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República de Colombia

Lloyd's Register Educational Trust

UNIVERSITY OF Southampton
School of Ocean and Earth Science

Sea-level change in the Caribbean Sea over the last century

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Workshop on climate change in Mediterranean and Caribbean Seas. 7-10 May 2012

Introduction

- Sea level respond to oceanic processes which change in time and spatial scales

- Global sea-level rose for the 20th century in a rate of 1.7±0.5 mm/y, with considerable decadal and regional variability [IPCC AR4]

- How sea-level change in the Caribbean Sea is not well understood

- The Caribbean Sea is a high risk area with developing countries and small island nations [Nicholls and Cazenave, 2010]

- We need to understand how the sea level behaves in the region, and which changes have taken place during the last century

Semana.com
Cartagena de Indias
sea-flooding August/10.

Scientific Background

Observed sea level (i,j) =

$$X(t) = Z_0 + T(t) + S(t) + e(t)$$

mean sea level + tide + meteorological surge [Pugh, 1987]

Mean sea level =

$$Z_0(t) = \overline{Z_0} + at + N + C_a + C_{sa} + W + e(t)$$

= long term MSL + trend + long term tidal modulation

+ seasonal cycle + weather effect + errors

Sea-level change in the Caribbean Sea over the last century

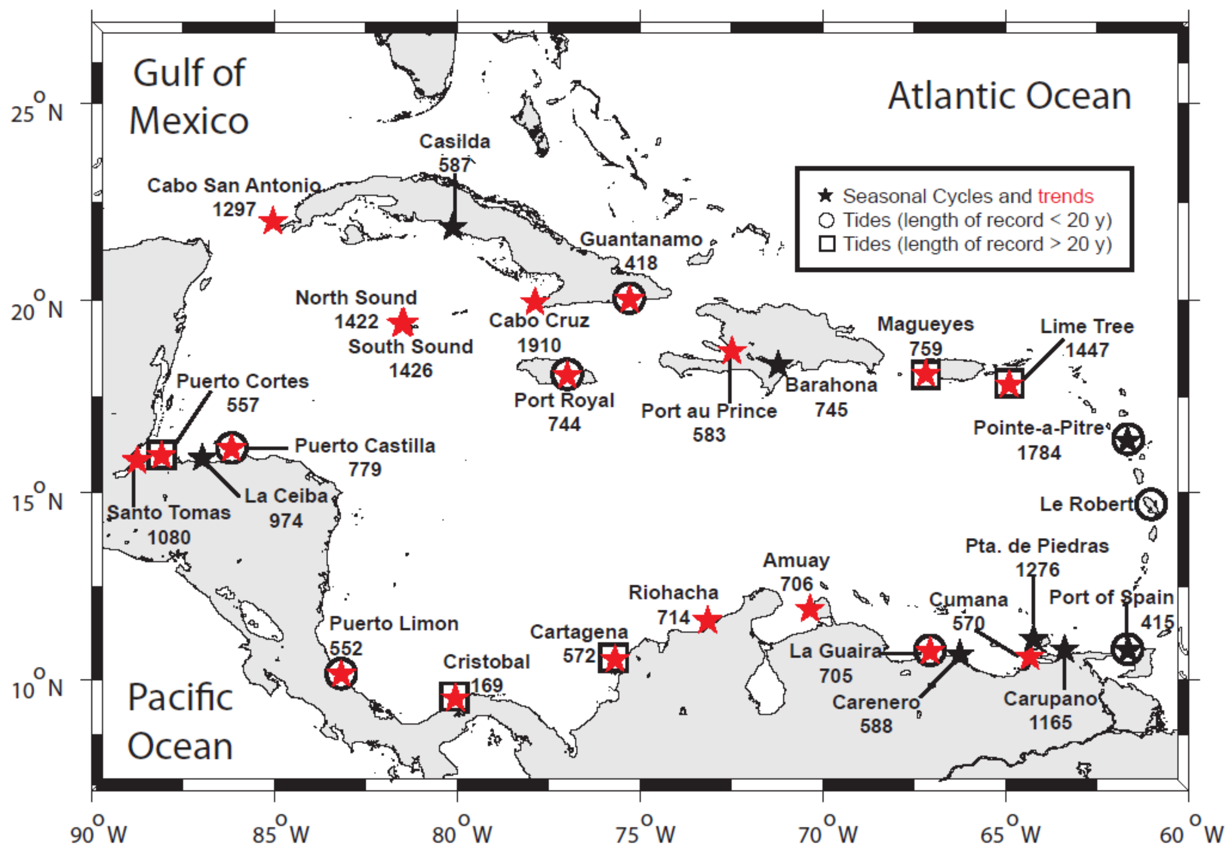
1. Tides and long term modulations
2. Storm events and extremes
3. Sea level seasonal cycle
4. Sea-level rise and interannual variability
5. Impact of sea-level change in the Caribbean Sea

Outline

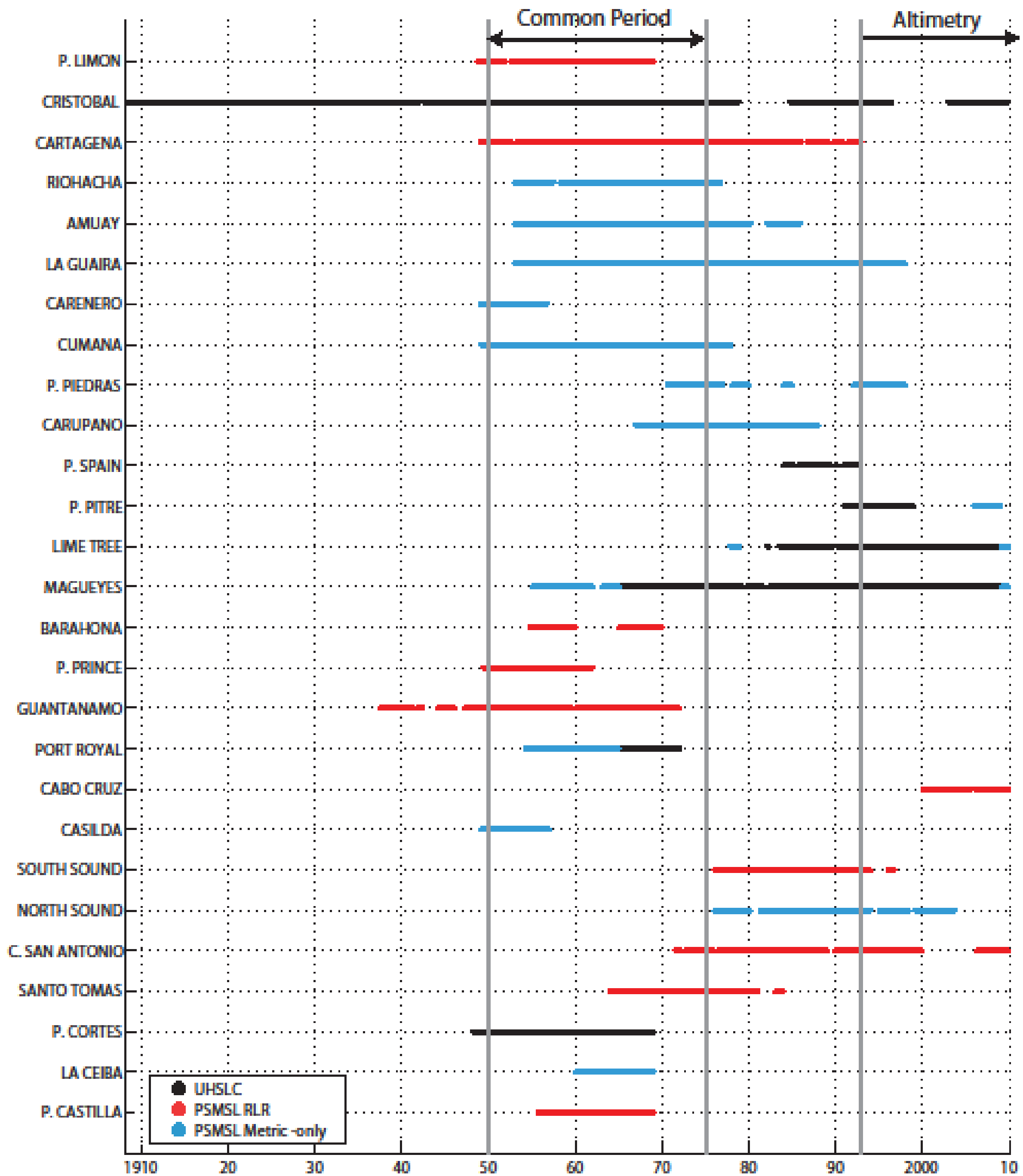
- Introduction
- Scientific background
- Data sources
- Results
  - Tides and long term modulations
  - Seasonal sea level cycle
  - Sea level trends
- Future work

