Sea Level Rise Effects on Coastal Erosion: Review of Observations for the Past Few Decades

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With contributions from
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brgm

Key message from previous presentation:

- **Coastal morphological changes are due to multiple parameters, acting at multiple time and space scales**
- **How important is contemporary sea level rise in causing shoreline changes?**

> 2

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Depends on Timescales

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- Short term: e.g. storm, cyclones, tsunamis
- Combined effects of higher sea level and waves
- Xynthia France 2010
  - Sea level reached 4,5m NGF (> expected centenial event)
  - shoreline retreats: up to 20m and often 2 to 5m

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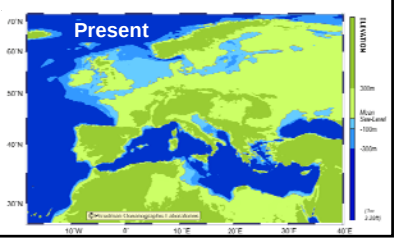
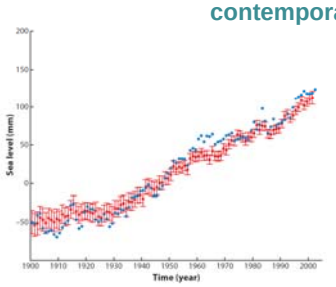
- Combined effects of higher sea level and waves
- Xynthia France 2010
  - Sea level reached 4,5m NGF (> expected centenial event)
  - shoreline retreats up to 20m and often 2 to 5m
- Shoreline retreat since last glacial maximum
  - Sea level rose by 120m from -18000 to -6000yr
  - Shoreline changes: several 10-100km



Images: BRGM, Proudman Oceanographic Laboratories and the Universities of Durham and Toronto - PSMSL

Sea level variations can cause shoreline changes at geological and event's timescales

What about the impacts of contemporary sea level rise?



- Expected consequence: as sea level rises, waves reach higher elevations in the upper-beach and generate erosion

Cazenave and Llowel, 2009; Church et al., 2004; Jevrejeva et al., 2006

The statement: shorelines are eroding worldwide

> Bird (1985) – survey of the International Union of Geography
- « *Most of shorelines have advanced or retreated less than 1m/year* »
- « *continued retreat of erodible cliffs* »
- « *many delta and swamps are retreating* »
- « *70% of beaches are retreating* »

> Difficulties:
- Collection of a huge amount of local data
- Shoreline changes are better known in some places (e.g. USA, UK…)
- Worth revisiting this statement?

> Why are shorelines eroding?
- A global cause to global shoreline erosion: Sea level rise ? (Vellinga and Leatherman, 1987)
- Shortages of coastal sediments? (e.g. Paskoff, 2004)

Marine Pollution Bulletin, 18 (4), 1987

The Modern Prevalence of Beach Erosion

Eric C.F. Bird

Somers, south-eastern Australia. *Photo:* Eric Bird

Approaches for assessing the impacts of sea level rise on shoreline changes

> **Attribution:** evaluation of the contribution of sea level rise to shoreline erosion

> Requires a comparison of shoreline change observations to a model

Bruun rule

$$R = S\left(\frac{L}{B+h}\right)$$

> **Not accurate enough**

> **Not validated**

> **Detection:** analyzing if a signal due to sea level rise can be identified in shoreline changes observations

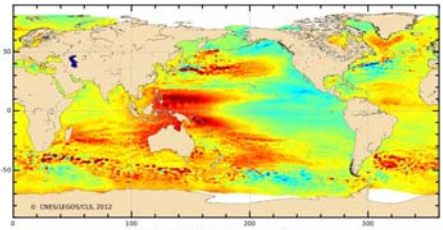
Cooper and Pilkey, 2004

Principle of detection studies

> Use the fact that sea level has not risen uniformly in the past.

> Consider coastal sites where sea level has deviated from the global average (climate, GIA, local subsidences).

> All other factors being similar, can we observe that erosion is more likely when sea level is rising faster?



