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IMPACTS OF CLIMATE CHANGE ON COASTAL AREAS: Modeling and Predictions

Dr. Shakira Khan & Prof. Edward Robinson

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Ensemble Climate Modeling

The Science of Climate Change and Climate Change Vulnerability and Adaptation

Overview

- What is climate change ?
- Impacts on coastal areas
- Sea level rise
- Measuring sea level rise
- Hurricanes & Storm surge
- Modeling & projections
- Case study – Negril & Mammee Bay

What is Climate Change?

- It is simply a change of climate, that is, a regional change in temperature and/or weather patterns.

- This term is commonly used interchangeably with "global warming" and "the greenhouse effect," but is a more descriptive term and *refers to any change in climate over time, whether due to natural variability or as a result of human activity* (IPCC, 2007) .

- The latter refers primarily to the buildup of man-made gases in the atmosphere that trap the suns heat, causing changes in weather patterns on a global scale. The effects include changes in rainfall patterns, sea level rise, potential droughts, habitat loss and heat stress. The greenhouse gases of most concern are carbon dioxide, methane, and nitrous oxides (www.nsc.org/ehc/glossary.htm)

Climate change - What does this mean to us?

Scientists have identified some of the likely effects:-

- *Sea level - t*he sea level could rise by more than a **<u>metre</u>** by the end of the century.
- *Rainfall -* Some regions will experience more extreme rainfall while others will experience drought.
- *Storms*- More intense storms. With rising sea-level these will affect vulnerable shoreline structures more frequently
- *Temperature* -both atmospheric and sea surface temperate are projected to increase

Coastal Erosion & Washovers

Impacting vulnerable transport routes and critical facilites in low lying areas

The Palisadoes
Post hurricane Ivan

At high tide

Hurricane Emily 2005

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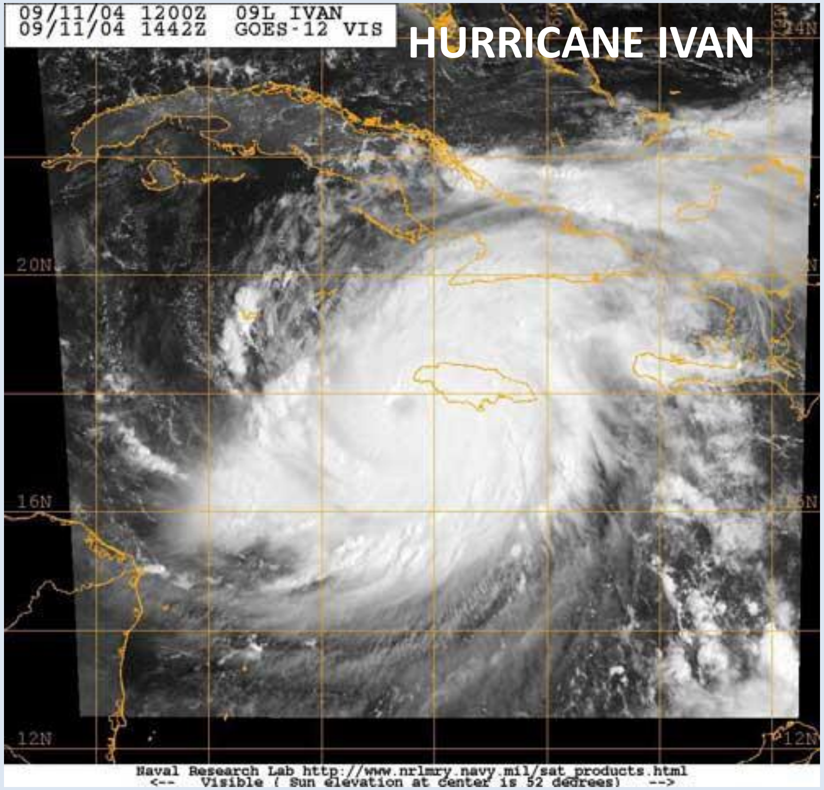
More intense & frequent storms



http://www.haitiaction.net/News/storm/IVAN/9_9_4.html

13 month period -September 2004- October 2005 : there were 4 storms that impacted Jamaica

Ivan -September 2004

Dennis –July 2005

Emily – July 2005

Wilma – October 2005

Dean - August 2007

Felix – September 2007

Gustav - August 2008

Photo: AP
http://www.telegraph.co.uk/news/worldnews/centralamericaandthecaribbean/jamaica/2644346/Tropical-storm-Gus

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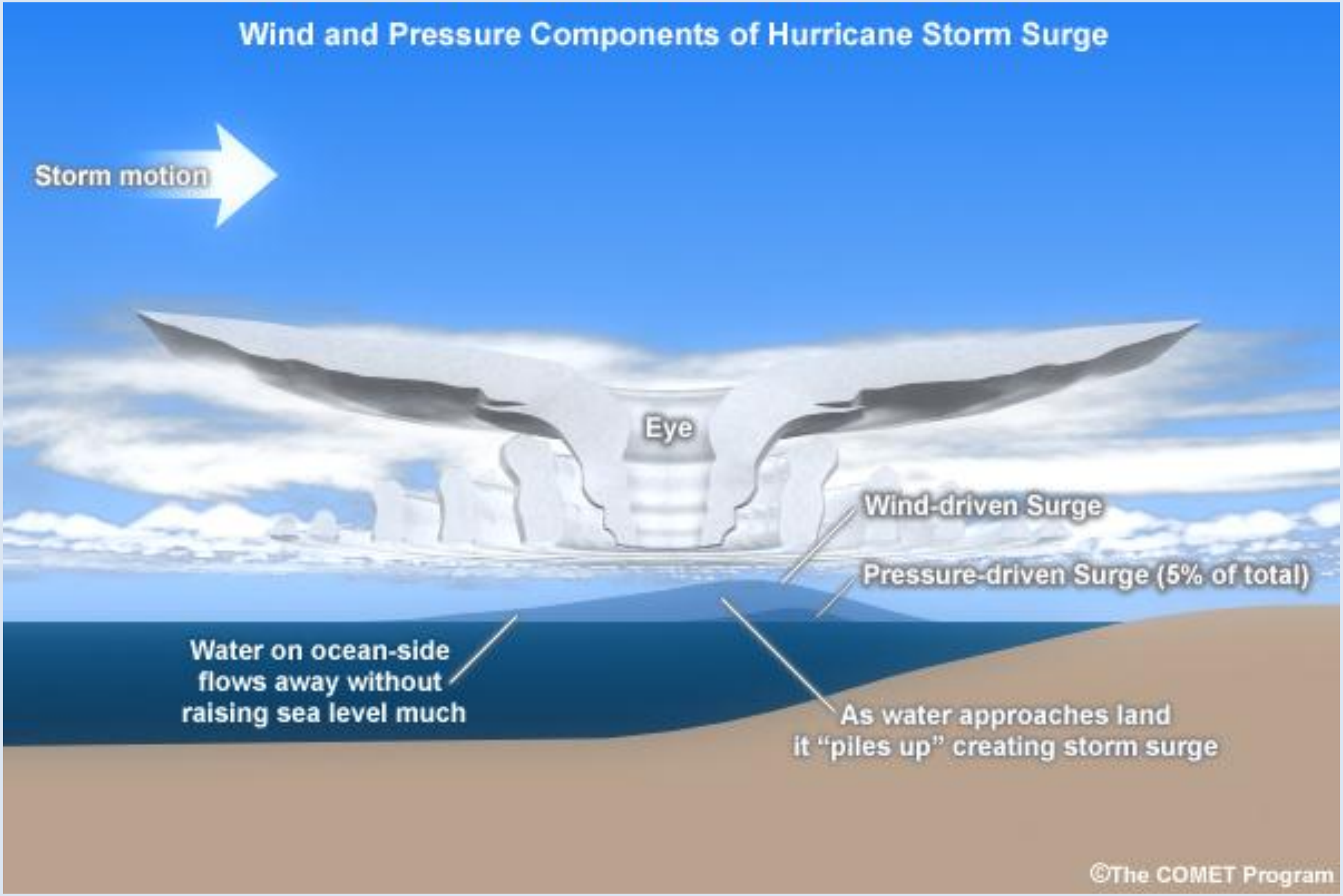
Storm Surge



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Storm Surge

STORM SURGE

Annotto Bay – Storm surge inundation distances

Photo: N. Butterfield

Intense storms generate Giant waves that Impact cliffed coastlines

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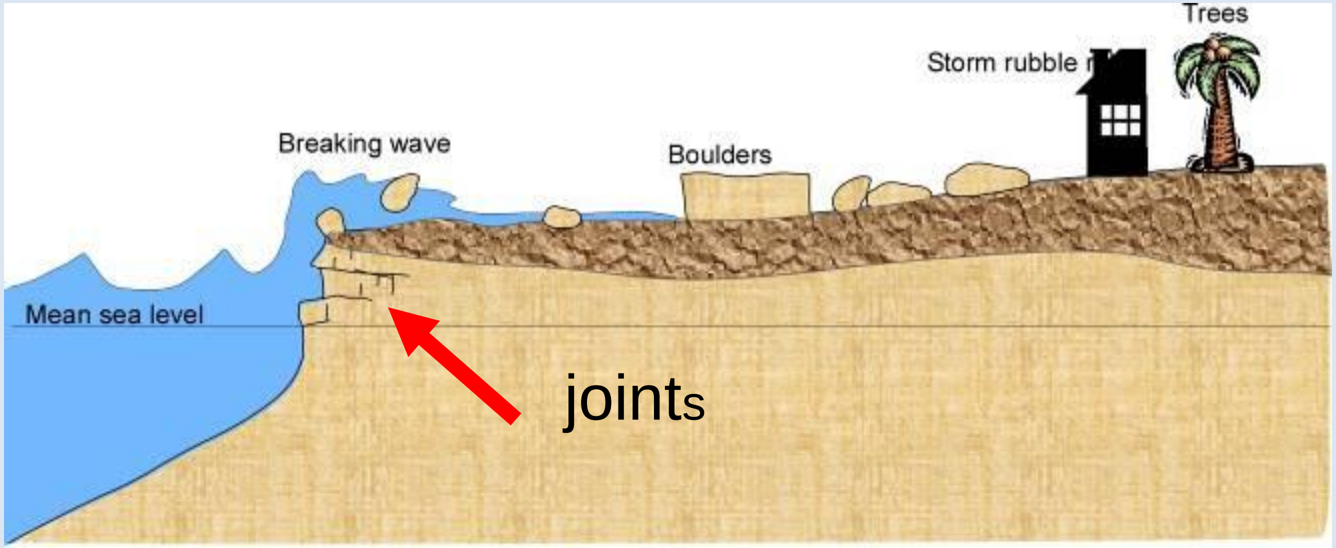
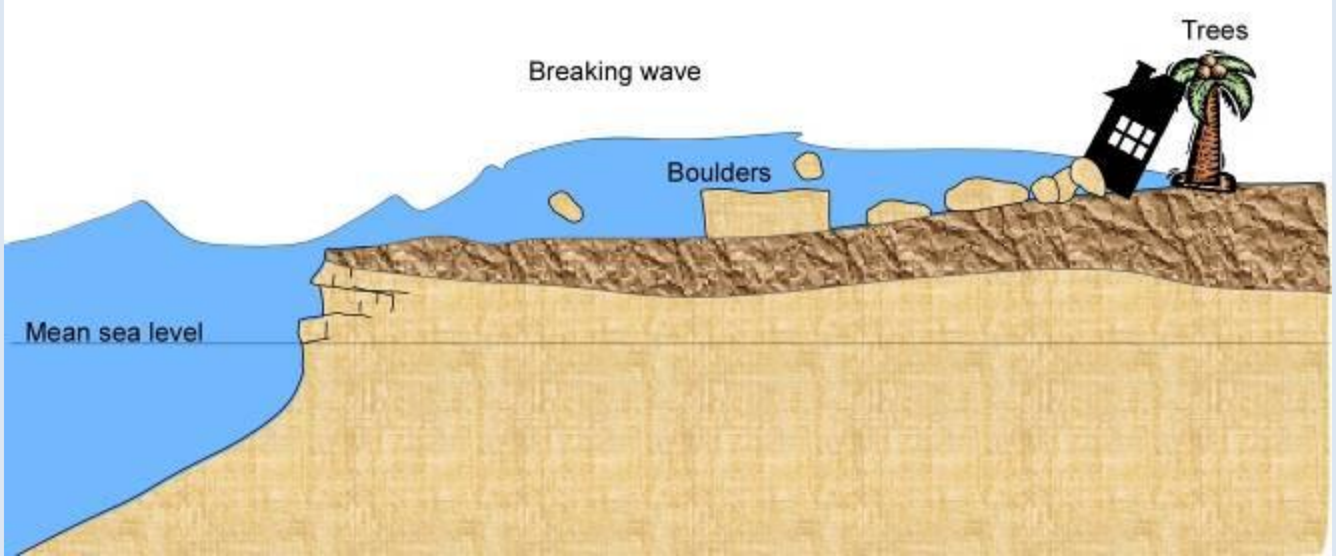
Intense storms result in Boulders moving



