# Monitoring bridges from space: from measurements to end-user tools

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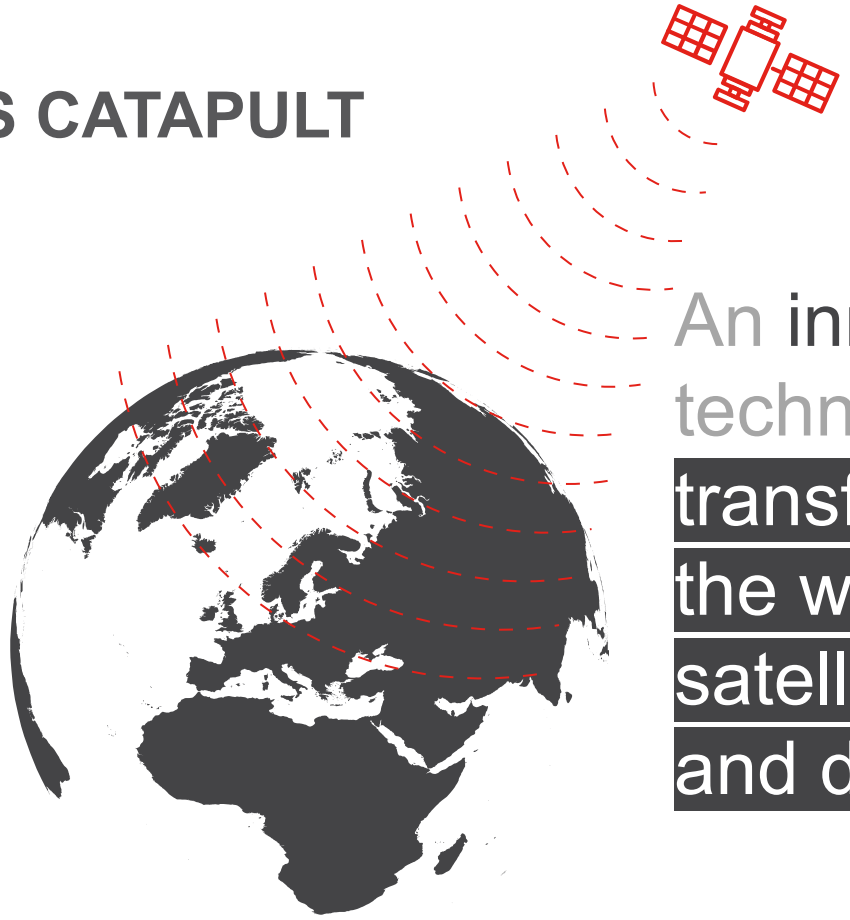
We work with
Innovate UK

CATAPULT
Satellite Applications

SATELLITE APPLICATIONS CATAPULT

# Who are we?



An innovation and technology company transforming the way the world uses satellite technology and data.

## WE HELP ORGANISATIONS GROW THEIR BUSINESS

We help organisations to use satellite applications to grow their business in the UK and internationally.

## WE ARE INDEPENDENT

We bring together industry, researchers, end-users and government to explore and develop new ideas.

## WE ARE GOVERNMENT BACKED

We are partly-funded by the Government and work closely with Innovate UK, UK Space Agency, UK Science & Innovation Network, and other public bodies.

# The NRC at a glance

## *Three key roles:*

*- Advancing knowledge, through strategic R&D*
*- Business innovation, through TS and IRAP*
*- Federal policy mandates.*

- 3,700 scientists, engineers & technicians, including 255 SME technology advisors.
- Manages 178 buildings in 72 locations.
- $1.1 B annual budget, including $271 M in funding for SMEs.
- Expertise in 14 areas of S&T


## We work with

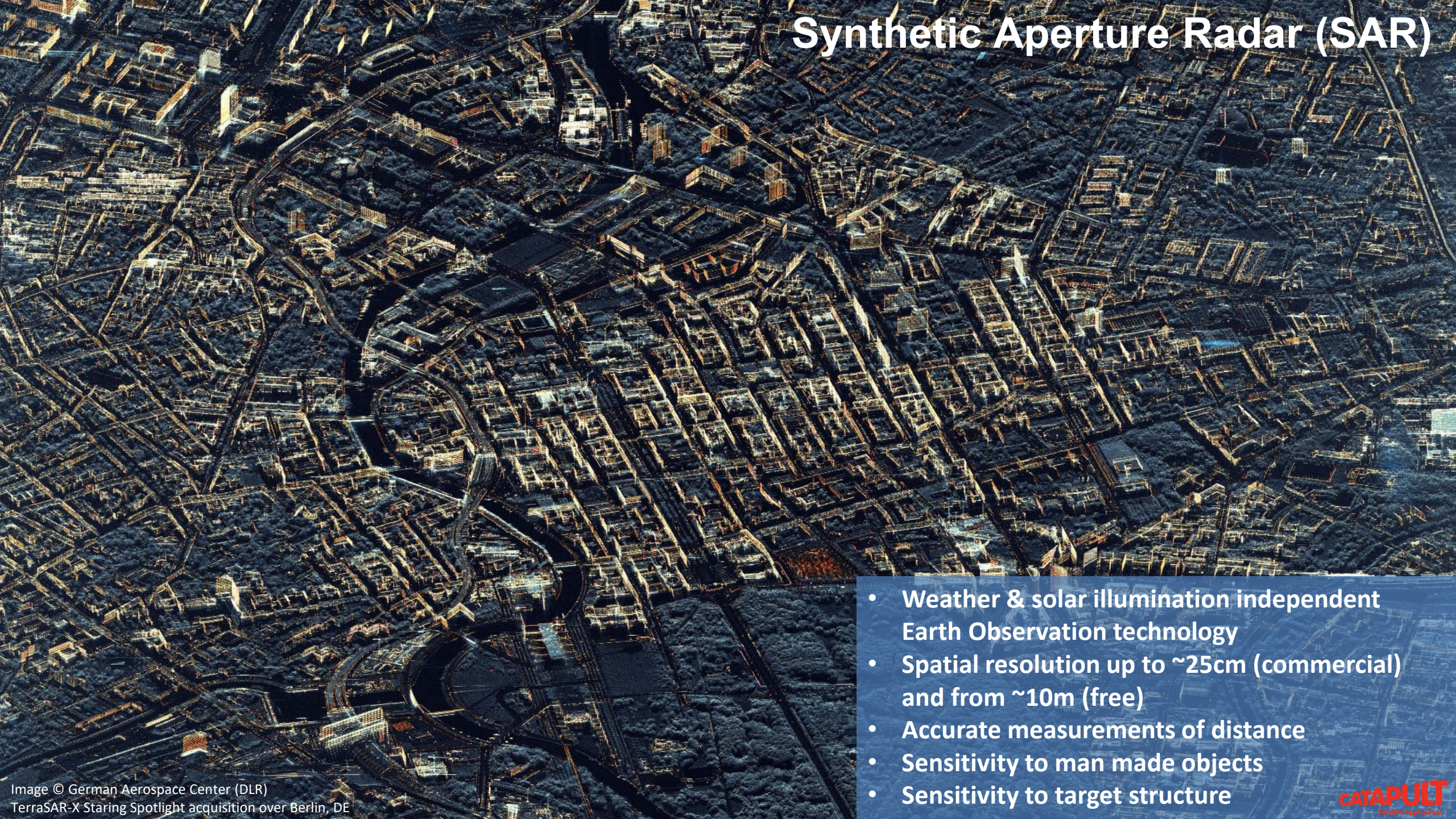
- **8,000** SMEs (advice & funding)
- **1,000** companies (R&D)
- **150** hospitals
- **70** colleges and universities
- **35** federal departments
- **36** countries

# Motivation

- Bridges are critical to transportation networks across the country
- Bridge infrastructure is aging and in need of rehabilitation
- Inspection and maintenance budgets are limited
- Bridge owners need modern structural health monitoring technologies
- New technologies need to be validated in the field for wider acceptance

→ *Satellite monitoring of bridges is considered as a promising technology*

# Synthetic Aperture Radar (SAR)



- Weather & solar illumination independent Earth Observation technology
- Spatial resolution up to ~25cm (commercial) and from ~10m (free)
- Accurate measurements of distance
- Sensitivity to man made objects
- Sensitivity to target structure

Image © German Aerospace Center (DLR)
TerraSAR-X Staring Spotlight acquisition over Berlin, DE

# Displacement model

- Displacement pattern can be modelled to take into account thermal expansion:

$$d(t) = v \cdot t + k \cdot T + d_{nl}(t)$$

deformation mean velocity [mm/year]

thermal coefficient [mm/°C]

temperature [°C]

non-linear motion

- In the literature accuracy up to 0.04 mm/°C has been reported for the thermal sensitivity