1. Eastern coast of USA

(Zhang et al., 2004; Gutierrez et al., 2011)

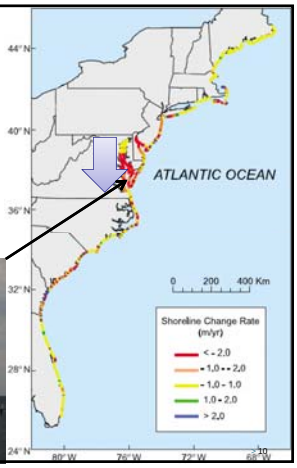
> large and consistent database of shoreline data

> long and relatively dense tide gauge records

> Along this coast: different rates of sea level rise during the 20th century

> GIA-induced subsidence

Photo: A. Riecken, W. Post
Arenstam Gibbons and Nicholls, 2006



1. Eastern coast of USA

(Zhang et al., 2004; Gutierrez et al., 2011)

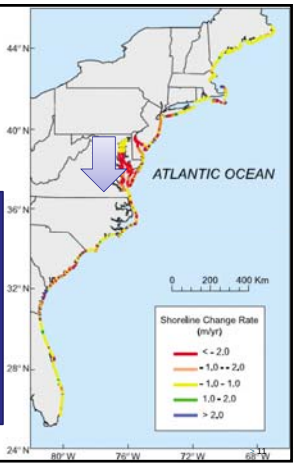
> But: shoreline mobility is affected by local factors (e.g. longshore transport)

⇒Zhang et al, (2004): Comparison of geomorphologic units affected by similar factors, except sea level rise

Conclusions:

- This dataset suggests *a relationship between the rate of relative sea level rise and shoreline change* (Zhang et al., 2004; Gutierrez et al., 2010)

- Sea level rise involved:
  - 2 to 4mm/yr *at tide gauges*
  - Relative sea level is dropping since several 1000 years

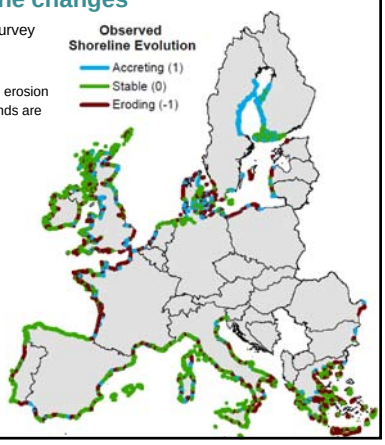


2. European shoreline changes

> European shoreline change survey (Eurosion, 2004)

> Quantified statement:
- 40% of European beaches in erosion
- 48% of French coastal wetlands are accreting
- …

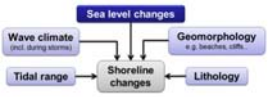
> Worth updating this database

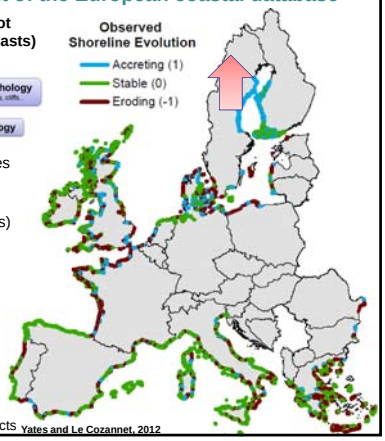


Eurosion, 2004

2. Exploring the content of the European coastal database

> **Simple statistical model (not considering artificialized coasts)**





> Results: the model reproduces 65% of the observations

> Relative importance of the variables (statistical indicators)

1. Geomorphology
2. Sea level changes
3. Other factors

> Limitations:

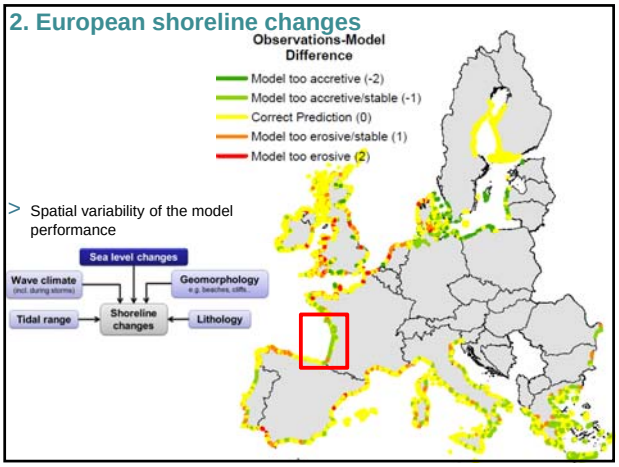
- restrictive consideration of forcing factors
- Statistical relationship only