When severe wave events occur (hurricanes or tsunami) blocks of rock can be torn off the cliff face and hurled inland



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Communities on rocky shores can be engulfed by storm wave debris

Some wave debris can be very big…

More intense & frequent storms

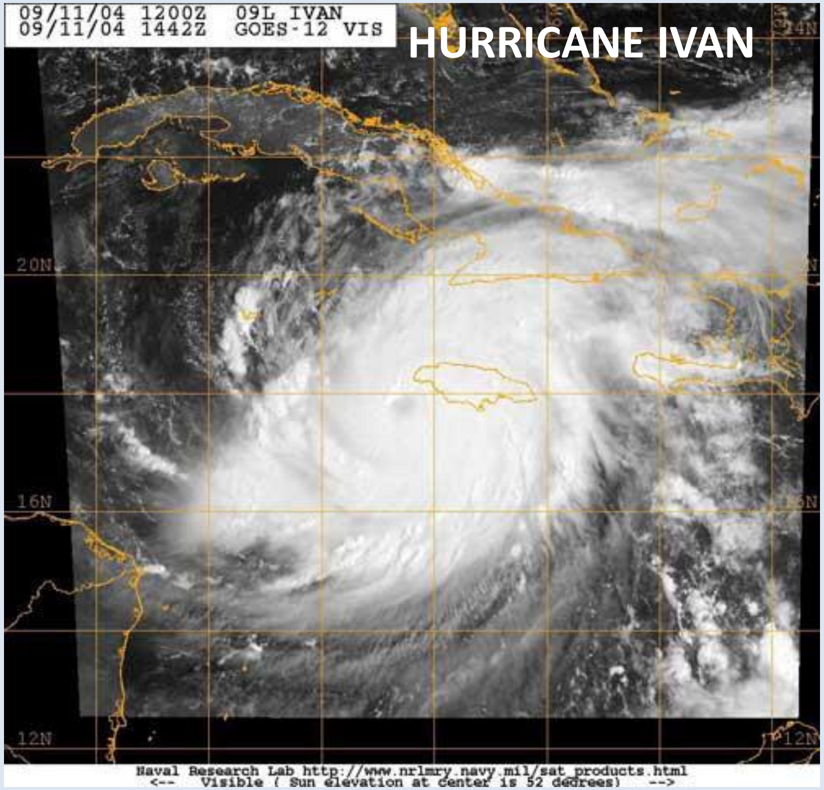

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Photo: AP
http://www.telegraph.co.uk/news/worldnews/centralamericaandthecaribbean/jamaica/2644346/Tropical-storm-Gus

Repeated impacts in vulnerable areas

Damage: Hurricane Ivan 2004

Damage: Hurricane Dean 2007

Impact of storm surge on Mangroves

Threat to Wild life – destruction of Habitat

Threat to breeding areas, roosting, nesting and fish nurseries

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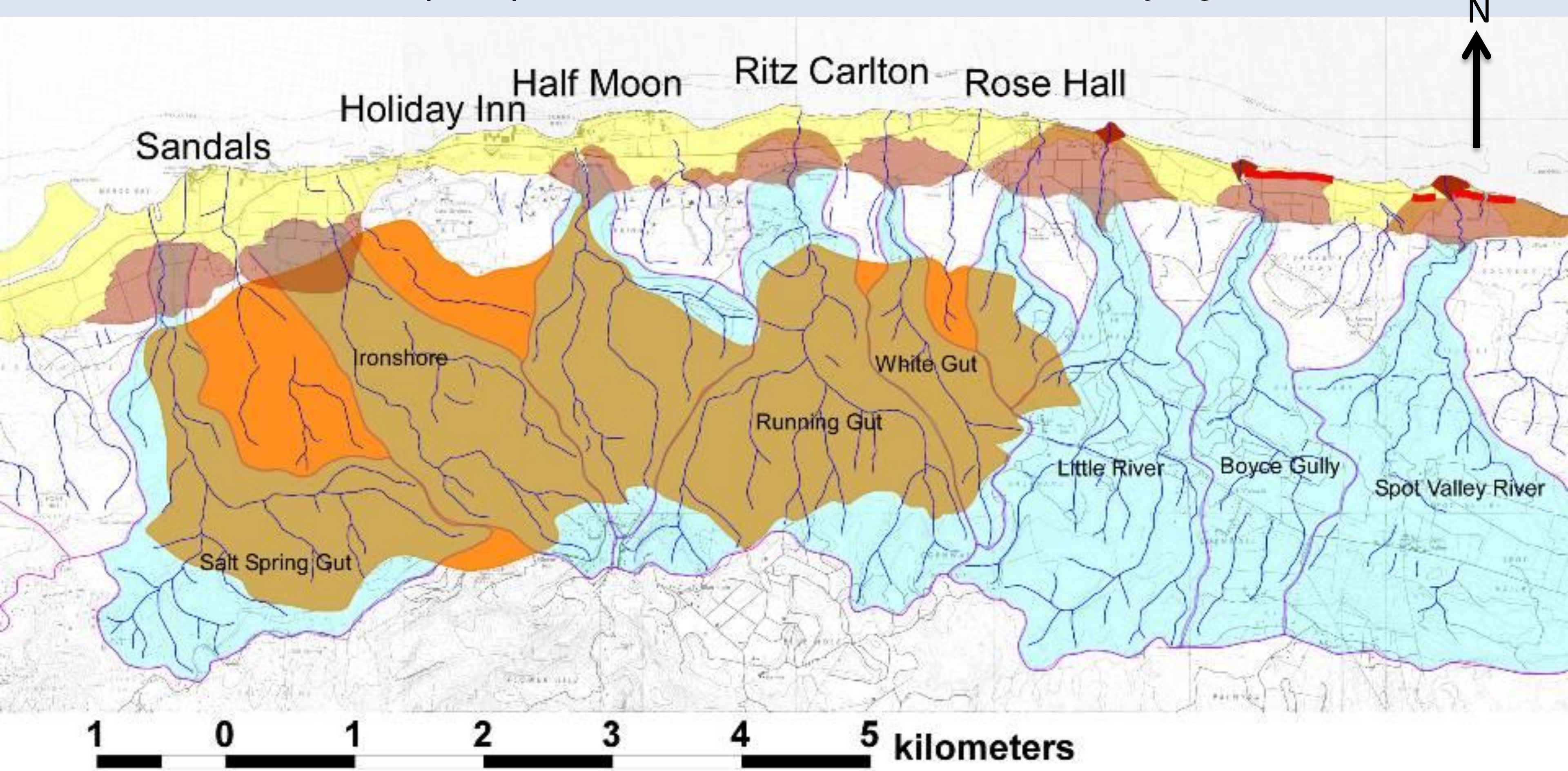
Increased Rainfall -The Debris Flow

Flooding and debris flows occur when normally dry gullies fill to overflowing as infiltration is overwhelmed and all precipitation becomes surface runoff, carrying rock debris.



Geological evidence for this kind of hazard:

Gullies (blue); Marls and muddy sandstones (brown & orange); Debris fans (darker browns); Significant recent marine erosion event (red bands).

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*The activity in such systems at Bluefields was well described by Eleanor Jones (1981)

Rising sea levels lead to increased inundation from storm surge…..




What will this do to beaches?

It is well established that our beaches have suffered from recession in recent times

2006 orange bay

2004 Negril

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Sea Level

If you were to try to measure sea level with a measuring rod you would find it to be impossible -- the level changes by the second (waves), by the hour (tides) and by the week (planetary and solar orbit changes).

Measuring sea level is difficult, one must consider that there are so many things that affect it.

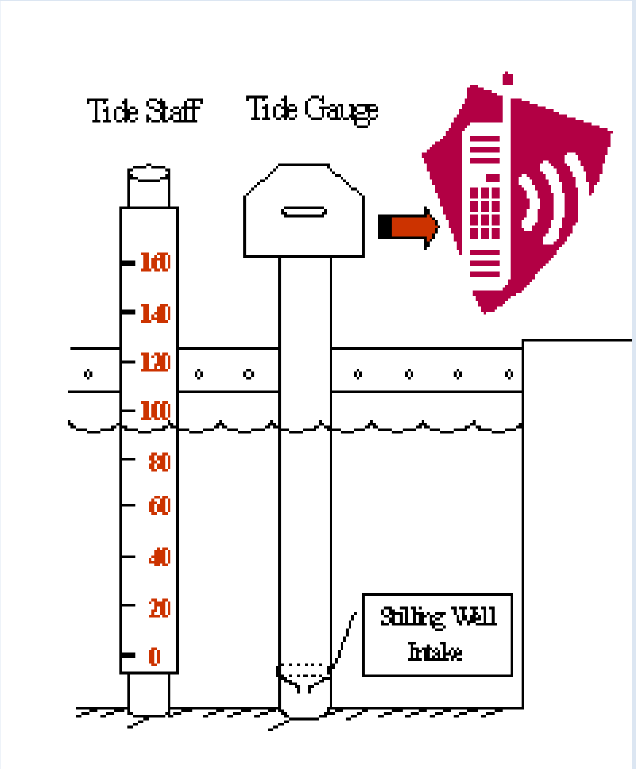
Water level at any given point is changing -

- The tides, caused by the moon
- Large and small waves caused by wind and the tides
- High- and low-pressure areas in the atmosphere, which change the surface level of the ocean
- Temperature changes in the ocean, which change the density and volume of the water
- Rainfall and river water flowing into the ocean

Measuring sea level rise

- **Tide gauges.**

A tide gauge is a large (1 foot [30 cm] or more in diameter), long pipe with a small hole below the water line. This pipe is often called a **stilling well**. Even though waves are changing the water level outside the gauge constantly, they have little effect inside the gauge. The sea level can be read relatively accurately inside this pipe. If read on a regular basis over a time span of years and then averaged, you can get a measurement of sea level.



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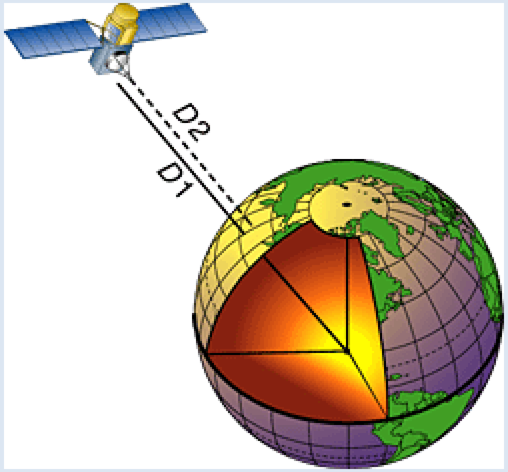
Measuring sea level rise



Satellite altimetry

Satellites (E.g. TOPEX and Jason series of satellite radar altimeters) are now used as well. These measurements are continuously calibrated against a network of tide gauges. When seasonal and other variations are subtracted, they allow estimation of the global mean sea level rate.

Mean sea level is the average level of the sea, and measuring sea level is usually based on hourly values taken over a period of at least a year.

