Radar coherence to monitor gully erosion impairing water quality of the Great Barrier Reef

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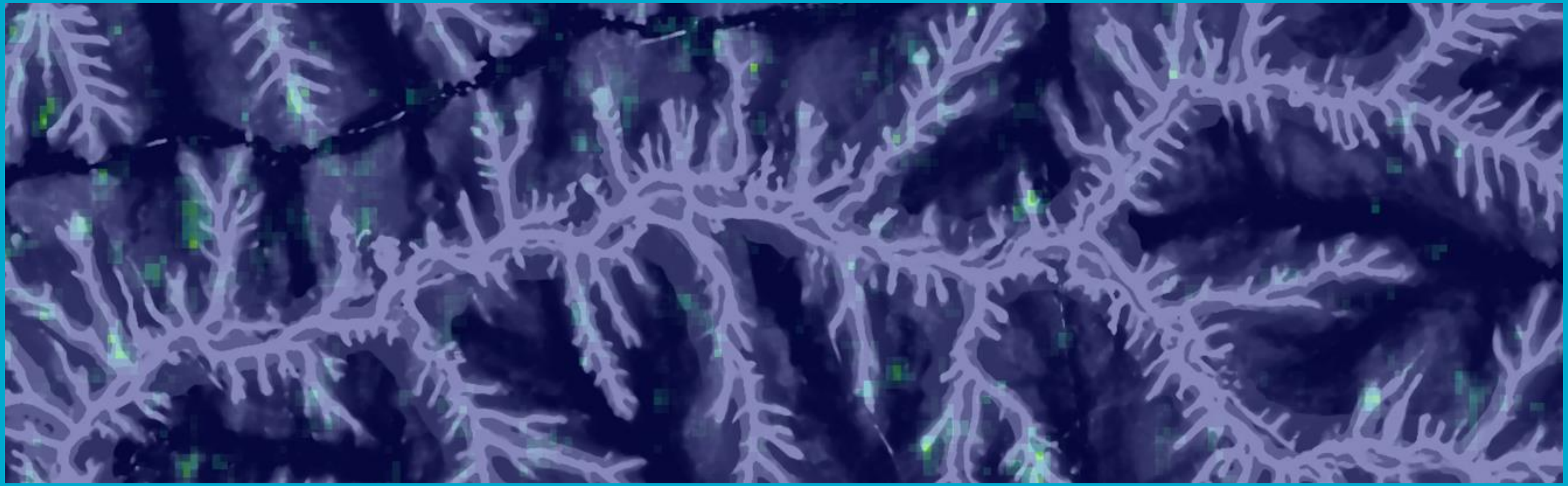
CSIRO L&W
University of Southern California



December 2022

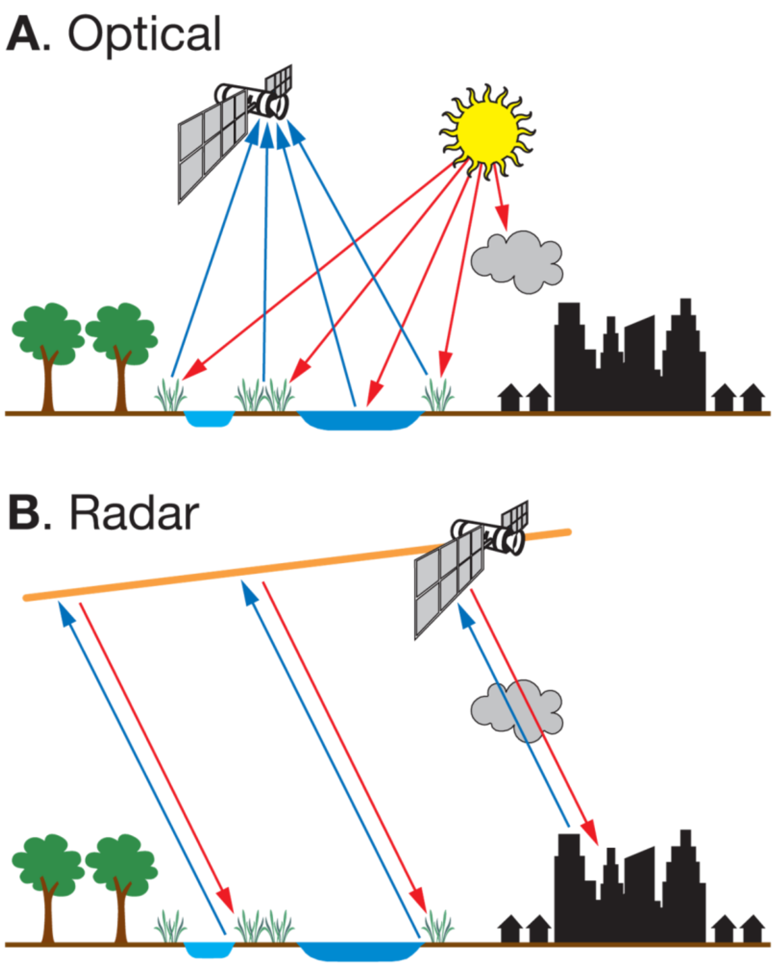
1. Introduction

1. Applications of radar imagery at CSIRO

1. Mapping erosion with radar coherence

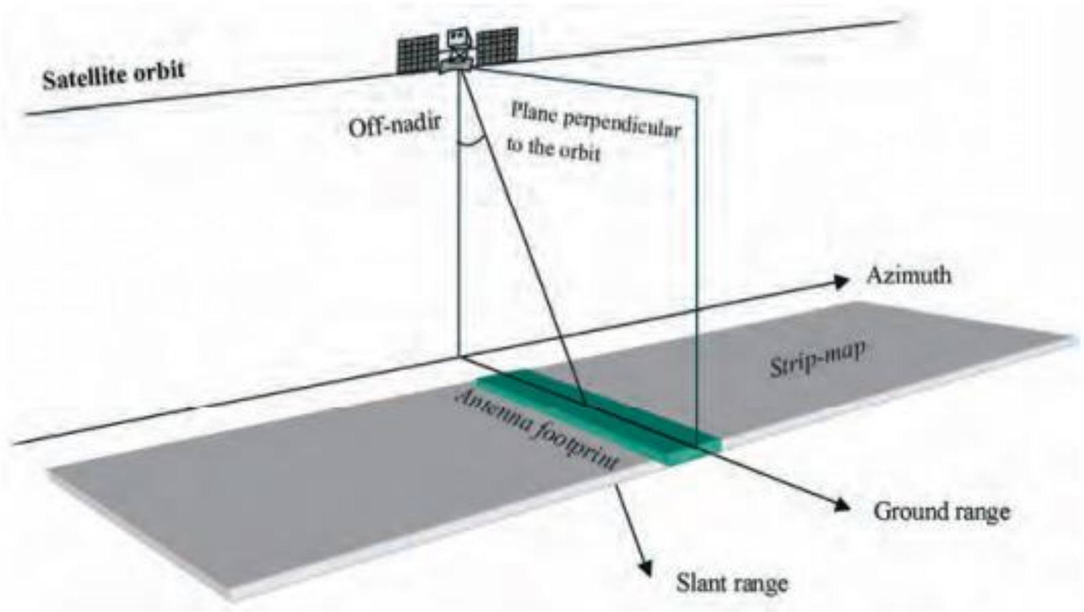
1. Perspectives

Introduction

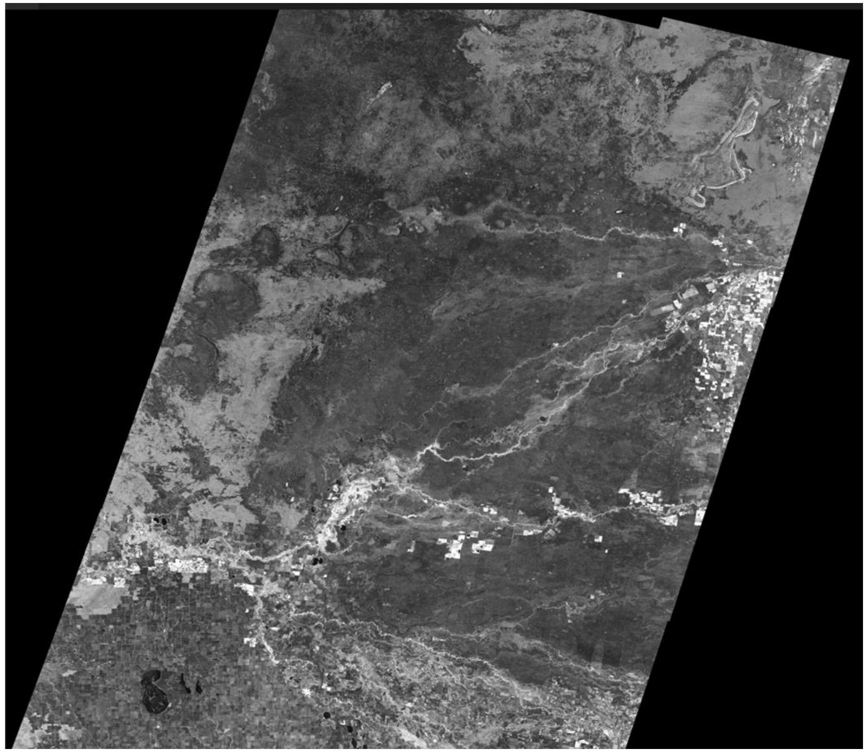


- ➢ **Optical sensors measure reflectance in narrow bands of the light/electromagnetic spectrum (wavelength in nanometres)**
- ➢ **Radar sensors measure the backscattering signal from a radiofrequency/electromagnetic wave emitted by the satellite (wavelength in centimetres)**