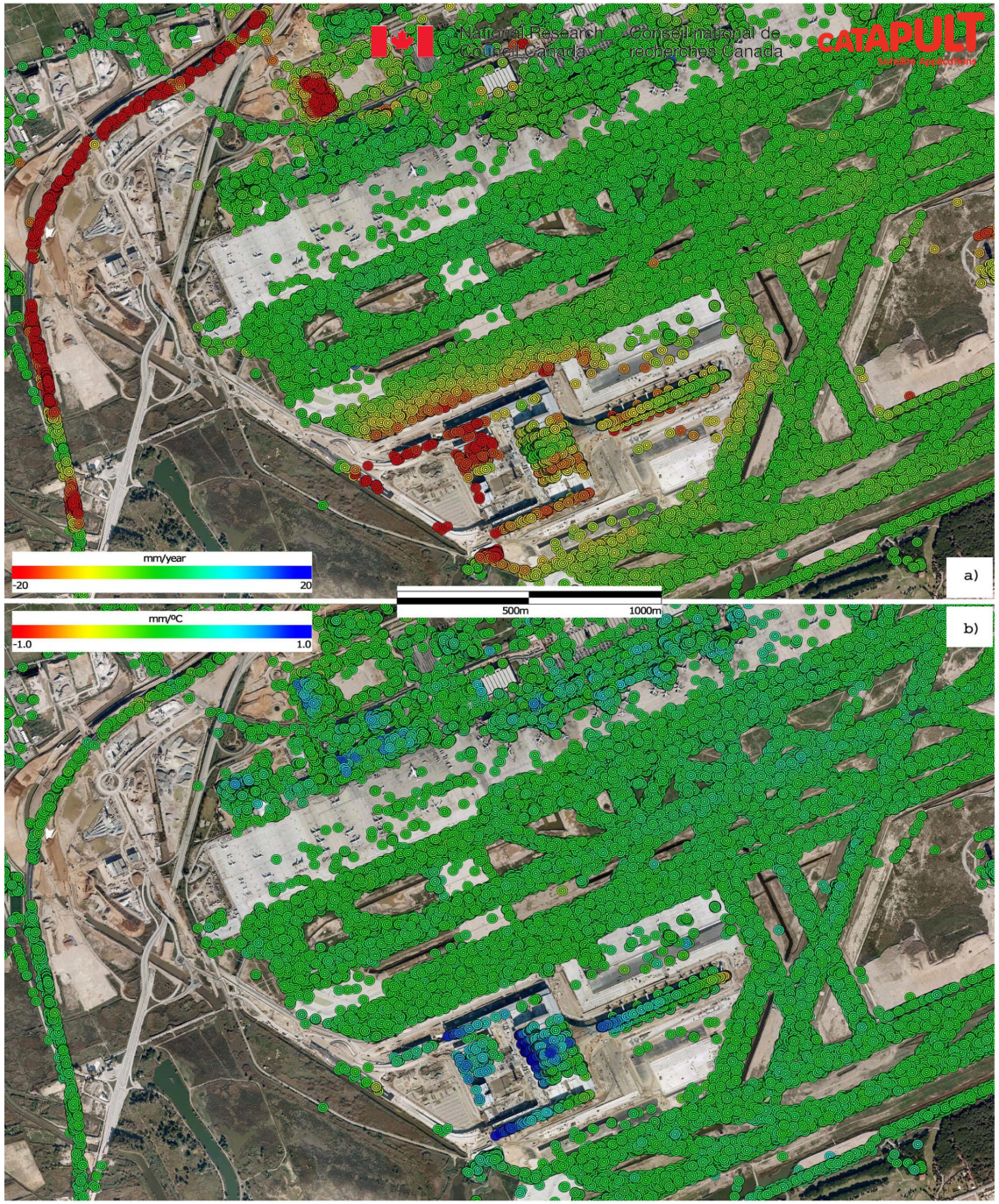
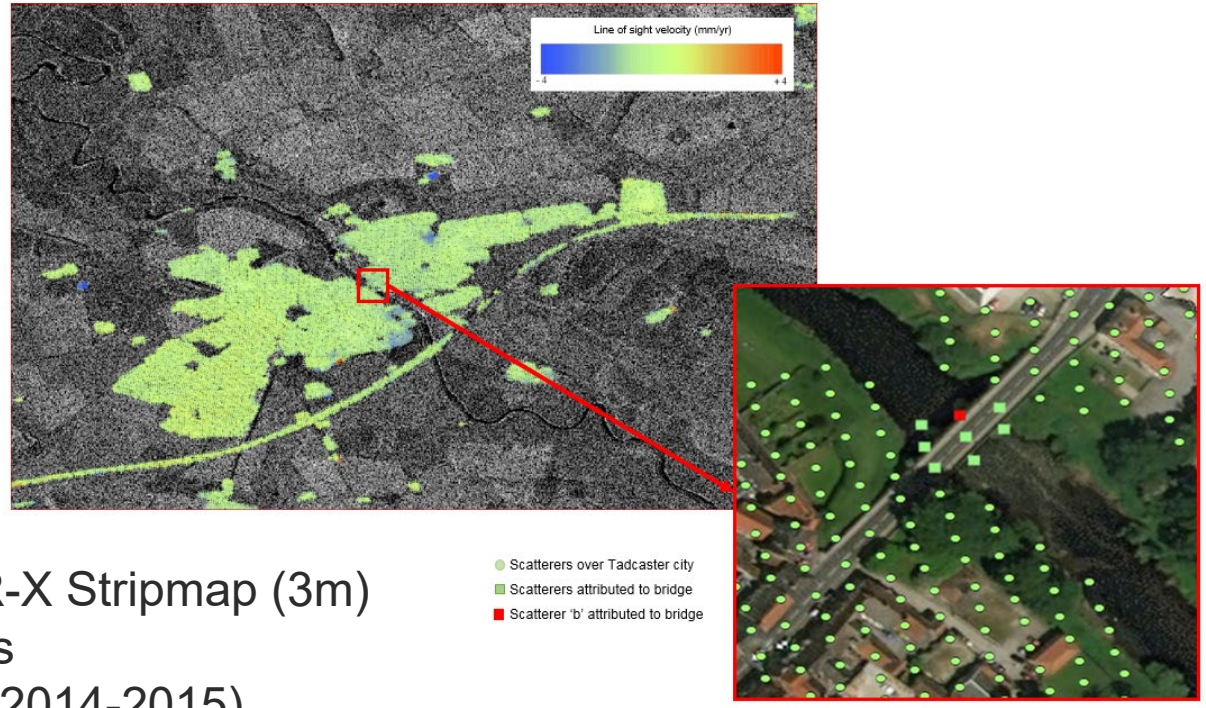


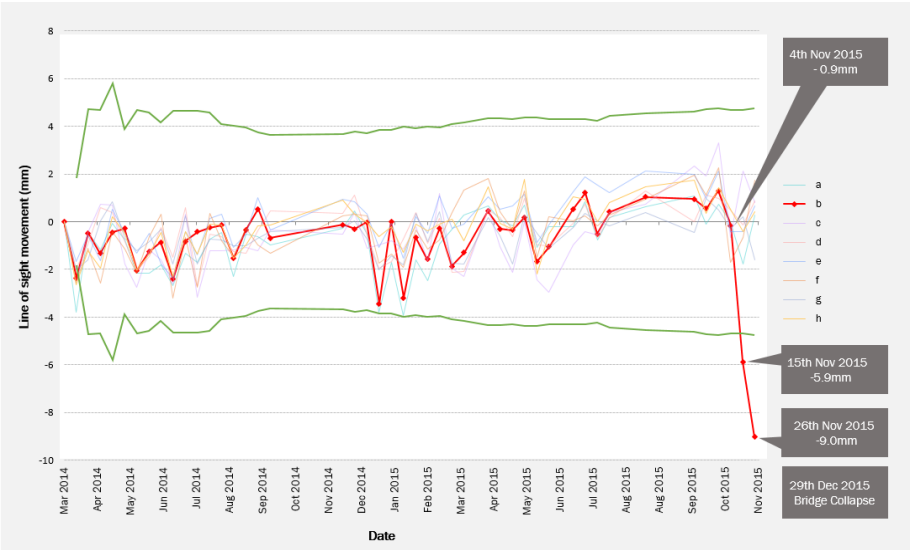

Image © Monserrat et al, GRLS (IEEE), 2011
Deformation and thermal maps over the Barcelona airport

# Tadcaster Bridge, Tadcaster, UK (Selvakumaran, 2018)


- Road bridge
- 100 m
- Masonry bridge
- Collapse on the 29/12/2015 due to scouring

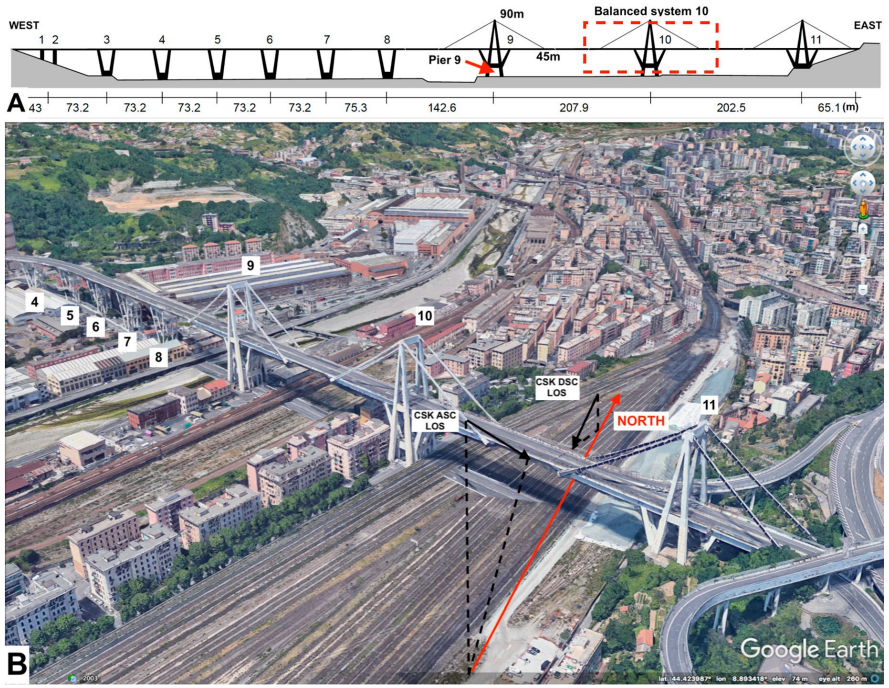



- TerraSAR-X Stripmap (3m)
- 48 scenes
- 1.5 year (2014-2015)



