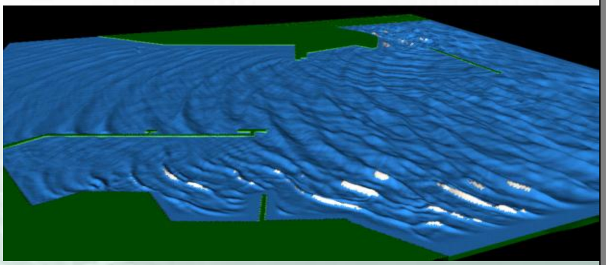
The Causes of Sea Level Rise in the Caribbean Region



**Environmentally Sustainable Construction-
Mitigation and Adaptation to Climate Change**

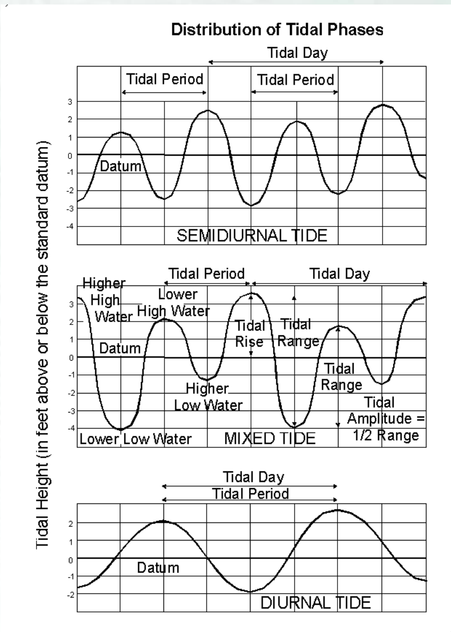
IStructE Trinidad, 2011

**Presented by: Mr. Frank Teelucksingh
Physical Oceanographer and Director,
Coastal Dynamics Limited**

Agenda

- What is Mean Sea Level?
- Why does the Sea Level Rise and Fall?
  - Short Term
  - Long Term
- The Impact of Global Warming on Sea Level Rise.
- Sea Level Rise Uncertainties
- The Impact of Sea Level Rise in Trinidad and Tobago
- Conclusion

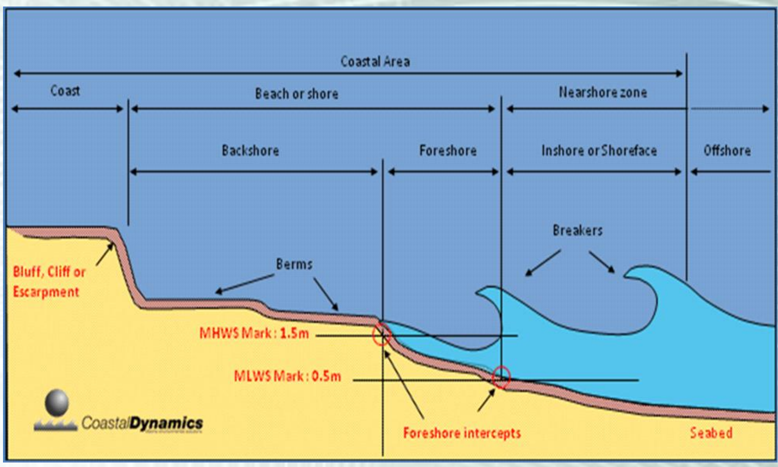
What is Mean Sea Level?



Why does the Sea Level Rise and Fall?

There are natural very short term (daily) variations in the Mean Sea Level Rise:

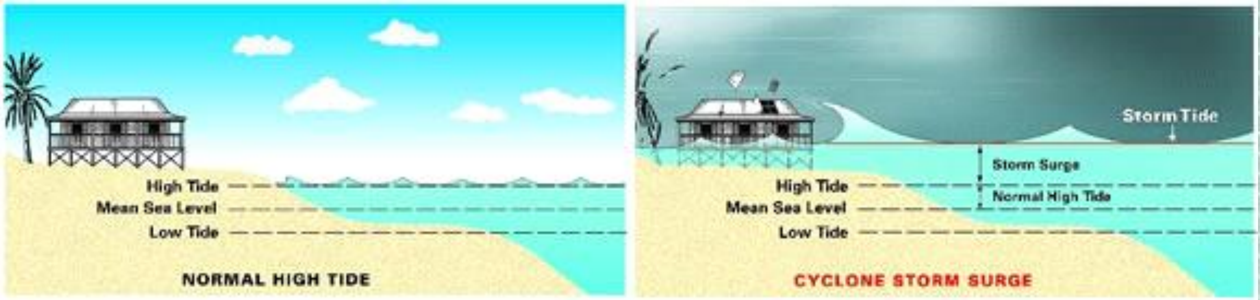
- Astronomical Tidal Variations: Caused by gravitational forces on the sea
- Waves
- Atmospheric Tides



Why does the Sea Level Rise and Fall?

