# City Coastal Resilience in Africa

CityCORE Africa

Open Data for Resilience Initiative

GPSURR
P166688
FY18-20

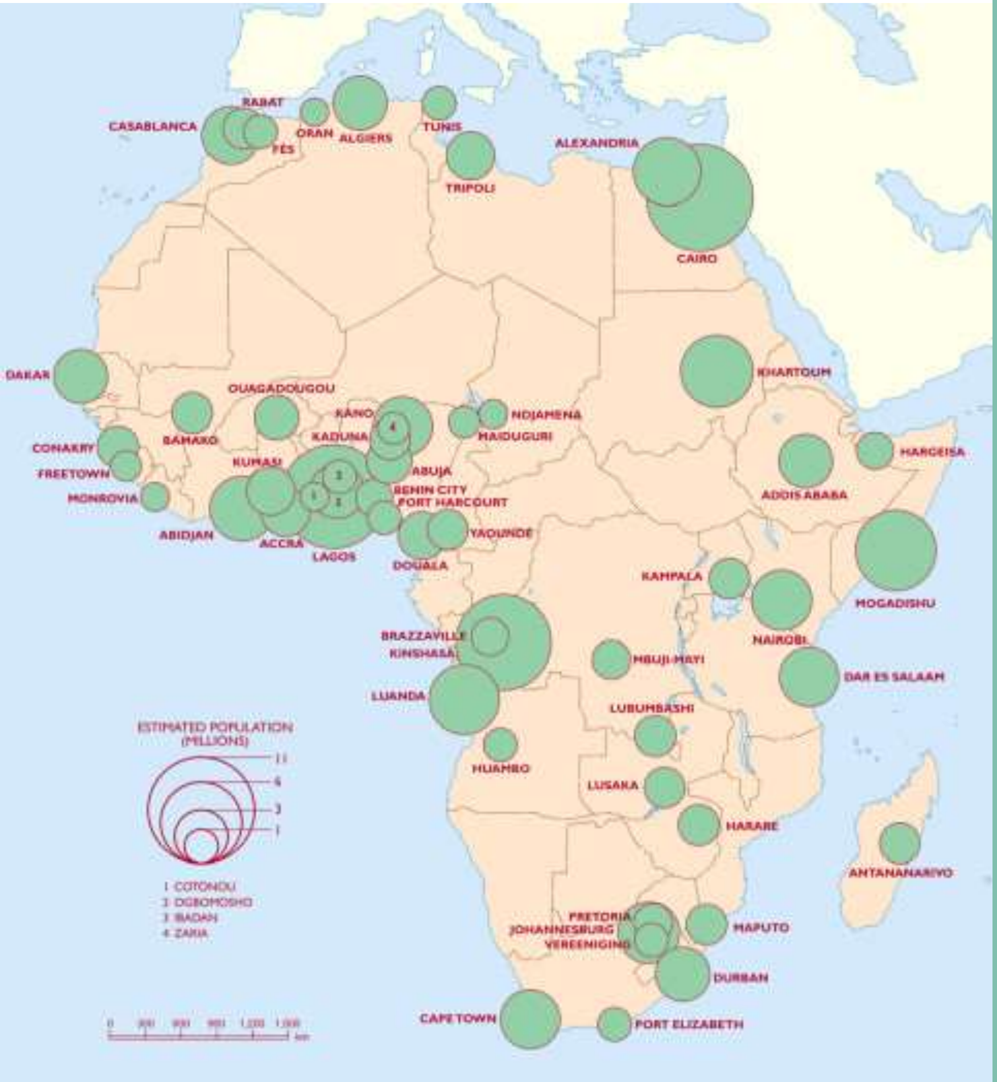
# Cities at Risk: Africa's Vulnerable Coast

Urban populations in Africa's low elevation coastal zones (LECZ) will increase by:

- 2-fold by 2030
- 10-fold by 2060

Urbanization & climate change will rapidly escalate coastal populations' exposure to:

- Sea Level Rise (SLR)
- Erosion
- Land Subsidence
- Storm Surge




Beall, Parnell, & Albertyn, 2015

# CityCORE Africa

*Improving the capacity of coastal cities to prepare, adapt, and grow.*

**CityCORE** - a technical assistance enabling World Bank teams to:

- *Improve the understanding* of the interaction between human and environmental pressures.
- *Design tailored city-level solutions* to integrate coastal and urban resilience.
- Leverage public-private *partnerships*, external partnerships, or donor co-financing for *multi-sector investment packages*.

# Selected Cities

Nouakchott, Mauritania

Saint-Louis, Senegal

Banjul, The Gambia

Conakry, Guinea

Monrovia, Liberia

Abidjan, Ivory Coast

Lomé, Togo

Cotonou, Benin

Lagos, Nigeria

Luanda, Angola

Mogadishu, Somalia

Mombasa, Kenya

Zanzibar, Tanzania

Dar es Salaam, Tanzania

Nacala, Mozambique

Quelimane, Mozambique

# Preliminary Results

*Screening of risk across coastal African cities.*

## Common Hazards

- Some of the worst hit cities are those with combined issues of extreme precipitation, coastal flooding, and river flooding
- Inland flooding and erosion are often linked, particularly in wetlands and the banks of rivers
- Storm surge and coastline retreat are destructive to the shoreline and are expected to worsen with sea level rise
- Mangrove deforestation and sand mining are weakening cities' defenses against coastal storms

# Preliminary Results

*Screening of risk across coastal African cities.*

## Human Impacts

- Informal settlements are common throughout coastal sub-Saharan cities and frequently the most vulnerable neighborhoods to hazards
- Household displacement after flood and erosion events is endemic and will worsen with climate change
- Cities face disease outbreak – including cholera, malaria, and diarrhea - from contaminated freshwater sources and water stagnation
- Ecosystem change and damage to shoreline threatens fishing, a major livelihood in many cities
- Flooding and erosion can cause dozens of mortalities each year due to drowning, building collapse, falls down steep erosive slopes, and electrocution

# Preliminary Results

*Screening of risk across coastal African cities.*

## Infrastructural Impacts

- Dwellings on the coastline and in wetlands face inundation and collapse from coastal and fluvial flooding
- Transportation: streets are washed out or blocked. Several airports are located at low elevation near the shoreline
- Most cities feature inadequate drainage and sewers that reach over-capacity during even frequent floods
- Poor waste management and sanitation practices result in clogged drains and contaminated water sources during rains
- Unstable soils from erosion and subsidence threaten building instability and collapse

# Preliminary Results

*Screening of risk across coastal African cities.*

## Data Gaps

- Drainage systems data outdated or inaccessible
- Risk maps at municipal level rare or outdated
- Population data rarely exists for sub-municipal areas
- Aerial imagery too low resolution

# Preliminary Results

*Screening of risk across coastal African cities.*

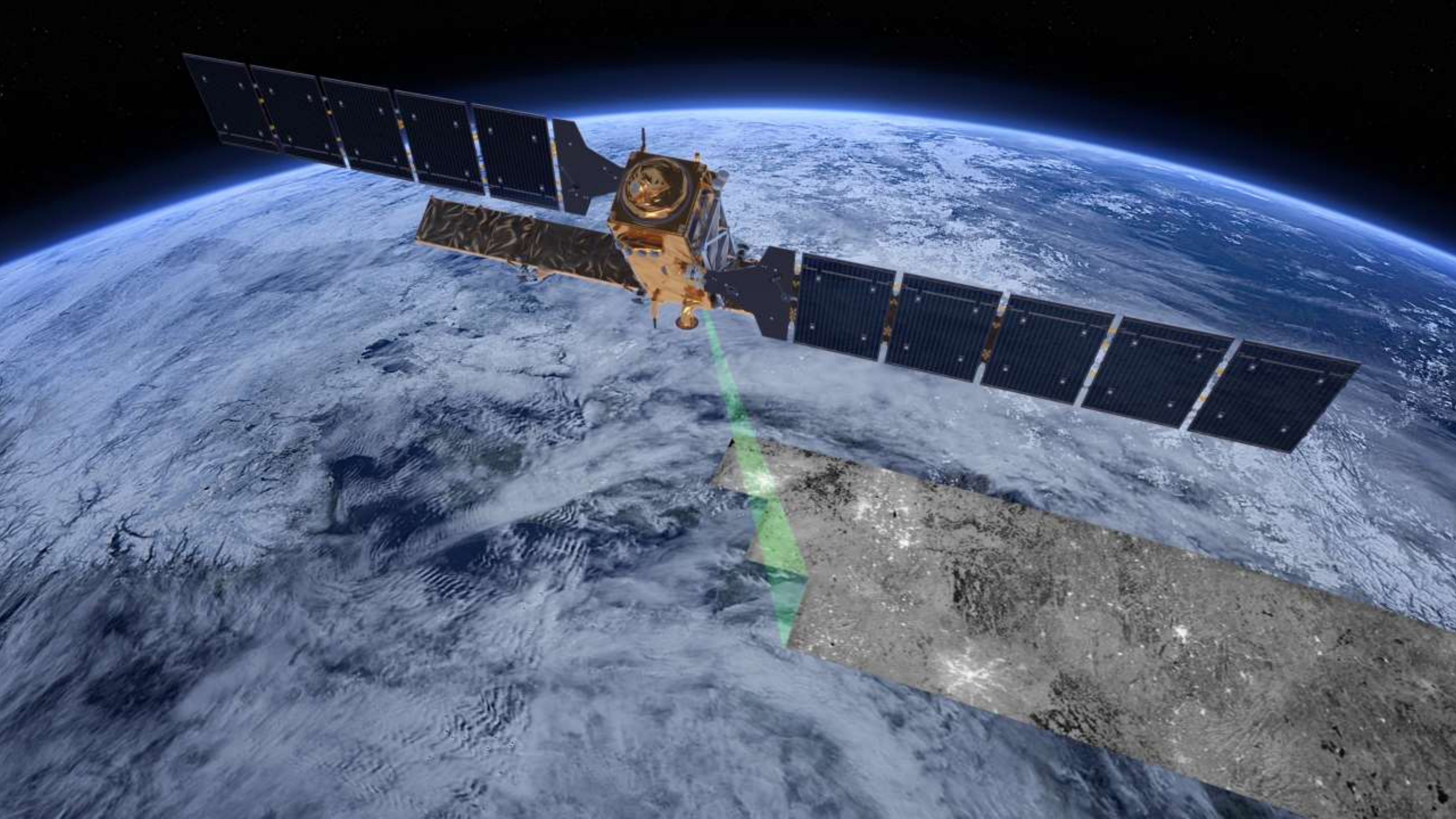
## Investment Priorities across Cities

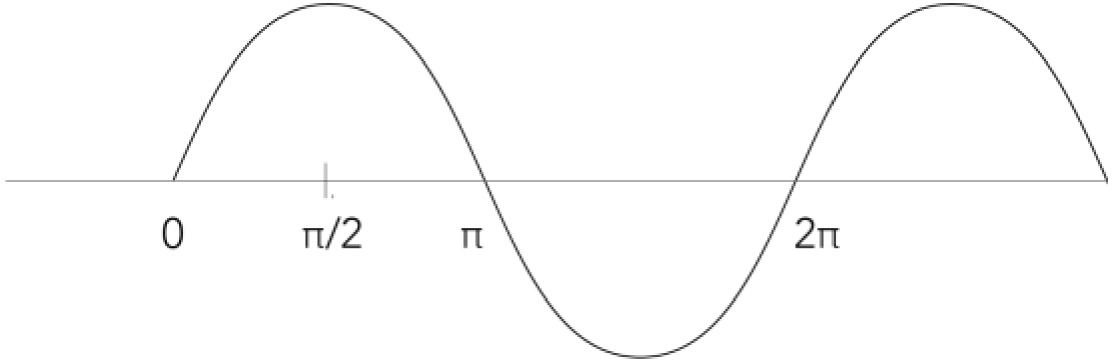
- Drainage systems: assessment, maintenance, improvement, and expansion are all vital to mitigating flood risk
- Flood protection infrastructure especially along shorelines are considered, including dune bar restoration, groynes, riprap, and wetland restoration
- Early warning systems and stormwater management legislation
- Unplanned settlements: affordable housing and relocation will be necessary in some cities, but intensive
- Passing and enforcement of zoning laws and community awareness campaigns for sand mining and other destructive practices