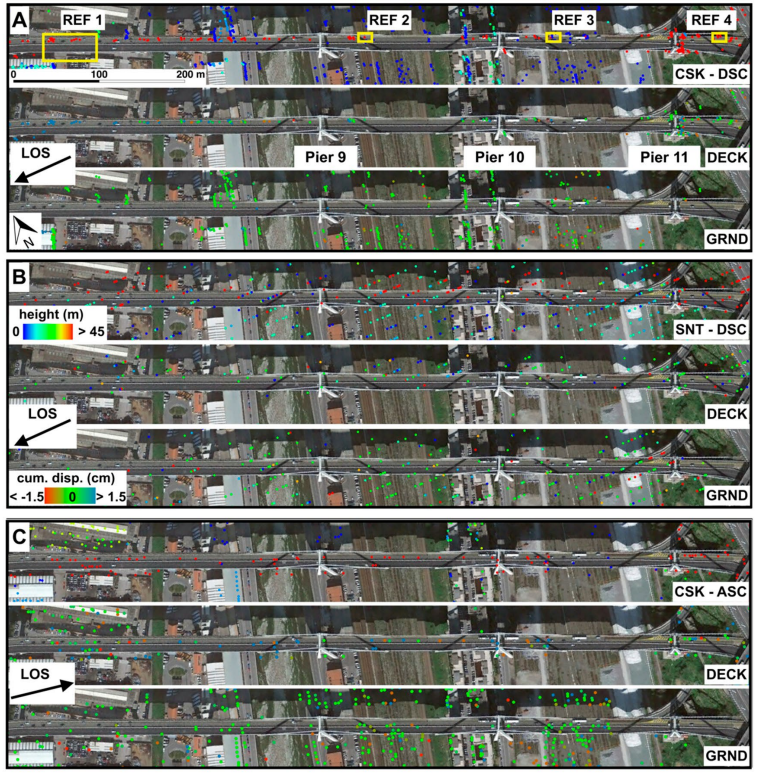

- Few measurements on the bridge with a single outlier at the collapse location
- Correlation with precipitation and gauged daily flow
- First demonstration towards early warning systems

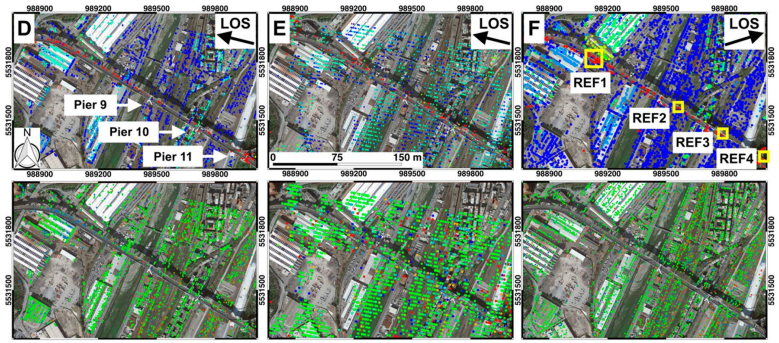
# Morandi Bridge, Genoa, Italy (Milillo, 2019)




- Highway bridge
- 1300 m
- Concrete cable-stayed bridge,11 piers
- System 9 and 240m of deck collapsed on 14/08/2018
- 43 casualties

  - 130/148 CSK stripmap (3m)
  - 134/136 S1 (20x5m), full set
  - 9 years (2009-2018) CSK

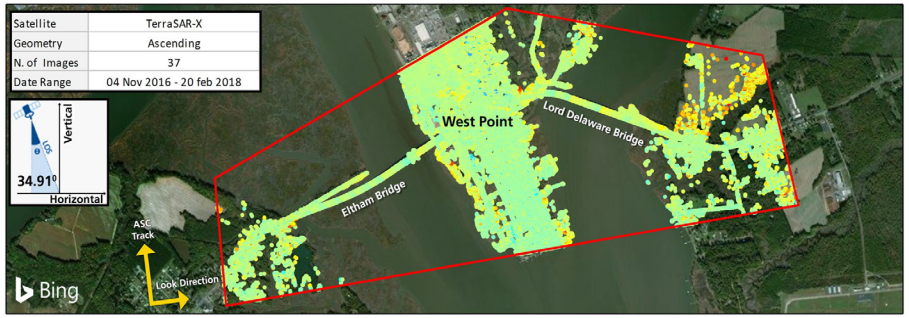


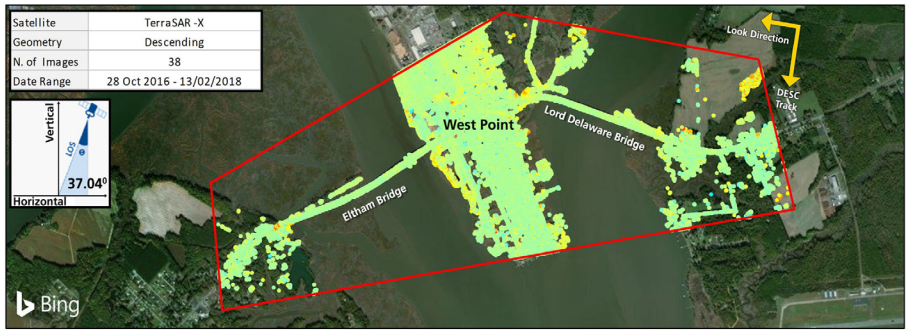




- Multi-sensor approach to derive 3D movements
- Increased accumulation of relative displacements of deck 9 vs 10,11
- Anomalous behaviour of few PSs in the collapse area from 12/03/2017 showing increased acceleration
- Controversy with public government report not showing anomalies with CSK data (2016-2018)

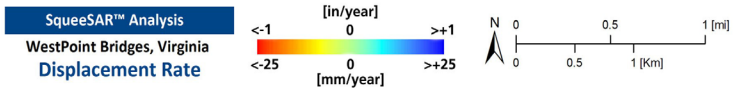
# Eltham Bridge, West Point, USA (Hoppe, 2019)

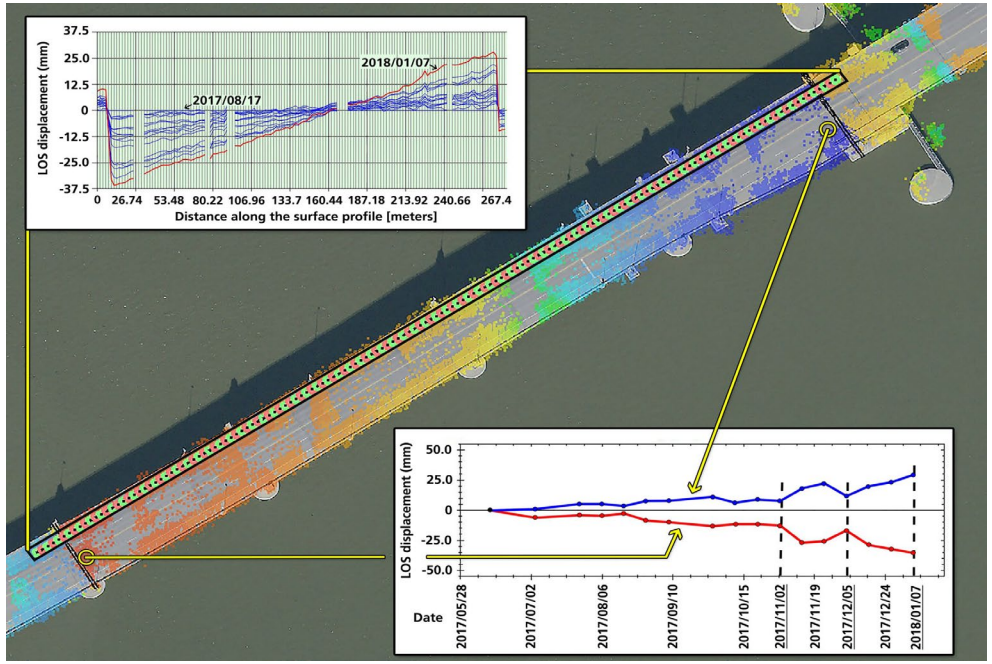

- Highway bridge
- 1629 m, 49 spans
- Concrete bridge




- TerraSAR-X Staring Spotlight (0.25x0.6m)
- 37/38 scenes (a/d)
- 1.5 year (2016-2018)