There are natural very short term (daily) variations in the Mean Sea Level Rise:

- Storm Surge
  - Build up water along coast by approaching storm



Short Term Variations in Sea Level

Short-term (periodic) causes	Time scale (P = period)	Vertical effect
Periodic sea level changes		
Diurnal and semidiurnal astronomical tides	12–24 h P	0.2–10+ m
Long-period tides		
Rotational variations (Chandler wobble)	14 month P	
Lunar Node astronomical tides	18.613 year	
Meteorological and oceanographic fluctuations		
Atmospheric pressure	Hours to months	−0.7 to 1.3 m
Winds (storm surges)	1–5 days	Up to 5 m
Evaporation and precipitation (may also follow long-term pattern)	Days to weeks	
Ocean surface topography (changes in water density and currents)	Days to weeks	Up to 1 m
El Niño/southern oscillation	6 mo every 5–10 yr	Up to 0.6 m
Seasonal variations		
Seasonal water balance among oceans (Atlantic, Pacific, Indian)		
Seasonal variations in slope of water surface		
River runoff/floods	2 months	1 m
Seasonal water density changes (temperature and salinity)	6 months	0.2 m
Seiches		
Seiches (standing waves)	Minutes to hours	Up to 2 m
Earthquakes		
Tsunamis (generate catastrophic long-period waves)	Hours	Up to 10 m
Abrupt change in land level	Minutes	Up to 10 m

Long Term Variations in Sea Level

Long-term causes of sea level change

1. **Tectonic instability** - Regional, slow land level changes , for example, along the U.S. western continental margin affect relative long-term sea level changes. Parts of the coast are rising and falling at different rates.

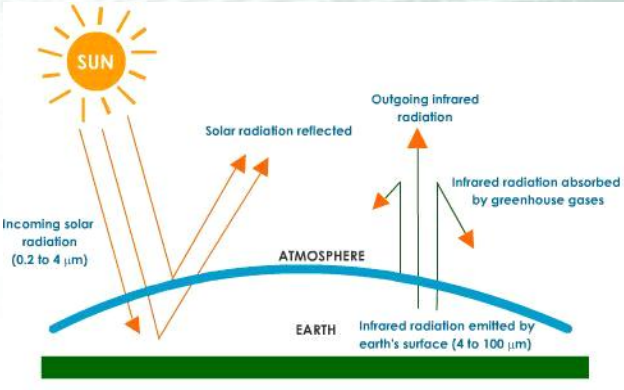
2. **Isostacy** - Isostatic adjustment is the process by which the crust of the Earth attains gravitational equilibrium with respect to superimposed forces. If a gravitational imbalance occurs, the crust rises or sinks to correct the imbalance.

3. **Sediment compaction** - Compaction occurs when poorly packed sediments reorient into a more dense matrix. Compaction can occur because of vertical loading from other sediments, by draining of fluids from the sediment pore space (usually a man-made effect), by desiccation (drying) and by vibration. **Groundwater and hydrocarbon withdrawal** is probably the main cause of sediment compaction on a local scale.

4. What about **Global Warming**?

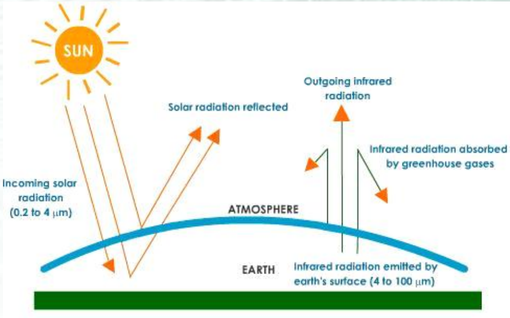
Greenhouse Effect

- Energy emitted from the sun (solar radiation) is concentrated in a region of short wavelengths including visible light.
- This radiation travels unimpeded through the Earth's atmosphere to the surface.
- A portion of the solar radiation is reflected back into space by Earth's surface.