# Land Subsidence Monitoring in coastal Africa by means of InSAR

**Fabio Cian**, PhD

**City Coastal Resilience** (CityCore)
*The World Bank*




0
π/2
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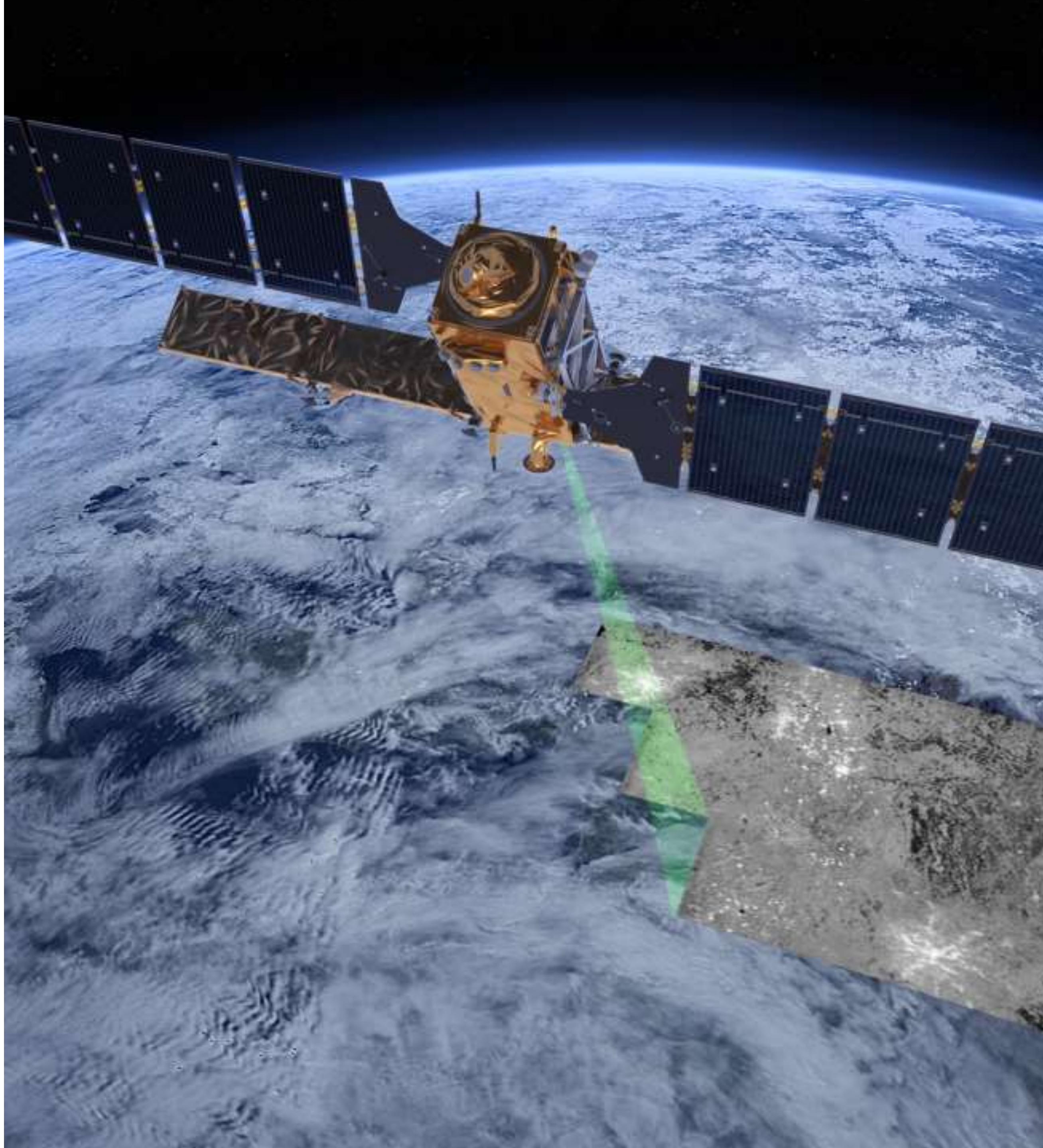
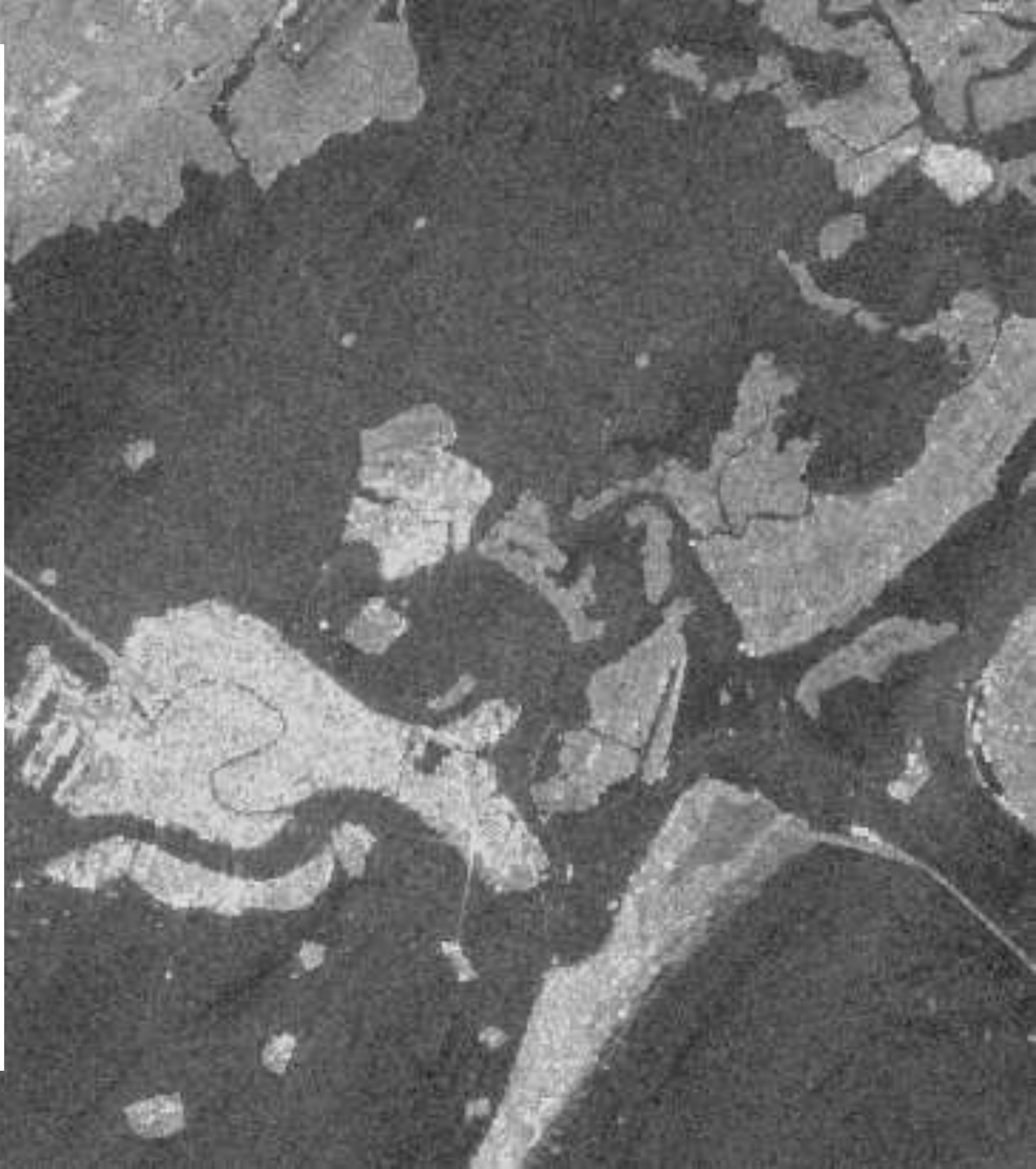
2π



# What is SAR and InSAR?

- **Amplitude** can be interpreted in terms of the scattering **properties** of the Earth’s surface
- **Phase** is determined mainly by the **distance** between the antenna and the target
- The **difference in phase** between two images can be interpreted in terms of **change in distance** from the instrument to the ground



# Sentinel 1 SAR Constellation

10 meter resolution

2 satellites in polar orbit

Earth Observation Big Data

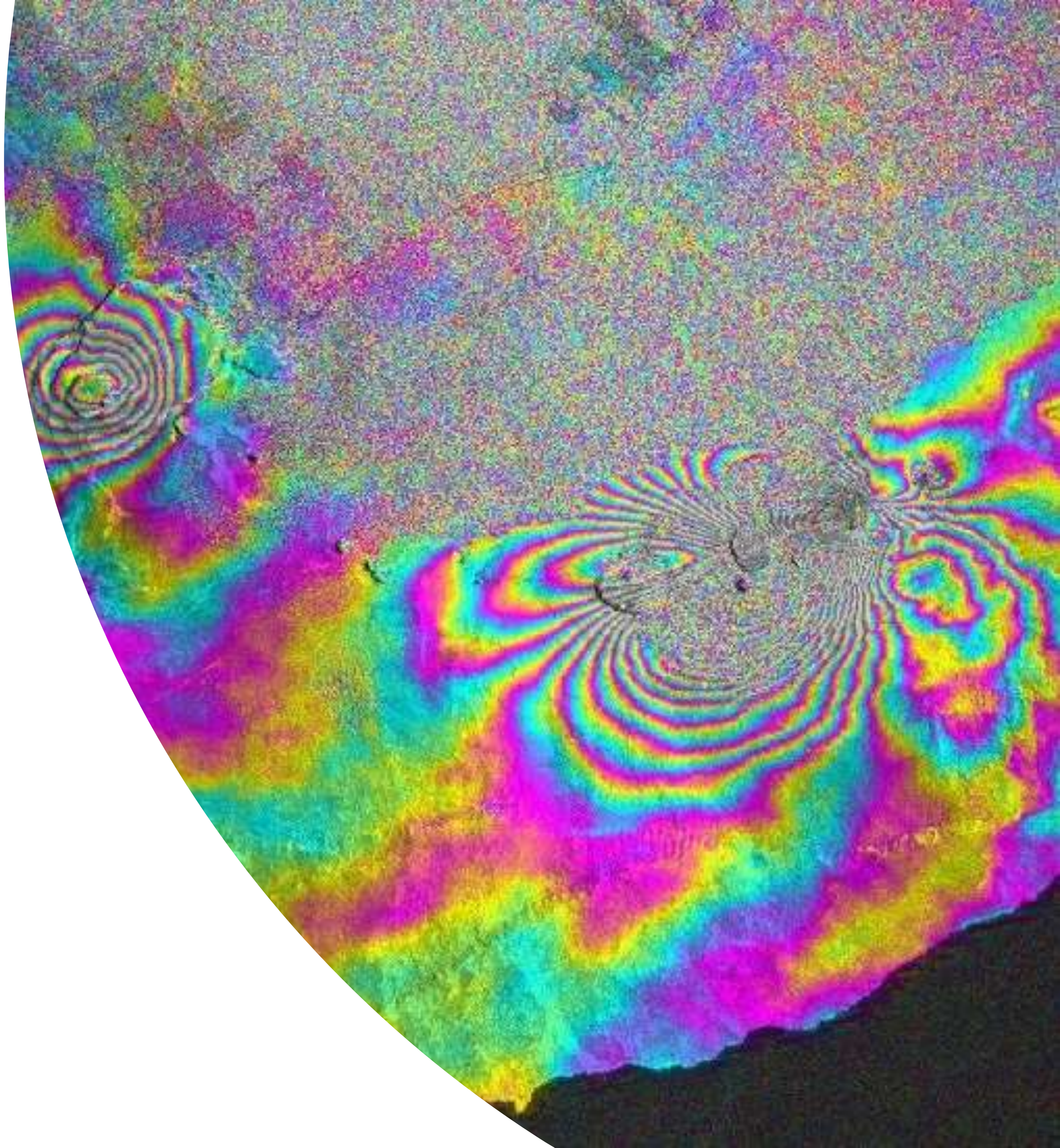
- 6 days repeat cycle (theoretical)
  - for Africa 12 days in most of the cases

Free Data Access

Interferometric Capabilities

# What is SAR and InSAR?

- **Interferometry** exploits the phase difference between two SAR images taken from slightly different sensor positions and extracts **information about Earth's surface**
- An **interferogram** is formed by combining the phase of two images after coregistration.