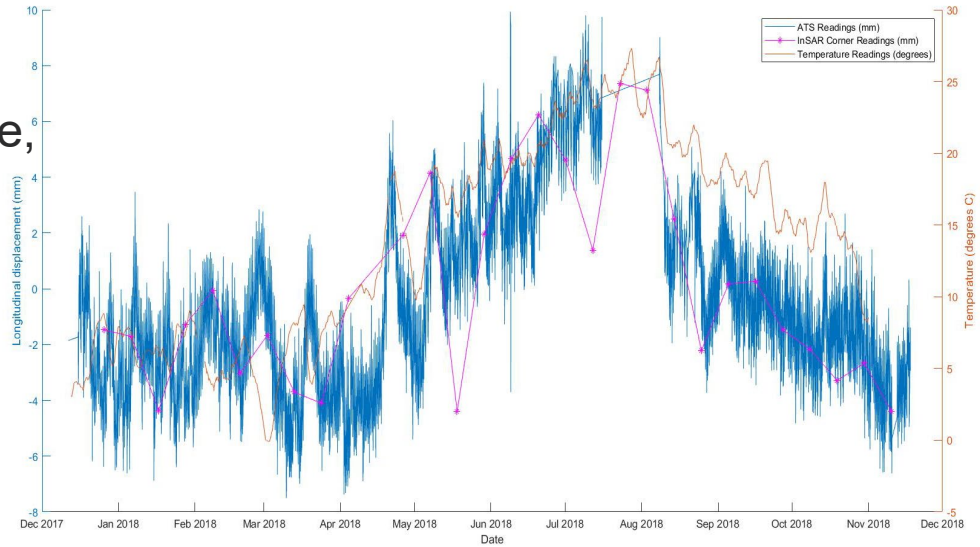




- No thermal decomposition but displacement linked to thermal expansion (37 °C gradient)
- Test with stripmap data (3m) shows much sparser measurements

*"In order to be of practical application to bridge owners, the presentation of InSAR results demands advanced data visualization techniques, including heavy reliance on the geographic information system (GIS) representation. Additional research is needed in this area to advance the current practice, with successful implementation requiring a coordinated multidisciplinary team effort. The ultimate objective is to develop a decision support system that translates the complexities of satellite-based InSAR data processing into a process control tool that can be effectively managed by bridge engineers."*

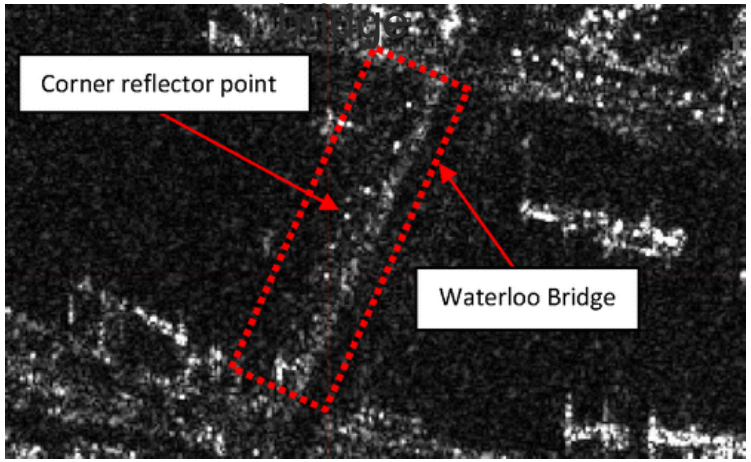
# Waterloo Bridge, London, UK (Selvakumaran, 2019)


- Road bridge
- 434 m
- Concrete bridge, five spans




- TerraSAR-X stripmap (3m)
- 27/27 scenes (a/d)
- 1 year (2017-2018)

- 6 corner reflectors (CR) mounted on both side of the

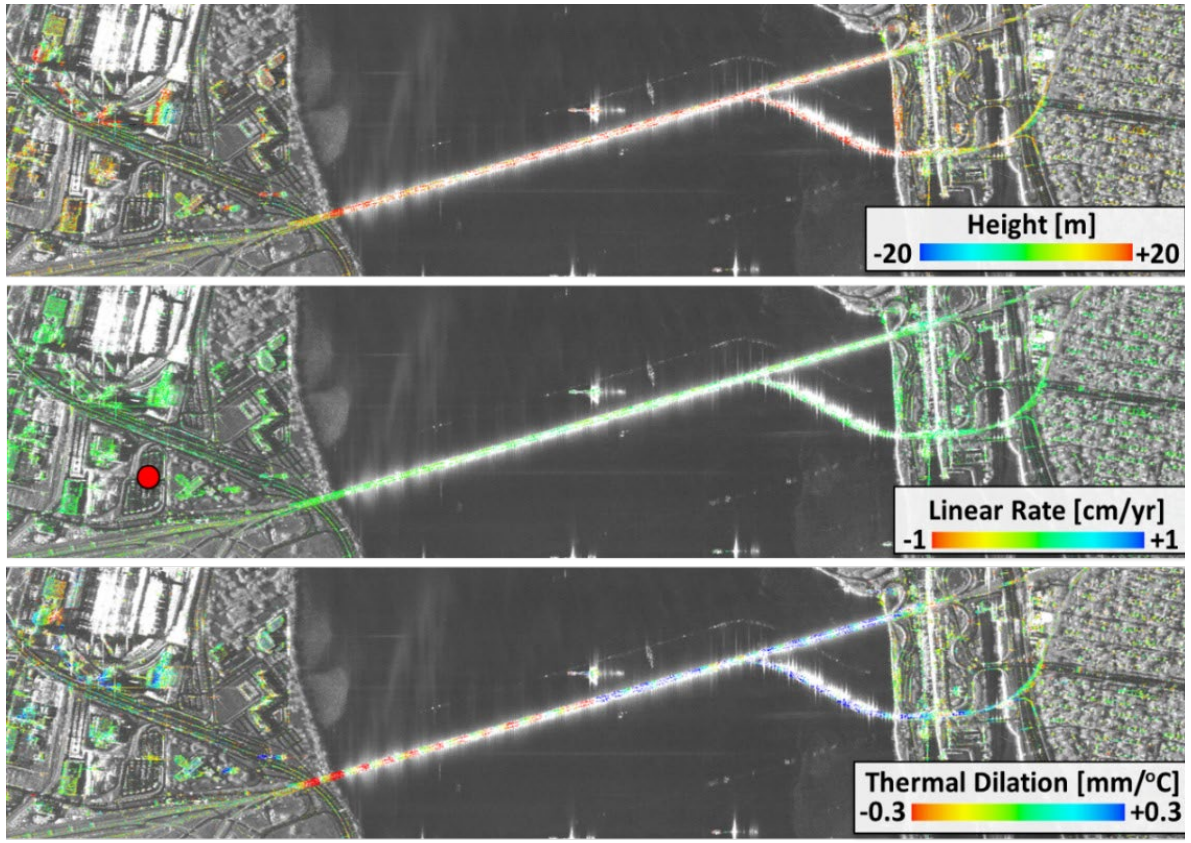



- CR experiment on land
- First InSAR validation with in-situ data over bridges
- Good but not perfect match
- Necessity of CR installation at 3m resolution
- **AMSIT project test case**

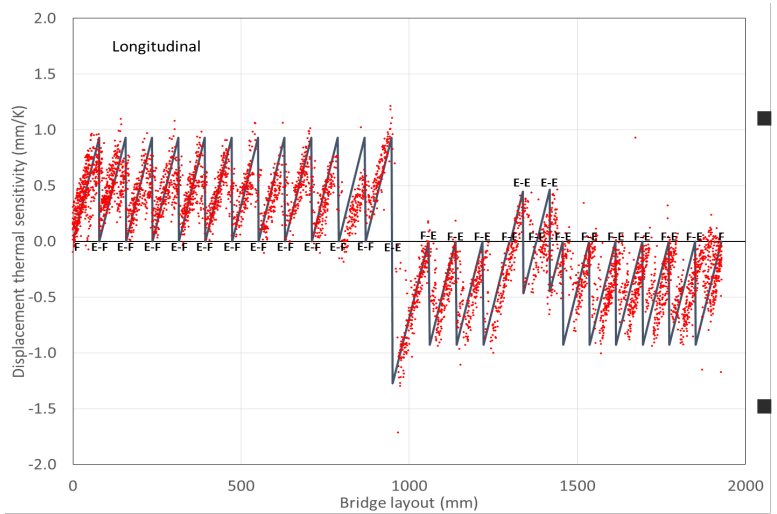
# Victoria Bridge, Montreal, Canada (Cusson, 2019)

- Road and rail bridge in use
- 3 km
- 26 spans

- Radarsat-2 spotlight (1.6x0.8m)
- Ascending (19 scenes) and descending (28 scenes)
- 2 years (2016-2018)