> Scandinavian coasts are

- mostly accreting
- uplifting because of GIA effects

Yates and Le Cozannet, 2012

2. European shoreline changes



> Spatial variability of the model performance

2b. Aquitaine (France) longshore sediment transport

> Longshore gradient of sediment fluxes can cause shoreline changes

> Not taken into account in the simple statistical model

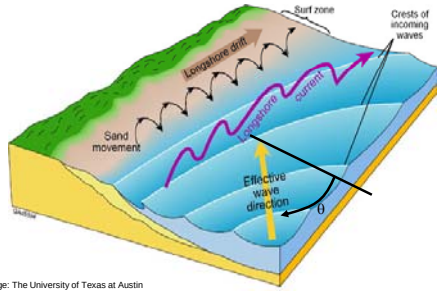
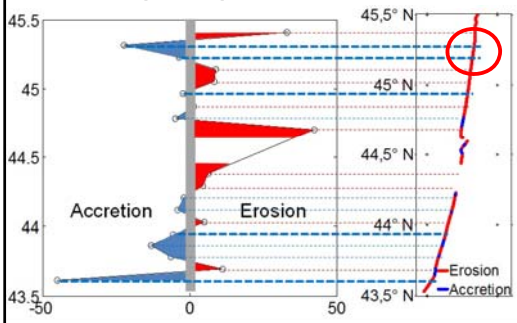


Image: The University of Texas at Austin

2b Aquitaine (France): longshore gradients

Modelled Longshore gradient of sediment fluxes [1966-2000]

Observed shoreline evolution [1966-2000]



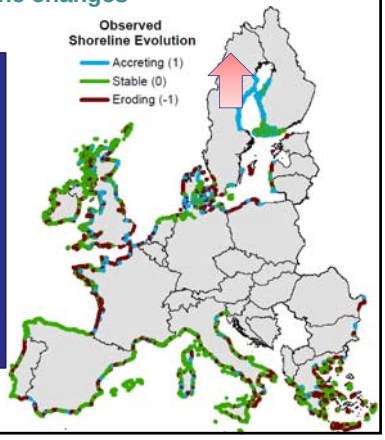
Fair agreement – Longshore gradients could explain part of the spatial variability of shoreline changes in Aquitaine

Idier et al., 2013

2. European shoreline changes

Conclusions:

- Possibly, a signal due to sea level changes can be detected?
- Many limitations
- Sea level rise involved:
  - a few mm/year to more than 1cm/year
  - Relative sea level is dropping since several 1000 years

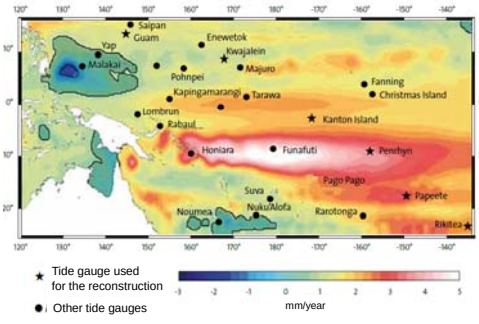


3. Pacific Atoll islands

> Concerns about atoll's sustainability due to sea level rise

> Sea level has risen more than the global average over the last 60 years

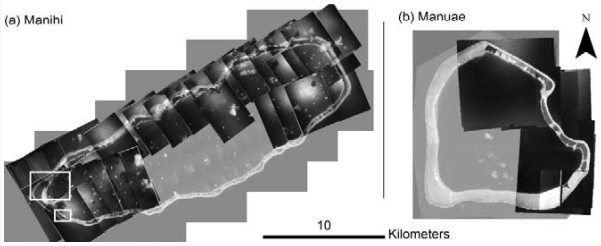
> Shoreline changes are poorly known (no coastal database)



Becker et al., 2012; Meyssignac et al., 2012a; Meyssignac et al., 2012b

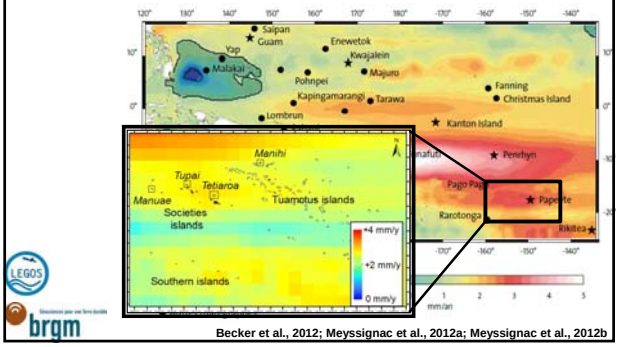
3. Pacific Atoll islands

> Several studies dedicated to the investigations of causes of atoll's shoreline changes:
  - Webb and Kench, 2010 (4 atolls); Ford, 2012 (1 atoll); Yates et al., 2013 (2 atolls); Ford, 2013 (1 atoll); Le Cozannet et al., 2013 (2 atolls); Biribo and Woodroffe, 2013 (1 atoll)…
  - 83 atolls only in French Polynesia
> Use of aerial photographs since the 50's and satellite images to monitor shoreline changes