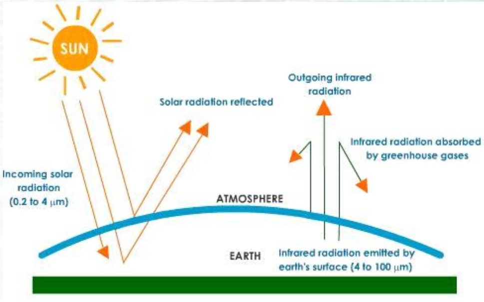
Greenhouse Effect

- A greater portion of the solar radiation is absorbed at the earth's surface, causing the surface and the lower parts of the atmosphere to warm.
- The Earth acts as a radiator and emits heat upwards.
- Without any atmosphere, the mean surface temperature would be a around -18˚C, 33˚. (Denyse Mahabir and Leonard Nurse, An assessment of the vulnerability of the Cocal area, Manzanilla, Trinidad, to coastal erosion and projected sea level rise and some implications for land use)



Greenhouse Effect

- Why is the earth's temperature what it is?
- Presence of the Atmosphere: Absorption of heat causes the atmosphere to warm and emit its own radiation.
- That, plus the directly reflected solar radiation, balance the absorbed energy coming in from the sun.
- Result, the surface temperature of the globe is around 15 C on average.
- This is called the Natural Greenhouse Effect. (Denyse Mahabir and Leonard Nurse, An assessment of the vulnerability of the Cocal area, Manzanilla, Trinidad, to coastal erosion and projected sea level rise and some implications for land use)



Greenhouse Effect

- The oceans contain 50% more CO_2 than the Atmosphere: absorbs much of the $CO_{2.}$. General balance should exist.
- However, during latter half of 20th Century, sharp increase in CO_2 levels plus other GHG such as Methane, Chlorofluorocarbons, Nitrous oxides and Sulphur dioxide.
- The Greenhouse Effect is now enhanced, increasing the Earth's average Temperature.
- Increase may be 5 deg C over the next 100yrs.

Mars: Little Atmosphere – Temperatures of -55 deg C

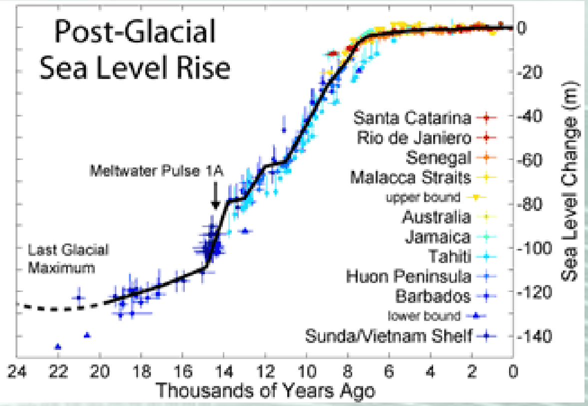
Venus: Greenhouse Effect rampant: Temperatures of 400 deg C

Why is the Mean Sea Level Rising?

- Thermal Expansion of the Sea. Over the 21st century, the IPCC's Fourth Assessment projected that thermal expansion will lead to sea level rise of about 17-28 cm (plus or minus about 50%).

- Melting of Ice Sheets and Glaciers; For the 21st century, IPCC projected that melting of glaciers and ice caps will contribute roughly 10-12 cm to sea level rise, with an uncertainty of roughly a third.

- Loss of ice from the Greenland and West Antarctic ice sheets. IPCC: Greenland may cause 2cm rise. WAIC may cause 2cm fall.