Scientists do the best they can, using extremely long time spans, to try to figure out what the sea level is and whether or not it is rising.

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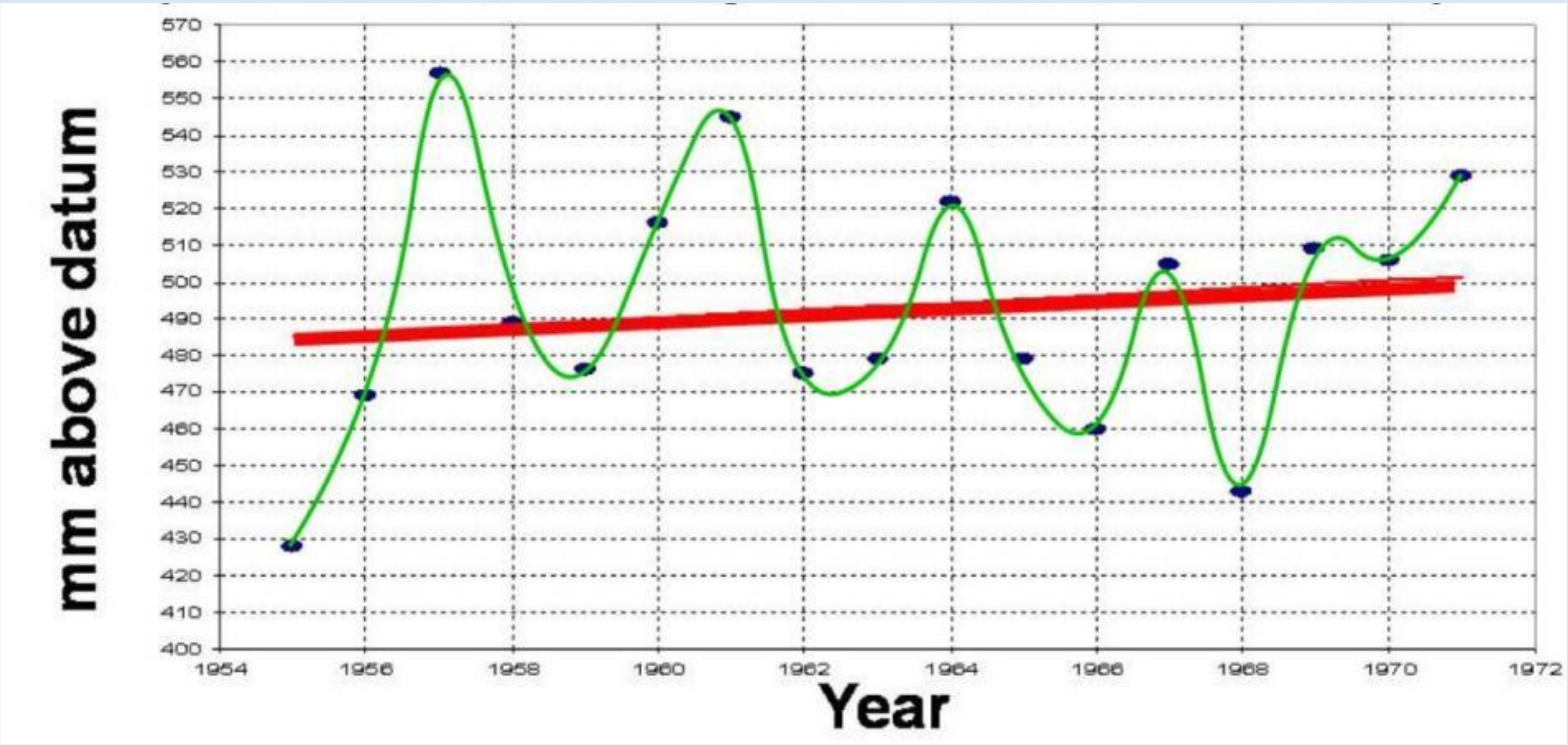
Sea level records for Jamaica



Mean annual sea-levels at Port Royal, 1955-1971 (modified from Cambray, 1973). Green line is year-to-year fluctuation in mean annual sea-level; red line is overall trend. Largest year-to-year fluctuation is 8.8 cm, smallest is 0.3 cm; overall trend shows rise of 1.5 cm.

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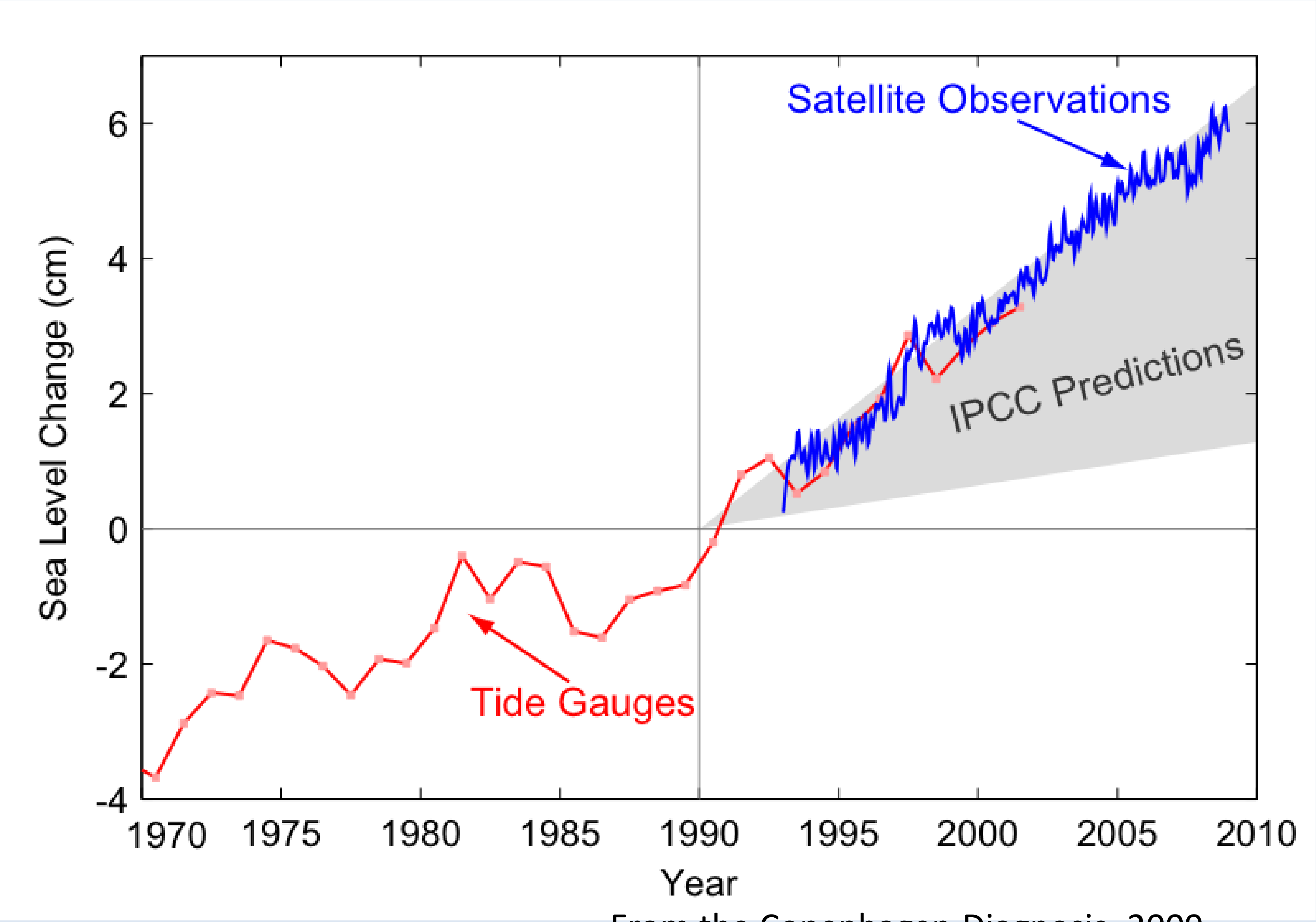

From the Copenhagen Diagnosis, 2009.

Negril's vanishing beaches

by water sports and, to a lesser extent, overfishing.

They've identified three main problems associated with the erosion. They believe that little or no beach sand is being produced because the reef is dying at a rapid rate; corals have decreased dramatically so they can't protect Negril's beaches (especially in the Long Bay area) from increased erosional forces, and reef health in Negril continues to decline. That they say, signals that the loss of the beach will continue, as ...

PATRICK CAMPBELL/Staff Photographer

Above: The famous seven-mile Negril Beach which is taking a severe beating from erosion.

Rescue plan for Negril's beach

Front page of the Observer, March 2002

What does this mean?.....
Ans: We must act now!

* House destroyed by encroaching sea, Parish of Portland

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Modeling & Projections

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Useful Tools for climate change V&A assessments

- **Bruun rule** - equilibrium profile model
- **Historical Trend Extrapolation**-End point rate /shoreline change method and linear regression
- **Monte Carlo simulation** – Numerical model
- **MIKE21**- Computer software that will simulate Free surface flows and can be useful for storm surge inundation modeling
- UNEP/RIVAMP project includes coastline position projections

http://www.grid.unep.ch/index.php?option=com_content&view=article&id=47&Itemid=253&lang=en&project_id=204F6705

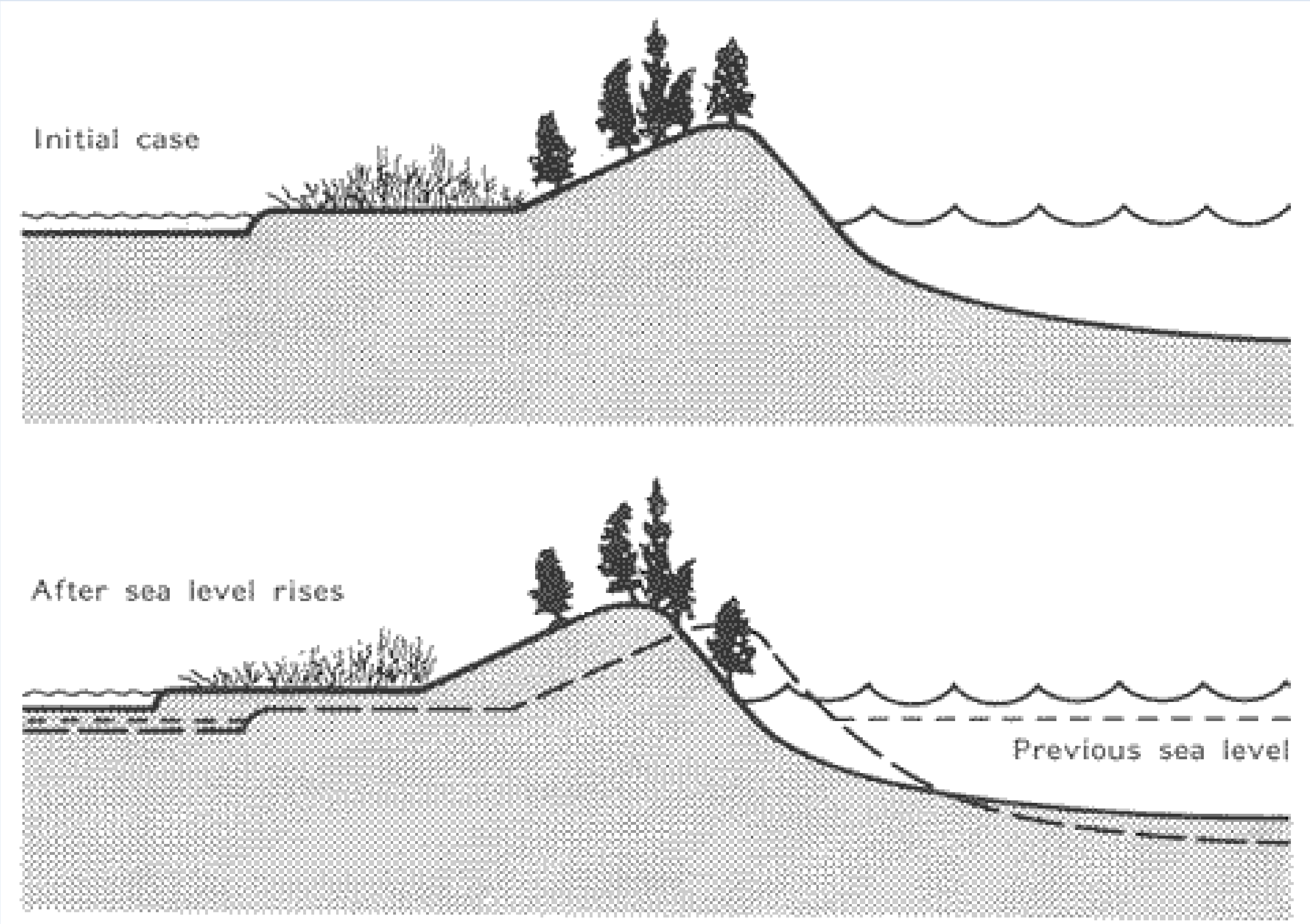
Bruun Rule

- The first and best known model relating shoreline retreat to an increase in local sea level is that proposed by Per Bruun (1962).