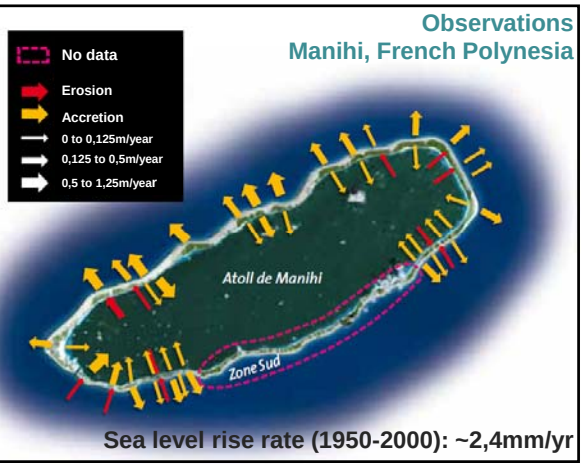
3. Pacific Atoll islands: French Polynesia

> Regional ground motions (Pirazzoli and Montaggioni, 1988)
> Sea level reconstruction



Becker et al., 2012; Meyssignac et al., 2012a; Meyssignac et al., 2012b

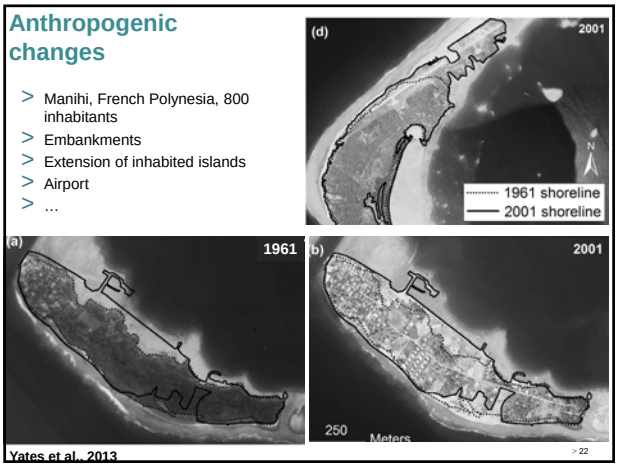
Observations
Manihi, French Polynesia



Sea level rise rate (1950-2000): ~2,4mm/yr

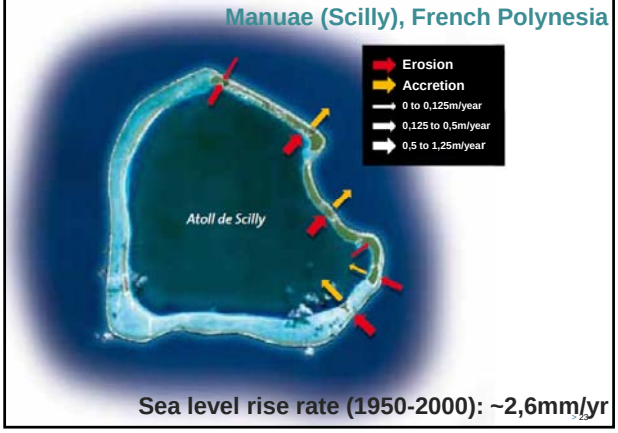
Anthropogenic changes

> Manihi, French Polynesia, 800 inhabitants
> Embankments
> Extension of inhabited islands
> Airport
> …



Yates et al., 2013

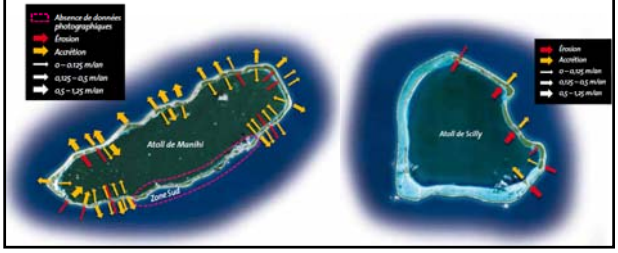
Observations
Manuae (Scilly), French Polynesia



