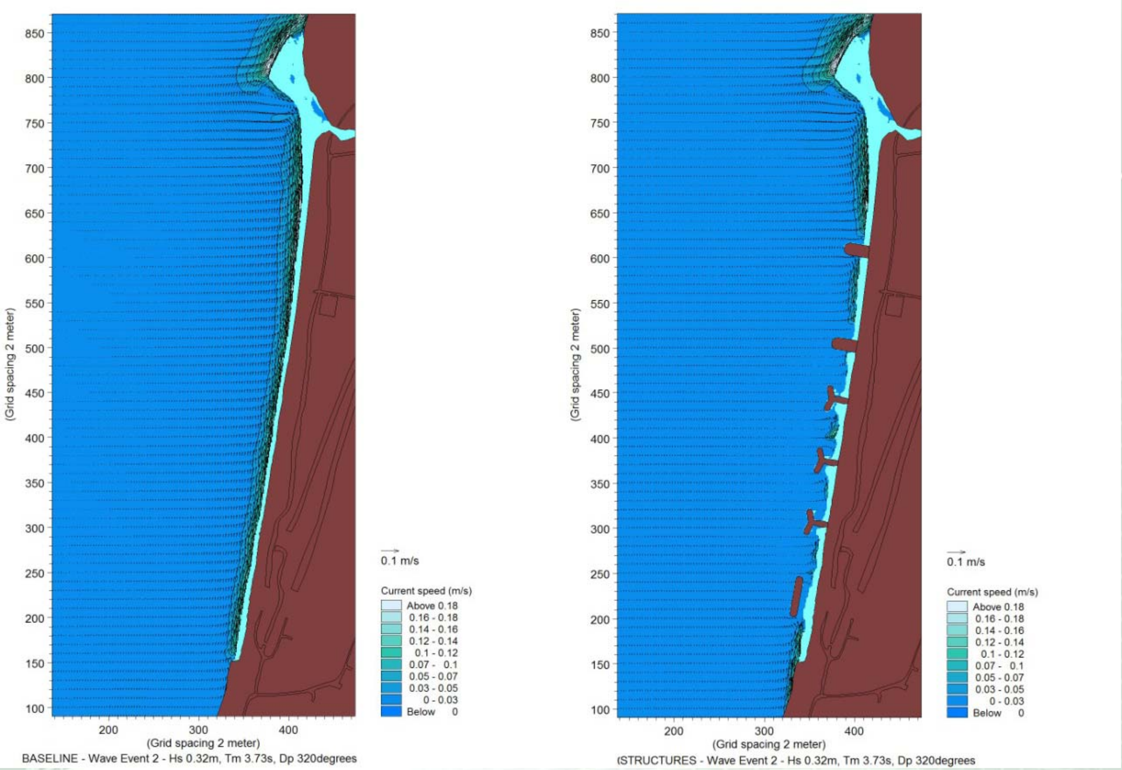
Hindcast Models

- Hindcast models are used to describe a past event and typically used to try to understand a past occurrence of a flood, tsunami, or even to try and predict how a historical event occurred.
- Validation exercises are an example of a hindcast that is then used to compare to measured values to establish the accuracy of the model.
- Hindcast data are useful in providing a background or baseline dataset that can be used to describe the region of the model. We often use models in this way to describe an area where we have few measurements and we need to obtain an understanding of the currents, wave transformation or sediment transport.
- A good example is a study that can be used to understand the environment prior to the construction of say a breakwater along the shoreline. By setting up the model in a hindcast mode we can then determine what the environment was like before the structure was built.