# Interferogram formation

$$\phi_1 = \frac{4\pi R}{\lambda}$$

$$\phi_2 = \frac{4\pi(R+\Delta R)}{\lambda}$$

$$\Delta\phi = \phi_1 - \phi_2 = \frac{4\pi\Delta R}{\lambda}$$

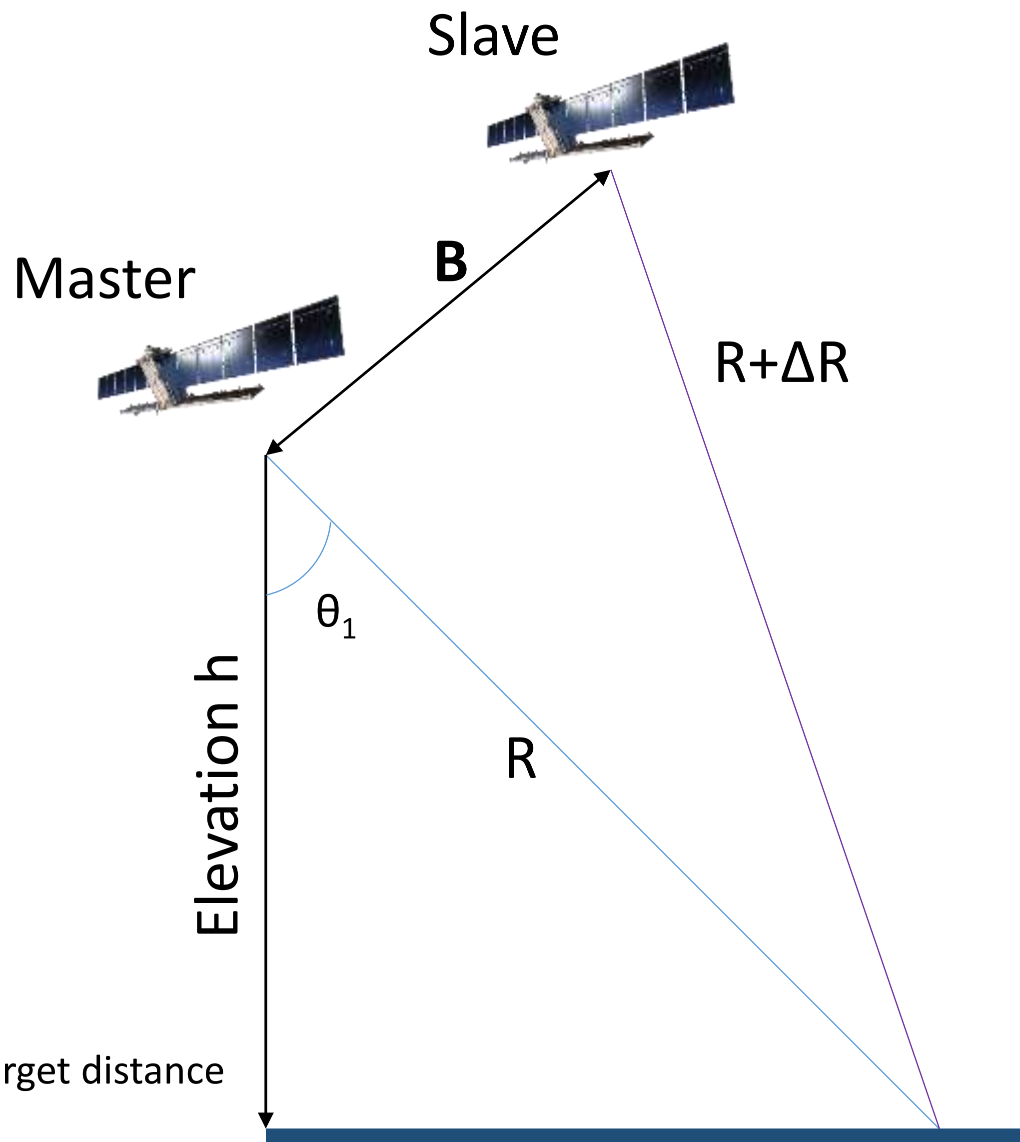
$\Delta\phi_{flat}$

$\Delta\phi_{elevation}$

$\boldsymbol{\Delta\phi_{displacement}}$

$\Delta\phi_{atmosphere}$

$\Delta\phi_{noise}$




R = satellite – target distance

B = baseline

# InSAR and Land Subsidence

- InSAR allows remote detection of **deformation** at the Earth’s surface
- Used for measuring **displacements** associated with:
  - Earthquakes
  - Volcanic activity
  - Subsidence due to extraction of hydrocarbons and water from the ground
- Analysis of **time series** of SAR images allows detection of small displacements and **reduction of error** sources
- Thanks to new SAR data we are able to monitoring wide areas for land deformation

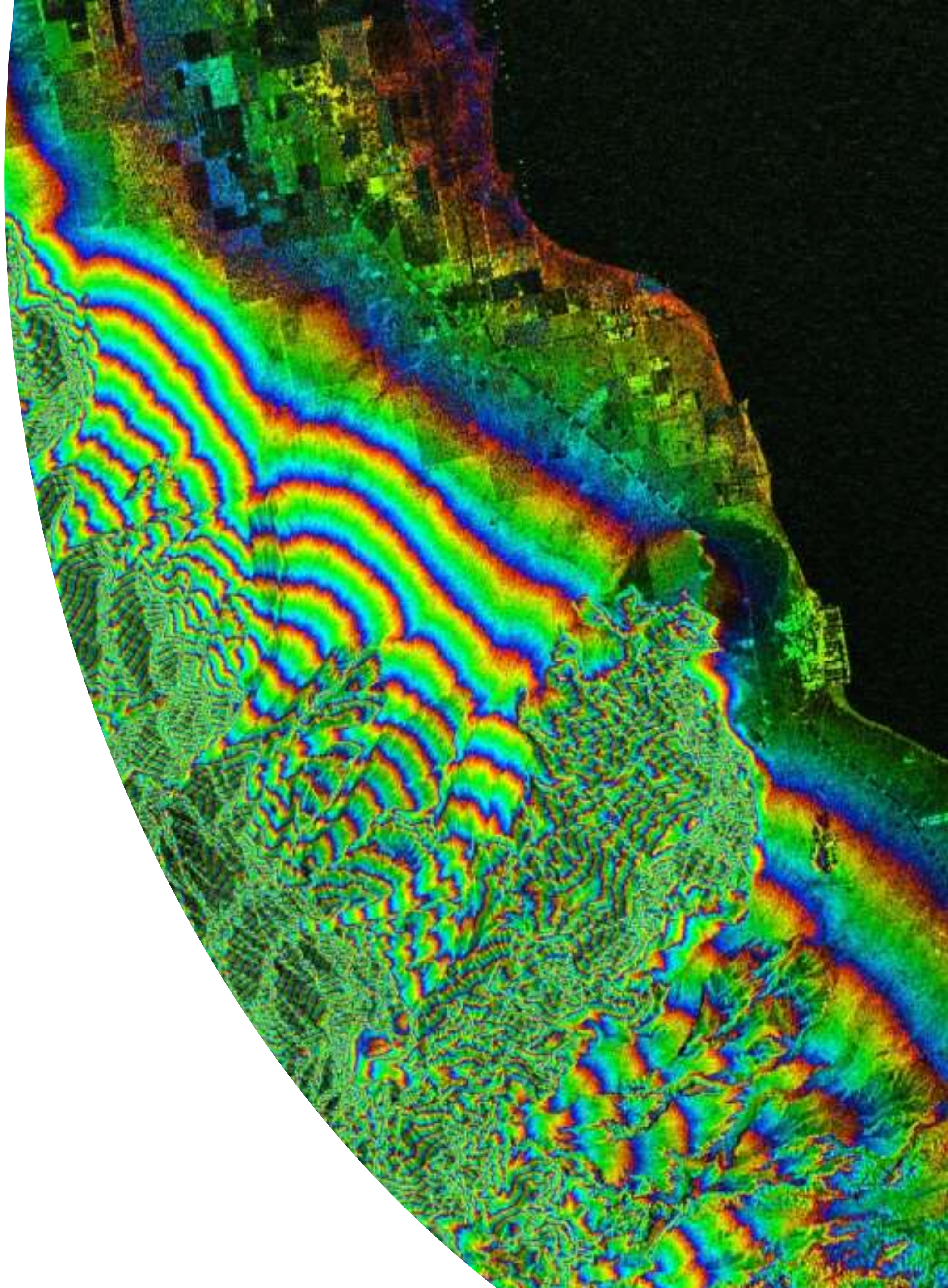
# Limitations

**Impossibility** to compute interferograms due to:

- Changes in **scattering properties** of the Earth's surface with time
- Different **incidence angle** of acquisition

**Difficulties** in estimation surface deformation due to:

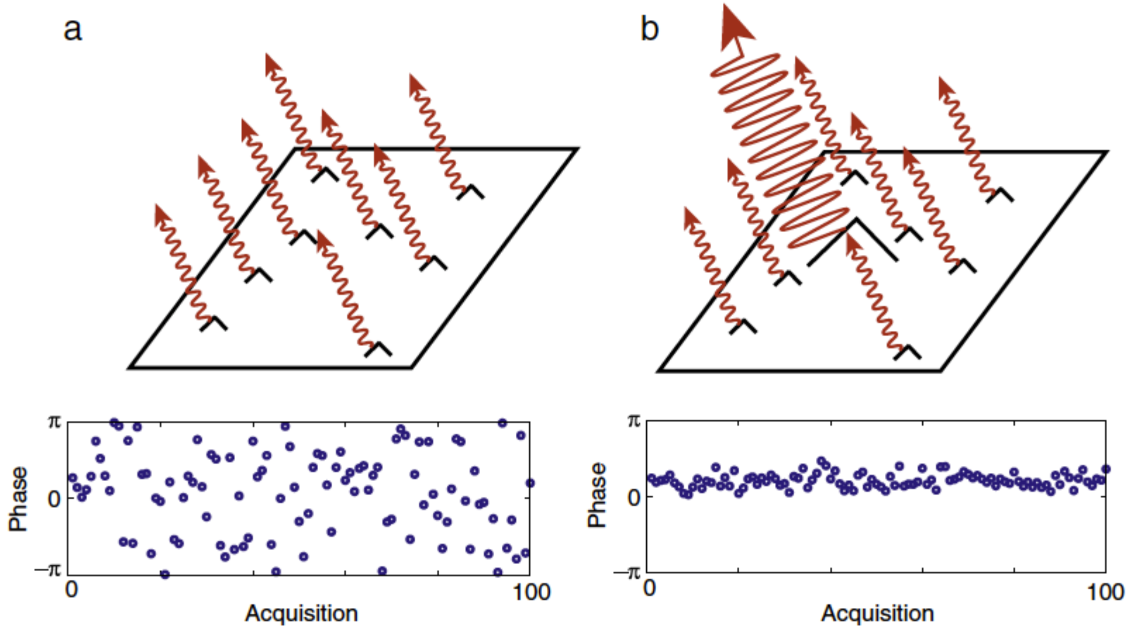
- Variation in **atmospheric** properties
- Errors in **satellite orbit** and surface **elevation** determination
- The **non-deformation signal** can swamp the deformation signal