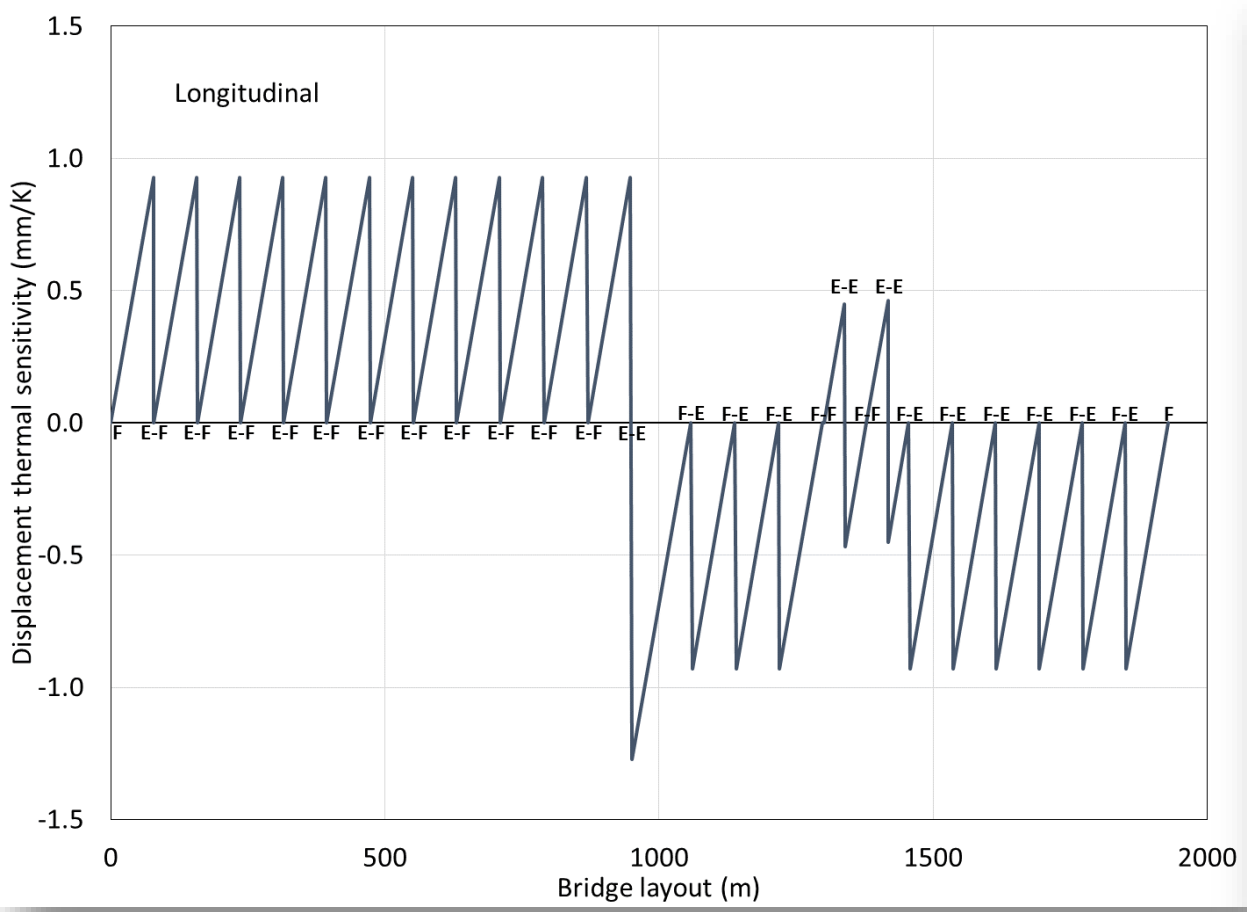



- No significant displacements
- Regular thermal movement cycles with change in polarity in the middle

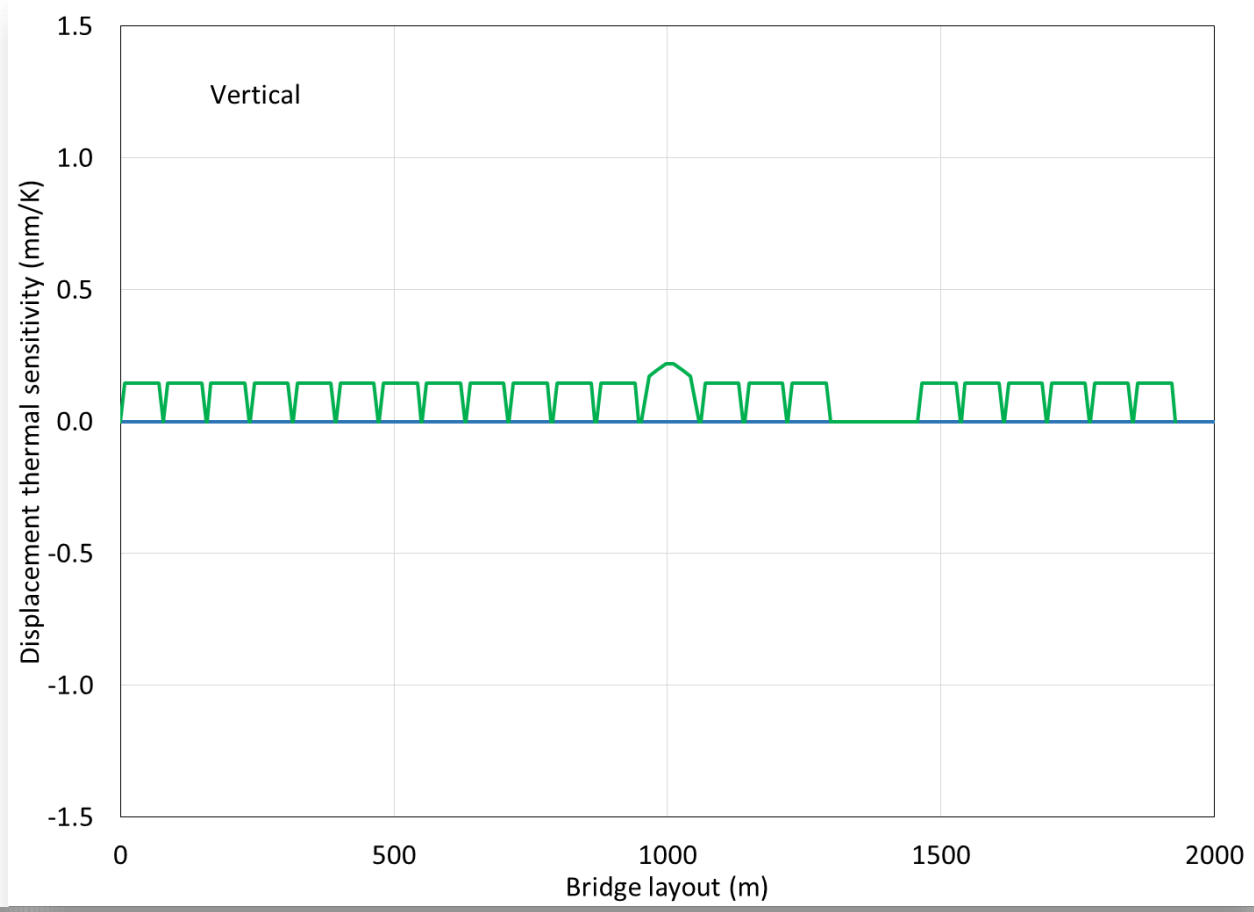



- Very good matching of thermal movement prediction vs InSAR measurements
- **Brigital test case**