- The Bruun rule can be applied to correlate sea-level rise with eroding beaches. The Bruun rule estimates the response of the shoreline profile to sea-level rise. This simple model states that the beach profile is a parabolic function whose parameters are entirely determined by the mean water level and the sand grain size. The analysis by Bruun assumes that with a rise in sea level, the equilibrium profile of the beach and shallow offshore moves upward and landward.

  The analysis is two-dimensional and assumes that, The upper beach is eroded due to the landward translation of the profile; The material eroded from the upper beach is transported immediately into the offshore and deposited, such that the volume eroded is equal to the volume deposited;

Bruun Rule



The Bruun rule states that a typical concave-upward beach profile erodes sand from the beach face and deposits it offshore to maintain constant water depth.

- **Scope**The Bruun rule is only applicable for small scale local sites.

  Over long stretches of coast, the Bruun rule and associated cross-shore transport models become complex. There has been a number of critiques e.g. Cooper and Pilkey (2004).

  Key Output Shoreline recession (in metres relative to sea-level rise).

  Key Input An increase in sea level, (S), cross shore distance/Profile (L) to the water depth (h) taken by Bruun as the depth to which nearshore sediments exist (depth of closure), Profile slope angle (ø) and Berm height/elevation (B)

$$R = S(L/(B+h)) = (S)1/\tan Ø$$

  Ease of Use Easy to use with numerous assumptions.

  Training Required Familiarity with the coastal zone being investigated.

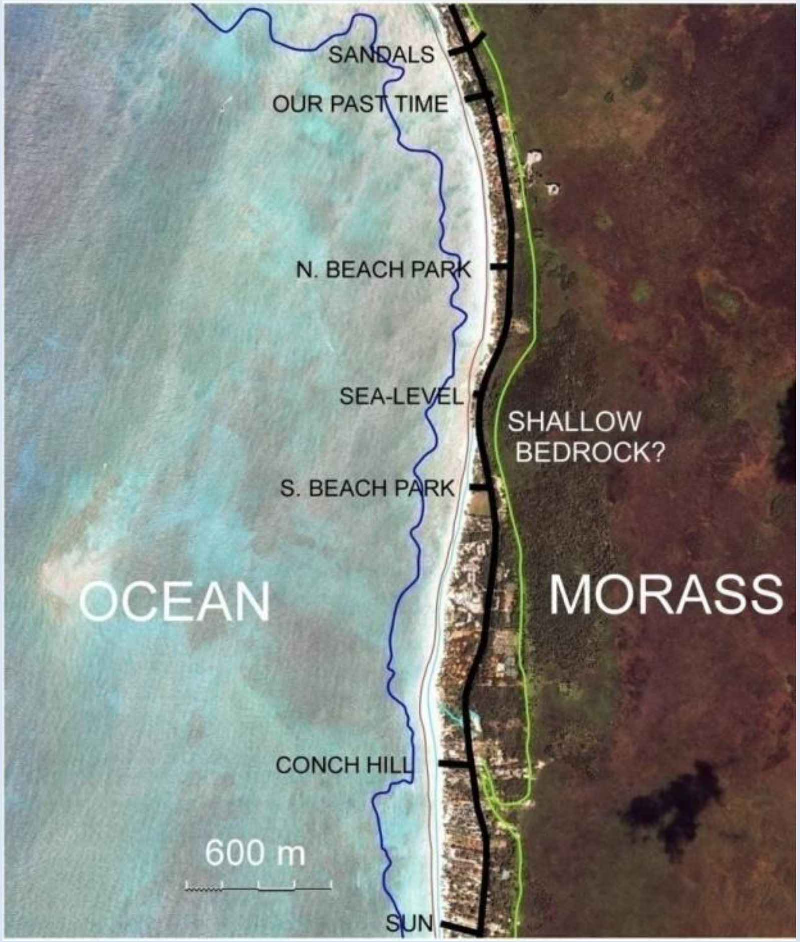
  Computer Requirements None, unless it is incorporated into a model.

  Cost No cost to use the Bruun rule.

  Validity: Bruun rule has been applied but caution needs to be exercised where other factors influence sediment budget or control profile.

BRUUN RULE: SURVEYED CROSS-SECTIONS AT NEGRIL

NORTHERN LONG BAY (BLUE LINE, 3 M CONTOUR)



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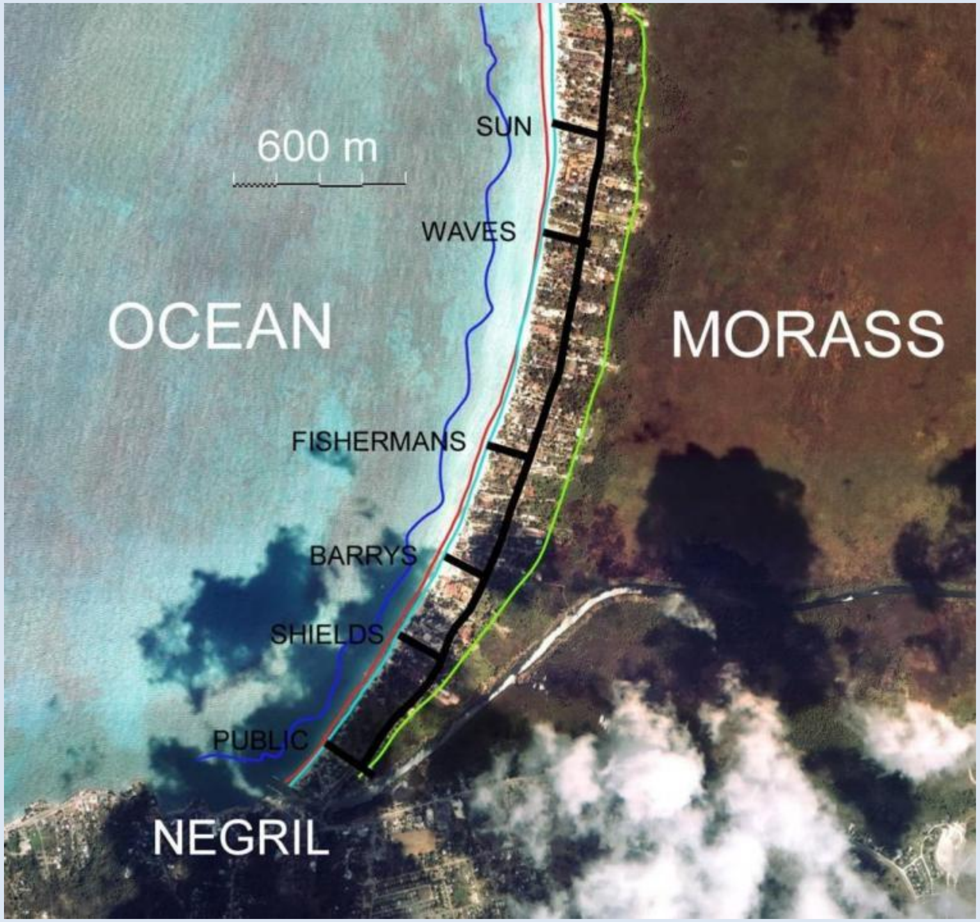
BRUUN RULE SURVEYED CROSS-SECTIONS

SOUTHERN LONG BAY (BLUE LINE, 3 M CONTOUR)



PROJECTED SHORELINE RECESSION (METRES) FOR ELEVEN SURVEYED TRANSECTS, LONG BAY, USING THE BRUUN RULE

Date of surveys, May 2008; projections based on the A1F1 scenario of the IPCC (2007)

	IPCC PROJECTION				RAHMSTORF PROJECTION			
NEGRIL 2008	**2015**	**2030**	**2050**	**2100**	**2015**	**2030**	**2050**	**2100**
SLR in m	0.02	0.07	0.14	0.46	0.03	0.12	0.25	0.95
Sandals	1	4	9	29	2	7	16	59
Our Past Time	2	5	11	35	2	9	19	73
North Park	1	2	5	15	1	4	8	32
South Park	1	4	9	29	2	7	16	32
Conch Hill	1	2	4	14	1	4	8	29
Sun	1	3	7	21	1	5	12	43
Waves	1	4	8	25	2	6	14	51
Fishermans	1	3	7	22	1	6	12	46
Barry's	1	3	6	19	-1	5	11	40
Shields	0	1	3	10	1	2	5	20
Public	1	2	4	14	1	4	8	29
MEAN RECESSIONS	**1**	**3**	**7**	**21**	**1**	**5**	**12**	**41**

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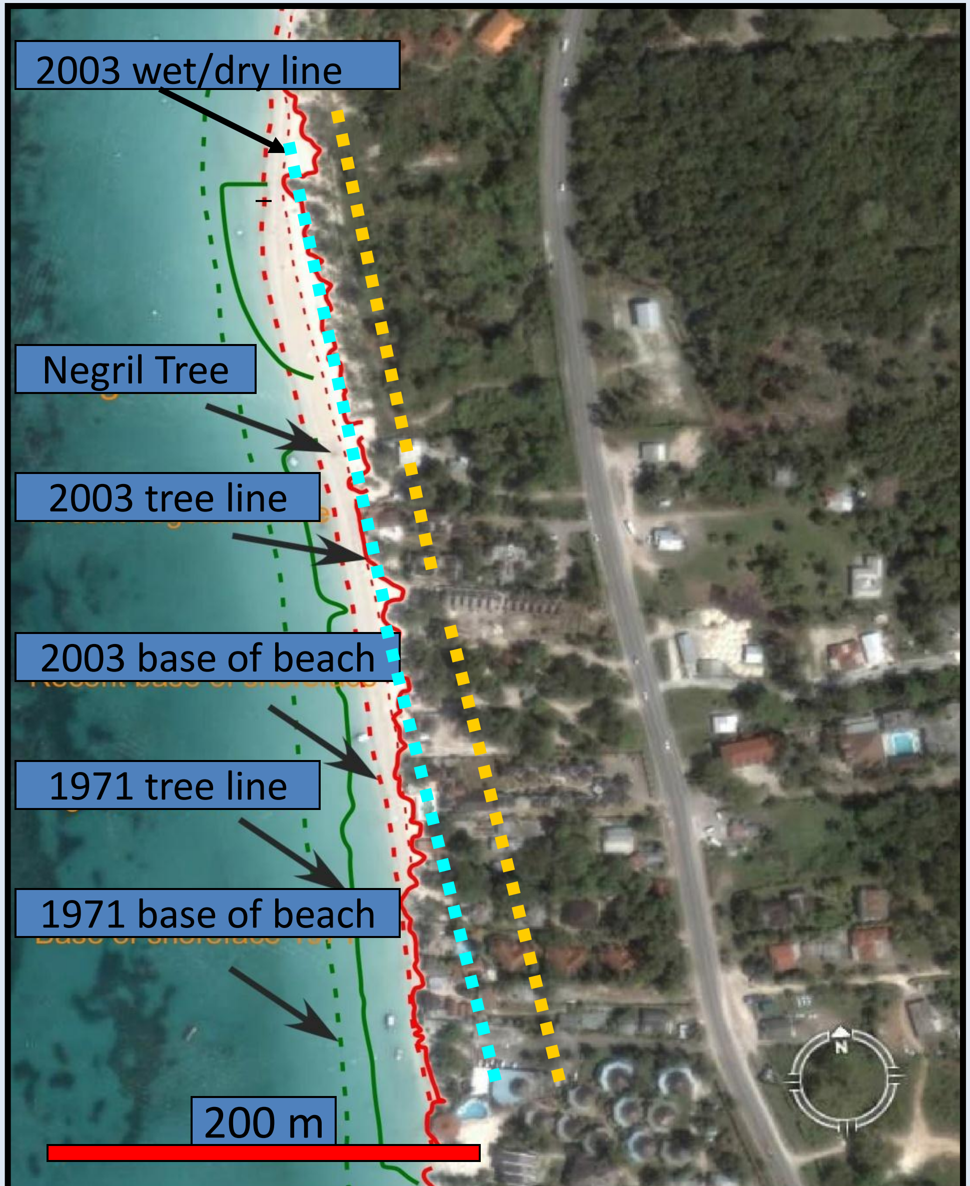
Possible Shoreline Retreat by 2030, Long Bay, Negril