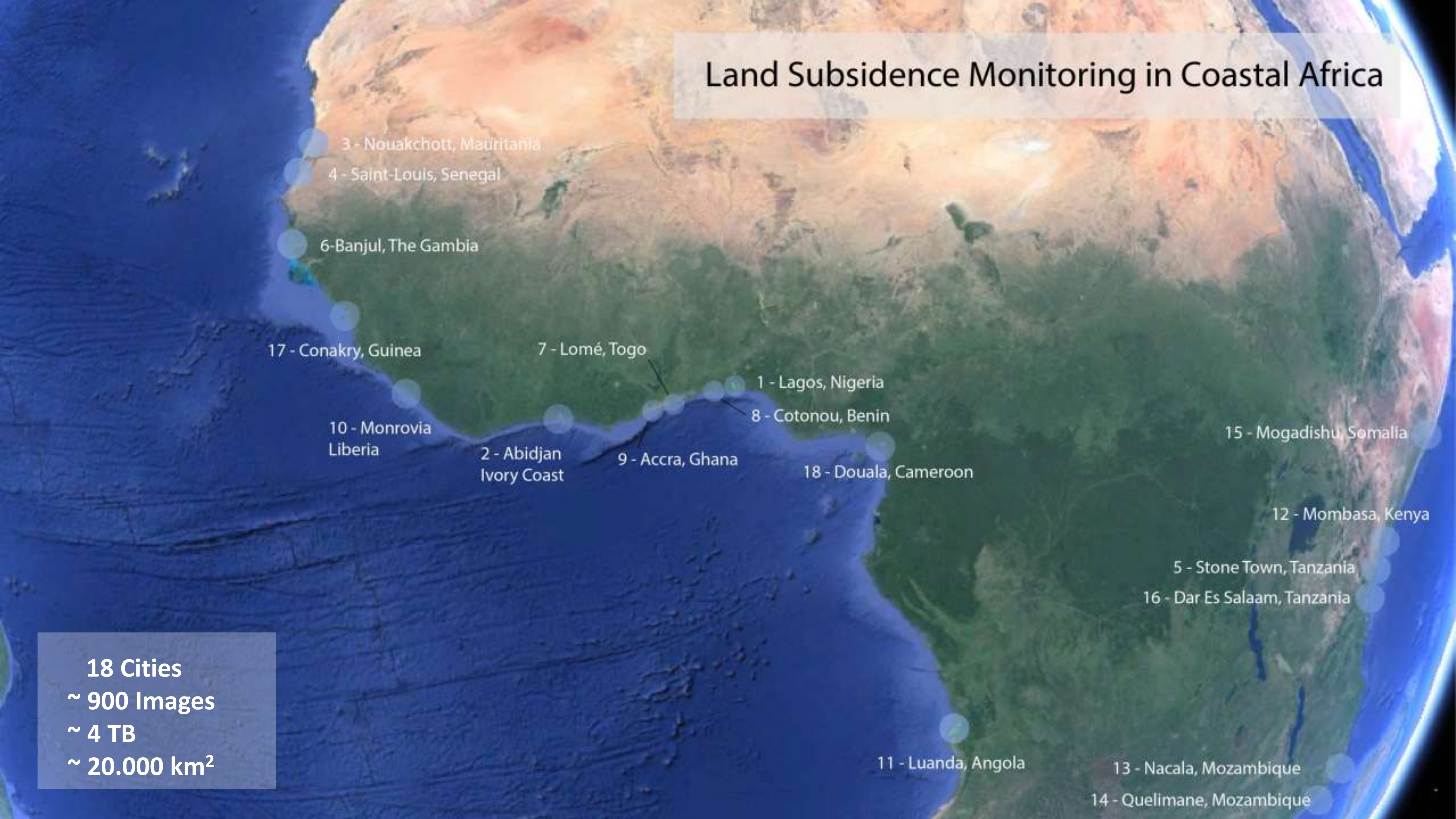


# Methodology

Time series of interferograms allow to extract small displacements since the deformation signal reinforces, whereas other signals typically do not.

- **PSI: Persistent Scatterer Interferometry**
  - Analysis of pixels (scatterers) remaining stable in time and from different angles of observation
  - Optimised for resolution cells containing a single point scatterer

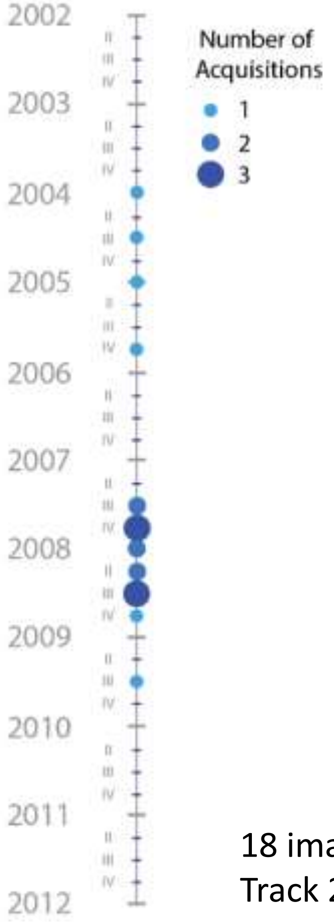



Land Subsidence Monitoring in Coastal Africa
3 - Nouakchott, Mauritania
4 - Saint-Louis, Senegal
6-Banjul, The Gambia
17 - Conakry, Guinea
7 - Lomé, Togo
1 - Lagos, Nigeria
8 - Cotonou, Benin
10 - Monrovia Liberia
2 - Abidjan Ivory Coast
9 - Accra, Ghana
18 - Douala, Cameroon
15 - Mogadishu, Somalia
12 - Mombasa, Kenya
5 - Stone Town, Tanzania
16 - Dar Es Salaam, Tanzania
11 - Luanda, Angola
13 - Nacala, Mozambique
14 - Quelimane, Mozambique
18 Cities
~ 900 Images
~ 4 TB
~ 20.000 km²

# Saint-Louis – Senegal

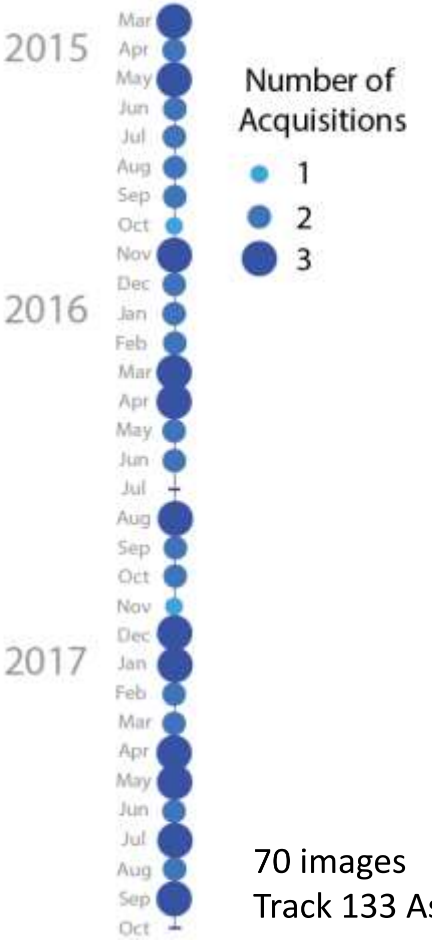
# Saint-Louis – Data Availability

**Envisat – ASAR Data**




18 images
Track 266 Descending

**Sentinel-1 Data**

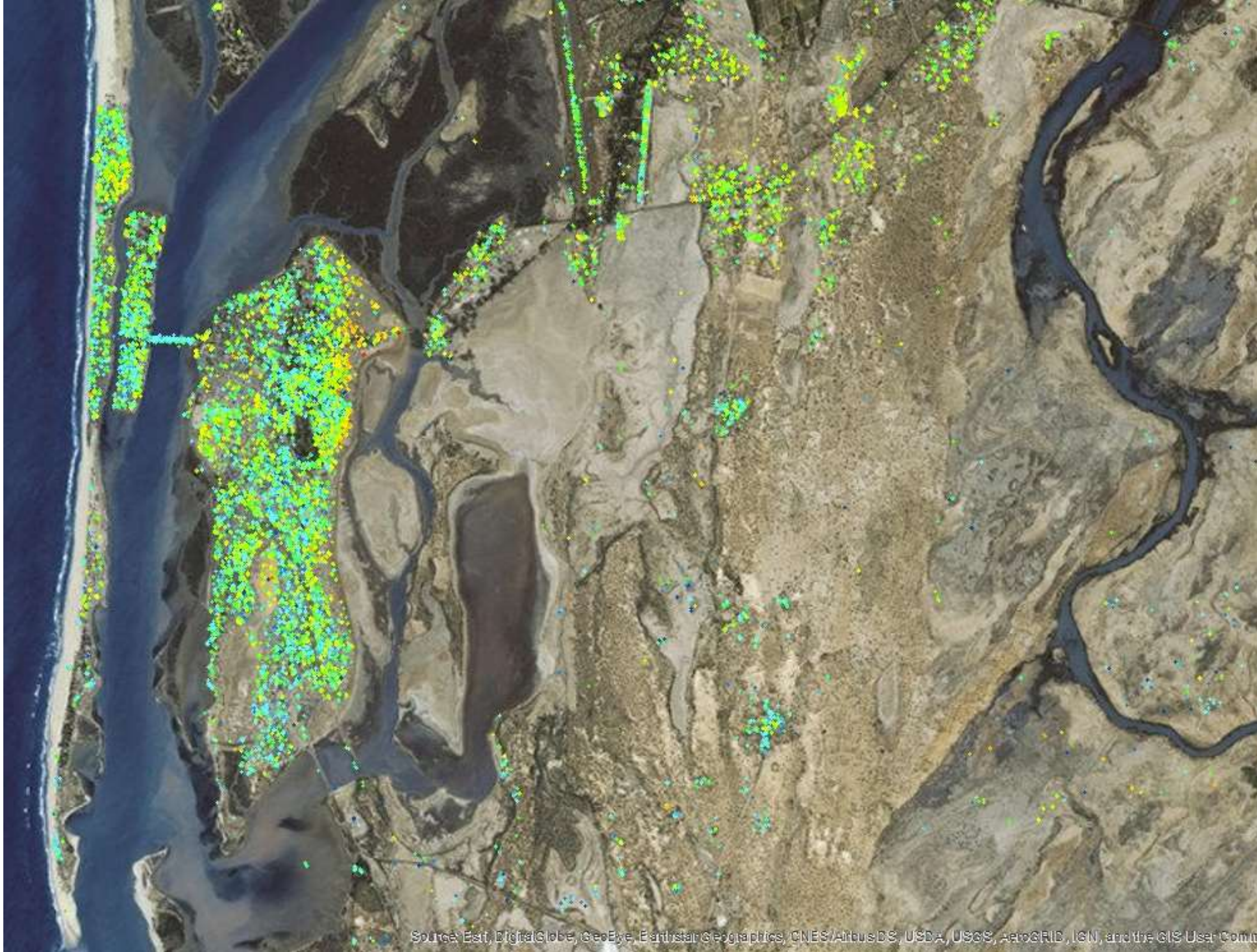



70 images
Track 133 Ascending

# Results
# Sentinel-1

Land Deformation [mm/year]

- < -9
- -8 to -8.9
- -7 to -7.9
- -6 to -6.9
- -5 to -5.9
- -4 to -4.9
- -3 to -3.9
- -2 to -2.9
- -1 to -1.9
- 0 to -0.9
- 0.1 to 1
- 1.1 to 2
- 2.1 to 3
- 3.1 to 4
- 4.1 to 5



# Results Sentinel-1

Land Deformation [mm/year]

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- -5 to -5.9
- -4 to -4.9
- -3 to -3.9
- -2 to -2.9

- 2.1 to 3
- 3.1 to 4
- 4.1 to 5

# Results Sentinel-1

Land Deformation [mm/year]