Data sources

- Maps of Absolute Dynamic Topography distributed by AVISO
- NCAR/NCEP reanalysis [Kalnay et al., 1996]
- UHSLC and PSMSL

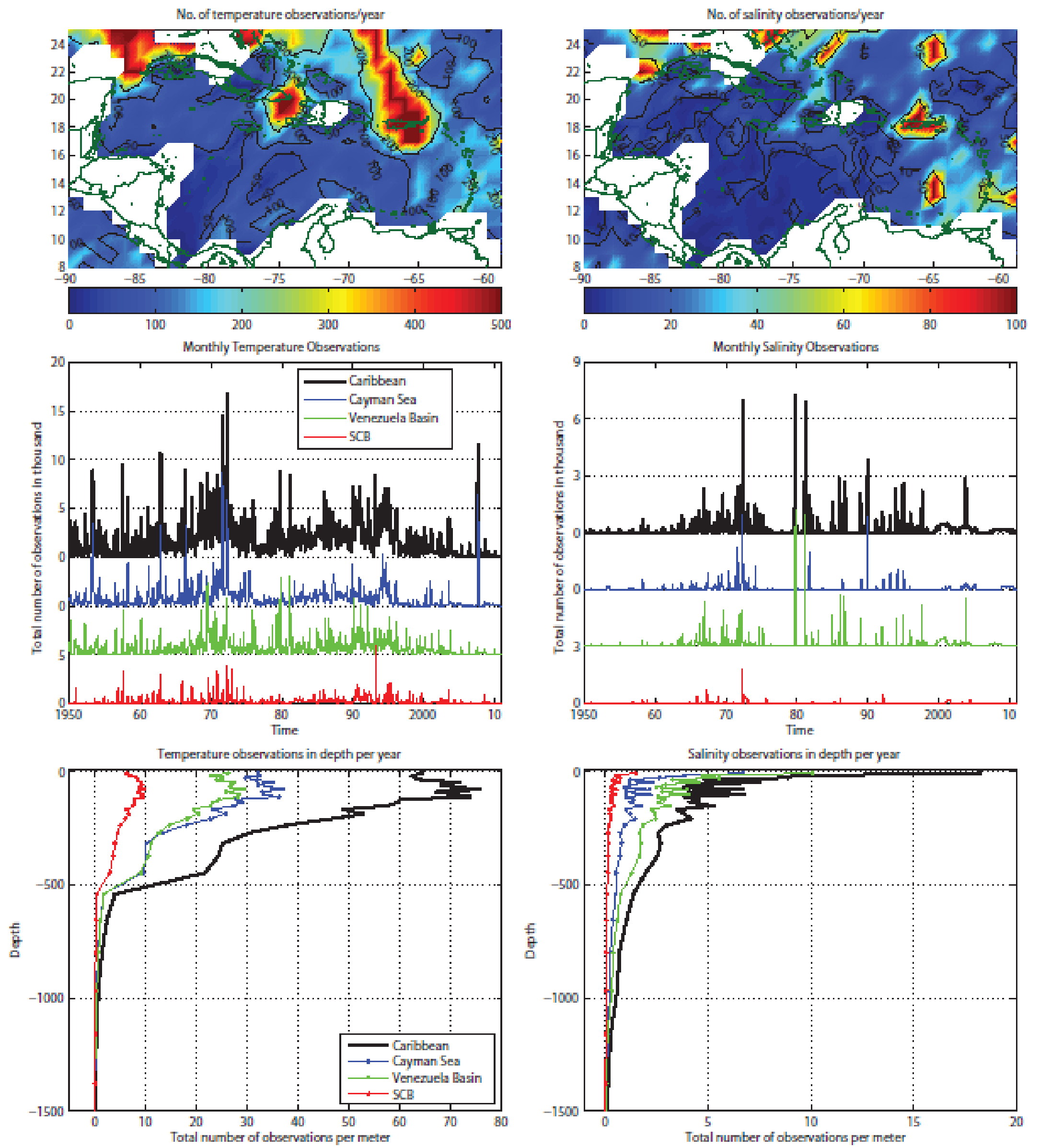


Data sources



Data sources

- EN3_v2a temperature and salinity dataset, uses objective analysis based on climatology and data assimilation from WOD05, GTSPP, Argo and ASBO projects [Ingleby and Huddleston, 2007]



[EN3_v2a: 1950 – 2010]

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    J. Geophys. Res., doi:10.1029/2011JC006973, 2011.
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- Future work

Tides and long term modulations

(1) Observed sea level =

$$X(t) = Z_0 + T(t) + S(t) + e(t)$$

mean sea level + tide + meteorological surge

- Assess for M_f, K_1, O_1, P_1, M_2, N_2 , S_2 :

  1) Tidal behaviour in the region

  2) Secular trends in the tidal constituents

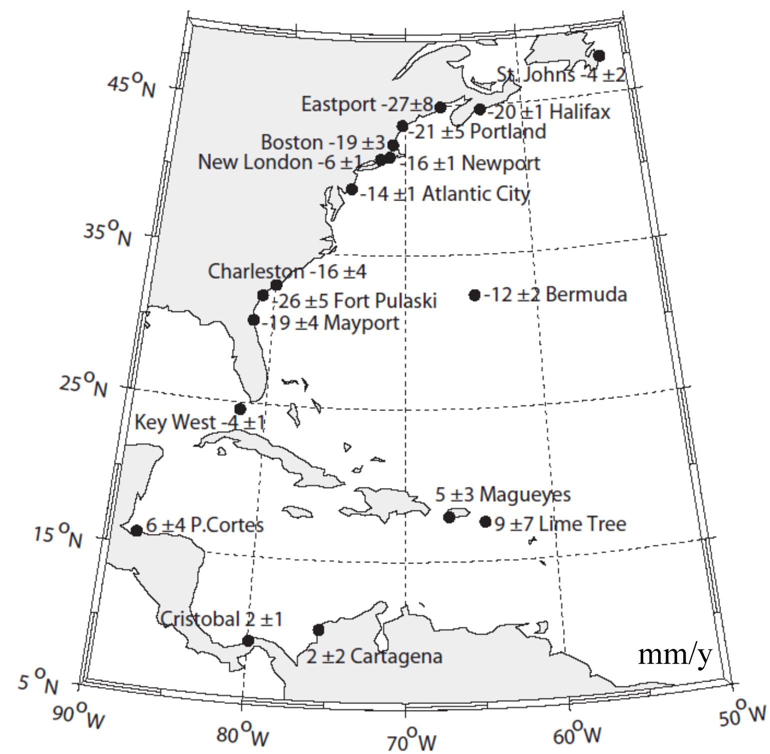
  3) Long term tidal cycles, and if they are in accordance with the gravitational potential