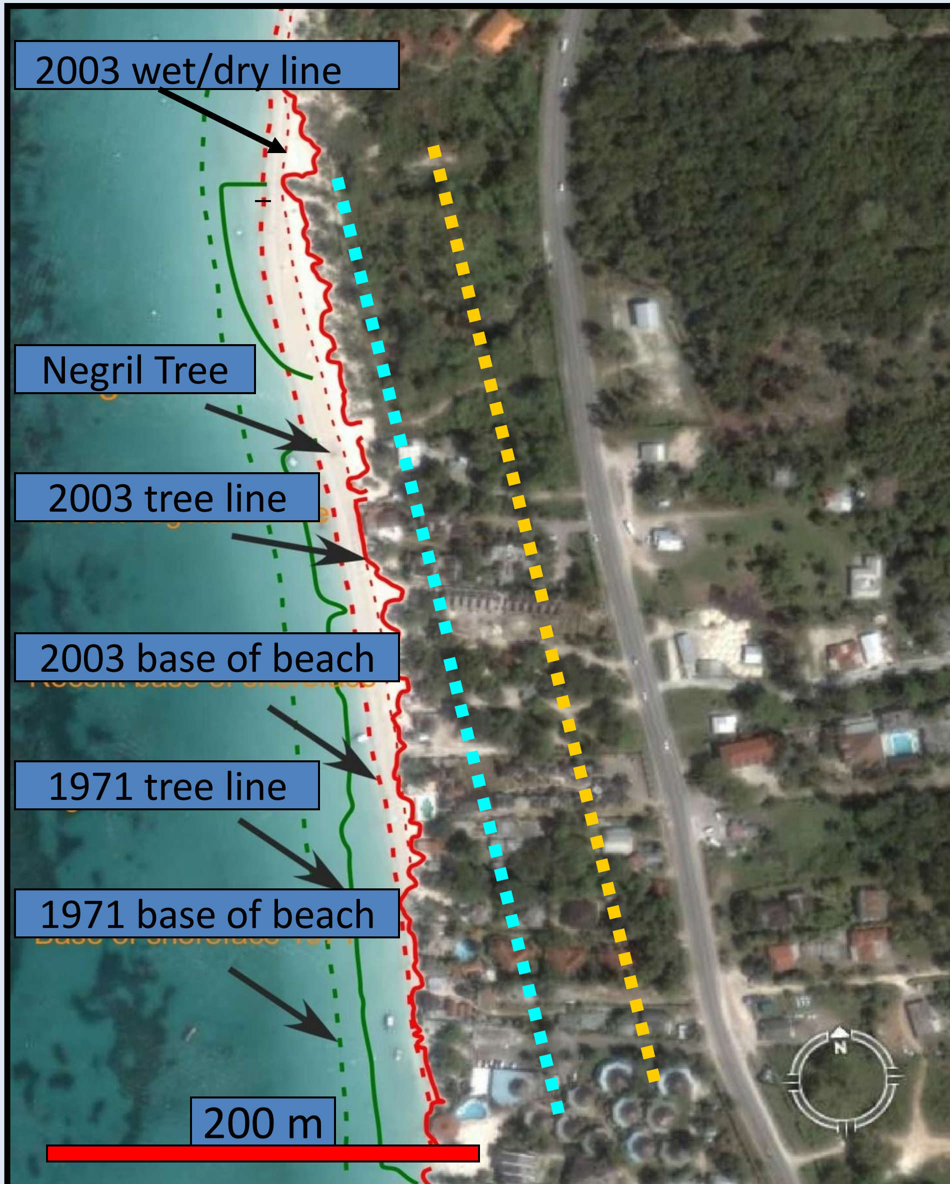


Linear trend based on observed retreat, 1971-2003, using Rahmstorf's high projection of 16 cm (YELLOW) & IPCC mean of 6 cm (BLUE)

Between 1971 and 2003 sea level rose about 7 cm (IPCC Report , 2007)

Scene from Google Earth

……and by 2050? Long Bay, Negril



Linear trends based on observed retreat, 1971-2003, using Rahmstorf's high projection of 36 cm (YELLOW) & the IPCC mean of 16 cm (BLUE)

Between 1971 and 2003 sea level rose about 7 cm
(IPCC Report , 2007)

Scene from Google Earth

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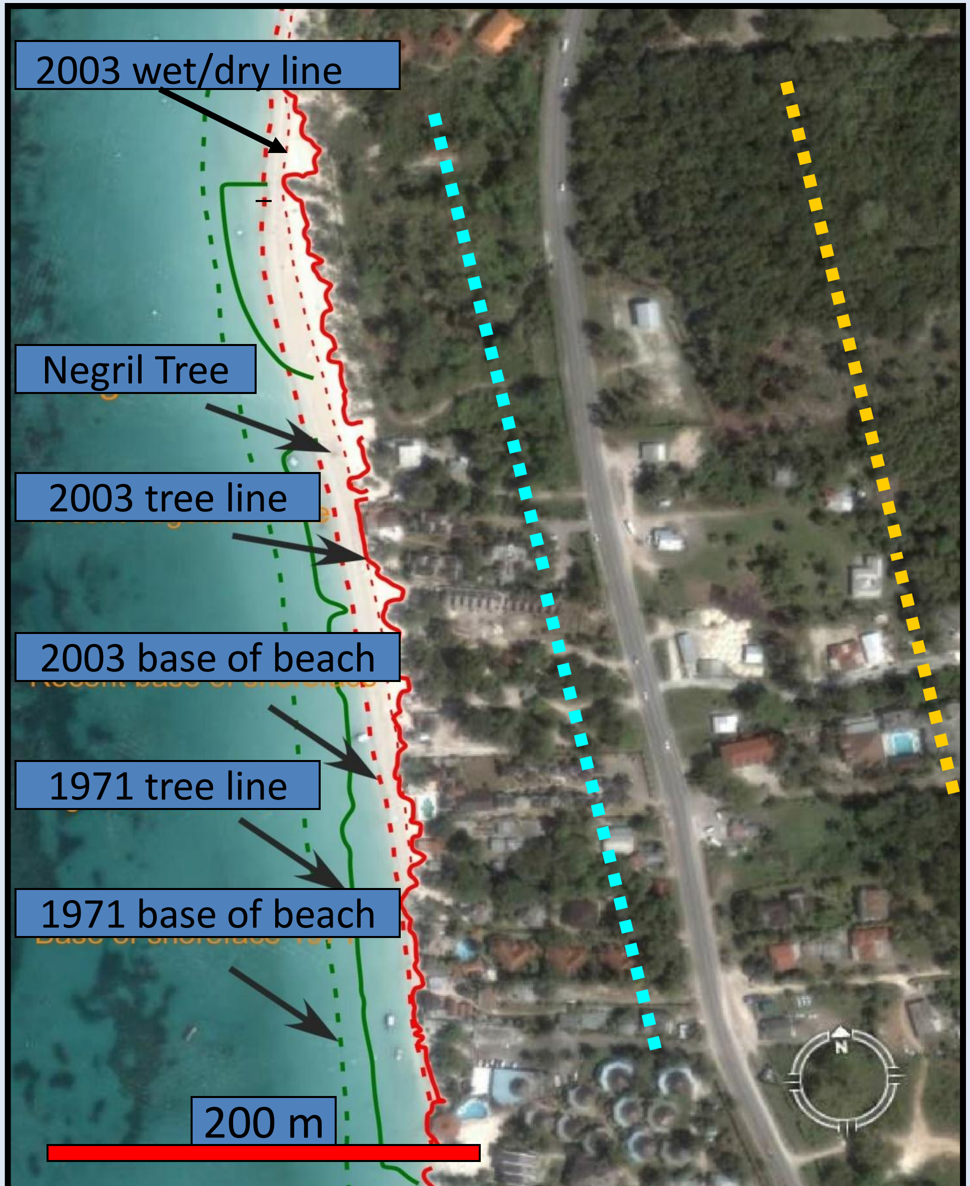
……and by 2100? Long Bay, Negril



Linear trend based on observed retreat, 1971-2003, using Rahmstorf's high projection of 134 cm (YELLOW) & IPCC mean of 33 cm (BLUE)

Between 1971 and 2003 sea level rose about 7 cm (IPCC Report , 2007)

Scene from Google Earth

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ERRORS AND UNCERTAINTIES

FOR THE BRUUN RULE CALCULATIONS:

1. **IT WAS ASSUMED THAT NO APPRECIABLE LONG-SHORE TRANSPORT OF SAND IS OCCURRING. WHILE THIS IS NOT STRICTLY TRUE SUCH MOVEMENT WAS IGNORED FOR THE PURPOSES OF THIS PRELIMINARY ACCOUNT.**

2. **WHILE THE BEACH TOE POSITION REFLECTS DAILY CHANGES ON THE SHOREFACE, WE SUGGEST THAT THE DEPTH OF CLOSURE IS ESSENTIALLY MARKED BY THE SEAWARD EXTENT OF SAND LACKING PERMANENT OVERGROWTH OF MARINE BIOTA SUCH AS SEA-GRASS AND CALCAREOUS ALGAE. THE BOUNDARY BETWEEN THE TWO REGIMES IS QUITE SHARP OVER MUCH OF LONG BAY, IS EASILY VISIBLE ON AIR PHOTOS, AND LIES AT ABOUT THREE METRES DEPTH.**

   SAND MOVEMENT OVER MONTHLY OR YEARLY TIME PERIODS IS THOUGHT TO INHIBIT EXTENSIVE COLONISATION AND OVERGROWTH.

   ON THE OTHER HAND OVERGROWTH OF BOTTOM SEDIMENTS EFFECTIVELY BINDS THE SEDIMENT, INHIBITING APPRECIABLE SAND MOVEMENT.

   WE USED THE 3 METRE ISOBATH AS MARKING THE DEPTH OF CLOSURE.

   FOR ALL THESE FUTURE PROJECTIONS THE ASSUMPTION BY THE IPCC THAT SEA-LEVEL RISE IN THE JAMAICAN REGION WILL PROBABLY APPROXIMATE GLOBAL PROJECTIONS WAS ACCEPTED.