- < -9
- -8 to -8.9
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- 2.1 to 3
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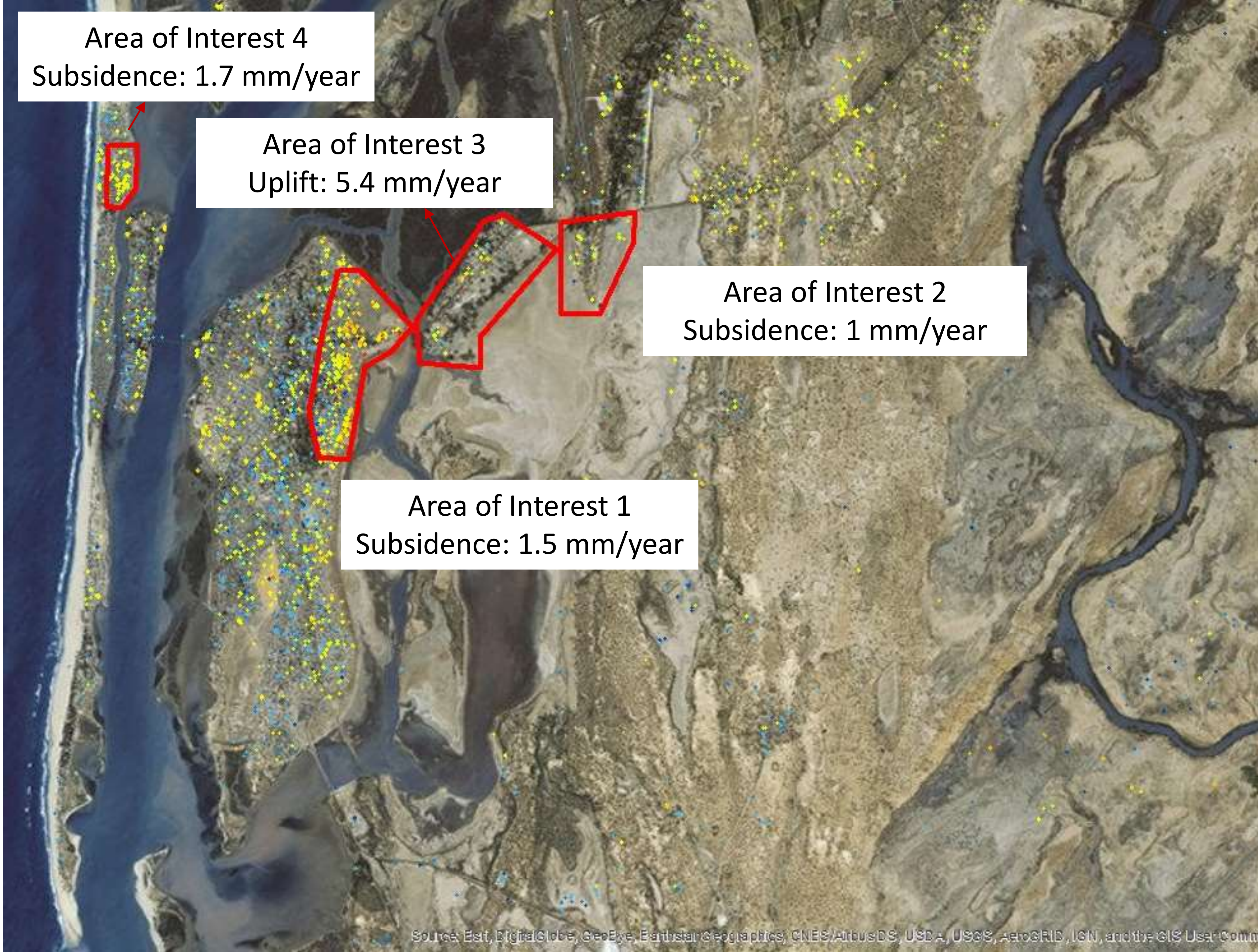
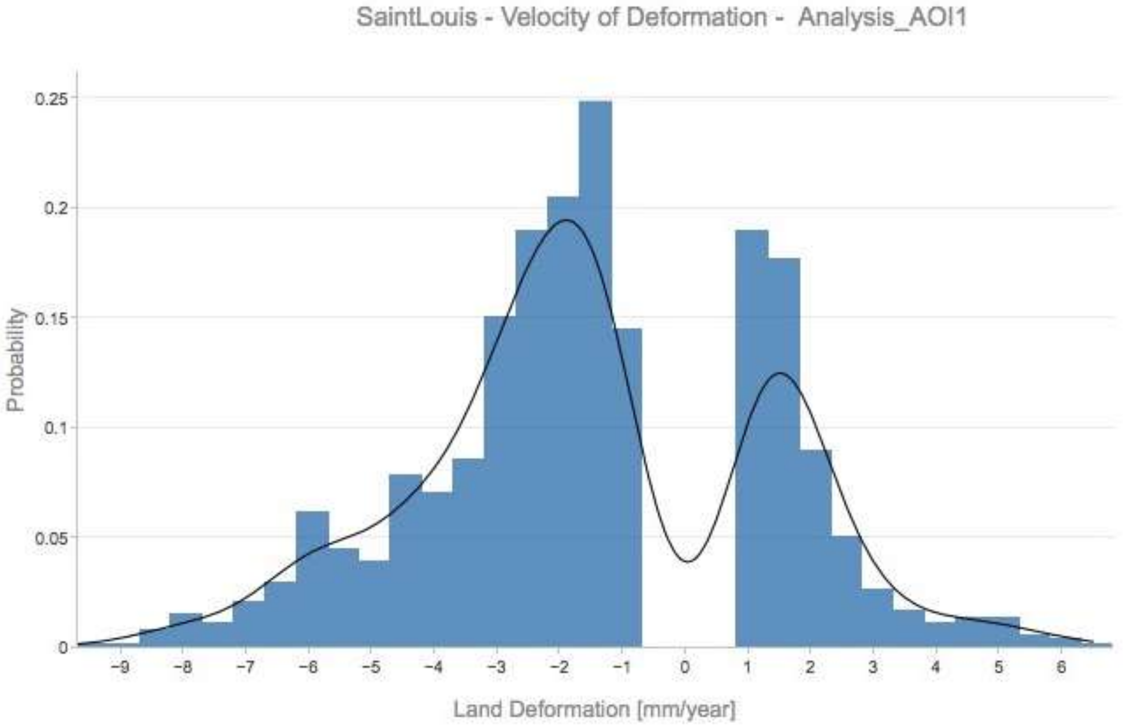
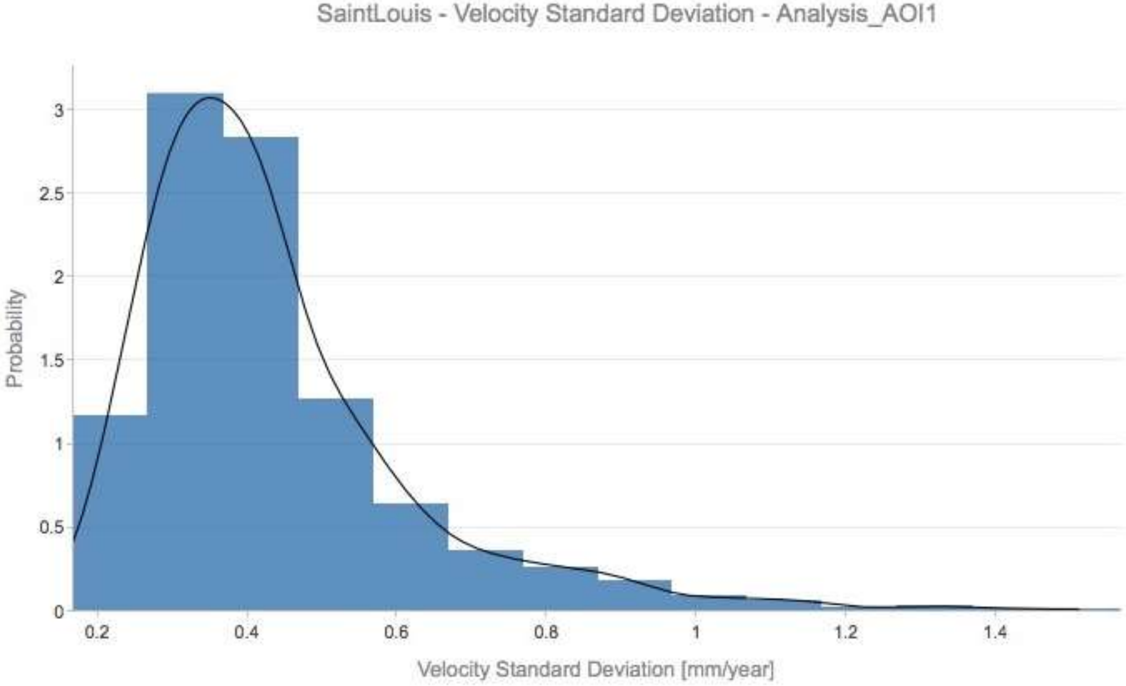
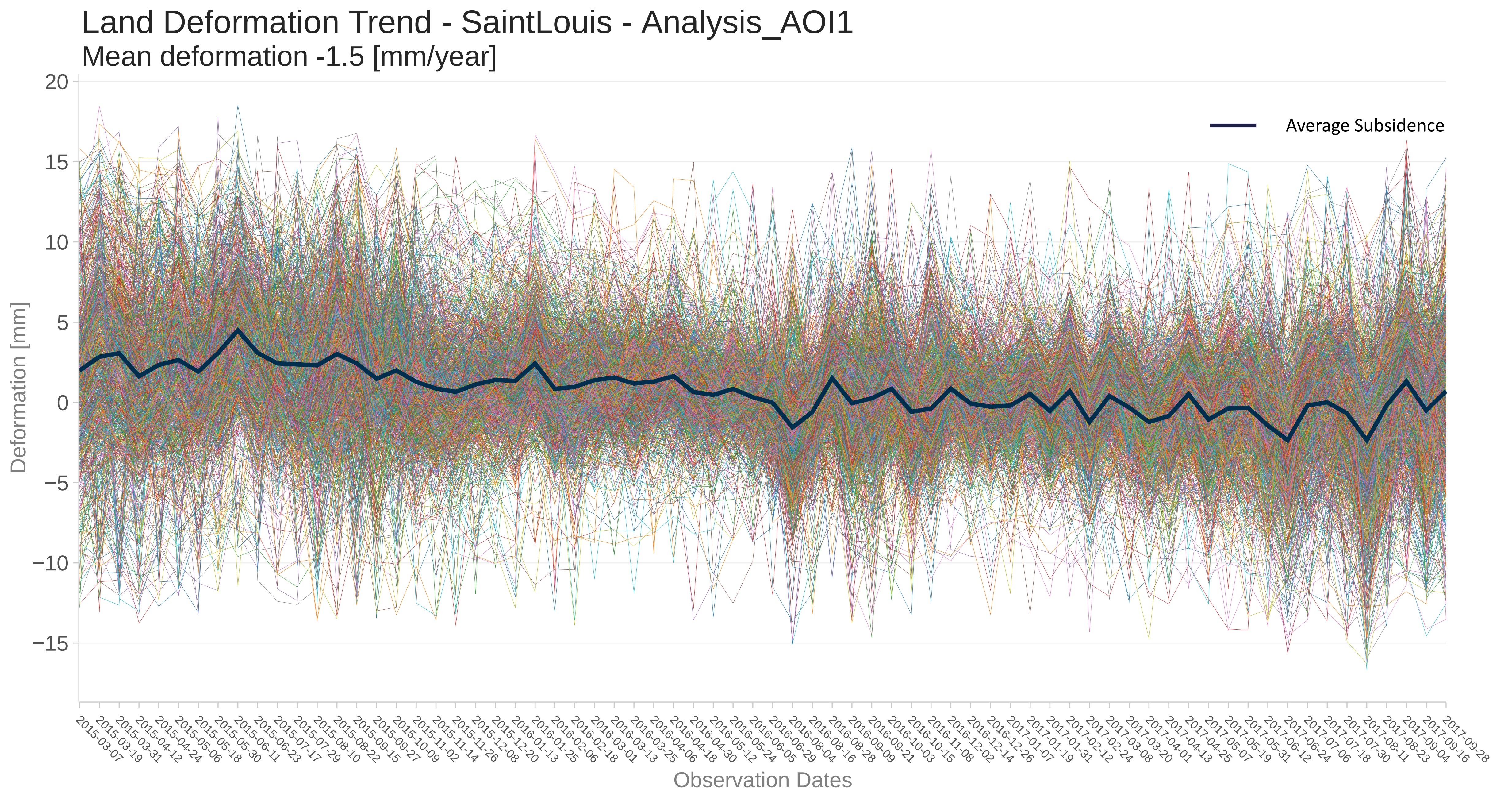


Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Comm

# Results  Sentinel-1 - Area of Interest 1
# Average subsidence: 1.5 mm/year






Export to plot.ly »