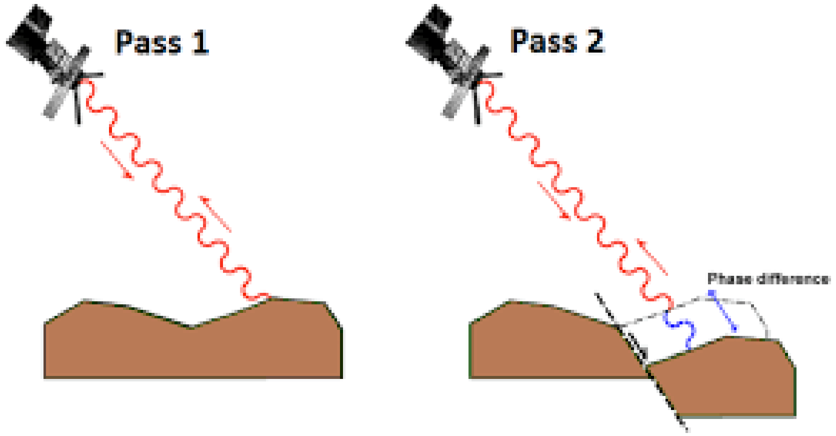
Introduction



Source: European Space Agency



- The sensor records the intensity (or amplitude) of the return and the phase value for every pixel
- Working with the phase implies the use of repeat path time-series (the only way phase information can be interpreted is via comparison of two images!)
  - ✓ Radarsat 1/2 : 24 days
  - ✓ Envisat : 35 days
  - ✓ ALOS-1: 46 days
  - ✓ TerraSAR: 11 days
  - ✓ ALOS-2: 14 days
  - ✓ Sentinel-1/2: 12 or 6 days



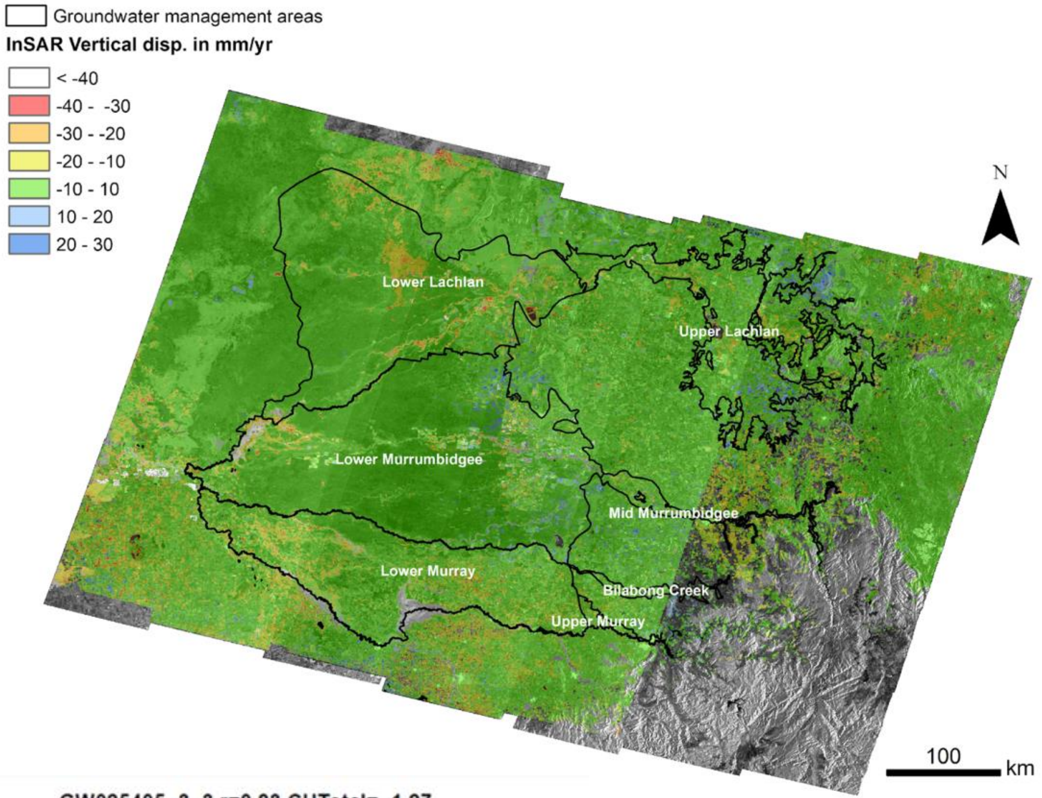
Applications of radar imagery

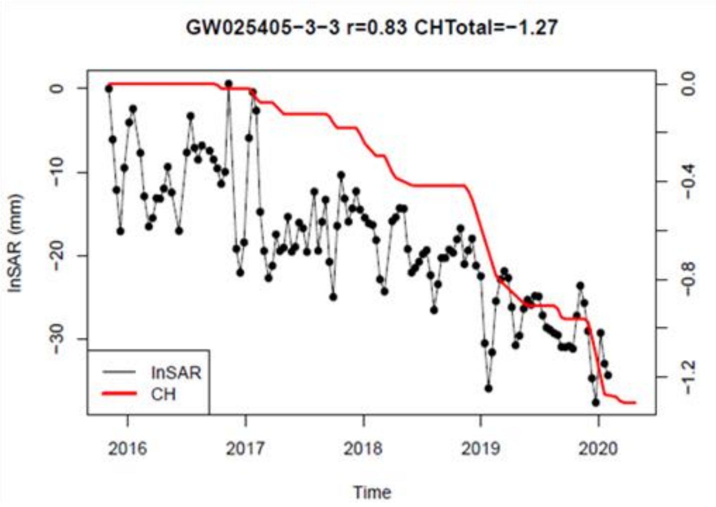
1. Generation of ground deformation maps (volcanoes, landslides, earthquakes, groundwater depletion)

1. Surface water mapping

1. Land cover mapping work (urban, vegetation etc.)

1. Erosion mapping via signal decorrelation metrics





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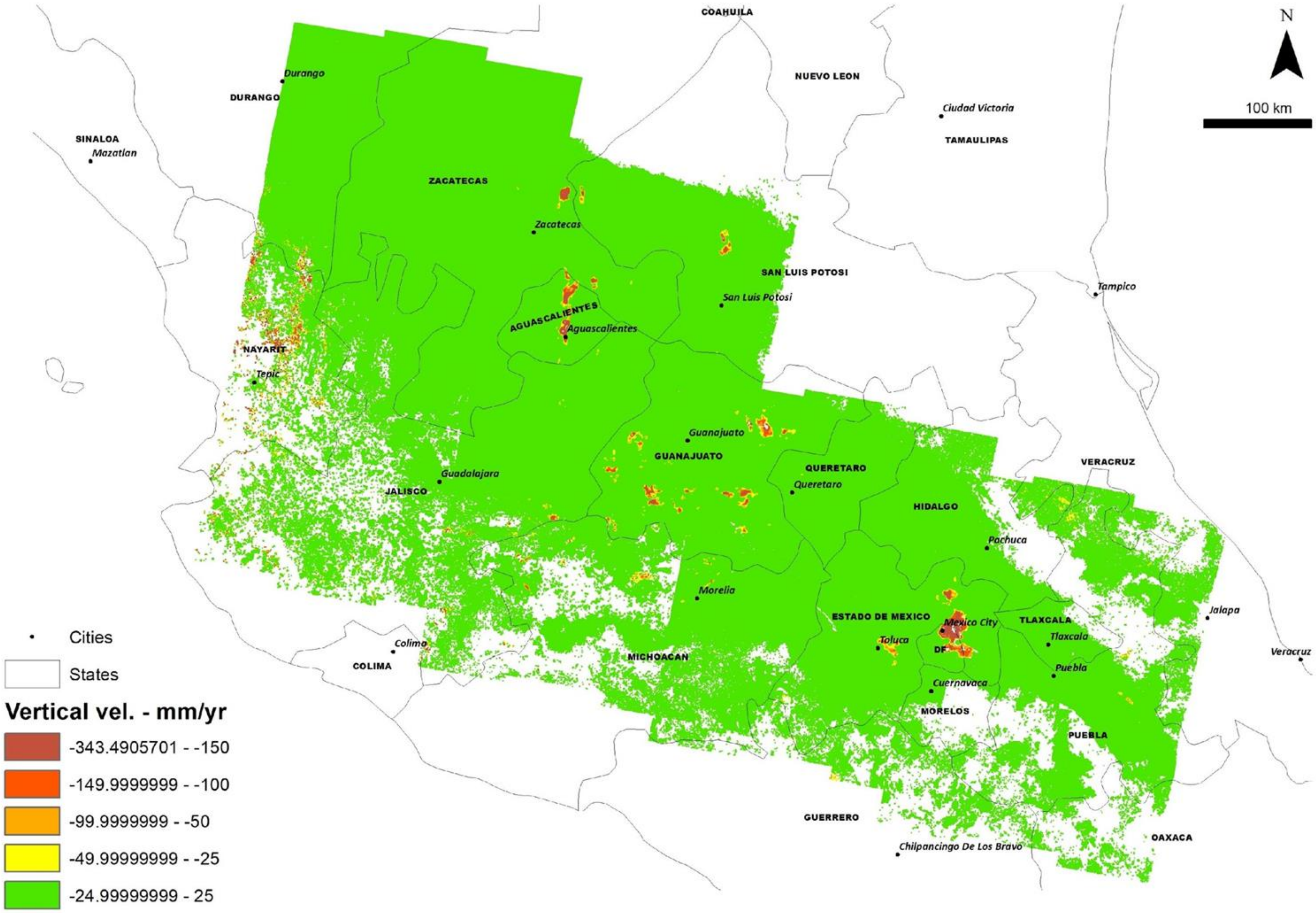