# Predicted longitudinal and vertical thermal displacements

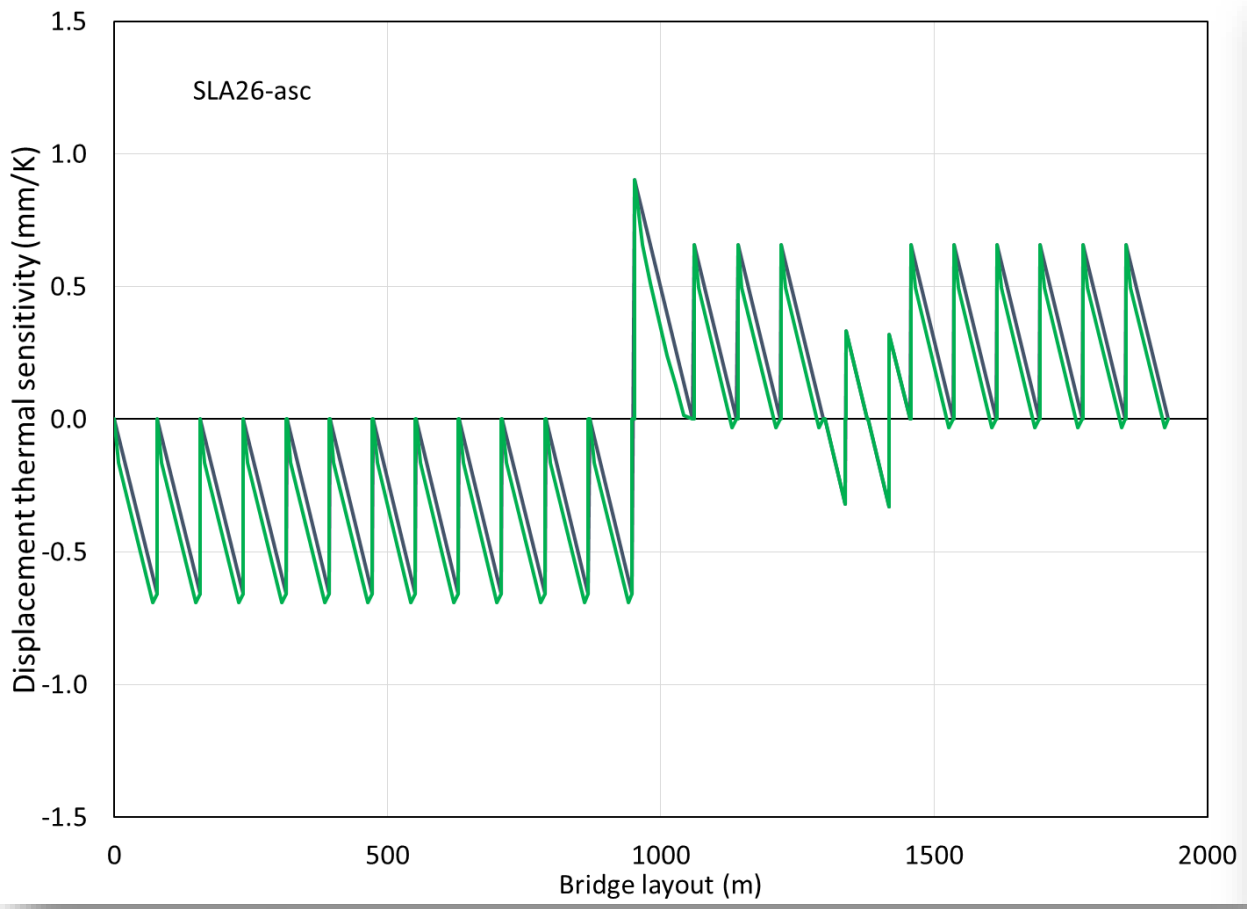



Longitudinal displacement thermal sensitivity

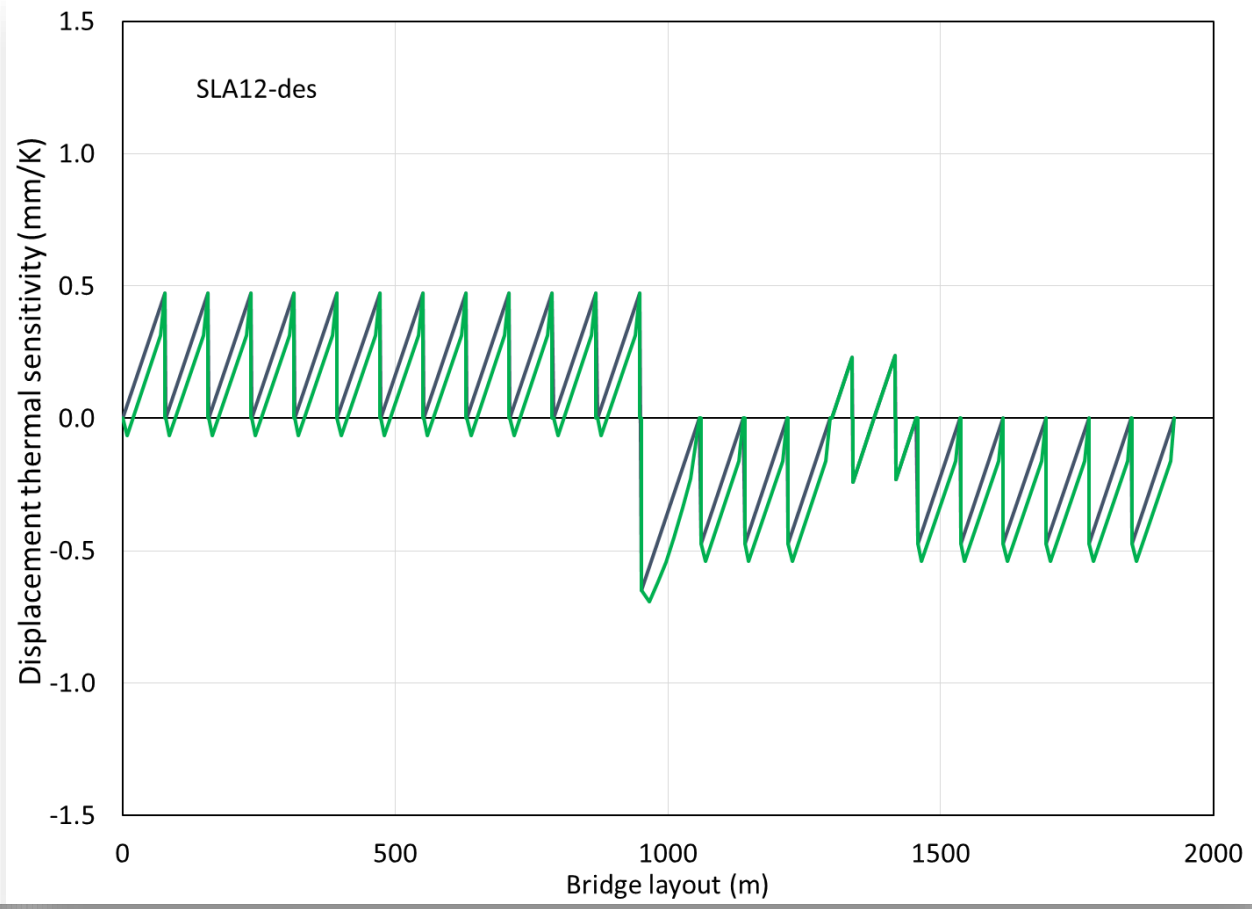



Vertical displacement thermal sensitivity

# Predicted LOS thermal displacements

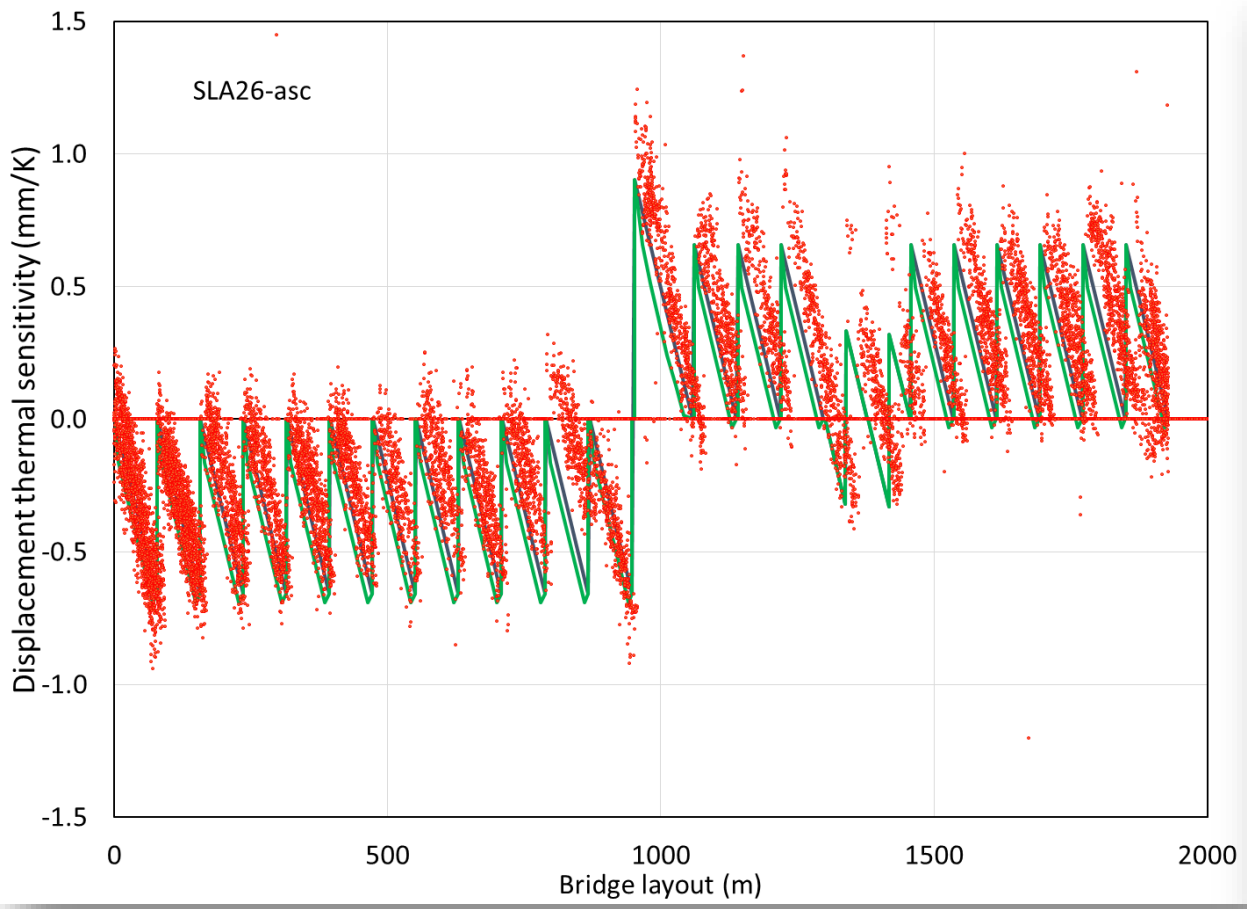



LOS displacement thermal sensitivity
(SLA26-asc; a = 48°)