Historical Trend Extrapolation

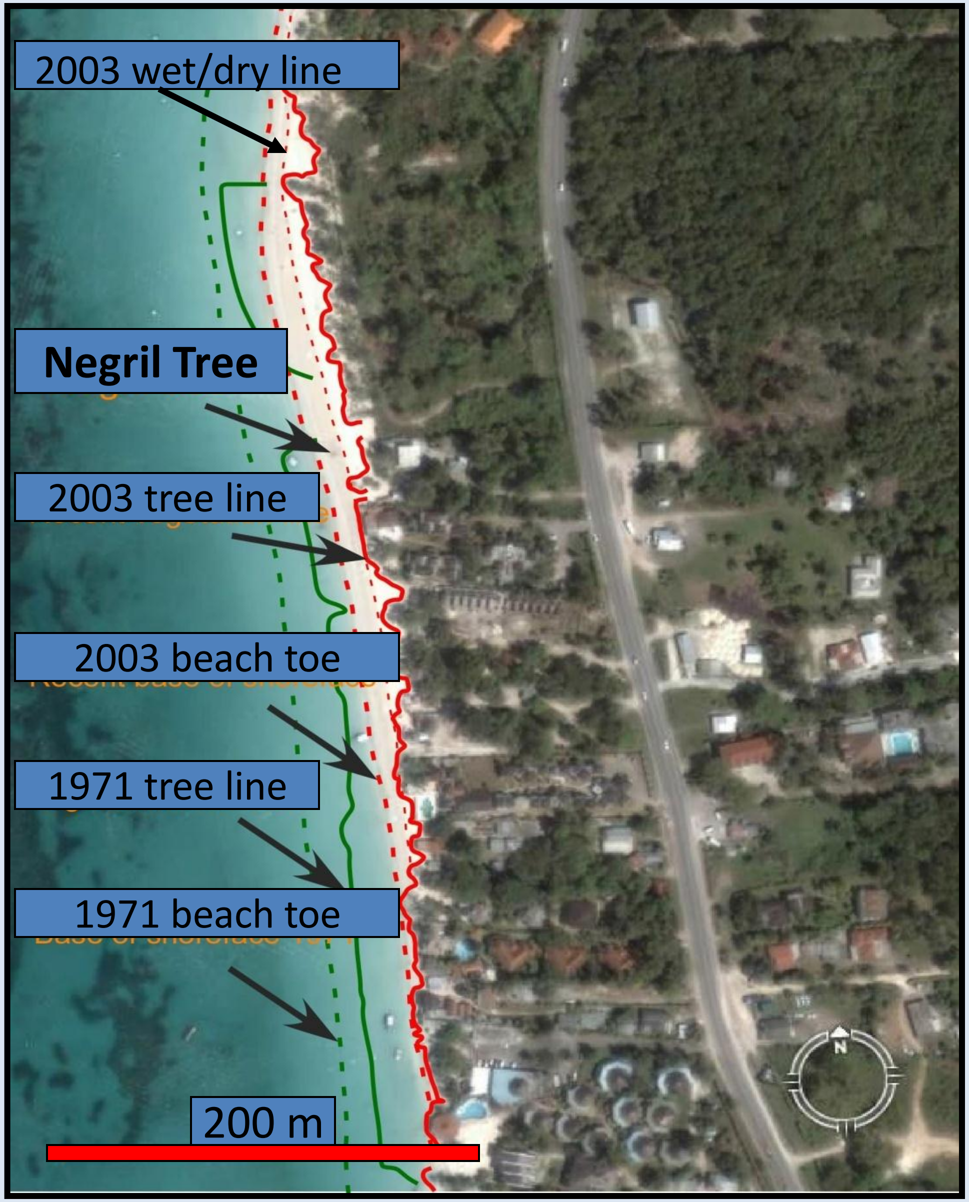
1. A SIMPLE EMPIRICAL TIME-BASED COMPARISON WAS MADE BY PROJECTING HISTORICAL CHANGE RATES INTO THE FUTURE WITHOUT REFERENCE TO SEA-LEVEL CHANGES.

Historical Trend Extrapolation-Thirty three years of Shoreline Retreat, 1971 to 2003, Long Bay, Negril

1971 positions In green

2003 positions In red

wet/dry line (dotted) is for 2003 only



using air photo (1971) and satellite image (2003) positions of beach toe (dashed lines) & vegetation line (continuous lines)

Between 1971 and 2003 mean sea level rose about 7 cm (**IPCC Report , 2007**)

Scene from Google Earth

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POSSIBLE FUTURE SHORELINE RECESSION BASED ON HISTORICAL CHANGE

1a. ASSUMING NO INFLUENCE FROM SEA-LEVEL CHANGES

We used a simple end-point rate calculation to project the average situation for the whole of Long Bay, assuming no hardened engineering structures are present, for the years 2015, 2030 and 2050, and based on observed past change. The end-points for the first calculation are 1971 and 2008.

Whole bay mean recession, 1971-2008 (end points), 8.4 m / 37 yrs = 0.23 m/yr

Projected whole bay mean recession 2008 -2015,	1.6 m
Projected whole bay mean recession 2008-2030	5.1 m
Projected whole bay mean recession 2008-2050	9.7 m

However, the available data suggest that the recession rate increased over the period 1991 to 2008 so that use of the end points for the higher rate may be more advisable for future projections:

Whole bay mean recession, 1991-2008, 6.93 m / 17 yrs = 0.41 m per year

Projected recession 2008-2015	2.9 m
Projected recession 2008-2030	9.0 m
Projected recession 2008-2050	17.2 m

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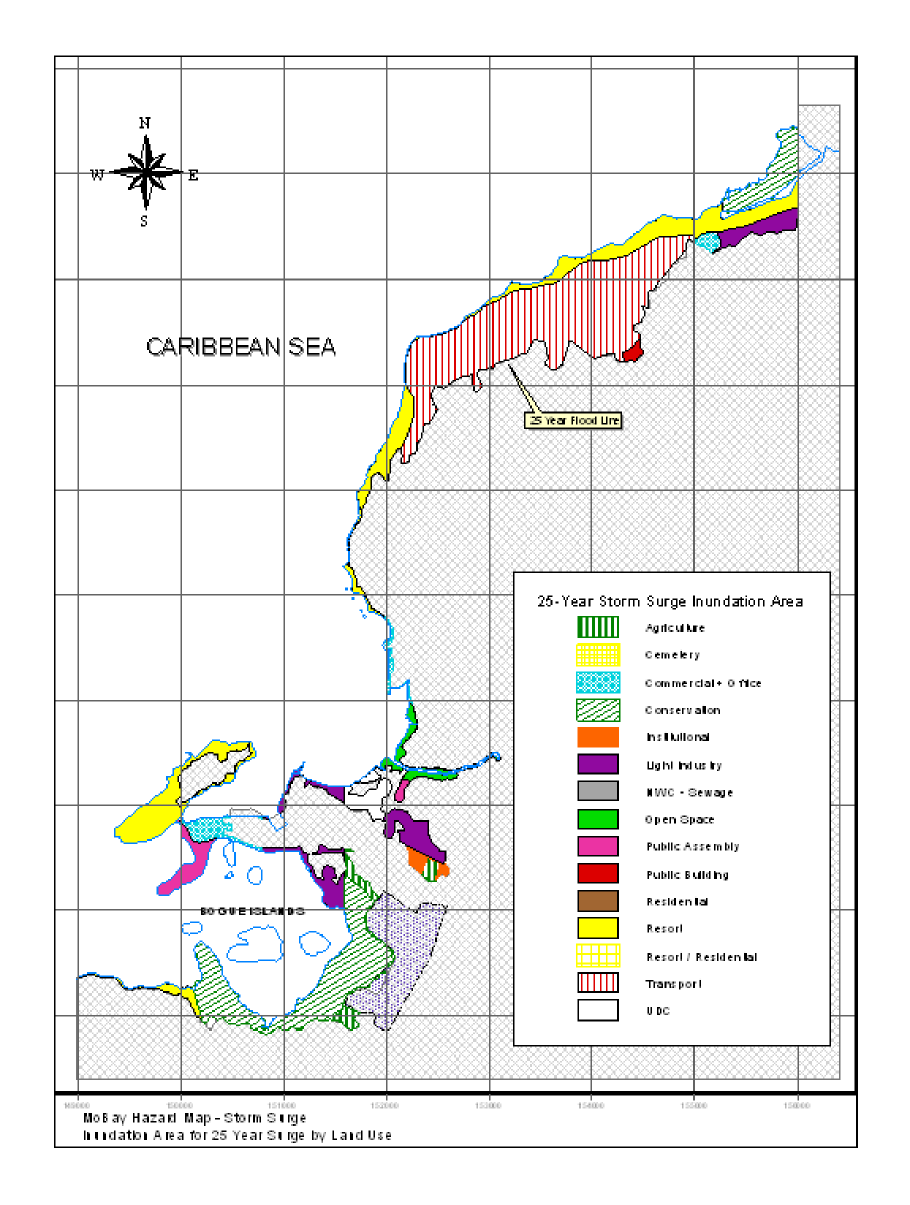
Storm surge modeling

Input data:-

- Near shore Bathymetry
- Coastal Topography
- Wave Climate



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BEACH EROSION AND SEA-LEVEL RISE AT LONG BAY, NEGRIL, WESTERN JAMAICA

Case Study

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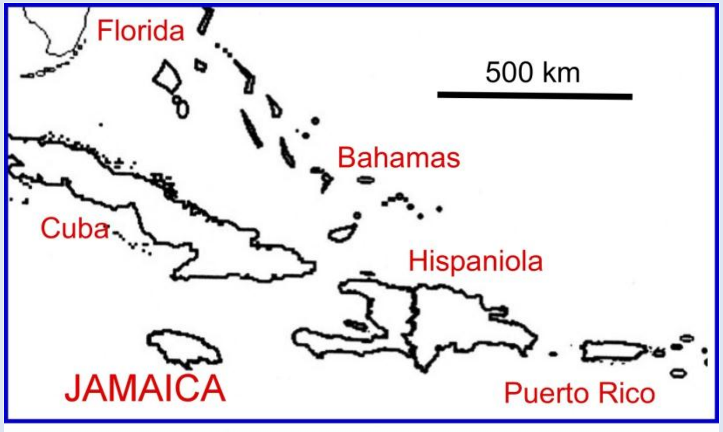
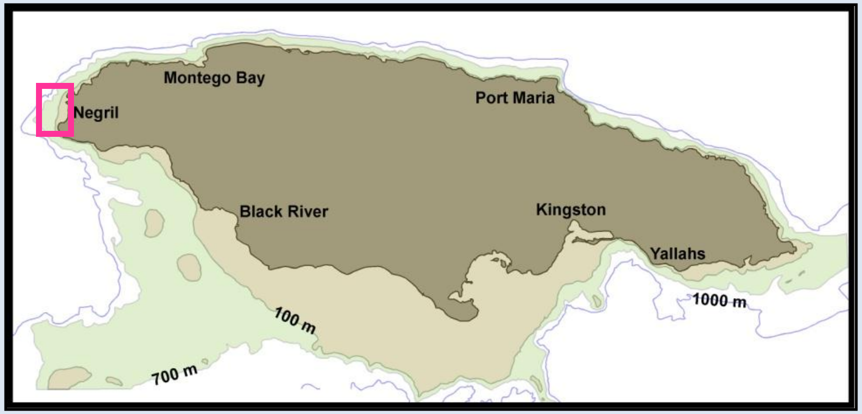
NEGRIL LOCATION



The world-famous resort area of Negril is located at the extreme western end of Jamaica.

The two beaches of long bay and bloody bay are in effect small barrier systems in a micro-tidal regime backed by the extensive wetland of the great morass. Seaward of the beaches small patch reefs sit on a shallow limestone platform.