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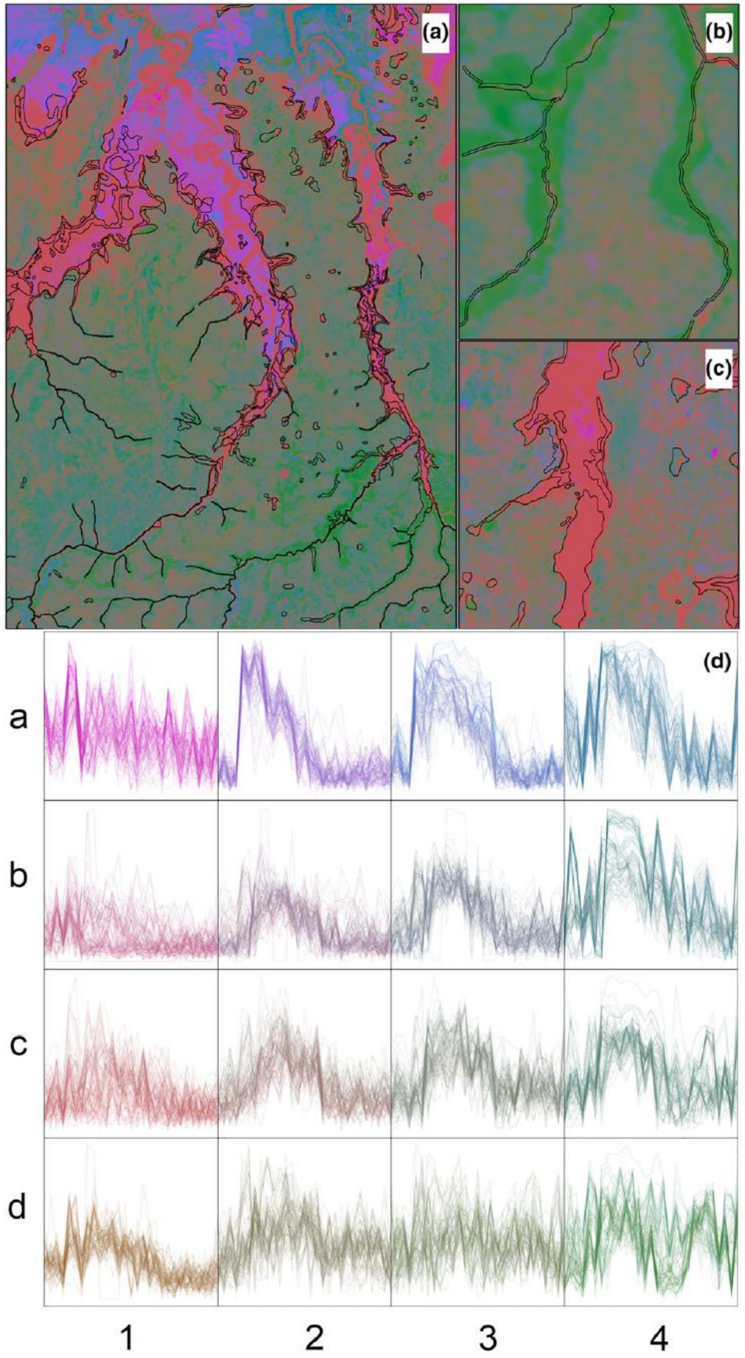

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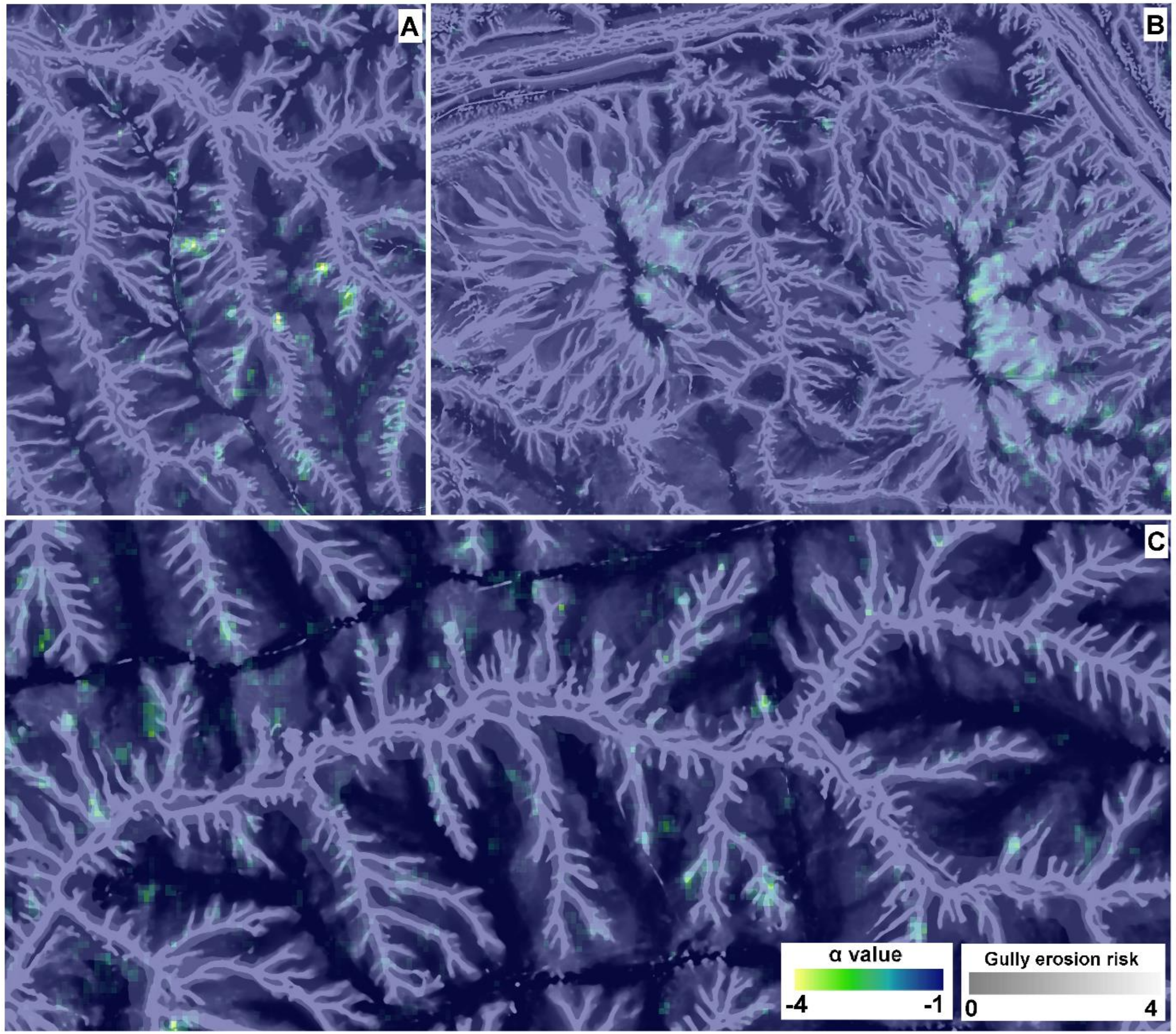


Mapping erosion with radar coherence, why?

- Gully erosion supplies ~40% of the fine sediment (from 0.1% of the area)
- Australian and Queensland Government spending ~$100 m
- Need for data/evidence on effectiveness of remediation approaches
- Need for catchment-scale mapping of land erosion rates

Mapping erosion with radar coherence

ELSEVIER

Remote Sensing of Environment
Volume 237, February 2020, 111544

Surface materials and landforms as controls on InSAR permanent and transient responses to precipitation events in a hyperarid desert, Chile

Teresa E. Jordan [a], Rowena B. Lohman [a], Lorenzo Tapia [b], Marco Pfeiffer [c], Chelsea P. Scott [d], Ronald Amundson [e], Linda Godfrey [f], Rodrigo Riquelme [b]