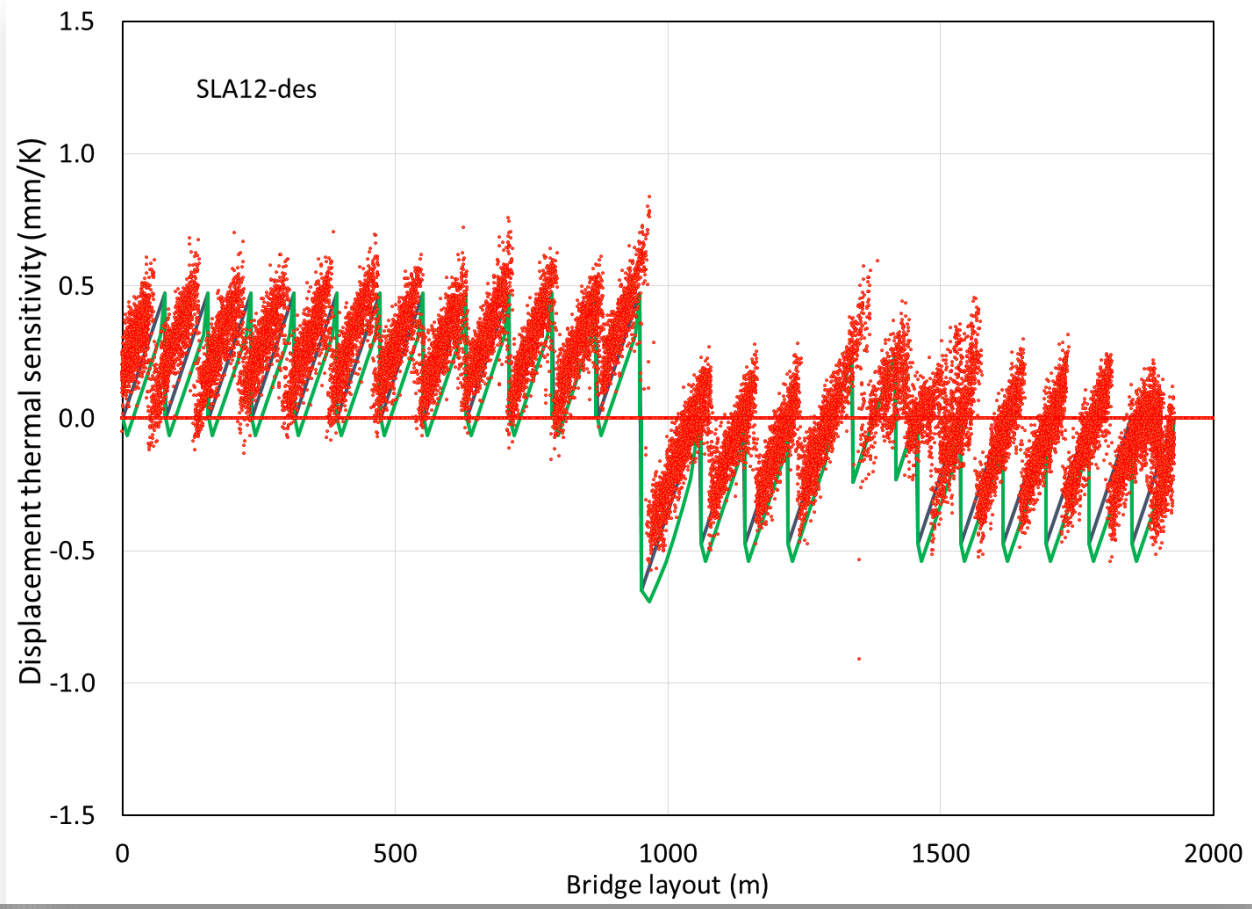



LOS displacement thermal sensitivity
(SLA12-des; a = 39°)

# Comparison InSAR against theoretical predictions




SLA26-asc (16,700 points)




SLA12-des (32,500 points)

# The BRIGITAL concept

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**Visualisation**
Phase I

- 4x UK and Canada end-user consultations
- Demonstrator on 2 bridges in Montreal
- Satellite measurements 3D visualisation
- Radarsat-2 and Sentinel-1 point clouds
  - Static mode (*average values*)
  - Temporal mode (*actual values*)
- In-situ measurements 3D visualisation
  - 2 GPS campaigns and difference

- Unity build
  - Flexible camera control
  - Fluidity

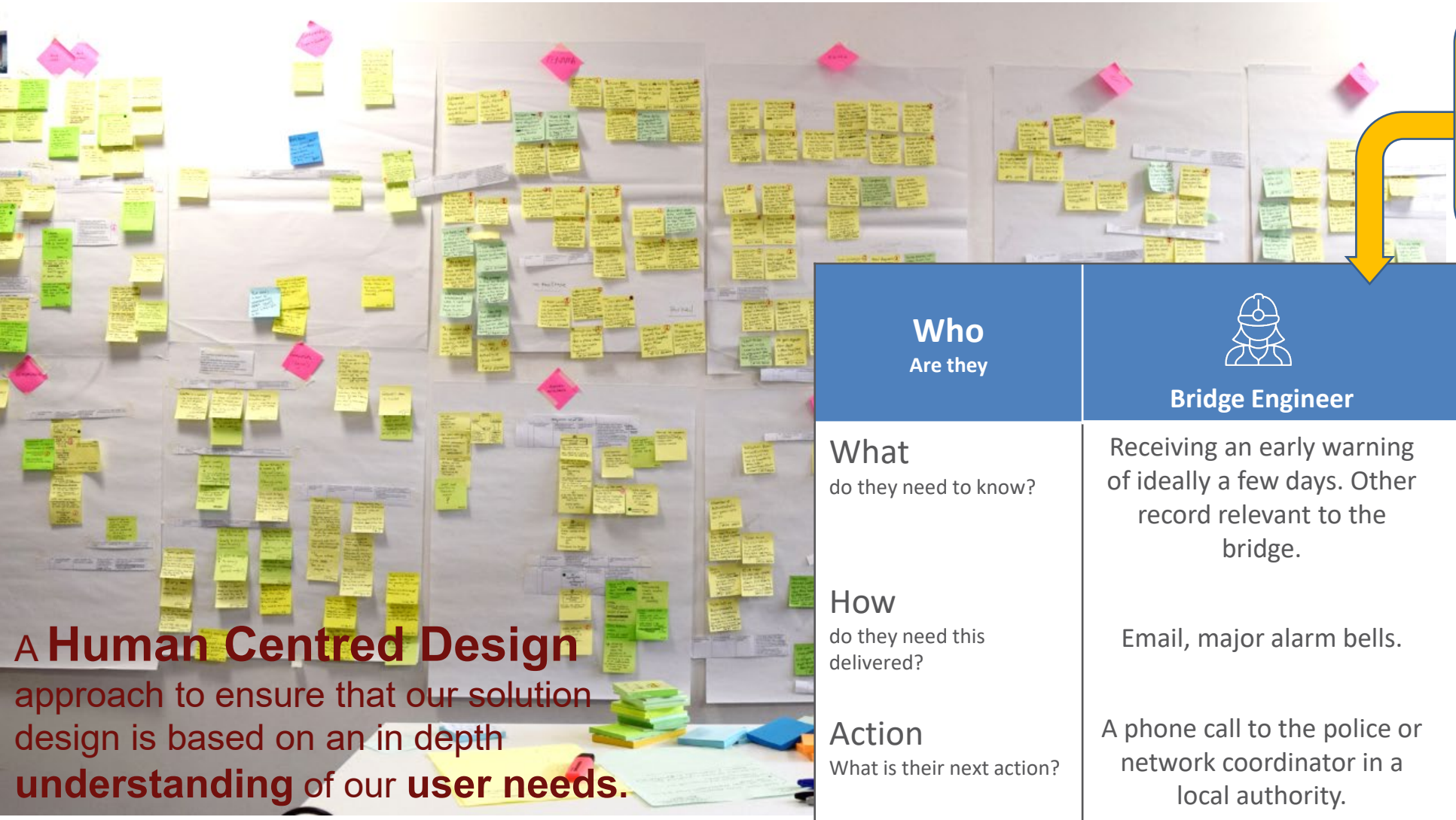
**Risk assessment**
Phase II

- Displacement prediction
- Warning system
- Historical temperature retrieval

**Corrective action**
Phase III

- Bridge ranking
- Maintenance identification
- Extension to all bridges

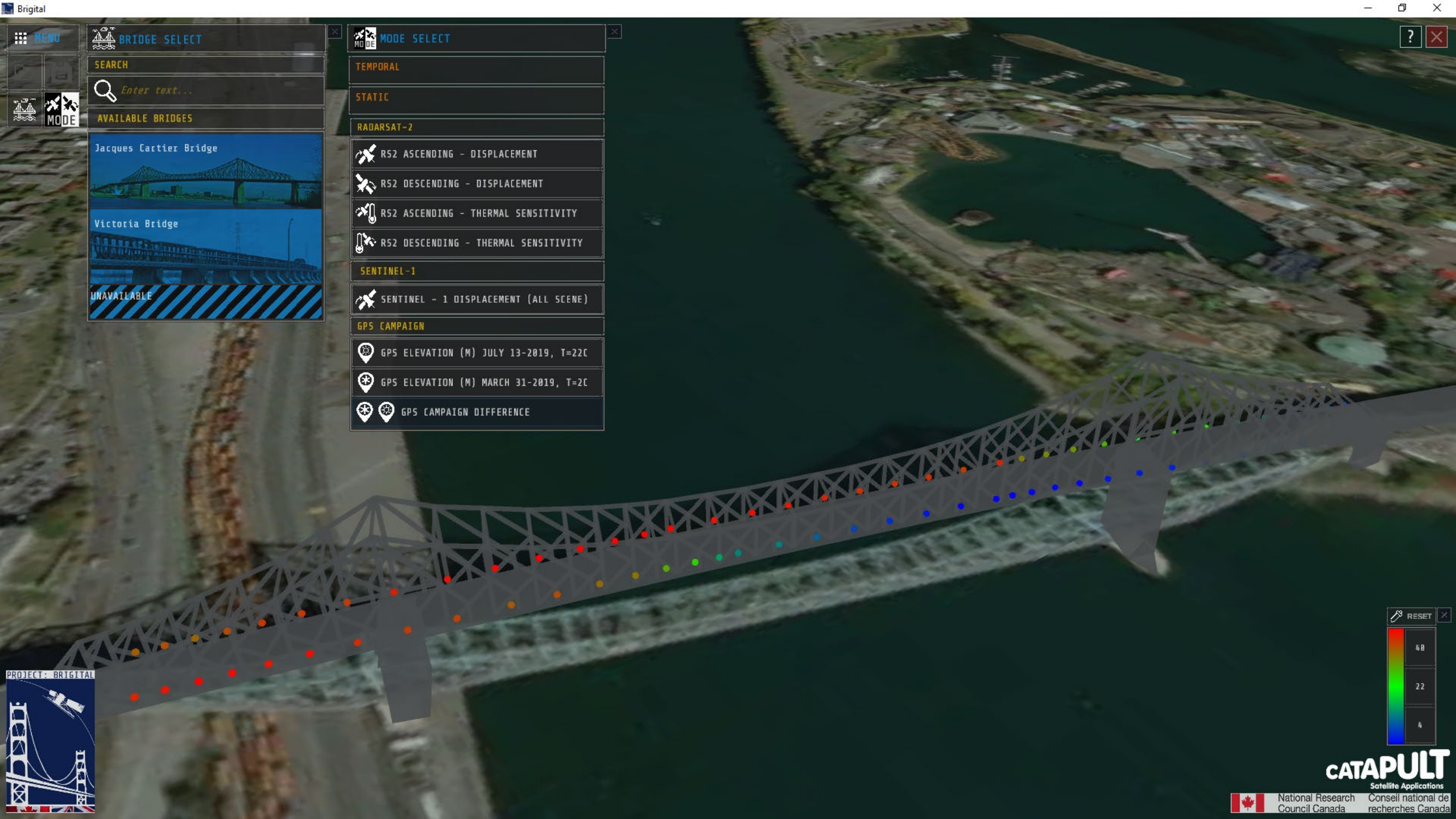
# User consultations



A **Human Centred Design** approach to ensure that our solution design is based on an in depth **understanding** of our **user needs.**