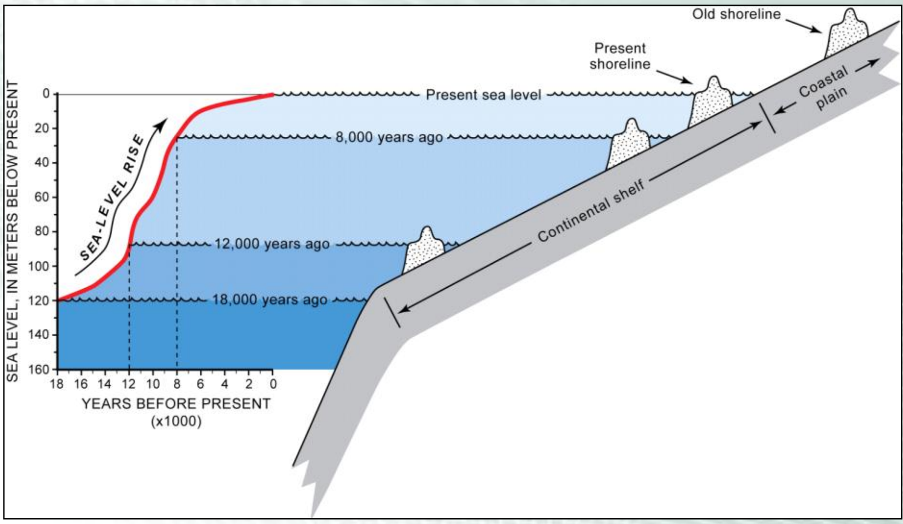


In its recently released Fourth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) estimated that sea level would rise by between 0.18m and 0.59m between 1990 and 2100.

Why is the Mean Sea Level Rising?

- Compared to the past there is actually stability of sea level change over the period of human civilization.
- For the past six thousand years, shorelines have remained unusually stable.
- Therefore, coastal communities have increased.
- But the geological record tells us that this long-term stability is the exception rather than the rule.
- Sea level has risen rapidly in the past and ongoing emissions of greenhouse gasses greatly increase the likelihood that it will do so again in the future.
- The risk of a sudden and significant increase in the rate of sea level rise to rates seen during past meltwater pulses, potentially critical for the future of many coastal cities, cannot yet be evaluated by current models which do not capture the dynamic ice processes that would be involved.http://www.climate.org/topics/sea-level/climate-change-sea-level-rise.html : **Putting Climate Change in a Geologic Context - Are Models Under-predicting Future Changes in Sea Level?** *By Frances Moore, Research Associate, The Climate Institute)*

Why is the Mean Sea Level Rising?



Sea Level Rise Uncertainties

- Thermal Expansion of the Sea:
  - There are questions about the amount of heat that has been taken up by the oceans. Various types of instruments that have been used over time to measure ocean temperatures- different instruments create different results. At present, simulations of 20th century heat uptake by the oceans and of the amount of sea level rise do not fully match, making it more difficult to project the amount of thermal expansion that can be expected in the 21st century. **(Putting Climate Change in a Geologic Context - Are Models Under-predicting Future Changes in Sea Level?** *By Frances Moore, Research Associate, The Climate Institute).*

- Difficulty in determining the extent of the loss of Glaciers and Ice Sheets.
  - Observations of the retreat of glaciers have been, in a number of situations, more rapid than models have simulated. Is this due to natural variations or is the impact of Global Warming more serious than thought?

- Uncertainties relating to the potential loss of ice from the Greenland and West Antarctic ice sheets.
  - Modelling is challenging due to insufficient knowledge of the physics behind movement of ice sheets

Why the Uncertainty?

Incorporating the following in the modelling is difficult:

1.Tectonic instability - Regional, slow land level changes , for example, along the U.S. western continental margin affect relative long-term sea level changes. Parts of the coast are rising and falling at different rates.

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The Impact of Sea Level Rise – Trinidad and Tobago

- Coastal Flooding
  - Particularly a problem for low lying areas in proximity to the coast – Caroni Plains.

- Loss of Wetlands
  - Wetlands can keep pace with slow SLR. As SLR occurs so do deposition of sediment. If deposition keeps pace the wetland will rise with the SLR. If not the wetland will submerge. Dynamics response. Small tidal range areas more vulnerable than large tidal range. Nariva Swamp tidal range is approximately 1m. Loss is also offset by upwards migration of wetlands. However, if hard coastal engineering practices are in place, upwards migration cannot take place.

The Impact of Sea Level Rise – Trinidad and Tobago

Erosion

- In many areas the total shoreline retreat from a Sea level rise would be much greater than suggested by the amount of the land below the level of the rise since the shoreline will also erode.
- Brunn (1962) showed that as sea level rises, the upper part of the beach will erode and be deposited offshore and that the beach profile will be restored with respect to the sea level.
- The "Brunn Rule" indicates that a one-meter rise (for example) would generally cause erosion of 50 to 200 meters along sandy beaches.

This impact is very relevant to Trinidad and Tobago as there are several areas under erosion at present: Cocos Bay and Icacos Point are prime examples.