Earth Surface Processes and Landforms
BSG British Society for Geomorphology

Research Article | Full Access

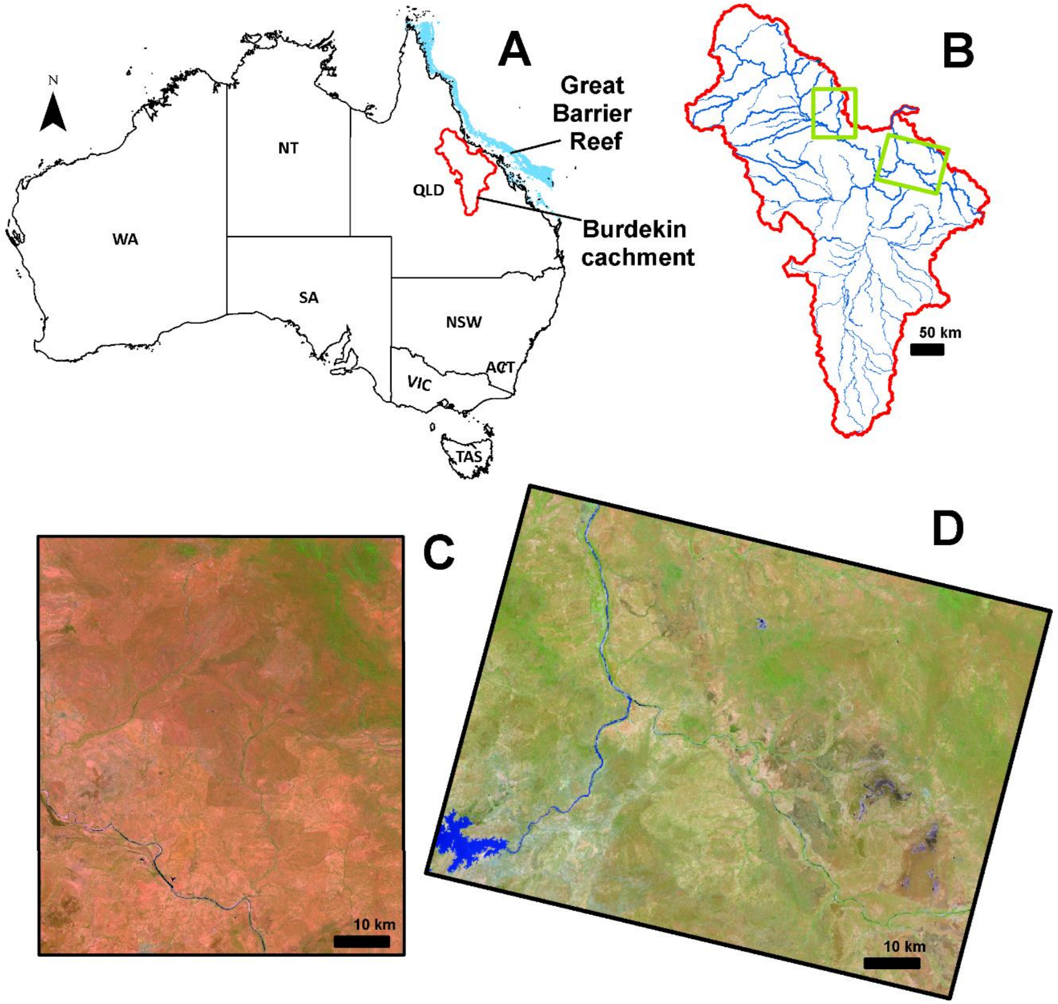
Mapping rainstorm erosion associated with an individual storm from InSAR coherence loss validated by field evidence for the Atacama Desert

Albert Cabré, Dominique Remy, Germán Aguilar, Sebastien Carretier, Rodrigo Riquelme

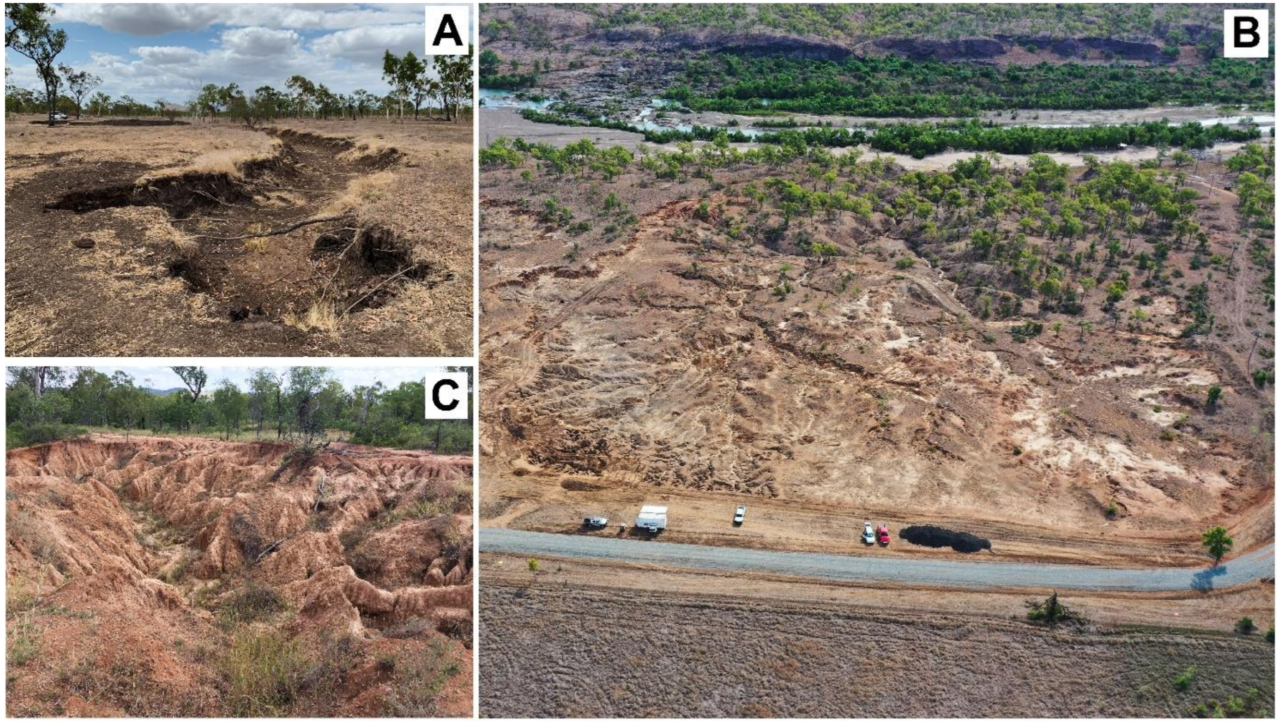
First published: 15 April 2020 | https://doi.org/10.1002/esp.4868 | Citations: 10

Mapping erosion with radar coherence

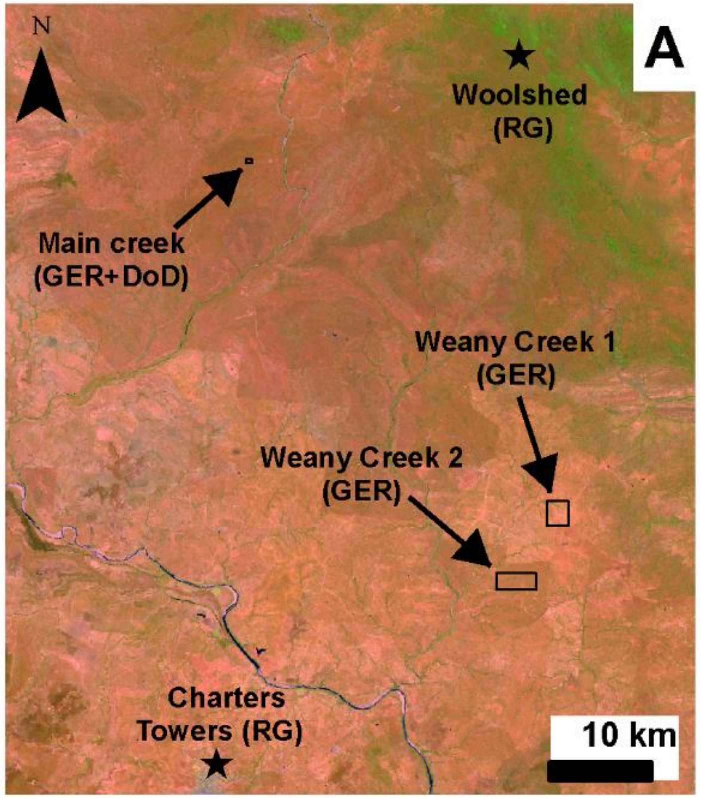
Test over two study areas of the Burdekin catchment

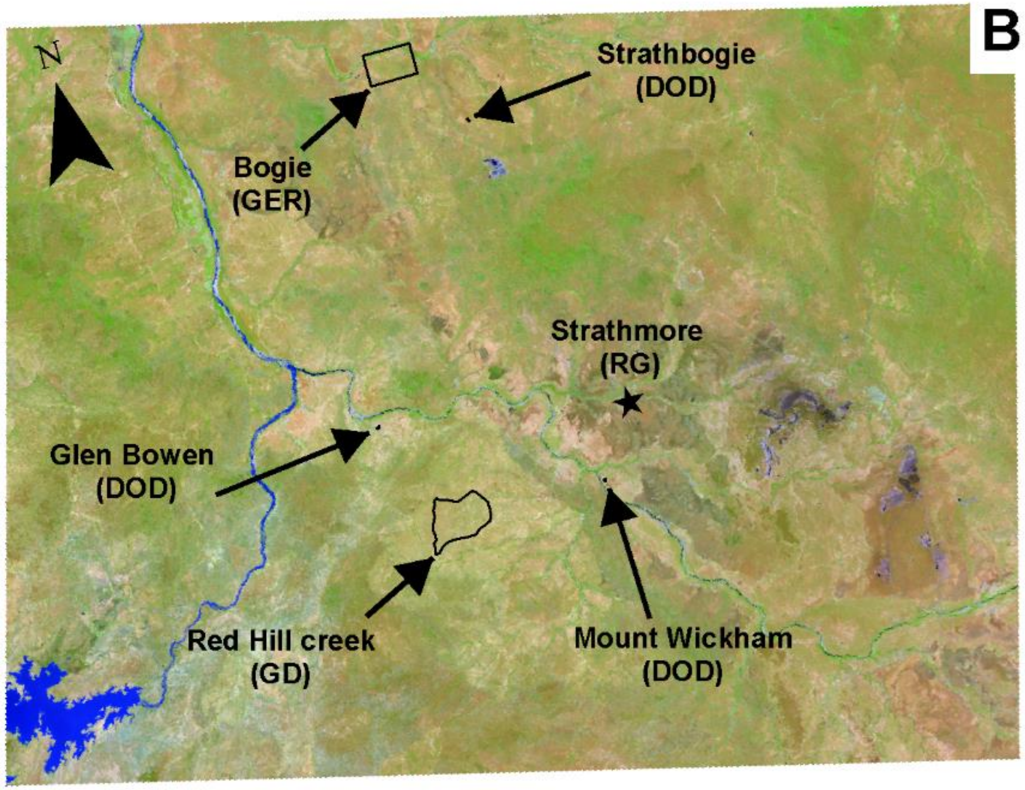


… where erosion issues have been well identified and monitored



Mapping erosion with radar coherence





Auxiliary data

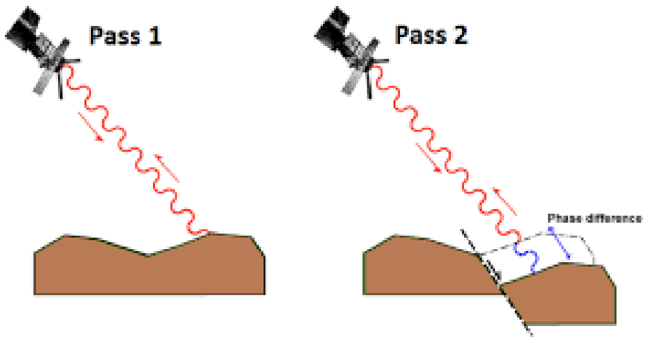
<u>Constraint in the workflow:</u>
RG: Rain Gauges