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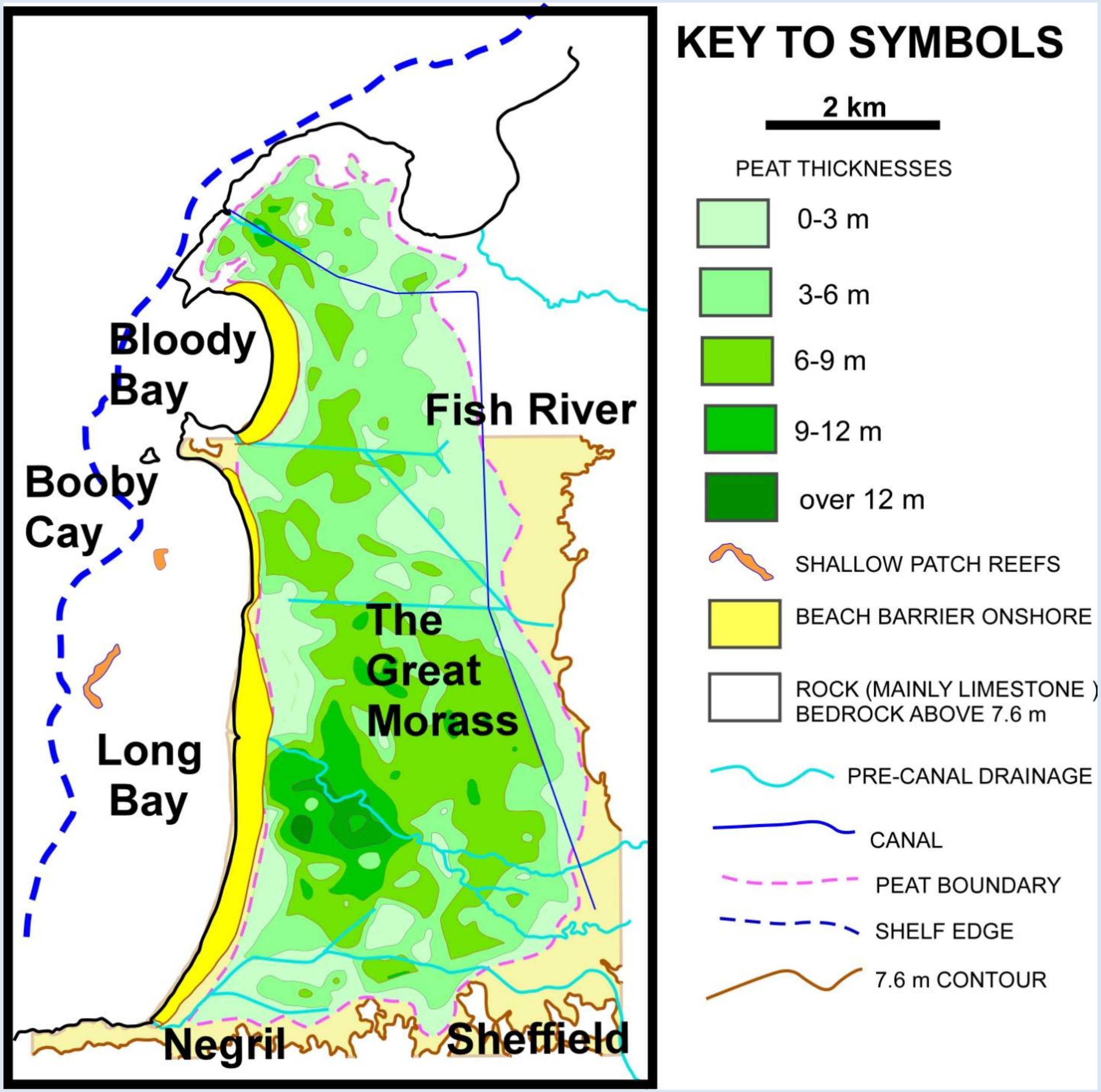
NEGRIL, PHYSICAL FEATURES



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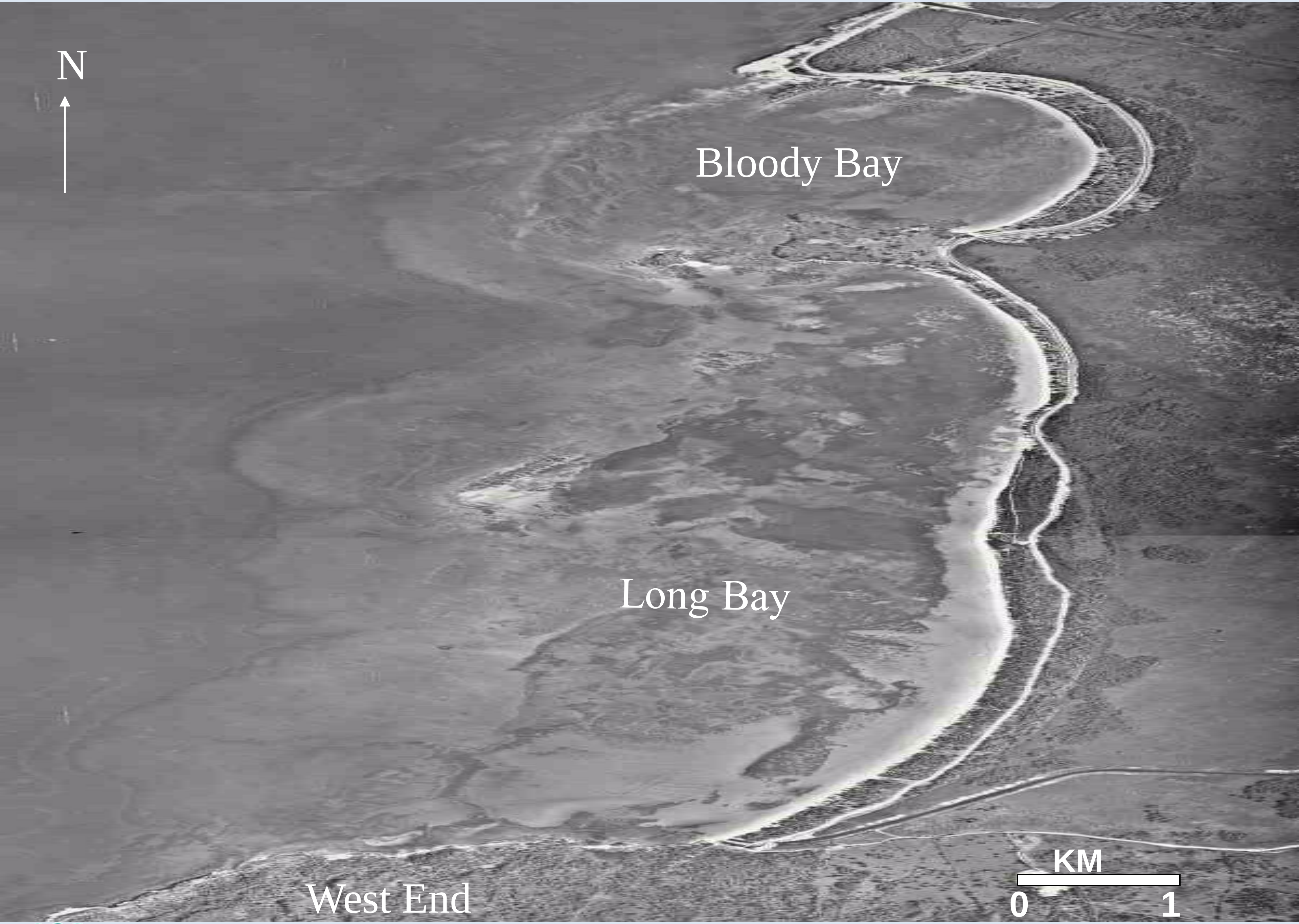
N
Bloody Bay
Long Bay
West End
KM
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THE GREAT MORASS
SEA-GRASS BEDS
BEACH TOE
BOTH ARE SHORE-FACING FLANKS OF SMALL BARRIER SYSTEMS IN A MICRO-TIDAL REGIME, BACKED BY THE EXTENSIVE WETLAND.

At many locations the physical evidence for beach recession is typified by the remnants of forest vegetation, now in the sea.

NEGRIL BEACH TREE, AUGUST 2005

Long Bay, Negril 2003

Long Bay, Negril 2004

Tasks

1. ESTABLISH A SET OF ELEVATIONS OVER THE BARRIER SYSTEM AT LONG BAY

2. ASCERTAIN CHANGES AND RATES OF CHANGES OF THE SHORELINE POSITION OVER THE PERIOD 1971 T0 2008

3. EXAMINE POSSIBLE CHANGES OF SHORELINE POSITION INTO THE FUTURE

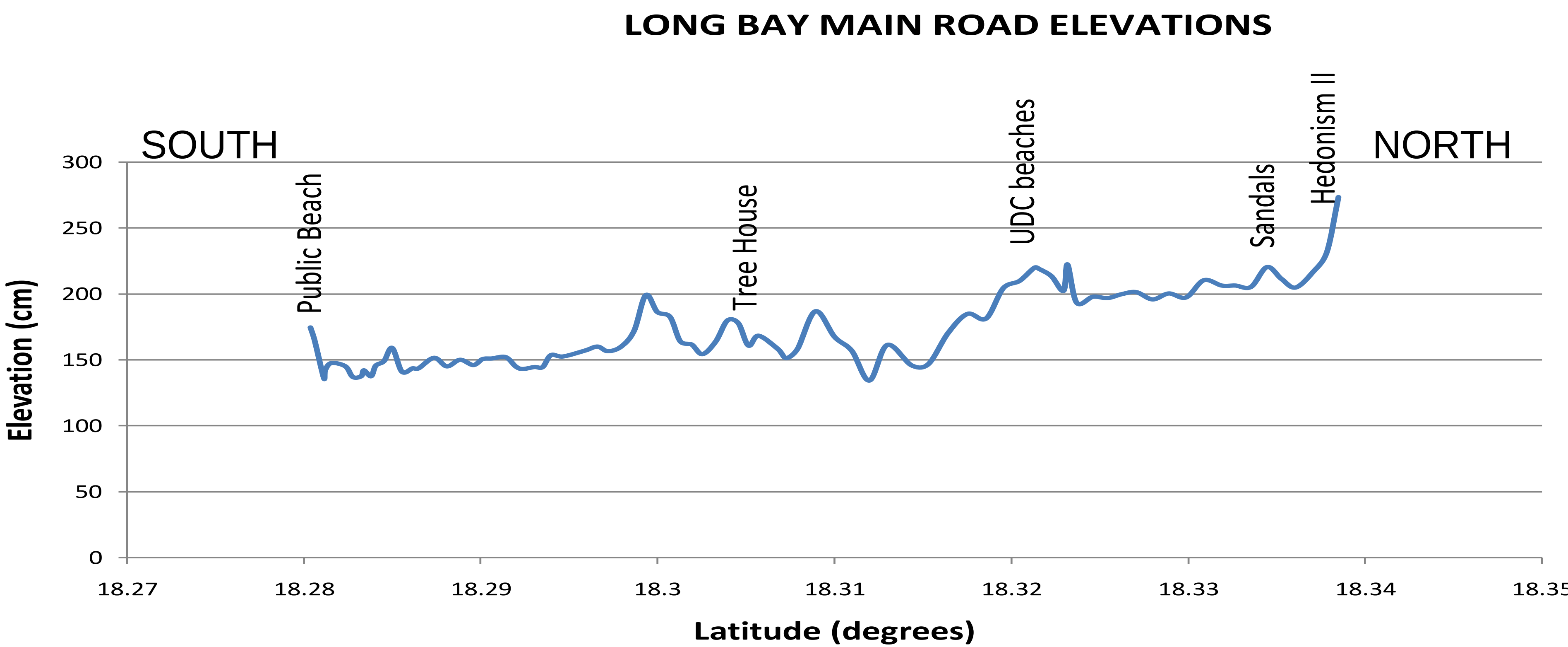
1. ESTABLISHING ELEVATIONS ON THE BARRIER SYSTEM

- OLDER SURVEY DATA WAS CONFLICTING AND SURVEY DEPARTMENT BENCH-MARKS HAD BEEN DESTROYED.

- OUR ELEVATIONS WERE ESTABLISHED BY SURVEYING ABOUT 200 LOCATIONS USING LEVELS AND STAFFS, REFERENCED TO A BASE SITE. THE BASE SITE WAS TIED TO MEAN SEA-LEVEL AT THE TIME OF THE SURVEY.

- HIGHEST ELEVATIONS WERE ALONG THE MAIN HIGHWAY. THESE RANGE UP TO 2.5 m ABOVE SEA-LEVEL

LONG BAY MAIN ROAD ELEVATIONS



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2. LONG BAY SHORELINE POSITIONS

- Periodic monitoring of the beach showed that the width of the beach varies over time with reference to fixed points.

- So is the erosion seasonal or progressive and is sea level rise driving this erosion?