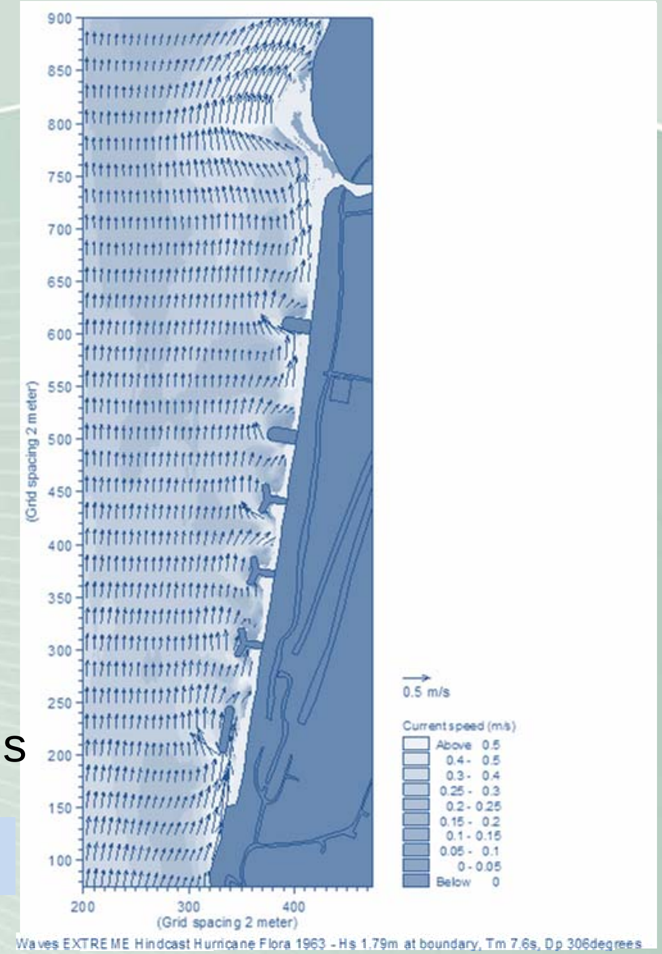
Models Applied to EIAs

- Models can be used to predict changes that may arise out of development activities such as:
  - Oil spills
  - Offshore disposal, such as dredge material
  - Shoreline changes
  - Drill cuttings dispersion
  - To define an area of impact
  - Placement of structures and the effects generated such as rip currents
  - Storm surge impacts along shoreline
  - Flood risk
  - Wastewater

Models used in EIAs



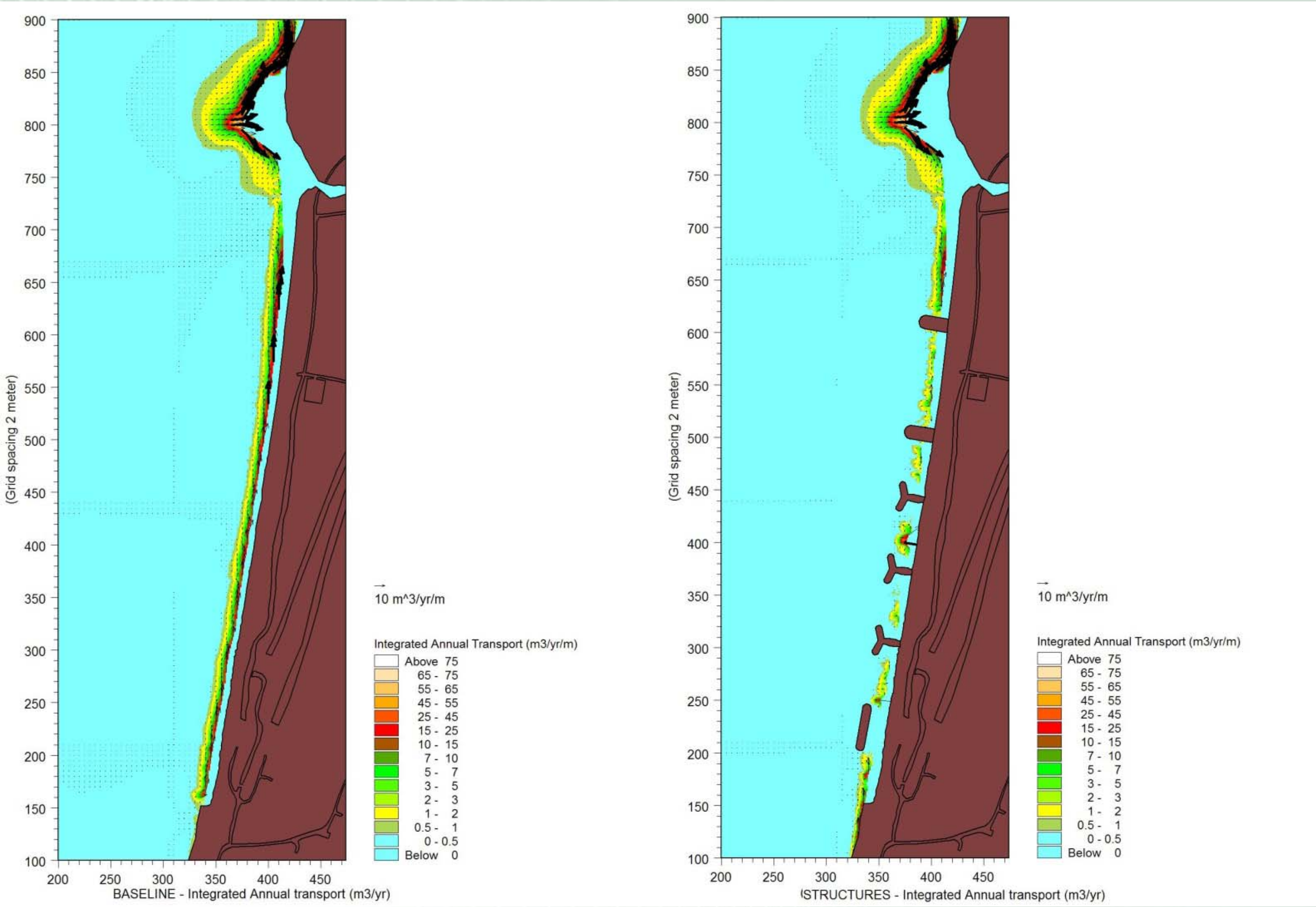
Before and After Structures – Normal wave conditions