- Regression:

$$SL_m(t) = \beta_1 + \beta_2 t + \beta_3 \cos(R_t) + \beta_4 \sin(R_t)$$

Tides and long term modulations

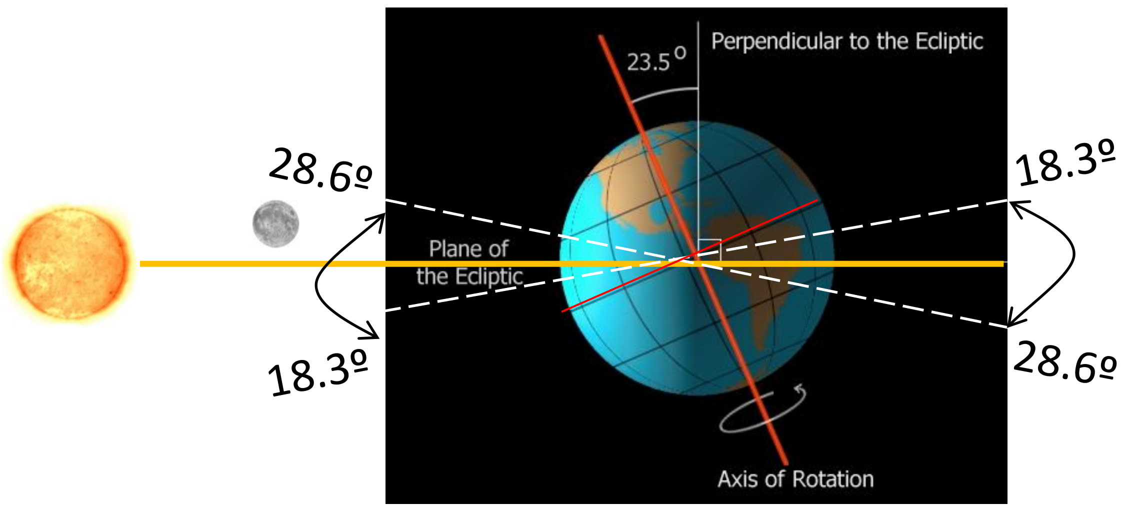
- Calculate amplitude/phase lag of 6 most important constituents at 13 ports:
  - Stable micro-tidal behaviour in good agreement with previous studies (Kjerfve 1981) and well represented by FES2004
- A consistent secular trend only in S_2 amplitude:
  - Probably due to radiational (meteorological) forcing
  - Decreasing trends in WN Atlantic
    [Ray, 2009]

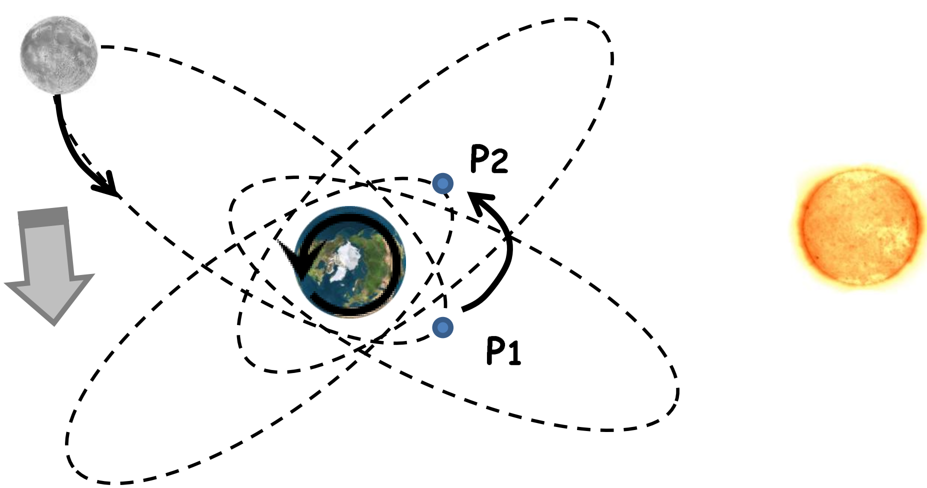


Tides and long term modulations

- Long term tidal cycles

<u>18.61 year nodal cycle:</u>
The plane of the Moon's orbit oscillate about the ecliptic changing the lunar declination.

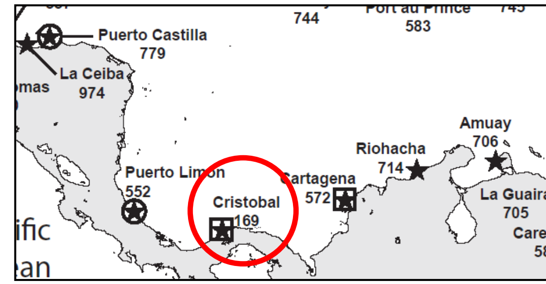




<u>8.85 year Moon's perigee cycle</u>
Moon's ellipse major axes orientation variation.

Tides and long term modulations

- 18.6-y cycle for M_f, K_1, O_1, M_2, N_2 and 8.8-y cycle for N_2
- Assessed at 5 stations and compared to gravitational potential
- E.g. K_1 - 18.6 year cycle in Cristobal:

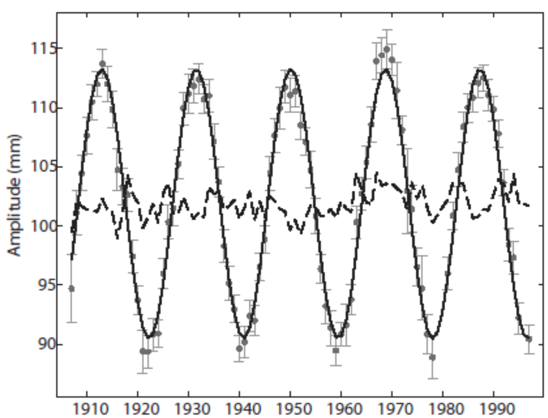


Amplitude

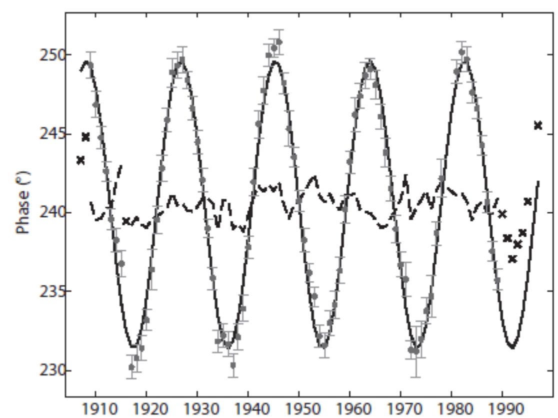
Amp: 10.2 cm
CA: 1.1 cm
CIM: 0.3 cm

CA/Amp: 11.2%
%EV: 97.6%

GTP CA/Amp: 11.5%



Phase



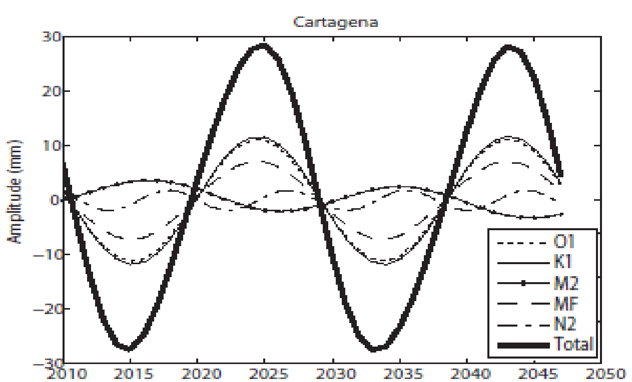
CIM: 2°
Pha: 241°
CA: 9.1°
%EV: 98.1%

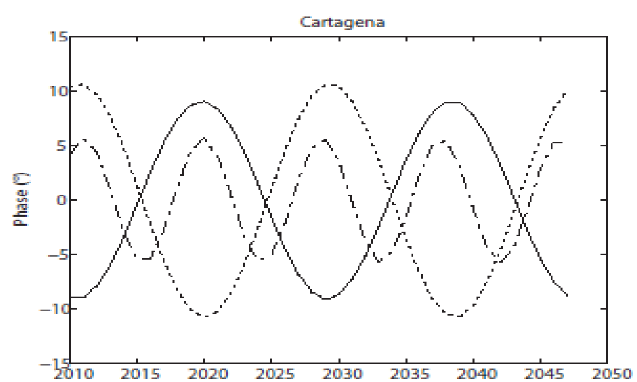
GTP C.Amp: 8.9°

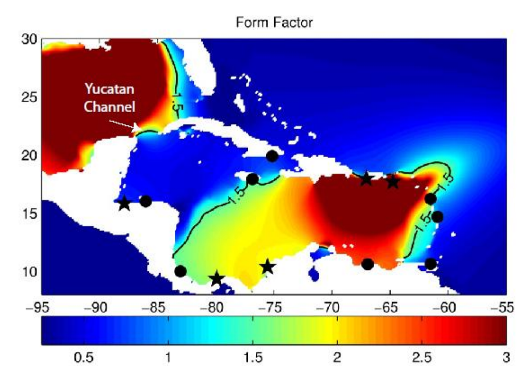
CIM: Confidence Interval Mean
Amp/Pha: Amplitude / Phase
CA: Cycle Amplitude
%EV: Explained Variance

Tides and long term modulations

- The net effect of the low frequency cycles can change the maximum tidal range up to 23% in a nodal cycle.
- Tidal range important for coastal vulnerability:
  - Coupled with sea level rise or extreme events
  - Modulation of tidal currents (tidal regimens)







FES2004 (Lyard et al. 2006).

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  - Seasonal sea level cycle
  - Sea level trends
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Seasonal sea level cycle

(2) Mean sea level =

$$Z_0(t) = \overline{Z_0} + at + N + C_a + C_{sa} + W + e(t)$$

= long term MSL + trend + long term tidal modulation

+ seasonal cycle + weather effect + errors

- Regression:

$$Z_0(t) = \overline{Z_0} + at + C_a \cos\left[\frac{2\pi}{12}(t - \Phi_a)\right] + C_{sa} \cos\left[\frac{2\pi}{6}(t - \Phi_{sa})\right]$$

- Assess:

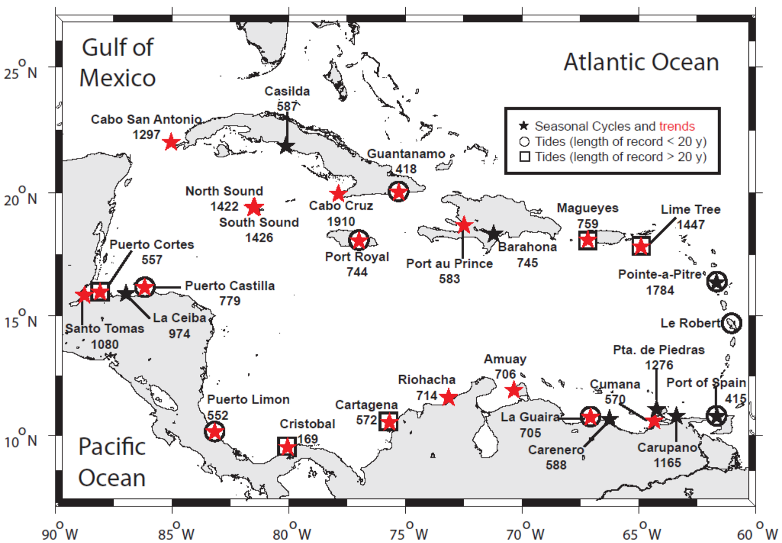
1) Deep-ocean and coastal sea level seasonal cycle

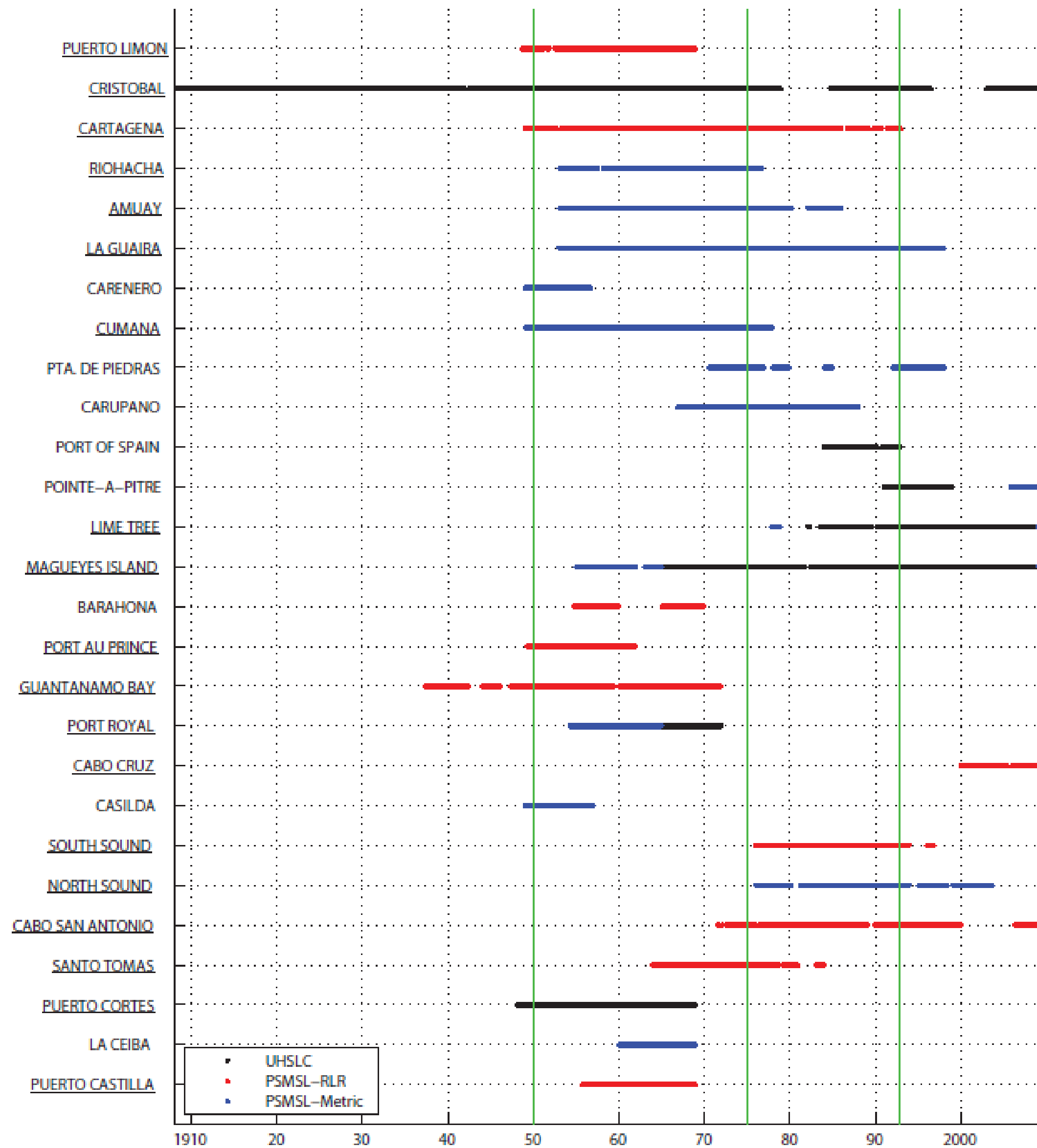
2) Contributions to the sea level seasonal cycle