"A structure monitoring tool that remotely measures displacement, supporting engineering decisions"

| **Who** Are they | **Bridge Engineer** | **Highways Authority Ports Authority** |
|---|---|---|
| What do they need to know? | Receiving an early warning of ideally a few days. Other record relevant to the bridge. | Is the structure safe? What load can they correctly manage. What change over time has occurred. |
| How do they need this delivered? | Email, major alarm bells. | Email, major alarm bells. Dashboard to monitor all bridges from a single point |
| Action What is their next action? | A phone call to the police or network coordinator in a local authority. | Closing a road, lowering a bridges load capacity, inspecting the bridge in-person. |


Brigital
MENU
BRIDGE SELECT
SEARCH
Enter text...
AVAILABLE BRIDGES
Jacques Cartier Bridge
Victoria Bridge
UNAVAILABLE
MODE SELECT
TEMPORAL
STATIC
RADARSAT-2
RS2 ASCENDING - DISPLACEMENT
RS2 DESCENDING - DISPLACEMENT
RS2 ASCENDING - THERMAL SENSITIVITY
RS2 DESCENDING - THERMAL SENSITIVITY
SENTINEL-1
SENTINEL - 1 DISPLACEMENT (ALL SCENE)
GPS CAMPAIGN
GPS ELEVATION (M) JULY 13-2019, T=22C
GPS ELEVATION (M) MARCH 31-2019, T=2C
GPS CAMPAIGN DIFFERENCE
RESET
40
22
4
PROJECT: BRIGITAL
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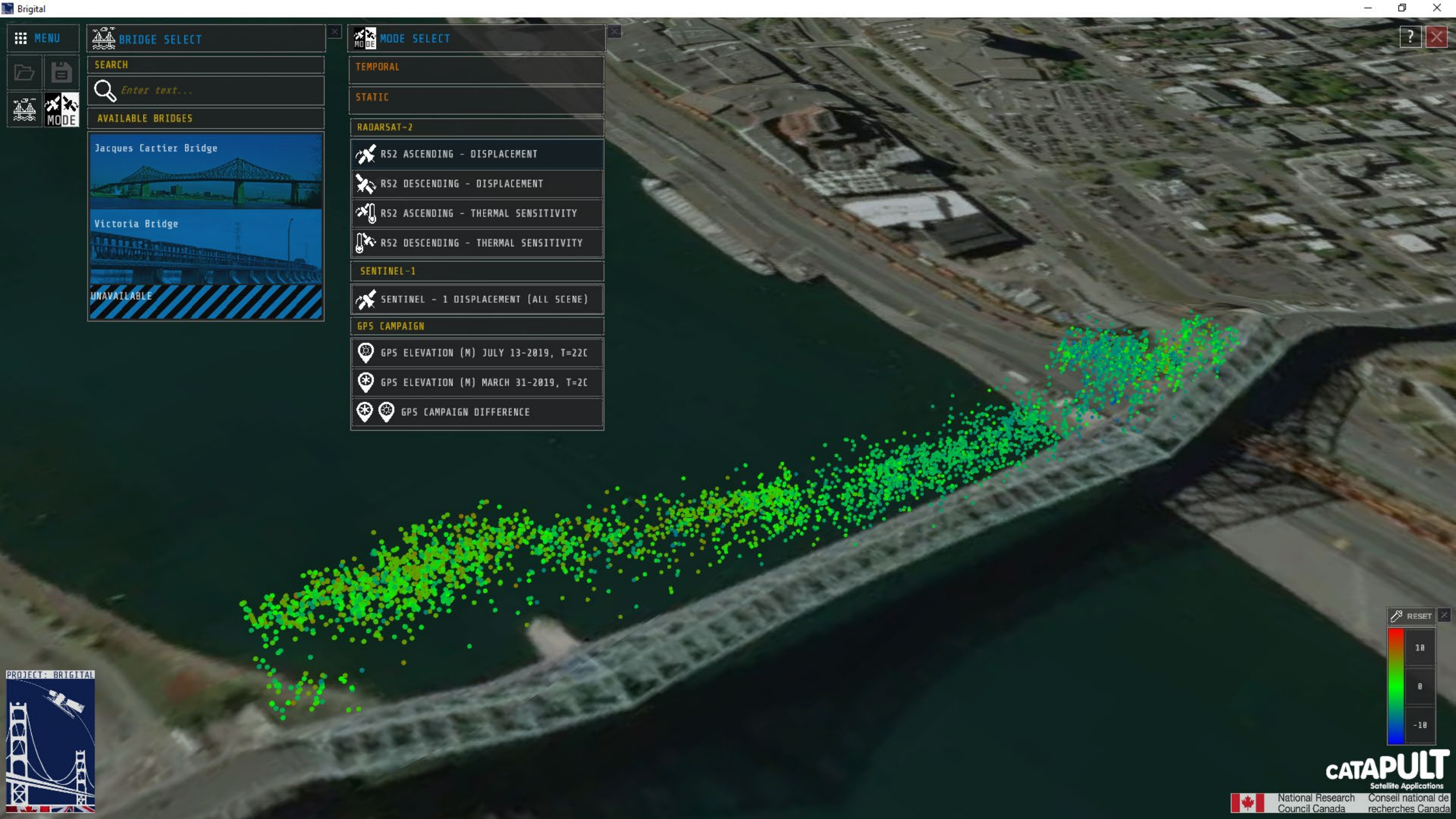
Brigital
MENU
BRIDGE SELECT
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Enter text...
AVAILABLE BRIDGES
Jacques Cartier Bridge
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UNAVAILABLE
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TEMPORAL
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RS2 ASCENDING - DISPLACEMENT
RS2 DESCENDING - DISPLACEMENT
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RS2 DESCENDING - THERMAL SENSITIVITY
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GPS CAMPAIGN
GPS ELEVATION (M) JULY 13-2019, T=22C
GPS ELEVATION (M) MARCH 31-2019, T=2C
GPS CAMPAIGN DIFFERENCE
PROJECT: BRIGITAL
RESET
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Brigital

MENU

BRIDGE SELECT

SEARCH

Enter text...

AVAILABLE BRIDGES

Jacques Cartier Bridge

Victoria Bridge

UNAVAILABLE

MODE SELECT

TEMPORAL

STATIC

RADARSAT-2

RS2 ASCENDING - DISPLACEMENT

RS2 DESCENDING - DISPLACEMENT

RS2 ASCENDING - THERMAL SENSITIVITY

RS2 DESCENDING - THERMAL SENSITIVITY

SENTINEL-1

SENTINEL - 1 DISPLACEMENT (ALL SCENE)

GPS CAMPAIGN

GPS ELEVATION (M) JULY 13-2019, T=22C

GPS ELEVATION (M) MARCH 31-2019, T=2C

GPS CAMPAIGN DIFFERENCE

POINT INFORMATION

Summary

| | |
|---|---|
| Lat (deg): | -73.54166 |
| Lon (deg): | 45.52159 |
| Altitude (m): | 52.32555 |

Parameters

| | |
|---|---|
| ID: | 1470 |
| Average Linear Rate (mm/year): | 1.43 |
| Quality: | 0.89 |
| Thermal Sensitivity (mm/°C): | 1.46 |

RESET

2

0

-2

PROJECT: BRIGITAL

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Brigital
MENU
BRIDGE SELECT
SEARCH
Enter text...
AVAILABLE BRIDGES
Jacques Cartier Bridge
Victoria Bridge
UNAVAILABLE
MODE SELECT
TEMPORAL
RADARSAT-2
R2 ASCENDING - DISPLACEMENT
R2 DESCENDING - DISPLACEMENT
SENTINEL-1
SENTINEL - 1 DISPLACEMENT (ALL SCENE)
STATIC
SELECTED DATE & TIME
06/12/2016
PROJECT: BRIGITAL
TIME SLIDER
DATA SOURCE: Victoria//R2//Ascending
TIME CONTROLS
RESET
40
0
-40
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# Conclusions

## Accomplishments

- Demonstrated use of PS-InSAR for bridge displacement detection and measurement
- Validated approach on several major bridges in Canada and UK
- Development of the first phase of BRIGITAL (visualisation)

## Next steps and expected outcomes

- Development of further phases of BRIGITAL (assist owners in their decision making)
  - Performance indicators on structural stability and safety
- Regularly updated bridge deformation profiles to complement annual inspection data
- Identification of bridges with abnormal behaviour within bridge network
- Prioritization and optimization of bridge inspection and maintenance

# Thank you!

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