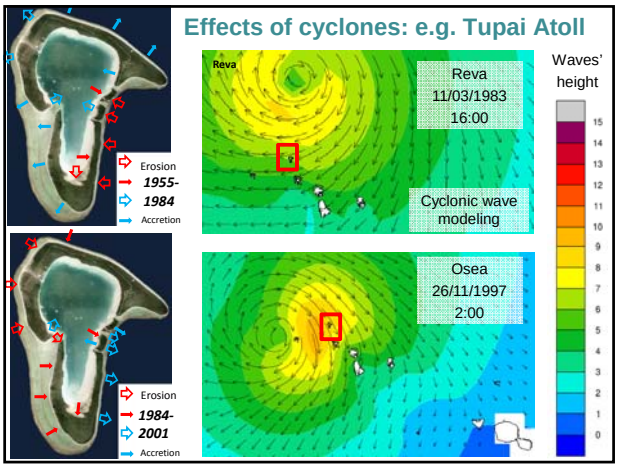
Sea level rise rate (1950-2000): ~2,6mm/yr

Observations

> Similar rates of sea level changes…
> … but different hydro-sedimentary behavior
> Observation: contrasting behaviors of islets: islet extension, lagoonward migration, ocean-ward migration, islet erosion…
> Questions the common opinion that shorelines are always eroding when sea level is rising

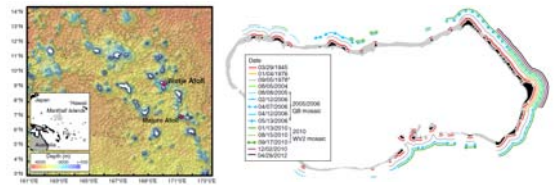


Effects of cyclones: e.g. Tupai Atoll

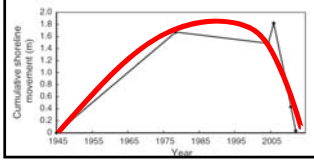


Monitoring recent erosional shifts

Ford, 2013



2004 and 2012 suggests a possible erosion shift in recent years



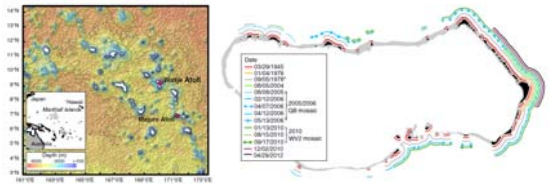
> Why?

> 3 possibilities: 2004-2012 could be…

- … part of a transition toward island erosion
- … part of the inherent shoreline dynamism

Monitoring recent erosional shifts

Ford, 2013



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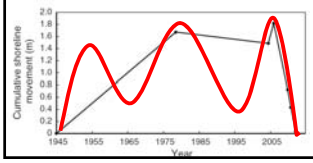


> Why?

> 3 possibilities: 2004-2012 could be…

- … part of a transition toward island erosion
- … part of the inherent shoreline dynamism
- … a sampling issue ?

3. Pacific Atoll islands

Conclusions:

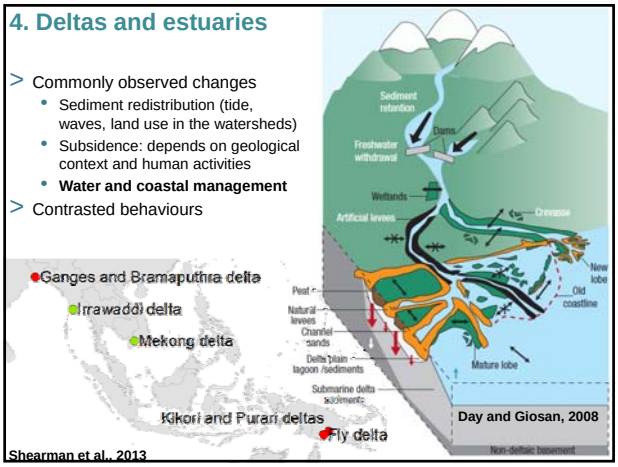
- Many observations suggest that variability of shoreline changes in atolls is presently dominated by waves, currents and human impacts.
- But: too few observations of shoreline changes to draw any definitive conclusion.
- Sea level rise involved: 2 to 6mm/yr *(use of sea level reconstruction)*

4. Deltas and estuaries

> Commonly observed changes

- Sediment redistribution (tide, waves, land use in the watersheds)
- Subsidence: depends on geological context and human activities
- **Water and coastal management**

> Contrasted behaviours



Shearman et al., 2013

What causes of shoreline changes have been detected?