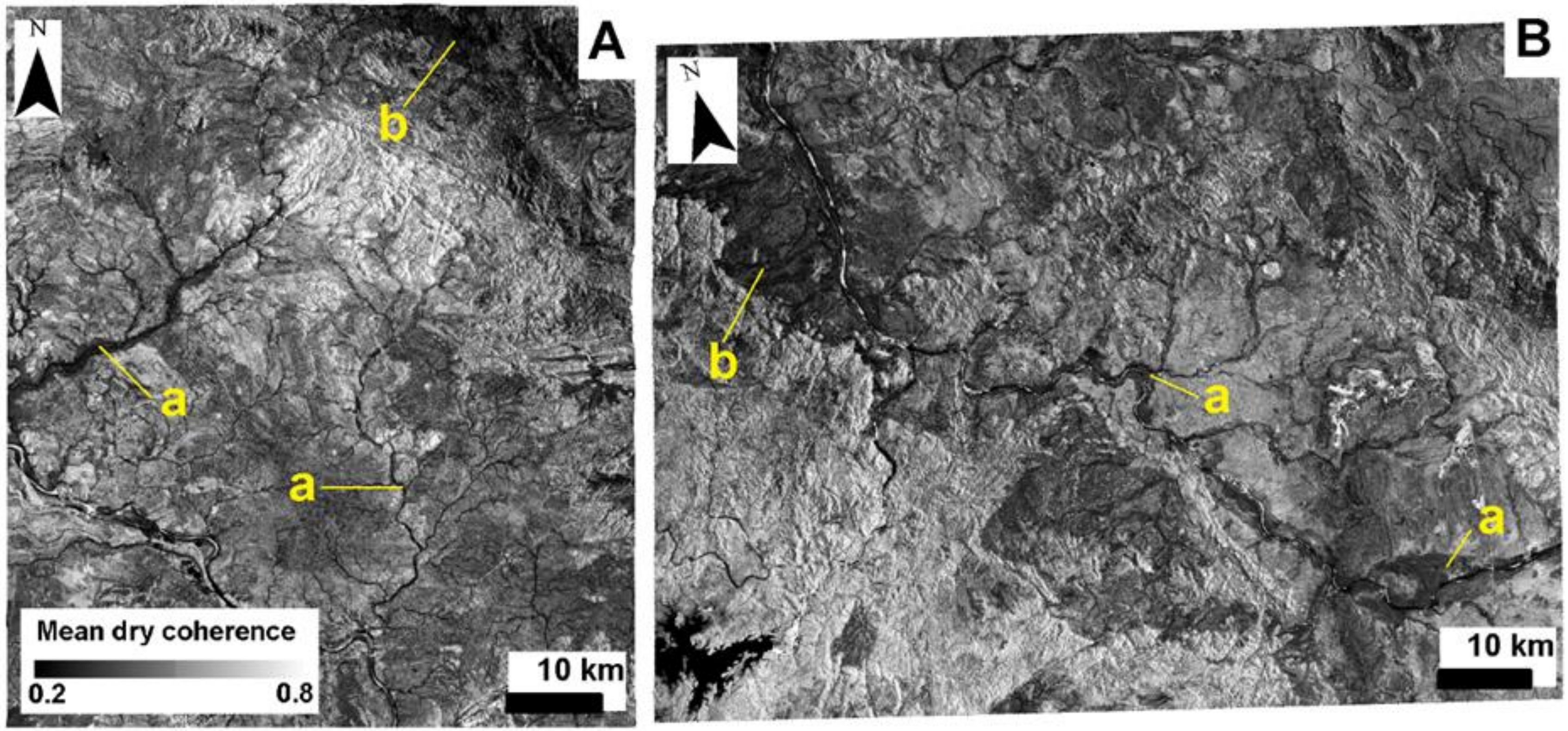
<u>Validation data:</u>
DoD: DEM of Difference
GD: in situ Gully Delineation
GER: Gully Erosion Risk maps, potential gullying

Mapping erosion with radar coherence

What is InSAR coherence?

InSAR coherence is a index of similarity between two radar images, integrating both the phase and the intensity of the signal to determine if the ground targets have changed between two acquisitions
-> high coherence is important to invert phase change into deformation
-> low coherence means that the phase values cannot be inverted into absolute deformation, it is a sign of texture change on the ground surface





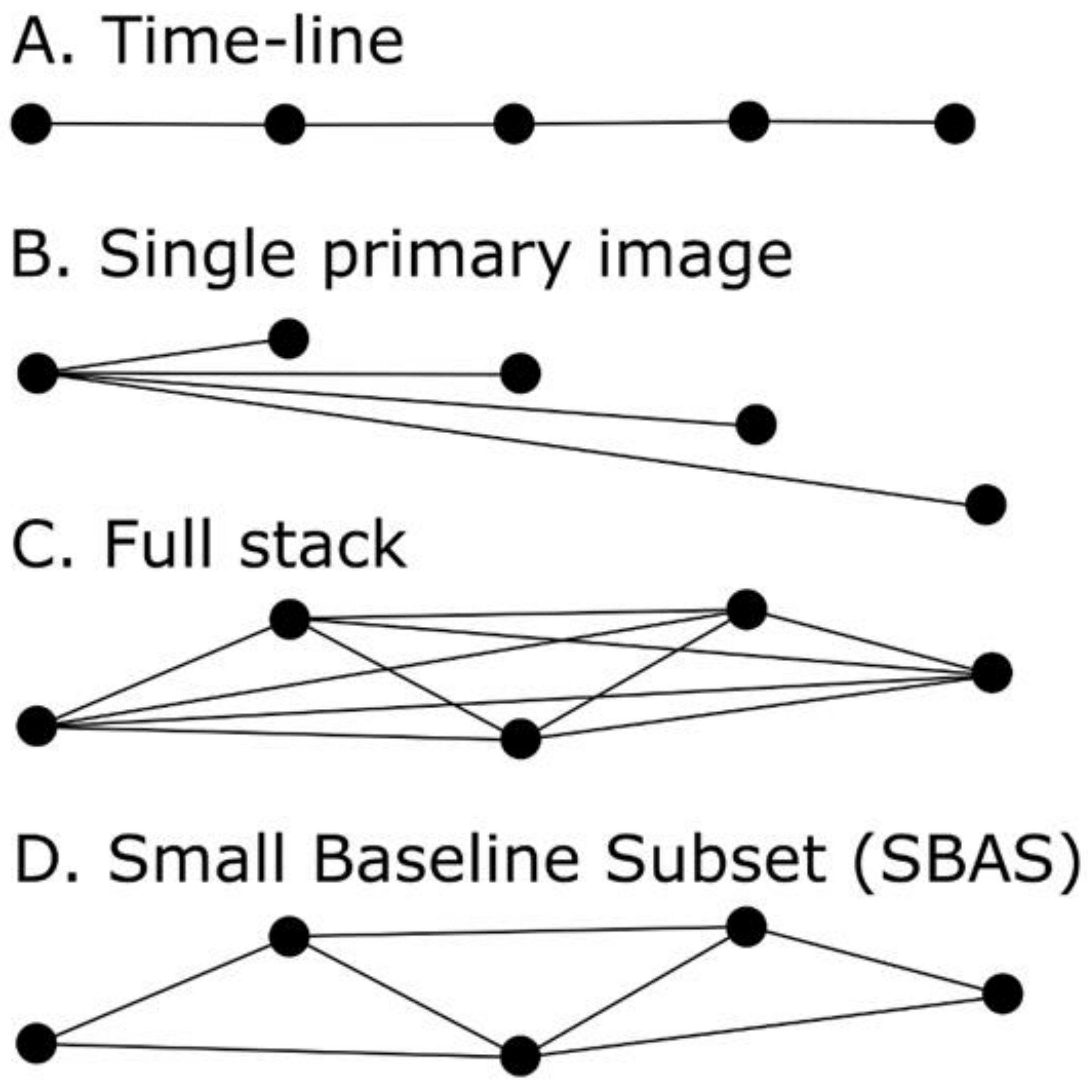
$$\gamma = \frac{\left|\sum s_1(x)\cdot s_2(x)^*\right|}{\sqrt{\sum\left|s_1(x)\right|^2\cdot\sum\left|s_2(x)\right|^2}}$$

Zebker, Howard A., and John Villasenor. "Decorrelation in interferometric radar echoes." *IEEE Transactions on geoscience and remote sensing* 30.5 (1992): 950-959.