METHODS- Historical Trend Extrapolation

- Available images of aerial photos from 1971, 1991, and satellite imagery from 2003 and 2008 were digitized and rectified, using ACD canvas, following methodology described by Fletcher et al (2003)

- Point to point image rectification was carried out using the previously rectified and georeferenced 2003 IKONOS image as the reference image

- The position of the beach toe is the most easily observable feature of this microtidal (tide range 18-40 cm), carbonate beach system and so was used as the reference from which beach changes over time were measured

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METHODS CONTINUED

- For the historical changes, the tree/vegetation line of the 1971 aerial photos was used as the shoreline change reference.
- These are the earliest photos clearly showing the beach toe, and with adequate control for rectification purposes, as well as being the latest shoreline still in its natural state.
- Later vegetation lines suffer from anthropogenic intrusions
- 66 shore-normal profiles were constructed approximately 100 m apart
- Positions of the beach toe were located for each profile, for the images 1971, 1991, 2003, 2008.

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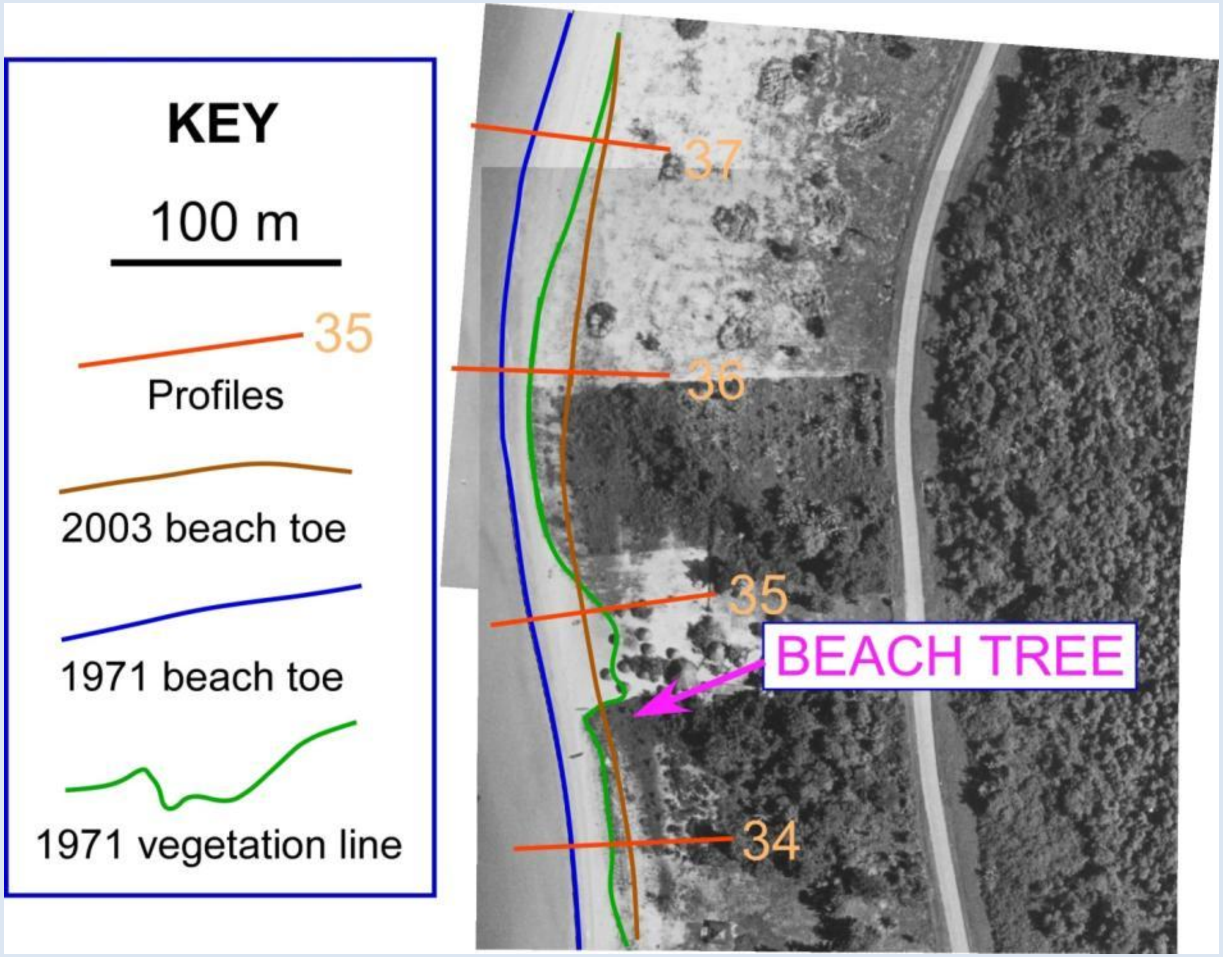
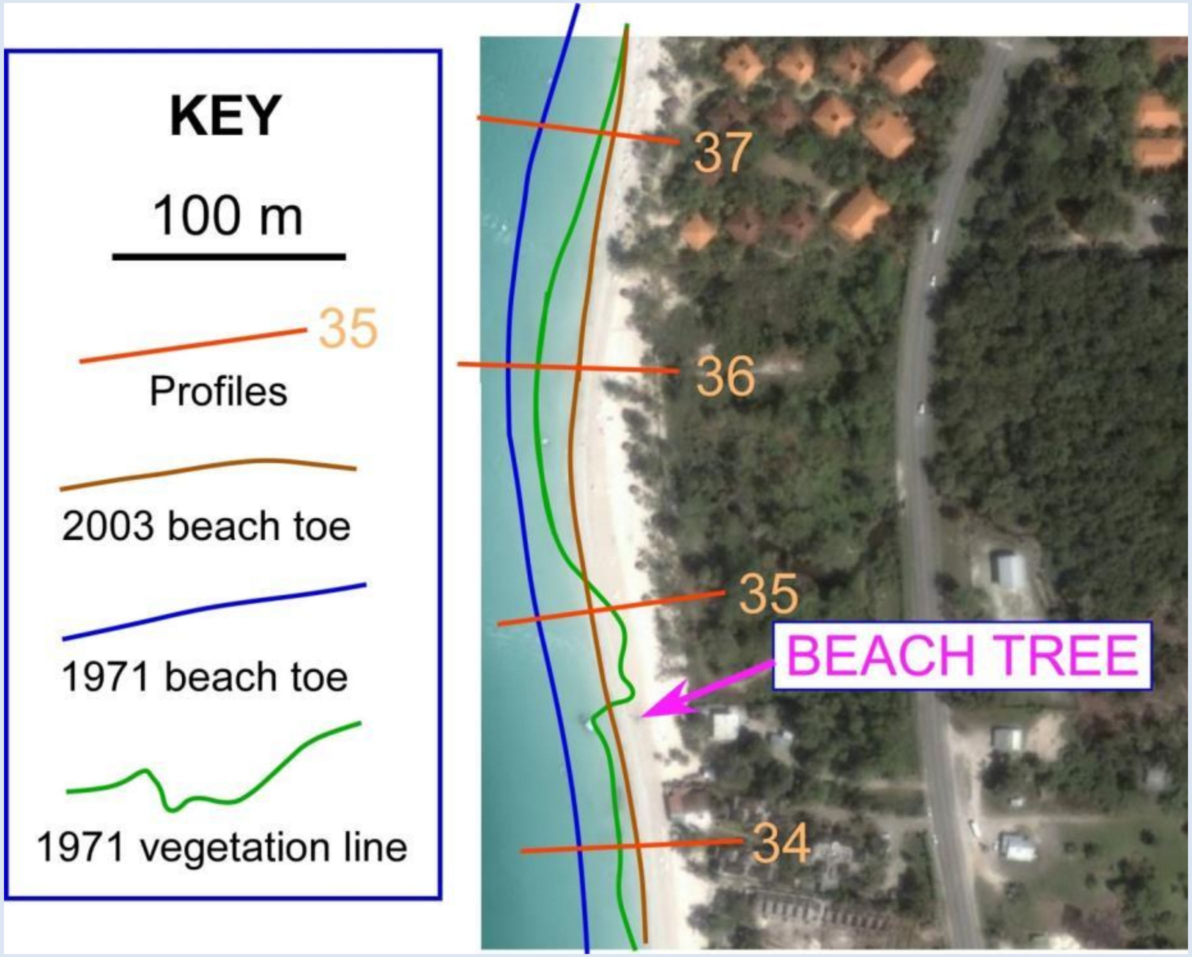
1971 PHOTO AND SITUATION



2003 IMAGE AND SITUATION



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ERRORS AND UNCERTAINTIES

THE MAIN SOURCES OF ERROR ARE:

1. LOCATIONAL ERRORS RESULTING FROM TRANSCRIPTIONS FROM ONE IMAGE TO ANOTHER
2. LOCATIONAL ERRORS RESULTING FROM LIMITATIONS OF RESOLUTION
3. HUMAN ERRORS AND THE STATE OF THE TIDE.

UNCERTAINTIES ARISE FROM:

1. THE FACT THAT THE AVAILABLE IMAGERY REPRESENTS ISOLATED SNAPSHOTS OF THE BEACH CONDITIONS AND NOT A CONTINUOUS STORY. THE FOUR IMAGE SERIES WE USED WERE CAPTURED IN THE EARLY PART OF THE YEAR.
2. THE TIME FRAME OF THE STUDY IS ONLY 37 YEARS, WITH ONLY 4 SNAPSHOTS.

   OLDER AIR PHOTOS, DATING BACK TO 1940, ARE AVAILABLE BUT THE RESOLUTION IS RELATIVELY POOR AND THEY PRE-DATE THE CONSTRUCTION ALONG THE WATERFRONT, SO THAT ONLY TREES AND PATHS ARE USABLE AS REFERENCE POINTS. WORK IS IN PROGRESS TO IMPROVE THE QUALITY OF THESE EARLIER PHOTOS.

POSSIBLE FUTURE SHORELINE RECESSION BASED ON HISTORICAL CHANGE

2a. ASSUMING RECESSION IS DIRECTLY RELATED TO SEA-LEVEL RISE

While the projections made base on historical rates of erosion with no reference to seal level rise may be reasonably valid for the near-future, i.e. for 2015 and, perhaps, 2030, they are clearly less reliable as one progresses into the more distant future.

In this situation it may be more appropriate to link future recession to the rate at which sea-level is rising and is expected to rise in the future (Leatherman, 1990).

For this example we have used values approximating the high side of projections published by the IPCC (2007) as well as the higher projections suggested by Rahmstorf et al. (2007).

POSSIBLE FUTURE SHORELINE RECESSION BASED ON HISTORICAL CHANGE

2b. ASSUMING RECESSION IS DIRECTLY RELATED TO SEA-LEVEL RISE

For the whole bay average discussed above:

Sea-level rise, 1971-2008 (based on IPCC 2007) was about **0.08 m**.
Average annual recession (whole bay), 0.23 m per year; total mean **8.38 m**.
Rate based only on sea-level rise, **8.38/0.08**, or **105.8 m recession per metre rise.**

Projected sea-level rise, **2008-2015**, AR4 high, 0.02 m; Rahmstorf high 0.03 m
Projected whole bay mean recession 105.8 x 0.02 = **2.1 m**; 105.8 x .03 = **3.2 m**

Projected sea-level rise, **2008-2030**, AR4 high, 0.07 m, Rahmstorf high, 0.12 m
Projected whole bay mean recession 105.8 x 0.07 = **7.4 m**, 105.8 x 0.12 = **12.7 m**

Projected sea-level rise, **2008-2050**, AR4 high, 0.14 m, Rahmstorf high, 0.25 m
Projected whole bay mean recession 105.8 x 0.14 = **14.8 m**, 105.8 x 0.25 = **26.5 m**

Projected sea-level rise, **2003-2100**, AR4 high, 0.46 m, Rahmstorf high, 0.95 m
Projected whole bay mean recession 105.8 x 0.46 = **48.7 m**, 105.8 x 0.95 **100.5 m**

Remarks

1. In examining possible future shoreline change scenarios, the magnitudes of those obtained by projecting data from historically observed changes into the future were found to be about twice the magnitudes of those obtained from using the Bruun Rule.

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