3) Temporal variability of the seasonal sea level cycle

Seasonal sea level cycle

- Quality control to 27 monthly coastal sea level time series





Seasonal sea level cycle

- Contributions to the seasonal cycle [Gill and Niller, 1973]

Seasonal changes in sea level

$$\eta' = \eta'_a + \eta'_s + \eta'_b$$

Barometric + Steric + Barotropic

- Coastal annual cycle
  - Amplitudes form 2 cm to 9 cm, peaking August and October
- Coastal semi-annual cycle
  - Insignificant P. Limon and maximum amplitude of 6 cm, with most stations peaking in April and October
- Together explain variance 13% - 76%

Seasonal sea level cycle

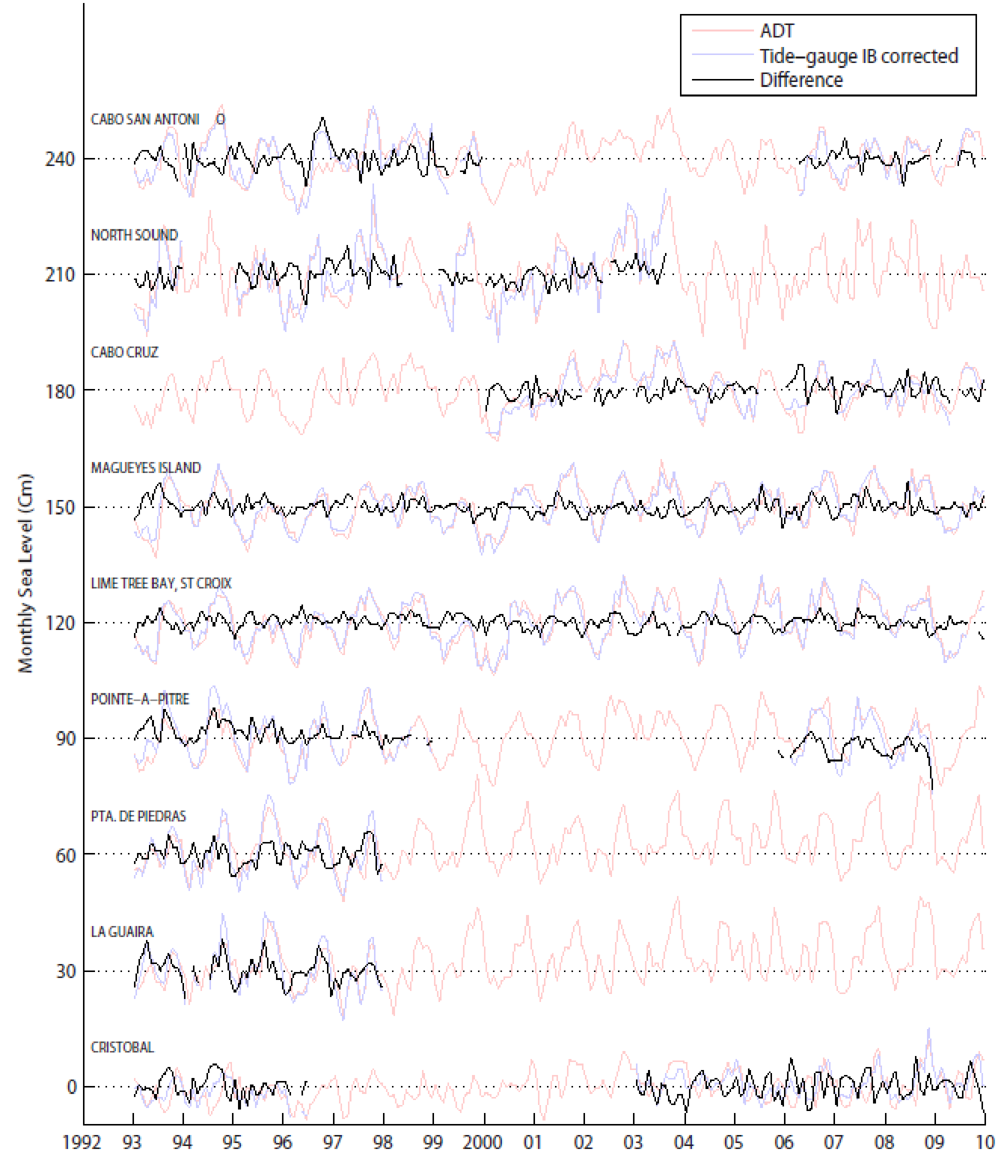
$$\eta' = \eta'_a + \eta'_s + \eta'_b$$

Barometric effect on coastal sea level seasonal cycle:

- Insignificant in the annual cycle, in the semi-annual cycle the main forcing at 8 stations.

Comparison of barometrically corrected coastal and open-ocean sea level time series:

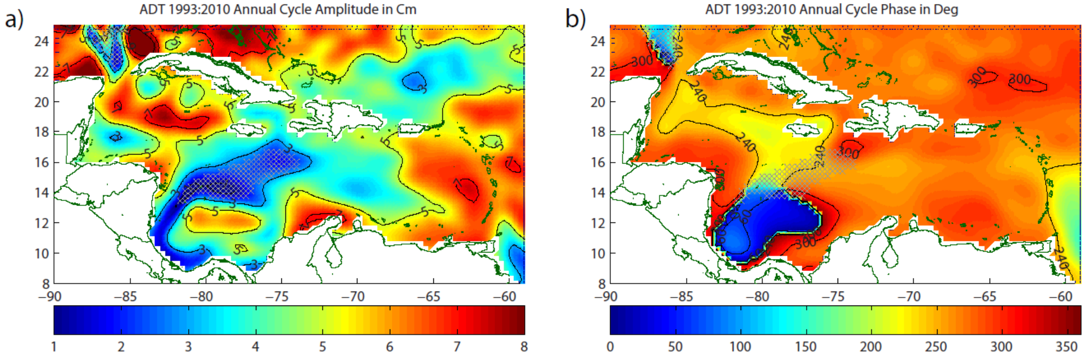
- Sea level seasonal cycle computed from altimetry near the coast is insignificantly different to coastal seasonal harmonics



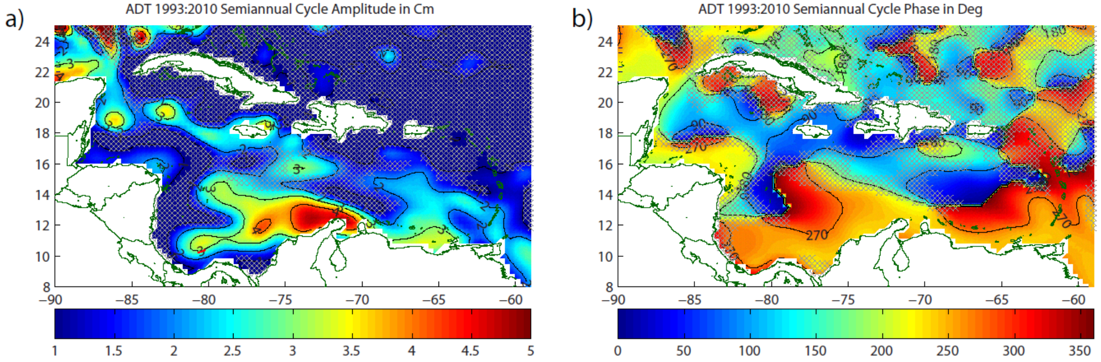
Seasonal sea level cycle

$$\eta' - \eta'_a = \eta'_s + \eta'_b$$

- Open-ocean annual cycle (1993-2010)
  - Amplitudes up to 8 cm, peaking August and October except SCB