Sea Level Change and the Bruun Rule

- One of the best-known shoreface response models was proposed by Bruun in 1962 (re-derived in 1988). Bruun's concept was that beaches adjust to the dominant wave conditions at the site. Clearly they had adjusted and evolved historically as sea level had changed.

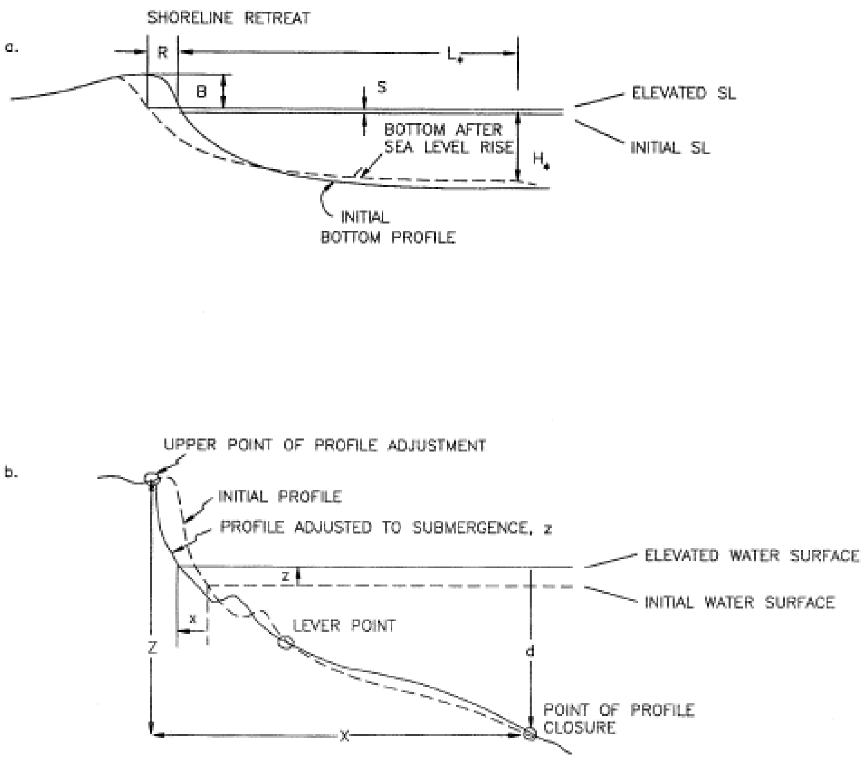
- Earlier studies of summer/winter beach morphology provided clues that beaches responded even to seasonal changes in wave climate, resulting in shoreline shifts/movements.

- The basic assumption behind Bruun's model is that with a rise in sea level, the equilibrium profile of the beach and the shallow offshore moves upward and landward. Bruun made several assumptions in his two-dimensional analysis:

1. The upper beach erodes because of a landward translation of the profile.
2. Sediment eroded from the upper beach is deposited immediately offshore; the eroded and deposited volumes are equal (i.e., longshore transport is not a factor).
3. The rise in the seafloor offshore is equal to the rise in sea level. Thus, offshore, the water depth stays constant.

Sea Level Change and the Bruun Rule

The Bruun Rule can be expressed as the figure below (taken from the CEM):



Engineering response and policy

(a) Whatever the academic arguments about sea level rise predictions, engineers and coastal planners must anticipate that changes in relative sea level may occur in their project areas and need to incorporate the anticipated changes in their designs and management plans.

(b) Because of the uncertainties surrounding sea level, the U.S. Army Corps of Engineers (USACE) has not endorsed a particular rise (or fall) scenario. It directs that feasibility studies should consider which designs are most appropriate for a range of possible future rates of rise.

(c) Potential rise should be considered in every coastal engineering feasibility study that any local firm undertakes. Project planning should consider what impact a higher sea level rise would have on designs based on local, historical rates.