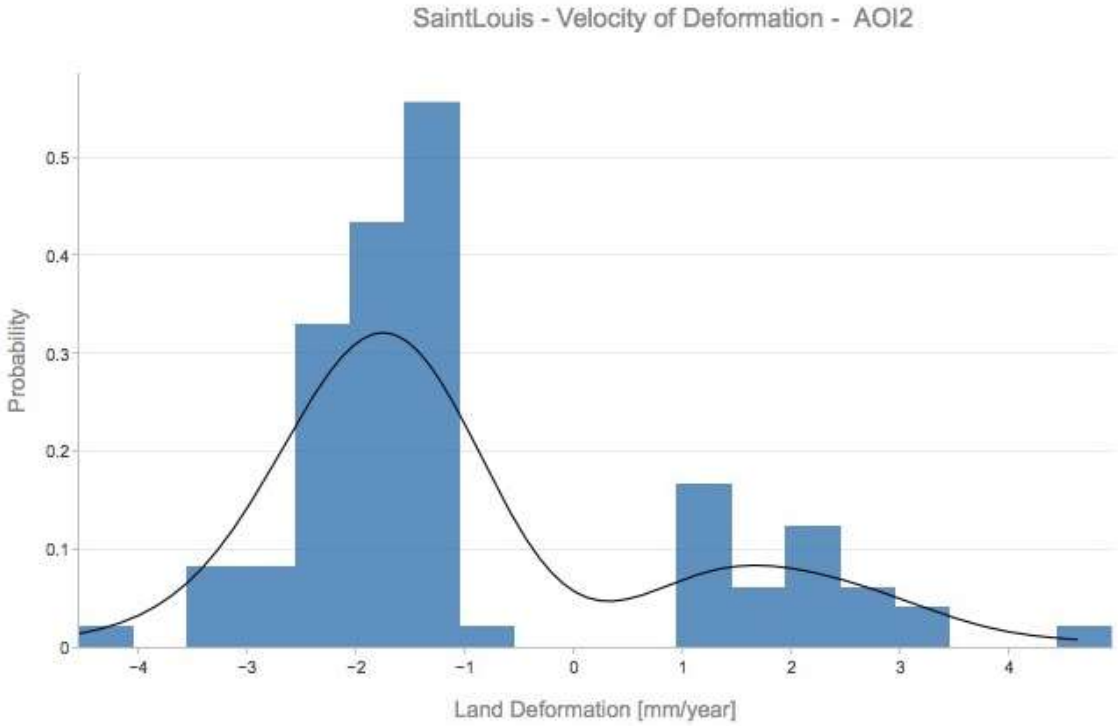
Results Sentinel-1
Area of Interest 1

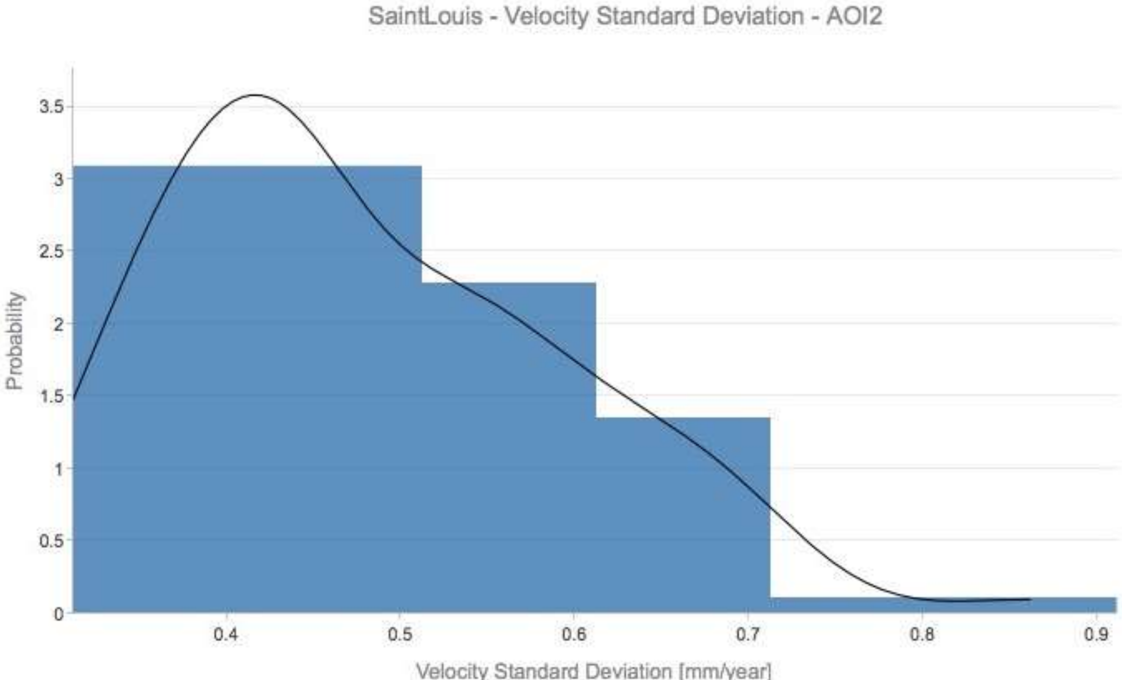
# Darou

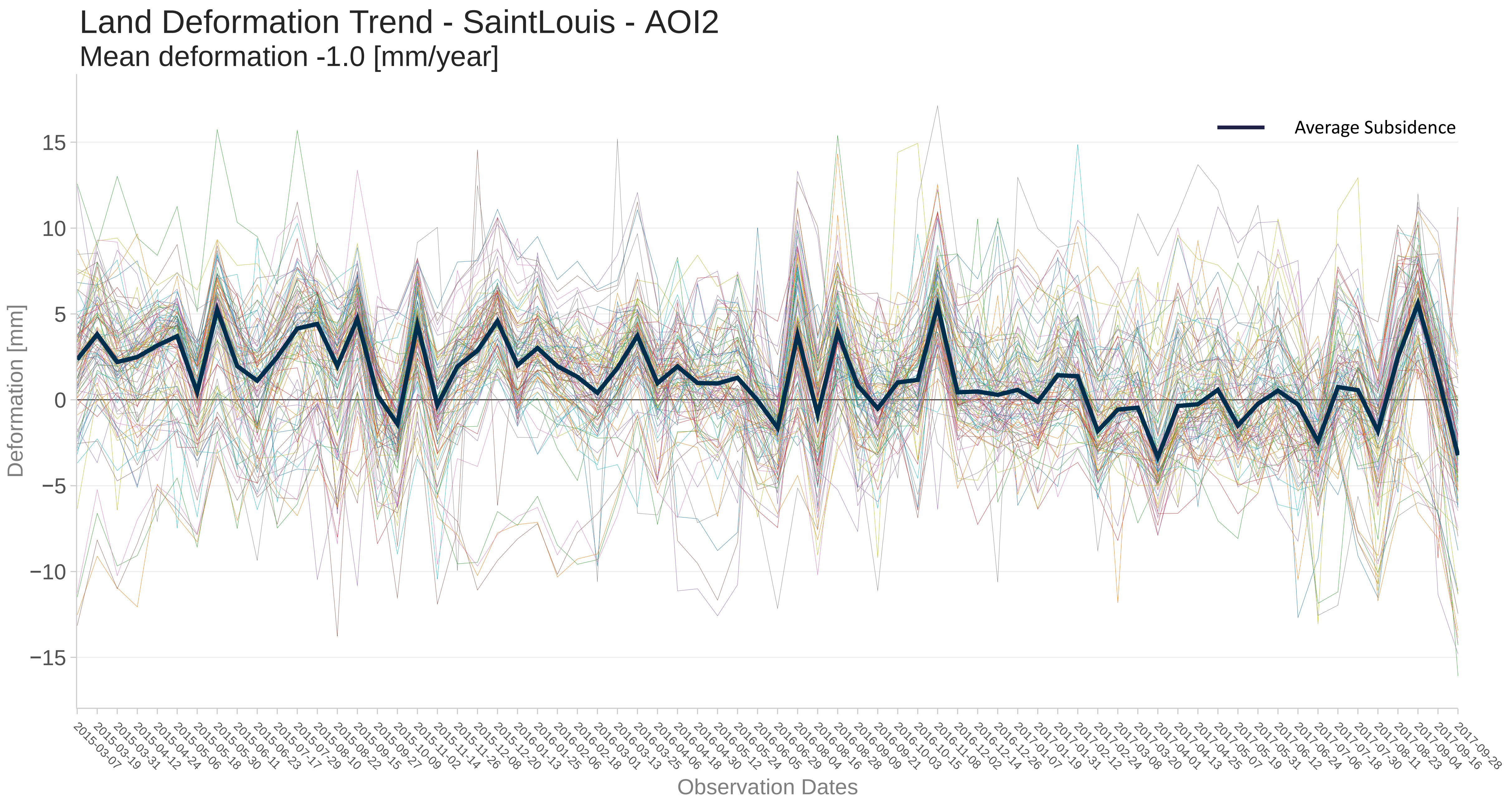
January 2004

Subsidence > 4 mm/year – Mar 2015 – Sep 2017

# Results  Sentinel-1 - Area of Interest 2
# Average subsidence: 1 mm/year



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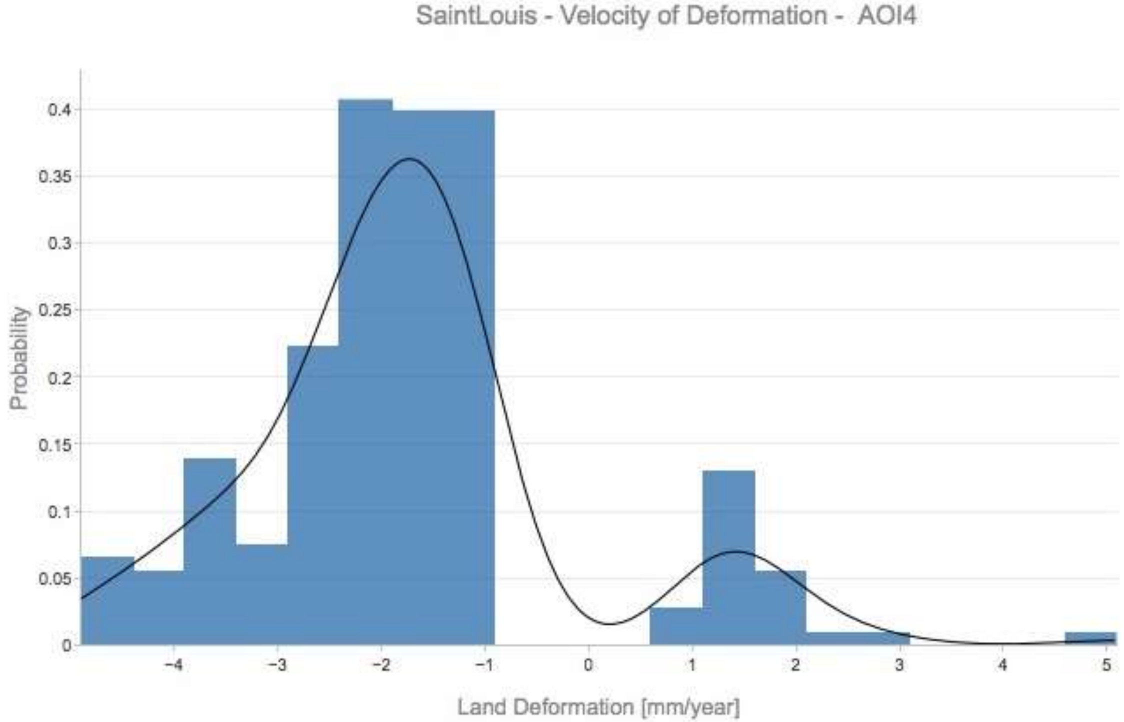
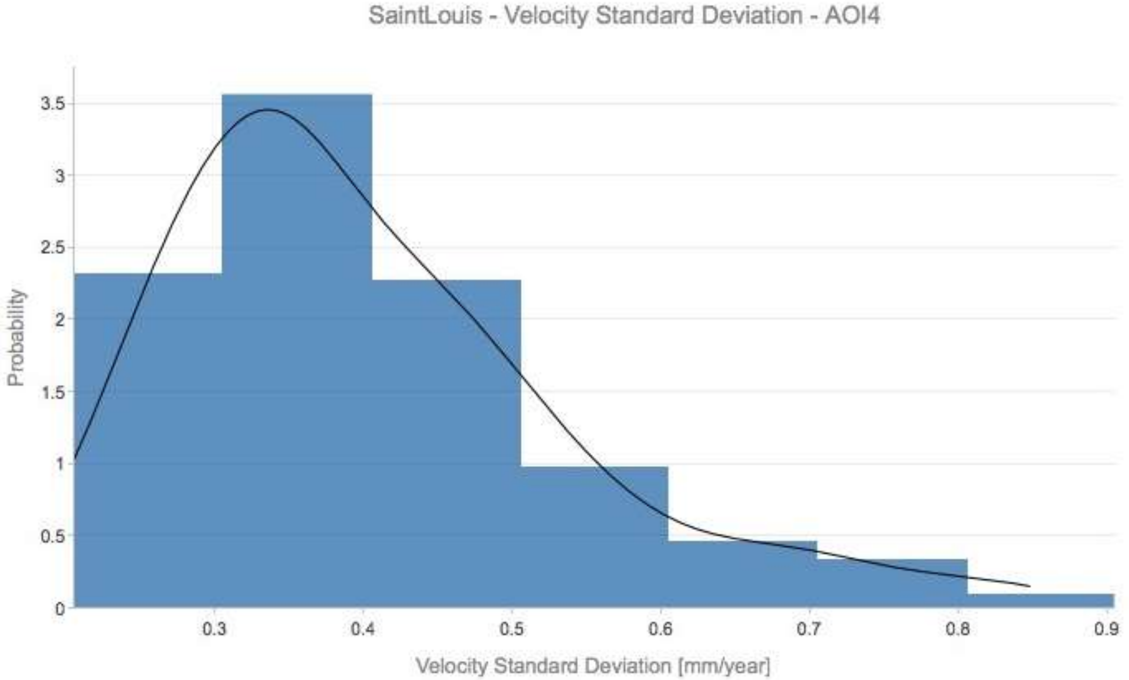
# Results Sentinel-1 - Area of Interest 2