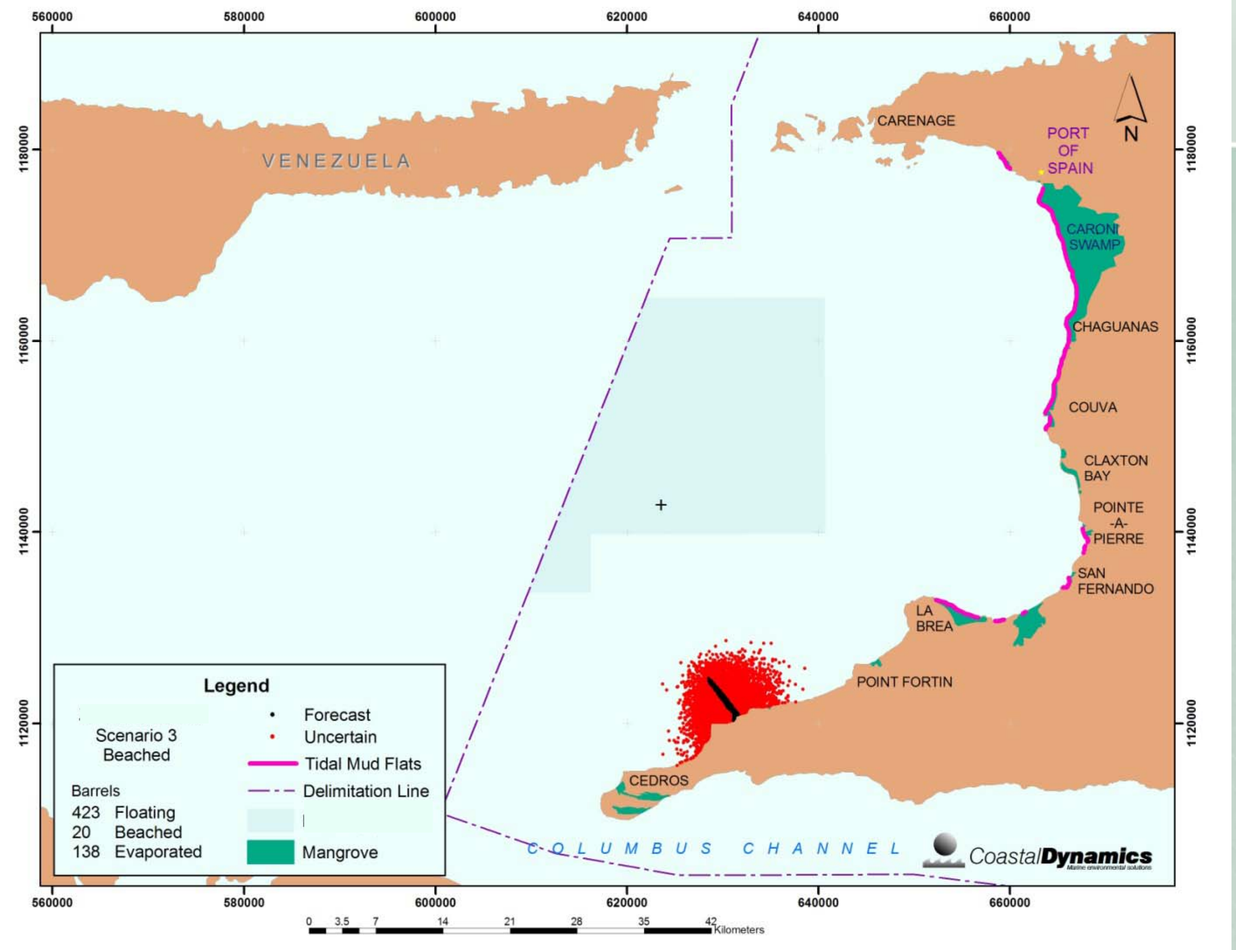
After Structures – Extreme hindcast wave condition

Before and after placement of structures

Sediment Transport Potential



Oil Spill Modelling



Drill Cuttings