Mapping erosion with radar coherence

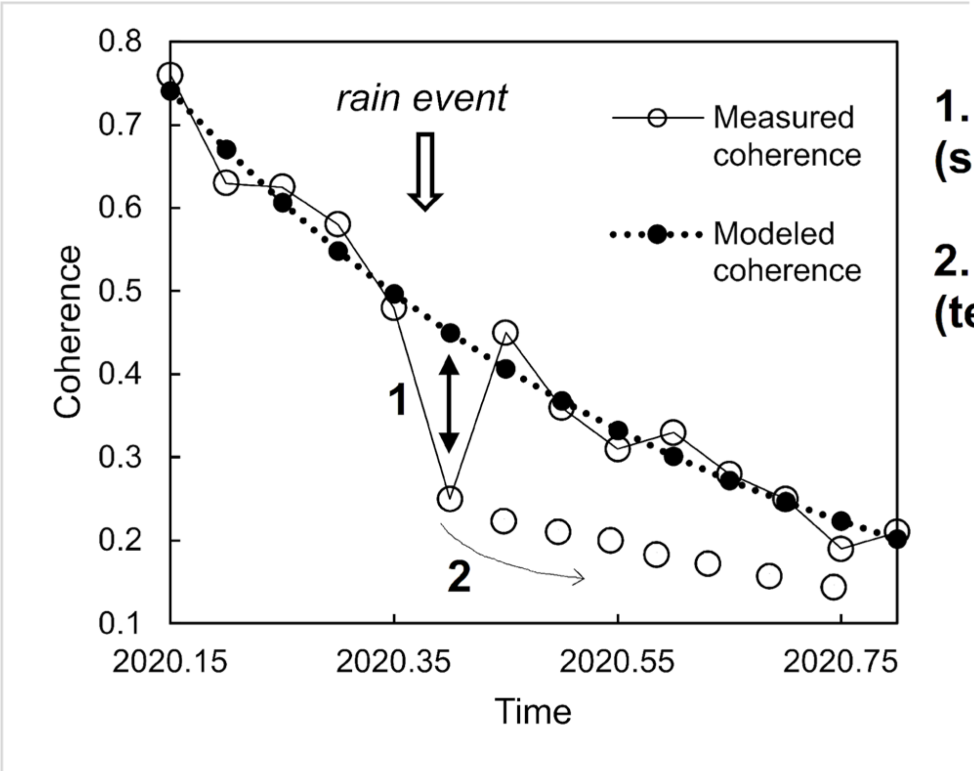
Strategies for creation of a set of coherence pairs with a time-series of radar images

- Time-line is optimized for high coherence
- Full stack is computing intensive and often unnecessary
- SBAS is often optimal for deformation mapping, interesting signal/noise trade-off



Mapping erosion with radar coherence

Understanding the temporal patterns in coherence time-series



1. Transient loss (soil moisture changes)

2. Permanent loss (texture changes)

$$\gamma = \gamma_b + \gamma_t + \gamma_p$$

Yb: background coherence loss (related to land

cover)

Yt: transient coherence loss (soil moisture)

Yp: permanent coherence loss (unrecoverable

texture changes)

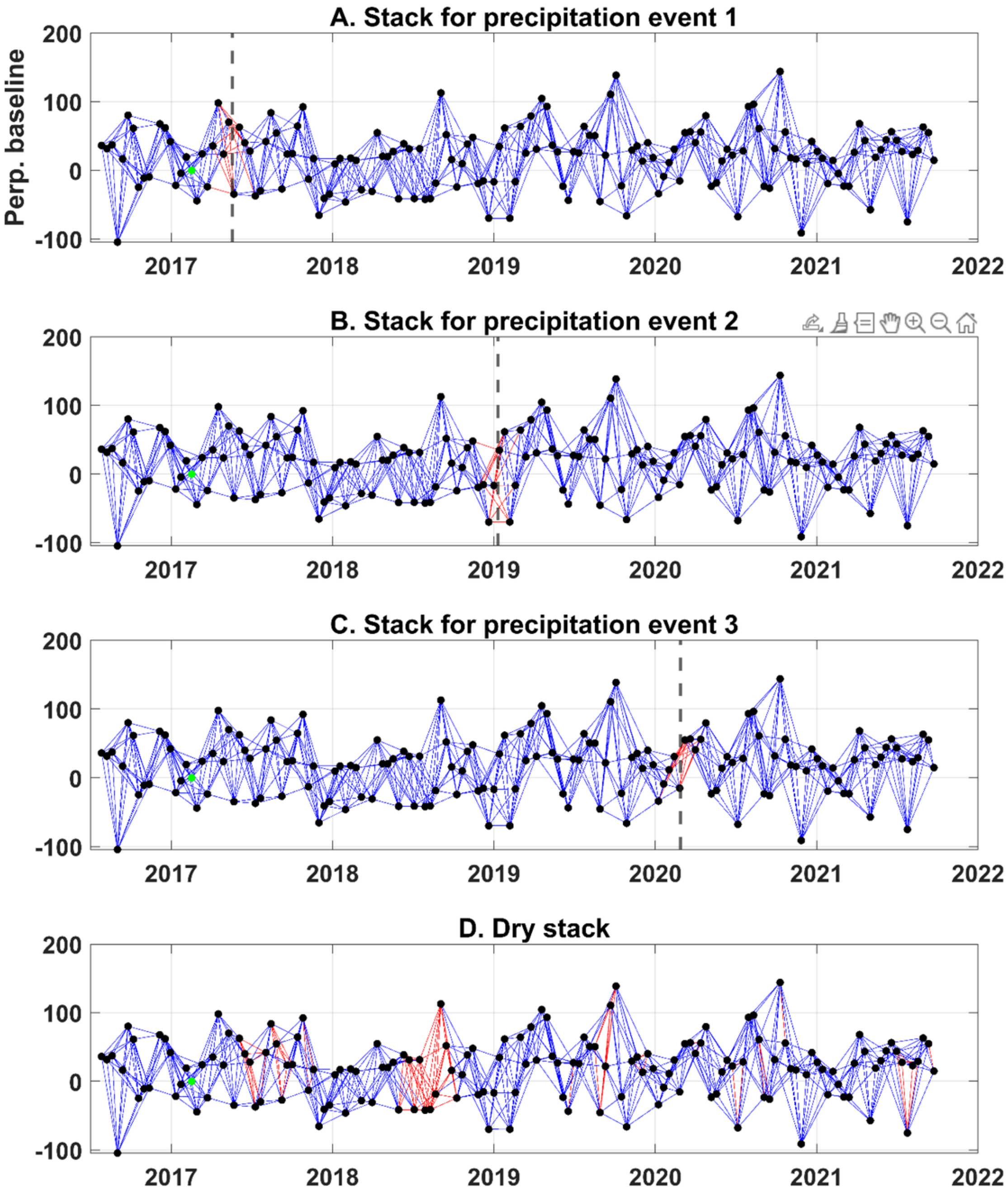
How to isolate the permanent coherence loss contributor (*yp*) ?

Mapping erosion with radar coherence

Approach: how to detect permanent coherence losses ?

Study areas	Sentinel-1 orbital track	Time-series start/end		Number of images/coherence maps	Extent (km^2)
1	89	2016-08-01	2021-09-28	156/755	5006
2	16	2016-07-27	2021-09-23	156/772	7015

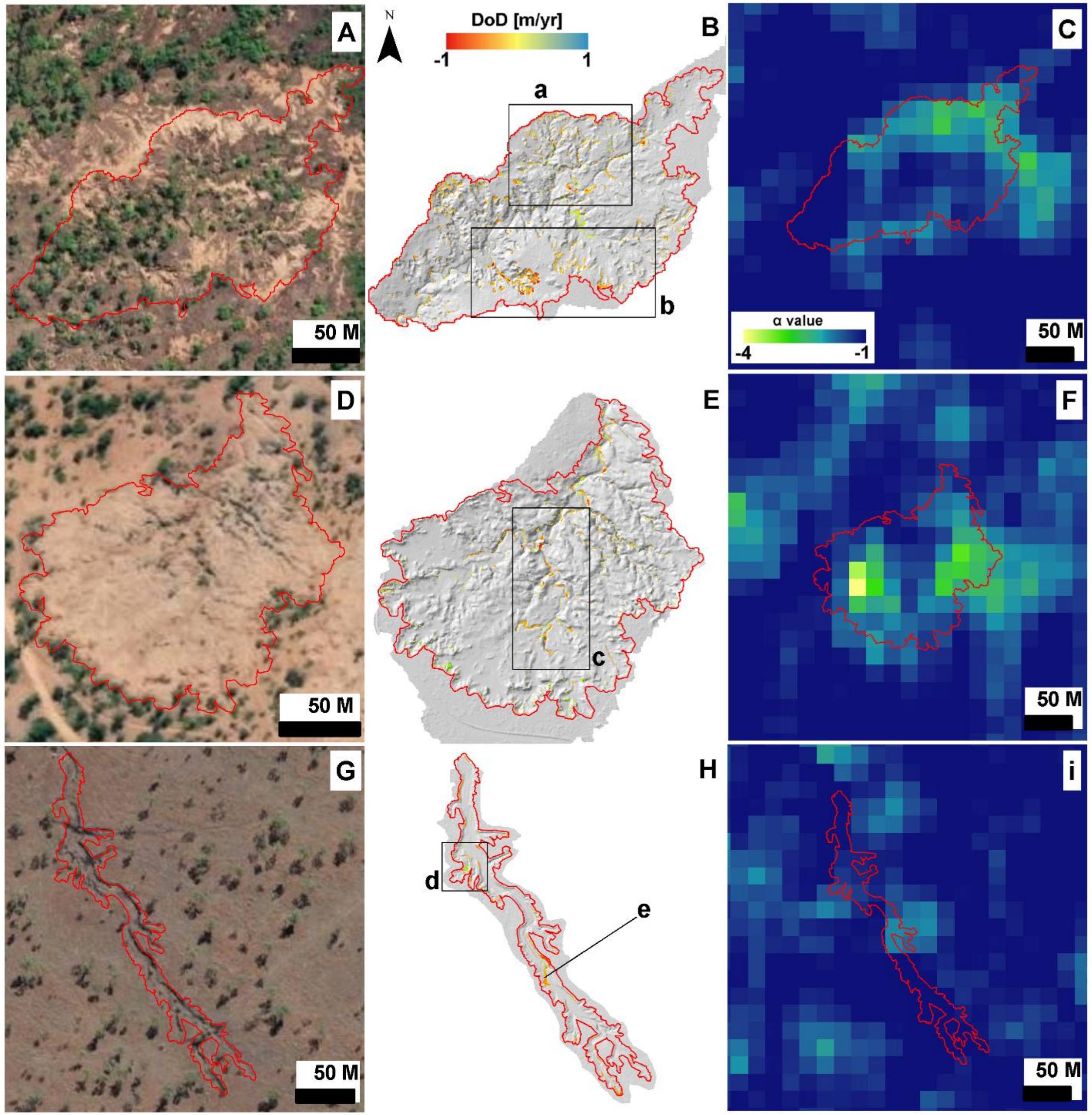
- Rain gauge data allow to separate the coherence images with/without erosion signal
- ‘Dry coherence’ allows to evaluate the contributors to coherence other than erosion and correct the coherence maps containing erosion signal
- After correction, variation of coherence WITH erosion is expressed in proportion of coherence WITHOUT erosion