Conclusion

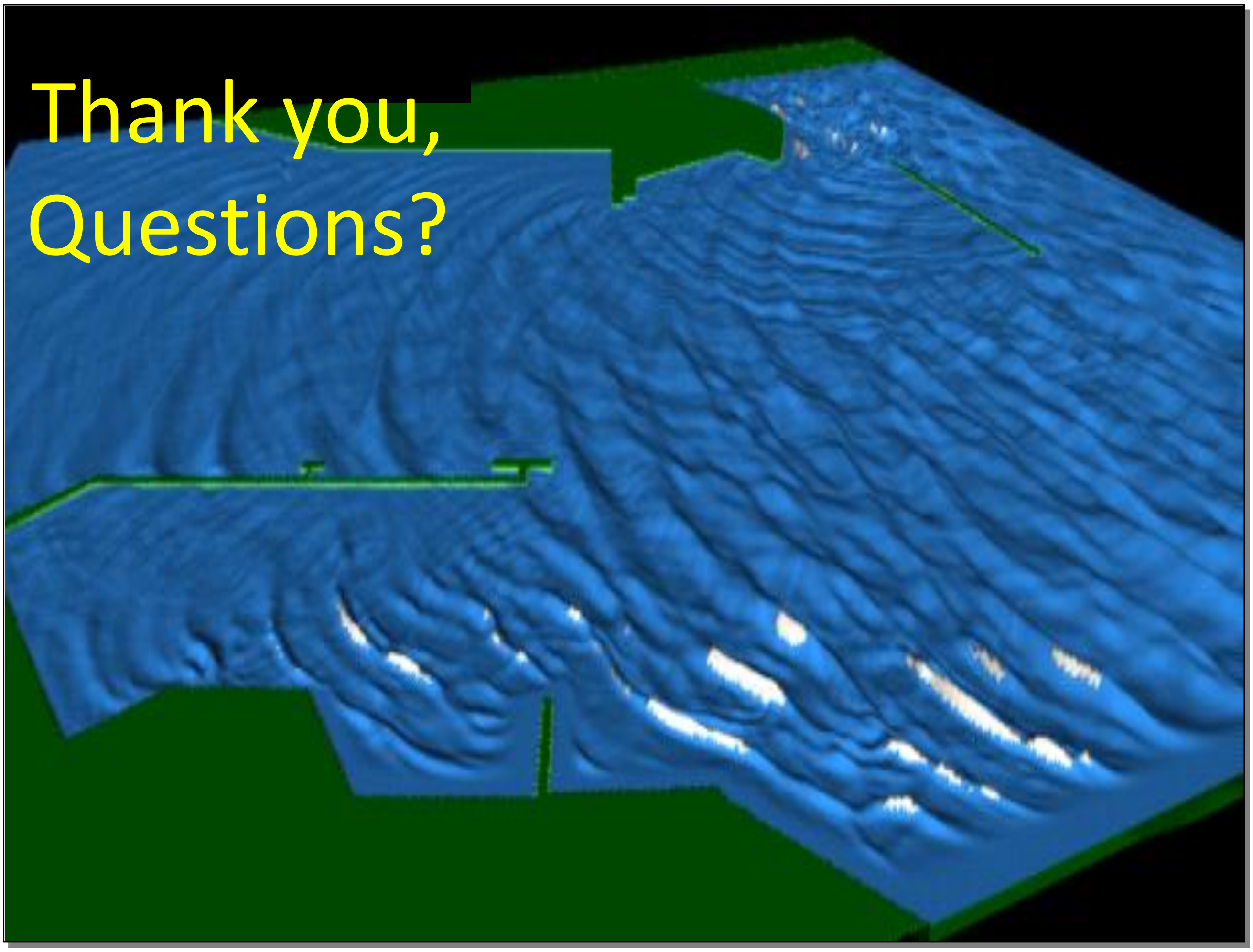
- Sea Level Rise appears to be real.
- The interaction of the sea with the coastline of Trinidad and Tobago is clearly already a problem - Coastal Flooding and Erosion.
- Historically Trinidad and Tobago's response to its coastal erosion problems have not been sustainable.
- Too much emphasis on immediate hard coastal protection structures that deal with a site specific issue with little or no consideration to impacts adjacent to the project site.
- In many areas, coastal management (mismanagement) practices have the greatest influence on erosion, and sea level changes are a secondary effect.

Conclusion

- T+T needs a project specific appraisal of the issues to determine the present erosion and future erosion that include near field and far field effects– including an assessment of future Sea Level Rise. This is where sediment and erosion modelling comes into play.

- More field and laboratory studies are needed to better evaluate the response of beaches to rising (and falling) sea level. Conceptual advances need to be incorporated in the theoretical models. How sediment has moved onshore in some locations following sea level rise also needs to be evaluated, because there is evidence that in some areas beach sand compositions reflect offshore rather than onshore sources.

- Let us be creative with coastal management solutions – Is hard structure solutions the only way to go? What about Ecosystem Adaptation Projects such as Mangrove Community Development.


Thank you,
Questions?