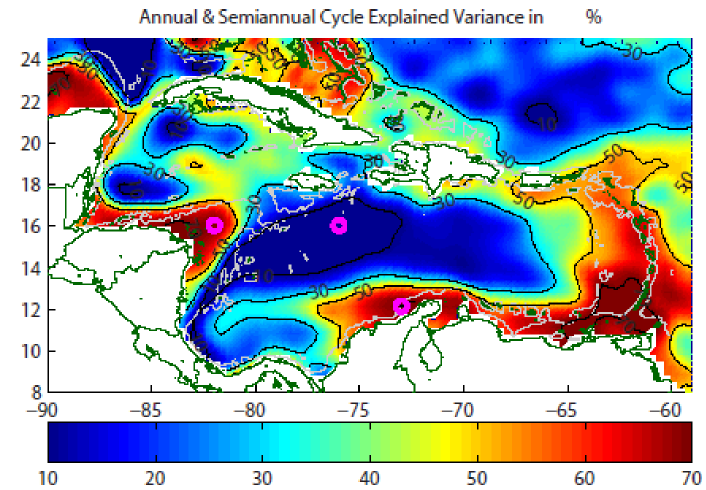
- Open-ocean semi-annual cycle
  - Amplitude up to 5 cm, with a meridional dipole in phase lag



Seasonal sea level cycle

$$\underline{\eta' - \eta'_a} = \eta'_s + \eta'_b$$

- Good agreement between barometrically corrected seasonal sea level cycle from altimetry and tide gauges.



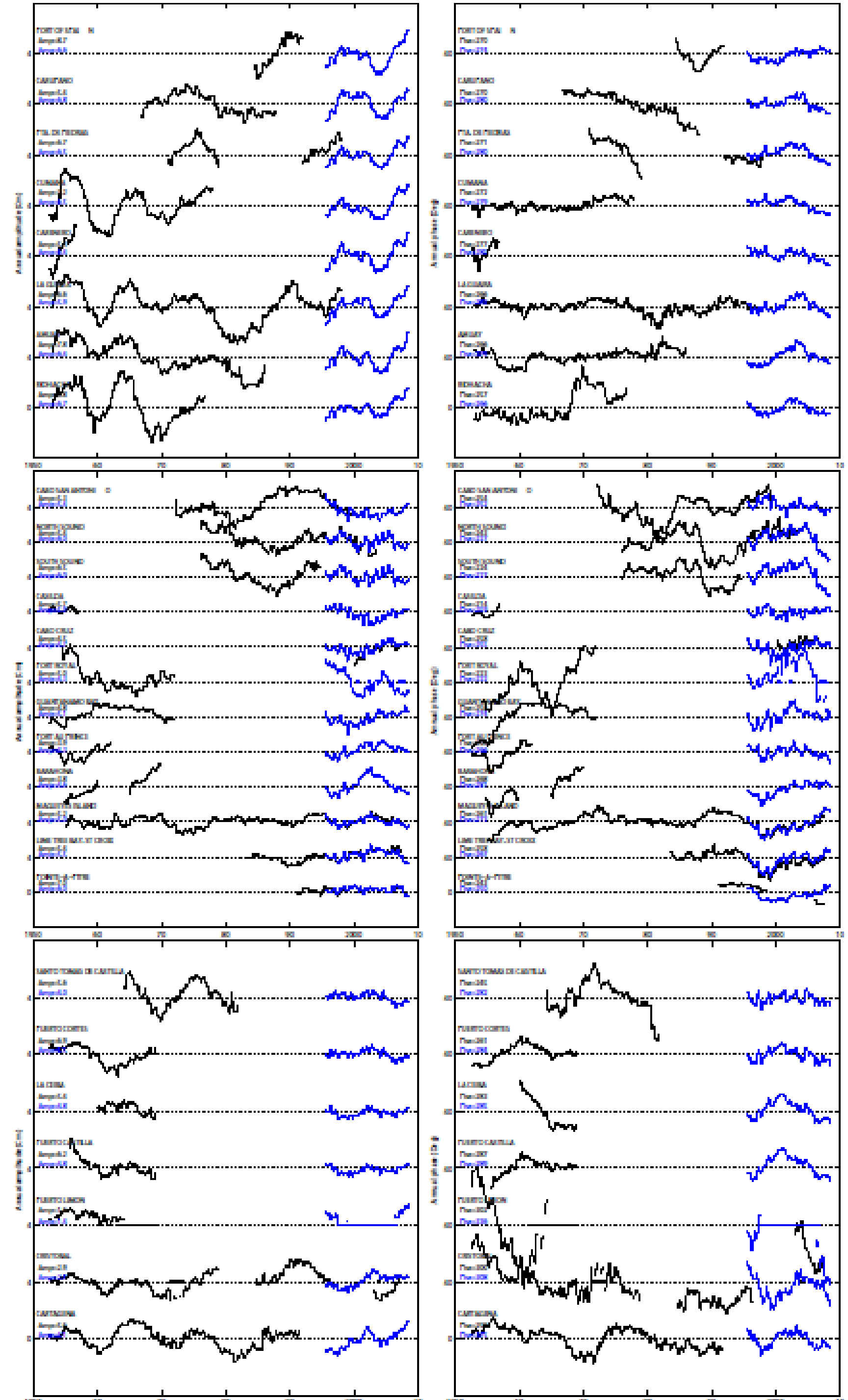
- Together explain variance 2% - 77% (importance near coasts)

- Analysis of seasonal cycles contributions:
  - The sea level seasonal cycle has a dominant steric effect toward the north of the basin (>17°N) and primarily a wind effect elsewhere. [Fu and Chelton, 2001; Gill and Niller, 1973; Pattullo et al., 1955]
  - Local effects can modify this general behaviour at some stations.

Seasonal sea level cycle

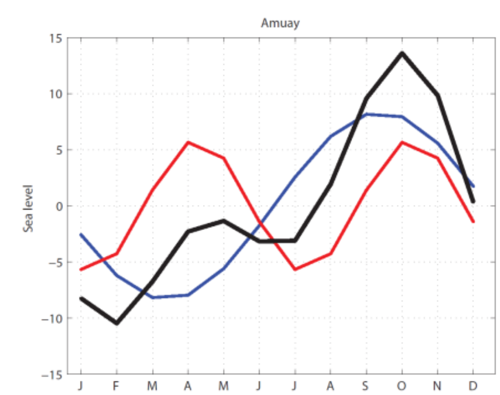
Time variability

- The seasonal sea level cycle (amplitude/phase-lag) are unsteady in time (5-y periods)
- Larger variability at stations where the wind contribution dominate
- 5-year annual amplitudes can reach values over 10 cm in the northern South America coast
- No basin-wide coherency in the changes in time



Seasonal sea level cycle

- It is of the same order of magnitude as the tidal signal (12 stations)
  - E.g. P. Cortes the annual cycle amplitude (7.0±0.7 cm) is larger than any tidal constituent
- Changes in time of tidal constituents can be accurately predicted but not those from the seasonal cycle
- Annual and semi-annual cycle together produce highest sea levels in September-October and lower levels from January – March (range up to 23 cm).
- If temporal change is included, range up to 29 cm.