Mapping erosion with radar coherence

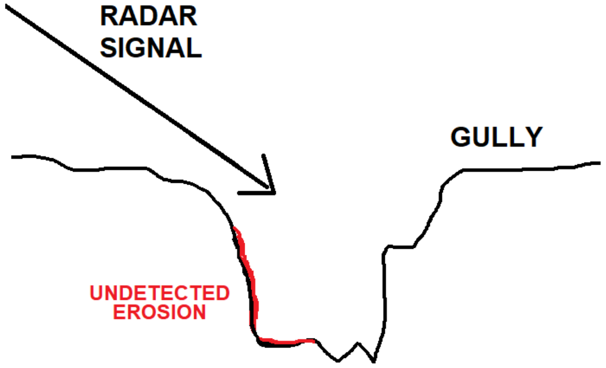
Stack	Precipitation of major rainy day in the stack (mm)	Precipitation between the coherence pairs [range] – mean (in mm)	Number of coherence maps
Study area 1			
Dry stack	NA	[0 - 2] - 0.40	80
Stack for rain event 1	225	[977 - 1416] - 1229	15
Stack for rain event 2	91	[148 - 216] - 159	15
Stack for rain event 3	83	[276 - 550] - 401	15
Study area 2			
Dry stack	NA	[0 - 1.1] – 0.19	117
Stack for rain event 1	122	[175 280] - 186	15
Stack for rain event 2	118	[161 - 468] - 291	15
Stack for rain event 3	112	[212 347] - 253	15

Mapping erosion with radar coherence

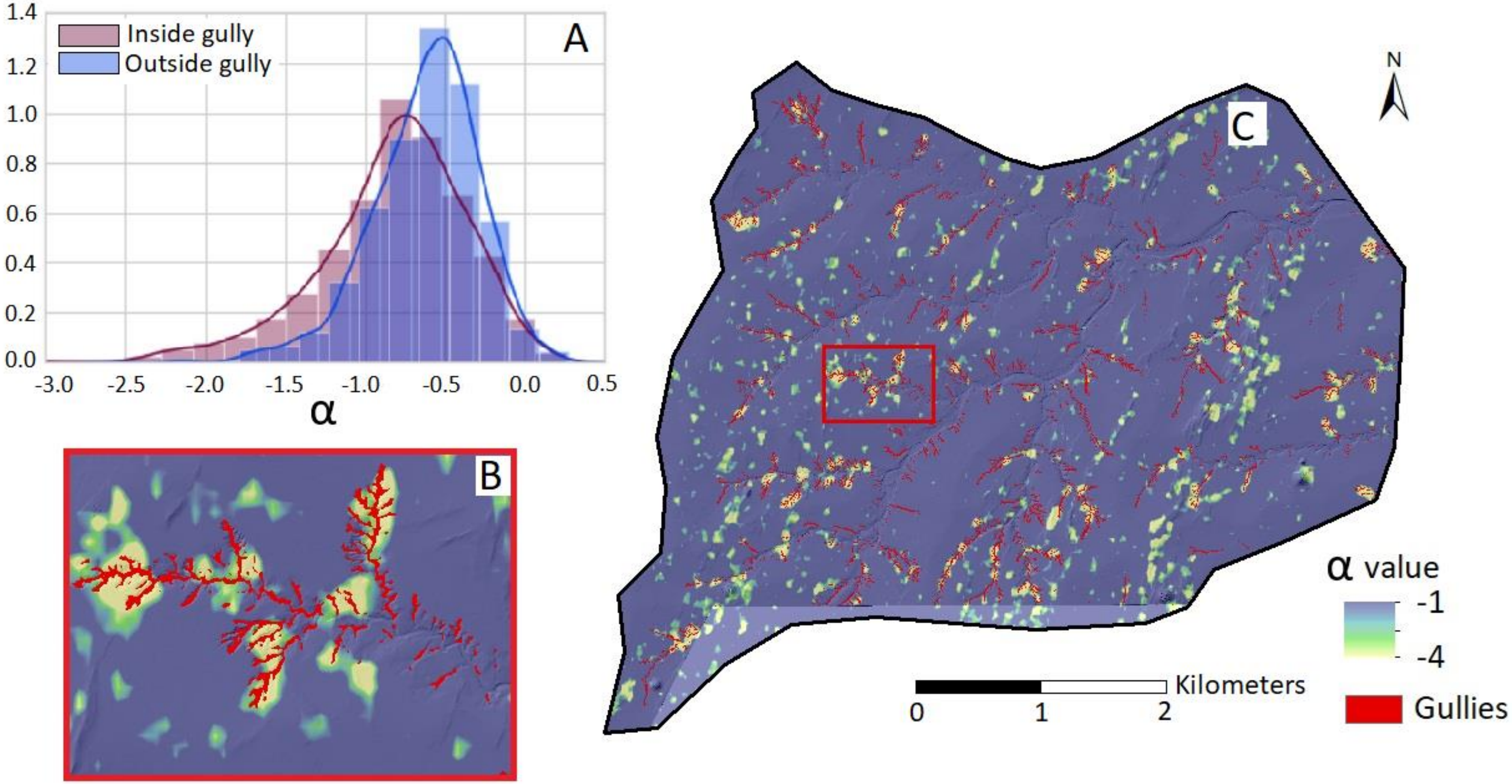


Comparison with DoD data

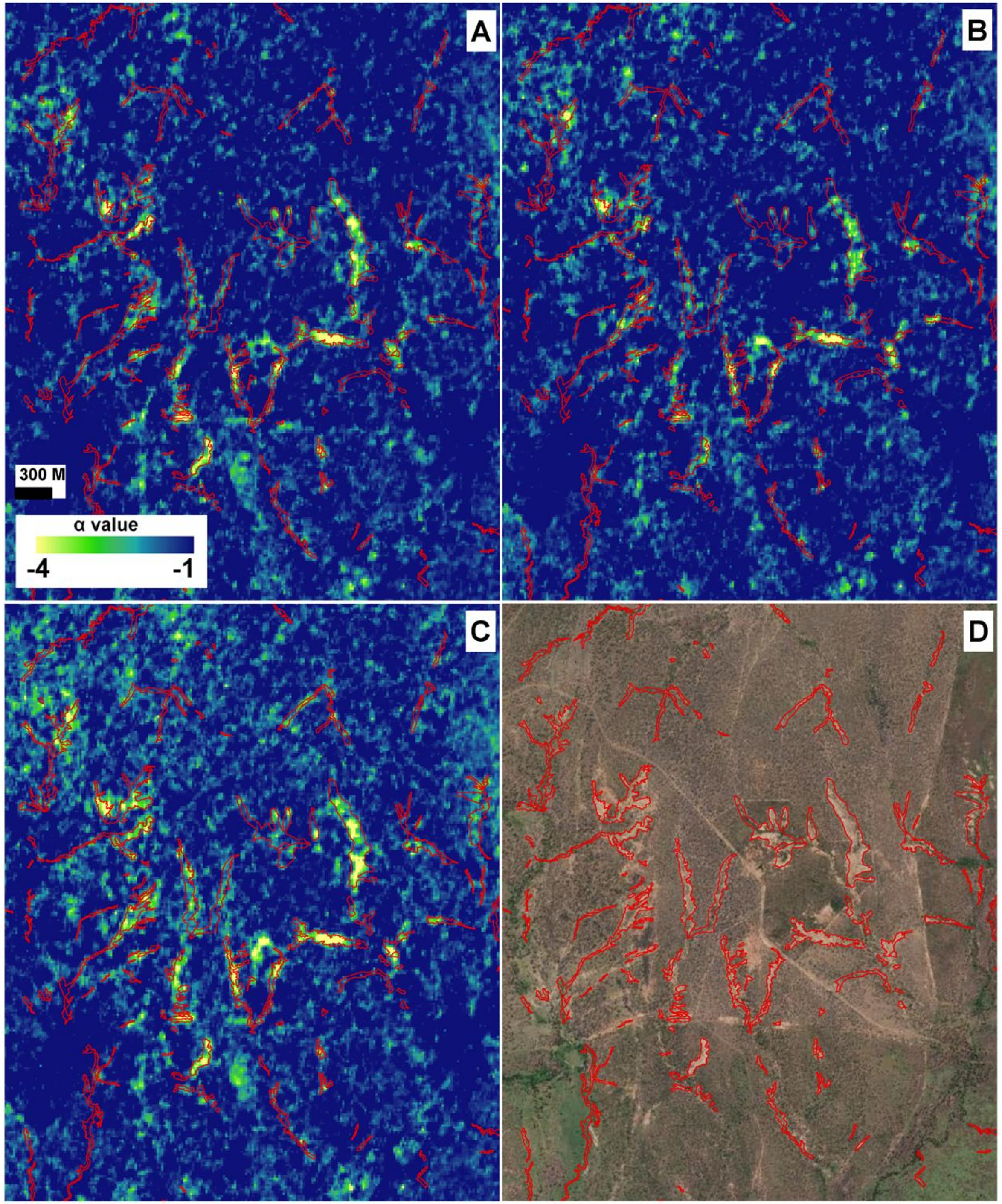
- Frequent and notable detection of anomalous coherence loss in alluvial gullies
- No detection in hillslope gullies
- Line-Of-Sight angle plays an important role
- Sensitivity is higher for features facing the sensor, lower for other features, and null in the shadows