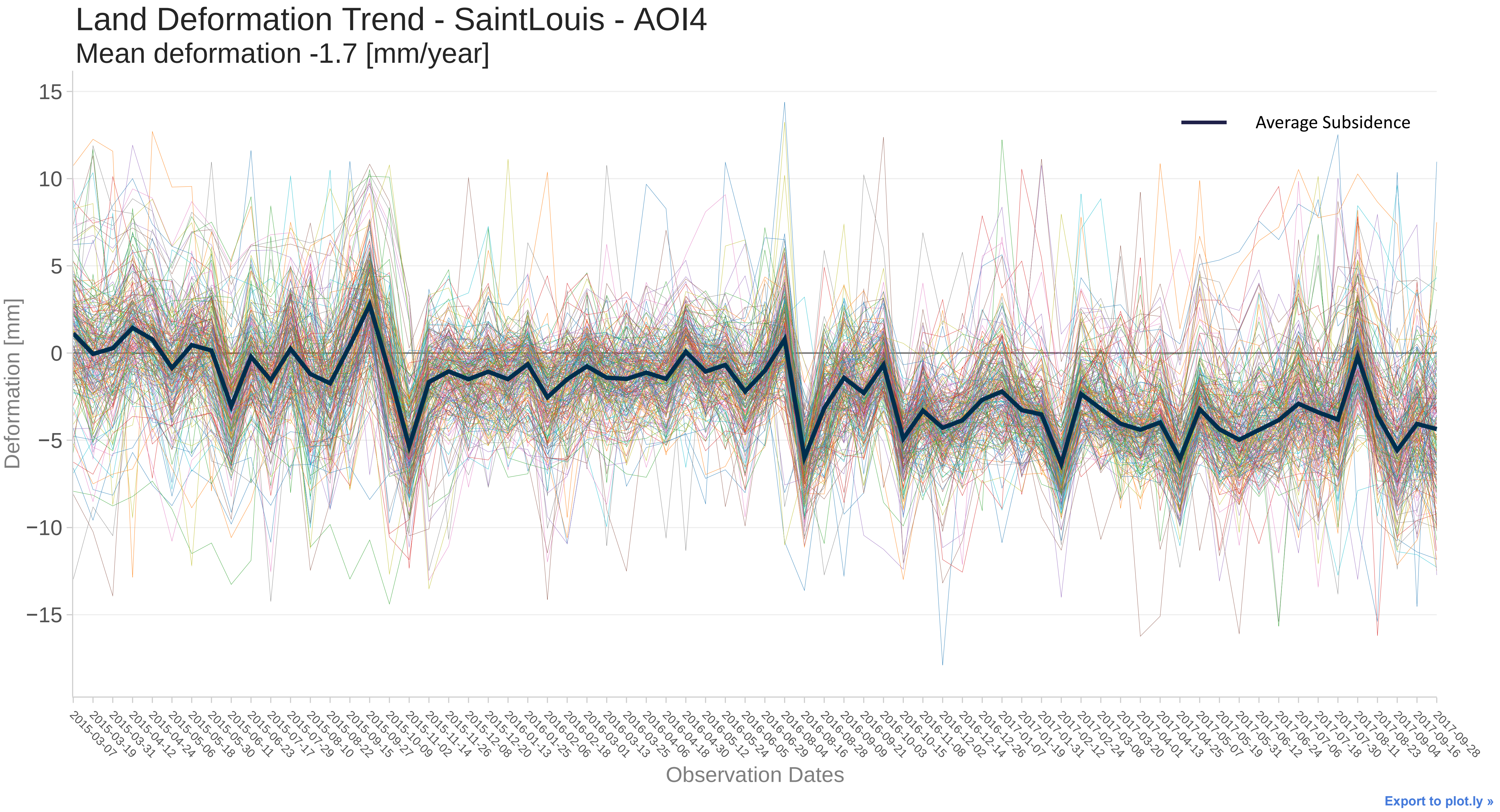
2009


2018

# Results Sentinel-1 - Area of Interest 4
# Average subsidence: 1.7 mm/year





Land Deformation Trend - SaintLouis - AOI4
Mean deformation -1.7 [mm/year]
Average Subsidence
Deformation [mm]
15
10
5
0
−5
−10
−15
2015-03-07
2015-03-19
2015-03-31
2015-04-12
2015-04-24
2015-05-06
2015-05-18
2015-05-30
2015-06-11
2015-06-23
2015-07-17
2015-07-29
2015-08-10
2015-08-22
2015-09-15
2015-09-27
2015-10-09
2015-11-02
2015-11-14
2015-11-26
2015-12-08
2015-12-20
2016-01-13
2016-01-25
2016-02-06
2016-02-18
2016-03-01
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2017-06-24
2017-07-06
2017-07-18
2017-07-30
2017-08-11
2017-08-23
2017-09-04
2017-09-16
2017-09-28
Observation Dates
Export to plot.ly »

# Results Sentinel-1
# Area of Interest 1

## **Darou**

2009


2018

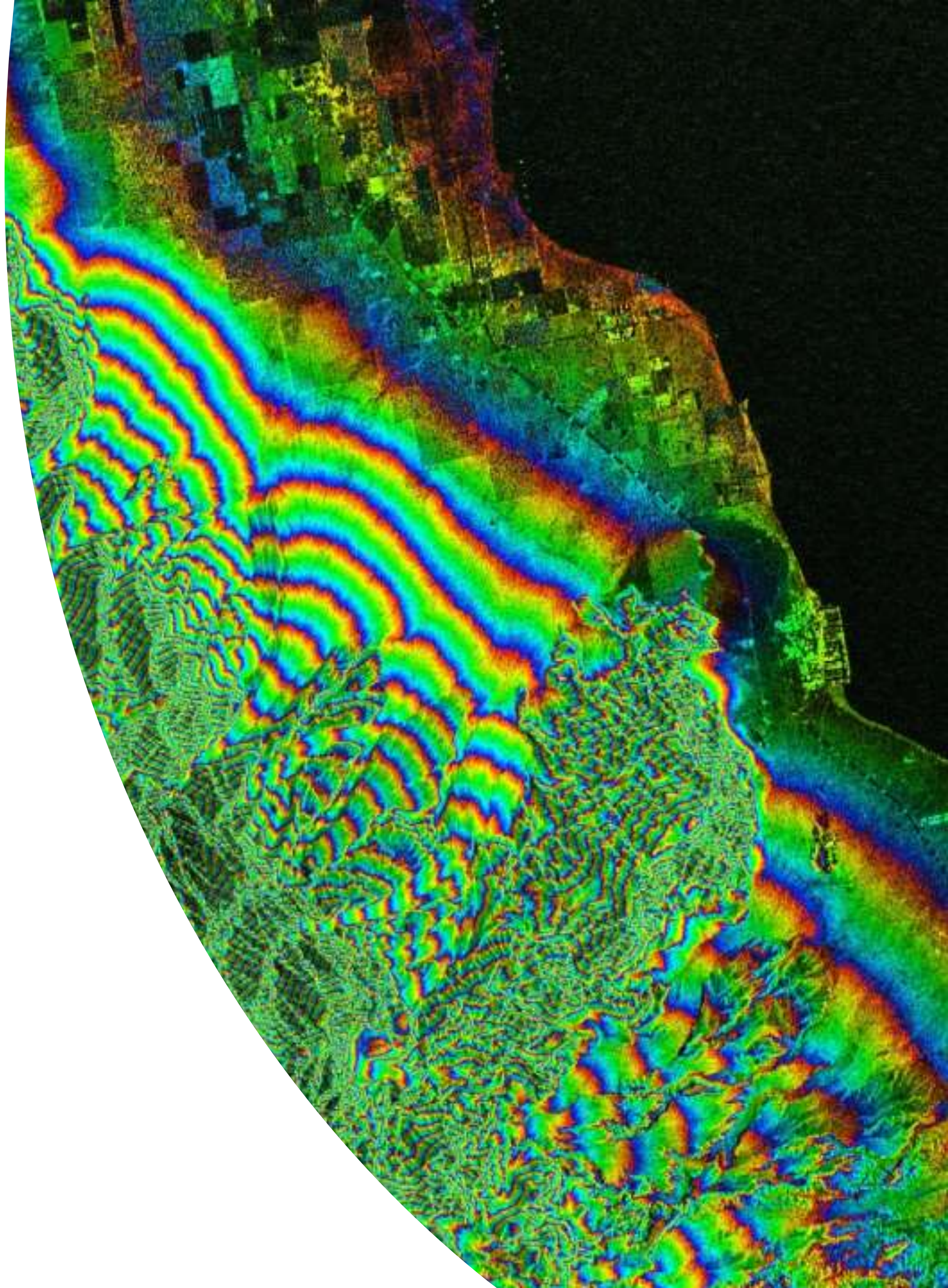
# Conclusions

Thanks to **new SAR data** and **InSAR technology** we can monitor with **precision** land deformation at a **large scale**

Availability of **open data** allows saving resources

The analysis can expose hotspots for which an **in-depth analysis** (high resolution and in-situ measurements) can be performed

We had the support of the **Research Support Service** of the **European Space Agency**