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  - Sea level trends (preliminary results)
- Future work

Sea level trends

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= long term MSL + trend + long term tidal modulation
+ seasonal cycle + weather effect + errors

- Regression:

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- Assess:

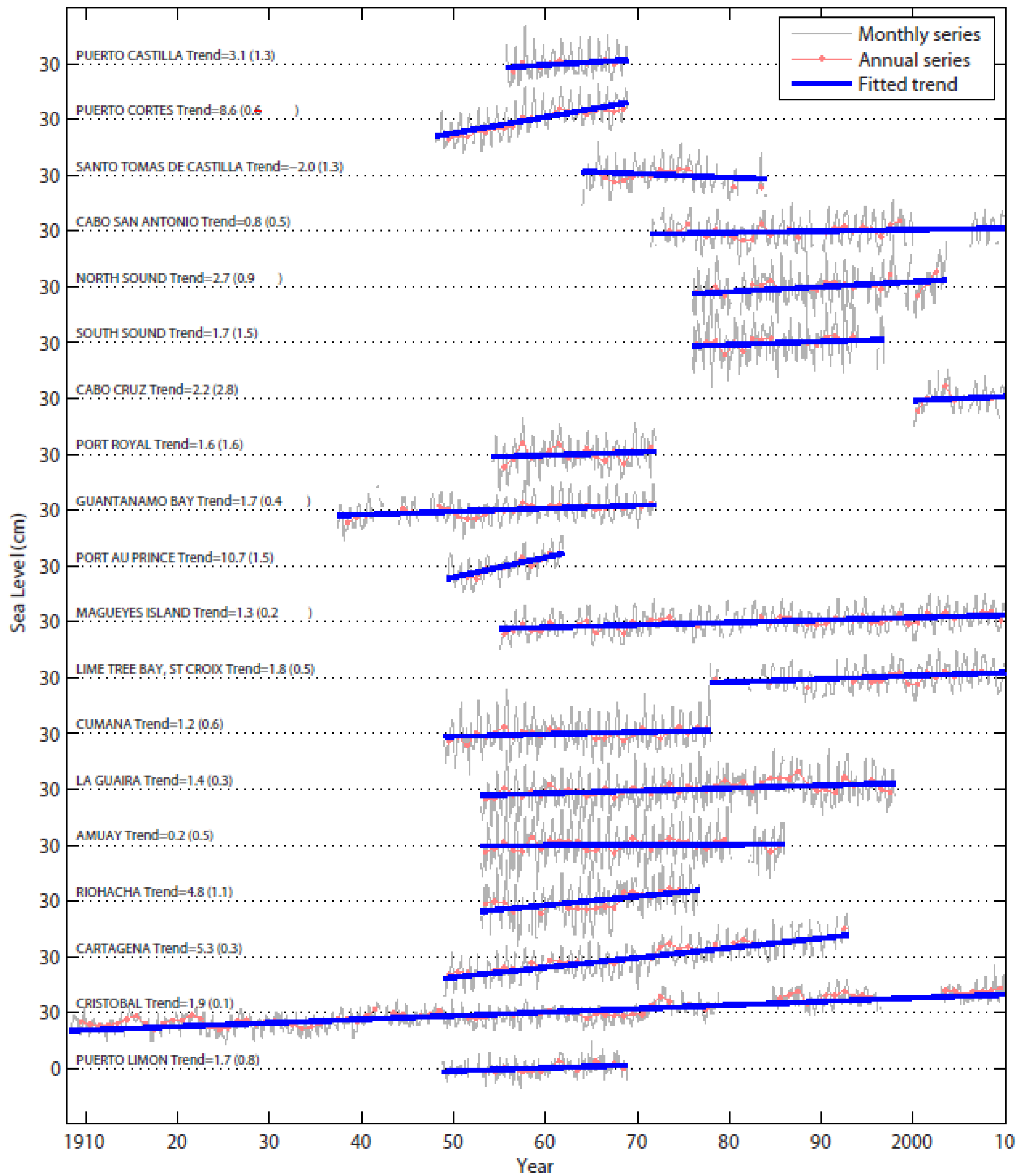
1) Deep-ocean (absolute) and coastal (relative) sea level trends

2) Contributions to the sea level trends

3) Temporal variability of the sea level trends

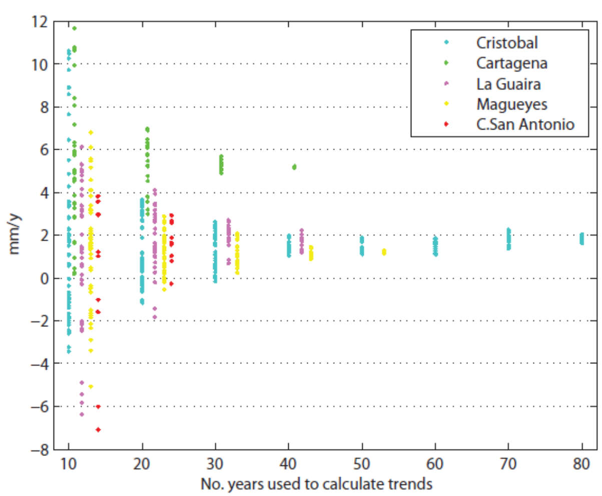
Sea level trends

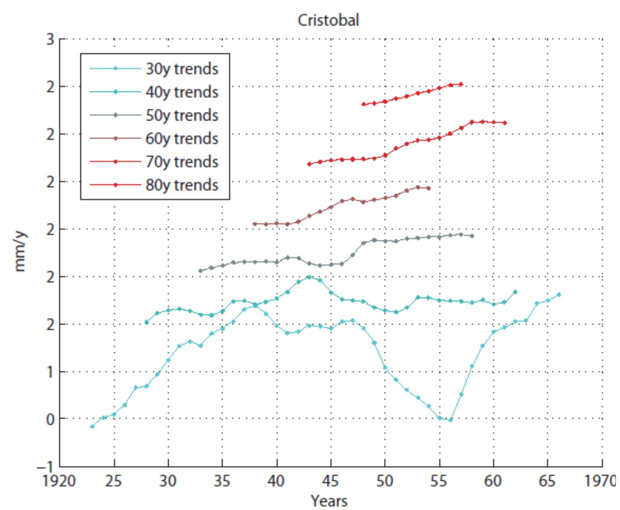
- Relative Sea Level trends
  - In 19 stations: from -2.0±1.3 mm/y in Santo Tomas to 10.7±1.5 mm/y in Port au Prince
  - Not secular RSL trends

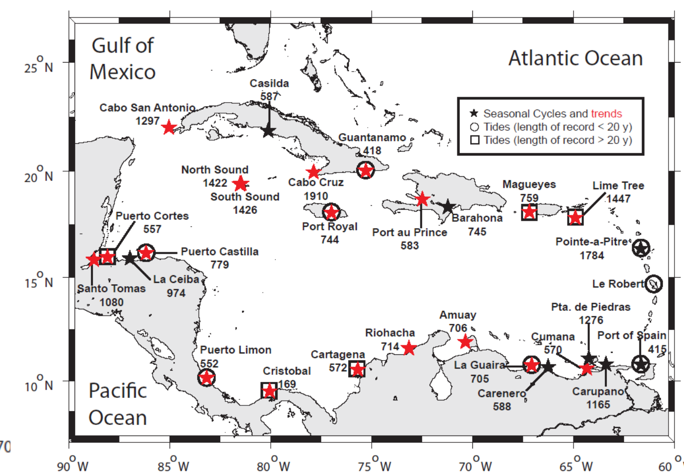


Sea level trends

- Relative Sea Level secular trends (>40 years)
  - 40 Y trends in La Guaira converge to 1.6±0.4 mm/y; 5.2±0.3 mm/y in Cartagena;
  - 50 Y trends converge to 1.2±0.2 mm/y in Magueyes.
  - 80 Y trends range between 1.6±0.1 mm/y to 2.0±0.1 mm/y in Cristobal. Acceleration of 1.6±0.3 mm/y/cy