Mapping erosion with radar coherence

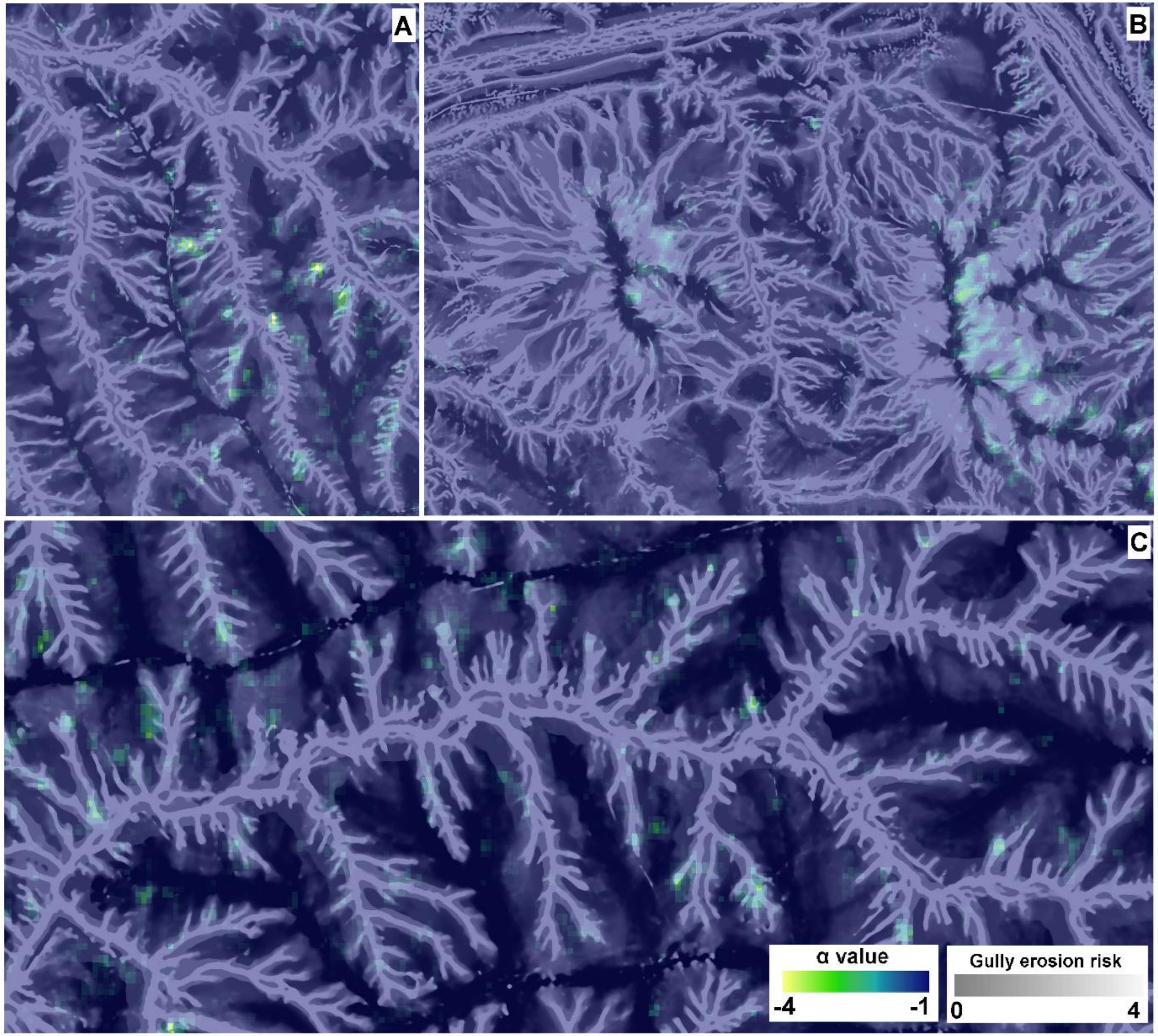


Comparison with gully delineation products (Walker et al., 2020)



Comparison with gully delineation maps

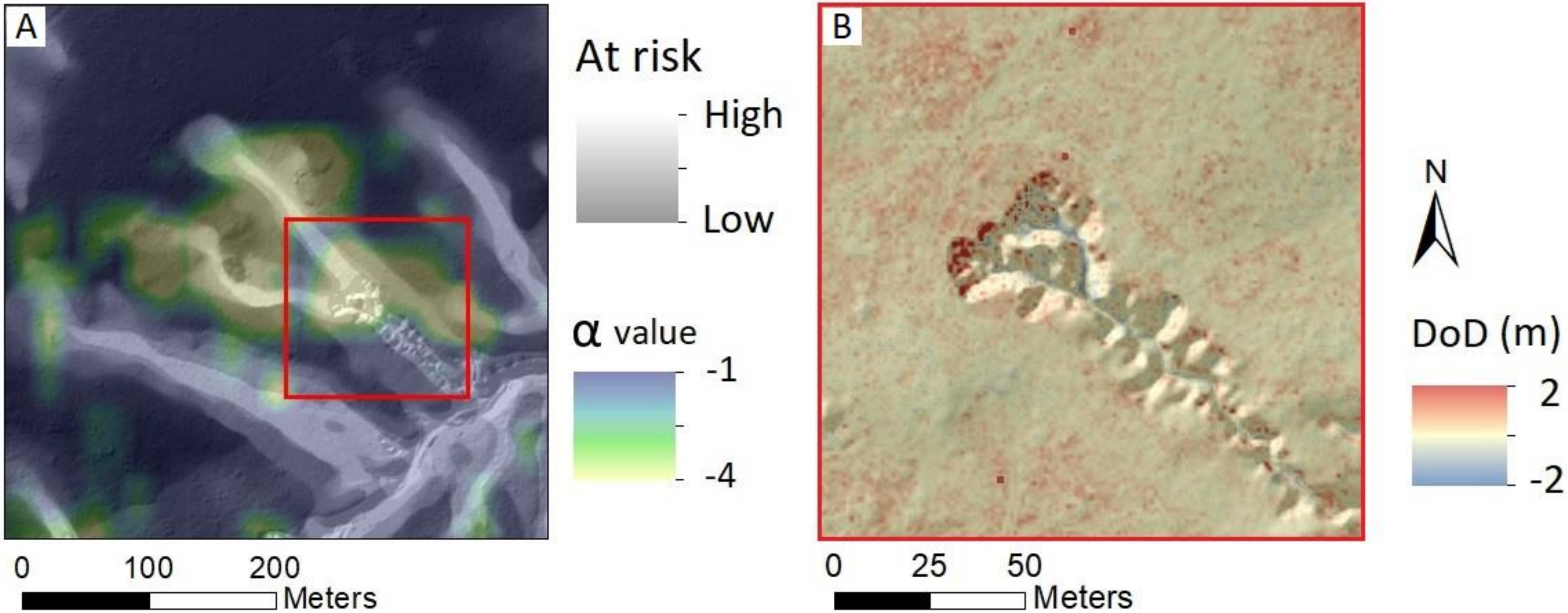
Based on:
Daley, J., Stout, J., Curwen, G., Brooks, A., Spencer, J., 2021. Development and application of automated tools for high resolution gully mapping and classification from lidar data. Report to the National Environmental Science Program. Reef and Rainforest Research Centre Limited, Cairns (169pp.).



Comparison with maps of potential gullying

<u>*Based on:*</u>
Walker S, Wilkinson S, Levick S. 2022. Metre-resolution gully and erosion hazard mapping from airborne LiDAR in catchments of the Great Barrier Reef. CSIRO. https://doi.org/10.25919/7dsj-2r16

Mapping erosion with radar coherence



InSAR vs DoD vs Potential gullying

Conclusion – take-away messages

- InSAR coherence provides information on texture changes – erosion and deposition are both observed similarly
- Line of Sight angle plays a significant role in the spatial sensitivity when monitoring erosion inside gullies
- Can be deployed over large-scale, data are open access, globally accessible for free
- Sensitivity in C-band (5.6cm) challenges the comparison with DOD data
- Interesting complementarity with potential gully mapping to guide prevention efforts

Perspectives

Near future

- **Testing L-band data (ALOS-2, NiSAR, 23cm) to evaluate the value added of a decreased sensitivity, but potentially better dynamic range**
- **In situ verification of coherence anomalies**
- **Obtaining more radar imagery with different characteristics (Line Of Sight angle, resolution, temporal frequency, wavelength)**

Next 3 years (Strategic project)

- **PhD student**
- **Large-scale implementation to all GBR catchments (from C or L band data)**
- **Testing a similar approach for coastal erosion, for post-fire erosion and around nuclear waste disposal sites**