Region	Sediments redistribution (longshore…)	Effects of human actions	Storms	Role of contemporary sea level rise
Eastern coast USA	✓	✓	✓	✓
Europe	✓	✓	✓	✓
Aquitaine	✓	✓	✓	?
Pacific atoll islands	✓	✓	✓	~?
Deltas	✓	✓	✓	~?

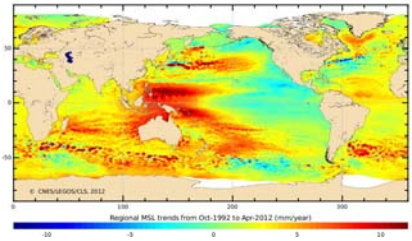
- Statistical relationship
- GIA induced effects
- Rates of sea level rise involved: a few mm/yr to ~1 cm/yr

Depends on local subsidences (often unknown)

Are-we able to observe the actual impacts of climate-induced sea level rise?

> Not presently.

> No definitive conclusion on the actual role of contemporary climate-induced sea level rise.



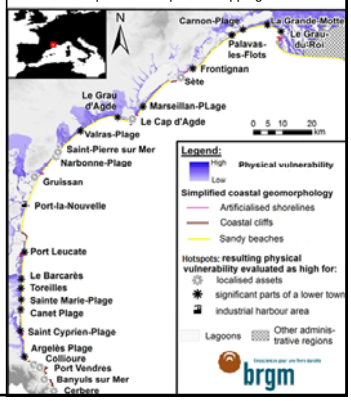
Consequence: assessing future effects of sea level rise is difficult !

> Expected impacts:
- increased erosion
- more frequent marine flooding
- saline intrusions in coastal aquifers

> Quantified estimates of SLR consequences are:
- either poorly quantified
- or suffer from a lot of uncertainties

> Alternatives to quantified statements:
- mapping « hotspots »
- scenarios
- probabilistic approaches

Example of « hotspots » mapping in France



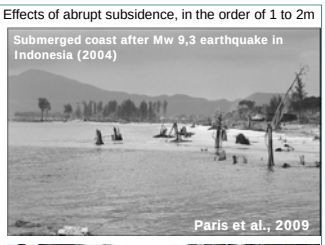
Conclusion

> Sea level changes are an important driver of coastal changes.

> However, the actual impacts of recent climate-induced sea level rise are unclear.

> Too limited knowledge of:
- sea level rise at the coast (incl. ground motions)
- cross-shore coastal morphodynamic processes
- shoreline changes

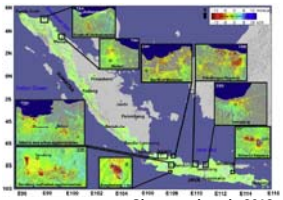
Effects of abrupt subsidence, in the order of 1 to 2m



What can we do to better understand future effects of sea level rise?

1. Improve knowledge of sea level rise at the coast

> New approaches: combined use of data:
- Reconstructions of past sea level
- Tide Gauges
- Permanent GPS
- InSAR
- Leveling data



Chaussard et al., 2013

2. Monitoring shoreline changes

> At different spatial scales (Regional to local)
> Save and share existing coastal datasets
> Sustain recuring coastal observations (coastal observatories)

3. Improve coastal modelling capabilities (many recent developments)

Thank you for your attention

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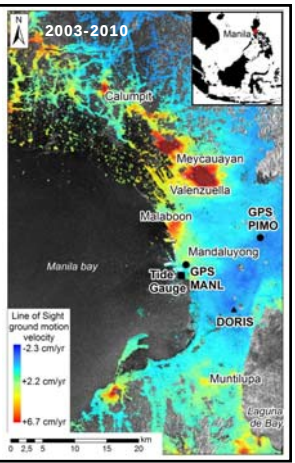
Subsidence implications for flooding hazard

> Manilla: coastal city on a flood plain

> Ground deformation context:
- groundwater pumping, seismic fault
- highly variable subsidence and uplift (spatially and temporally)
- up to a few tens of cm/yr

> Flooding hazard:
- increasing concern for authorities
- multiple factors involved: typhoons, rains, water management, sea level and subsidence…
- related risks: loss of lives, properties, de-watering…



Raucoules et al., subm.