# Saint-Louis, Senegal

## Natural Hazards

### Flooding
- Storm surge
- River flooding
- Extreme precipitation

### Erosion
- Coastal erosion
- Mangrove deforestation

## Impacts

### Infrastructure
- Damaged housing & property
- Threat to cultural heritage sites

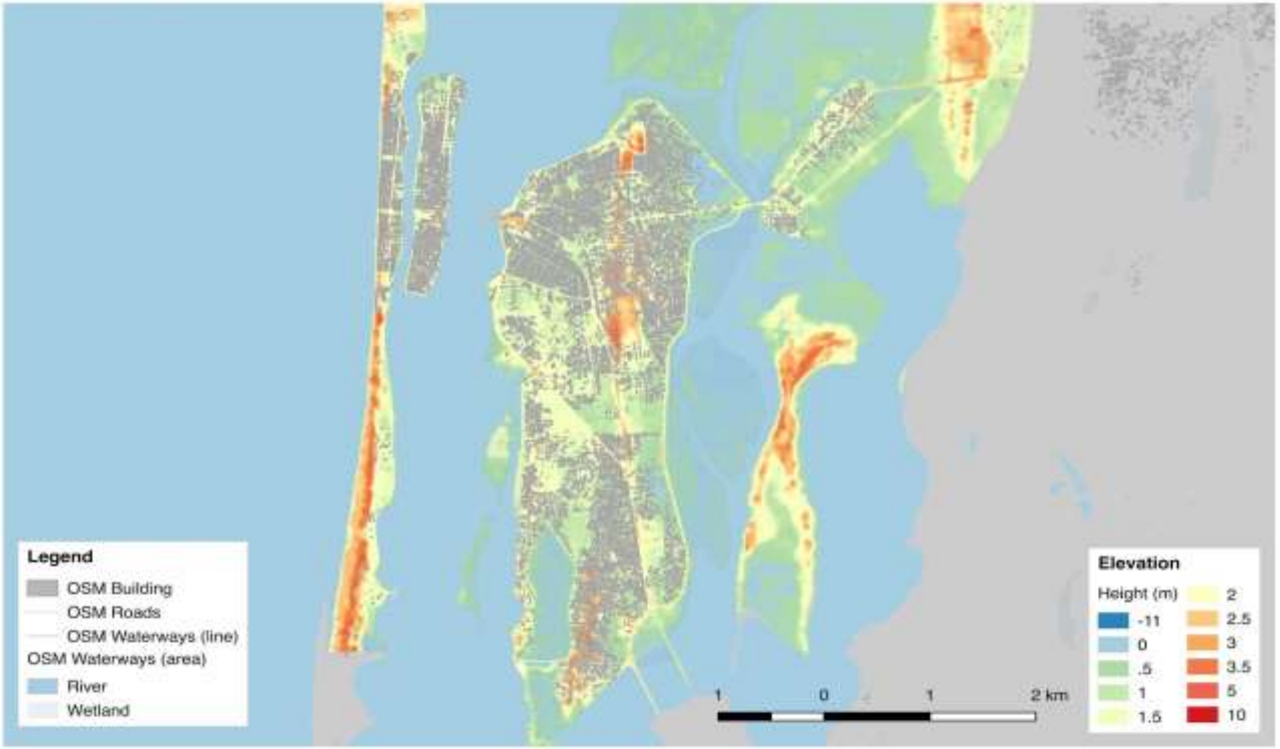
### Human
- Population displacement
- Tourist sites damaged
- Disease outbreak

## Investment Priorities

**Heavy flood protection infrastructure along the shoreline**

**Expand & improve drainage system**

**Relocation of residents along coastal peninsula**




# 2050 Scenario

## Climate & Extreme Weather
- **Sea level rise** up to 50 cm
- Increase in frequency & severity of **annual floods and storm surge**
  - Coastal storms increase **coastline retreat** along the Langue de Barbarie

## Anthropogenic Factors
- **Settlement continues** along the Langue de Barbarie and low-lying areas if no intervention
- **Critical sea wall barriers** status if no intervention
- **Tourism severely impacted** if no intervention

# Nouakchott, Mauritania

## Natural Hazards

**Flooding**
- Heavy rainfall
- Rising groundwater

**Erosion**
- Dune bar degradation
- Up to 80ft of beach lost per year

## Impacts

**Loss of dune bars and sea level rise lead to increased flooding**
- Thousands of inhabitants already displaced
- Water systems contaminated by saltwater

## Investment Priorities

**Expand & improve the city's drainage system**
- Improve water capture & supply to mitigate flooding & reduce contamination
- Build drainage networks to account for scenarios of unpredictability and precipitation reduction.
- Underground irrigation system

**Increase the city's coastal dune bar restoration**
- Reinforce measures to protect the coastal dune bars taking into account sea level rise, coastal erosion, and human interventions.
- Blocking of breaches

*The Guardian*

# 2050 Scenario

## Climate & Extreme Weather
- **Sea level rise** up to 50 cm
- Increased **subsidence**
- Increase in frequency and severity of **annual floods**

## Anthropogenic Factors
- **Population 2050: 1.6 million** (up from 960,000 in 2013)
  - More households will settle in the **lowest areas of the city** if no intervention
- **Critical drainage system** status if no intervention
- **Critical coastal dune bars** if no intervention
- More **development at the port** and **disturbed sediment flow**

# Mogadishu, Somalia

## Natural Hazards

### Flooding
- River & flash flooding
- Urban runoff

### Drought
- Inducing internal displacement

## Impacts

### Infrastructure
- Access routes to shelter, food, & medical care blocked

### Human
- Morbidity & mortality from flooding
- Water contact diseases from groundwater contamination
- Food insecurity from drought

## Investment Priorities

### Managing urban growth
- Create extension plans contiguous with existing urban fabric

### Upgrading basic infrastructure
- Upgrading strategic roads & drainage; rehabilitation of water supplies

### Durable solutions for IDP settlements
- Affordable housing program in infill areas; improved connectivity

# 2050 Scenario

## Climate & Extreme Weather
- **Sea level rise** up to 50 cm
- Increase in frequency & severity of **annual floods and storm surge**

## Anthropogenic Factors
- **IDP camps 30% larger** than today
- **Population 2050: 4.6 million** (up from 2.4m in 2017)
- **Critical drainage system** status if no intervention
- **Critical river system** status if no intervention

# Beira, Mozambique

## Natural Hazards

### Flooding
- Storm surge
- Cyclones

### Erosion & Soils
- Coastal & dune erosion
- Land subsidence

## Impacts

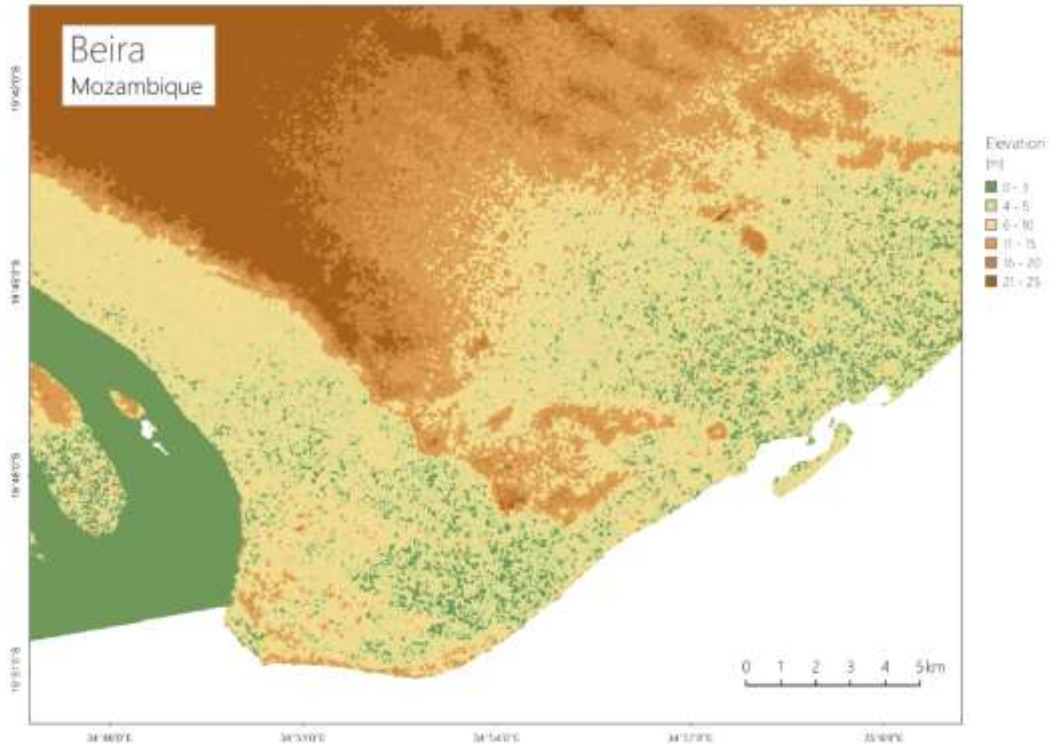
### Infrastructure
- Sea wall for port and vegetation & dune barriers will not withstand future SLR
- Existing stormwater drainage and sanitation systems are under capacity

### Human
- Settlements along the coast and in floodplains flooded
- Salt intrusion into municipal and sugar plantation freshwater sources

## Investment Priorities

### Upgrading basic infrastructure (grey & green)
- Chiveve River has been rehabilitated, green park investment under implementation
- Tidal defense and coastal protection systems

### Mitigating Health Impacts
- Access to sustainable water, sanitation, and hygiene must be prioritized




# 2050 Scenario

## Climate & Extreme Weather
- **Sea level rise** up to 50 cm
- Increase in frequency & severity of **annual floods (Chiveve and Pungue rivers) and storm surge**
- Increased level of **salt intrusion** in Pungue River

## Anthropogenic Factors
- **Population 2050: 850,000 (up from 530,000 in 2017)**
- **Sea wall** protecting the port will be useless without intervention
- **Critical coastal protection** structures if no intervention

# How would YOU protect Africa’s coastal cities from climate change?

Disaster Risk Management Planning
for Resilient Coastal Cities

**Goal:** Find the best array of solutions for improving your city's resilience to natural hazards.

Your DRM plan must address the extreme climate & human impact scenario for 2050.
Your DRM plan should **satisfy stakeholders** and be **innovative**, **financially sustainable** and **resilient**.

## Limitations

Each team has 250 tokens available for spending from now until 2050.

Each team must present their plan to the audience!

# Pricing



Build your resilience plan from the following categories:

**Infrastructure** construction or rehabilitation

- “Grey” infrastructure (e.g. pipes, pumps, roads, reservoirs…)
- “Green” infrastructure, aka nature-based solutions (e.g. watershed restoration, wetland barriers…)

**Data collection**

- Traditional data collection (e.g. bathymetric surveying, sediment transport analysis, etc.)
- Community data collection (e.g. participatory mapping, stakeholder workshops, etc.)

**Study** (e.g. feasibility study, assessment of infrastructure, etc.)

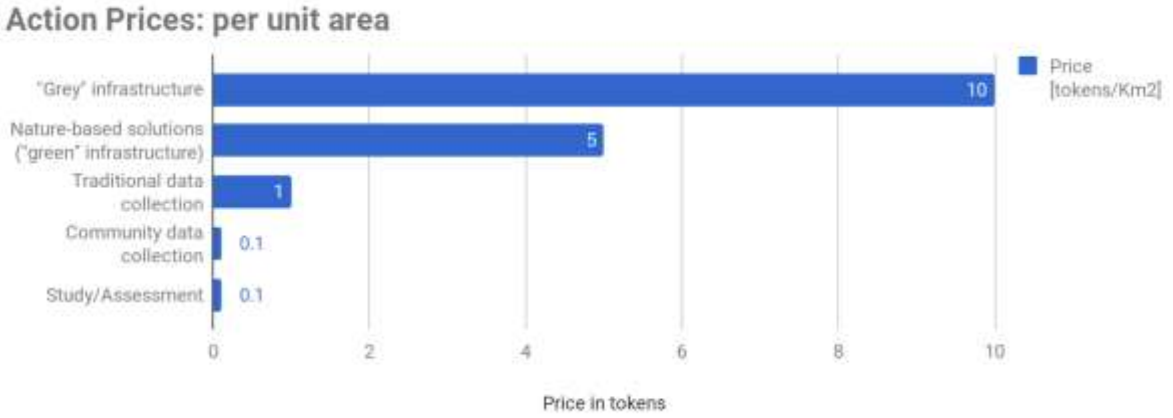
**Technical systems** (e.g. early warning system)

**Data tools** (e.g. data collection app, database, interactive maps, etc.)

**Policy** design and implementation (e.g. wetland protection, zoning laws, etc.)

**Capacity-building** (for government or community stakeholders)

250 tokens from now until 2050

**These worksheets are useful but OPTIONAL:**

- Pricing chart
- Solutions sheets
- Self-evaluation

Use your maps and your city adviser!