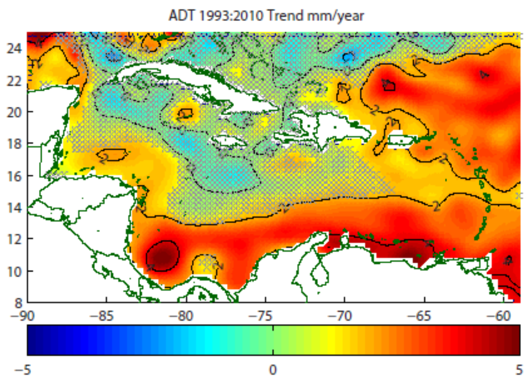


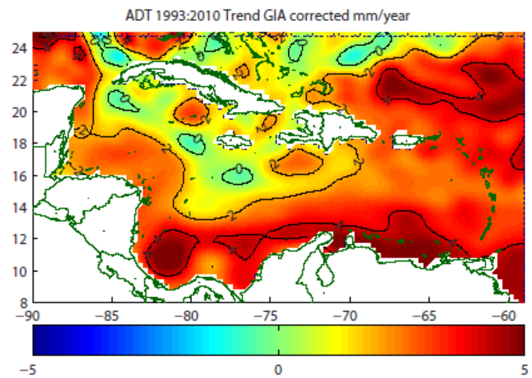




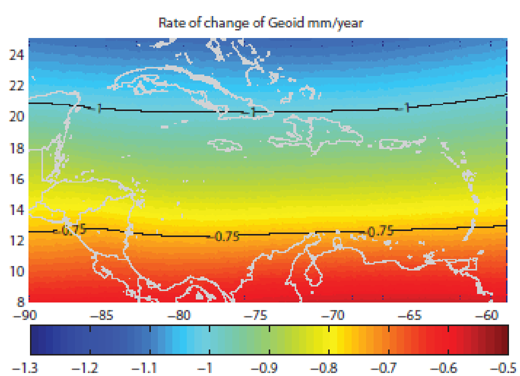
Sea level trends

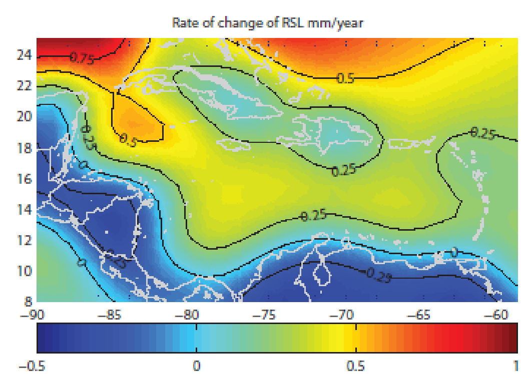
- Altimetric Sea Level trends (1993-2010). All significant trends are positive and up to 5.2 mm/y.





- Glacial Isostatic Adjustment (GIA) effect in altimetric trends from -0.5 to -1 mm/y. Coastal correction form -0.3 to 0.5 mm/y. [ICE-5Gv1.2b (VM2) Peltier (2004).]

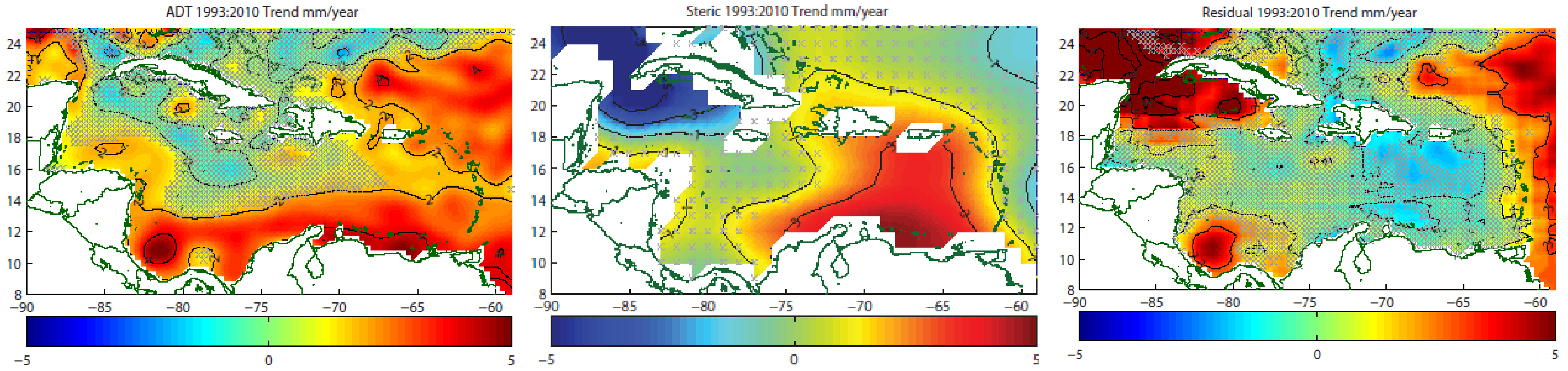




Sea level trends

- Steric trends (1993-2010) are negative (up to -7.0 mm/y) and positive (up to 4.9 mm/y).

- Residual trends up to 7.0 mm/y, probably due to mass addition and steric variability below 800 m.



- Large spatial and temporal variability in trends indicate complex oceanographic processes in the region.

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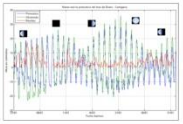
AÉREA DE OCEANOGRAFÍA OPERACIONAL

SISTEMA DE ALERTA DE AMENAZAS DE ORIGEN MARINO

OBSERVACIÓN Y MONITOREO

NOAA

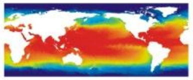
Niveles del mar



Información Satelital

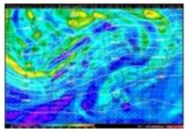
Cruceros Oceanograficos

Modelo UKMO



Estaciones Satelitales EMAS

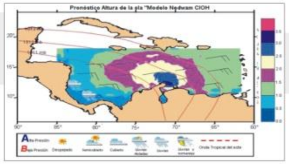
Modelo AVN



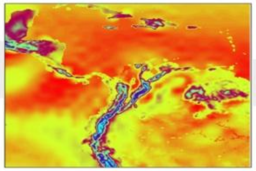
Boyas de oleaje direccional

HERRAMIENTAS DE PREDICCIÓN

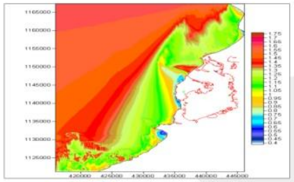
Modelo de oleaje regional



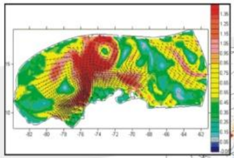
Modelo atmosferico WRF

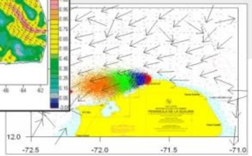


Modelo de oleaje Local



Modelo de Circulacion Oceanica





PRODUCTOS (INFORMACIÓN Y ALERTA)

- Boletín meteomarino
- Boletín mensual

- Pronostico operacional
- Pronostico de ruta

- Comunicados especiales
  - → Derrames de hidrocarburos
  - → Temporada ciclónica
  - → Frentes fríos
  - → Mar de Leva
  - → Búsqueda y rescate